

RESEARCH ARTICLE

Current status and management options for invasive plants at the Mihintale Wildlife Sanctuary

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Abstract: The present study describes the current spread of plant invaders and management efforts at Mihintale, Sri Lanka's first recorded Wildlife Sanctuary. Among the five land use zones identified, roadside (RS), village (VA) and reservoir associated (RA) zones were subjected to a detailed analysis of diversity and abundance of Invasive Alien Plants (IAP) using stratified random sampling plots of 20 m x 20 m (n=09). Encroachment of IAP into the forested (FO) zone was studied using three 50 m transects established from edge to interior of the forest. The above ground diversity of IAP was assessed *via* Margalef's, Shannon –Weiner, Shannon evenness, abundance and important value indices. Aquatic IAP were also identified. Below ground diversity of IAP was estimated by enumerating soil seed banks *via* seedling establishment method. A questionnaire (n=60) was used to ascertain the invasion history, awareness on IAP, their interference on human activities, uses and control measures adopted by the villagers. Nearly half of the IAP reported for Sri Lanka were present in the Mihintale Sanctuary. Richness of IAP was high in RA but the abundance was high at RS zone. *Lantana camara* and *Chromolaena odorata* had the highest spread, extending even >25 m into the forests. *Salvinia* was the most abundant aquatic IAP. Top soil layer contained the highest number of germinable IAP seeds. The villagers were well aware of the impacts of IAP and indicated their attempts and potential in IAP management. The study revealed that spread of IAP at the Mihintale Sanctuary currently lies at a manageable level. Better awareness among villagers on “do's and dont's with IAP” would assist in opening up more opportunities for community participation in effective IAP management.

Keywords: *Chromolaena odorata*, invasive plants, *Lantana camara*, Mihintale, *Salvinia*.

INTRODUCTION

Invasive alien species (IAS), defined as those non- native plants and animals that threaten ecosystems, habitats or

species (CBD, 2008) are considered as the second most important agents responsible for biodiversity loss and extinction (Jayasuriya, 2000; Balckburn *et al.*, 2004; Cassey *et al.*, 2004; Gurevitch & Padilla, 2004; Mc Neely & Jeffery, 2004). Plant invaders reduce richness and abundance of native species by preventing seedling establishment, inhibiting growth and development, modifying plant-pollinator interactions, increasing above and below ground competition and swamping native gene pools *via* interbreeding with native species of the environment (Schei, 1996; Ellstrandia & Schierenbeck, 2000; Vranjic *et al.*, 2000; Vilà & Weiner 2004; Yurkonis *et al.*, 2005; Bjerknæs *et al.*, 2007). They also modify ecological processes and physical resources of the ecosystem such as nutrient cycling, sedimentation and disturbance regimes (Mack *et al.*, 2000; Lindsay & French, 2004) and ultimately hamper ecosystem services, which are fundamental to human well-being and survival (Pejchar & Mooney, 2009). The economic costs of biological invasions due to losses in crops, pastures, forests, tourism, recreation together with expenditure on control measures have been estimated to be in hundreds of billions of units in monetary terms (Pimentel *et al.*, 2000).

Thirty plants and thirteen animal species have been identified as IAS in Sri Lanka (Marambe *et al.*, 2002) and their detrimental impacts on several ecosystems have been documented (Amarasinghe, 1999; Bambaradeniya *et al.*, 1999; Algama & Seneviratne, 2000; Pushpakumara *et al.*, 2000). Responding to the principles of CBD, the Government of Sri Lanka implemented a strategy to prevent/minimize adverse impacts of IAS (Ministry of Forestry and Environment, 1999), and as a result national programmes were conducted to control and eradicate

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aquatic (Amarasinghe, 2008) and terrestrial plant invaders in the National Parks at Uda-Walawa, Bundala and Horton Plains (Weerakoon, 2008). In addition, there have been a few small scale programmes conducted by Non-Governmental Agencies to control and eradicate IAS at several locations in Sri Lanka (Marambe, 2008). The Policy for Management and Procedural Synopsis of IAS in Protected Areas of Sri Lanka, drafted by the Department of Wildlife Conservation has also emphasized on the eradication and control of plant invaders (especially the non palatable species) that have threatened biota in the protected areas (Marambe *et al.*, 2006).

Surveys for documentation of occurrence and spread of invaders are imperative for IAS management programmes on selection of priority sites and species (Marambe, 2008). However, at present very limited baseline information is available on the distribution and abundance of invasive alien plant species in many protected areas of Sri Lanka (Weerakoon, 2008).

Protected areas, which occupy about 15% of the land area of the country, harbour most of the country's unique wealth of biodiversity. Among the 321 protected sites, the Mihintale Sanctuary established in 246 BC, occupies a prestigious position as being the oldest sanctuary in Sri Lanka (and perhaps the world's first Sanctuary) with a continuous record for 2560 yrs (Cummings, 2006). Being a historically important sacred pilgrimage site where Buddhist philosophy and concepts of biodiversity conservation were first advertised to Sri Lanka, Mihintale provides strong links with religious, cultural and biodiversity conservation foundations of the country. According to the National Conservation Review (Ministry of Forestry and Environment and World Conservation Union, 1997) the biota of Mihintale comprises 41 plant species from 36 genera belonging to 31 families, including 06 endemic and 01 threatened plant species and 37 faunal species from 33 genera belonging to 26 families, including 04 endemics and 03 threatened animal species. A recent survey on medicinal plants at the Mihintale Sanctuary has reported 159 plant species from 111 genera belong to 54 families, including 03 threatened plants, namely, *Salacia reticulata*, *Munronia pinnata* and *Vernonia zeylanica* (Herath *et al.*, 2009).

Today the sanctuary is a mosaic of fragmented zones of different land use and vegetation types segregated by footpaths, tanks and villages. The land within and around the boundary of the sanctuary is highly disturbed by chenas, irrigated cultivations and home gardens (Divisional Secretariat, Mihintale, 2006). Thus the indigenous biota of Mihintale has simultaneously received challenges from IAS.

There are no previous records on the occurrence and spatial distribution of Invasive Alien Plants (IAP) in the Mihintale Sanctuary. The present study was therefore designed to document the current distribution of IAP in relation to the land use pattern of the Sanctuary and to identify human activities that influence the spread of IAP within the Sanctuary. As above ground observations of plant invaders reflect only a part of the diversity and below ground storage of seeds plays a vital role in the potential for regeneration (Richardson *et al.*, 1989), our investigations were extended to enumerate the soil seed bank of invasive alien plants within the Sanctuary. Following analysis of the present situation, effective measures for the control of plant invaders have been suggested.

METHODS AND MATERIALS

Study site: Mihintale situated in the Anuradhapura district of the North-Central Province of Sri Lanka is approximately 1000 ha in extent of land and aquatic water bodies is bounded north by the main road from Anuradhapura to Trincomalee (A₁₂), east by a portion of the Mahakanadara tank, south by a small foot path from A₉ road and Katukeliyawa, Katupotha Kanda and west by the Kandy- Jaffna (A₉) main road (Divisional Secretariat, Mihintale, 2006) (Figure 1).

Mihintale receives an annual rainfall between 1000-1,500 mm/year mainly from the North – East monsoon and inter-monsoonal rains and experiences a temperature of 19 °C to 35 °C. The five villages established in the sanctuary depend highly on Kaludiyapokuna, Kudakirindegama, Mahakirindegama, Ihala-Mudawa, and Mahakanadara tanks. The major types of vegetation in the sanctuary are disturbed secondary forests, scrub lands, paddy fields, chena lands, aquatic habitats and rock outcrops (Divisional Secretariat, Mihintale, 2006).

Preliminary observations of the study site has identified five major zones of different land use patterns including a roadside zone (RS) associated with the Kandy-Jaffna, Trincomalee-Anuradhapura and Katukaliyawa roads, a village zone (VA) with inhabitants and their cultivations, a zone associated with reservoirs (RA) including Kaludiyapokuna, Kudakirindegama and Ihala-Mudawa tanks, a forested zone (FO) consisting of patches of forests in Katupothakanda and Kaludiyapokuna areas and the sacred zone (ST) associated with the sacred temple. Following a reconnaissance survey on plant invaders in all zones, FO and ST zones were excluded from sampling due to the scarcity of IAP. Data collection was done as follows from November 2008 to April 2009.

Above ground diversity of IAP: The above ground diversity of IAP in RS, VA and RA zones of the Sanctuary was assessed via few approaches found in literature including diversity indices, abundance index and the important value index. Stratified random sampling of three 20 m x 20 m plots per zone (Figure 1) was used for obtaining data on density, frequency and cover using the Braun-Blanquet cover abundance ratings (Mullellier-Dombois & Ellenburg, 1974) of invasive alien shrubs. Species composition of IAP in the Sanctuary was also determined and listed (Senaratne, 2001). The relative richness, abundance and evenness of IAP in each zone was assessed using Margalef's

diversity, $D_{Mg} = (S - 1) / \ln N$, Shannon Wiener

diversity, $H = - \sum_{i=1}^s \left(\frac{n_i}{N} \right) \ln \frac{n_i}{N}$ and Shannon evenness

$E = H / \ln S$ indices, respectively where, S = number of IAP, N = total number of individuals of IAP, n_i = number of individuals of i^{th} invasive plant in each study zone and H = Shannon Wiener diversity (Mullellier-Dombois & Ellenburg, 1974).

Further, abundance index (AI) of each invasive shrub species was calculated according to Moeini *et al.* (2008). Three quantitative measures (frequency, field uniformity and mean field density) were used to determine AI, $(AI = F_k + U_k + MFD_k)$, where F_k = frequency of species

k , $[F_k = \frac{\sum Y_i}{n} \times 100]$, (Y_i = presence of species k in zone i and n = number of zones), U_k = field uniformity value for

species k , $U_k = \frac{\sum_{i=1}^n \sum_{j=1}^m X_{ij}}{\sum_{i=1}^n m_i}$ (X_{ij} = presence of species k

in j sample plots of the i zone and m = number of sample plots per zone) and mean field density for species k ,

MFD_{ki} ; $MFD_{ki} = \frac{\sum_{j=1}^m D_{kij}}{n}$ [calculated using density,

D_{ki} ; $D_k = \frac{\sum_{i=1}^m Z_i}{m} \times \frac{1}{400}$ (where density is expressed as number /m² of species k in i zone and Z_j = number of IAP in j sample plots)].

In addition, the relative abundance (RA) for each invasive shrub species was also determined using the following equation. $RA = RF_k + RU_k + RD_k$ where relative frequency, $RF_k = (\text{frequency value of species } k \times 100) / (\text{sum of frequency values of all species})$, relative uniformity, $(RU_k) = (\text{uniformity value of species } k \times 100) / (\text{sum of uniformity values of all species})$, relative

density, $(RD_k) = (\text{mean field density value of species } k \times 100) / (\text{sum of mean field density values of all species})$.

The important value index, $IVI = RD_k + RF_k + RC_k$ was calculated for invasive alien shrub species using relative cover $(RC_k) = (\text{cover value of species } k \times 100) / (\text{sum of cover values of all species})$ together with RD_k and RF_k values (Moeini *et al.*, 2008).

In order to identify the level of encroachment of IAP into the forest patches of the sanctuary, three 50 m random line transects of at least 10 m were established in the RA zone in the vicinity of the Kudakirindegama, Kaludiyapokuna and Ihala-Mudawa tanks, from the forest edge towards the interior and the presence of dominant IAP in a total number of 30 quadrats (1 m x 1 m) placed at 5 m intervals on these transects was recorded.

The aquatic IAP in tanks at Kudakirindegama, Ihala-Mudawa and Kaludiyapokuna were identified but not sampled quantitatively.

Below ground diversity of IAP: The soil seed bank of IAP was assessed using soil samples obtained from a 10 cm diameter soil cores placed up to two depths

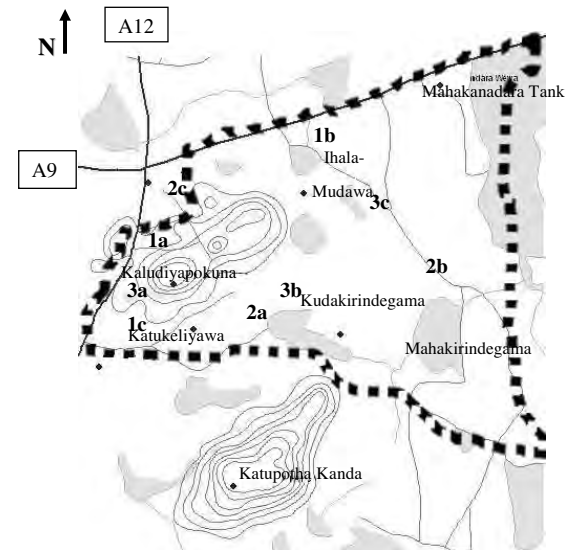


Figure 1: Map of the Mihintale Sanctuary. Symbols 1a, 1b, 1c, 2a, 2b, 2c, 3a, 3b, 3c denote sampling sites. Numbers in symbols (1,2,3) represent roadside (RS), village (VA) and reservoir associated (RA) zones respectively, whereas letters (a,b,c) indicate location of the three plots per zone. Dotted line indicates the boundary. (Scale; 1:50,000)

Table 1: List of invasive alien plants (IAP) identified at Mihintale Sanctuary

Botanical name, common names and plant family	Habit	Dispersal method	RS	Distribution		
				Disturbed	Aquatic	Forested
					RA	VA
<i>Chromolaena odorata</i> Siam weed (E) Podisinchomaran (S) (Asteraceae)	Herb	Wind	+	+		+
<i>Mikania cordata</i> Mile-a-minute weed (E) Wathupalu (S) (Asteraceae)	Herb	Wind	+	+		+
<i>Tithonia diversifolia</i> Wild Sunflower (E) Naththasooriya (S) (Asteraceae)	Shrub	Wind				+
<i>Cuscuta campestris</i> Cuscuta (E,S) (Cuscutaceae)	Herb			+		
<i>Leucaena leucocephala</i> Popinac (E), Ipil Ipil (S) (Fabaceae)	Tree	Wind Animals	+			+
<i>Mimosa invisa</i> Wal nidikumba (S) (Fabaceae)	Herb	Wind Animal	+			+
<i>Imperata cylindrica</i> Cogon grass (E), Illuk (S) (Poaceae)	Herb	Wind	+	+		+
<i>Panicum maximum</i> Guinea grass (E),Gini Thana (S) (Poaceae)	Herb	Wind Animal	+	+		+
<i>Pennisetum polystachyon</i> Bottle brush grass (E), Rila Thana (S) (Poaceae)	Herb	Wind Animal	+	+		+
<i>Hydrilla verticillata</i> Hydrilla (E, S) (Hydrocharitaceae)	Herb				+	
<i>Salvinia molesta</i> Salvinia (E, S) (Salviniaceae)	Herb				+	
<i>Typha angustifolia</i> Cattail (E), Hambu (S) (Typhaceae)	Herb	Wind		+	+	
<i>Lantana camara</i> Prickly Lantana (E) Higuru/Gandapana (S) (Verbenaceae)	Shrub	Animals	+	+		+

E: English; S: Sinhala

(0 – 3 cm, 4 – 8 cm) in the sampling locations of the three zones, RA, RS and VA (Figure 1). In addition, another two composite soil samples were obtained from the RA zone representing sites in which debris of IAP were dumped by the villages with and without burning. The soil samples were placed separately in shallow germination trays (65 mm diameter and 23 mm height) in a greenhouse (Richardson *et al.*, 1989) in a randomized complete block design with four replicates. Soils were kept moist and the emergence of seedlings was monitored every 3 d for 6 wks until no more seedlings emerged. At each observation the soil was disturbed using a small stick to stimulate germination and emergence of IAP. Emerged seedlings were transferred into separate trays and allowed to grow until identification was possible. Soil physical parameters such as pH, total moisture content, soil type and texture of each sample were also determined. Differences in seedling emergence from soils obtained from different land use zones were identified using Analysis of Variances (ANOVA), Proc. GLM, Minitab Software (Minitab Statistical Software, Release 2003, Minitab Inc.).

Human activities and the spread of IAP: Information on the degree of awareness on problematic plants/weeds including IAP, invasion history of the dominant IAP, their interference on day-to-day human activities and attempts for any control measures adopted by the villagers and local agencies were obtained by randomly interviewing 60 adult inhabitants using an open and close ended questionnaire.

RESULTS

Above ground diversity of IAP

A total of 15 IAP belonging to 15 genera and 09 families were identified from the Mihintale Sanctuary. Among them, 03 were aquatic species (Table 1).

The diversity of IAP in the Mihintale Sanctuary varied among the landuse zones. According to Margalef's diversity index, species richness of IAP was highest at RS (1.844) followed by RA(0.985) and VA(0.950). The same pattern was observed for evenness of the distribution of IAP [RS(1.297)> RA(0.734)> VA(0.724)]. As indicated by Shannon-Wiener index, the relative abundance of IAP varied RA(1.844)> RS (1.367)> VA(0.763). *Lantana camara* and *Chromolaena odorata* were identified as aggressive invaders in the Mihintale Sanctuary based on their higher AI, RA and IVI values (Tables 2a & b).

Table 2a: Abundance index (AI) and relative abundance (RA) of invasive alien shrubs

Invasive alien plant species	AI	RA
<i>Chromolaena odorata</i>	2.014	64.890
<i>Lantana camara</i>	2.053	64.463
<i>Panicum maximum</i>	1.760	32.179
<i>Pennisetum polystachyon</i>	1.470	27.618
<i>Tithonia diversifolia</i>	0.427	13.906
<i>Leucaena leucocephala</i>	0.789	12.258

Table 2b: Importance value index (IVI) of invasive alien shrubs in roadside (RS), reservoir (RA) and village (VA) zones of the Mihintale Sanctuary

Invasive alien plant species	RS	RA	VA
<i>Chromolaena odorata</i>	1.008	0.781	1.130
<i>Lantana camara</i>	1.154	0.663	1.082
<i>Panicum maximum</i>	0.468	0.388	0.120
<i>Pennisetum polystachyon</i>	0.214	0.376	0.090
<i>Leucaena leucocephala</i>	0.1194	-	0.100
<i>Tithonia diversifolia</i>	-	-	0.478

Distribution of plant invaders at forest edge

Among the seven IAP identified at the forest edge (Table 1), *Lantana camara* and *Chromolaena odorata* extended their distribution > 25 m towards the forest interior indicating a growing threat and potential for further spread (Figures 2 a, b & c). Another noxious invasive plant, *Panicum maximum* was also highly abundant at the forest edge and exhibited a trend of encroaching the forest gaps especially in the vicinity of the Kudakirindegama tank (Figure 2b). Potential threat to forests from Ipil Ipil (*Leucaena leucocephala*) was also exhibited around the Ihala-Mudawa tank.

Distribution of aquatic invasive plants

The well known aquatic invader *Salvinia molesta* was the most abundant species at Kaludiyapokuna tank but surprisingly it was not found at Ihala-Mudawa tank. Other aggressive aquatic invaders such as Hydrilla (*Hydrilla verticillata*) and Hambu (*Typha angustifolia*) also exhibited a considerable spread in all tanks (Figure 3). Though, not considered as an IAP, *Nelumbo* (*Nelumbo nucifera*) also showed an abundant growth in all three tanks.

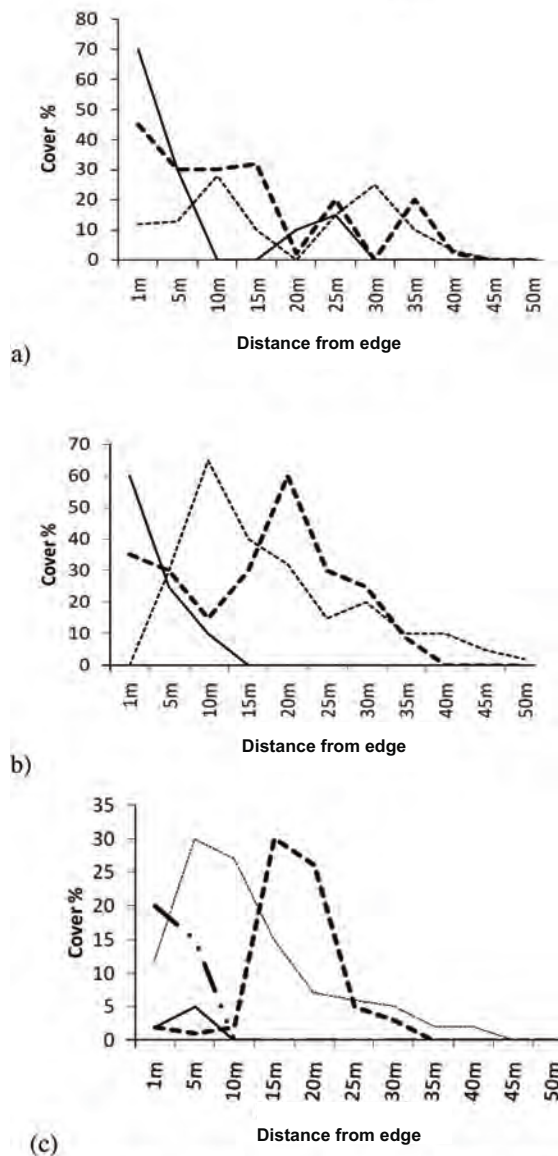


Figure 2: Dominant IAP from the edge towards the interior of the forested areas of the RA zone (a) Kudakirindegama Tank area (b) Kaludiyapokuna Tank area, (c) Ihala-mudawa Tank area. Symbols: - - - *Lantana camara*, *Chromolaena odorata*, — *Panicum maximum*, - · - · - *Leucaena leucocephala*

Below ground diversity of IAP

No significant difference ($p > 0.05$) was observed in the distribution of seeds of IAP among the study zones, RS, VA and RA although a significant difference ($p < 0.05$) was reported between top and bottom layers of soil.

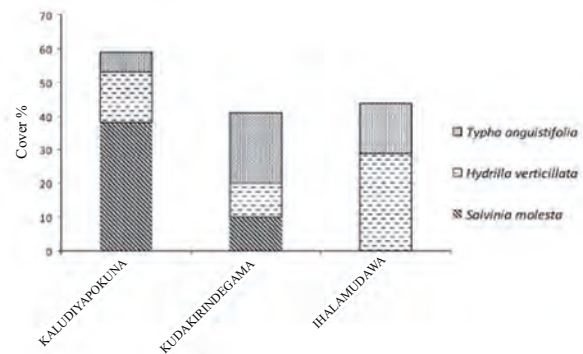


Figure 3: Distribution of aquatic IAP in three selected tanks; Kaludiyapokuna, Kudakirindegama and Ihala-Mudawa within Mihintale Sanctuary

Common Ipil ipil (*Leucaena leucocephala*) exhibited the highest number of seedlings in samples obtained from Mahakirindegama tank area (3b) while more or less equal numbers of seedlings of *Mimosa invisa*, *Mikania cordata*, *Chromolaena odorata* were identified from other sampling sites.

The soils of the study sites were mainly Reddish Brown Earth except for Low Humic Gley soil at the premises of Kudakirindegama tank. The pH varied from 6.93–7.03 while the moisture content of the study zones were RA (8.39) > VA (7.92) > RS (5.57) g per 100 g dry soil.

Human activities and the spread of IAP

About 90% of villagers were able to identify Podisinchnomaran (*Chromolaena odorata*), Gandapana (*Lantana camara*), Salvinia (*Salvinia molesta*), Hydrilla (*Hydrilla verticillata*) and Gini thana (*Panicum maximum*) plants as major problematic species despite their poor understanding on the definition of IAP and/or related terminologies. Inhabitants commented that aquatic IAP were more problematic than terrestrial IAP as the spread of IAP in tanks has been a major problem for their day-to-day activities. About 34% of the inhabitants reported that all IAP found at present (Table 1) were not seen in the sanctuary about 10–15 years ago. According to 92% of inhabitants, two-three decades ago *Chromolaena odorata*, *Lantana camara*, *Panicum maximum* were not as abundant as now and had been restricted to a few patches only in the RS zone.

Villagers believe that the introduction of *P. maximum* was due to its usage as fodder. Disturbances to the ecosystem *via* clearing and fuel wood collection seemed

to have further influenced the spread of IAP within the Sanctuary. Fishing nets were responsible for the introduction of aquatic IAP from one tank to another as the villagers did not have the habit of picking up the plants or their propagules trapped in nets after use. This was evident from the absence of *Salvinia molesta* in Ihala-Mudawa tank, which was not used for fishing activities for some time.

At present, IAP are marginally utilized as fodder, food, weaving material and medicinal purposes by the villagers. It was identified that villagers were not aware of the potential commercial uses of IAP except for the use of *Salvinia* and *Naththasooriya* (*Tithonia diversifolia*) as green manure. It had been a traditional practice to use dried *Salvinia molesta* as fertilizer by farmers inhabiting the Kudakirindegama tank area and this clearly coincided with the low abundance of *Salvinia molesta* in these premises. On the other hand, presence of *Tithonia diversifolia* only in the VA indicates a risk of spread into other zones in the future.

Nearly 85% of the villagers expressed their commitment towards eradicating 'troublesome species' as they identified such plants to be competitors, disease carriers, toxic plants and species that interfere with their day-to-day activities such as bathing, washing of clothes and fishing. Their enthusiastic maintenance of the environment by eradicating IAP was clearly demonstrated by the 'IAP free areas' such as the ST zone. Further, it was identified that the spread of IAP was kept minimal in home gardens of inhabitants due to regular uprooting of weeds, regular cleaning, and sweeping. Their attempts to control the spread of *Lantana camara* and *Chromolaena odorata* within home gardens by mechanical methods including slashing, hand pulling and hoeing have helped to minimize their spread, but the forest edge has been a major dumping site for these plant debris. It was evident that their inadequate knowledge on biology and ecology of IAP had resulted in careless introductions of plant parts from their home gardens to forest edge. Establishment of waste (mainly organic) dumping sites seemed to encourage the richness and abundance of IAP and their subsequent spread towards the interior of the forest.

Villagers appreciated the attention and assistance provided by the relevant government authorities to clear aquatic invasive alien species during 'Poson Poya programmes'. They also expressed their unhappiness on the insufficient attention paid to terrestrial IAP. Almost all villages expressed their willingness to participate in community programmes for eradication of IAP from the Mihintale Sanctuary.

DISCUSSION

The Mihintale Sanctuary has not escaped from the growing threats of IAP as nearly half of the IAP recorded in Sri Lanka were reported during this survey. The most prevalent IAP in the Mihintale Sanctuary were *Lantana camara*, *Chromolaena odorata*, *Panicum maximum*, *Salvinia molesta*, *Hydrilla verticillata*, *Mikania corata* and *Imperata cylindrica*, most of which are the world's worst weeds (World Conservation Union, 2001). Currently RS and RA zones of the Sanctuary are highly affected by IAP whereas ST zone seem to be 'out of danger' and VA zone is kept 'under control' by the villagers. However, intrusion of *Lantana camara* and *Chromolaena odorata* towards the forest interior poses a sign of danger and potential threat of IAP to the FO zone. These plant invaders, as found in all national parks and other protected areas (Weerakoon, 2008) could be identified as priority species for control and eradication of IAP at the Mihintale Sanctuary. Both the above species are well known to be serious invaders that have shown to reduce richness and abundance of native species. *Lantana camara* is reported to limit recruitment of native species and alter ecosystem structure and function especially in the disturbed habitats when the cover is >75% (Gentle & Duggin, 1997; Duggin & Gentle, 1998; Sharma *et al.*, 2005; Kohli *et al.*, 2006; Gooden *et al.*, 2009). Disturbances to forests such as canopy removal and gap formation have shown to increase the capacity of *Lantana camara* to suppress native species via greater resource acquisition and space utilization (Grice, 2004; Totland *et al.*, 2005). Similarly, *Chromolaena odorata* causes reduction of richness of native species and alter the structure and function of ecosystems. (Mahindapala *et al.*, 1980; Prasad, 2009). As it had been shown that the spread of bird and wind dispersed species is high in the connected, relative to the unconnected habitat patches in fragmented habitats (Fox & Fox, 1986; Rajmáněk, 1989; Tewksbury *et al.*, 2002; Ohlemuller *et al.*, 2006), it could be emphasized that the forests of the Mihintale Sanctuary are at a greater risk of encroachment by *Lantana camara* and *Chromolaena odorata*, as they are highly degraded interconnected patches of forests and scrub lands subjected to varying degrees of disturbances by villagers. Another giant invader, *Panicum maximum* also showed a clear trend of occupying forest gaps in a few locations, increasing threats from IAP to the FO zone in the Sanctuary.

The top layers of soil of the RS, VA and RA zones of the Sanctuary were responsible for the persistence of IAP by storing and producing a greater number of viable seeds of plant invaders. The variation of the moisture content

of soil and the nutrients probably supplied by the plant debris at dumping sites could be possible factors that influence the establishment, fast growth, reproduction and spread of invasive plants in the VA zone. Clearing of forests would also promote spread of IAP as it provides suitable niches for plant establishment. Present study clearly supports the idea that invasions are more prevalent in areas subject to anthropogenic disturbances especially in fragmented landscapes.

It has been well understood that insufficient attention and effort to detect infestations, lack of timely control and monitoring activities had compromised the possibility to eradicate IAS in many instances. Most cases of successful control of IAS have been initiated during early stages of invasion as low abundance of IAS in the habitat make them realistic targets for control even with limited resources (Witterberg *et al.*, 2001; Tu, 2009). As findings of this study reveal that the spread of IAP at the Mihintale Sanctuary lies at a manageable level if suitable management options could be adopted, necessary action should be taken immediately to protect the affected zones of the sanctuary from the growing threats of serious plant invaders. The current practices of utilization of IAP as green manure could be further encouraged and supported while guidance on developing and practicing novel methods on utilization of priority species will be greatly helpful in controlling their populations as this is the best available and easiest method for the control of IAS (Marambe, 2008).

Villagers have been an integral part of the Mihintale Sanctuary for a long time and thus the sanctuary could be considered as a socio-ecological system (Divisional Secretariat, Mihintale, 2006) in which the natural landscape has been transformed by human actions and the landscape qualities have shaped the way of life of the villages. Moreover, the capacity of local communities in managing and maintaining IAP free zones in the environment was clearly revealed by the present study. Therefore, development of an adaptive management strategy by involving community participation would be a realistic measure in managing IAP at the Mihintale Sanctuary. Participation of the local communities in selecting, developing and monitoring control measures has shown promising results in many IAS management programmes (Tu, 2009). Regular monitoring of the spread of IAP is also essential to maintain the weed populations at a controllable level to reduce impacts from IAP. Thus, promoting regular cleaning and habitat restoration practices would also contribute to minimize populations of IAP in the Sanctuary. Conducting education programmes on identification of IAP at premature stages, “do’s and don’t’s with IAS” and the biology and ecology

of troublesome weeds could help create enthusiasm and better awareness on IAP among local communities to effectively manage plant invaders in the Sanctuary. It will also avoid future detrimental introductions. Such upgrading of knowledge will add more value to their lives to make them the most effective guardians of the landscape in the Mihintale Sanctuary while reducing the pressure and costs on the Sri Lankan government in controlling and managing the alien invaders.

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