Journal of Threatened Taxa

Building evidence for conservation globally

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

COMMUNICATION

SHOLA TREE REGENERATION IS LOWER UNDER *LANTANA CAMARA* L. THICKETS IN THE UPPER NILGIRIS PLATEAU, INDIA

Muneer Ul Islam Najar, Jean-Philippe Puyravaud & Priya Davidar

26 September 2019 | Vol. 11 | No. 12 | Pages: 14562–14568
DOI: 10.11609/jott.4918.11.12.14562-14568

COMMUNICATION

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 September 2019 | 11(12): 14562–14568

ISSN 0974-7907 (Online)
ISSN 0974-7893 (Print)

PLATINUM OPEN ACCESS

Shola tree regeneration is lower under *Lantana camara* L. thickets in the upper Nilgiris plateau, India

Muneer Ul Islam Najar [1], Jean-Philippe Puyravaud [2] & Priya Davidar [3]

[1,3] Pondicherry University, Bharat Ratna Dr. B.R. Ambedkar Administrative Building, R.V. Nagar, Kalapet, Puducherry 605014, India.
[2] The Sigur Nature Trust, Chadapatti, Masinagudi PO, Nilgiris, Tamil Nadu 643223, India.
[1] mislam.esst@gmail.com (corresponding author), [2] jp.puyravaud@gmail.com, [3] pdavidar@gmail.com

Abstract: *Lantana camara* is a dominant invasive shrub in many protected areas of India including the Nilgiri Biosphere Reserve (NBR). We conducted a study to assess the regeneration potential of endemic native (shola) trees under different levels of *Lantana* infestation in the upper plateau of NBR. A total of 61 plots in a total area of 0.73ha were sampled, out of which 0.57ha was in *Lantana* dominated sites and 0.16ha in undisturbed shola forests. The plots were classified as per the level of *Lantana* infestation (intensive, moderate, and low infestation). We found that regeneration of shola trees, including endemics decreased with increasing intensity of *Lantana* invasion. No regeneration occurred in the intensively infested plots whereas regeneration was high in undisturbed shola forests.

Keywords: India, invasive alien species, *Lantana* infestation, Nilgiris, shola forest, regeneration.

DOI: https://doi.org/10.11609/jott.4918.11.12.14562-14568

Editor: D. Narasimhan, Madras Christian College (Autonomous), Chennai, India. **Date of publication:** 26 September 2019 (online & print)

Manuscript details: #4918 | Received 28 February 2019 | Final received 21 May 2019 | Finally accepted 24 August 2019

Citation: Najar, U.I.N., J-P. Puyravaud & P. Davidar (2019). Shola tree regeneration is lower under *Lantana camara* L. thickets in the upper Nilgiris plateau, India. *Journal of Threatened Taxa* 11(12): 14562–14568. https://doi.org/10.11609/jott.4918.11.12.14562-14568

Funding: None.

Competing interests: The authors declare no competing interests.

Author details: Mr. Muneer Ul Islam Najar is a PhD scholar in the Department of Ecology and Environmental Sciences, Pondicherry University, Puducherry, India. His study focuses on the ecology of invasive alien plants. Dr. Priya Davidar retired as a Professor in Ecology and Environmental Sciences, Pondicherry University, India. She received her PhD in Zoology (Ornithology) from Bombay University in 1979 under the guidance of Dr. Salim Ali. She was a post-doctoral fellow at the Smithsonian Institution and Harvard University, USA. She is active in the field of conservation advocacy and research. Dr. Jean-Philippe Puyravaud is the director of the Sigur Nature Trust. He received his PhD in ecology from University Pierre and Marie Curie, Paris, France. He works in landscape ecology and conservation.

Author contribution: MUIN carried out the field work and data analyses. JPP and PD helped with study design, statistical analyses and editing.

Acknowledgements: We thank the Tamil Nadu Forest Department for permission to carry out this study. We especially thank the Chief Wildlife Warden and the DFO Nilgiris South Division, Shri C. Badraswamy. We also thank Mr. Rathish for helping in the field.

INTRODUCTION

Invasion by alien species is one of the major threats to the local and global biological diversity (D'Antonio & Kark 2002), and is regarded as one among the five top ecosystem disrupters (Millennium Ecosystem Assessment 2005). Besides affecting the native flora and fauna, a single invasive plant can alter biodiversity (Powell et al. 2011), hydrology (Le Maitre 2004), soil properties (Ehrenfeld 2010), disturbance regimes (Mack & D'Antonio 1998), fire frequency (Brooks et al. 2004), as well as above and below ground trophic interactions (Levine et al. 2003). There is a close link between invasion by exotics and extinction of native species because deforestation, decline of native species, and spread of invasive species occur simultaneously (Gurevitch & Padilla 2004). Plant extinctions, however, are least noticeable as they happen over a larger time scale (Gilbert & Levine 2013).

Lantana camara L. (hereafter referred to as *Lantana*) is one of the most successful invasive alien plants with its origin in Neotropical region. This plant has successfully established itself in more than 60 countries (Day et al. 2003). It was first introduced into India at the National Botanical Garden of Calcutta in the early 19th Century by the British as an ornamental plant (Iyengar 1933; Anonymous 1942). Since then *Lantana* has spread extensively throughout the country up to altitudes of 2,000m (Sharma et al. 1988). It occurs in a wide variety of habitat types ranging from tropical evergreen forests, tropical moist- and dry deciduous forests, tropical scrub forests to subtropical moist and dry deciduous forests (Hiremath & Sundaram 2013). It is prevalent in the Himalaya and Western Ghats (WG) biodiversity hotspots (Shaanker et al. 2010) where it affects native plant diversity (Cruz et al. 1986). Presently, *Lantana* is a dominant shrub in many important protected areas of the Nilgiri Biosphere Reserve which includes Mudumalai National Park, Bandipur National Park, and Wayanad Wildlife Sanctuary (Hiremath & Sundaram 2013). In these ecosystems, *Lantana* negatively impacts biota (Sharma & Raghubanshi 2007; Prasad 2010) by reducing grass cover which is important for the survival of herbivores like elephants (Kumar et al. 2012; Prasad 2012). In Mudumalai, it is reported that the presence of excessive amounts of *Lantana* has led to a decrease in the feeding rates and changes in the behavior of elephants (Wilson et al. 2014). *Lantana* invasion increases the fuel load making an area prone to fire and the fire in turn, paves the way for more invasion (Hiremath & Sundaram 2005).

The upper plateau of the Nilgiri Mountains (≥ 1,800m), part of the Western Ghats biodiversity hotspot, supports the unique tropical montane evergreen forests locally called 'sholas', interspersed with grasslands. Sholas support many endemic plants including *Cinnamomum wightii*, *Daphniphyllum neilgherrense, Lasianthus venulosus*, *Litsea wightiana*, *Magnolia nilagirica*, *Mahonia leschenaultii*, *Neolitsea cassia*, *Psychotria nilgiriensis*, *Symplocos foliosa*, and *Syzygium tamilnadensis* (Mohandass & Davidar 2009). These forests are highly threatened due to extensive deforestation and other anthropogenic pressures (Rawat 2008; Rao 2012). There has been a considerable loss of shola forests since 1850 A.D. due to conversion to monoculture plantations (Rawat et al. 2003).

Lantana invasion could potentially alter the successional processes operating in shola forests (Mohandass & Davidar 2010), that could affect the recruitment of slow growing native trees and lianas, leading to decreased diversity and biomass. The invasion is so extreme in some parts of the Nilgiris that it has rendered some agricultural lands barren (Muneer Ul Islam Najar pers. obs. 15 February 2017) making it very difficult for poor farmers to afford the costs of removal and subsequent management of the fields.

In this study we selected 61 plots with differing densities of *Lantana* including four control plots in shola forests in different sites above 1,800m in the Nilgiris South Division of the Nilgiri Biosphere Reserve (NBR). We assessed *Lantana* densities, and densities of regenerating shola trees including endemic species under *Lantana* cover and in shola forests. Our objective was to assess regeneration of shola trees under different levels of *Lantana* infestation, and to see which shola species survive under *Lantana*, because these species could be more useful for shola restoration under *Lantana* cover. We tested the null hypothesis that shola tree densities would not be associated with differing *Lantana* densities.

MATERIAL AND METHODS

Study area

This study was conducted in the reserved forests of Nilgiris South Division (11.20–11.49^{0}N & 76.55–76.68^{0}E; Fig. 1) of the Nilgiri Biosphere Reserve (NBR), India. Located in the Nilgiris District of Tamil Nadu, the Nilgiris South Division includes mostly the upper plateau of the biosphere reserve at about 2,200m and some areas extend to lower elevations of about 900m.

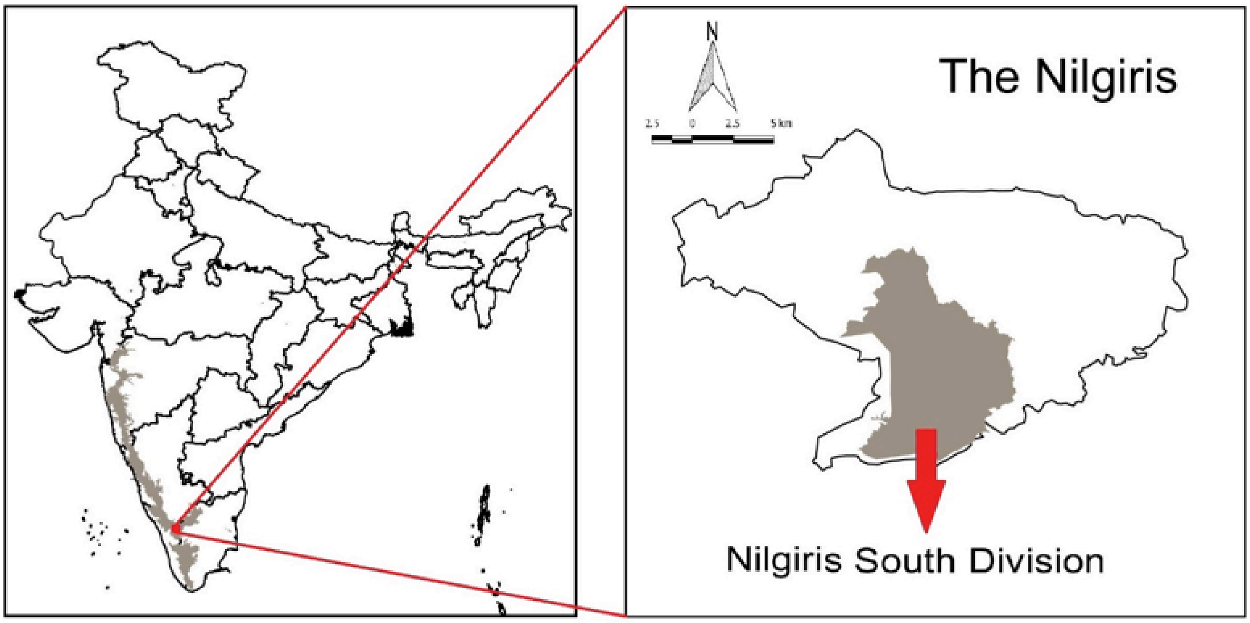

Figure. 1. Study area in the Western Ghats and in the Nilgiris District of Tamil Nadu.

The forest department of Tamil Nadu has divided it into seven forest ranges. Two ranges namely, Kundah and Naduvattam, have been extensively invaded by *Lantana.*

The Nilgiris upper plateau receives rainfall annually from both the southwest and northeast monsoons. Temperature ranges from a mean maximum of 24^{0}C in April to a mean minimum of 5^{0}C in December. Frost occurs between November and March and mainly in the valleys rather than on the higher hill slopes (Caner et al. 2007).

Nilgiris is home to many endemic plant and animal species. Some of these plant genera having maximum endemic taxa are *Actinodaphne*, *Cinnamomum*, *Glochidion*, *Litsea*, *Memecylon*, *Symplocos*, and *Syzygium* (Rao 2012). The Nilgiris has viable populations of the Endangered and endemic Nilgiri Tahr *Nilgiritragus hylocrius*, the Asian Elephant *Elephas maximus*, and the Lion-tailed Macaque *Macaca silenus*.

Methods

This study was conducted between April 2016 and May 2017 in the study sites at altitudes ranging 913–2,033 m. All the ranges of Nilgiris South Division were covered except Naduvattam.

A total of 61 plots were studied: 57 plots each of size 10×10 m in the *Lantana* dominated sites, the total area sampled being 0.57ha, and four control plots each of size 20×20 m in undisturbed shola patches of total area 0.16ha (Table 1; Image 1). The number of trees (tree density, ≥10cm GBH) and the number of *Lantana* stems (*Lantana* density) inside the plots was recorded. The number of endemic trees was noted separately. The plots were assigned to different classes as per intensity of *Lantana* invasion: plots with >400 *Lantana* stems were assigned to the 'Intensive' infestation class, those with 200–400 stems to the 'moderately' infested class, and those with <200 stems to the 'low' infestation class.

The data were checked for normal distribution by Shapiro-Wilk test and the Spearman's rank correlation coefficient was used to test for association between *Lantana* and tree densities. The analysis was carried out using R (R Core Team 2019).

RESULTS

The distribution of *Lantana* densities differed significantly from normality (Shapiro-Wilk test=0.95, p=0.03). Similarly the distribution of tree densities (Shapiro-Wilk test=0.5, p<0.0001), and endemic tree densities (Shapiro-Wilk test=0.33, p<0.0001) also deviated from normality.

As the density values were not normally distributed, the median was used as a measure of density. The *Lantana* density in 57 plots ranged from a minimum of zero stems to a maximum of 908 stems per plot with a median of 330. Tree density ranged from zero to 117 with a median of six trees per plot. There were zero to 33 endemic trees with a median of zero trees per plot (Table 1). In contrast, the four control plots were

Table 1. Median values (Range: minimum to maximum) of *Lantana*, tree and endemic tree densities in the plots with different levels of *Lantana* infestation. Area sampled was 0.57ha in the experimental plots and 0.16ha in the control plots.

Category	*Lantana* infestation				Total
	Intensive (20 plots)	Moderate (26 plots)	Low (11 plots)	Control (shola, 4 plots)	61 plots
Lantana	473 (405–908)	322.5 (227–395)	119 (63–197)	0 (0)	330 (0–908)
All trees	1 (0–9)	5.5 (0–10)	15 (8–25)	99.5 (88–117)	6 (0–117)
Endemic species	0 (0)	0 (0–3)	1 (0–3)	25.5 (19–33)	0 (0–33)

Image 1. A plot showing *Lantana* infestation in the upper Nilgiris plateau.

composed of shola trees belonging to the following genera: *Cinnamomum, Daphniphyllum, Ilex, Lasianthus, Litsea, Meliosma, Microtropis, Neolitsea, Nothapodytes, Psychotria, Rapanea, Rhododendron, Rhodomyrtus, Saprosma, Strobilanthes, Symplocos,* and *Syzygium*.

The 20 intensively infested plots had a median of 473 *Lantana* stems per plot and a median of one tree per plot but no endemic tree species (Table 1). The 26 moderately *Lantana*-infested plots had a median of 322.5 *Lantana* stems per plot, 5.5 trees but no endemic species per plot. Similarly, the 11 plots with low *Lantana* infestation had a median of 119 *Lantana* stems per plot, 15 trees, and one endemic tree per plot. Both the tree density and the density of endemic tree species was highest in the shola (control) plots with a median tree density of 99.5 trees per plot and a median of 25.5 endemic trees per plot (Table 1).

Endemic tree density decreased significantly and negatively with increase in *Lantana* density (Spearman rank correlation coefficient r_s=−0.72, p<0.0001).

DISCUSSION

Our study shows that the regeneration of shola trees including endemic species decreases with increase in *Lantana* density. Few shola trees survive under moderate *Lantana* cover and none under heavy infestation. These results support the findings of Prasad (2012) who found a negative relationship between *Lantana* abundance and tree density. We found species of *Lasianthus*, *Litsea*, *Neolitsea*, *Symplocos*, and *Syzygium* growing in plots with moderate and low infestation.

It has been found that a forest with a composition of about 75% of native species effectively prevents the establishment of *Lantana* (Stock 2004), however, as the *Lantana* cover increases and crosses 75% mark, the richness of native species decreases (Gooden et al. 2009). This is because of the effects of *Lantana* on soil fertility (Bhatt et al. 1994) and soil seed banks (Fensham et al. 1994). In the Himalayan foothills of India, Sharma & Raghubanshi (2007) found reduced native tree species richness and regeneration in *Lantana* dominated plots. In another study, Sharma & Raghubanshi (2010) found that *Lantana* alters the tree composition and structure, due possibly to suppression of native tree regeneration. Similarly, in the Nilgiri Biosphere Reserve, *Lantana* has been found to adversely affect the regeneration of native trees, and reduce plant diversity and alter species composition in the forest under-storey in Bandipur Tiger Reserve (Prasad 2010), and in Mudumalai Tiger Reserve (Ramaswami & Sukumar 2013). Other researchers (Lamb 1991; Fensham et al. 1994; Sharma & Raghubanshi 2007) too have found a negative relationship between the regeneration of trees and *Lantana* density.

The regeneration of 52 shola species was studied by Madhu et al. (2017) in the Nilgiris. They found the highest survival rates for the two species of *Syzygium* (*S. cumini* and *S. gardneri*) at all elevations and aspects, with an average of 77% regeneration. *Syzygium* spp. could be beneficial for the restoration of shola patches because of their highest chances of survival, but need protection at the initial stages as livestock and wild herbivores forage on their leaves due to their high nutritional value (Mohandass et al. 2016). Moreover, *Syzygium cumini* can grow well in open conditions, whereas most shola species including other *Syzygium* spp. cannot, as they need shade to regenerate. Therefore, planting *Syzygium cumini* will facilitate regeneration of shola trees. Thus, growing a mix of species including both shade tolerant and light tolerant pioneer species as advocated by Sekar (2008) and Mohandass et al. (2016) could be a better strategy. In addition to *Syzygium cumini*, *Rhododendron nilagiricum*, *Syzygium calophyllifolium*, and *Viburnum hebanthum* which are common can be planted (Murugan 2006; Mohandass et al. 2016). *Viburnum hebanthum* has an added advantage that it tolerates poorly drained or water soaked soils. Murugan (2006) found the seed viability of two species of *Syzygium* (*S. tamilnadensis* and S*. calophyllifolium*) to be 70–80% followed by *Rhododendron nilagiricum* (50–60%), and *Viburnum hebanthum* (50%). The species of *Rhododendron*, *Syzygium*, and *Viburnum* have long been used as enrichment plants to assist natural regeneration (Chandrasekhara & Muraleedharan 2001). We also advise growing *Rhodomyrtus tomentosa* for it acts as a nurse plant for other shola species (Yang et al. 2010). The nurse plants create favorable microhabitats for seed germination and seedling recruitment (Franco & Nobel 1989), however, the nursing effects depend on the shade tolerance of the species to be restored. The species with greater shade tolerance help to accelerate the restoration process.

Once the *Lantana* is removed, planting of early successional species like *Berberis tinctoria*, *Daphniphylum neilgherrense*, *Syzygium densiflorum* (Mohandass et al. 2016), *Rhododendron nilagiricum* (Mohandass & Davidar 2010), and *Rhodomyrtus tomentosa* (Yang et al. 2010) could be helpful. As pointed out by Mohandass & Davidar (2010) the frost resistant species of *Rhododendron* along with *Rhodomyrtus* sp. act as pioneers in the ecotones and grasslands and over time pave the way for more shade tolerant species. Hence we suggest the planting of *Rhododendron nilagiricum*, *Rhodomyrtus tomentosa*, *Syzygium calophyllifolium*, *Syzygium cumini*, *Syzygium tamilnadensis*, and *Viburnum hebanthum* for the successful restoration of sholas in the Nilgiris post *Lantana* removal.

The cut root stock method as described by Love et al*.* (2009) could be used to remove *Lantana* as it has been found to be highly efficient to control its reinvasion. Babu et al. (2009) in India (Corbett Tiger Reserve), Woodford (2000) and Somerville et al. (2011) in Australia have effectively managed *Lantana* and successfully regenerated native plants post *Lantana* removal. What is common in these studies is that the *Lantana* was removed manually, a herbicide was sprayed over the area, or the removed *Lantana* was set on fire. After this, seeds of native trees were planted and allowed to germinate with continuous monitoring and de-weeding until the trees were high enough to prevent the reinvasion by *Lantana*. As Nilgiris South Division is one of the wettest areas of the reserve, the chances of shola restoration are high, as recovery of native species was higher in wetter areas (Prasad et al. 2018) in NBR.

Challenges to restoration

Climate change allows alien species to expand their ranges (Dukes & Mooney 1999; Simberloff 2000) particularly at higher altitudes due to the alleviation of cold limitation (Dukes et al. 2009) and makes the influence of invasions difficult to predict (Tylianakis et al. 2008). In case of *Lantana* which has greater genetic variability (Day et al. 2003) some genes can adapt to the new climatic conditions and can help it to colonize new landscapes (Ledig et al. 1997). Climate change may also lead to extirpation of those species which are not genetically diverse because a narrower genotype range makes them least adaptable to environmental conditions (Rice & Emery 2003). All this can severely impact the regeneration of shola trees and other native and endemic species in the upper Nilgiris. Another challenge is restoration of species with smaller population sizes like some endemic or rare species (Bell et al. 2003), where a minimum viable population number is necessary for the establishment of these species (Falk et al. 2006).

CONCLUSION

The invasion by *Lantana* in the upper Nilgiris is disastrous to the biological wealth of this plateau and necessary steps for its removal need to be taken. In the last few years, the forest department has taken measures to stop its spread by planting native plant species but with little success. The removal of *Lantana* and *Acacia* has been carried out in the reserve forests of the Nilgiris for many years, however, studies are necessary to assess its effectiveness. The measures have to be taken persistently, and fast growing native plants have to be planted in the cleared plots with continuous monitoring for the first few years to restore the habitats. Doing this would prevent the sites from functioning as a source for further invasion deep into the forests. An adaptive management system needs to be developed in which *Lantana* removal could be used to enhance the local population livelihoods (Shaanker et al. 2010). Although, there is no hard and fast solution to completely remove *Lantana* at this moment, we must continue working to develop innovative approaches. The efforts of Woodford (2000), Babu et al. (2009), and Somerville et al. (2011) have shown us the way forward for the effective management of *Lantana* and successful regeneration of native plants post *Lantana* removal. With some persistence and coordination between different stakeholders, similar plans could be worked out for *Lantana* in the Nilgiris.

REFERENCES

Anonymous (1942). Control of *Lantana* in Madras. *Nature* 150: 399–400.

Babu, S., A. Love & C.R. Babu (2009). Ecological restoration of lantana-invaded landscapes in Corbett Tiger Reserve, India. *Ecological Restoration* 27(4): 467–477. https://doi.org/10.3368/er.27.4.467

Bell, T.J., M.L. Bowles & A.K. McEachern (2003). Projecting the success of plant population restoration with viability analysis, pp. 313–348. In: Brigham, C.A. & M.W. Schwartz (eds.). *Population viability in plants: conservation, management, and modeling of rare plants*. Ecological Studies (Analysis and Synthesis), Vol. 165. Springer-Verlag, Berlin, Heidelberg, 369pp.

Bhatt, Y.D., Y.S. Rawat & S.P. Singh (1994). Changes in ecosystem functioning after replacement of forest by Lantana shrubland in Kumaun Himalaya. *Journal of Vegetation Science* 5(1): 67–70. https://doi.org/10.2307/3235639

Brooks, M.L., C.M. D'antonio, D.M. Richardson, J.B. Grace, J.E. Keeley, J.M. DiTomaso, R.J. Hobbs, M. Pellant & D. Pyke (2004). Effects of invasive alien plants on fire regimes. *BioScience* 54(7): 677–688. https://doi.org/10.1641/0006-3568(2004)054[0677:EOIAPO]2.0.CO;2

Caner, L., D.L. Seen, Y. Gunnell, B.R. Ramesh & G. Bourgeon (2007). Spatial heterogeneity of land cover response to climatic change in the Nilgiri highlands (southern India) since the Last Glacial Maximum. *The Holocene* 17(2): 195–205. https://doi.org/10.1177/0959683607075833

Chandrasekhara, U.M. & P.K. Muraleedharan (2001). Studies on Disturbed Shola Forests for Evolving Strategies for the Conservation and Management (No. 196). KFR1 Research Report, 110pp.

Cruz, F., J. Cruz & J.E. Lawesson (1986). *Lantana camara* L., a threat to native plants and animals. *Noticias de Galápagos* 43: 10–11.

D'Antonio, C.M. & S. Kark (2002). Impacts and Extent of Biotic Invasions in Terrestrial Ecosystems. *Trends in Ecology and Evolution* 17: 202–204. https://doi.org/10.1016/S0169-5347(02)02454-0

Day, M.D., C.J. Wiley, J. Playford & M.P. Zalucki (2003). *Lantana: current management status and future prospects.* ACIAR Monograph No. 435-2016-33733, Canberra, 102pp.

Dukes, J.S. & H.A. Mooney (1999). Does global change increase the success of biological invaders? *Trends in Ecology & Evolution* 14(4): 135–139. https://doi.org/10.1016/S0169-5347(98)01554-7

Dukes, J.S., J. Pontius, D. Orwig, J.R. Garnas, V.L. Rodgers, N. Brazee, B. Cooke, K.A. Theoharides, E.E. Stange, R. Harrington & J. Ehrenfeld (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? *Canadian Journal of Forest Research* 39(2): 231–248; https://doi.org/10.1139/X08-171

Ehrenfeld, J.G. (2010). Ecosystem consequences of biological invasions. *Annual Review of Ecology, Evolution, and Systematics* 41: 59–80; https://doi.org/10.1146/annurev-ecolsys-102209-144650

Falk, D.A., C.M. Richards, A.M. Montalvo & E.E. Knapp (2006). Population and ecological genetics in restoration ecology, pp. 14–41. In: Falk D.A., M.A. Palmer & J.B. Zedler (eds.). *Foundations of Restoration Ecology*. Island Press, 1718 Connecticut Avenue NW, Suite 300, Washington, D.C. 20009, USA, 364pp.

Fensham, R.J., R.J. Fairfax & R.J. Cannell (1994). The invasion of Lantana camara L. in forty mile scrub National Park, north Queensland. *Australian Journal of Ecology* 19(3): 297–305. https://doi.org/10.1111/j.1442-9993.1994.tb00493.x

Franco, A. & P. Nobel (1989). Effect of Nurse Plants on the Microhabitat and Growth of Cacti. *Journal of Ecology* 77(3): 870–886.

Gilbert, B. & J.M. Levine (2013). Plant invasions and extinction debts. *Proceedings of the National Academy of Sciences* 110(5): 1744–1749. https://doi.org/10.1073/pnas.1212375110

Gooden, B., K. French, P.J. Turner & P.O. Downey (2009). Impact threshold for an alien plant invader, Lantana camara L., on native plant communities. *Biological conservation* 142(11): 2631–2641. https://doi.org/10.1016/j.biocon.2009.06.012

Gurevitch, J. & D.K. Padilla (2004). Are invasive species a major cause of extinctions? *Trends in ecology & evolution* 19(9): 470–474. https://doi.org/10.1016/j.tree.2004.07.005

Hiremath, A.J. & B. Sundaram (2005). The fire-lantana cycle hypothesis in Indian forests. *Conservation and Society* 3(1): 26–42.

Hiremath, A.J. & B. Sundaram (2013). Invasive plant species in Indian protected areas: conserving biodiversity in cultural landscapes, pp. 241–266. In: Foxcroft L.C., P. Pysek, D.M. Richardson & P. Genovesi (eds.). *Plant invasions in protected areas: Patterns, Problems and Challenges*. Invading Nature, Springer Series in Invasion Ecology 7, Springer, Dordrecht, 656pp.

Iyengar, A.V. (1933). The problem of the Lantana. *Current Science* 1(9): 266–269.

Kumar, K.M.P., V. Sreeraj, B. Thomas, K.M. Manudev & A. Rajendran (2012). Validation and documentation of rare endemic and threatened (RET) plants from Nilgiri, Kanuvai and Madukkarai forests of southern Western Ghats, India. *Journal of Threatened Taxa* 4(15): 3436–3442. https://doi.org/10.11609/JoTT.o3145.3436-42

Lamb, D. (1991). Forest regeneration research for reserve management: some questions deserving answers, pp. 177–181 . In: N. Goudberg, M. Bonell & D. Benzaken (eds.). *Tropical Rainforest Research in Australia: present status and future directions for the Institute for Tropical Rainforest Studies*. Institute for Tropical Rainforest Studies, Townsville, Queensland, Australia, 210pp.

Le Maitre, D.C. (2004). Predicting invasive species impacts on hydrological processes: the consequences of plant physiology for landscape processes. *Weed Technology* 18: 1408–1410. https://doi.org/10.1614/0890-037X(2004)018[1408:PISIOH]2.0.CO;2

Ledig, F.T., V. Jacob-Cervantes, P.D. Hodgskiss & T. Eguiluz-Piedra (1997). Recent evolution and divergence among populations of a rare Mexican endemic, Chihuahua spruce, following Holocene climatic warming. *Evolution* 51(6): 1815–1827. https://doi.org/10.1111/j.1558-5646.1997.tb05105.x

Levine, J.M., M. Vila, C.M.D. Antonio, J.S. Dukes, K. Grigulis & S. Lavorel (2003). Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society of London. Series B: Biological Sciences* 270(1517): 775–781; https://doi.org/10.1098/rspb.2003.2327

Love, A., S. Babu & C.R. Babu (2009). Management of Lantana, an invasive alien weed, in forest ecosystems of India. *Current Science* 97(10): 1421–1429.

Mack, M.C. & C.M. D'Antonio (1998). Impacts of biological invasions on disturbance regimes. *Trends in Ecology & Evolution* 13(5): 195–198. https://doi.org/10.1016/S0169-5347(97)01286-X

Madhu, M., R. Ragupathy, H.C. Hombegowda, P. Muralidhara, & O.P.S. Khola (2017). Initial growth performance of Shola species under enrichment plantation in the Nilgiris, Tamil Nadu. *Journal of Environmental Biology* 38(1): 91–95.

Millennium Ecosystem Assessment (2005). Ecosystems and Human

Well-Being: Biodiversity Synthesis. World Resources Institute, Washington, DC. Indicators. Leaflet. ECNC.

Mohandass, D. & P. Davidar (2009). Floristic structure and diversity of a tropical montane evergreen forest (shola) of the Nilgiri Mountains, southern India. *Tropical Ecology* 50(2): 219–229.

Mohandass, D. & P. Davidar (2010). The relationship between area, and vegetation structure and diversity in montane forest (shola) patches in southern India. *Plant Ecology & Diversity* 3: 67–76. https://doi.org/10.1080/17550874.2010.492843

Mohandass, D., T. Chhabra, R.S. Pannu & K.C. Beng (2016). Recruitment of saplings in active tea plantations of the Nilgiri Mountains: Implications for restoration ecology. *Tropical Ecology* 57(1): 101–118.

Murugan, A. (2006). Studies on some selected endangered and endemic tree seeds seedlings of Shola forest in Nilgiris. Doctoral thesis, Manonmaniam Sundaranar University, Tamil Nadu, India, 108pp.

Powell, K.I., J.M. Chase & T.M. Knight (2011). A synthesis of plant invasion effects on biodiversity across spatial scales. *American Journal of Botany* 98(3): 539–548. https://doi.org/10.3732/ajb.1000402

Prasad, A.E. (2010). Effects of an exotic plant invasion on native understory plants in a tropical dry forest. *Conservation Biology* 24(3): 747–757. https://doi.org/10.1111/j.1523-1739.2009.01420.x

Prasad, A.E. (2012). Landscape-scale relationships between the exotic invasive shrub Lantana camara and native plants in a tropical deciduous forest in southern India. *Journal of Tropical Ecology* 28(1): 55–64. https://doi.org/10.1017/S0266467411000563

Prasad, A., J. Ratnam & M. Sankaran (2018). Rainfall and removal method influence eradication success for Lantana camara. *Biological Invasions* 20(12): 3399–3407. https://doi.org/10.1007/s10530-018-1785-1

R Core Team. (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-Project.org/

Ramaswami, G. & R. Sukumar (2013). Long-term environmental correlates of invasion by *Lantana camara* (Verbenaceae) in a seasonally dry tropical forest. *PloS one* 8(10): e76995. https://doi.org/10.1371/journal.pone.0076995

Rao, R. (2012). Floristic Diversity in Western Ghats: Documentation, Conservation and Bioprospection-A Priority Agenda for Action, Shaydari E News, Issue 38. Website accessed on 22 February 2019. http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue38/index.htm

Rawat, G.S. (2008). Special habitats and threatened plants of India. *ENVIS Bulletin: Wildlife and Protected Areas*, 11(1), Wildlife Institute of India, Dehradun, India, 239pp.

Rawat, G.S., P.V. Karunakaran & V.K. Uniyal (2003). Shola Grasslands of Western Ghats–Conservation status and management needs. *ENVIS bulletin on Grassland Ecosystem and Agroforestry* 1(1): 57–64.

Rice, K.J. & N.C. Emery (2003). Managing microevolution: restoration in the face of global change. *Frontiers in Ecology and the Environment* 1(9): 469–478. https://doi.org/10.1890/1540-9295(2003)001[0469:MMRITF]2.0.CO;2

Sekar, T. (2008). Observations on survival and growth of different shola species under a shola afforestation programme in Nilgiris District, Tamil Nadu. *Indian Forester* 134(4): 451–457.

Shaanker U.R., G. Joseph, N.A. Aravind, R. Kannan & K.N. Ganeshaiah (2010). Invasive plants in tropical human-dominated landscapes: Need for an inclusive management strategy, pp. 202–219. In: Perrings C., H. Mooney & M. Williamson (eds.). *Bioinvasions and globalization: ecology, economics, management and policy*. Oxford University Press, Oxford, 267pp.

Sharma, G.P. & A.S. Raghubanshi (2007). Effect of *Lantana camara* L. cover on local depletion of tree population in the Vindhyan tropical dry deciduous forest of India. *Applied Ecology and Environmental Research* 5(1): 109–121.

Sharma, G.P. & A.S. Raghubanshi (2010). How *Lantana* invades dry deciduous forest: a case study from Vindhyan highlands, India. *Tropical Ecology* 51(2): 305–316.

Sharma, O.P., H.P.S. Makkar & R.K. Dawra (1988). A review of the noxious plant *Lantana camara*. *Toxicon* 26(11): 975–987. https://doi.org/10.1016/0041-0101(88)90196-1

Simberloff, D. (2013). Eradication: pipe dream or real option? pp. 549–559. In: Foxcroft L.C., P. Pysek, D.M. Richardson & P. Genovesi (eds.). *Plant invasions in protected areas: Patterns, Problems and Challenges*. Invading Nature, Springer Series in Invasion Ecology 7, Springer, Dordrecht, 656pp.

Somerville, S., W. Somerville & R. Coyle (2011). Regenerating native forest using splatter gun techniques to remove lantana. *Ecological Management & Restoration* 12(3): 164–174. https://doi.org/10.1111/j.1442-8903.2011.00608.x

Stock, D. (2004). The Dynamics of Lantana Camara (L.) Invasion of Subtropical Rainforest in Southeast Queensland. PhD Thesis. School of Environmental and Applied Science, Griffith University, xxvi+318pp.

Tylianakis, J.M., R.K. Didham, J. Bascompte & D.A. Wardle (2008). Global change and species interactions in terrestrial ecosystems. *Ecology Letters* 11(12): 1351–1363. https://doi.org/10.1111/j.1461-0248.2008.01250.x

Wilson, G., M.A. Gruber & P.J. Lester (2014). Foraging relationships between elephants and *Lantana camara* invasion in Mudumalai Tiger Reserve, India. *Biotropica* 46(2): 194–201. https://doi.org/10.1111/btp.12094

Woodford, R. (2000). Converting a dairy farm back to a rainforest water catchment. *Ecological Management & Restoration* 1(2): 83–92. https://doi.org/10.1046/j.1442-8903.2000.00028.x

Yang, L., H. Ren, N. Liu & J. Wang (2010). The shrub *Rhodomyrtus tomentosa* acts as a nurse plant for seedlings differing in shade tolerance in degraded land of South China. *Journal of Vegetation Science* 21(2): 262–272. https://doi.org/10.1111/j.1654-1103.2009.01140.x

Journal of Threatened Taxa

PLATINUM OPEN ACCESS

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

September 2019 | Vol. 11 | No. 12 | Pages: 14471–14630
Date of Publication: 26 September 2019 (Online & Print)
DOI: 10.11609/jott.2019.11.12.14471-14630

Article

Communications

Short Communications

Notes

Response & Reply

Partner

صندوق محمد بن زايد
للمحافظة على
الكائنات الحية
The Mohamed bin Zayed
SPECIES CONSERVATION FUND

Member

FJN

Publisher & Host

WILD
ZOOREACH
Threatened Taxa