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Ecology and Impacts of the Invasive Species, *Lantana camara*, in a Social-Ecological System in South India: Perspectives from Local Knowledge

Bharath Sundaram · Siddhartha Krishnan · Ankila J. Hiremath · Gladwin Joseph

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Abstract We explored how the forest-dwelling Soliga community of South India views and explains biological invasions, and how local knowledge can inform scientific knowledge on biological invasions. We used an interview schedule with open-ended questions to solicit Soliga opinion on *Lantana camara* (lantana) invasion. The Soliga cited three reasons for lantana spread: its prolific fruit output and wide seed dispersal, change in fire management, and historical extraction of grass and bamboo. The Soliga believe that lantana invasion has had negative effects on the ecosystem and their livelihoods. Tabling scientific knowledge with local knowledge has improved our understanding of lantana invasion. The role of existing lantana in colonizing neighboring areas, and the response of native tree communities to lantana were common to both local and scientific sources. However, the Soliga view provides a more nuanced perspective of the lantana-fire relationship (contextually based on lantana density) with fires suppressing lantana when lantana density was low. This is contrary to views held by foresters and biologists, that fires are uniformly detrimental and promote lantana. Our study shows that examining Soliga observations has improved understanding of the invasion process and presents avenues for future lantana management.

Keywords Local knowledge · Adaptive management · Forest fires · Soliga · Invasive species · *Lantana camara* - South India

B. Sundaram · S. Krishnan · G. Joseph
Ashoka Trust for Research in Ecology and the Environment (ATREE),
Sriramapura, Jakkur Post,
Bangalore 560064, India

A. J. Hiremath
Ashoka Trust for Research in Ecology and the Environment (ATREE),
2nd Floor, 1, K Block Commercial Complex, Birbal Road,
Jungpura Extension,
New Delhi, 110014, India

Present Address:
B. Sundaram (✉)
Azim Premji University,
5th Floor, Pixel Block 'A', PES College Campus, Hosur Road,
Bangalore 560100, India
e-mail: b.sundaram@apu.edu.in

Introduction

The explicit inclusion of local knowledge within the ambit of ecological research on biological invasions could provide different perspectives on how forest-dwellers view and deal with biological invasions (e.g., Shackleton *et al.* 2007; Neogi *et al.* 1989). Most forest-dwelling people have historically been—and some continue to be—hunter-gatherers (Fortier 2009; Patin *et al.* 2009; Peluso *et al.* 1995; Bahuchet *et al.* 1991; Hart and Hart 1986;). Indigenous people use the natural areas where they live for hunting animals and for collecting non-timber forest products (NTFP), fuel-wood, and medicinal plants (McNeely 2004; Bird-David 1992; Guha and Gadgil 1989). Through these activities, which may be daily or periodic, indigenous people interact in varied and sustained ways with the landscapes where they reside. In addition to ecological knowledge creation and propagation in this 'traditional' fashion, what has been termed Traditional Ecological Knowledge (TEK; Berkes *et al.* 2000), people's knowledge base is likely to be influenced and enriched by the assimilation of information from other 'local' sources embedded within the larger society of which indigenous people are a part (e.g., forest managers, recent forest dwellers, NTFP traders, researchers). We use the terms TEK and local knowledge interchangeably in order to include knowledge that exists both traditionally as well as knowledge that has been recently assimilated.

The role of traditional or local knowledge in forest management has been explored in various ways. Research on indigenous botanical and zoological knowledge systems (e.g., Sears *et al.* 2007; Shackleton *et al.* 2007; Shrivastava and Heinen 2005; Basset *et al.* 2004; Bhargava 1983) has improved our understanding of natural resource management in peopled landscapes, e.g., whale conservation in Alaska (Huntington *et al.* 2000), fire management in agro-pastoral systems in Bolivia (McDaniel *et al.* 2005), or management of NTFP resources in India (Setty *et al.* 2008). These studies suggest that the incorporation of local knowledge with prevailing knowledge systems could lead to long-term sustainable management regimes. Indeed, TEK systems have been likened to adaptive management with "emphasis on feedback learning, and its treatment of uncertainty and unpredictability intrinsic to all ecosystems" (Berkes *et al.* 2000). Additionally, Agrawal *et al.* (2008) posit that globally, local communities who rely on natural resources from forests are largely voiceless when it comes to management as 86 % of forested and wooded areas are under exclusive State control. Studies that urge researchers and managers to incorporate local knowledge in their way of thinking could therefore be considered as seeking to bring into the mainstream such knowledge sources, and eventually legitimize the use of natural resources by local communities within a power structure that is largely exclusive in its management regime.

There may be therefore an intrinsic value in developing approaches that seek common ground between local and scientific knowledge by discussing complementarity and differences between them. In the context of biological invasions, such methods would enrich our overall knowledge of the dynamics of human impacts on natural landscapes and the effects of invasive species-impacted natural landscapes on humans. Invasive species are considered a significant threat to biodiversity. Invasive species are defined as non-native species that cause negative impacts in recipient systems (Colautti and MacIsaac 2004). The negative effects of invasive species are seen at multiple scales. At the ecosystem level invasive species have been found to increase flammability (Nunez and Simberloff 2005), alter nutrient cycling (Funk and Vitousek 2007), and affect hydrology (Le Maitre *et al.* 2002). At the level of biological communities invasive species can out-compete native species, thus resulting in loss of biodiversity over time (Strayer *et al.* 2006). Additionally, invasive species can disrupt native species regeneration and negatively affect the composition and structure of invaded habitats (Gooden *et al.* 2009; Kennard *et al.* 2002).

Due to their largely negative effects, invasive species affect human society across local and regional scales. Local societal effects of invasive species could take the form of reduced livelihoods for forest-dependent communities resulting from suppression of species that are otherwise consumed or sold (Ticktin *et al.* 2012; Jones *et al.* 2009; Chapin *et al.* 2000). Regionally, societal effects of invasive species could take the form of a reduction in the supply of ecosystem services e.g., water (Pejchar and Mooney 2009; Le Maitre *et al.* 2002). As a result, many countries now allocate substantial resources to the control and eradication of invasive species (Lovell *et al.* 2006; Perrings *et al.* 2002; Zavaleta 2000), with some countries like the United States spending up to USD 120 billion annually (Pimentel *et al.* 2005).

Given the many deleterious effects of invasive species, ecological monitoring has been recognized as an important tool to track the spread and effects of invasive species worldwide (Delaney *et al.* 2008; Ricciardi *et al.* 2000; Blossey 1999). Data for tracking biological invasions can come directly for instance from long-term monitoring plots or by using indirect methods such as comparing the accumulation of known invasive species within floras over time. Examples of systematic long-term monitoring are rare due to the high costs of implementation (Basset *et al.* 2004; but see Bogich *et al.* 2008), and an inadequate appreciation of the intrinsic value of ecological monitoring (Perrings *et al.* 2002). Furthermore, the lack of ecological monitoring projects is often due to the absence of requisite long term and collaborative/institutional arrangements to oversee their design and implementation. Lastly, ecological monitoring efforts that are recent in their genesis cannot shed light on the spread of invasive species that may have begun decades or centuries ago.

But there are ways to overcome the lack of long-term information regarding invasive species, e.g., through historical forest cover or vegetation maps and aerial photographs (Von Holle and Motzkin 2007; Civille *et al.* 2005), or through the compilation of anecdotal information from news articles, popular science writings, or travel writings (e.g., Coates 2006; Hansen and Clavinger 2005; Crosby 2004). Additionally, records kept by amateur naturalists could also be used to track the trajectory of biological invasions (Silvertown 2009). However, one aspect that has been hitherto under-researched but could provide valuable information is examining how forest-dwelling and dependent communities observe and interpret biological invasions.

The objectives of this study are to examine the perceptions of the indigenous Soliga community about *Lantana camara* invasion and its impacts on forest process and structure in a social-ecological system in the Western Ghats in peninsular India. Soliga's responses are discussed in relation to current scientific understanding of *Lantana camara* ecology and management. This study is an attempt to seek a convergence of local and scientific knowledge to enrich our understanding of *Lantana camara* invasion and its impacts, with the potential to improve ecosystem management. We also attempt to 'expand modes of evaluation' of local knowledge with scientific knowledge to table, rather than only cross-validate, information from these two different worldviews, as suggested by Bohensky and Maru (2011).

Methods

Study Area

We conducted this study in the Biligiri Rangaswamy Temple Wildlife Sanctuary (hereafter BRT), located in the Western Ghats mountain range in Karnataka State, India. The sanctuary covers an area of 540 km^2, and is located between 77°–77° 16′ E, and 11° 47′–12° 09′ N. The BRT terrain is hilly, with elevation ranging from 600–1800 m above sea level. The sanctuary receives rainfall from both the southwest monsoon (June-September) and the northeast monsoon (October-December), with a pronounced dry period between January and March. Further details of the area are given in Sundaram and Hiremath (2011).

The BRT sanctuary is part of the Western Ghats biodiversity hotspot (Mittermeier *et al.* 2004; Myers 2003) and was designated as a wildlife sanctuary in 1973 (Barve *et al.* 2005). Prior to 1973, Soliga resident in BRT practiced shifting agriculture. They also hunted game and gathered wild tubers, fruits, and honey to supplement their diet. Additionally, the forest department managed areas within present-day BRT for timber, bamboo, and grass resources (Sundaram 2011). Post-1973, once BRT came under the purview of the Wildlife Protection Act, the Soliga practices of shifting agriculture and hunting were banned (Setty *et al.* 2008). The extraction of timber, bamboo, and grass by the Forest Department was also suspended. Additionally, as mandated by the Wildlife Protection Act, fire prevention was initiated and the setting of forest fires was declared illegal (Madegowda 2009). Forest fires continue to occur in BRT, albeit on an infrequent basis (Sundaram 2011).

Lantana camara in BRT

Lantana camara (hereafter lantana) is a straggling shrub native to Central and South America, and is one of the most widely distributed invasive species in India. Lantana was introduced into multiple locations in India at different times (Sharma *et al.* 2005; Cronk and Fuller 1995), although its earliest documented introduction dates back to 1809 (Cronk and Fuller 1995). Reports about the invasive nature of lantana, including its spread and effects on timber species, began to appear in the literature during the early twentieth century (Anon 1942; Iyengar 1933; Tireman 1916), i.e., within approximately a century of its arrival. These accounts consist largely of observations made by foresters and are immensely valuable to trace the trajectory of lantana invasion in India. In BRT we know that lantana was first reported in 1934 (Ranganathan 1934). Preliminary conversations with the resident Soliga community indicated that the rapid spread of lantana commenced during the 1970s, possibly due to the occurrence of forest fires that created an empty understory for lantana to occupy (Hiremath and Sundaram 2005). Additionally, because lantana is resistant to fire and can resprout in response to being burnt, Hiremath and Sundaram (2005) hypothesized that lantana invasion could be encouraged by fire occurrence, while frequent fires, in turn, would be encouraged by lantana—a positive feedback.

Vegetation in BRT was first inventoried in 1997 and indicated that lantana was restricted in its spatial extent and density (Murali and Setty 2001). This inventory was repeated by Sundaram and Hiremath (2011) in 2008, and indicated that lantana had not only increased in spatial extent, but also in density, and was accompanied by significant negative effects on native biodiversity. Investigations into the mechanisms underlying lantana invasion in BRT suggest that proximity to existing lantana and the high density of lantana seeds in soil vis-à-vis seeds of native species have played important roles in enhancing lantana's success (Sundaram *et al.* unpublished). However, given that systematic monitoring of lantana began only in 1997, and given that lantana was first observed in BRT in 1934, gathering information from the Soliga could provide more long-term insights into the invasion process.

The Soliga

The Soliga (literally, 'people of the bamboo') are a tribal people largely concentrated in the Chamrajnagar, Kollegal, Yelandur, and Gundlupet talukas (provinces) of the Indian state of Karnataka. The Soliga are genetically related to other tribal groups in the region, such as the Jenu Kuruba and Kadu Kuruba (Kumar 2008). The Soliga speak a language they call Soliga *nudi* (literally, 'Soliga language'), which has been classified as a South Indian Dravidian dialect closely related to the larger Kannada and Tamil languages. The Soliga language is a spoken one, and has no script.

The Soliga trace their history in BRT back several generations, suggesting that they have resided in this area for a few centuries at least. However, in the last few decades their interactions with this landscape have been punctuated by a series of administrative and legal changes. After BRT was declared a wildlife sanctuary in 1973, the Soliga shifting-cultivator and hunter-gatherer lifestyles changed significantly. Most Soliga living in the forest interior were sedentarized in settlements called 'podus,' and some Soliga received titles to plots of cultivable land ranging in size from 0.5 to 2 ha. Landed Soliga now subsist from cultivating rain-fed crops of finger millet, maize, and vegetables. Although shifting cultivation and hunting were banned, the Soliga retained usufruct rights to the collection of NTFP and a large proportion, nearly 50 % (Hegde *et al.* 1996), of their income was generated through the sale of NTFPs such as honey and *Phyllanthus sp.* fruits. A 2002 amendment to the Wildlife Protection Act put a stop to this practice in 2005–06, restricting the collection of NTFPs strictly to subsistence use, although in practice collection has been permitted intermittently. However, affirmative-action legislation like the Forest Rights Act (Government of India 2006), which seeks to empower tribal communities in India, has recently resulted in the Soliga community gaining *bona fide* usufruct rights for the collection of NTFPs in BRT (Shrivastava 2011).

Today there are 62 Soliga settlements either within or in close proximity to BRT and the population of Soliga in BRT is approximately 16,000 (Madegowda 2009). In addition to income from cultivation and NTFP collection, some Soliga also augment their income by seeking seasonal employment in coffee plantations in BRT during the coffee picking season, or by working for the Karnataka Forest Department to clear lantana and maintain forest roads within BRT.

Interview Schedule

We used an interview schedule to gather information on various aspects of lantana invasion (Appendix 1). Interview schedules, where the interaction is informal, conversational and flexible compared to other purely stimuli-response style instruments like questionnaires, were an appropriate instrument to generate such qualitative information. In order to build a sample of interviewees in a 'purposive' (a non-random sampling method employed in qualitative social science) manner, village elders from five podus were consulted. Elders were given details about the objectives of the study and were asked to provide names of potential interviewees who would fit in one or more of three broad a priori categories: (a) other village elders, (b) NTFP collectors, and (c) fuel-wood gatherers. These categories were generated in order to ensure a representative proportion of interviewees who had long-term knowledge of the forest (village elders), or who accessed the forest on a regular basis (NTFP collectors, fuel-wood collectors). In order to maximize the spatial representation of respondents, elders were also requested to provide details of potential interviewees from podus as widely spread across the landscape as their knowledge would permit.

Names of 55 potential interviewees belonging to 17 podus from across BRT were provided. Of these the responses of a total of 47 people were recorded between July and October 2008. Prior informed consent was obtained from each respondent after explaining the aims and objectives of the study. Interviews were conducted in Kannada. The mean duration of interviews varied from 45 to 96 min, and was on average 55 min. A digital voice recorder was used to record data. All interviews were then transcribed and translated into English. Thereafter, individual responses to each conversation topic (e.g., natural history of lantana invasion) were collated in a single file, along with corresponding details like respondent age and respondent location. Similar responses were then grouped together for analysis and to calculate summary statistics.

The age of respondents ranged from 35–65 years, with a mean age of 44 years. All 47 respondents were male. Although attempts were made to interview women, it was not possible to do so. Soliga society is largely male-dominated. Moreover, the people who conducted interviews were male, and interviewing women was not possible. The information presented in this study therefore lacks gendered perspectives of lantana invasion in BRT.

Ecological Data

Soliga responses regarding lantana invasion were juxtaposed with corresponding ecological data (Sundaram 2011; Sundaram and Hiremath 2011; Sundaram *et al.* unpublished data). These data included the long-term (11 year) change in the basal area of lantana, change in the basal area of native species, and change in the density of important tree species (both NTFP species and canopy dominants) in BRT. The first two components (change in basal area of lantana and of native species) are related to changes in forest structure, while the third (changes in the density of important tree species, including NTFP species) is related to the effects of lantana on Soliga livelihoods. Changes in tree species could have occurred due to other reasons, such as illegal logging, and may not be directly attributable to lantana alone. However, since BRT was declared a protected area in 1973, illegal logging, though it probably occurs, is perhaps not as prevalent here as in neighboring forests in the region. Thus its effects on species richness are likely to be minimal.

Basal area of native species in each plot was calculated by summing the cross-sectional area of all stems occurring within the plot. Baseline data for basal area and tree density came from a 1997 study conducted by Murali and Setty (2001). Changes in basal area and density from 1997 to 2008 were assessed using data collected during 2007–08 (Sundaram and Hiremath 2011). A *t* test was then used to check for differences in the basal area of native species between 1997 and 2008. Change in basal area of lantana from 1997 to 2008 was assessed the same way. Statistical analyses were performed using R 2.9.0. (R Development Core Team 2009).

Studies indicate that the five economically important NTFP species in BRT are *Phyllanthus emblica* and P. *indo-fischieri* (collectively known as *amla*; Indian gooseberry), *Acacia sinuata* (*seege*; soap-nut), *Sapindus laurifolius* (*antuwala*; soap-berry), *Terminalia bellerica* (*taare*; belliric myrobalan), and *Terminalia chebula* (*arale*; black myrobalan) (Setty *et al.* 2008; Hegde *et al.* 1996). We calculated the change in the average number of stems per plot from 1997 to 2008 of each of these important NTFP species. Similarly, we calculated the change in density from 1997 to 2008 of important canopy dominants such as *Anogeissus latifolia*, *Terminalia crenulata*, *Dalbergia latifolia*, *Pterocarpus marsupium*, and *Kydia calycina*.

Results

Natural History of Lantana Invasion in BRT (Origin, Spread, and Mechanisms of Spread)

More than half the respondents (26/47; 55 %) were unaware of lantana's geographical origins. Respondents who expressed knowledge about lantana's origins (21/47; 45 %) said that it was from 'abroad.'

A large majority of respondents (~40 %) believed that lantana's rapid spread has occurred over the past 15 years (Fig. 1). However, about a fifth of the respondents felt that the spread of lantana began 30 years ago (Fig. 1). All respondents who felt that lantana spread began 30 years ago were from podus located in the forest interior (Banglipodu, Bhutani, Boodipadaga, Kanneri Colony, Bedguli, Seegebetta) relative to other podus (X^2=16.69, *d.f.*=1, p<0.0001, n=47). It may be that lantana was introduced as a hedge plant in coffee plantations located in the BRT interior before making an appearance in the plains, thus possibly influencing their response. Additionally, respondents who felt that lantana spread began 30 years ago were on average older (mean 53.2±2.5 years) than all other respondents (48.4±3.4 years). This difference in ages was statistically significant (X^2=13.45, *d.f.*=1, p=0.0002, n=47).

The Soliga largely attributed the rapid spread of lantana in BRT to four factors. The first was lantana's prolific fruit production and wide dispersal. A large proportion of respondents (37/47; 79 %) believed that birds and mammals like chital, sambar, civet, pig, and sloth bear are responsible for the spread of lantana in BRT. The copious fruiting of lantana provides food that is easy for these animals to gather, with lantana gaining dispersal advantages.

The second factor cited was the change in fire regimes in BRT. Half the respondents (24/47; 51 %) believed that the spread of lantana in BRT was due to the decrease in fire frequency, which occurred due to fire prevention measures that were put in place by the Forest Department after 1973, when the BRT wildlife sanctuary was created. The Soliga believe that regular fires suppressed lantana because fires killed young lantana plants as well as lantana seeds present on the soil surface. Another reason proposed was that fires dry the soil, thus preventing lantana establishment. Respondents who attributed the spread of lantana to the decrease in fire frequency also believed that native species remain unaffected by forest fires because they have been exposed to forest fires historically. Of the respondents who believed that lantana was benefitted by an increase in fire frequency (19/47; 40 %), most mentioned that lantana resprouts readily in response to fire. They also explained that dense lantana leads to the occurrence of intense fires, and that native species present in the midst of dense lantana are killed by fire, leading to a decrease in the abundance of native species over time.

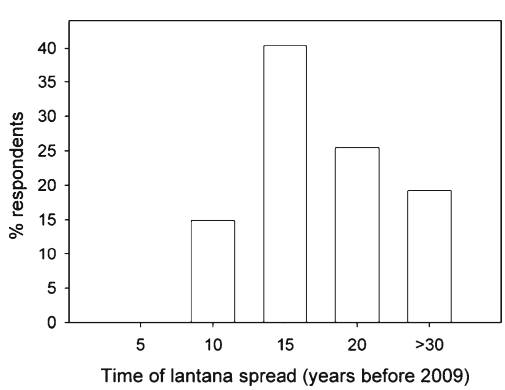

Fig. 1 Distribution of the responses (n=47) related to the time of lantana spread in BRT

Observations and interpretations about the role of fire regime in lantana spread seemed to be influenced by age of the respondent. Respondents who believed that a decrease in fire frequency had led to an increase in lantana were on average older (mean 55.4±4.5 years) than respondents who believed that lantana was benefited by an increase in fire frequency (mean 43.5±5.2 years; X^2=1.47, *d.f.*=1, p=0.23, n=43). Four respondents did not have an opinion on fire as a factor underlying lantana spread.

Although respondents had differing thoughts on the link between forest fires and lantana invasion, almost all respondents (45/47; 96 %) believed that early-dry season forest fires ('*tharagu benki*;' litter fires) that were traditionally set prior to 1973, were important to maintain what they called the 'health' of the forest. They said that fires occurring in the early dry season (January, February) did not harm saplings of native species, because only the litter burnt. These ground fires passed through an area quickly, minimizing the exposure of plants. Furthermore, ash from these fires was considered good fertilizer for native species. Burning the understory was likened to cleansing, with many saying that a clean and clear understory was necessary for a healthy forest. However, almost all respondents (45/47; 96 %) believed that it was not possible to return to the early dry season fire regime now due to extensive lantana invasion. Due to the thick growth of lantana, fires would become destructive canopy fires. Many (23/47; 49 %) cited recent large fires that occurred in 2007, where entire trees burnt, adding that fires in areas with dense lantana would be catastrophic to trees in those areas.

The third factor to which the Soliga attributed the spread of lantana in BRT was historical over-extraction of grass and bamboo resources, a practice common prior to 1973. More than half the respondents (24/47; 51 %) believed that bamboo and grass were over-extracted from BRT, with bamboo being extracted before it could seed. The empty spaces left behind after grass and bamboo extraction were quickly occupied by lantana. Once lantana had established, bamboo seedlings were shaded out, resulting in the gradual reduction of bamboo over time. Similarly, the regeneration of light-demanding grasses was also affected by the increase in lantana density, leading to their gradual decline. About 38 % (18/47) of respondents did not believe bamboo and grass extraction to be a driver of lantana spread and fell back upon the seed dispersal argument for their explanation of lantana spread. Five respondents did not have an opinion.

Lastly, the Soliga described the effects of lantana invasion on the regeneration of native species as further contributing to lantana success in BRT. These reasons included seed germination limitations, and reduced seedling survival of native species under lantana. A large proportion of respondents (41/47; 87 %) believed that lantana success was enhanced because seedlings of native species are unable to establish on the thick layer of leaf litter that accumulates under lantana. These respondents believed that if native species germinate on lantana litter, the seedlings' roots are unable to reach the soil and therefore they do not survive. Additionally, respondents cited shading by the lantana canopy limiting survivorship of native seedlings. The same respondents reasoned that lantana germination is unaffected by lantana leaf litter because lantana seedlings possess fast growing roots that reach the soil before seedlings desiccated and died.

From the perspective of propagation of local knowledge, this detailed—and unanimous—answer to an open-ended question about the effect of lantana on the regeneration of native species was remarkable. The formulation of responses in this manner could be related to vocation. For example, NTFP collectors, irrespective of geographical location, pool their produce before transport to markets, and probably had opportunities to discuss many issues over the years about lantana invasions, leading to a consensus.

Changes in Forest Composition and Structure due to Lantana Invasion

A majority of respondents (45/47; 96 %) believed that subsequent to lantana invasion the forests in BRT had become degraded in terms of their species composition. They talked about the deciduous forests of BRT having a grassy understory prior to lantana invasion. Most respondents (42/47; 89 %) believed that the quantity of grass and bamboo had declined due to lantana invasion.

In addition, many respondents (40/47; 85 %) believed that the density of common tree species such as *Anogeissus latifolia*, *Terminalia crenulata*, *Dalbergia latifolia*, *Pterocarpus marsupium*, *Kydia calycina*, had reduced drastically as a result of lantana invasion. Field measurements support the perception of drastic reductions in tree density in the case of *Anogeissus latifolia* and *Kydia calycina*, but suggest that densities of the other species are largely unchanged (Table 1).

A large majority of respondents (40/47; 85 %) believed that there have been structural changes in the lantana-invaded forests of BRT particularly due to the reduction in the density of saplings (Sundaram and Hiremath 2011). People said that there are no young trees now, only old ones. Many respondents (40/47; 85 %) feared that once the old trees die, there will be nothing but lantana left in the forests of BRT.

The mean basal area of native species showed a reduction from 1997 (29.22±2.25 m^2/ha) to 2008 (26.68±2.16 m^2/ha; Fig. 2). However these differences were not statistically significant (t=0.81, p=0.42). On the other hand, the mean

Table 1 The density (± 1 s.e.) of important NTFP species and canopy trees in 1997 and 2008

Species	1997		2008	
	Mean density (stems/ha)	Number of plots in which present	Mean density (stems/ha)	Number of plots in which present
NTFP species				
Acacia sinuata	110.0±38.9	20	57.1±15.2	7
Phyllanthus emblica	162.2±23.7	74	154.2±46.4	42
Sapindus laurifolius	25.0±0.0	2	75.0±0.0	1
Terminalia bellerica	32.1±7.1	7	28.9±2.6	13
Terminalia chebula	83.7±13.7	26	53.9±10.5	13
Canopy dominants				
Anogeissus latifolia	985.3±117.9	90	350.6±48.6	88
Terminalia crenulata	117.1±15.6	57	94.0±13.7	62
Dalbergia latifolia	66.7±14.9	24	70.0±12.4	25
Pterocarpus marsupium	48.7±7.1	37	63.7±9.3	31
Kydia calycina	203.6±39.4	28	72.7±31.7	11

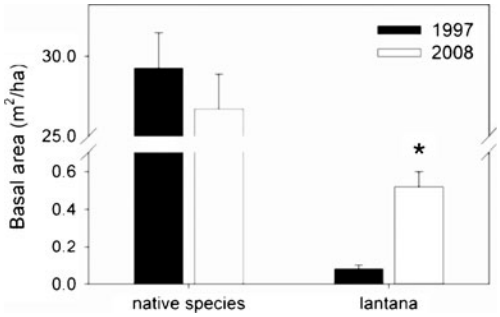

Fig. 2 The differences between mean basal area per plot of native species and of lantana in 1997 and 2008. Significant differences in the average values as identified by a *t* test are labeled with *. Error bars signify 1 standard deviation from the mean basal area

basal area of lantana showed a tremendous and significant increase from 1997 (0.08±0.02 m^2/ha) to 2008 (0.52±0.08; t=5.60, p<0.0001; Fig. 2).

In addition to the effects of lantana invasion on vegetation dynamics and structure, respondents also said that due to the negative effects of lantana invasion on native plants, negative effects on animal communities are observed in BRT. A large proportion of respondents (42/47; 89 %) believed that herbivores are suffering due to lantana invasion because lantana is largely unpalatable to wild herbivores. Since there is very little grass and bamboo left in BRT now, many animals are in an unhealthy condition and resort to crop-raiding to augment their diet (Table 2).

Lantana Invasion and Soliga Livelihoods

All respondents believed that lantana was making their daily lives more difficult. Lantana growth over forest paths impeded the collection of fuel-wood and other NTFP. All respondents said that as a result of the thick lantana undergrowth, they have either stopped or greatly minimized efforts at trying to maintain their forest paths. All respondents said that lantana had reduced the visibility inside the forest and that their encounters with dangerous animals such as elephants and bears are now more frequent than before.

Table 2 Summary and comparison of information available from local knowledge and scientific knowledge on lantana invasions in BRT

Aspect of lantana invasion	Local knowledge	Ecological studies	Concordance
1. Spread			
(a) Time of rapid spread	15 years (younger Soliga)- 30 years (older Soliga)	10 years (Sundaram and Hiremath 2011)	Little
(b) Dispersal syndrome	Birds, chital, sambar, wild pigs, sloth bear	Birds (Corlett 1998; Bhatt and Kumar 2001) and sloth bear (personal observations)	Some
(c) Dispersal limitations	Lack of dispersal limitations due to year-round fruiting and the production of large fruit crops	Year-round fruiting (Day *et al.* 2003), large fruit crops (Kaushik *et al.* unpublished), high density in the soil seed bank (Sundaram *et al.* unpublished)	Much
(d) Change in fire regimes	Fires control lantana when density is low, fires enhance lantana invasions when density is high	Increase in fire frequency increases lantana density (Hiremath and Sundaram 2005, Duggin and Gentle 1998)	Some
(e) Fire effects on lantana seeds	Fires kill lantana seeds on surface of soil	Fire kills seeds stored in soil (Sundaram *et al.* unpublished)	Much
(f) Extraction of grass and bamboo	Overextraction of grass and bamboo enhances lantana invasion	No data	
(g) Supressed native species regeneration	Lantana shades out seedlings and saplings of native species, forests in BRT are now bereft of saplings as a result	Reduction in sapling density with lantana invasion (Sundaram and Hiremath 2011, Ganesan unpublished data)	Much
2. Changes in forest composition and structure			
(a) Understory composition	Shift from a grass-dominated to lantana-dominated understory	No data	
(b) Overstory composition	Reduction in the density of several canopy species	Reductions in the density of some canopy species (Sundaram and Hiremath 2011)	Some
3. Effects on Soliga livelihoods			
(a) Density of importantant NTFP species	Reduction in the abundance of several NTFP species	Reduction in the abundance of several NTFP species (this study), reduced regeneration of amla in dense lantana (Setty *et al.* 2008; Ganesan and Setty 2004; Ticktin *et al.* 2012)	Much
(b) Human-wildlife conflict	Increase in crop-raiding by wild herbivores due to reduction in forage avail ability resulting from lantana invasion	Decrease in forage availability (herbs and shrubs) in areas invaded by lantana (Prasad 2010; Ticktin *et al.* 2012)	Much

Additionally, all respondents said that it is now exceedingly difficult for them to search for edible tubers due to the thick growth of lantana. Lantana invasion in the forest was also leading to increased crop raiding by animals such as wild pigs, all respondents said.

Respondents also said that the density of important NTFP species such as amla, soap-nut, soap-berry, belliric and black myrobalan have reduced as a result of lantana spread. Field measurements indicated that numbers of all NTFP species, with the exception of *Terminalia bellerica*, had decreased between 1997 and 2008. The number of plots in which these species were encountered in 2008 was less than the number of plots in which they were observed in 1997, indicating shrinkage in their occurrence (Table 1). Further, in the case of *Acacia sinuata* and *Terminalia chebula* not only was there a decline in the number of plots where these species occurred between 1997 and 2008, there was also a decline in their density between 1997 and 2008, indicating a reduction in their relative abundance.

Discussion

A Soliga Theory of Lantana Invasion

Adaptability or 'feedback learning' according to Berkes *et al.* (2000) is an intrinsic part of TEK systems. The development of world views based on the accumulation of traditional and local knowledge over time have shaped management regimes that deal with multiple species (e.g., in fisheries; Huntington *et al.* 2000), landscape patchiness (e.g., fires; McDaniel *et al.* 2005), and ecological surprises (e.g., fluctuation in the production of NTFP; Setty *et al.* 2008). The Soligas' historical association with the BRT forest has no doubt helped them develop an adaptive theory of lantana invasion, based on knowledge they have accumulated of its natural history, the mechanisms of its success, and its ecological impacts on native plant and animal communities. However, respondent age plays an important role. While the Soliga differ on how long ago lantana started to spread almost 80 % agree that the rapid spread of lantana has been a recent (in the past 30 years) rather than a historical phenomenon. Those respondents who believed that lantana's spread began earlier were typically older and are therefore more likely to recollect what the forests of BRT were like in the 1970s or even in the 1960s. Younger respondents, on the other hand, probably mention lantana increase as mostly occurring during the past 3 decades because they were too young to have any recollection of the forest during the 1970s or 1980s. From a methodological perspective, a question in which time plays an important role (in this case, time of rapid spread of lantana) is probably an inappropriate one to ask of young respondents, since their knowledge is fairly recent. However, the response of young Soliga to other questions without an explicit temporal component (e.g., does lantana affect native plants) is less problematic since responses would be indicative not only of their own knowledge, but also of the adaptive and feedback oriented learning process intrinsic in LK. This difference in recall based on respondent age is sometimes referred to as a shifting or moving baseline, and occurs due to the absence of standards for comparison (Huntington *et al.* 2004).

Studies from elsewhere have shown that traditional and local knowledge systems typically treat causality as complex and nuanced. For example, McDaniel *et al.* (2005) found that Chiquitano Indians took into account multiple factors influencing the behavior and impacts of fire in their use of fire as a management tool in savannas in Bolivia. These factors included wind direction, relative humidity, soil moisture, and the trade-off between fire intensity and soil fertility. Similarly, whilst describing the reasons for lantana spread, the Soliga invoke multiple reasons, citing lantana's lack of dispersal limitation, the historical extraction of bamboo and grasses, and the change in anthropogenic fire regime.

The link that the Soliga make between forest fires and lantana invasion is particularly noteworthy for the nuance that they bring to the understanding of fire regimes. The Soliga view of fire is not static but has evolved with the changing landscape and changing management practices. On the one hand, older Soliga support the use of fire as a management tool of benefit to the forest and credit burning for having prevented the spread of lantana historically. Frequent burning was a widespread management practice prior to the creation of the protected area. This was also a time when lantana density was lower than what is it is today, and the understory was presumably dominated by grasses and bamboo. Younger Soliga, on the other hand hold that an increase in fire frequency would be of detriment to the forest and would encourage the spread of lantana. They base this on their observation of the present-day forest, where intense fires in lantana dominated areas cause damage to native trees. These Soliga are too young to recall the forests of BRT with a grassy understory and bamboo before lantana became widespread. Be that as it may, the Soliga people (both old and young) are clear that a return to historical fire regimes is out of the question due to the present state of lantana invasion in BRT. Fires, if they occurred now, would indeed be destructive, due to the accumulation of lantana biomass, resulting in more intense fires. Thus, knowledge of older Soliga is likely shaped by the present invaded condition of the forest. However, they are aware of a set of conditions under which fires were beneficial. Younger Soliga, on the other hand, augment their own perception of the forest system with knowledge additions from older Soliga as well. Adaptability and feedback learning is therefore probably occurring in older and younger Soliga. Additionally, it could be assumed that both older and younger Soliga adapt to, and assimilate, knowledge from members of the larger BRT society.

The Soliga perception of fire as a management tool is similar to how the Kraho, an indigenous people native to the Brazilian savanna, use and perceives fires. Mistry *et al.* (2005) found that the Kraho use of fire in a savanna landscape was dynamic and nuanced. The Kraho refer to fires as being 'good and bad at the same time' (Mistry *et al.* 2005). Depending on the purpose of the fire, the timing of the lighting changed. For example, fires to protect swidden agriculture were lit during April each year, while fires to induce the fresh growth of grass for livestock were lit during May (Mistry *et al.* 2005).

By comparing results from this study on Soliga local knowledge with results from other scientific studies on lantana in BRT, it is possible to examine the levels of concordance between them. Overall there was broad agreement between the results of this study on Soliga local knowledge and the results of studies that used scientific approaches to study lantana invasions in BRT (Table 2). However, there are some aspects of local knowledge that have not been empirically tested by scientific studies yet (e.g., over-extraction of grass and bamboo resulting in lantana invasion). A deeper understanding of lantana invasions in BRT will no doubt emerge when future studies examine these gaps.

Revisiting the Lantana-Fire-Cycle Hypothesis

Information on the link between forest fires and lantana invasion has been enriched by Soliga knowledge, and could potentially challenge existing views of fire prevention—views held by biologists and managers alike. The Indian Forest Act of 1927 stated that the setting of fire in any reserved forest was an offense punishable by the levying of fines, or the suspension of rights such as grazing or firewood collection (Government of India 1927). However, the no-fire rule could not be strictly enforced due to logistical difficulties. People continued to burn forests to facilitate their collection of forest products or sometimes as acts of retaliation against restrictive state policies (Hiremath and Sundaram 2005). Anecdotal accounts indicate that fire was an almost annual phenomenon in BRT (Anon. 1905; Sanderson 1882). Contemporary data also indicate that elsewhere in the Western Ghats, the frequency of forest fires have increased, a phenomenon attributed to increasing habitat fragmentation and demographic pressure (Kodandapani *et al.* 2004).

It has been proposed that lantana could benefit from an increase in fire frequency (e.g., Hiremath and Sundaram 2005; Sharma *et al.* 2005). Adult lantana plants are not killed by fire, and resprout after being burnt (Day *et al.* 2003). Fires that occur in lantana-invaded areas are likely to burn hotter, thereby affecting native species. Over time, the mortality of native tree species that cannot withstand the effects of fire, coupled with resprouting lantana, creates a feedback loop that benefits lantana (the 'lantana-fire-cycle hypothesis;' Hiremath and Sundaram 2005).

Results from this study suggest that the lantana-fire-cycle hypothesis may indeed be valid, but its validity is specific to a certain phase of the lantana invasion trajectory (Fig. 3). Invasive species typically go through three phases—arrival, establishment, and spread (Sakai *et al.* 2001). It is possible that frequent early-dry-season fires could have potentially kept lantana in check between the 1930s (1934 is the earliest record of lantana in BRT) and 1970s (when BRT became a wildlife sanctuary and fire prevention was strengthened), coinciding with the period between lantana's arrival in BRT, but before it had become widespread. After 1973 and in the years succeeding it, either due to strict fire prevention, or because lantana had gradually become more widespread by this time, (i.e., the spread phase), or both, infrequent fires that occurred in by-now lantana-invaded areas were probably to the detriment of native species, but to lantana's advantage, resulting in its further spread. This would be consistent with the Soliga understanding of the role of fire, with older Soliga suggesting that fires had a beneficial role to play and helped control lantana, and younger Soliga suggesting that fires played a detrimental role and helped to spread lantana. The development of the lantana-fire-cycle hypothesis by Hiremath and Sundaram (2005) is similar to the way younger Soliga view the relationship between forest fires and lantana, since the hypothesis was proposed based on observation of lantana and fire between 2000 and 2003, by which time lantana was already widespread.

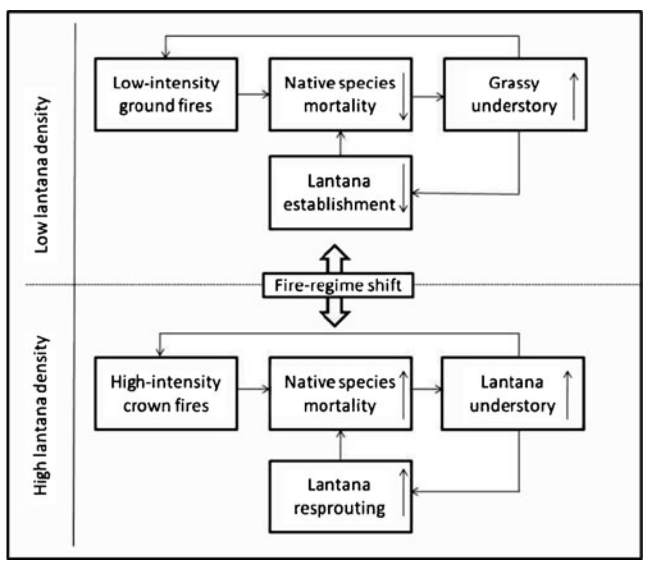

Fig. 3 Schematic representing Soliga views of the relationship between forest fires and lantana invasion in BRT, suggesting a shift in fire regime as lantana density changes. Adapted from Hiremath and Sundaram (2005)

The conservation implications of drawing from both local knowledge sources and scientific sources are manifold. Drawing from local knowledge and scientific sources has challenged and helped refine existing knowledge, in this case the lantana-fire-cycle hypothesis. It becomes apparent from this study that documenting the Soliga view on lantana invasions has also helped provide insights into the potential role of fire in the dynamics of these forests. Indeed Soliga TEK has benefitted other studies, particularly those on non-timber forest products such as *Phyllanthus emblica* and *P. indofischieri* (Rist *et al.* 2010; Setty *et al.* 2008). Setty *et al.* (2008) found high levels of agreement between Soliga estimates and scientific monitoring estimates of *Phyllanthus* yield. However, Rist *et al.* (2010) found that Soliga TEK about mistletoe infections of NTFP species in BRT provided both concordant and discordant information when examined alongside ecological data. For example, Soliga TEK and scientific data indicated that the forest types affected by a mistletoe hemi-parasite and the seasonal fruiting patterns of mistletoe were concordant. However, Soliga TEK on how mistletoe fruits were dispersed and the degree of susceptibility of species to being infected by mistletoe differed from conclusions drawn from scientific approaches (Rist *et al.* 2010). Be that as it may, Soliga knowledge on other ecological issues, such as decline in honey bee populations and human-wildlife conflict are now being explored in detail, and appear to complement existing ecological information (Nitin Rai and R. Siddappa Setty, personal communication). From these studies, the value of tabling local knowledge with scientific knowledge is evident. At the same time, the limitations of both scientific and local knowledge could no doubt initiate more reconciliatory research.

Progressive legislation in India, such as the recent Forest Rights Act (Government of India 2006) recognizes co-management as a viable management alternative in peopled ecosystems, and may provide a legal framework for evolving adaptive management systems for lantana-invaded forests. The first steps of recognizing livelihood rights for the Soliga in BRT, and allowing the collection and sale of NTFP have recently occurred (Shrivastava 2011). Additionally, since the Act also solicits the involvement of local communities in protecting and regenerating their forests for livelihood security, co-management solutions could be actively explored and be legally tenable. Participatory and inter-disciplinary research involving indigenous people, scientists and park managers has been recognized as a priority for achieving biodiversity conservation and livelihood protection in human-dominated landscapes (Chazdon *et al.* 2009). In this instance, a logical next step would be further empirical investigation of hypotheses arising out of Soliga local knowledge. The growing body of research on Soliga knowledge of several aspects of BRT as a landscape could technically lead to the formulation of adaptive management approaches that address the restoration of the lantana-invaded landscape.

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Appendix 1

Broad conversation topics about lantana invasions in BRT that were used in the interview schedule. Topics were not necessarily broached with respondents in the order in which they are listed here.

1. Where did lantana originate?
2. When did lantana begin to spread rapidly?
3. Why is lantana such a successful plant?
4. What is the relationship between forest fires and lantana invasion?
5. Does lantana affect native plants?
6. Does lantana affect wild animals?
7. How has the forest changed after lantana invasion?
8. Does lantana affect your livelihood?

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