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Chapter X

DRY FOREST DEGRADATION AND TRADITIONAL LAND-USE IN THE CONTEXT OF SUSTAINABLE FOREST MANAGEMENT IN SRI LANKA

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Abstract

Understanding the impacts of anthropogenic disturbances on forest tree communities and the traditional knowledge associated with forest ecosystems will improve our understanding of dry forest service provision, and effective conservation and restoration interventions. In the Hurulu Forest Reserve, a tropical dry forest in north-central Sri Lanka, disturbance was classified into three levels (viz., least, moderately, and highly disturbed), and forest structure, tree species traits and tree species composition were determined at each level of disturbance. We studied traditional knowledge on forest agrarian systems and classification by interviewing local people. Results showed maximum number of tree species in highly disturbed forests, while the species diversity per plot was highest in least disturbed forests. The tree community composition under the different disturbance intensities was clearly distinct. Relatively high numbers of pioneer and early-successional species were recorded from the highly disturbed forests, whereas least disturbed forests were dominated by late-successional tree species that were also found geographically more broadly distributed in the intermediate and wet zone forest elements in Sri Lanka. Traditional knowledge on forest use classification and agronomic practices revealed similarities with a scientific approach and biodiversity conservation associated with Man and Biosphere (MAB) concepts, and also demonstrated their limits. Species composition, structure and traits are suitable as complementary guides to evaluate dry forest degradation, while traditional knowledge on land use is also important to develop answers for conservation and management of tropical dry forests..

Keywords: forest restoration, Hurulu Forest Reserve, shifting cultivation traditional knowledge

Introduction

Tropical forests cover less than 10% of the world’s land area, and are considered as the largest terrestrial biodiversity reservoir (Ghazoul & Sheil 2010, Gibson *et al*. 2011). Nevertheless, anthropogenic activities leading to habitat loss, land conversion, fragmentation and over-exploitation have caused severe loss and degradation of forest vegetation, and the associated biodiversity (Tittensor *et al*. 2014). Whilst, defining forest degradation is challenging (Ghazoul *et al*. 2015), we consider it here as a process leading to a temporary or permanent deterioration in the floristic attributes of the forest ecosystem, and subsequent loss of biodiversity and potential species extinctions, coupled with reduced productivity and increased carbon dioxide emissions (Grainger 1998, Pimm *et al*. 2014, Goetz *et al*. 2015). The rate of tropical forest degradation is increasing over time; it is thus imperative to understand the impacts of degradation on forest species composition and ecosystem services, and particularly their importance for the sustenance of forest-dependent communities.

Tropical dry forests experience a pronounced seasonality in rainfall and 2 to 6 months of drought each year, and are one of the most threatened, yet comparatively least protected, biomes (Janzen 1988, Hoekstra *et al*. 2005). They are often under greater threat than more humid forests due to denser populations and many of them are subjected to slash-and-burn (shifting cultivation) practices, fuelwood extraction, cattle grazing and expansion of agriculture (Hoekstra *et al*. 2005, Blackie *et al*. 2014). Tropical dry forests occur over large areas in central and south America, Africa, India and Sri Lanka, mainland South-east Asia and northern Australia (Gerhardt & Hytteborn 1992, Miles *et al*. 2006). Approximately, 70% (over 1 million hectares) of the forest cover in Sri Lanka are the dry forests (also commonly known as tropical dry mixed evergreen forests), restricted to the plains in the northern and eastern parts of the island that receive a mean annual precipitation of less than 2000 mm. Sri Lankan dry forests contain over 600 plant species, of which around 6% are endemic, and form part of the Western Ghats and Sri Lanka biodiversity hotspot (Gunawardena *et al*. 2004).

Human usage of forests in Sri Lanka has been recorded back to the Pleistocene (Roberts *et al*. 2015a,b), and has continued at various intensities since then. Dry zone forests of Sri Lanka were heavily affected by slash-and-burn agriculture during the first millennium BC until a change into an irrigated agricultural system occurred as a consequence of hydraulic civilization from 500 BC to 1200 AD (Webb 2002). However, the abandonment of the north-central kingdom in the thirteenth century provided an opportunity for the degraded dry forests to regenerate into a closed canopy forest and species to re-colonize and expand their distribution (De Rosayro 1961, Perera 2001). During the colonial period, ebony (*Diospyros ebenum*) and other timber species were exported, and rising socio-economic impacts in the pre- and post-independence period was responsible for extensive degradation of forests in Sri Lanka (Perera 2001, Laurance 2007). At present, illicit felling, illegal extraction of non-timber forest products, fuel wood collection, grazing/browsing, illegal cultivation of narcotic plant species, unplanned fires, spread of invasive species, pest and disease attacks on forest trees, and resource extraction disturb forest ecosystems at various intensities and spatial scales (Jayasingam *et al*. 1992, Perera 2001; Gunatilleke *et al*. 2008). This chronic degradation pressure from various anthropogenic sources reduces the dry forest's ability to recover effectively (Singh 1998) and arrests the establishment of late successional species (Medawatte *et al*. 2014).

Understanding and monitoring the ecology of forests is crucial to directly support policy development and decision making processes to conserve and restore them and for sustainable management. Using satellite imagery, Bastin *et al*. (2017) have provided an improved estimate of the extent of forests in dryland biomes, which has future implications for conservation and restoration of dry forests and hence the sustenance of forest dependent communities. According to the UNESCO's Programme on Man and the Biosphere (MAB), understanding the link between traditional knowledge and ecological aspects is important for sustainable use and conservation, as well as for the improvement of the affinity between people and their environment. Many researchers have reported that traditional knowledge is a valuable resource base for maintaining the balance between forest conservation and farming activities (Chun 2014, McNeely& Schroth 2006, Mulyoutami *et al*. 2009, Wangpakapattanawong *et al*. 2010). Hence, phyto-sociological studies are vital instruments to estimate floristic and structural changes in the forest and monitor the success of forest conservation mechanisms (Shono *et al*. 2007, Miles & Kapos 2008, Jayasuriya *et al*. 2011, Goetz *et al*. 2015). Whilst, studies from dry forests in central and southern India have elaborated human impact on forest structure, floristics (Sagar *et al*. 2003) and functional properties (Mandle & Ticktin 2015), comprehensive studies on dry forest degradation are still lacking in Sri Lanka (Jayasuriya *et al*. 2011).

Broadly, objective of this chapter is to assess the impacts of dry forest degradation on the forest plant communities through comparing the structure, community composition, and traditional forest-use practices of areas of the Hurulu Forest Reserve in the north-central dry zone of Sri Lanka subjected to different intensities anthropogenic disturbances.

METHODS

Study area and delineation of degradation gradients

The Hurulu Forest Reserve (hereafter Hurulu), with an extent of 25,217 ha, is an International Man and Biosphere (MAB) Reserve located in the north-central region of the dry zone of Sri Lanka (8°13' N, 80°52' E), which experiences a drought period (< 50 mm precipitation per month) from May to August. The north-eastern monsoon brings a mean annual precipitation of c. 1400 mm (based on the data collected from 2000 to 2010, at the nearest meteorological station, at Mahailuppallama, located c. 20 km from Hurulu; Fig. 1).

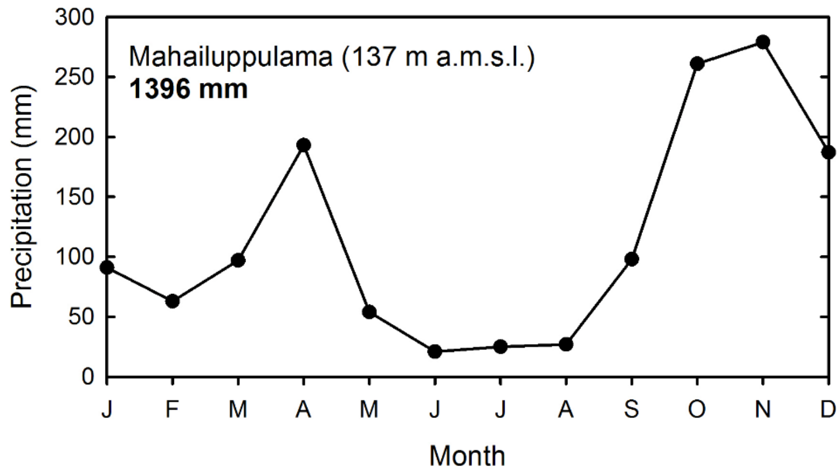

Figure 1. Mean monthly precipitation from 2001 to 2010 at Mahailuppallama, which is the nearest meteorological station to Hurulu Forest Reserve, Sri Lanka.

Sampling sites were ranked according to their past and existing degree of disturbance. Information on site history and traditional knowledge on forest use were obtained by interviewing local people, through ground surveys and consultation of available maps (Jayasuriya *et al*. 2011). Google Earth satellite images (Fig. 2) were used to determine trends in changes of vegetation cover in and around the Hurulu landscape. The Google Earth satellite images were sub-setted to include the entire area of Hurulu by dividing it into 400 grid cells (1 km x 1 km). The presence or absence of nine forest disturbance factors: (1) roads, and jeep or cart tracks, (2) human settlements, (3) forest plantations, (4) fragmented forest patches, (5) grasslands, (6) shifting cultivation areas, (7) paddy fields, (8) other agricultural lands, and (9) others, were recorded for each grid cell. The presence of any factor within a grid cell was assigned a 1 and the absence a 0, with the sum of these providing an 'impact factor' to quantify the level of disturbance in each grid cell. Grid cells with impact factors of 0 or 1 were considered least disturbed (LD), grid cells with impact factors of 2 or 3 were considered moderately disturbed (MD) and those with impacts factors of 4 or above as highly disturbed (HD) areas (Fig. 3).


Image © 2015 CNES / Astrium
Google earth
Imagery Date: 9/11/2014 8°15'53.69" N 80°52'33.25" E elev 143 m eye alt 1.61 km


Image © 2015 CNES / Astrium
Google earth
Imagery Date: 11/7/2014 8°11'41.53" N 80°48'58.30" E elev 124 m eye alt 2.32 km

Figure 2. Representative Google Earth images of land under different disturbance intensities in the Hurulu Forest Reserve, Sri Lanka: least disturbed (top), moderately disturbed (centre) and highly disturbed (bottom).

Floristic surveys and data collection

The tree flora of the study site was assessed using 20 quadrats of 10-m x 20-m that were placed randomly in each of the three disturbance intensities for a total of 1.2 ha surveyed. Each quadrat was divided into eight sub-quadrats (5-m x 5-m) to record the plant species, diameter and height of all living trees ≥1 cm diameter at breast height (dbh; 1.3 m). Voucher specimens of all species were prepared and deposited in the herbarium of the National Institute of Fundamental Studies, Kandy, Sri Lanka. Canopy cover readings were taken by the same observer with a convex spherical densiometer model A (Lemmon 1956) that was placed on a levelled tripod, 1 m from the ground.

Community perspective

The causes of forest degradation were identified through a questionnaire-based survey to respondants who were involved in farming in the area. Questions related to forest usage practices by local communities, their knowledge of local biodiversity, and perceptions of forest condition and management regimes (results will be reported more fully elsewhere).

Data analysis

The origin, biogeographic distribution, and conservation status of tree species were identified using a checklist of flowering plants, field guides and the National Red List of Sri Lanka (Ashton *et al*. 1997, Senaratna 2001, MOE 2012). Floristic diversity among sites subjected to different disturbance intensities was quantified by Shannon's diversity index, Simpson's diversity index and the reciprocal Berger-Parker index (Magurran 1988). Stem diameter frequencies of trees were calculated and the dominant trees of forest areas subjected to different disturbance intensities were identified by the Importance Value Index (Greig-Smith 1957) calculated as sum of the relative basal area (percentage of basal area of the species in all sample plots) relative density (percentage of the individuals of the species in all sample plots) and relative frequency (percentage of plots in which the species was found), of each species. Forest diversity, structural attributed and and canopy openness among the disturbance intensities were compared with one-way ANOVAs and subsequent Tukey's test.

The similarity of the forest tree communities under different disturbance intensities was determined using a Non-Metric Multi-Dimensional Scaling (NMDS) ordination, using Bray–Curtis similarities on square-root transformed abundances with an analysis of similarity (ANOSIM) test conducted to detect differences among the disturbance intensities. All the data were analysed using R statistical software (R i386 3.1.1) and BiodiversityR package version 2.5-3.

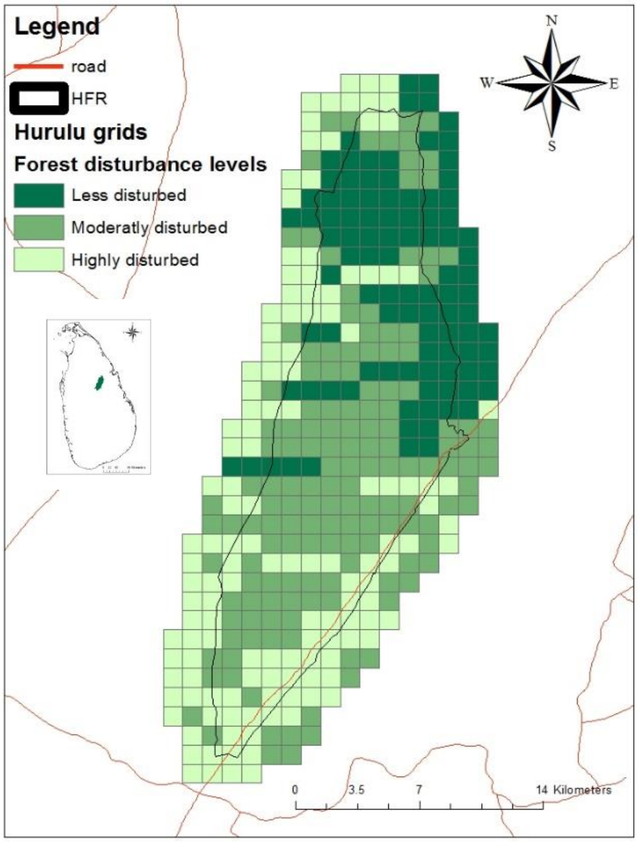
Legend
road
HFR
Hurulu grids
Forest disturbance levels
Less disturbed
Moderatly disturbed
Highly disturbed
N
W
E
S
0
3.5
7
14 Kilometers

Figure 3. Map of the Hurulu Forest Reserve and its location in north-central Sri Lanka (inset) showing six disturbance impact factors (0 to 5) calculated as defined in the text. Impact factors 0 and 1 correspond to least disturbed (LD) forest, impact factors 2 and 3 correspond to moderately disturbed (MD) forest, and impact factors 4 and 5 correspond to highly disturbed (HD) forest.

RESULTS

It was evident that shifting cultivation, settlements, road developments, establishment of forest plantations and subsequent forest fragmentation has transformed numerous parts of the closed canopy forests of Hurulu into degraded forests of different disturbance regimes, particularly in the western part of the reserve (Fig. 3).

Forest structure

The diameter size-class distribution of trees in the LD forest resembled a typical reverse 'J'-shaped curve compared to that of the MD and HD areas, as trees with a diameter greater than 80 cm were not observed in the MD and HD areas (Fig. 4). We recorded significantly lower stem densities for HD than LD and MD areas (Table 1). The density of large trees (diameter ≥ 50 cm) was reduced by 50 % in the HD areas, compared to the LD areas, and consequently the total basal area was reduced by a similar amount (Table 1). The vertical profile of the LD area of the forest showed a maximum tree height of 25 m arranged in three layers (understory: 0-10 m, canopy: 15-20 m, and emergent: > 25 m), whereas MD and HD forest areas had two and one layers, respectively. The least open canopy were recorded for LD, compared to the MD and HD (Table 1).

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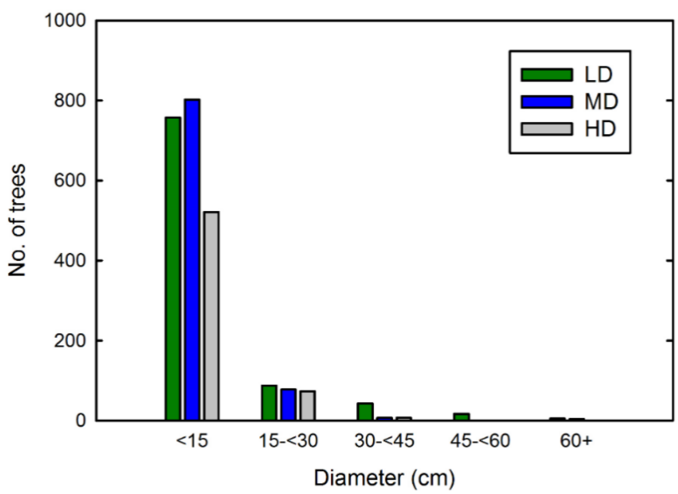

Figure 4.

Diameter size class distributions for tree communities of three different forest disturbance intensities in Hurulu Forest Reserve, Sri Lanka: least disturbed (LD), moderately disturbed (MD), and highly disturbed (HD).

Table 1. Tree species richness, origin, conservation status, geographical distribution, diversity and structural differences in areas of Hurulu Forest Reserve in Sri Lanka subjected to different disturbance intensities (LD = Least disturbed, MD = Moderately disturbed, HD = Highly disturbed; percentages are indicated in parentheses; letters within a row indicate differences according to a Tukey's test).

Vegetation attributes	LD	MD	HD
Taxa in different categories			
Species richness	54	59	68
Family richness	20	21	30
Endemic species	8 (15%)	6 (10%)	6 (9%)
Non-endemic (indigenous) species	39 (72%)	50 (85%)	55 (81%)
Introduced and naturalized species	0 (%)	2 (3%)	7 (10%)
Identified to genus level only	7 (13%)	1 (2%)	4 (6%)
Conservation Status (National Red List Sri Lanka 2012)			
Critically endangered	0 (0%)	0 (0%)	0 (0%)
Endangered	1 (2%)	1 (2%)	1 (1%)
Near threatened	5 (9%)	5 (7%)	6 (9%)
Vulnerable	2 (4%)	4 (7%)	2 (3%)
Least Concerned	38 (70%)	44 (75%)	50 (74%)
Total	47 (85%)	56 (95%)	61 (90%)
Not in the list	9 (16%)	3 (5%)	7 (10%)
Geographical distribution of top thirty dominant species (based on IVI value)			
(excluding introduced species)			
Dry lowland	12 (40%)	15 (50%)	15 (50%)
Dry lowland + Intermediate	8 (27%)	8 (27%)	9 (30%)
Dry lowland + Intermediate + Wet	10 (33%)	7 (23%)	6 (20%)

Diversity indices			
Shannon diversity	2.11±0.05 a	2.00±0.08 ab	1.90±0.09 b
Simpson's diversity	0.86±0.01 a	0.81±0.02 b	0.79±0.03 b
Berger-Parker evenness	0.28±0.01 a	0.36±0.03 b	0.39±0.03 b
Forest structure			
Total basal area (m^2 ha^{-1})	38.63±4.21 a	20.07±3.59 b	16.10±3.38 b
Total tree density (ha^{-1})	2275±201 a	2235±167 a	1515±135 b
Tree (dbh >75 cm) density (ha^{-1})	12±6.15 a	2±2.50 a	5±5.00 a
Canopy openness (%)	4.27±0.46 a	6.98±0.82 b	8.71±0.57 b

Forest diversity, composition and conservation status

A total of 102 species, belonging to 38 families, were recorded from the Hurulu plots; 92 were identified to species and the remaining 10 to genus only. The most species-rich families were Rutaceae (12 species), Euphorbiaceae (9), Fabaceae (8) and Rubiaceae (8). Whilst there was an increase in the total number of species and families recorded as the level of disturbance increased (Table 1), there were significant declines in species diversity indices at the plot level (Table 1). Though, the number of threatened categories showed no difference among the three disturbance classes, a greater proportion of species were considered as 'least concern' as disturbance intensity increased (Table 1).

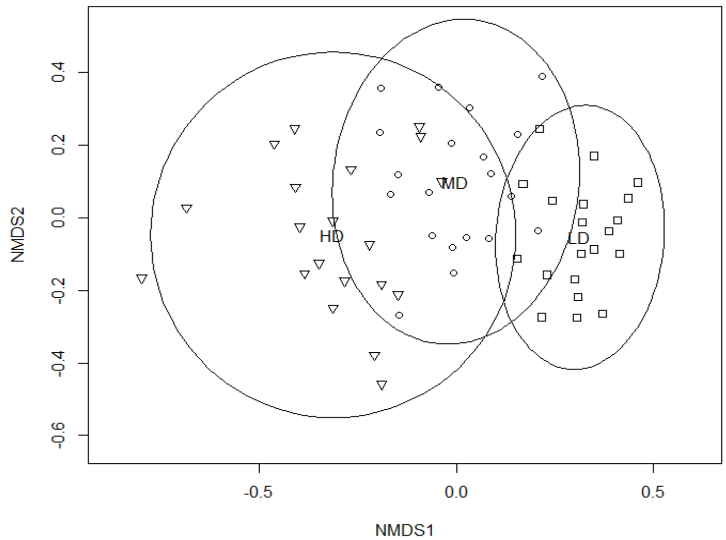

Figure 5. Non-metric multidimensional scaling ordination for tree communities of three different forest disturbance intensities in Hurulu Forest Reserve, Sri Lanka. Circled groups are significantly different at a probability level of 0.001 (ANOSIM). Squares = least disturbed (LD) forest, circles = moderately disturbed (MD) forest, inverted triangles = highly disturbed (HD) forest.

The 'important' species, i.e. those with high IVI, for the sampling areas along the disturbance gradient were different. In the LD areas, *Drypetes sepiaria* was the most important species followed by *Dimocarpus longan*, *Glycosmis mauritiana*, *Dimorphocalyx glabellus* and *Diospyros ebenum*. In the MD areas, the most important species were *Diplodiscus verrucosus* and *Mallotus philippensis*, while in the HD areas, *Streblus asper* and *Grewia damine* were most important (Tables 2, 3 & 4). The NMDS (Stress = 0.21), and corresponding ANOSIM analysis showed that the three forest disturbance intensities were significantly different from one another with respect to their tree communities (R = 0.711, P = 0.001; Fig. 5). The HD areas had a relatively high proportion of introduced and naturalized tree species, such as *Albizia odoratissima*, *Azadirachta indica*, *Gliricidia sepium*, *Lantana camara*, *Leucaena leucocephala*, *Ricinus communis*, *Senna siamea*, and *Tamarindus indica*. Pioneer and early successional species such as *Allophylus cobbe*, *Bridelia retusa*,

Table 2: Top thirty tree species that have highest IVI values for least disturbed (LD) forest in Hurulu Forest Reserve, Sri Lanka (DL = Dry lowland zone, IN = Intermediate zone, W = Wet zone).

Species	Ecology	Distribution	Frequency (%)	Density (%)	Dominance (%)	Importance value
Drypetes sepiaria	Sub canopy/ Scrubland	DL	5.71	5.27	25.13	36.12
Glycosmis mauritiana	Understory/ Scrubland	DL	7.76	15.60	1.87	25.22
Dimocarpus longan	Sub canopy	DL/IN/W	5.31	9.23	9.57	24.10
Diospyros ebenum	Canopy	DL/IN	5.71	2.42	12.03	20.16
Dimorphocalyx glabellus	Understory/ Scrubland	DL	6.12	10.88	2.52	19.52
Polyalthia korinti	Disturbed vegetation	DL/IN/W	7.35	9.01	2.05	18.41
Mischodon zeylanicus	Sub canopy/ Scrubland	DL	1.63	6.48	6.64	14.76
Pterospermum suberifolium	Canopy /Scrubland	DL/IN	5.71	2.75	4.40	12.86
Diospyros ovalifolia	Sub canopy /Scrubland	DL/IN/W	5.31	3.96	2.80	12.07
Mallotus philippensis	Understory	DL/IN/W	5.31	6.04	0.62	11.97
Memecylon sylvaticum	Understory	DL/IN/W	3.27	4.95	0.42	8.63
Discospermum sphaerocarpum	Understory/ Scrubland	DL/IN	3.27	2.42	2.25	7.93
Glenniea unijuga	Sub canopy	DL/IN	2.04	2.64	2.18	6.86
Diplodiscus verrucosus	Scrub/Sub canopy	DL	2.04	1.76	1.31	5.11
Vitex altissima	Canopy	DL/IN/W	0.82	0.22	4.02	5.05
Nothopegia beddomei	Sub canopy	DL/IN/W	2.45	1.65	0.75	4.84

Chloroxylon swietenia	Canopy	DL/IN	0.82	0.22	3.67	4.71
Manilkara hexandra	Canopy	DL/IN	0.41	0.33	3.79	4.52
Eugenia involucrata	Secondary vegetation	DL/IN	2.45	1.43	0.09	3.96
Cynometra zeylanica	Sub canopy	DL	1.22	1.10	1.63	3.96
Memecylon umbellatum	Understory	DL/IN/W	2.45	1.10	0.07	3.62
Syzygium cumini	Canopy	DL	0.82	0.22	2.57	3.61
Mesua ferrea	Canopy	DL/IN/W	0.41	0.66	2.49	3.56
Mitrephora heyneana	Understory	DL/IN	1.63	0.88	0.25	2.76
Diospyros vera	Sub canopy	DL	1.63	0.88	0.20	2.72
Pleiospermium alatum	Understory/ Scrubland	DL	0.82	0.88	0.96	2.66
Murraya paniculata	Understory/ Scrubland	DL	1.63	0.55	0.11	2.29
Lepisanthes tetraphylla	Canopy	DL	1.22	0.33	0.66	2.21
Haldina cordifolia	Canopy	DL	1.22	0.66	0.08	1.97
Litsea glutinosa	Sub canopy	DL/IN/W	0.82	0.33	0.74	1.89

Table 3: Top thirty tree species that have highest IVI values for moderately disturbed (MD) forest in Hurulu Forest Reserve, Sri Lanka (DL = Dry lowland zone, IN = Intermediate zone, W = Wet zone).

Species	Ecology	Distribution	Frequency (%)	Density (%)	Dominance (%)	Importance value
Diplodiscus verrucosus	Sub canopy /Scrub	DL	4.86	20.47	11.96	37.29
Mallotus philippensis	Understory	DL/IN/W	4.86	16.44	6.26	27.56
Schleichera oleosa	Canopy	DL/IN	2.43	1.34	15.44	19.22
Pterospermum suberifolium	Sub canopy	DL/IN	4.86	6.82	4.92	16.60
Drypetes sepiaria	Sub canopy/ Scrubland	DL	3.24	1.23	9.10	13.57
Azadirachta indica	Home gardens	DL/IN	1.21	3.02	9.21	13.45
Phyllanthus polyphyllus	Scrubland	DL	4.86	7.05	0.82	12.73
Holoptelea integrifolia	Canopy	DL	1.62	0.67	10.06	12.35
Syzygium cumini	Canopy	DL	2.02	1.12	8.31	11.45
Eugenia involucrata	Understory	DL/IN	5.26	3.13	0.19	8.59
Polyalthia korinti	Disturbed vegetation	DL/IN/W	4.05	2.91	0.43	7.38
Lepisanthes tetraphylla	Canopy	DL	4.45	1.57	1.30	7.32
Diospyros ebenum	Canopy	DL/IN	3.24	2.35	0.98	6.56
Dimorphocalyx glabellus	Understory/Scrubland	DL	2.43	3.02	0.60	6.05
Vitex altissima	Canopy	DL/IN/W	2.83	1.23	1.44	5.51
Cassia fistula	Home gardens/Sub canopy	DL	3.64	1.12	0.71	5.47

Murraya paniculata	Understory/scrub	DL	2.02	2.57	0.76	5.36
Dimocarpus longan	Sub canopy	DL/IN/W	2.02	1.79	1.50	5.31
Bauhinia racemosa	Scrubland	DL	1.62	1.01	2.36	4.99
Croton laccifer	Scrubland	DL/IN/W	2.43	1.34	0.80	4.58
Ixora pavetta	Understory	DL	2.02	1.57	0.81	4.40
Chloroxylon swietenia	Canopy	DL/IN	1.62	1.01	1.76	4.39
Litsea glutinosa	Sub canopy	DL/IN/W	2.02	1.68	0.61	4.31
Cordia dichotoma	Understory	DL	2.02	0.89	1.12	4.04
Glenniea unijuga	Sub canopy	DL/IN	2.43	1.12	0.32	3.87
Bridelia retusa	Sub canopy	DL/IN/W	1.62	0.56	1.48	3.66
Diospyros vera	Sub canopy	DL	2.43	0.78	0.07	3.28
Flueggea leucopyrus	Scrubland	DL	1.21	1.23	0.61	3.06
Haldina cordifolia	Canopy	DL	1.21	1.12	0.48	2.82
Diospyros ovalifolia	Sub canopy/Scrubland	DL/IN	1.21	1.23	0.35	2.80

Table 4: Top thirty tree species that have highest IVI values for highly disturbed (HD) forest in Hurulu Forest Reserve, Sri Lanka, excluding introduced species (DL = Dry lowland zone, IN = Intermediate zone, W = Wet zone).

Species	Ecology	Distribution	Frequency (%)	Density (%)	Dominance (%)	Importance value
Streblus asper	Disturbed vegetation	DL/IN/W	4.55	21.12	7.12	32.79
Grewia damine	Scrubland	DL/IN	6.82	9.08	13.82	29.71
Schleichera oleosa	Canopy	DL/IN	3.18	1.82	14.12	19.12
Pterospermum suberifolium	Canopy/Scrubland	DL/IN	6.82	6.93	5.13	18.88
Bridelia retusa	Sub canopy	DL/IN/W	3.18	3.63	5.37	12.19
Mallotus philippensis	Understory	DL/IN/W	3.64	5.94	1.40	10.98
Strychnos nux-vomica	Secondary vegetation/Scrubland	DL	0.45	0.17	9.86	10.48
Senna siamea	Canopy/Home gardens	DL/IN	2.27	1.65	3.75	7.67
Phyllanthus polyphyllus	Scrubland	DL	3.64	3.14	0.20	6.98
Bauhinia racemosa	Scrubland	DL	1.36	2.48	2.15	5.99
Diospyros ferrea	Understory/ Scrubland	DL	1.36	0.83	3.50	5.69
Cordia dichotoma	Understory	DL	2.27	0.99	2.01	5.27
Vitex altissima	Canopy	DL/IN/W	2.73	1.32	0.80	4.85
Discospermum sphaerocarpum	Understory/ Scrubland	DL/IN	0.91	0.33	3.09	4.33
Allophylus cobbe	Secondary vegetation	DL/IN/W	2.73	1.49	0.07	4.28
Albizia odoratissima	Roadside/Home gardens	DL/IN/W	0.45	1.32	2.16	3.94

Lepisanthes tetraphylla	Canopy	DL	1.82	0.99	1.13	3.93
Flueggea leucopyrus	Scrubland	DL	0.91	0.66	2.35	3.92
Premna tomentosa	Scrubland	DL/IN	2.27	1.32	0.19	3.79
Syzygium cumini	Canopy	DL	1.82	0.66	1.30	3.78
Holoptelea integrifolia	Canopy	DL	1.82	0.83	0.89	3.53
Diospyros vera	Understory/ Scrubland	DL	2.27	1.16	0.10	3.53
Chloroxylon swietenia	Canopy	DL/IN	1.36	0.50	1.42	3.28
Pamburus missionis	Understory/ Scrubland	DL	1.82	0.66	0.76	3.24
Micromelum minutum	Understory/ Scrubland	DL	1.82	1.16	0.08	3.05
Eugenia involucrata	Secondary vegetation	DL/IN	1.82	0.99	0.03	2.84
Pleiospermium alatum	Understory/ Scrubland	DL	1.36	1.32	0.04	2.72
Lannea coromandelica	Sub-canopy/Scrubland	DL	0.91	0.50	1.18	2.58
Murraya paniculata	Understory/scrub	DL	1.36	0.99	0.07	2.42
Glycosmis mauritiana	Understory/ Scrubland	DL	0.91	0.99	0.27	2.17

Grewia damine, *Phyllanthus polyphyllus* and *Streblus asper* were also recorded from the HD areas of forest in which elements of scrubland, disturbed and secondary dry forests were found. In contrast, the LD forest had the greatest percentage of tree species having a wide geographical distribution over dry, intermediate and wet zones of Sri Lanka (Table 1). *Chloroxylon swietenia*, *Diospyros vera*, *Eugenia involucrata*, *Holoptelea integrifolia*, *Mallotus philippensis*, *Pterospermum suberifolium*, *Syzygium cumini* and *Vitex altissima* were among the top thirty dominant species at all the sites along the disturbance gradient, suggesting their low sensitivity to forest disturbance.

Community perspective

Through our surveys, we found that our concept of LD, MD and HD, and core, buffer and transition zones in MAB concept are already known to the forest villagers (Fig. 6). The LD, MD and HD forests' vegetation were identified by vernacular names such as *Mukalana*, *Maha bedda* and *Heen bedda* (or *Thora bedda*), respectively, for the purposes of shifting cultivation and forest conservation. Thus, in the dry season, shifting cultivation is practiced on ~0.5 ha of *Maha bedda* or *Heen bedda*. Traditionally, villages prepare land for shifting cultivation in the final days of the dry season, targeting the inter-monsoonal rains. During this time, trees and vines are slashed down (to knee level) and burned. However, existing large trees (> 60 cm dbh) are not cut in the cleared areas. The slashed trees and branches are used to fence the land and also used as fuel wood and pole wood by the villagers. After the rains, the nutrient-enriched burned land is prepared for sowing, without removing the tree stumps, and disturbing the soil profile (Fig. 7a). After one to three cycles of farming, the land is abandoned due to rapid re-growth, forming a fallow forest. Rapid re-growth of tree stumps prevents encroachment of grass and weed species immediately after the cultivated field is abandoned (Fig. 7b). Rotational shifting cultivation systems with long fallow period were sufficient for regeneration and maintaining this unique *Heen bedda* forest ecosystem. Shifting cultivation does not use any fertilizer, herbicides and other agrochemicals; thus abandoned shifting cultivated lands have considerable potential for natural regrowth of remaining cultivated crops with forest recovery. Villagers continue to harvest crops from the abandoned shifting cultivated lands, provided that they are protected from fire and cattle grazing/browsing. Furthermore, villagers harvest medicinal plants, timber and non-timber forest products (NTFPs) from HD and MD forests (*Heen bedda* and *Maha bedda*) to meet their subsistence needs. They never use the remote LD forest for shifting cultivation, which is set aside exclusively for long term protection. Traditionally, the LD forest type is called *Mukalana*, which corresponds to the core zone of the Man and Biosphere (MAB) forest concept. According to traditional knowledge, a characteristic feature of the *Mukalana* forest is the greatest abundance of *Dimocarpus longan* trees and long range of visibility under the forest due to sparse shrub layer in the understory. Other tree species characteristic of this forest are considered *Chloroxylon swietenia*, *Diospyros ebenum*, *Holoptelea integrifolia*, *Manilkara hexandra*, *Pterospermum suberifolium*, *Schleichera oleosa*, and *Vitex altissima*. The area between the LD and HD forest is occupied by MD forest (*Maha bedda*), corresponding to the buffer zone of the MAB forest concept. A characteristic feature of the *Maha bedda* and *Heen bedda* forest is the high abundance of *Diplodiscus verrucosus* and *Grewia damine* trees, respectively. These results support our findings on tree species composition of the LD, MD and HD forests elucidated above.

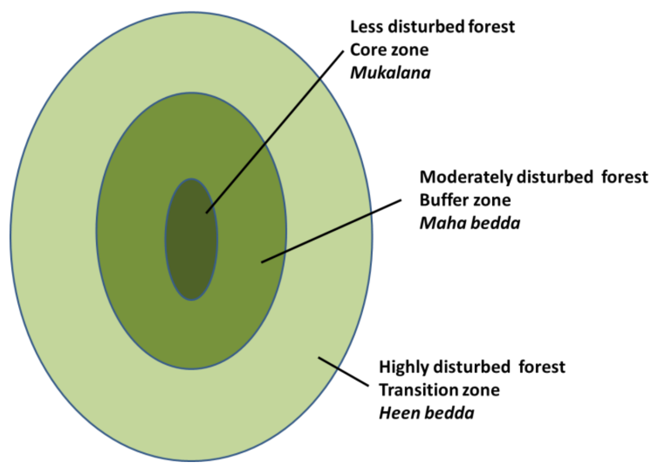

Figure 6. Less disturbed (LD), moderately disturbed (MD), and highly disturbed (HD) forests correspond to Core, Buffer and Transition zones in the Man and Biosphere concept and *Mukalana*, *Maha bedda* and *Heen bedda* in traditional concepts, respectively, in the dry zone forests of Sri Lanka.

DISCUSSION

We show here that, despite Hurulu Forest Reserve being a formally protected area, it is subjected to numerous anthropogenic disturbances, as seen in many other tropical forest reserves globally (Parthasarathy 1999, Porter-Bolland *et al*. 2012, Newman *et al*. 2014). We further provide evidence for the importance of floristic parameters in determining the degree of degradation of dry forests and their congruence with both traditional concepts of forest usage and forest conservation planning methodologies.

Figure 7. (a) Burned shifting cultivated land with tree stumps and (b) regenerating shifting cultivated land from tree stumps in the Hurulu Forest Reserve, Sri Lanka.

The canopy of the LD forest is high in Sri Lankan dry forests (< 20 m with some emergent up to 25 m) and the floristic composition showed similarities with other dry zone forests, particularly the presence and dominance of *Drypetes sepiaria*, which is a common small tree throughout much of the region and also the presence of a number of canopy trees such as *Chloroxylon swietenia*, *Diospyros ebenum*, *Manilkara hexandra* and *Vitex altissima*. A high proportion of late-successional species in the LD forests also showed a wide distribution in the dry, intermediate, and notably, in the wet zone of Sri Lanka. The environmental and ecological features of the LD forest in the dry zone, may lead to the presence of these late successional species adapted to moister micro-climatic conditions under the more closed canopy with a mean canopy cover of over 95 %.

The tree species composition at Hurulu varied significantly with the disturbance gradient as shown by the ANOSIM analysis. This is due, at least partly, to changes in the relative abundance of species and, especially the absence of late successional species that are replaced by fast-growing pioneer, early successional, opportunistic and exotic species in more disturbed forest communities. Perera (2001) reported these opportunistic species to be heavily exploited in other parts of the dry zone in Sri Lanka. Modified canopy conditions, particularly increased openness due to anthropogenic disturbance, have the potential to negatively affect late successional species, which have a narrow tolerance range, thus making disturbed forest more vulnerable to colonization by opportunistic and pioneer species (Medawatte *et al*. 2014).

In our study, the total number of species recorded increased with increasing disturbance, likely due to variable disturbance regimes from multiple agents leading to some aspects of the intermediate disturbance hypothesis applying across a spatially patchy landscape (Sheil & Burslem 2003). However, the species richness per plot declined with increasing disturbance with a concomitant increase in the Berger–Parker index, showing greater dominance by the most abundant species in HD and MD areas compared to LD areas. This decline in richness is also seen in other studies on the impacts of land-use disturbance gradients on tropical tree diversity (Sagar *et al*. 2003; Kessler *et al*. 2005; Waltert *et al*. 2011). However, the proportion of endemic and native species, and conservation status of tree species among disturbance groups showed no major differences. The degree of dry forest degradation at Hurulu was strongly reflected by species dominance at different strata of the forest profile, which appeared to be a good indicator of disturbance. For instance, the potential late successional tree species (e.g. *Chloroxylon swietenia*, *Diospyros ebenum*, *Holoptelea integrifolia*, *Manilkara hexandra, Pterospermum suberifolium*, *Schleichera oleosa*, *Vitex altissima*) were the most dominant tree species in LD areas with a high IVI value compared to other tree species. Most of the dominant tree species in MD forest belonged to pioneer and early successional categories (Perera 2001). However, the high relative abundance of *Drypetes sepiaria* in this forest disturbance category is likely due to the low preference by local people for its extraction for timber, due to its irregularly-shaped trunk. Pioneer, early successional and introduced trees (e.g. *Azadirachta indica*, *Bridelia retusa*, *Gliricidia sepium*, *Grewia damine*, *Senna siamea*, *Streblus asper*, *Strychnos nux-vomica*) and many weeds dominated the HD forest compared to other forests. Moreover, the understory of the HD forest was dominated by *Lantana camara*, which is of concern, given the highly invasive nature of this species and the major impacts it can have on the forest ecosystems (Bhagwat *et al*. 2011; Ranwala *et al*. 2012); the presence of *Leucaena leucocephala* in the HD forest further indicates the potential for spread of invasive species.

Distinct differences in diameter size class distribution and basal area of woody species was evident in the three disturbance intensity categories. The diameter size class distribution of individuals of the LD area resembled a typical reverse ‘J’-shaped curve, with most of the trees in the smaller size classes and fewer in the larger ones as expected for a mature undisturbed forest (Whitmore 1998).

Moderately disturbed forests and HD forests did not show such a clear pattern; the lack of individuals in the larger size classes in disturbed areas could be due to over-exploitation of larger trees by the local people for their requirement for timber for various construction purposes. These species were observed to be logged above their minimum harvestable diameter (>10 cm), which accounted for their low density, due to lack of individuals in the larger size classes which, in turn, contributed to a reduced basal area. The reverse J-shaped curve of LD area of the forest also indicated potential for regeneration of this forest compared to disturbed forests (Poorter *et al*. 1996). In the MD forest, reduced basal area was associated with a high abundance of saplings and often a lack of individuals in the larger size classes (diameter >80 cm) as also observed in the LD area of the forest. However, the existing high density of young trees and low basal area suggested that the MD forest is presently at the stage of regeneration and recovering from disturbances. The decline in the tree density and basal area in HD areas can be associated with increasing extraction of pole wood and logging of fully grown timber trees in the forest as well as localised seasonal fire events. After a disturbance, there is much dead wood and litter that accumulates making the forest more susceptible to fires. This can also be related to easy accessibility by the nearby communities and ineffective fire protection measures.

Restoration plantings are the most ambitious attempts to re-establish original forest ecosystems to generate ecological services although suitable techniques are still being developed (Lamb *et al*. 2005). Restoration of highly degraded forest areas with canopy dominants and protection of understory dominant species are recommended measures, which should be implemented for regeneration of degraded forest areas to their original state. However, the immediate priority should be the control of further disturbance, particularly timber, fuel wood extraction and seasonal fires, as they are the major causes that alter the characteristic of forest vegetation. The first approach is to use native species that show low sensitivity to forest disturbance and nurse trees to create a well-developed canopy. These would shade out grasses, weeds and invasive species, diminish the fire risk, and facilitate colonization of the site by a wider range of species including late successional species that can also be planted once canopy closure has occurred.

Indigenous villagers possess a vast knowledge of plant species associated with different disturbance regimes of the forest, and of fallow dynamics associated with shifting cultivation. Their traditional knowledge on forest classification (similar to the Man and Biosphere (MAB) concepts of core, buffer and transition zones) and regulation of land-use in shifting cultivation was a significant practice in traditional forest conservation. *Heen bedda* vegetation, which corresponds to the

HD forest in our current study, is located in the transition zone of the Hurulu forest according to the MAB concepts of forest conservation. This vegetation develops rapidly from vegetative parts of trees (e.g. *Diplodiscus verrucosus* and *Grewia damine*) remaining from abandoned shifting cultivated areas, and provides numerous products to the villagers (Perera 2001). Most of the isolated large trees (e.g. *Manilkara hexandra*, *Schleichera oleosa*, *Syzygium cumini*) protected from shifting cultivation in the forest are corresponding to MAB framework species concepts. These are important for restoration and to achieve a complete and rapid biodiversity recovery returning the tree species composition to that of the original primary forest (Elliott & Kuaraksa, 2008). Consequently, this traditional tree-based agrarian system, associated with long follow periods, was sufficient to maintain biodiversity and the livelihood of the community in a dynamic balance of the *Heen bedda* vegetation. Maintaining *Heen bedda* vegetation associated with traditional shifting cultivation systems, along with a MAB conceptual view on natural resource management, will offer the widest range of opportunities for adapting to changing economic, social, and forest conservation scenarios. Land allocation for traditional shifting cultivation practices and enforcement of customary laws in the transition zone of the forest vegetation are effective measures to improve livelihood and land productivity, while avoiding deforestation and forest degradation in the core forest zone.

Our survey found that forest exploitation activities were primarily due to the economic necessity of the people. Thus, we suggest that an uplift of their economic status would directly contribute to a decline in forest degradation. This was evident from our survey where programs conducted by the state custodians of the national forest cover, the Forest Department (FD), and the Department of Wildlife Conservation of Sri Lanka (DWC), had led to a decline in degradation. Small scale projects had a lasting impact; however, the villagers emphasized that continuity of the programs was essential. The absence of a clear demarcation of boundaries between the forest and the homesteads of the villagers was a cause of conflict between the villagers and the state agencies. The absence of legal entitlement to their lands denied them opportunities to seek loans from banks to begin any enterprise. The small-scale enterprises conducted by the villagers, with the assistance of the FD and the DWC, included cottage industries on dairy, vegetable farming, organic fertilisers and poultry farming (this reduced the hunting activities in the forest). Thus, an intervention by the state through its agencies, the FD and DWC to alleviate poverty of the villagers, could play a role in mitigating forest degradation.

CONCLUSIONS

Changes in forest structure together with alterations in species diversity, composition and dominance from least disturbed areas of the forest depict the present status of forest degradation in the dry forest formation at Hurulu Forest Reserve in Sri Lanka. Clear changes in species composition with replacement of dominant late-successional trees with abundant pioneer and fast-growing, introduced tree species in more disturbed communities were seen. Relatively high numbers of pioneer and early-successional species were recorded from the highly disturbed forests, whereas least disturbed forests were dominated by late-successional tree species that were also found geographically more broadly in the intermediate and wet zone forest elements in Sri Lanka. Alterations in species climatic envelopes have the potential to lead to a feedback, whereby the disturbed forest may become more drought tolerant. Traditional knowledge on forest use classification and agronomic practices revealed similarities with a scientific approach and to support biodiversity conservation associated with MAB concepts. Moreover, the species composition in forests are complementary guides to evaluate dry forest degradation, whilst integrating traditional knowledge on land use is also important to develop answers for succesful and sustainable conservation and management of dry forests.

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