

Research Article

A preliminary study on the impact of changing shifting cultivation practices on dry season forage for Asian elephants in Sri Lanka

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Abstract

Shifting cultivation, in which fields are traditionally cultivated for two or three consecutive years and left fallow for four to five years, is an ancient practice still prevalent in the dry zone of Sri Lanka. Traditionally, shifting agriculture is rain dependent and is limited to the wet season. However, traditional patterns are now changing due to population pressures. We assessed the use of shifting agriculture areas by Asian elephants (*Elephas maximus*) and the availability of fodder in active fields during the dry season, to evaluate the impact of changing cultivation practices on elephants. We radio-tracked a juvenile and an adult male, representative of the two social groupings of herds and adult males respectively, based on the sexually dimorphic social structure of elephants. Although the small sample size precluded definitive conclusions, the tracking data were consistent with extensive elephant use of shifting cultivation areas during the dry season. We conducted line transects and plots in fields cultivated continuously for 1-20 years, assessing the growth of grasses and four browse species selected as indicators of elephant food. Grass was plentiful in early dry season, representing an important but transient food source. Browse density and volume remained constant through the dry season. Browse density but not volume decreased with increasing number of consecutive years of cultivation. We conclude that shifting agriculture fields under active cultivation are a significant dry season food source for elephants. This benefit is likely to decrease with additional years of continued cultivation and/or longer cultivation seasons.

Key words: Asian elephant, *Elephas maximus*, shifting cultivation, succession, pioneer species

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Introduction

Shifting agriculture has been practiced for millennia around the world [1-2]. It is commonly seen as an environmentally detrimental conversion of natural habitats into agriculture areas with little conservation value [2-4]. However, 'shifting agriculture' refers to a diversity of agricultural practices with varied environmental impacts ranging from beneficial to detrimental [5]. Consequently the role of shifting agriculture in biodiversity conservation needs to be re-assessed [2, 5-6].

In Sri Lanka, shifting agriculture is common in the country's markedly seasonal dry zone. The practice consists of cutting and burning the natural vegetation at the end of the dry season, and cultivation with the rains. Harvesting is completed by the end of the wet season. Natural vegetation in post-harvest fields regenerates throughout the dry season. Traditionally, fields are cultivated for 2-3 consecutive years and left fallow for 4-5 years. Fallow fields revert to scrub and scrub-forest through succession. Due to the low investment in ground preparation some areas cannot be cultivated and remain as forest patches. As a result, shifting agriculture areas represent a fine-scale mosaic of active fields and those in various stages of succession, interspersed with tracts of mature forest.

Recently, constraints of space, legal obstacles to clearing forest, and the desire to obtain greater harvests have resulted in changes to the traditional regime. Increasingly, some fields are cultivated for longer each year and some for more consecutive years before being abandoned. Others are cultivated continuously, without a fallow period. A more intensive cultivation regime with use of fertilizer and irrigation is gradually supplanting the traditional shifting regime, which relied on combusted natural growth for adding nutrients to the soil.

Asian elephants (*Elephas maximus*) are considered a 'forest species,' as they mostly occupy forested habitat [7]. More specifically, they are also defined as an 'edge species,' exploiting the eco-tone at forest edges [8-9]. Heterogeneous forest habitats with a mosaic of successional stages have greater elephant densities than homogeneous mature forests [8-9]. Elephants are generalist feeders, consuming a large number of species found in the environment [9-12]. However elephants also show preference, and a few species constitute a major part of their diet [12]. Elephants feed preferentially on grass but can subsist entirely on browse [11-13].

Asian elephants have co-existed with humans for millennia, adapting to anthropogenic habitat change [8]. In southern Sri Lanka, elephants are known to use shifting agriculture areas intensively during the dry season [14-15]. Herds of >80 elephants and single males were commonly observed in shifting agriculture fields in the study area during the dry season (PF, HKJ pers. obs.). Many of the browse species favoured by elephants are pioneer species, which rely on rapid growth and mechanical rather than chemical defences against herbivores [8]. Pioneer species constitute the dominant vegetation in shifting agriculture areas.

Shifting agriculture landscapes represent a fine-scale mosaic of different successional stages created by the two distinct temporal scales of disturbance. In active fields, natural vegetation is cleared at the end of each dry season and regenerates annually after harvest (post-harvest regeneration). In abandoned fields, regeneration and succession continue unchecked for a number of years (fallow regeneration). Our study intended to:

1. Confirm the use of shifting agriculture fields by elephants in the dry season.
2. Quantify the foraging benefits from annual post-harvest regeneration.
3. Assess the potential impact of intensification in agricultural practices on elephants.

The results provide important insights into the value of traditional agricultural practices for elephant conservation and management in Asia.

Methods

Study area

The study area was adjacent to the western boundary of the Yala National Park in southern Sri Lanka, between coordinates N6.2405° - N6.3311° latitude and E81.3187° - E81.3950° longitude. The climate is highly seasonal with distinct wet and dry periods. Rainfall is largely limited to the months of October to January, and dry conditions prevail from about March to September (Department of Meteorology, <<http://www.meteo.gov.lk>>). The natural vegetation consists of scrub, thorn forest, and dry evergreen forest.

Radio telemetry

We used data from two radio-collared elephants to assess elephant use of shifting agriculture areas. One was a five to six-year-old juvenile representing the ranging of a female group of about 15 elephants, and the other was an adult male. The elephants were collared on 30th October 2004 and 8th May 2005 as part of a collaborative study by the Department of Wildlife Conservation Sri Lanka (DWC) and the Centre for Conservation and Research to obtain baseline information for elephant conservation enhancement and human-elephant conflict mitigation. Tranquilizing the elephants for collaring was done by a team of 15-20 DWC personnel led by two DWC veterinarians, according to guidelines set out by the DWC.

The collars consisted of a GPS unit, a VHF transmitter beacon, a satellite transmitter for data transmission and batteries packaged into one integrated unit (Telonics, Inc.). Collars were programmed to collect GPS locations every 4 hours and transmit the data every 24 hours. GPS locations obtained were tabulated in Excel, exported into Quantum GIS version 1.7 (QGIS) and plotted on Google Earth satellite imagery.

Vegetation assessment

Grasses and herbs, the tree species *Bauhinia racemosa* (local name 'maila'; other common name 'bidi leaf tree') and the three shrub species *Dichrostachys cinerea* (local name 'andara'; other common names 'sicklebush', 'Kalahari Christmas tree'), *Catunaregam spinosa* (local name 'kukuruman'; other common name 'mountain pomegranate'), and *Capparis rotundifolia* (local name 'horobalal wal'; other common name 'round leaf caper') were selected as indicators of elephant food. The browse species were chosen based on presence in shifting cultivations and on preference by elephants. All four browse species were pioneer species. Two of them, *D. cinerea* and *C. spinosa* formed the bulk of elephant diet in the study area, while *B. racemosa* and *C. rotundifolia* were used less (PF personal obs.).

For our study, we used a total of 45 fields continuously cultivated for up to 20 years. They were divided into five approximate age categories based on the number of years cultivated (1 year, n = 8; 5 years, n = 8; 10 years, n = 11; 15 years, n = 10; and 20 years, n = 8). The size of the fields ranged from one to five acres (9,348 ± 3,683 m²).

A 100 m x 4 m strip transect was conducted in each field in May and August 2005, corresponding to the beginning and end of the dry season respectively. Three of the fields were not monitored in August because they were already cleared for the next round of cultivation.

Transects were centred on the field in a straight line. If the field was less than 100 m in length, the transect was continued in a straight line after a 90 degree turn. Individuals of the four selected browse species falling within the strip were counted and measured.

Plant volume was used as a surrogate for biomass, as cutting and weighing the plants would have precluded repeat sampling. For each individual of the four browse species 20 cm or more in height, the maximum height (H), the maximum length (L), and the maximum width (W) perpendicular to the maximum length were measured. If a portion of a measured individual fell outside a transect, that part was not measured. When several individuals of the same species grew close together with overlapping branches, they were measured as one unit, but the number of individuals was noted.

The volume (V) of each individual measured was calculated using the formula $V = H \times \pi \times ((L + W) / 4)^2$. Trees higher than 2 m were few and were excluded from the analyses, as they did not represent annual post-harvest-period growth.

Grass/herb cover was estimated every 25 m along each transect (at 0, 25, 50, 75 and 100 m). A 1 x 1 m plot was laid at each assessment point and the percent ground cover of grass/herbs was estimated visually.

The data were analyzed with JMP® 9.0. A One-way ANOVA was conducted to assess the relationship between the number of plants, plant volume or grass/herb cover, and the age of the field. Comparison between May and August was done using nonparametric Wilcoxon Tests (2-sample test, normal approximation).

Results

Elephant use of shifting agriculture areas

During the cultivation season (October to March), the juvenile elephant ranged in the Yala National Park (20.0% of GPS locations) and in the northern part of the study area (Fig. 1). The entire dry season range was outside the park (Fig. 2). The cultivation season range outside the park included a larger portion of uncultivated areas to the north of the study area. The dry season range encompassed a greater extent of shifting-agriculture areas to the south.

The adult male ranged exclusively outside the park (Fig. 1). Its cultivation-season range was largely centred on the Nimalawa Sanctuary (77.0% of GPS locations) while the dry season range encompassed more of the shifting agriculture areas to its north (Fig. 2).

Grass/herb cover

In May the average grass/herb cover was $10.4 \pm 13.3\%$, which ranged from $4.1 \pm 3.0\%$ in 5-year fields to $13.6 \pm 14.7\%$ in 20-year fields. The greatest grass cover of 66% was found in a 10-year field. In August, average grass cover was $2.0 \pm 2.1\%$ and similar among fields of all ages (Fig. 3). The grass/herb layer was mostly dead and dry in the second sampling period.

Total grass cover was significantly higher in May (Wilcoxon, $P < 0.0001$). No significant difference in grass/herb cover was found in 1-year and 10-year fields between May and August ($P = 0.71$ and $P = 0.053$ respectively). However, 5-, 15- and 20-year fields had significantly less grass/herb cover in August ($P < 0.05$).

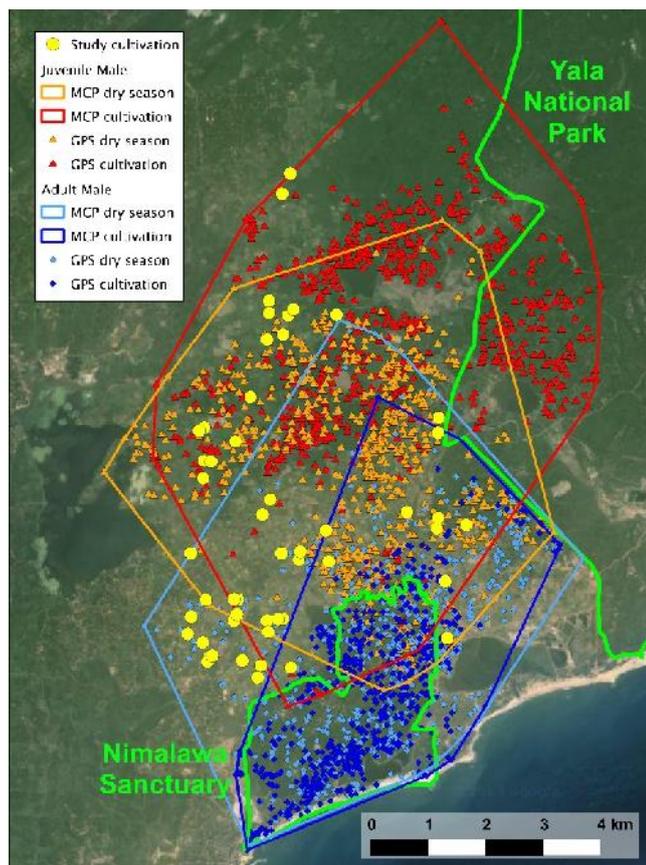


Fig. 1. Map of the study area showing the shifting agriculture fields assessed and the GPS locations and MCP home ranges of the two tracked elephants. The green line delineates protected area boundaries

No significant differences in grass/herb cover were found among the five age classes, in May only (ANOVA, $P = 0.33$), August only ($P = 0.18$) or May and August combined ($P = 0.24$, Fig. 3).

Number of browse plants

The area assessed on the 87 strip transects totalled 34,800 m² in which 6,312 plants were counted. The four study species *D. cinerea*, *C. spinosa*, *B. racemosa* and *C. rotundifolia*, respectively comprised 54.7%, 41.0%, 3.1% and 1.2% of the total number of plants. The total number of plants decreased with increasing age of fields, which was significant at the 0.1 level (ANOVA, $P = 0.07$). In species-wise analyses, *C. spinosa* showed significant variation among field age classes ($P = 0.0015$) but *D. cinerea* did not ($P = 0.34$). As the number of *B. racemosa* and *C. rotundifolia* encountered was very low, they were excluded from the species-wise analyses.

In the first sampling period in May, 10-year fields had the highest (77.4 ± 77.0) and 20-year fields the lowest number of plants (42.0 ± 21.0). However, there was no significant difference among age classes for the number of plants (ANOVA, $P = 0.49$). The mean number of *D. cinerea* was similar in fields of different age classes (Fig. 4, ANOVA, $P = 0.45$). The same applied for *C. spinosa* (ANOVA, $P = 0.11$).

In the second sampling period in August there was also a trend of decreasing total number of plants with increasing field age (Fig. 4), which, however, was not significant (ANOVA, $P = 0.22$). The mean number of *D. cinerea* was similar ($P = 0.57$). However, *C. spinosa* was significantly different among field age classes ($P = 0.026$).

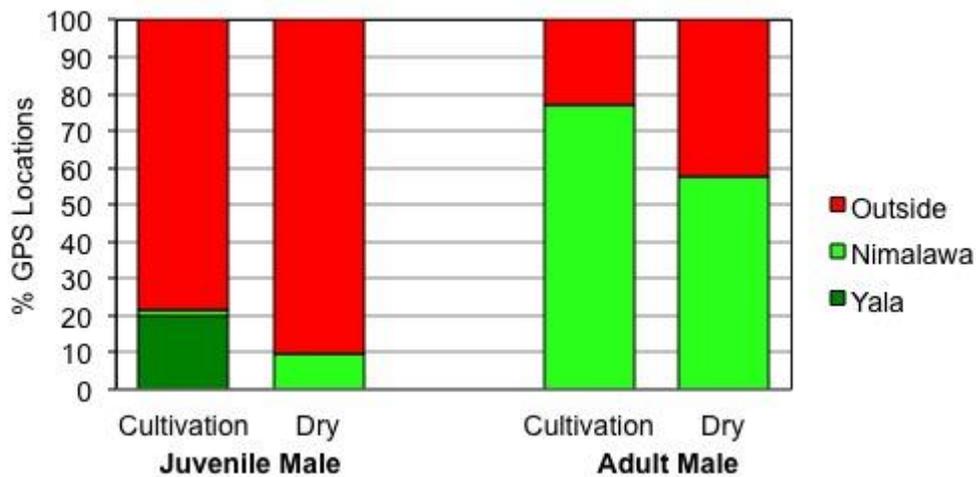


Fig. 2. Percentage of GPS locations in the Yala National Park, Nimalawa Sanctuary and outside areas from the adult and juvenile male during the cultivation and dry season.

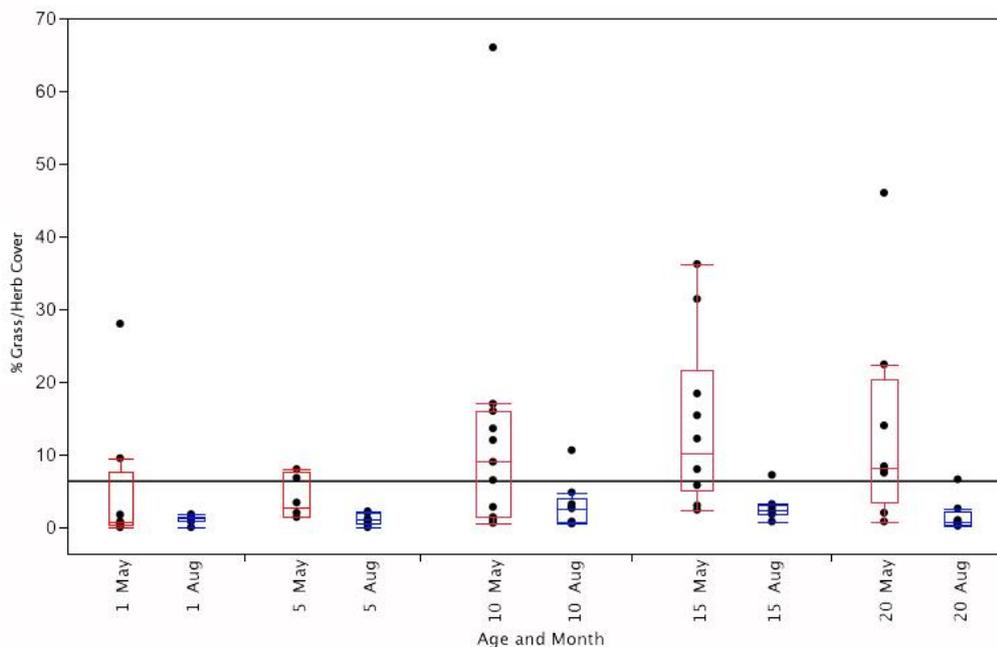


Fig. 3. Percentage ground cover of grasses/herbs in different aged fields in May and August. The horizontal line represents the grand mean.

No significant differences were found between first and second sampling periods (Wilcoxon Test, $P > 0.05$), in the total number of plants or the number of plants in the same field-age class, in pooled or species-wise analyses.

Browse volume

The total (May and August combined) volume of plants was 3,205.8 m³ with *D. cinerea*, *C. spinosa*, *B. racemosa* and *C. rotundifolia* accounting for 81.1%, 12.6%, 4.9% and 1.4% respectively.

No significant differences were found in total plant volumes in fields of different age classes (Fig. 5), for May only (ANOVA, $P = 0.55$), August only ($P = 0.67$) or May and August combined ($P = 0.55$). In species-wise analysis, no significant differences were found in *D. cinerea*. For

May and August combined data, *C. spinosa* volume was significantly different among field age classes ($P = 0.022$) with the volume decreasing with increasing age of fields (Fig. 4).

The total plant volume in May was 1,478.6 m³ (in 45 fields), and in August it was 1,727.2 m³ (in 42 fields). When comparing May and August (Fig. 5), no significant differences were found for pooled data (Wilcoxon, $P = 0.41$), for each field age class separately ($P \geq 0.37$), or in species-wise analyses ($P \geq 0.16$).

No obvious difference in the condition of browse plants was observed between the two sampling periods. Although not quantified, signs of browsing were noted on the assessed species in both sampling periods.

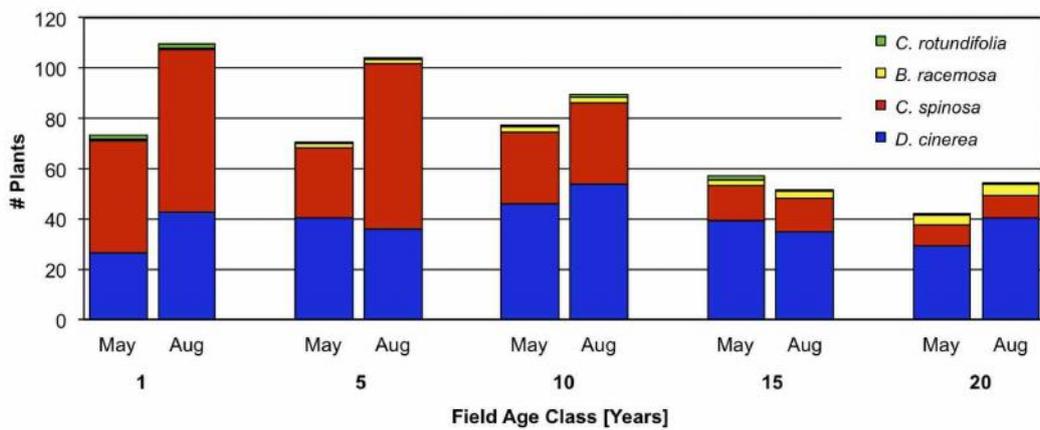


Fig. 4. Number of plants of each browse species in May and August.

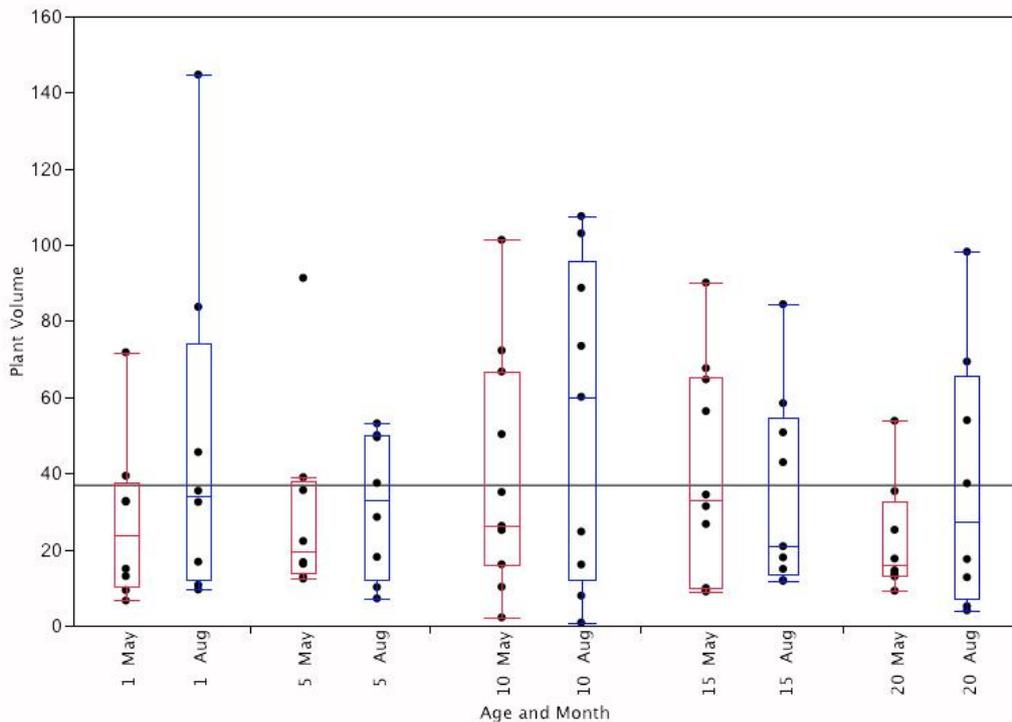


Fig. 5. Plant volume box plots in May and August for fields of five age classes. The horizontal line represents the grand mean

Discussion

Elephant use of shifting agriculture areas

Both tracked elephants used the shifting agriculture areas more extensively in the dry season (Figs. 1 & 2). Asian elephants have a sexually dimorphic social organization with group-living females and young. Male offspring stay in the natal herd till about 10 years of age, but as adult males they lead a solitary life [14]. Although the small sample size precluded definitive conclusions, as we tracked a juvenile male of 5-6 years and an adult male, their tracking data were indicative of the ranging pattern of herds and adult males respectively. Hence our data are consistent with extensive dry season use of outside areas by both herds and adult males. Elephants feed for 12-18 hours a day [16]. Therefore, their extended presence in an area is indicative of foraging in that area. As the farmers vacated the fields after harvesting at the end of the wet season, the elephants moved into the shifting agriculture area. During the cultivation period the protected areas (Yala National Park and Nimalawa Sanctuary) served as refuges for elephants. The strict seasonality of shifting cultivation thus enabled temporal partitioning of resources between farmers and elephants with little conflict.

As vegetative growth proliferated in the wet season, food was plentiful both in the protected areas and outside. The two tracked elephants also used outside areas in the cultivation season, indicating spatial resource partitioning between elephants and people at a fine scale, consequent to the habitat heterogeneity created by shifting agriculture. The somewhat greater use of protected areas in the wet season was probably a response to anthropogenic activity in the shifting agriculture areas. In seasonal habitats dry season forage availability is a limiting factor for most herbivores, including elephants. Therefore, the greater dry season use of shifting agriculture areas by elephants may indicate that it was a better and perhaps a critical dry season resource. A more comprehensive sample of tracked elephants will provide a better understanding of the importance and patterns of resource partitioning between people and elephants in such landscapes.

Graze

Post-harvest shifting-cultivation fields of all age classes had considerable grass/herb cover early in the dry season. Grass is a preferred food of elephants, as it does not have toxic secondary compounds and has a high protein content, especially when young [11-12]. Elephants could only access the fields with grass after the harvest. Also, as elephants fed on grass by kicking it out of the ground, the substratum had to be dry for them to collect it. As the dry season progressed, the grasses dried up and died. Therefore, graze was available only in a short window of time in early dry season. Based on our findings, we suggest that grass is likely to be an important, but short-lived supplementary forage to the diet of elephants in the study area.

There was a trend of increasing grass with increased age of fields, although a significant relationship was not found, largely due to a few outliers in fields cultivated for a smaller number of consecutive years (Fig. 3). Grass availability tended to vary widely within a given age class of fields, suggesting that factors not assessed in our study had a major influence on its growth. Such factors may include soil conditions, method of ground preparation, crop type, and fertilizers and herbicides used in the preceding cultivation season.

Browse

The density of the four browse species in all fields was 0.181 plants/m², or around 1 plant per 5.5 m². The average volume of each plant was 0.508 m³. The volume of plants in the two sampling periods was 0.092 m³/m², which corresponds to a 9.2 cm high plant blanket over the

fields. These figures indicate fairly sparse cover. However, all this was post-harvest growth, consisting of young plants, which require less handling time, are easier to digest and assimilate, hence have a high benefit-cost ratio. Compared to normal browsing, where elephants exploit dispersed low-quality food sources, the post-harvest fields provided a higher quality and more concentrated food source.

Fields cultivated for fewer consecutive years had greater densities of browse plants (especially *C. spinosa*) than those cultivated continuously for many years. Contrary to expectations of decreased soil fertility from more intensive cultivation [17] we did not find browse volume to be inversely related to field age. The possible explanations for this are, skewing of results by the chance presence of a few large individuals in older fields, or greater fertilizer use in older fields positively impacting post-harvest regeneration. In the absence of such confounding factors, more intensive cultivation is likely to result in decreased browse. The potential for regeneration upon fallowing may also decrease with increased age of fields. Therefore, either not fallowing, or cultivating fields for longer time periods, will likely decrease the benefit for elephants.

We found no significant difference in the number of plants in May and August. The result suggests that most of the post-harvest germination/regeneration of plants occurred early in the dry season. The more adverse climatic conditions as the dry season progressed may retard the initiation of such activity. In more recent times (after the study was done), there has been a trend toward extending the cultivation period in a given year, by digging irrigation wells or constructing small reservoirs and irrigating by electric water pumps. Such changes are likely to decrease the regeneration potential of natural cover in the cultivations, as the post-harvest regeneration would then commence later in the dry season.

The volume of plants was not significantly different from May to August. The measured plant volume represented the standing crop minus what was consumed by herbivores. Although decreased growth due to the more adverse environmental conditions as the dry season progressed cannot be ruled out, no major differences in the condition of the assessed browse plants were noted between the two sampling periods. Therefore, it is likely that the major reason for non-accumulation of biomass between the two assessments was consumption by herbivores, and post-harvest fields were likely a significant food source for elephants and other herbivores throughout the dry season.

Species-wise analysis

Although *C. spinosa* was more abundant, *D. cinerea* accounted for a much greater volume. The disparity was mainly due to differences in the morphology of the two species in the young stages. *D. cinerea* is more shrub-like with a higher degree of branching, while *C. spinosa* has only a few branches.

Observed differences in the number and volume of plants in relation to field age, with *D. cinerea* showing no relation and *C. spinosa* decreasing with increasing field age, may be explained by differences in propagation. *D. cinerea* regenerates mainly from rootstock while *C. spinosa* mainly sprouts from seedlings. With continued cultivation, the seed bank of *C. spinosa* probably decreased.

Implications for conservation

Post-harvest shifting-cultivation fields provided a large amount of high quality food for elephants throughout the dry season. Grasses are not a component of the natural vegetation

in the study area. Therefore, the grass availability in post-harvest fields represented anthropogenic habitat enrichment for elephants and other herbivores. Similarly, the regenerating browse species in post-harvest fields were all pioneer species, benefitting by the clearing for cultivation. We conclude that post-harvest regeneration in shifting agriculture fields is an important component of the agro-eco system function of such areas.

Extending the cultivation season within a given year, or seasonal cultivation for more consecutive years, causes decreased regeneration of natural vegetation. Over the long term, more intensive cultivation is likely to result in fields becoming barren and non-productive [17], removing them as a resource for elephants.

Extending the cultivation period into the dry season with irrigation would also disrupt the existing temporal resource partitioning between farmers and elephants and cause more conflict between them. Regulating and managing shifting cultivations with a prescribed shifting regime and annual cultivation period would benefit both cultivation and elephant conservation.

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References

- [1] Lasanta, T., Beguería, S. and García-Ruiz, J. M. 2006. Geomorphic and hydrological effects of traditional shifting agriculture in a mediterranean mountain area, Central Spanish Pyrenees. *Mountain Research and Development* 26:146-152.
- [2] Kafle, G. 2011. An overview of shifting cultivation with reference to Nepal. *International Journal of Biodiversity and Conservation* 3:147-154.
- [3] Marcot, B. G., Kumar, A., Roy, P. S., Sawarkar, V. B., Gupta, A. and Sangma, S. N. 2002. Towards a landscape conservation strategy: Analysis of Jhum landscape and proposed corridors for managing elephants in South Garo Hills District and Nokrek area, Meghalaya. *Indian Forester* 128:207-216.
- [4] Borggaard, O. K., Gafur, A. and Petersen, L. 2003. Sustainability appraisal of shifting cultivation in the Chittagong Hill Tracts of Bangladesh. *Ambio* 32:118-123.
- [5] Fox, J., Truong, D. M., Rambo, A. T., Tuyen, N. P., Cuc, L. T. and Leisz, S. 2000. Shifting cultivation: A new old paradigm for managing tropical forests. *BioScience* 50:521-528.
- [6] Oba, G., Stenseth, N. C. and Weladji, R. B. 2002. Impacts of shifting agriculture on a floodplain woodland regeneration in dryland, Kenya. *Agriculture, Ecosystems & Environment* 90:211-216.
- [7] Blake, S. and Hedges, S. 2004. Sinking the flagship: the case of forest elephants in Asia and Africa. *Conservation Biology* 18:1191-1202.
- [8] Fernando, P. and Leimgruber, P. 2011. Asian elephants and seasonally dry forests. In: *Ecology and Conservation of Seasonally Dry Forests in Asia*. McShea, W. J., Davies, S. J. and Bhumpakphan, N. (Eds.), pp. 151-163. Smithsonian Scholarly Press.
- [9] Mueller-Dombois, D. 1971. Crown distortion and elephant distribution in the woody vegetations of Ruhuna National Park, Ceylon. *Ecology* 53:208-226.
- [10] Samansiri, K. A. P. and Weerakoon, D. K. 2007. Feeding behaviour of Asian elephants in the northwestern region of Sri Lanka. *Gajah* 27:27-34.

- [11] McKay, G. M. 1973. *Behavior and Ecology of the Asiatic Elephant in Southeastern Ceylon*. Smithsonian Contributions to Zoology, No.125.
- [12] Sukumar, R. 1990. Ecology of the Asian elephant in southern India. II. Feeding habits and crop raiding patterns. *Journal of Tropical Ecology* 6:33-53.
- [13] Ishwaran, N. 1993. Ecology of the Asian elephant in lowland dry zone habitats of the Mahaweli river basin, Sri Lanka. *Journal of Tropical Ecology* 9:169-182.
- [14] Fernando, P., Wikramanayake, E. D., Janaka, H. K., Jayasinghe, L. K. A., Gunawardena, M., Kotagama, S. W., Weerakoon, D. and Pastorini, J. 2008. Ranging behavior of the Asian elephant in Sri Lanka. *Mammalian Biology* 73:2-13.
- [15] Pastorini, J., Nishantha, H. G., Janaka, H. K., Isler, K., and Fernando, P. 2010. Water-body use by Asian elephants in Southern Sri Lanka. *Tropical Conservation Science* 3:412-422.
- [16] Sukumar, R. 2006. A brief review of the status, distribution and biology of wild Asian elephants *Elephas maximus*. *International Zoo Yearbook* 40:1-8.
- [17] Arnason, T., Lambert, J. D. H., Gale, J., Cal, J. and Vernon, H. 1982. Decline of soil fertility due to intensification of land use by shifting agriculturists in Belize, Central America. *Agro-Ecosystems* 8:27-37.