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Evaluating the status of forest understory plants on high demand in an “open access” setting for restoration and community engagement

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Abstract

Knowledge of how human harvest impacts plants on high demand for non-timber forest products is essential for targeted conservation. Herbs and shrubs are some of the main sources of such products. However, documentation of human impact on forest flora usually focuses trees. We assessed the status of three forest understory shrubs on high demand for various non-timber forest product uses around Mabira Central Forest Reserve, Uganda. *Acalypha neptunica* is popular for commercial meat roasting and vending. *Citropsis articulata* and *Calamus deerratus* are collected for medicine and furniture making respectively. Harvest impact on *A. neptunica* and *C. articulata* was assessed using transects with human trails as a reference in 12 of the 66 management compartments of the reserve. *C. deerratus*, was assessed through a reserve-wide search. *A. neptunica* and *C. articulata* increased significantly with distance from human trails (Jonckheere-Terpstra Tests: *A. neptunica*, $p = 0.022$; *C. articulata*, $p < 0.0001$) suggesting occurrence of human harvest impact on density. All species showed significant decrease uphill from the valley bottoms (Jonckheere-Terpstra Tests: *C. articulata*, $p < 0.0001$; *C. deerratus*, $p < 0.0001$; and *A. neptunica*, $p = 0.004$) indicating intrinsic vulnerability due to habitat

specificity. Interspecies comparisons of density showed *A. neptunica* to be much more abundant than *C. articulata*. *C. deerratus* was localized to patches along some, but not all valley bottoms. *A. neptunica* exhibited a high level of post-harvest re-sprouting and appeared favored by moderate forest disturbance. *C. articulata* also showed frequent re-sprouting. These results complement prevailing understanding that conservation actions are urgently needed for *C. articulata* and *C. deerratus*. The results also show that further long-term investigation is required to fully understand the plants' response to harvesting and this needs to be facilitated by enforcing the existing strict nature reserve status of the core of the forest.

Keywords: Environmental science, Ecology, Plant biology

1. Introduction

Characterizing and monitoring herbaceous/shrub vegetation trends is essential for proper management of biodiversity, species at risk, ecological restoration, climate change effects among various forms of anthropogenic and natural perturbations of natural areas. Species in these categories form a large proportion of those harvested for non-timber forest products (NTFPs) (e.g. Olupot et al., 2009a, b). However, the sustainability of harvesting NTFPs is an ongoing concern (Arnold and Ruiz-Perez, 2001) and a lot of evidence points towards unsustainability (Hall and Bawa, 1993). Considering the important role that herbs and shrubs play in NTFPs supply, it is surprising that they have not attracted as much attention as trees (Gayton, 2013). In this study, we assess the status of three non-timber forest understory plants on high demand for NTFPs in Mabira Central Forest Reserve (hereafter referred to simply as “Mabira” or “the reserve”), a forest that has been little studied for these products and their harvest impact.

Mabira (300 km²) is one of the largest remaining forests in Uganda. It shares the management weaknesses that other forest reserves in Uganda experience, namely, weak law enforcement and primary focus on controlling encroachment and illegal tree felling. The situation of this forest is further complicated by the wavy and invaginated boundaries and occurrence of farmed and settled human enclaves. These result in a high perimeter to area ratio difficult to police. Law enforcement in the forest is further complicated by the fact that the reserve is located closer to the country's major urbanizing and industrializing areas than other Ugandan forests of similar or larger size. As a result, and despite some law enforcement, access to non-timber forest products in this forest is akin to “open”.

The three plants assessed were: *Acalypha neptunica* (Müll. Arg.), the African cherry orange *Citropsis articulata* (Swingle & Kellerman), and the rattan species *Calamus deerratus* (G.Mann & H.Wendl.). They are currently the NTFP source plants of the highest conservation concern to managers of the reserve.

A. neptunica, in the family Euphorbiaceae is a forest shrub widespread in central and eastern Africa ([KewScience](#)). Little is published of this species. In East Africa a root decoction is taken as a diuretic and twigs used as arrow shafts in Ghana ([http://uses.plantnet-project.org/en/Acalypha_fruticosa_\(PROTA\)](http://uses.plantnet-project.org/en/Acalypha_fruticosa_(PROTA))). Stems are weak and plants with stems >5 m tend to scramble (W. Olupot, pers. obs). Its status in Mabira is of interest because of heavy use of the stems for commercial meat roasting and vending in a highway market located at the edge of the reserve which practice goes back at least two and a half decades. Nothing is known about how this use may be impacting the plants.

C. articulata is a species in the citrus family Rutaceae. It is an understory plant of intact humid tropical forest. It is usually a shrub, sometimes a tree ([Swingle and Reece, 1967](#)). A root extract is popular in Uganda as a herbal aphrodisiac and it is believed that the high commercial demand of the roots may lead to its overexploitation ([BBC News, 25th 2007](#); [Kamatenesi-Mugisha and Oryem-Origa, 2005](#)).

More is known about *C. deerratus* than the other two species. It is a single species of the genus *Calamus* in the palm family Arecaceae. It is very widely distributed, from the Gambia, southwards to northern Angola and Zambia and eastwards to southern Sudan and Uganda ([Sunderland, 2012](#)). It occurs in lowlands in West and Central Africa at altitudes less than 500 m and in the higher altitude regions of East Africa at 1,000–1,500 m ([Dransfield, 1986](#)). They are mostly leaf-climbing lianas with slender, reedy stems. Stems may grow to lengths of 200m ([Dransfield, 1978](#)). It is common in swamp and riparian forests and may occur in open areas where it often forms dense thickets ([Tuley, 1995](#); [Sunderland, 2012](#)). The stem is used as a source of rattan cane and is traded in West, Southern and Eastern Africa ([Sunderland, 2001](#)). The canes are used for making furniture, baskets, and house construction. Palm hearts are eaten in Ghana and Sierra Leone, and leaves are used for medicine in Senegal ([Burkill, 1997](#); [Gruca et al., 2015](#), [PROTA](#)).

C. deerratus is listed in the IUCN Redlist as “Least Concern” “due to its wide distribution and the absence of major threats to its survival”. It is known to be represented inside protected areas and in ex situ conservation collections ([Cosiaux et al., 2016](#)). However, in Mabira, overexploitation is believed to have caused severe reduction of the population. According to reserve managers, the forest was a major source of the cane during mid to late 1980s but no commercial rattan is available from the reserve anymore. This attracted some restoration effort ([Kalungi, 2004](#)) which was not successful. Although believed to have been suppressed significantly by harvesting, the impact has not been demonstrated quantitatively. Its reserve-wide distribution has also not been demonstrated.

This paper presents the results of a study to determine which of the three species is imperiled by harvesting. We hypothesize that if impact is heavy, there will be a pronounced increase in density and stature of plants away from human trails, forest

edges, and a major market adjacent to the reserve. We also expected fruiting and flowering to show significant variation along these anthropogenic gradients.

2. Methods

2.1. Study area

Mabira Central Forest Reserve, 300 m² in size, is one of Uganda's larger natural forest reserves. It is located approximately 60 km east of the capital, Kampala. It is managed under a plan that partitions it into three zones. The inner zone is "strict nature reserve" in which no activities are permitted except scientific research and law enforcement. The outer zone is comprised of a "buffer zone" and a "production zone". Recreational activities and collection of NTFPs are permitted in the buffer zone, and the production zone" is managed for, sustainable supply of round wood for plywood and veneer industry (Ministry of Water and Environment, 2010). In reality, NTFPs are collected throughout the reserve.

2.2. Sampling

In deciding on the sampling approach, we take into account the understanding that the best method for sampling a large, heterogeneous area is to establish multiple transects, preferably parallel, which run along any topographical, climatic or other clines that exist. We also take into account the logic that if harvest intensity varies spatially along or across a gradient, it is important to establish paired transects between harvested and undisturbed habitats in this area (Hall and Bawa, 1993). Our anecdotal observations before the study suggested *A. neptunica* to be commoner than *C. articulata* which occurred primarily on lower slopes and *C. deerratus* in patches along valleys with streams. Data for the assessment of human impact was generated from field samples and GIS modelling. Design of the technique of field survey was informed by prior assessment of distribution patterns in relation to topography and map of the reserve. Field data for *A. neptunica* and *C. articulata* were collected from September 2017 to January 2018 while those for *C. deerratus* were collected from December 2016 to January 2017 and December 2017 to January 2018.

Belt transects and plots were used to collect data for assessment of distribution patterns related to location along a slope. The transects were 100 m long and originated from valley bottoms while directed towards hilltops. They were marked at 10 m intervals. Within each 10m segment, *C. deerratus* and *C. articulata* were sampled from widths of 10 m of either side of the transect center line while *A. neptunica* was sampled 2.5 m on either side. Plots were established at valley bottoms/lower slopes and on upper slopes/hilltops and measured 30 m × 30 m (Fig. 1). *C. deerratus* and *C. articulata* were sampled within the entire plot while *A. neptunica* was sampled within 15 m × 15 m nested in the bigger plot. The plots on the hilltop/upper

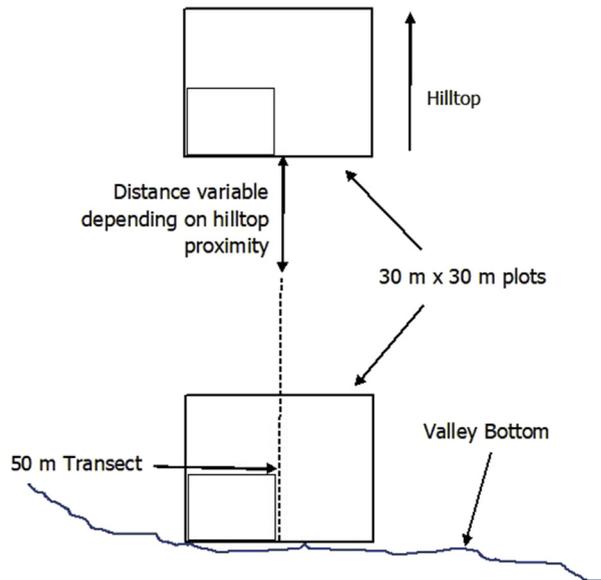


Fig. 1. Location of plots and topographic transects.

slopes were established in the general direction of transect bearings but never within 50 m of the reserve boundary. Within each plot, the number of individuals of each species was counted and stem lengths measured. Altogether, twenty transects and 20 pairs of plots were sampled. Because of its patchy distribution and tendency not to occur in randomly placed sample units, a half of the transects were not started at random points but at locations where *C. deerratus* was sighted.

Collection of data for trail-related anthropogenic gradients for *A. neptunica* and *C. articulata* were conducted using 50 m-long trail-perpendicular transects. The transects originated from existing human trails and ran perpendicularly to them. This design was based on prior knowledge that humans entering the forest to harvest resources typically use trails (W. Olupot, pers. obs.) and the logic that resources close to trails would have a higher likelihood of being detected by collectors and therefore harvested than those further away. Randomly-directed transects for each trail-based transect were established as controls. The randomly-directed transects were started 50 m from the end points of trail-based transect along the same bearings. These transects were ran along any of three randomly pre-selected bearings: perpendicular to the bearing of trail-perpendicular transect at 90 or 180° or in the same direction. Start points of trail-perpendicular transects were spaced at 200 m intervals along trails and transects were set in an alternating manner on either side of the trails (Fig. 2). GPS recordings were taken at each transect start point using a GARMIN GPSMAP 64 unit with a GPS and GLONASS receiver. The average precision of the points was ± 3 m.

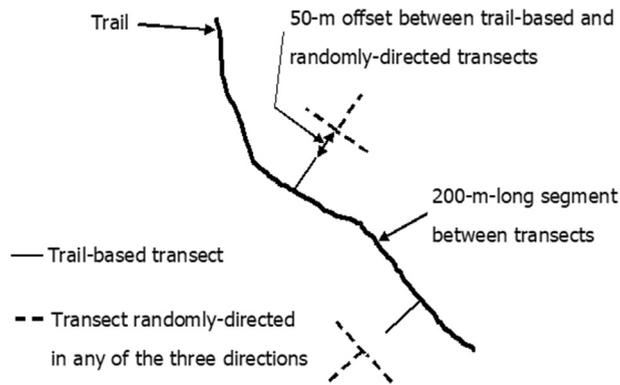


Fig. 2. Location of trail-perpendicular and randomly-directed transects.

Transects were partitioned into ten 5 m-long segments. Within each of the segments, *A. neptunica* stems were counted 2.5 m and *C. articulata* plants 5 m on either side of the transect centerline. The lengths/heights of the plants were recorded in centimeters. Number of plants flowering or fruiting, number of plants cut and number of cut stems with re-sprouts were also recorded. The rarer *C. articulata* was sampled in 10 m-wide transects. A total of 276 transects were covered (trail based = 139, random/control = 137) translating to an overall total transect distance coverage of 6.95 km of trail-perpendicular and 6.85 km of random/control transects. In total, 10 pairs of transects were sampled in each of 12 of the reserve's 66 management compartments. The survey compartments were selected from the map to achieve a reasonable degree of spatial coverage of the reserve. Altogether, trail-perpendicular and randomly-directed transects contained 2,760 5 m × 5 m plots. To check that a sample of 20 transects (10 trail-perpendicular and 10 randomly-directed) was adequate per compartment, we compared densities from two independent samples of 20 transects of *A. neptunica* in one compartment. There was no statistical difference in the median number of plants per plot between the transects (Mann-Whitney Rank Sum Test, $p = 0.157$; medians = 3 and 4; $n_1, n_2 = 200$ each). Accordingly, samples from 20 transects were considered to be representative of densities in each compartment.

Due to its restriction to valleys and patchy distribution, it made no sense to sample *C. deerratus* using transects. Data on it were collected through a search along valleys; within 20 m of either side of stream beds. The search team comprised of four teams of 4–5 people each. When patches were encountered, culms were counted according to the following categories: young, mature, fruiting, flowering, and harvested. GPS readings of each patch were recorded.

Using GIS (ArcGIS v10.4.1), we generated Euclidean distances from transect start points to Najjembe market (see Figs. 3, 4, and 5 below). This market is what we think is the main sales point for these NTFPs and is certainly the main consumption

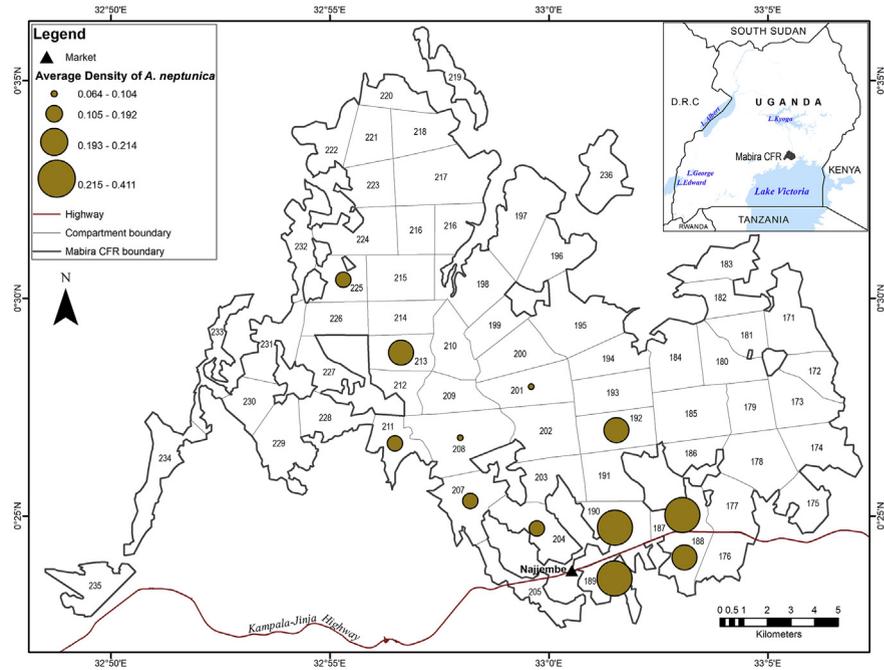


Fig. 3. Inter-compartment variation of the density (stems m^{-2}) of *A. neptunica* stems among the 12 compartments sampled.

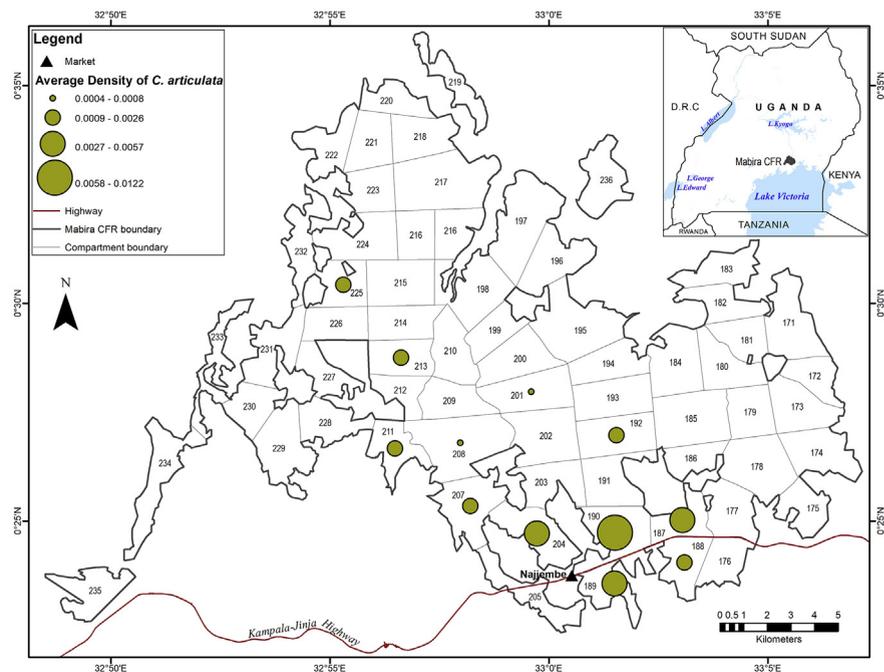


Fig. 4. Inter-compartment variation of the density (plants m^{-2}) of *C. articulata* plants among the 12 compartments sampled.

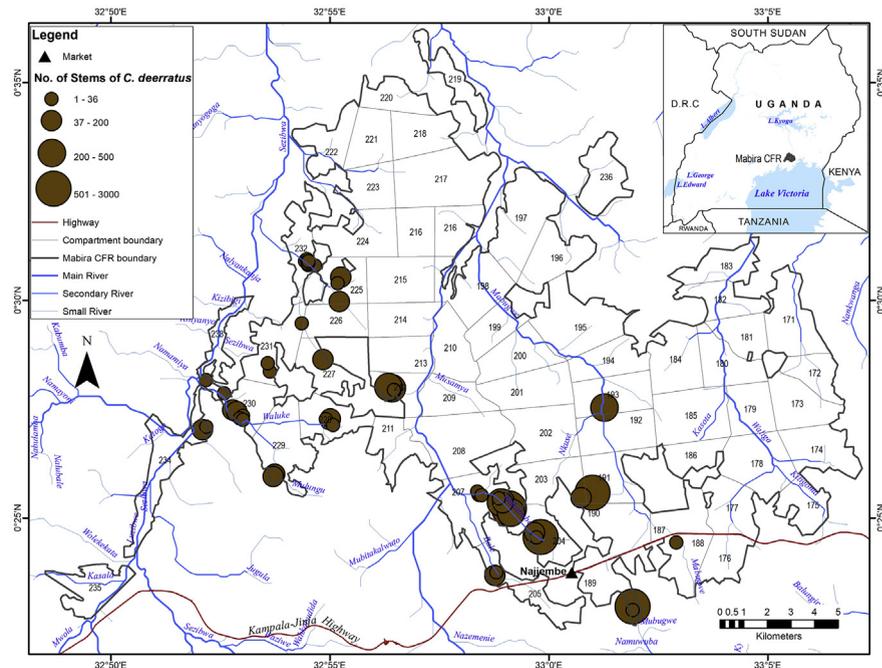


Fig. 5. Forest-wide inter-compartment variation in abundance (no. of stems counted) of *C. deerratus*.

point for harvested *A. neptunica*. GIS was also used to calculate Euclidean distances from transects to the nearest reserve boundary.

2.3. Analyses

Depending on available data, we calculated densities and means. Values presented as reserve-wide density and stem length means for each species are based on the sampling approach yielding the largest possible sample for the species. For *A. neptunica* and *C. articulata*, they were based on data from trail-perpendicular and the matching randomly-directed transects as the total area covered by these transects was vastly larger than that of the 30 m × 30 m plots. For *C. deerratus*, density estimates apply only to localities in which they were purposively sampled using 30 m × 30 m plots.

Harvest impact was assessed in two ways. First using Jonckheere-Terpstra Tests to determine patterns of change in density of plants and stem lengths with distance from trails. This was applicable to *A. neptunica* and *C. articulata* only as no *C. deerratus* were encountered using this approach. The second approach for assessing harvest impact was linear regression using GIS-calculated distances. In other analyses, non-parametric tests were used except where assumptions for corresponding parametric alternatives were met. All statistical analyses were conducted using SYSTAT v13.1 or SIGMASTAT v4.0.

3. Results

3.1. General statistics

A total of 14,227 *A. neptunica* plants ranging from 0 to 78 per plot were counted (mean per plot = 5.184, SD = 7.050). These plants were not observed in 37.6% of the plots. Their stem lengths ranged from 4 to 1,800 cm (Mean = 271.9, SD = 227.4). Overall density was 0.207 (SD = 0.282) plants per m⁻² and the density in trail-perpendicular transects was statistically similar to that in randomly-directed transects (Two-Tail Kolmogorov-Smirnov Test, $p = 0.243$; $n = 1370$). Plant heights were also similar between the two transect types (Two-Tail Kolmogorov-Smirnov Test, $p = 0.210$, plots in trail-perpendicular transects: mean = 305.402, SD = 170.316, $n = 888$; plots in randomly-directed transects: mean = 305.213, SD = 169.620, $n = 831$).

For *C. articulata*, 281 plants ranged from 0 to 16 per plot (mean per plot = 0.001, SD = 0.007). The species was not found in 97.9% of the plots. Plant heights ranged from 13 to 813 cm (Mean = 237, SD = 179). Density in trail-perpendicular transects was similar to that in randomly-directed transects (Two-tailed Kolmogorov-Smirnov Test $p = 0.902$, $n = 1370$) and mean plant height did not differ significantly between the two transect types (Two-tailed Kolmogorov-Smirnov Test $p = 0.210$, plots in trail-perpendicular transects: mean = 244.364, SD = 168.133, $n = 78$; plots in randomly-directed transects: mean = 305.213, SD = 169.620, $n = 831$). *C. deerratus* was very rare and sighted in only two plots bearing 19 stems.

A total of 66 patches of *C. deerratus* containing 2–3,000 stems each (mean = 134, SD = 403) were encountered. The number of cut and uncut stems totaled 8,862. Of these, 46% were mature and not cut. 17.5% of the stems were observed to have been harvested within four weeks or so of the survey. Culms bearing mature fruit were not seen but those with unripe fruits and flowers were 12 and 14 respectively. The ratio of fruiting culms to mature harvestable culms was 0.460. No re-sprouts were observed from bases of cut culms. Many stream courses and river plains were judged as potentially suitable for rattan but encounter of the plants was considerably low. Rattan stands were found mainly in the south and west of the reserve.

3.2. Assessment of the relationship between impact and reproduction indicators

A. neptunica was observed flowering and fruiting primarily during the months of September to December. A total of 1,707 plants (12% of the total) were recorded as flower-bearing and 1,499 (11% of the total) fruit-bearing in both trail-perpendicular and randomly-directed transects. *A. neptunica* flowered and fruited profusely with >1000 flowers and >1000 fruits counted on some plants. The ratio of flowering and fruiting plants to the total counted per plot was 0.120 and 0.105 respectively.

C. articulata plants bore fruits during September to January and flowers during October to December but plants with flowers or fruits were uncommon. Only 28 (10% of the total) flower-bearing and 5 (2% of the total) fruit-bearing plants were counted in both trail-perpendicular and randomly-directed transects. Flowers were borne in clusters of 2–13 with up to 70 flowers per plant. Up to 6 fruits were found on any single fruiting plant. The ratio of flowering and fruiting plants for *C. articulata* to the total was 0.100 and 0.018 respectively.

As any incidence of harvesting potentially affects density or stem length, correlations between abundance, mean stem lengths, and numbers of plants flowering or fruiting were explored. A Canonical Correlation analysis was used to assess relationships between density and stem length on one hand; and numbers of plants in flower or fruit on the other. *A. neptunica* showed strong correlations (Table 1) suggesting that any harvesting would significantly impact the amount of seed available.

For *C. articulata*, correlations were strong only in so far as they were related to density and flowering but not level of fruiting or stem length (Table 2).

3.3. Assessment of vulnerability due to habitat specificity

Topography is one of the major natural causes for variation in plant density and understanding its effect is key for determining suitable sampling approaches for each species as well as for evaluating vulnerability related to habitat specificity.

Table 1. p-Values for Betas in a Canonical Correlation analysis of *A. neptunica* plants between harvest impact indicators and reproduction indicators. Full results are provided in Appendix 1.

	p-Values for <i>A. neptunica</i> Betas	
	Number with Flowers	Number with Fruits
Plant Density	<0.001	<0.001
Mean Stem Lengths	<0.001	<0.001

Table 2. p-Values for Betas in a Canonical Correlation analyses of *C. articulata* plants of harvest impact indicators and reproduction indicators. Full results are provided in Appendix 1.

	p-Values for <i>C. articulata</i> Betas	
	Number with Flowers	Number with Fruits
Plant Density	0.008	0.687
Mean Stem Lengths	0.964	0.752

A. neptunica significantly decreased in stem density uphill (Jonckheere-Terpstra Test, $Z = -2.653$, $p = 0.004$, $n = 210 \ 5 \times 10$ m plots) but there was no statistical difference in stem density between plots placed at valley bottoms and those on the upper slopes (Two-sample t-Test, $t = 1.646$, $p = 0.109$, $n = 19 \ 15 \times 15$ m plots). Transect data did not show detectable variation in stem length by slope (Jonckheere-Terpstra Test, $Z = -1.190$, $p = 0.117$, $n = 1551$ plants). Nevertheless, plants in the valley bottoms and lower slopes had significantly longer stems than those in the upper slopes and hilltops (Kolmogorov-Smirnov Two-Sample test, $p = 0.003$, $n = 497$ and 349 plants for lower and upper slopes respectively).

For *C. articulata*, transect data showed plant density to decrease uphill (Jonckheere-Terpstra Test, $Z = -3.954$, $p < 0.001$, $n = 210 \ 10 \times 20$ m plots) but plots placed at valley bottoms and hilltops/upper slopes showed no pronounced differences in density (Kolmogorov-Smirnov Two-Sample test, $p = 0.206$). For stature, there was no detectable trend in change of plant height from valley bottoms uphill (Jonckheere-Terpstra Test, $Z = 1.087$, $p = 0.139$, $n = 94$ plants) and plots placed at valley bottoms/lower slopes did not show significant differences in plant height from those on upper slopes and hilltops (Kolmogorov-Smirnov Two-Sample test, $p = 0.410$).

For *C. deerratus*, stem density strongly decreased uphill (Jonckheere-Terpstra Test, $Z = -6.110$, $p < 0.001$, $n = 210 \ 10 \times 20$ m plots) and plot data showed significantly higher density in valley bottoms than upper slopes/hilltops (Kolmogorov-Smirnov Two-Sample test, $p = 0.022$). On the other hand, plant height showed a mild trend of decrease uphill (Jonckheere-Terpstra Test, $Z = -1.424$, $p = 0.077$, $n = 444$ stems). This was confirmed by plot data which showed that plants in valley bottoms had stems significantly longer than those located further up the slope (Kolmogorov-Smirnov Two-Sample test, $p < 0.001$).

3.4. Inter-compartment variation in plant abundance

For *A. neptunica*, One-way ANOVA showed significant density variation across compartments ($F = 21.872$, $p < 0.001$, $df = 11$). Contrary to expectation however, density significantly decreased away from Najjembe Market which is the main point of consumption and decreased away from the nearest forest boundaries (Multiple Linear Regression; $R^2 = 0.024$; $t = -5.879$, $p < 0.001$ for market proximity; $t = -5.833$, $p < 0.001$ for boundary proximity) (Fig. 3).

Similar patterns were evident for *C. articulata* (Kruskal-Wallis One-way ANOVA, Test Statistic = 38.064 , $p < 0.001$, $df = 11$). Contrary to expectation, density significantly decreased away from Najjembe Market which is the main point of consumption and decreased away from the nearest forest boundaries (Multiple Linear Regression; $R^2 = 0.008$; $t = -3.915$, $p < 0.001$ for market proximity; $t = -3.045$, $p = 0.002$ for boundary proximity) (Fig. 4).

For *C. deerratus*, there were significant inter-compartment differences in abundance (Kruskal-Wallis One-way ANOVA, Test Statistic = 30.023, $p = 0.002$, $df = 11$). Abundance was negatively correlated with distance from the market, but there was no detectable variation with respect to boundary proximity (Multiple Linear Regression; $R^2 = 0.008$; $t = -2.865$, $p = 0.006$ for market proximity; $t = 1.186$, $p = 0.240$ for boundary proximity) (Fig. 5).

3.5. Variation along trail-perpendicular bearings

The main expectation for trail-based data was that because plants near trails have a likely higher likelihood of being detected and harvested, plant densities and abundances should increase with increasing distance from the trail.

Exploratory analyses showed that for *A. neptunica*, there were no differences in density between sequential plots in transects (Kruskal-Wallis One-way ANOVA, $p = 0.778$, $n = 1390$) and no pairwise comparisons were significant (Dwass-Steel-Christchlow-Fligner Test, $p > 0.670$ for all combinations). For stem lengths, differences between the plots were profound (Kruskal-Wallis One-way ANOVA, $p < 0.001$, $n = 7,216$). Contrary to expectation, the definitive analysis showed a strong trend of density decrease away from the trails for this species (Jonckheere-Terpstra Test, $Z = -2.021$, $p = 0.022$, $n = 1390$ plots). However as expected, randomly-directed transects showed no density variation with distance along transects (Jonckheere-Terpstra Test, $Z = -0.817$, $p = 0.207$, $n = 1370$ plots). A pattern of decrease away from trails was also evident for stem lengths (Jonckheere-Terpstra Test, $Z = -2.224$, $p = 0.013$, $n = 7,216$ stems) as it was for the number of plants flowering or fruiting respectively (Jonckheere-Terpstra Test, $Z = -2.674$, $p = 0.004$ and $Z = -3.096$, $p = 0.001$ respectively). Of 2,391 stems observed cut for whatever reason, 98% were seen with re-sprouts.

For *C. articulata*, exploratory analysis showed significant variation in plant density between the sequential plots of the transects (Kruskal-Wallis-One-way ANOVA, $p = 0.001$, $df = 9$) but no such variation was evident for plant heights (Kruskal-Wallis One-way ANOVA, $p = 0.294$, $df = 9$). The definitive analysis showed a clear pattern of density increase with distance from trails (Jonckheere-Terpstra Test, Standardized Statistic (Tscore) = 32.194, $p < 0.001$) and the same was true for numbers of plants flowering or fruiting ($Z = 9.728$, $p < 0.001$ and $Z = 5.180$, $p < 0.001$ respectively). As expected, such patterns were not evident for randomly-directed transects seen from density variation (Jonckheere-Terpstra Test, $Z = -1.287$, $p = 0.099$, $n = 1370$ plots). Plant heights exhibited no trail-related patterns (Jonckheere-Terpstra Test, $Z = 0.405$, $p = 0.343$, $n = 90$ plants) and as expected, plants in randomly set transects showed no such pattern (Jonckheere-Terpstra Test, $Z = 1.268$, $p = 0.102$, $n = 193$ plants). 100% of 79 stems observed cut were seen to re-sprout.

4. Discussion

Although access to non-timber forest products is sometimes advanced as a tool to facilitate forest conservation through ownership of the local people, several studies have demonstrated that there are negative impacts to it (Zuidema and Boot, 2002; Ticktin, 2004; Ticktin and Nantel, 2004) that need to be borne in mind and addressed. Some studies in Uganda have assessed human impact on forest using edge-based assessment in a forest in which law enforcement is strong but is surrounded by a densely populated community with a strong demand for NTFPs (Olupot, 2009; Olupot et al., 2009a, 2009b). This study has used trail-based sampling to assess harvest impact in a forest with weak law enforcement and where NTFP access is akin to “open”. It has demonstrated occurrence or non-occurrence of impact on three species.

For *A. neptunica*, the study has shown that the species occurs in relatively high density and is fairly well distributed with respect to slope location. Its apparent preference for lower slopes and valley bottoms is evident from significant density decreases uphill and plants in valley bottoms/lower slopes having significantly longer stems than those on the upper slopes and hilltops. There was also no evidence of negative harvest impact when trail-perpendicular patterns in density and stem lengths are considered. Both parameters showed significant decreases away from trails. Trail-related variation in number of plants fruiting and flowering also did not suggest negative impact as significant decreases away from trails were evident for both parameters. Further evidence of low harvest impact was apparent from regressions of density on distances from Najjembe market, the main point of use and distances from reserve boundaries which showed the reverse of expected trends: i.e. decrease rather than increase away from the two types of reference location.

The apparently undetectable negative harvest impact for *A. neptunica* may be due to several factors including a very low ratio of offtake to stems available; a high degree of resilience in terms of growth rate, number of propagules, modes of reproduction, and resistance to habitat disturbance; and the methods used here not being powerful enough to detect impact. We have no elaborate thoughts from hindsight on how we would have better measured impact over years as intended here other than those that measure density, plant stature, and reproduction indicators. Analyses related to the distribution of stem lengths can also help detect long term impact if actual distributions are available from populations that are not harvested but such information is not available. However, current harvest impact can be measured by timing sampling to take place in a given location at the same time as harvesting is ongoing. Since stem cutting is selective and limited to those stems of about the size of an average pen, the possibility that harvest impact is countered by resilience is plausible. Observation of re-sprouting by a majority of stems cut, the large number of fruits produced per plant, occurrence of new root and shoot sprouts from stems of recumbent stems,

occurrence of relatively young plants less than 1.2m tall flowering and fruiting, and of seedling sprouts from locations in which charcoal had been burnt are all suggestive of a high degree of resilience which makes up for harvesting and smothering impact.

Preceding text has shown that *A. neptunica* is resilient to harvesting and is somewhat favored by disturbance. In this respect, the species appears to exhibit traits of species that are known to prevail in the face of harvesting at least under moderate habitat disturbance (Cunningham and Mbenkum, 1993; Peters, 1994). Its higher abundance near the use point as demonstrated by negative correlation of its abundance with distance from use points is likely due to the coincidence of the use point being near the most preferred habitat. This remains to be demonstrated.

C. articulata showed response to a socio-economic gradient and its density was very low; 120 times lower than that of *A. neptunica*. Unlike *A. neptunica*, the trend of *C. articulata* decrease uphill was stronger indicating a stronger degree of habitat specificity. A combination of strong preference for lower slopes and valley bottoms and low density makes it highly vulnerable to extinction from harvesting. This vulnerability is increased by low fruiting success as only a few fruits (up to 6) were found on each of the 5 out of the 281 plants counted in trail-perpendicular and randomly-directed transects. Strong canonical correlations observed as related to density and flowering but not level of fruiting or stem length could be due to incidental cutting by users seeking other resources and coppicing so that plants apparently short in stature can still flower or fruit after re-sprouting. While the relationship between plant density and number of plants flowering is expected, absence of correlation with number of fruits or plants fruiting is not readily explained unless the fruits are also specifically sought by collectors or have natural predators and plant abundance increases the likelihood of the fruits being removed. We have observed that red tail monkeys (*Cercopithecus ascanius*) in this forest eat the fruits of *C. articulata*.

The vulnerability of *C. articulata* to harvesting is compounded by roots being the parts sought, its apparent preference for canopy-shaded locations and the ease with which they are harvested. The tap root is the only root and anchor of the plant in the ground. Whole plants are uprooted or dug up. Negative harvest impact is indicated by its demonstrable density increase along trail-perpendicular transects. Given the ease of its harvesting and apparent low reproduction success; the pattern of its density decrease away from potential use points is like *A. neptunica*, attributable to its natural habitat being coincidentally located near these areas. It can also be attributed to the high likelihood that the majority of the locals are not aware of its perceived medicinal value. Thus, conservation actions involving community engagement should not involve the locals collectively for risk of raising negative awareness but rather carefully identify and engage specialist medicine collectors.

Conservation of the species can also be helped by determining techniques of increasing its fruiting success in-situ.

For *C. deerratus*, it was shown that the sampling approach used for determining its distribution on a wide spatial scale was not useful for estimating reserve-wide densities and harvest impact as standard sample units were not used. However, it for the first time provides a picture of where the main populations of the species are found for further research and on-the-ground conservation intervention. Although we are unable demonstrate past and ongoing harvest impact on the species, results show that *C. deerratus* has a very high degree of habitat specialization, occurring in distinct patches near small slow running streams where the valley bottoms are wide and bear accumulations of mud and debris. Its apparent high abundance near potential use locations is like the other species due to the coincidence of its natural habitat occurring in these locations and as far as we know not a result of response to disturbance. This pattern of distribution pre-disposes it to easy detection by collectors and therefore over-harvesting. Reduction of its post-harvest survival rate is potentially a result of mortality of rhizomes and sexual reproduction being impaired by removal of mature stems before fruiting. If these indeed happen, the size of existing clumps will reduce, be comprised more of younger stems, and colonization of new areas by the species will be impaired.

5. Conclusions

- This study has demonstrated that in reserves where NTFP collection is more-or-less unrestricted both quantitatively and spatially, trail-based assessments can be useful in detecting harvest impact on species sought. Other studies (e.g. [Olupot et al., 2009b](#)) have shown that where access by collectors is restricted, edge-based assessments can be useful for demonstrating such impact.
- *Acalypha neptunica* (known by the English common name “Copperleaf” which is generally applied to species in the genus *Acalypha*) is currently not threatened by harvesting for meat sticks. Accordingly, no management actions to regulate harvest, conduct enrichment, or sensitize communities on best practices are needed at the moment.
- *Citropsis articulata* (the African cherry orange) is vulnerable and at risk of local extinction if overharvested. Research is needed to increase fruiting success. Community engagement at a local level targeting known collectors is needed. However, the specialist collectors need to be identified, sensitized, and engaged.
- *Calamus deerratus* (a rattan cane species) is naturally threatened in this forest due to its high degree of habitat specialization and low spatial coverage. Studies are needed to establish whether stumps of cut stems die or re-sprout, and the

average lengths of fruit bearing culms. Apart from the enrichment effort previously started (and that was not successful to the extent expected) with seedlings in the western part of the forest by forest management, promotion of regeneration by re-seeding should be experimented. To achieve this, seeds should preferably be sourced from the same forest but can also be obtained from other forests within the country where supply is possible as it is the only species of rattan known to be in Uganda.

- For the three species studied here, monitoring populations should be done at two temporal stages: first assessing the immediate short-term impacts of harvesting on current population structure, and second, determining long term change in population dynamics (e.g., effects of temporal variation in recruitment and mortality on population structure).
- As with the analysis of distribution and abundance, all monitoring studies must include populations that are not subjected to harvesting which occur in the same range of habitats harvested populations are found when such populations are determined to exist in the locality. In the case of Mabira, this means effectively enforcing the existing strict nature reserve status of the core of the reserve to establish a permanent undisturbed area and repeating observations through the years.

Declarations

Author contribution statement

William Olupot: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Eric Sande: Performed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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References

- Arnold, J.E.M., Ruiz-Perez, M., 2001. Can non-timber forest products match tropical forest conservation and development objectives? *Ecol. Econ.* 39, 437–447.
- BBC News 25 July, 2007. Uganda's 'Sex Tree' Under Threat. <http://news.bbc.co.uk/2/hi/africa/6915509.stm>. Last accessed June 4th 2018.
- Burkill, H.M., 1997. *The Useful Plants of West Tropical Africa*. Royal Botanic Gardens, Kew.
- Cosiaux, A., Gardiner, L.M., Couvreur, T., 2016. *Calamus deerratus*. The IUCN Red List of Threatened Species 2016: e.T95315744A95315747.
- Cunningham, A.B., Mbenkum, F.T., 1993. Sustainability of Harvesting Prunus Africana Bark in Cameroon. People and Plants Working Paper No. 2. UNESCO, Paris, France.
- Dransfield, J., 1978. Growth forms of rain forest palms. In: Tomlinson, P.B., Zimmermann, M.H. (Eds.), *Tropical Trees as Living Systems*. Cambridge University Press, Cambridge, pp. 232–246.
- Dransfield, J., 1986. Palmae. In: Polhill, R.M. (Ed.), *Flora of Tropical East Africa*. A.A. Balkema, Rotterdam.
- Gayton, D., 2013. Grassland and forest understorey vegetation monitoring: an introduction to field methods. *J. Ecosyst. Manag.* 14, 1–9. <http://jem.forrex.org/index.php/jem/article/viewFile/173/494>. Last accessed on March 28th 2019.
- Gruca, M., Blach-Overgaard, A., Balslev, H., 2015. African palm ethno-medicine. *J. Ethnopharmacol.* 165, 227–237.
- Hall, P., Bawa, K., 1993. Methods to assess the impact of extraction of non-timber tropical forest products on plant populations. *Econ. Bot.* 47, 234–247.
- Kalungi, E., 2004. Experiences of Rattan Cane (*Calamus Deerratus*) Propagation Trials in Uganda. EAC (East African Community) IRC Repository. <http://repository.eac.int>. Last accessed on June 4th 2018.

Kamatenesi-Mugisha, M., Oryem-Origa, H., 2005. Traditional herbal remedies used in the management of sexual impotence and erectile dysfunction in western Uganda. *Afr. Health Sci.* 5, 40–49. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1831906/>. Last accessed on 28th March 2019.

KewScience: Plants of the World Online. <http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:337636-1>. Accessed January 30th 2018.

Ministry of Water and Environment, 2010. Forest Management Plan for Mabira Central Forest Reserves (Mabira, Nadagi, Namakupa, Namawanyi/Namananga & Kalagala Falls Central Forest Reserves) for the Period 1st July 2009-30th June 2019. Ministry of Water and Environment, Kampala.

Olupot, W., 2009. A variable edge effect on trees of Bwindi Impenetrable National Park, Uganda, and its bearing on measurement parameters. *Biol. Conserv.* 142, 789–797.

Olupot, W., Barigyira, R., Chapman, C.A., 2009a. The status of anthropogenic threat at the people-park interface of Bwindi Impenetrable National Park, Uganda. *Environ. Conserv.* 36, 41–50.

Olupot, W., Barigyira, R., McNeilage, A.J., 2009b. Edge-related variation in medicinal and other ‘useful’ wild plants of Bwindi Impenetrable National Park, Uganda. *Conserv. Biol.* 23, 1138–1145.

Peters, C.M., 1994. Sustainable Harvest of Non-timber Plant Resources in Tropical Moist forest: an Ecological Primer. Biodiversity Support Program, Washington DC.

PROTA. Calamus Deerratus. [http://uses.plantnet-project.org/en/Calamus_deerratus_\(PROTA\)](http://uses.plantnet-project.org/en/Calamus_deerratus_(PROTA)). Accessed June 4th 2018.

Sunderland, T.C.H., 2001. The rattans of West and central Africa: an overview. In: Sunderland, T.C.H., Profizi, J.-P. (Eds.), CARPE-funded International Expert Meeting on the Rattans of Africa. Limbe Botanic Garden.

Sunderland, T.C.H., 2012. A taxonomic revision of the rattans of Africa (Arecaaceae: Calamoideae). *Phytotaxa* 51, 1–76.

Swingle, W.T., Reece, P.C., 1967. In: Webber, H.J. (Ed.), Chapter 3: the Botany of Citrus and its Wild Relatives. University of California Press, Berkeley.

Ticktin, T., 2004. The ecological implications of harvesting non-timber forest products. *J. Appl. Ecol.* 41, 11–21.

Ticktin, T., Nantel, P., 2004. Dynamics of harvested populations of the tropical understory herb *Aechmea magdalenae* in old-growth versus secondary forests. *Biol. Conserv.* 120, 461–470.

Tuley, P., 1995. Palms of Africa. Trendrin, St.Ives.

Zuidema, P.A., Boot, R., 2002. Demography of Brazil nut tree (*Bertholletia excelsa*) in the Bolivian Amazon: impact of seed extraction on recruitment and population dynamics. J. Trop. Ecol. 18, 1–31.