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African Journal of Ecology

Matrix population models indicate that bark harvest of two medicinal plants in Uganda's Bwindi Impenetrable National Park is sustainable

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Abstract

Balancing forest conservation with resource extraction by local people is challenging. In the mountain forests of Bwindi Impenetrable National Park in Uganda, this was addressed by permitting regulated access to certain forest products in specific areas by authorized local people. However, it remained unclear whether harvest levels were biologically sustainable. Here, we used matrix population models and long-term data to examine the impacts of bark harvesting on population dynamics of two important medicinal plants, *Rytigynia kigeziensis* and *Ocotea usambarensis,* in Bwindi. Only 4% of *R. kigeziensis* and 3% of *O. usambarensis* stems (>1.3 m height) showed signs of bark harvest, mostly mild harvesting. We found that the harvested populations of both species appeared stable or will moderately grow in the long run. Modelled population growth rates were mostly determined by survival probabilities. Similarity between the stable stage distributions predicted by the model and observed population structures suggests that our estimated vital rates (growth, recruitment and survival rates) are a reasonable representation of actual values in these populations. Thus, recent harvest levels of *R. kigeziensis* and *O. usambarensis* appear sustainable. Nonetheless, monitoring of harvested and unharvested populations by tagging, marking and remeasuring individuals should continue for both species.

Key words: bark harvest, demography, matrix population models, non-timber forest products, sustainable use, Uganda

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Résumé

Il n'est pas facile d'équilibrer la conservation des forêts avec l'extraction des ressources par la population locale. Dans les forêts montagnardes du Bwindi Impenetrable National Park en Ouganda, cela s'est fait en permettant à des personnes autorisées un accès régulé à certains produits forestiers, et à certains endroits. Cependant, il n'était pas facile de savoir si le niveau de collecte était biologiquement durable. Ici, nous utilisons des modèles matriciels de population et des données de longue durée pour examiner l'impact de la récolte d'écorces sur la dynamique de population de deux plantes médicinales importantes, *Rytigynia kigeziensis* et *Ocotea usambarensis*, à Bwindi. Seuls 4% des plants de *R. kigeziensis* et 3% des *O. usambarensis* (>1.3 m de haut) montraient des traces de la récolte d'écorces, en majorité légères. Nous avons trouvé que les populations collectées des deux espèces semblaient stables ou qu'elles allaient pousser modérément avec le temps. Les taux de croissance de population modélisés étaient surtout déterminés par la probabilité de survie. La similarité entre les distributions d'un stade stable prédites par le modèle et les structures de population observées suggèrent que nos estimations d'indices vitaux (croissance, recrutement et taux de survie) sont une représentation raisonnable des valeurs réelles de ces populations. Donc, le taux récent des collectes de *R. kigeziensis* et *O. usambarensis* semblent durables. Néanmoins, le suivi des populations exploitées ou pas devrait continuer pour les deux espèces, par balisage, marquage et remesurage des individus.

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Introduction

Permitting the sustainable extraction of non-timber forest products (NTFPs) is one way to reconcile tropical forest conservation and the needs of local people. However, NTFPs are often overharvested, threatening these species and their sustained supply (Ticktin, 2004). Matrix population models project the size and structure of populations in time through repeated cycles of growth, recruitment and mortality and are used to study population dynamics (Caswell, 2001). Locally calibrated matrix models can be used to assess the sustainability of harvest practices and to identify the most critical life-history stage of the population (see Crone *et al.* (2011) and Liang & Picard (2013) for recent overviews of some strengths and weaknesses of applying this approach). Studies using matrix population models to simulate the impacts of NTFP harvest on population dynamics are heavily concentrated in the neotropics, while studies of Asian and African plant species are rare (Schmidt *et al.*, 2011). This study is among the first to apply matrix models to assess the sustainability of NTFP harvests in East Africa (but see Groenendijk *et al.*, 2012).

In the mountain forests of Bwindi Impenetrable National Park (henceforth 'Bwindi'), Uganda, certain areas were defined where specified people living near the forest are allowed to harvest small percentages of NTFPs from certain plants (Cunningham, 1996; Bitariho *et al.*, 2006). The sustainability of this harvest is uncertain.

The barks of the shrub *Rytigynia kigeziensis* Verdc. (Rubiaceae) and the tree *Ocotea usambarensis* Engl. (Lauraceae) are harvested by people living close to the forest and locally used as treatments for worms and stomach pain. Parasites and related intestinal problems have been a major health problem in the region with a prevalence of 89% for whipworm and 34% for *Ascaris* in one 1990 study (Ashford, Reid & Butynski, 1990). Previous research did not detect any marked difference in bark production for these two species between areas where controlled harvesting is allowed, so-called multiple-use zones (MUZs), and areas where harvesting is not allowed (non-MUZs), suggesting bark harvest had little impact and was likely to be sustainable (Bitariho *et al.*, 2006). However, such comparative studies have limitations and a more rigorous analysis on the consequences of the harvesting practices on the viability of exploited populations is lacking. In this study, we extend the earlier observations of Bitariho *et al.* (2006) concerning the impacts of bark harvest on *R. kigeziensis* and *O. usambarensis* populations in Bwindi. We used a longer-term data set and a matrix model approach to evaluate vital rates (growth, recruitment and survival rates), their elasticities and demographic consequences.

Material and methods

Study species

R. kigeziensis (local name 'Nyakibazi') is a multistemmed shrub endemic to the Albertine Rift occurring between 1800 and 2400 m a.s.l. It grows mainly on ridges, slopes and hilltops (Kamatenesi, 1997). This species appears vulnerable to overexploitation due to high local demand (Cunningham, 1996). *O. usambarensis* ('Mwiha' in local language) is a large forest tree that was once widely distributed in rainforests between 900 and 3000 m altitude throughout East Africa, where it prefers deep, fertile soils with good drainage (Katende, Birnie & Tengnäs, 1995; Okeyo, 2008). It has become rare due to exploitation for its high-value timber and is officially protected in Kenya and Tanzania (Okeyo, 2008).

Study area

Bwindi is located on the edge of the Albertine Rift in southwest Uganda. It was gazetted as a national park in 1991 and covers an area of 331 km^2, ranging from 1190 to 2560 m elevation. The climate is equatorial with two rainfall peaks from March to May and September to November. The mean annual temperature varies with location and spans 16.4–21.7°C. Annual rainfall varies between 1000 and 2000 mm (ITFC, 2010). Within the Albertine Rift, Bwindi is especially important for its conservation value with many endemic and globally threatened species, including mountain gorillas (*Gorilla beringei beringei*) (Plumptre *et al.*, 2007).

Field measurements

Starting in 2002, the Institute of Tropical Forest Conservation (ITFC) established permanent sample plots in several MUZs and non-MUZs in Bwindi to investigate the effects of harvesting on several vulnerable plant species. *R. kigeziensis* was sampled in plots of 20 × 20 m, which were placed on line transects of generally 265 m long and separated from each other by 15 m. Plots were established

alternately left and right of the transect lines. A total of 96 plots of 0.04 ha each (in total 3.84 ha) were used to measure *R. kigeziensis*, all located in the same geographical area, a non-MUZ. *O. usambarensis* was studied in 39 belt transects of ~0.53 ha each (20 m broad and mostly 265 m long, in total ~20.67 ha), distributed over six areas in Bwindi, one non-MUZ and five MUZs. For both species, the first transect was randomly selected and transects were 100 m apart within an area. Plant stem diameter (measured at breast height: 1.3 m from ground level or above buttresses) was recorded annually from 2004 to 2010 (except for 2009) for all stems >1.3 m height occurring in the plots and belt transects. Tree mortality was only recorded in 2010; the year of death was estimated based on the state of stem decay.

Data analysis

When the permanent sample plots were established, only a subset of stems within (or in a few cases adjacent to) the plots and belt transects were tagged and numbered. Because tagged samples were few, 60 *R. kigeziensis* and 76 *O. usambarensis* stems, we improved our estimates using additional diameter growth rates reconstructed from untagged stems by linking diameter measurements of plants in the same plot or transect over time. For some stems, links could be made over multiple years, while for others this was possible for just two years. Annual diameter growth rates from stems were calculated by regressing successive diameter values and dates and calculating the slope of this linear regression. We checked whether the reconstructed growth rates of untagged stems were within the range of growth rates obtained from the tagged stems, this was the case for all stems. Applying this procedure, we obtained realistic diameter growth rates for 619 *R. kigeziensis* and 223 *O. usambarensis* stems in the matrix models, based on 577–886 measurements of stems of *R. kigeziensis* over the years in the plots and 906–938 measurements of *O. usambarensis* in the transects (in 2004 and 2010, *O. usambarensis* was not sampled in all the areas and 340 and 734 stems, respectively, were measured in those years).

There were no data available about the transition probability from a sapling into the first diameter class (3–6 mm diameter for *R. kigeziensis* and 2–30 mm diameter for *O. usambarensis*). Therefore, annual recruitment rates were assumed equal to the sum of outgrowth and mortality of the first diameter class in 2010. Mortality probabilities for 2 years were estimated by dividing the number of stems that died between 2008 and 2010 (44 *R. kigeziensis* and 88 *O. usambarensis* stems) by the sum of this number of dead stems and the number of living stems measured in 2010. Annual survival probabilities were derived by calculating the square root of survival probabilities for 2 years, that is $\sqrt{}$(1-mortality probability for 2 years).

For each species, a matrix model was constructed. To this end, we divided the populations into seven (for *R. kigeziensis*) and six (*O. usambarensis*) size categories and calculated annual transition probabilities between these categories based on the derived growth, recruitment and survival rates. Matrix models take the form $\mathbf{n}(t+1) = \mathbf{A} \times \mathbf{n}(t)$, where $\mathbf{n}(t)$ and $\mathbf{n}(t+1)$ are vectors representing the population structure at time t and $t+1$, respectively, and $\mathbf{A}$ is a square matrix containing probabilities of transitions among categories in an interval of time (in our case, 1 year) (Caswell, 2001). The dominant eigenvalue of matrix $\mathbf{A}$ is the population growth rate (λ). Population growth rates assess whether population sizes are expected to increase ($\lambda > 1$), decrease ($\lambda < 1$) or remain stable ($\lambda = 1$). 95% confidence intervals for λ were calculated using the series approximation approach, which uses the sensitivities and variances of vital rates to determine the range of λ (Caswell, 2001). PopTools (Hood, 2010) was used to conduct matrix analyses. To clarify whether our estimated vital rates and population dynamics are representative of those occurring in recent decades, the stable stage distributions predicted by the models were compared with the stage distributions observed in the field. We assessed similarity with the 'proportional similarity index' (see Horvitz & Schemske, 1995). For analyses of harvest impacts, it is important to know the relative importance of vital rates in determining λ, which we quantified by calculating their elasticities (Caswell, 2001; Zuidema & Franco, 2001).

Results

Only 4% of the *R. kigeziensis* and 3% of the *O. usambarensis* stems (>1.3 m height) showed recent and/or old bark harvest signs in 2010 (Fig. 1). About half of these stems (49% of *R. kigeziensis* and 64% of *O. usambarensis*) had experienced minor harvesting; that is, less than 10% of the bark (up to 2 m trunk height) was removed. Harvested stems were encountered in the non-MUZ, as well as in some MUZs.

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Fig 1 Fresh (a, b) and old, healed (c) bark harvest signs of *R. kigeziensis* (photographs by S.M. Stas & E.M. Langbroek, 2010)

Table 1 Annual transition matrices for populations of *R. kigeziensis* (A) and *O. usambarensis* (B). Columns are stages at time *t* and rows are stages at time *t* + 1

(A)

	t	1	2	3	4	5	6	7
t + 1	1	0.890	0.027	0.031	0.036	0.041	0.054	0.183
	2	0.062	0.900	0.000	0.000	0.000	0.000	0.000
	3	0.000	0.042	0.922	0.000	0.000	0.000	0.000
	4	0.000	0.000	0.034	0.936	0.000	0.000	0.000
	5	0.000	0.000	0.000	0.031	0.946	0.000	0.000
	6	0.000	0.000	0.000	0.000	0.029	0.959	0.000
	7	0.000	0.000	0.000	0.000	0.000	0.027	0.990

(B)

	t	1	2	3	4	5	6
t + 1	1	0.843	0.023	0.023	0.275	0.275	0.275
	2	0.078	0.874	0.000	0.000	0.000	0.000
	3	0.000	0.093	0.917	0.000	0.000	0.000
	4	0.000	0.000	0.070	0.935	0.000	0.000
	5	0.000	0.000	0.000	0.051	0.957	0.000
	6	0.000	0.000	0.000	0.000	0.029	0.986

The transition matrices for populations of *R. kigeziensis* and *O. usambarensis* are shown in Table 1. The shape of the observed population structures (high proportion of small individuals) suggests that both species are regenerating (Fig. 2). Similarity between the stable stage distributions and the observed population structures (proportional similarity of 84% for *R. kigeziensis* and 91% for *O. usambarensis*) suggests that our estimated vital rates and the resulting population dynamics are representative of recent trends.

Asymptotic population growth (λ) of *R. kigeziensis* equalled 0.997 with a confidence interval of 0.980–

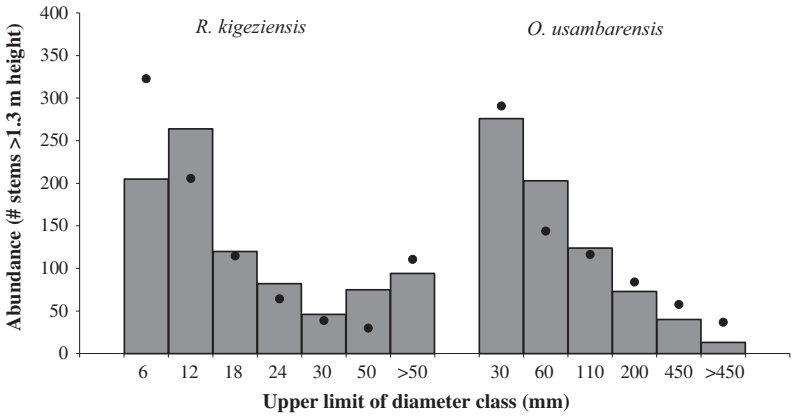


Fig 2 Population structures of harvested populations of *R. kigeziensis* (n = 886) and *O. usambarensis* (n = 729) in 2010. Dots show the number of stems expected per diameter class in the stable stage distribution

1.015, indicating a stable population size in the long run. For *O. usambarensis*, λ equalled 1.032 with a confidence interval of 1.014–1.050, indicating a moderately growing population. The recent low harvest levels thus appear sustainable for both species.

Modelled population growth rates were most sensitive to survival probabilities: elasticity values for survival accounted for 98% and 86% of the total vital rate elasticity for *R. kigeziensis* and *O. usambarensis*, respectively (Table 2).

Discussion

Low harvest levels were found for both populations. In some areas, the occurrence of alternative species for deworming and the large distance of the resources from the park boundary have likely reduced the harvest. In addition, access to local dispensaries and other health facilities has been much improved over the last two decades, making local people less dependent on traditional remedies. Although harvest is permitted in the MUZs, the regulations surrounding such use are time-consuming to follow and have likely discouraged many users as well (ITFC, various unpublished interviews). Nonetheless, there is some demand and harvested stems were encountered in some accessible areas where harvesting is not permitted.

Our results suggest that recent harvest levels of *R. kigeziensis* and *O. usambarensis* are sustainable. Bwindi's forest vegetation is still recovering from logging, fire and other disturbances during previous decades (Howard, 1991; Babaasa *et al.*, 2004). The ongoing recovery likely provides favourable conditions for some shade-tolerant species, such as *O. usambarensis*, which may explain the projected population increase. Our results seem at odds with demographic studies on bark harvesting elsewhere, which often indicate that such harvesting is unsustainable (Schmidt *et al.*, 2011). Sustainable bark extraction seems to be possible only if harvest intervals are long (e.g. Guedje *et al.*, 2007) or, as in our study, harvest intensities are low (e.g. Gaoue & Ticktin, 2007, 2008). Some species may possess particular physiological mechanisms that enable survival after bark harvest (Guedje *et al.*, 2007). It is unclear to what extent such characteristics influence harvest tolerance and recovery of our study species.

Table 2 Elasticities of vital rates (scaled to 100%) for both species

Vital rate elasticities (%)	*R. kigeziensis*	*O. usambarensis*
Survival	98.0	85.8
Growth	1.2	2.7
Recruitment	0.8	11.5

Elasticity analysis for both species showed that survival probabilities contributed most to λ. This is similar to findings of other long-lived plant species (Franco & Silvertown, 2004) as well as for bark-harvested tree species (Guedje *et al.*, 2007; Schmidt *et al.*, 2011). As the viability of populations of our study species – and other long-lived species – strongly depends on survival, it is crucial to ensure that harvesting does not increase mortality risk.

Although recent harvest levels appear sustainable, we stress that harvest impacts may change with local demands, practices, conditions and agreements. Continued monitoring thus remains important. This should involve tagging of all stems in the plots and transects and marking the point at which diameters are measured to reduce the uncertainties in estimating vital rates that we encountered using untagged and unpainted stems. Formal controls, that is unharvested populations, were absent in this study, as is often the case for NTFP

studies (Schmidt *et al.*, 2011). We recommend population monitoring by regular remeasurements in both harvested and unharvested populations.

The MUZ system focuses harvests in specific areas, which could be counterproductive in the longer term: permitting controlled harvests over a wider area, or rotated among areas, could be an improved option in the future if the process could be adequately managed and monitored. At present, we can at least confirm that recent harvest practices for *R. kigeziensis* and *O. usambarensis* around Bwindi appear sustainable.

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Author contributions

R.B. set up the multiple-use programme at ITFC; D.S. proposed this specific study as a collaboration between ITFC (R.B. and D.S.) and Utrecht University (P.Z.); all authors were involved in the study design; R.B. led the yearly data collection from 2004 to 2008; S.M.S. and E.M.L. collected the data in 2010 as part of their Masters degree under supervision from the other authors; S.M.S. analysed the data of *O. usambarensis* and E.M.L. of *R. kigeziensis*; S.M.S. wrote the manuscript with contributions from all the authors.

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