



Recruitment of *Pterocarpus angolensis* in the wild

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Abstract

Pterocarpus angolensis is a hardwood species subject to heavy exploitation throughout miombo woodlands of south-central Africa. Rates of natural recruitment measured in western Tanzania were found to be low, with only a third of parent trees generating any seedlings despite considerable seed production. Although heavily protected areas supported large parent trees, these adults had very few seedlings of >5 cm DBH nearby, possibly suggesting mortality caused by high densities of browsing ungulates. Outside these well protected areas, cutting has removed most large trees and remaining adults are small producing relatively few seeds. Factors affecting recruitment include location and elevation perhaps indicative of higher precipitation, whereas short grass and reduced parent canopy cover are associated with more seedlings suggesting competition for light. Given these recruitment rates, the prognosis for sustainable exploitation of *P. angolensis* looks bleak.

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1. Introduction

Much of the vegetation in the central and southern part of the African continent is dominated by miombo woodland, a dry, deciduous forest characterized by *Brachystegia*, *Julbernardia* and *Isoberlinia* (Campbell, 1996; Rodgers, 1996; Burgess et al., 2004). Low human population density means that the relatively intact biome still constitutes one of the few great wilderness areas on the continent (Mittermeier et al., 2003). Despite this, a number of hardwood species are

heavily exploited commercially within the miombo nations of Angola, the Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. Hardwoods are also harvested for export to Europe, Japan, and the Middle East. One of the principal hardwoods is *Pterocarpus angolensis* DC, used in construction, furniture and medicine. In Tanzania, the large quantities being removed from western, central and southern portions of the country raise the question of whether these logging practices are sustainable. A preliminary attempt to address this issue, based on proportion of felled adult trees of different sizes, indicated that rates of removal far exceeded recruitment into the adult population

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(Schwartz et al., 2002). Nonetheless, this study employed a matrix projection model that primarily used data on adult size distributions and extrapolation to inform assumptions regarding recruitment rates. If recruitment into the population is rapid, then the outcome of this model would be open to question.

An alternative way of producing *P. angolensis* is to grow it commercially for harvest. In an early attempt to determine the feasibility of this enterprise, Boaler (1966) conducted a comprehensive study of the ecology of the species but concluded that silvicultural problems occurred at all stages of development. These include difficulties in opening pods without damaging seeds, low rates of germination, annual dieback of seedlings, competition from other trees over sunlight, effects of fire, slow rates of tree growth, and delayed seed production. In practice, commercial attempts to grow *P. angolensis* have been largely unsuccessful (Van Daalen, 1991; Van der Reit et al., 1998).

In light of the greatly increased demand for *P. angolensis* in Tanzania since the time of Boaler's study, we decided to revisit some of his key findings on recruitment in this paper. Specifically, we wanted to confirm that estimations of recruitment were sufficiently low so as to preclude recovery of exploited populations in the wild or prevent profitable growth of nursery trees on a commercial scale.

2. Methods

Our study site is the Katavi ecosystem which lies in the Great Lakes Region of East Africa at the north end of the Rukwa Valley, north of Lake Rukwa in Mpanda District of Rukwa Region, Tanzania (Caro, 1999; Katavi-Rukwa Ecosystem Management Plan, 2002). The area is characterized by sandy soils and 611 mm of rainfall per year ($n = 27$ years) that falls between November and April. In August and September 2004 (late dry season), 300 adult *P. angolensis* were sampled in six different types of protected area: in Katavi National Park (NP) where no tree cutting has been allowed since 1912 when the area was first gazetted as a Game Reserve by German authorities; in Katavi National Park Extension (EXT) to the south-east where limited selective logging of trees was permitted in the wet season until 1998; in Lwafi District Game Reserve (GR) to the south west of the

NP where cutting is forbidden but is starting to occur illegally; in Mlele Game Controlled Area (GCA) to the east where cutting is sanctioned in the wet season; in Msanginia Forest Reserve (FR) to the north where cutting by business operations in Mpanda, the District capital, is permitted year round under license; and in Usevya Open Area (OA) to the south where logging by numerous entrepreneurs occurs throughout the year for local consumption (Fig. 1). In short, we sampled *Pterocarpus* across a gradient of cutting regimes.

In each type of protected area, we sampled 50 adult trees defined as having a DBH >25 cm; trees were selected if they had no other adult tree within 40 m although this was not always possible. At each tree we measured the DBH, number of recruits within a 10 m radius of the parent tree and again within a 20 m radius of the tree (these were subsequently combined in analyses); 20 m was chosen because Boaler (1966) had found that 92% of seeds fall within 10 m of the parent and few seeds were found beyond this distance. Size of all recruits was scored as follows: 0–0.5 m in height, 0.6–1.0, 1.1–1.5, 1.6–2.0, 2.1–2.5 m, and from then on the exact DBH of all larger recruits was measured. Most recruits were dormant at the time of sampling, during the dry season; seeds were present under most parent trees.

We measured several environmental variables at each parent tree (i) GPS location, (ii) altitude, (iii) whether the parent was less than 100 m from a standing water, (iv) soil texture (sand, silt, earth, rocks), (v) whether the area within 20 m of the parent tree had been burnt recently and/or trampled by ungulates, (vi) parent tree canopy size using a mean reading of a densitometer positioned on two sides of the parent tree trunk, and (vii) four measures of cover each on a six point scale: grass, herb, shrub and tree cover (see Caro, 2001). Data were analyzed using JMP 5.1 (SAS, 2000). We used a forward stepwise multiple regression procedure to assess whether combinations of variables were correlated with increased likelihood of seedling recruitment.

Finally, we recorded the relative numbers of standing and cut *P. angolensis* adult trees by driving a total of 232.5 km along minor roads in the six protected area types. These censuses were necessarily restricted to a 50 m bandwidth of visibility on either side of the road where cutting is relatively easy because of access yet endangers discovery by

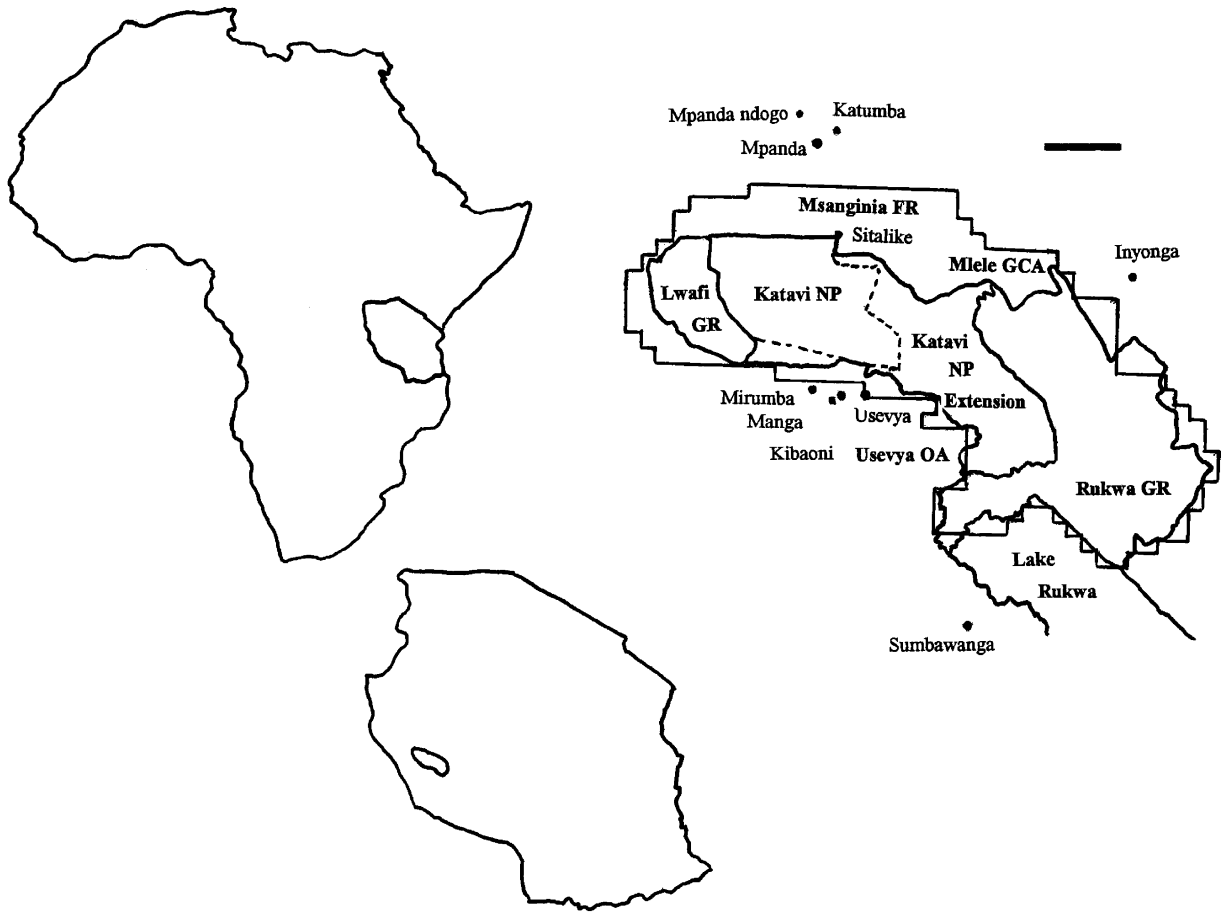


Fig. 1. Map of the Katavi ecosystem with approximate boundary denoted by rectangular border. Kibaoni, our research base, is the third village from the left, south of Katavi NP. Black bar denotes 25 km.

authorities. Thus it is not clear whether such censuses are representative of cutting throughout the protected area but they do provide unbiased comparisons across protected areas. Stumps and cut crowns indicative of felling reflect cutting activity over the last 5 years.

3. Results

3.1. Adult trees

The percent of adult *P. angolensis* cut in different protected areas is shown in Table 1. Trees in the NP and EXT were observed not to be cut at all; a small percentage in the GCA were cut; and a great many in the FR had been felled ($N = 1438$ trees counted, $\chi^2 = 493.7$,

d.f. = 5, $p < 0.001$). These cutting regimes were reflected in the sizes of the trees that we sampled. Trees differed significantly in size ($N = 300$ trees measured, $F = 43.7$, $p < 0.001$) with those in the NP being larger than anywhere else and those in the EXT being larger than anywhere but the NP (Fig. 2).

Table 1

Numbers of *P. angolensis* standing and cut in different protected areas as determined from road counts

	NP	EXT	GR	GCA	FR	OA
Cut	0	0	16	17	219	50
Standing	102	149	364	65	138	318
Cut (%)	0	0	4.2	20.4	61.3	13.6
Kilometers driven	42.0	18.5	54.5	20.5	31.9	65.1

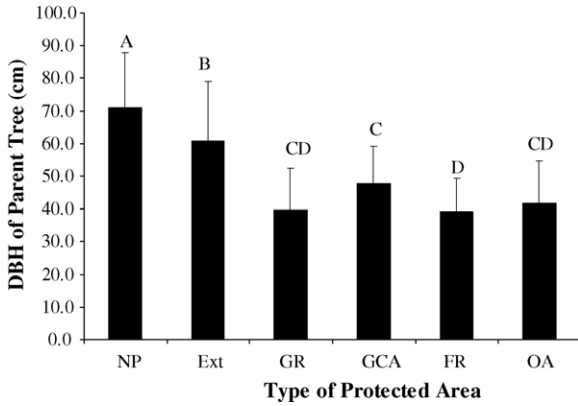


Fig. 2. Mean and S.E. DBH of parent *P. angolensis* trees sampled in the study. NP, National Park; EXT, National Park Extension; GR, Game Reserve; GCA, Game Controlled Area; FR, Forest Reserve; OA, Open Area. Different letters above the histograms show significant differences between protected areas.

Otherwise, trees in the FR were smaller than those in the GCA reflecting a history of relatively intense logging.

The majority of parent trees were in the 30–49 cm DBH size class although a substantial proportion was found in the 50–69 cm DBH range (Fig. 3). This size class distribution hints at episodic recruitment. The vast majority of very large trees (>80 cm DBH) were found in the NP and EXT.

3.2. Recruits

At the time of assessment in 2004, most parent trees had no recruits. Of 300 trees examined, only 102 had

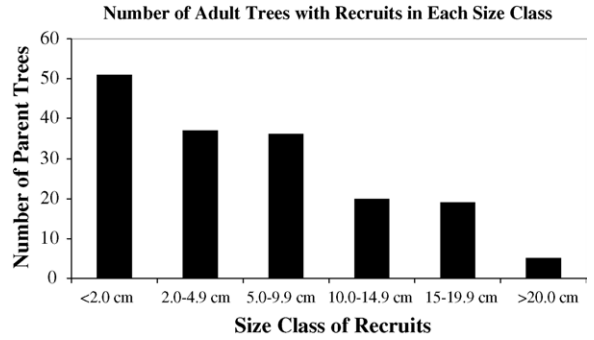


Fig. 4. Number of parent *P. angolensis* trees with *P. angolensis* recruits of different size.

one or more recruits within 20 m of the trunk. There was a significant difference in the proportion of trees with one or more recruits in the different types of protected area ($n = 50$ in all cases, NP 20%, EXT 36%, GR 67%, GCA 14%, FR 20%, OA 48%, $\chi^2 = 46.3$, d.f. = 5, $p < 0.0001$) with most in the GR and fewest in the GCA. Most recruits fell within the <2.0 cm DBH size class (i.e., were too small to be measured using DBH) and showed a progressive decline in frequency with increasing DBH (Fig. 4). The proportion of small (<5 cm DBH) recruits as opposed to recruits of any size differed across protected area categories (NP, $n = 77$ recruits, 0%; EXT, $n = 77$, 6.5%; GR, $n = 118$, 51.7%; GCA, $n = 63$, 7.9%; FR, $n = 67$, 32.8%; OA, $n = 97$, 28.9%, $\chi^2 = 99.2$, d.f. = 5, $p < 0.0001$), and examination of the data indicated that the NP, EXT and GCA, produced many small

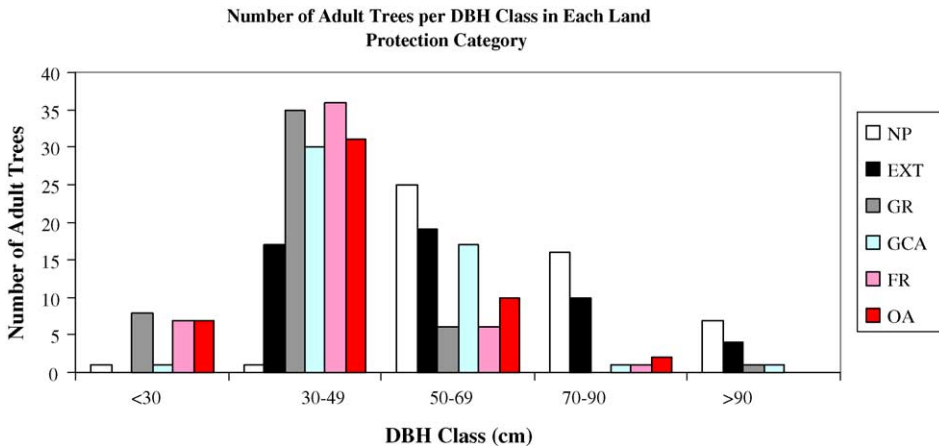


Fig. 3. Number of parent *P. angolensis* trees in each DBH class separated by protected area (see legend to Fig. 2).

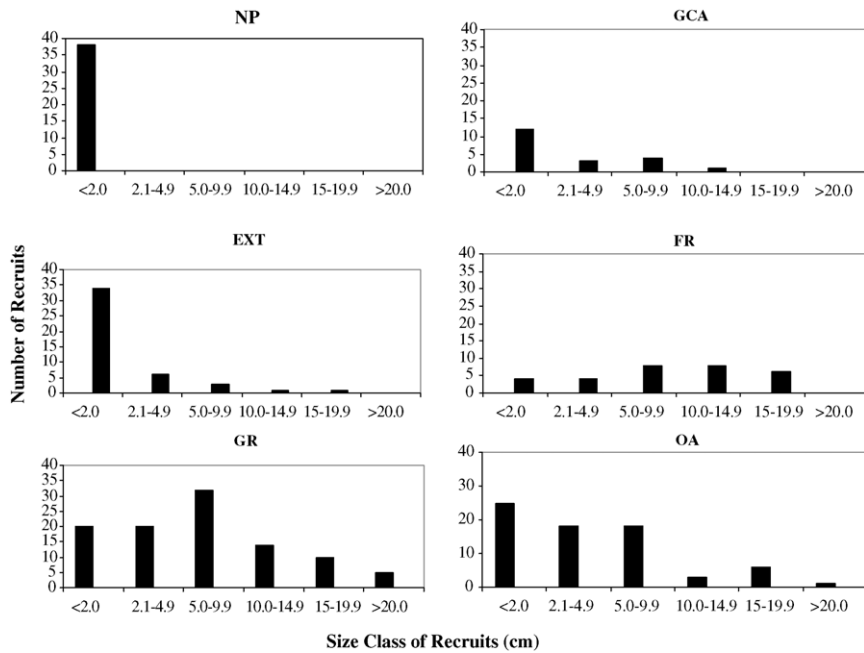


Fig. 5. Number of *P. angolensis* recruits of different size separated by protected area (see legend to Fig. 2).

recruits (<2 cm DBH) but very few large ones whereas those in the GR, FR, and OA exhibited a more even spread (Fig. 5).

When environmental variables were examined with respect to recruits, only latitude ($F = 10.625$, $p = 0.001$), longitude ($F = 14.878$, $p < 0.001$), higher elevation ($F = 4.874$, $p = 0.028$), lower grass height ($F = 8.097$, $p = 0.005$), parent trees with smaller canopies ($F = 8.566$, $p = 0.004$), and trees where surroundings had been burnt ($F = 4.750$, $p = 0.030$) predicted increased number of recruits. We conducted two stepwise regressions. In the first, we excluded latitude and longitude as problematic variables that may be a proxy for rainfall that increases toward Lake Tanganyika or may be a proxy for soil texture differing between the Ufipa plateau and the Rukwa Valley below. With latitude and longitude excluded, grass cover, size of the parent canopy and parent DBH all explained a significant portion of the variance with more recruits being found under parents with smaller canopies, smaller DBHs and less grass cover (Table 2A).

With latitude and longitude included in the stepwise regression, longitude, elevation, and parent

Table 2

Stepwise multiple regression, with forward selection of environmental variables, to explain the distribution of recruits associated with mature *P. angolensis* in the Rukwa region of western Tanzania

Parameter	Estimate	d.f.	SS	F-ratio	Prob > F
(A) Latitude and Longitude excluded					
Intercept	4.02	1	0	0.00	1.000
Grass cover	-0.18	1	24.9	3.28	0.071
Canopy tree cover	-0.30	1	42.3	5.57	0.019
DBH	-0.02	1	24.4	3.21	0.074
(B) Latitude and Longitude included					
Intercept	570.8	1	0	0.00	1.000
Longitude	-6.07×10^{-5}	1	102.3	14.0	0.0002
Elevation	-6.20×10^{-3}	1	64.1	8.78	0.003
DBH	-0.017	1	20.1	2.75	0.098
Canopy tree cover	-0.19	1	14.7	2.02	0.156
Grass cover	-0.13	1	12.65	1.73	0.189

Regression models were run using JMP 5.1 with (A) latitude and longitude excluded from the analysis; and (B) those variables included in the analysis. Non-significant variables: (A) landuse, elevation, distance to water, woody cover, herb cover, shrub cover, browse class, burn class and soil texture; (B) land use, latitude, distance to water, woody cover, herb cover, shrub cover, browse class, burn class and soil texture.

DBH explained significant portions of the variance, but still less than 8% of the variance. Trees further west at higher elevation, and those with smaller DBH produced more recruits (Table 2B).

4. Discussion

Most of the large parent trees sampled in this study were in the NP and EXT, probably reflecting the fact that no cutting has been permitted in the NP since 1912 when it was first gazetted as a Game Reserve; the EXT, which enjoyed only limited protection up until 1998, is a remote area further away from Mpanda than the FR and further from the villages to the south of the Park than the OA that surrounds them. Very few trees were recorded as felled in the NP and EXT.

Cutting in the FR was particularly severe with 61.3% of the observed tree boles felled. Cutting in the GR, GCA, FR and OA has focused on larger trees resulting in few large ones remaining. The legal size of tree that can be cut in Tanzania is 60 cm DBH or more but, as Fig. 2 shows, the average DBH of standing trees, particularly in the GR and FR, is far less than this, indicating that timber cutters are breaking the law by cutting trees smaller than the legal size limit. An earlier study in the FR found that the modal DBH for live *P. angolensis* in the FR was 25 cm and that the modal size of cut trees was 30 cm DBH, far below the legal limit (Schwartz et al., 2002). *P. angolensis* is under heavy cutting pressure in Rukwa Region, Tanzania.

Unfortunately, recruitment into the population is slow. Of 300 trees sampled, nearly two-thirds had no recruits within 20 m of the parent tree. These results were presaged by a pilot study that showed an almost complete absence of regeneration under both cut and uncut *P. angolensis* trees at the same study site (Schwartz and Caro, 2003). Of trees sampled here that boasted recruits, parents with smaller canopies were more likely to have recruits beneath them as well as those with smaller DBHs. Boaler (1966) found the opposite effect of a greater proportion of *Pterocarpus* in a stand when tree canopy was greater, although he also frequently drew attention in his monograph to the importance of light in promoting seedling and sapling growth.

Multiple factors apparently affect the probability of recruits being found beneath the parent tree, including

latitude, longitude, elevation, grass height, and whether the area had been burnt. Latitude, longitude and elevation are difficult variables to explain because they may be related to soil type and rainfall although not in straightforward way. For instance, local knowledge suggests higher rainfall in the west but this is not confirmed in computer generated rainfall isoclines, and there are no rain gauges in this area. In our study site, 200 trees were sampled in the Rukwa Valley while 100 were sampled on the Ufipa plateau to the southwest closer to Lake Tanganyika where rainfall may be slightly heavier and more prolonged during the year. Thus latitude, longitude and elevation may be proxies for a number of environmental variables and we suspect that the pattern or amount of precipitation or extent of drainage in the soil may be important factors affecting recruitment. For example, a tree standing 100 m from the Kapapa River in the GCA, a permanent water source, had 27 recruits in a 20 m wide band toward the river side but only four in a 20 m wide strip on the side away from the river. Nonetheless, we cannot demonstrate the importance of water in promoting seedling survival and growth at this stage.

In addition, we found fewer recruits when the grass cover was thick and when parent tree canopy cover was profuse, both of which suggest that *Pterocarpus* seedlings suffer competition for light. Finally, burnt areas apparently contain fewer recruits; this may be an artifact of fire mortality of small suffrutices (seedlings) which we would make them more difficult to identify during field sampling.

Our results are reminiscent of those of Boaler (1966) and Boaler and Sciwale (2002) who measured a great number of environmental variables and found many of them to affect the proportion of *P. angolensis* in stands of trees. He found a positive effect of slope, with *Pterocarpus* growing more on lightly textured, more permeable soils (see also Jeffers and Boaler, 1966). He also described a negative effect of understory wood cover and shrub cover and a positive effect of grazing indicating that reduced competition facilitates recruitment. His data showed that full light, absence of fire (but see Trapnell, 1959), absence of root competition, and an adequate supply of mineral nutrients all promoted rapid growth from seedling to sapling stage.

From a conservation standpoint, our results paint a bleak picture of the ability of *P. angolensis* to

withstand exploitation. We found that recruitment of seedlings into the population is slow and that in the fully protected area, a place that could provide source propagules for adjacent exploited sink populations, adult density is low and recruitment success is low. Those recruits that were observed tended to be sparse and small, with few greater than 5 cm in diameter. This low density of *Pterocarpus* in the protected areas might possibly be as a result of browsing by large numbers of ungulates (Caro, 2003) although we have no evidence for this. Such an effect would not show up in our trampling data that reflect only very recent visitation by ungulates, and only large herds, particularly buffalo (*Syncerus caffer*). Elsewhere, in areas where trees are being cut, recruitment is still low although recruits are more evenly distributed across size categories. Most worrying, perhaps, is that in these areas there are few large (>35 cm DBH) trees left that can produce large numbers of seeds (Boaler, 1966). While *Pterocarpus* can be propagated from stem sprouts, rates are low in the nursery (Lowore, 1993; Magingo and Dick, 2001) and we only saw two examples of stem sprouting in the wild during 3 years of work.

In sum, a previous analysis based on a matrix projection model showed that current rates of harvest in the Rukwa Region of Tanzania are unsustainable. This new data set on recruitment does not enable us to reverse this prognosis on the basis of healthy recruitment into the population. Thus, our prior conclusions that *Pterocarpus* is being driven to local extinction outside of protected areas at a rapid rate is strengthened. Further, this study points to particularly low recruitment in protected areas, suggesting that these populations might also be declining despite protection from harvest.

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