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The Pongola Bush: Tree diversity assessment in a KwaZulu-Natal forest patch

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The Pongola Bush Nature Reserve lies in a narrow band along the escarpment between Mpumalanga and KwaZulu-Natal (KZN). Although referred to as 'bush', this vegetation type may be considered to fit into the intersection of two types of scarp forest: the Northern Afrotemperate Forest and the Southern Mistbelt Forest. The area was heavily logged in the early 1900s with the need for timber for the emerging gold mining industry in Barberton. The forest fragment is now protected but lacks formal tree diversity assessments, and this study sets out to establish its community composition and richness using a range of standard techniques. Distributed throughout the forest, 127 circular plots (each 80 m^2) were surveyed. In these, 1152 stems were measured for species, height, and diameter at breast height (DBH). Four species contributed roughly 70% of the 70 Mg ha^{-1} above ground woody biomass. Stem size class distributions showed a high recruitment rate of small stemmed individuals and few large individuals. This pattern is consistent with the disturbance history of the site, with limited recruitment of certain species, mainly limited to early successional species. The Pongola Bush forest is particularly diverse in terms of tree species: 41 species were recorded, and it is estimated from the species area curve that there may be 70 tree species present.

Conservation implications: This survey is the first formal tree diversity survey conducted on the Pongola Bush which may assist future research and conservation strategies.

Keywords: Afromontane; forest ecology; fragmentation; tree ecology; above ground biomass.

Introduction

Roughly half of the world species are found in forests and they continue to be exploited for their socio-economic value, including the need for industrial timber, medicinal products, and use of productive agricultural land (Grainger 2013). This exploitation often leads to the transformation of systems, negatively influencing diversity and ecosystem functionality (Falk, Palmer & Zedler 2013; Hooper et al. 2005; Johnson et al. 1996). Subject to the extent of transformation, ecosystems can regenerate after disturbance events (Vieira & Scariot 2006). Regeneration is dependent on a variety of factors including seed dispersal and seedling establishment, structure and richness of existing species, and resprouting ability (Vieira & Scariot 2006). Identifying natural ecosystem restoration processes in forests is challenging and requires systematic assessment of structural composition (Chazdon et al. 2016).

Forests are scattered along eastern and southern margins of South Africa, from the Soutpansberg in the north and Maputaland in the east to the Cape Peninsula in the West (Mucina & Rutherford 2006a). With their patchy distribution within more open systems, limited to fire protected refugia and steep south facing slopes, indigenous forests account for less than 0.5% of the land cover in South Africa (Berliner 2009; FAO 2010; Geldenhuys 1994; Huntley 1984; Rutherford, Mucina & Powrie 2006). Mucina and Rutherford (2006a), using a floristic biogeographic classification of the indigenous forests of South Africa, recognised 26 forest types, grouped into eight zonal groups and one azonal group. Afrotemperate forests stretch from the Cape Peninsula via the Southern Cape Coast, the Eastern Cape and KwaZulu-Natal (KZN) Midlands and Drakensberg to the North-eastern Escarpment and Soutpansberg Mountains. Each of these forest types can have both high and scrub forest depending on climatic conditions and landscape. Afromontane forests are generally found on steep south-facing slopes with lowland forests on the coast having a lower canopy.

The Pongola Bush is placed in the Northern Afrotemperate zone by Mucina and Rutherford (2006b), but Lötter, Mucina and Witkowski (2014) provided an updated classification of the

indigenous forests of the Mpumalanga province and recommended that the Wakkerstroom Midlands Forest Subtype be embedded within the Northern Highveld Forest Type, and not the Low Escarpment Mistbelt Forest Type as is currently recognised in the National Forest Classification. It is unclear whether the Pongola Bush was included in the study by Lötter et al. (2014). The Pongola bush is believed to be a remnant of ancient forests (perhaps from the Tertiary), as evidenced by the presence of *Onychophora* (velvet worms or peripatus), for instance, that flourished in the area (Ruhberg & Hamer 2005). It does not have a formal inventory of tree species or community structure. This pilot study determined the tree diversity and community composition which would provide a foundation for a more extensive study on changes in the floristic-structural composition along an altitudinal gradient. The diversity and composition was achieved through the documentation of species and species metrics to quantify the richness and relative abundances as well as the total above ground biomass of species within the forest. This study also investigated whether there would be a high dominance of early successional species.

Methods

Study site

The Pongola Bush Nature Reserve covering 8.82 km² (882 ha) is managed by Ezemvelo Wildlife (KwaZulu-Natal Nature Conservation Board). It is situated immediately south of the border of Mpumalanga and KZN (Figure 1; 27.32349S, 30.47642N). The Pongola Bush is the largest remaining forest fragment in the area, which historically provided timber for the development of both the Barberton and Witwatersrand goldfields. Sawpits and wagon roads are present in the upper reaches of the forest, suggesting an extensive logging history. Much of the remaining extent of the Pongola Bush is situated within the reserve boundaries: an additional 3 km² lies outside the borders of the reserve. The forest extends less than 1 km wide in a north-south band, and several kilometres in an east-west direction. The forest lies along the southern edge of an escarpment cliff, extending down a steep slope to grassland on a gentle gradient, marking the southern forest edge. The vegetation is tall (>10 m) and has a closed, interlocking canopy with multiple layers. The climate in the area is temperate, with an average annual temperature of 14.1 °C, and is characterised by wet summers (November–February) and dry winters (May–August) with an average annual precipitation of 790 mm.

Species data collection

Transects were walked from the southern edge of the Pongola Bush patch towards the northern cliff base. Approximately every 50 m along each transect that was on average 600 m long (450 m – 800 m), a circular plot with a 5 m radius was surveyed. A total of 127 circular plots were sampled through the forest. All tree stems greater than 20 cm in circumference (diameter ≥ 6.37 cm) at breast height (1.3 m) where the centroid of the stem cross-section is within 5 m of the plot centre were identified, and the height of the top of the crown of that individual was estimated using a ranging rod and clinometer with a precision of about 1 m.

Statistical analyses

Species biomass values were estimated using the above ground biomass (AGB) model of Chave et al. (2014):
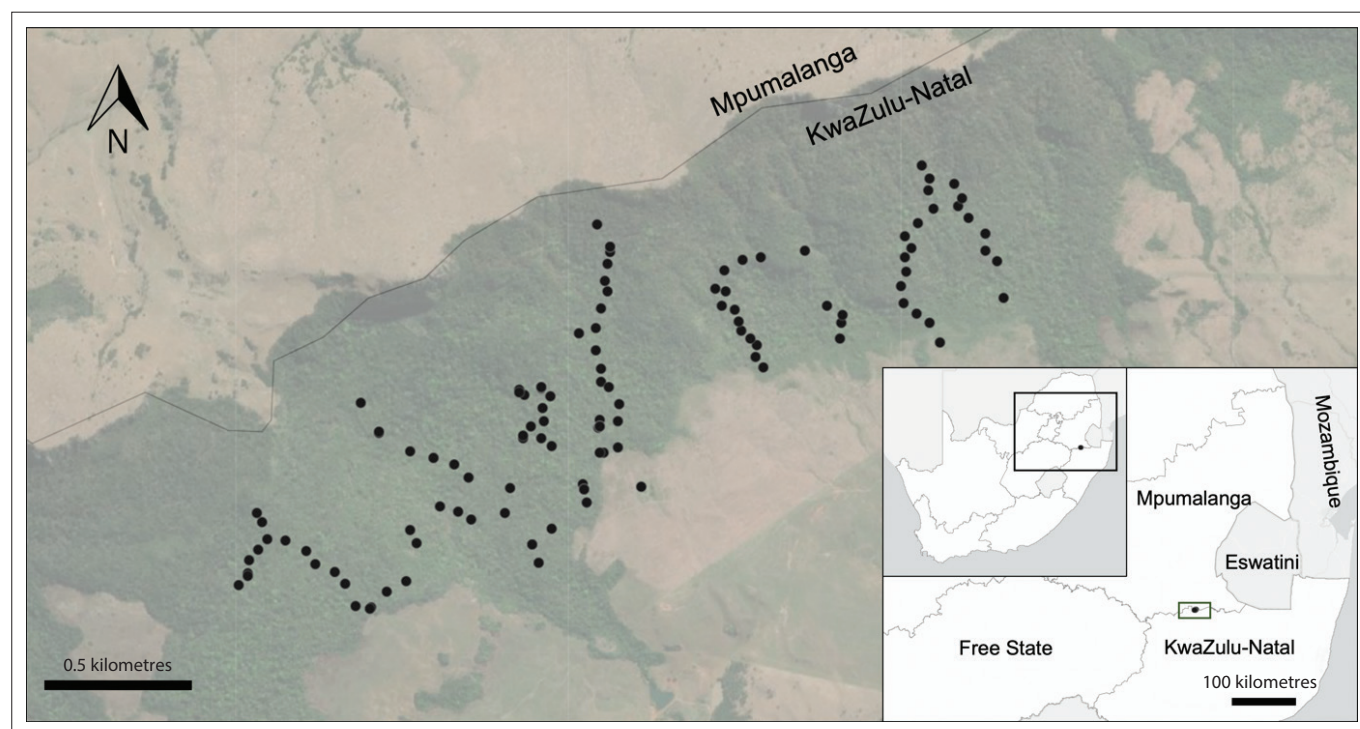
Source: Base-layer map created using ArcGIS® software by Esri®

FIGURE 1: The sampled locations in the Pongola Bush, situated on the border of Mpumalanga and KwaZulu-Natal.

$$\text{AGB}_{est} = 0.0673 \, (\rho D^2 H)^{0.976}$$

where ρ is wood density in Mg m^{-3}, D is stem diameter at breast height (DBH) in m and H is height in m. Wood densities of the species encountered were taken from the African Wood Density Database (Carsan et al. 2012), shown in Appendix 1 (Table 1-A1). Species were ranked based on their total above ground biomass (in Mg), and statistical significance for biomass measures among and between species was determined using an ANOVA and a post-hoc Tukey test at a 95% confidence interval ($\alpha = 0.05$). Stem density (stems ha^{-1}) was determined for all species using count data within the known plot area. Stem size-class distributions (in terms of DBH) were determined for the entire sampled population as well as the four most abundant species, plus an economically valuable species (*Afrocarpus falcatus* Thunb.). Species area relationship analyses were conducted using the 'sars' (species-area relationships) software developed by Matthews et al. (2019). The species-area model (the increase in species richness recorded as the sampled area increases) was computed using eight random bootstrapped samples from the plot data, which were then averaged.

Biodiversity and community structure estimates were conducted using Paleontological Statistical Software Package (PAST) 1.81 (Hammer, Harper & Ryan 2001). Diversity indices were calculated in two ways: firstly, for number of individuals, which is most appropriate for population dynamics interpretations, and secondly, based on contribution to biomass, which is more important for functionality (Mason et al. 2013; Schleuter et al. 2010). Three diversity indices were calculated: dominance (1-Simpson), Simpson 1-D and Shannon (entropy). Community composition analyses using ordination techniques were conducted using a presence-absence matrix to run a non-metric multi-dimensional scaling (NMDS). The similarity index input for the NMDS was the Bray-Curtis index, as it is the most valuable metric for showing the compositional dissimilarity of sites using abundance data (Gauch 1973).

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

Results

A total of 1152 stems with a circumference greater than 20 cm were sampled, in an aggregated area comprising one ha, from a forest with a total area of about 882 ha. The sampled stems represented 41 tree or tall shrub species (Table 1).

The equivalent AGB, estimated by allometric equations, is 70 Mg ha^{-1} ± 21 Mg ha^{-1}. Four canopy-forming species contributed 70% of the AGB, namely *Searsia chirindensis* (Baker F.), *Combretum kraussii* (Hochst.), *Kiggelaria africana* (L.) and *Celtis africana* (Burm.f.) of which *S. chirindensis* contributed to the greatest AGB, at roughly 18 Mg ha^{-1}

**TABLE 1:** The total estimated biomass, stem density and total basal area for the sampled species across 1 ha.

Species	Estimated total biomass (Mg/ha)	Stem density (stems/ha)	Total basal area (m²)
Afrocarpus falcatus	2.454	111	4.262
Apodytes dimidiata	0.003	1	0.008
Calpurnea aurea	0.086	20	0.184
Canthium ciliatum	0.001	1	0.004
Canthium inerme	0.004	1	0.010
Canthium kuntzeanum	0.113	16	0.229
Cassinopsis ilicifolia	0.008	6	0.029
Celtis africana	7.011	94	8.195
Chionanthus peglerae	0.741	29	0.963
Clausena anisata	0.185	35	0.537
Combretum kraussii	14.846	70	15.937
Cryptocarya woodii	2.511	81	4.293
Curtisia dentata	4.508	79	5.142
Cussonia spicata	3.744	105	7.893
Diospyros whyteana	1.051	105	1.459
Dovyalis lucida	0.001	1	0.003
Gymnosporia mossambicensis	0.722	114	1.857
Halleria lucida	1.901	43	2.765
Ilex mitis	0.031	1	0.084
Kiggelaria africana	10.749	45	11.315
Leucosidea sericea	0.254	25	0.681
Maesa lanceolata	0.044	1	0.073
Memecylon bachmannii	0.002	1	0.004
Myrsine africana	0.151	11	0.184
Olea woodiana	0.003	1	0.005
Oncoba spinosa	0.001	1	0.004
Oxyanthus speciosus	0.059	11	0.175
Pavetta inandensis	0.012	3	0.022
Ptaeroxylon obliquum	0.013	1	0.022
Rapanea melanophloeos	0.010	1	0.032
Rhamnus prinoides	0.014	8	0.034
Rinorea ilicifolia	0.003	1	0.005
Scolopia zeyheri	0.012	2	0.021
Scutia myrtina	0.004	1	0.009
Searsia chirindensis	17.917	64	17.872
Sideroxylon inerme	1.495	1	1.640
Solanum mauritianum	0.006	1	0.018
Strychnos mitis	0.201	20	0.280
Tricalysia capensis	0.095	9	0.190
Trimeria grandifolia	0.209	20	0.342
Zanthoxylum davyi	1.475	11	1.168

Mg, megagram; ha, hectare.

(Figure 2). Eleven of the species contributed 95% of the AGB with over 30 other species accounting for the remaining 5% of the Pongola Bush tree AGB (Figure 2).

There seems to be no clear dominance in terms of stem density within the Pongola Bush (Figure 3). The four species which constituted the greatest biomass are not the four species with the greatest stem densities, but they do appear in the quartile of species with the greatest stem densities. *Gymnosporia mossambicensis* (Koltzsch), *Afrocarpus falcatus*, *Cussonia spicata* (Thunb.) and *Diospyros whyteana* (Hiern) contributed the largest number of stems per unit ground area (Figure 3). *Gymnosporia mossambicensis* has the greatest stem density yet it does not fall into the list of species which contribute to the greatest AGB, because it is a multi-stemmed tall shrub, rather than a canopy-forming tree.
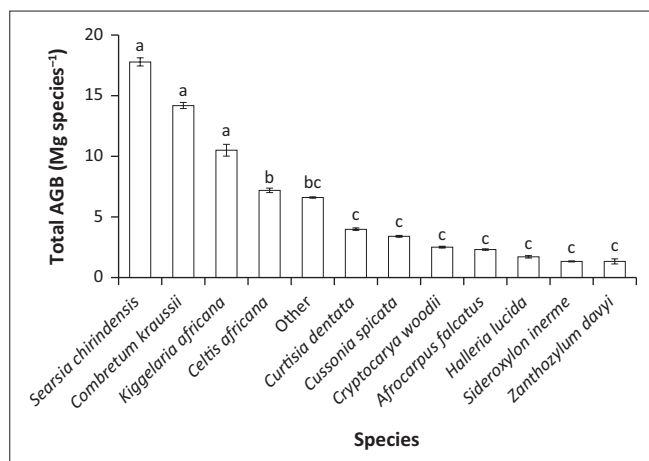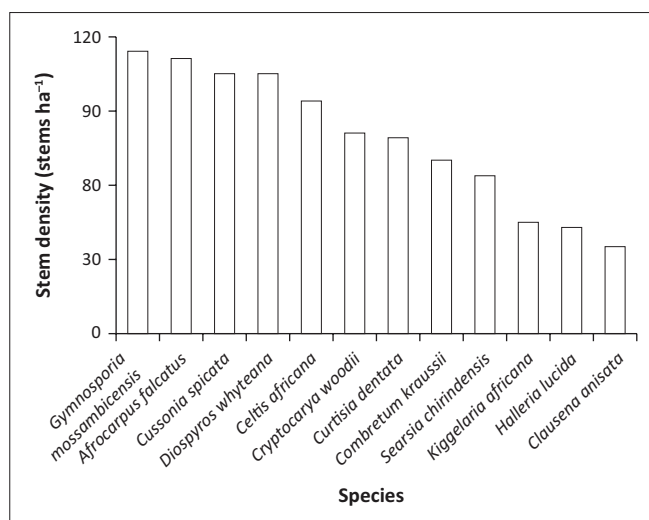
Note: If the letters above the bars differ then the total above ground biomass is significantly different across the species ($p < 0.05$).

AGB, above ground biomass; Mg, megagram.

FIGURE 2: Total above ground biomass (AGB) (Mg species^{-1}) of selected species within the Pongola Bush.

ha, hectare.

FIGURE 3: Stem densities (stems ha^{-1}) of selected species within the Pongola Bush.

The stem size distributions (in DBH) of all individuals of all species, and the stem size distributions for species with the highest biomass and a previously economically important species (*A. falcatus*) are shown in Figure 4. Stem diameters, both in aggregate and for some individual species populations, follow a classical 'reverse J' distribution – a more-or-less smooth exponential decrease in numbers with increasing stem diameter. This indicates steady recruitment following a period of past disturbance, and a constant stem mortality rate. The populations of *S. chirindensis*, *C. kraussii* and *K. africana* all show a hump-shaped distribution, with few small (< 20 cm) and very large (> 80 cm) stemmed individuals. The bulk of the population have medium stem diameters (20 cm – 60 cm), indicating an episode of strong recruitment a century ago, followed by reduced recruitment. This is contrasted by the size class distribution of *A. falcatus* and *C. africana,* which both have populations dominated by smaller stemmed individuals and fewer larger individuals, suggesting that the demographic is in a recruitment and regeneration phase, following exploitation in the past. For all

five of the chosen species, there are individuals within each population which have very large DBHs compared to the rest of the population, suggesting these are the remnants of large individuals that were established before the timber exploitation era, and were missed in harvesting operations.

The significant relationship between species richness and area, expressed as a log-shaped curve, shows the asymptotic species-area boundary of this curve has not been reached at 1 ha (10 000 m^2), the upper limit of the aggregate sample (Figure 5; $r^2 = 0.84$, $p < 0.01$). At this point, the graph still has an upward trend. Extrapolating the relationship to the full extent of the Pongola Bush (~882 ha) suggests that there may be 70 woody plant species in the forest as a whole, thus about 30 undiscovered by this survey.

Diversity indices, calculated on two fundamentals, are shown in Table 2. The dominance index ranges from 0 to 1 with 1 being total dominance by an individual species, in this case dominance was lower for species diversity (0.065) compared to functional diversity (0.1492), which is supported by the biomass dominance by a small number of species shown in Figure 3, and little dominance in Figure 4, in terms of the gradual decrease of stem densities with no clear dominance. The Simpsons index for individual counts (0.94) shows a high diversity and evenness (the scale is 0–1, with 1 high richness and evenness). When expressed as functional diversity, there is still a high degree of richness and evenness (0.85). The upper limit of the Shannon index is unbounded, and shows the species diversity (2.94) to be higher than that of the functional diversity (2.25).

One invasive species was identified in this study, *Solanum mauritianum* Scoop., but few individuals existed and were confined to areas where the canopy had been disturbed and establishment could take place, suggesting that the potential of rapid colonisation is unlikely given the interlocking canopy of the Pongola Bush. Upon calculating community composition using multi-dimensional scaling based on the Bray-Curtis similarity coefficient, there appeared to be no clear tree compositional changes along the forest gradient. In the field there were apparent compositional changes of canopy floor species (forbs) and species which fell outside of the threshold stem diameter; thus these were not explicitly addressed in this study. This means that there are no predictable communities of certain species based on depth into the forest (or equivalently, altitude, because the slope is always upward with distance into the forest), and that the spread of species is relatively even throughout the forest.

Discussion

The biomass is higher than those of fragmented dryer Afromontane forests found in Kenya and other regions (~50 Mg ha^{-1}), but lower than tropical African forests (150 Mg ha^{-1} – 300 Mg ha^{-1}) in the Albertine Rift region (Adhikari et al. 2017; Baccini et al. 2008; Glenday 2008; Imani et al. 2017). The Pongola Bush is similar in biomass compared to African scarp subtypes at roughly 70 Mg ha^{-1} (Glenday 2008), but, as expected, only roughly a third of the
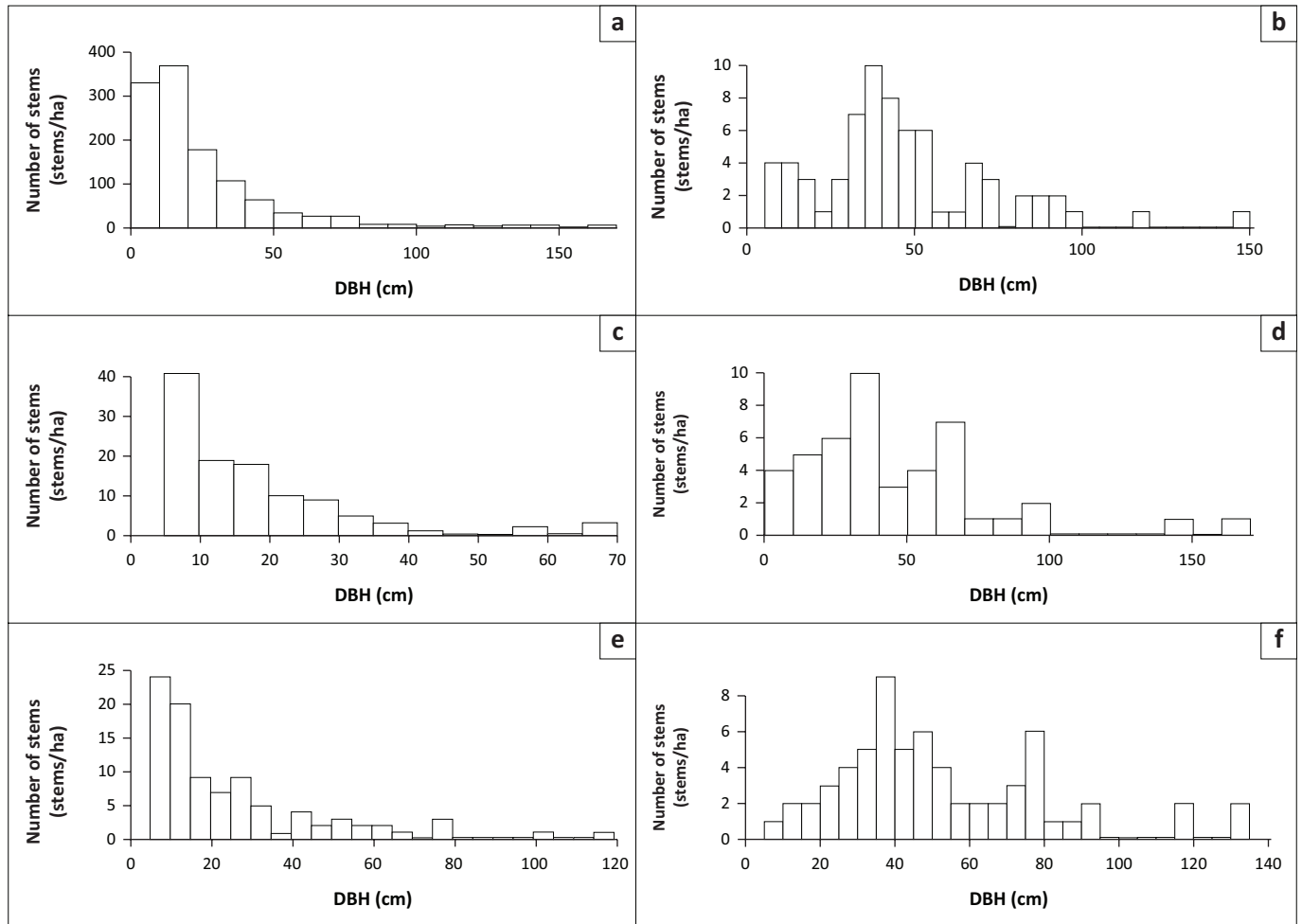
DBH, diameter breast height; ha, hectare; cm, centimetre.

FIGURE 4: Stem size class distribution in diameter at breast height of five common species as well as the total sampled species of the Pongola Bush. (a) Total sampled species; (b) *Combretum kraussii*; (c) *Afrocarpus falcatus*; (d) *Kiggelaria africana*; (e) *Celtis africana*; and (f) *Searsia chirindensis*.
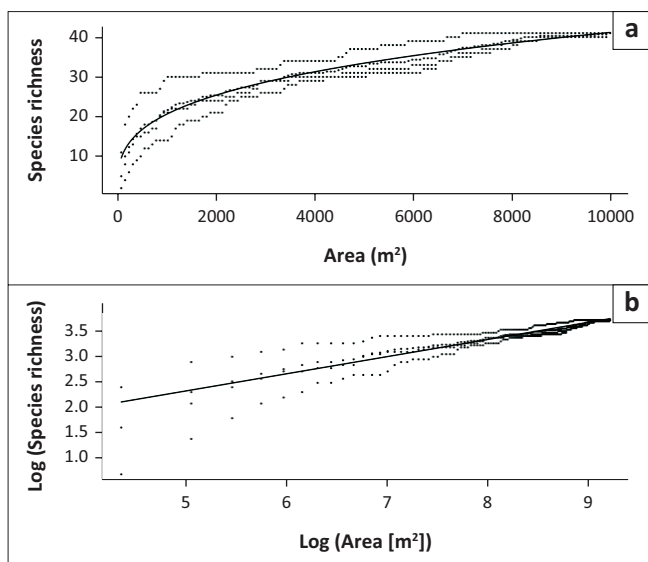
Note: Log-log relationship assumes a form S = bAz, where S is richness, A is area, and b and z are constants.

FIGURE 5: The multi modelled average species area relationship of the Pongola Bush both in terms of species richness against (a) area and (b) the log-log relationship.

TABLE 2: The functional and species diversity based on three indices.

Diversity indices	Functional diversity	Species diversity
Dominance (1-Simpson)	0.15	0.06
Simpson 1-D	0.85	0.94
Shannon (entropy)	2.25	2.94

by four species; this dominance mirrors some of the other Afrotemperate studies (Adie et al. 2013). Species that are commonly found in Northern Afrotemperate forests include many that were found in this study including, *Celtis*, *Afrocarpus*, *Halleria* and *Scolopia*; those missing were *Olinia, Pittosporum* and *Rothmania*. When extrapolated, the species area relationship of roughly 70 woody species in the forest patch as a whole is consistent with other Afromontane forest patches of similar size (50–110 species) (Gemeda, Lemenih & Gole 2018; Giliba et al. 2011; Mensah et al. 2020). These Northern Afrotemperate forest patches are generally dominated by late successional, canopy forming *Podocarpus* but due to relatively recent disturbance events common genera such as *Combretum* and *Celtis* have taken their place (Asrat et al. 2020) resulting in different types of forest.

Diversity indices coincide with forests of similar composition in areas around Africa, particularly Afromontane forests. In terms of dominance, Afromontane forests in Tanzania have

biomass of pristine mature Afrotemperate forests (Adie, Rushworth & Lawes 2013). Biomass in the Pongola Bush is not spread evenly among species but rather is dominated

a range of dominance (0.043–0.135) for differing forest subtypes and fragments (Giliba et al. 2011). In the cases where there was higher dominance, these were due to disturbances experienced by the forest subtypes (Mafupa 2006). Species richness is comparatively higher per ha in the Pongola Bush compared to patches seen both in specific studies in Ethiopia and Tanzania (Gemeda et al. 2018; Giliba et al. 2011), yet lower than southern African forests of like composition (Adie et al. 2013). Comparisons with other South African forests have also been made (Geldenhuys 1992; Mucina & Rutherford 2006). Shannon indices were generally lower in Ethiopian Afromontane forests (2.67–2.87). This may be due to various factors including disturbance and limited rainfall (500 mm per annum) compared to the Pongola Bush (Gemeda et al. 2018; Mekonnen 2006). Geldenhuys (1992) stated that the number of tree species in southern Africa is lower than that in the tropics. It was unfortunate that information on other plant forms and species, for example, ferns was not collected as this would have provided an additional element to this biodiversity study.

There are cases, in other scarp forests, of unsustainable harvesting to the point of local extinction of medicinal species such as *Ocotea bullata*. This species was not encountered in this survey, suggesting it may too have extirpated from this particular forest but has been known to occur in the forest in the past. Medicinal plant exploitation may reduce the species diversity of the forest which would be of concern if there was extensive extraction of all medicinal species.

Regeneration potential using stand density in the Pongola Bush forest fragment is similar to some other studies in Southern African Afromontane patches, but these studies show highly variable results based on a range of biotic and abiotic factors. The Pongola Bush shows a high recruitment of small stems to a decrease in larger stems in a 'reverse J' distribution, as demonstrated in other studies (Adie et al. 2013; Asrat et al. 2020; Eriksson, Teketay & Granström 2003; Mensah et al. 2020). Smaller-stemmed plants such as *S. mossambicensis* and many smaller individuals of potentially large trees, such as *A. falcatus* dominate the forest. Populations of *C. kraussii* have few small stems which contrasts with previous stem diameter studies of forests in the region (Mensah et al. 2020). The limited small stem recruits could potentially affect the future composition of the forest as *C. kraussii* is a significant contributor to AGB and stem density. Further studies on this species in this location should be included in an integrated monitoring plan. This trend of small stemmed recruits is also occurring for *S. chirindensis* and *K. africana*. *Combretum erythrophyllum* has been recorded in Northern Afrotemperate forests but the occurrence of *C. kraussi* and *K. africana* are interesting. Given that these species form a significant part of the forest composition there is likely to be a large shift in dominant species many decades into the future. Species such as *A. falcatus* and *C. africana* show the classical 'J' shaped curve which shows that there is a stable regeneration potential for the future of their populations (Botzat, Fischer & Farwig 2015).

These stem diameter differences between species may be due to previous exploitation which has put the forest in earlier stages of succession as seen with other South African forests as well as South American forests of similar composition (Adie et al. 2013; Echeverría et al. 2007).

Emergence of earlier successional features is correspondingly correlated to a decreased patch size or fragmentation (Echeverría et al. 2007), but this forest extent is regulated by various external factors such as historic grassland fire regimes and specific abiotic factors; hence, fragmentation or decreased patch size may not have induced the early successional traits.

Despite there being limited current forest fragmentation of this patch due to its conservation, other patches of like composition may be under threat from fragmentation, particularly from fire, and this patch may have been part of a much larger constellation of related forests in the distant past (e.g. in the Pliocene, when the climate was wetter).

In conclusion, the Pongola Bush is a highly diverse, relatively dense, and stable habitat at present due to current conservation efforts. At the time of the study, four species dominated in terms of biomass, but this was only a preliminary study. A much more detailed study over time is needed in order to contribute to the management and conservation of these types of forests. There remains an information gap on non-tree biodiversity elements within the forest, such as forest floor species, forbs and animal diversity. Having a comprehensive study on the full diversity of the forest will boost the knowledge of the forest and may aid in future conservation. Additionally, the dynamic between forest patches in the region and dispersal mechanisms of both seeds and pollen as genetic material between patches could be better understood. This forest is an understudied remnant of perhaps an early evolutionary stage in the Northern Afrotemperate forest system and its conservation should be encouraged to ensure further studies on the flora and fauna.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

R.J.S. conceived and designed the project, M.C.S. supervised the project and T.F.H. carried out the data collection, analysis and writing of the manuscript in consultation with R.J.S. and M.C.S.

Funding information

Data availability

Data supporting the findings of this study are available from the corresponding author, T.F.H., upon reasonable request.

Disclaimer

The views expressed in the submitted article are those of the authors and not an official position of the affiliated institution or those of the funders, or publisher.

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Appendix 1

TABLE 1-A1: Wood density (g cm⁻³) for the sampled species.

Species	Wood density g cm⁻³
Afrocarpus falcatus	0.52
Apodytes dimidiata	0.70
Calpurnea aurea	0.73
Canthium ciliatum	0.77
Canthium inerme	0.63
Canthium kuntzeanum	0.77
Cassinopsis ilicifolia	0.55
Celtis africana	0.72
Chionanthus peglerae	0.75
Clausena anisata	0.46
Combretum kraussii	0.77
Cryptocarya woodii	0.88
Curtisia dentata	0.88
Cussonia spicata	0.45
Diospyros whyteana	1.00
Dovyalis lucida	0.64
Gymnosporia mossambicensis	0.59
Halleria lucida	0.68
Ilex mitis	0.67
Kiggelaria africana	0.76
Leucosidea sericea	0.61
Maesa lanceolata	0.68
Memecylon bachmannii	0.77
Myrsine africana	0.99
Olea woodiana	1.20
Oncoba spinosa	0.65
Oxyanthus speciosus	0.50
Pavetta inandensis	0.60
Ptaeroxylon obliquum	0.84
Rapanea melanophloeos	0.63
Rhamnus prinoides	0.69
Rinorea ilicifolia	0.65
Scolopia zeyheri	0.72
Scutia myrtina	0.65
Searsia chirindensis	0.97
Sideroxylon inerme	0.90
Solanum mauritianum	0.44
Strychnos mitis	0.85
Tricalysia capensis	0.60
Trimeria grandifolia	0.69
Zanthoxylum davyi	0.70

Source: Carsan, S., Orwa, C., Harwood, C., Kindt, R., Stroebel, A., Neufeldt, H. et al., 2012, *African wood density database*, World Agroforestry Centre, Nairobi.
g, gram; cm, centimetre.