Southern Forests: a Journal of Forest Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tsfs20

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To cite this article: AP Starke, CJ Geldenhuys, TG O'Connor & CS Everson (2023) Secondary vegetation provides a reservoir of non-timber forest products and agroforestry service options for forestry plantation systems, Maputaland, South Africa, Southern Forests: a Journal of Forest Science, 85:3-4, 162-173, DOI: 10.2989/20702620.2023.2257663

To link to this article: https://doi.org/10.2989/20702620.2023.2257663

Southern Forests 2023, 85(3-4): 162–173
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SOUTHERN FORESTS
ISSN 2070-2620 EISSN 2070-2639
https://doi.org/10.2989/20702620.2023.2257663

Secondary vegetation provides a reservoir of non-timber forest products and agroforestry service options for forestry plantation systems, Maputaland, South Africa

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Tree species providing non-timber forest products (NTFPs) have the potential to enhance the socio-economic value of forestry plantation systems and mitigate biodiversity loss associated with production landscapes in Southern Africa. This can be accomplished by integrating NTFP agroforestry systems with forestry plantation systems but raises questions around which species and products are suited to the different environments that exist within large plantation systems or plantation landscapes. These questions can be answered by assessing the NTFP and agroforestry system (AFS) value of native species that form part of secondary vegetation within forestry plantations by shedding light on the disturbance regimes and environmental conditions that NTFP species prefer. This study assessed the NTFP value of secondary vegetation growing within abandoned clear-felled and abandoned unharvested forestry compartments. It addressed differences between the NTFP value of secondary vegetation and natural forest while providing options for how native species could be integrated into a forestry plantation system using agroforestry. We found that secondary vegetation growing in abandoned compartments provided roughly two-thirds of the NTFP uses provided by natural forest. The state of the compartment at the time of abandonment influenced which NTFPs were available. Secondary woodland developing in clear-felled compartments contained NTFPs which were associated with fire-adapted woodland species (e.g. fruit and oils from Marula trees). Naturalising forest in unfelled plantation compartments contained a composition of NTFPs associated with the provision of wood products. Our results show that native vegetation growing as secondary vegetation in forestry plantation systems has the potential to guide the development of native species agroforestry systems and, in general, can contribute to a more formalised approach for integrating NTFP supply in forestry plantation systems.

Keywords: agroforestry tree products, human-modified landscapes, managed natural regeneration, multipurpose trees, NTFPs, plantation ecosystem services

Online supplementary data for this article are available at https://doi.org/10.2989/20702620.2023.2257663

Introduction

Forests and woodlands of South Africa are valuable natural assets given their biodiversity value (Mucina et al. 2006) and because they provide plant-based ecosystem services to rural communities (Cunningham 1985; Shackleton et al. 2018). Specifically, many native plants provide rangeland value for livestock through the supply of grazing and browsing forages, and non-timber forest products (NTFP) to rural households that include fuel, building materials, fruit, fibre, medicines and spiritual products (Cunningham 1985; Bernard and Khumalo 2004). Alternatively, forestry plantation systems aim to supply commercial wood products and drive formal economic development in rural areas (Makhado and Saidi 2011). However, although forestry plantations can maintain ecosystem services (Baral et al. 2016) through the provision of large-scale ecological and hydrological networks (Samways and Pryke 2016; Everson et al. 2019) they do unfortunately reduce, but do not eliminate, biodiversity (Geldenhuys 1997). Rural communities thus face trade-offs between the economic benefits of forestray plantations with the socio-economic value provided by natural forests and woodlands (Everson et al. 2019; Leakey et al. 2022). Agroforestry systems that integrate the management of natural regeneration and cultivation of multipurpose native tree species within forestry plantations have the potential to mitigate these trade-offs (Orwa et al. 2009; Lelamo 2021; Leakey et al. 2022).

Many native species, in addition to their household livelihood value, provide economic value through the informal economy (Everson et al. 2019; Nkosi et al. 2020). For example, in the Indian Ocean Coastal Belt (IOCB) biome of South Africa, there are established informal industries centred around trees. *Sclerocarya birrea* trees supply fruit, oils and beverages to local markets (Cunningham 1985; Nkosi et al. 2020). *Warburgia salutaris* provides informal

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commercial value through its bark, which is harvested for medicinal purposes, but populations outside protected areas are threatened because of over-utilisation (Botha et al. 2004). These types of species are ideal candidates for commercial development (Nkosi et al. 2020; Leakey et al. 2022) which may be through integration with agroforestry systems (Everson et al. 2019). For a species to be considered an agroforestry species, it should be able to provide value other than NTFPs through the role within agroforestry practices such as intercropping or planted as hedges, or through active management of natural regeneration (Tsegu 2019). For example, *Melia volkensii* is used to provide a high-value timber and as part of living fences and boundary systems by farmers in the dry-lands of Kenya (Orwa et al. 2009); in the central Rift Valley in Ethiopia, farmers use a native leguminous tree, *Faidherbia albida*, to improve soil fertility in their cropping systems (Tsegu 2019). The agroforestry system (AFS) value of a species can therefore be referred to as the potential of a tree species to be purposefully integrated into an agricultural system to supply an agricultural product or to improve abiotic conditions for enhanced production (Orwa et al. 2009; Lelamo 2021). Several native tree species provide both NTFP and AFS values, meaning that they could potentially serve dual roles of supplying plant products while serving additional functions within a land-use system. *Strychnos spinosa* is an example of such a multipurpose species in the South African context. It has an AFS value because it is tolerant to high soil water deficits (Dzikiti et al. 2022) and provides livestock fodder (Orwa et al. 2009). It also provides NTFPs through its highly nutritional fruit (Nkosi et al. 2020), and its bark and sap which have medicinal properties (Hutchings et al. 1996).

Many native South African tree species, including those potentially with NTFP and AFS values, have the capacity to colonise forestry plantation compartments (Geldenhuys 1997) but forestry weed management programmes often constrain their development past seedling stages (Little 1999). However, in abandoned compartments native species have the opportunity to grow and develop into different types of secondary vegetation communities (Geldenhuys 1997; Starke et al. 2019). When abandoned planted compartments have replaced natural forest, the ecological recovery process is termed natural forest regeneration (Lugo and Helmer 2004), but when such abandoned compartments are planted in historically non-forested areas, such as grassland or fynbos, the recovery process is termed forest naturalisation (Geldenhuys 2011). Factors that influence the ability of native species to regenerate or naturalise in abandoned compartments include the distance from naturally occurring forest, structural conditions and stand density resulting from the previous silvicultural treatments, the type of plantation species and stand age (Geldenhuys 1997; Loumeto and Huttel 1997). Moreover, the composition of secondary vegetation can be influenced by the effects of harvesting or lack thereof after compartment abandonment. For example, Starke et al. (2019) found that clear-felled compartments which had been subjected to frequent fires due to the growth of grasses contained a higher proportion of fire-adapted woodland tree species. Alternatively, secondary vegetation in the understory of unfelled compartments resembled natural forest due to the low light conditions and the absence of fire. These studies provide insight into the ecology underpinning the occurrence of native species in abandoned forestry plantation compartments. However, further research is required to harness these ecological processes in an agroforestry context. Specifically, research is needed to improve our understanding of how the NTFP value of secondary vegetation systems compares to NTFP benchmarks of naturally occurring ecosystems such as natural forest, and how environmental variation resulting from disturbances affects the distribution of NTFP resources in forestry plantation systems. While recent research has emerged in South Africa shedding light on opportunities to integrate agroforestry and forestry plantation systems for improved water and livestock management (Mack and Dlala 2009; Everson et al. 2019; Maponya et al. 2020), significant knowledge gaps remain, hindering our ability to harness the synergies among NTFP species, agroforestry and forestry plantation systems.

This study assessed the NTFP and AFS resource value (RV) of secondary vegetation that occurred in different types of abandoned forestry plantation compartments, with the aim to characterise useful native woody species that can be used in an agroforestry context within forestry plantation systems. We asked the following specific questions: (1) Does the secondary vegetation growing in abandoned plantation compartments contain potentially valuable NTFPs? (2) Do different communities of secondary vegetation (naturalising forest and secondary woodland) provide different NTFP resources? (3) In what ways can the combined NTFP and AFS values of these species to be used to develop agroforestry systems within forestry plantation systems?

Material and methods

Site description and vegetation types

Manzengwenya plantation (27°12′ S, 32°43′ E; Figure 1a), (± 40–90 m asl), was established during the late 1950s and replaced approximately 15 000 ha of IOCB vegetation, a sub-tropical fire-adapted mosaic of grassland, seasonal wetlands, woodland and forest (Mucina et al. 2006). The region receives on average 964 mm of precipitation per annum and has a mean annual temperature of 21 °C (Mucina et al. 2006). In general, soils comprise nutrient poor aeolian-derived sands. However, interdunal areas or depressions (dystric regosols) hold reasonable amounts of clay and carbon (± 5–7%) compared with dunes which hold much less carbon and clay (Everson et al. 2019).

In actively managed compartments, *Pinus elliottii* is grown for structural timber on a 20-year rotation and *Eucalyptus* sp. for pulp-wood on a 7-year rotation. However, in some areas of the plantation, previously established compartments have been abandoned and unmanaged for the last 20 years. Reasons for compartment abandonment were a combination of socio-economic factors and natural disturbances (such as floods, droughts and fires). Some abandoned compartments are subject to regular fires which are set in neighbouring communal rangelands and by pastoral communities to promote green grass for livestock grazing.

Starke et al. (2019) characterised the floristic composition and co-environmental variables of woody vegetation within three 200 ha naturally occurring forests and their contiguous

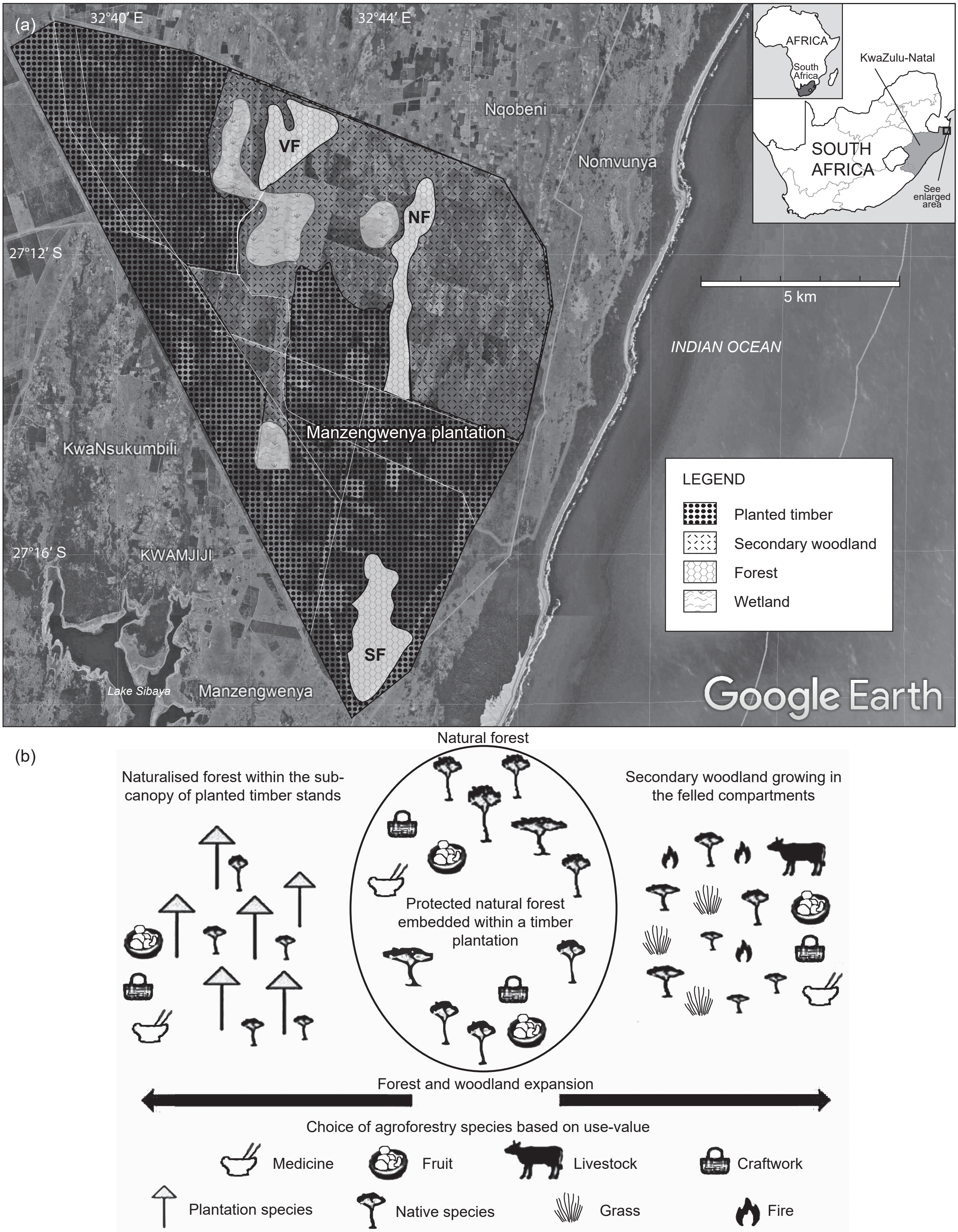

Figure 1: (a) Study area, showing the location of Manzengwenya plantation, the forests investigated and surrounding land uses. The patches of natural forest sampled were VF = Vasi forest, NF = Northern forest and SF = Southern forest. Transects of secondary vegetation were sampled on the immediate boundary (< 30 m away) of these forests. (b) Conceptual framework of forest and woodland expansion at Manzengwenya plantation, showing how plant resources would differ depending on environmental conditions

abandoned plantation compartments, some of which were clear-felled, and others unfelled. The study sampled woody vegetation within 109 circular plots measuring 400 m^2 while measuring co-environmental variables such as leaf area index (LAI) and fire-return interval for each plot.

Four main vegetation types within the plantation system were defined: two naturally occurring forest types; and two secondary vegetation types. Natural forest comprised (i) mature forest, which had the greatest stand basal area, a tree composition characterised by slow growing and recruiting species and a closed canopy (> 80% canopy cover); and (ii) regrowth forest that develops from degraded or cleared natural forest, defined by having many pioneer forest trees, shrubs and lianas, lower stand basal area, a canopy height comparable with mature forest and a heterogenous canopy cover (Geldenhuys 2011). Secondary vegetation (iii) comprised naturalising forest consisting of shade-tolerant native forest species growing in the understory of abandoned pine or eucalypt plantation compartments (LAI = 1.32–3.12), that had been infrequently burnt (fire-return approximately 6–8 years); and (iv) secondary woodland having an open canopy (LAI = 0.42–1.44), frequently burnt (fire-return approximately 2–6 years) and grazed by livestock.

Secondary woodland developed where timber had been clear-felled and the compartments subsequently repeatedly burned. In unfelled compartments, by contrast, a mixed composition of native forest species (termed 'naturalising natural forest' because this was historically grassland and not forest; Geldenhuys 2011) had developed within the shaded understory (Starke et al. 2019). Both secondary woodland and naturalising forest (collectively termed 'secondary vegetation') comprise communities of native tree, shrub, liana, palm and a limited amount of alien plant species. The naturally occurring mature and regrowth forests that pre-dated establishment of the plantation were contiguous with the study area (Figure 1a) and would likely have contributed to the propagule source of secondary vegetation (Starke et al. 2019) (Figure 1b). Further details of how these vegetation communities were sampled, classified and how their floristic composition corresponded with environmental co-variables are published in Everson et al. (2019) and Starke et al. (2019). Plant nomenclature follows the African Plant Database (2020).

Data preparation

Species occurrence and abundances within the two naturally occurring forest and two secondary vegetation (Starke et al. 2019) were used as the basis upon which to review individual plant uses. Specifically, a matrix of species-by-use-class was constructed (supplementary Table S1). Only published literature was consulted, and priority was given to peer-reviewed articles from the closest geographic location to the study area. The review consulted the following search engines and databases: Google Scholar; FAO AGRIS (Celli et al. 2015); Bielefeld Academic Search Engine (BASE; Bäcker et al. 2017); the ICRAF Agroforesty tree database (Orwa et al. 2009); and Plant Resources of Tropical Africa (PROTA; Lemmens et al. 2012). Two main categories of use-classes were used, namely NTFP and AFS and a third sub-category was included to closely examine medicinal plant use. NTFP use-classes included fuel, building materials, fibre, craft, food, beverage, gum/oil/resins (GOR), medicinal use and spiritual use (Pooley 1980; Cunningham 1985); and AFS use-classes were nitrogen fixation, browse, integrated pest management (IPM), microclimate manipulation, intercropping, boundary systems and restoration (Nair 1993; Orwa et al. 2009; Kindt et al. 2011). Medicinal uses (medicinal use-classes derived from Hutchings et al. 1996), included cardiac issues, childbirth, debility, ears, fever, gastrointestinal complaints, gynaecology, headache, infertility, nervous conditions, pain, renal disease, respiratory issues, skin, swelling, toothache and venereal disease.

To link the abundances and occurrences of woody plant species in vegetation types with their NTFP, AFS and medicinal use-class values, a multiplication of the species-by-use-class matrix with the species-by-abundance matrix (Starke et al. 2019) was conducted. This technique provided a third matrix, community-abundance-by-use-class, which formed the basis of the analysis for this study. This approach is considered appropriate because data collated by review can be used for *post hoc* analysis of predefined vegetation communities (Hoffman and Gallaher 2007; Starke et al. 2020).

Data analysis

Two metrics were used to assess the value of vegetation communities. The first, use value (UV), was defined as the sum of the use-classes for each species (Phillips and Gentry 1993) and accounted for the potential of a plot or vegetation community to deliver a certain number of uses. The second, RV, as the number of plant species within a use-class (Starke et al. 2020), accounted for the number of species within each use-class in a plot or vegetation community. To assess differences of UV (i.e., the sum of all use-classes) across the four vegetation types, plot UV totals were compared by Kruskal–Wallis tests, with group differences investigated using Dunn's test. Wilcoxon sign-rank tests (for paired samples) were used to assess whether the median RV (species counts per use-class category in a plot) in natural forest (mature and regrowth forest) differed from pooled secondary vegetation (naturalised forest and secondary woodland). Kruskal–Wallis and Wilcoxon sign-rank are non-parametric tests that are suited to data that is not normally distributed. Analysis was conducted using the Real Statistics package in Microsoft Excel (Zaiontz 2016).

To account for the variation in the abundances of co-occurring species and their impact on plant resources in different vegetation types, principal component analysis (PCA) and an importance performance analysis (IPA) were conducted. A correlation-type PCA was used to summarise the main patterns of difference in combined species UV and abundance, assess the positive and negative contributions of individual use-classes to vegetation types, and determine the association of species richness or dominant species with these patterns. The PCA was performed on a 'weighted' UV matrix, obtained by multiplying a species-abundance matrix (with cell values representing the number of occurrences of each species per hectare) with a species use-class matrix (with cell values indicating the presence or absence of each species for each use-class) (McCune and Mefford 2018). The vegetation communities were classified previously (Starke et al. 2019) and overlaid onto the ordination using convex hulls. Pearson's correlation coefficient was used to report correlations with species richness (S = number of species per plot) and species abundance, using the biplot function in PC-ORD Version 7. For PCA biplot correlations, the correlating matrix was a species-abundance matrix with log-transformed abundances and Beals smoothing applied (McCune and Mefford 2018).

To elucidate the combined patterns of species abundance and species UV and determine which species were the most useful within each of the two secondary vegetation types, we used an IPA, which employs scatter plots to provide a categorical summary of the relationship between two variables (Chen 2021). We conducted IPA on 27 prominent woody species occurring in secondary woodland and naturalised forest, using linear correlation scatterplots with the x-axis representing the relative rank of species UV and the y-axis representing the relative rank of species abundance in Microsoft Excel. The scatterplots were divided into quadrants, and each species was assigned a category based on its location within a quadrant: Q1, the lower left quadrant indicating low abundance and low UV value; Q2a, the upper left quadrant indicating high abundance but low UV; Q2b, the lower right quadrant indicating low abundance but high UV; and Q3, the upper right quadrant indicating combined high abundance and UV. Species that fell on a quadrant boundary were placed within the quadrant with the highest score.

Results

Species occurrence and use value across vegetation types

A total of 115 woody species were sampled across all vegetation types, of which 102 had one or more uses. Of these 102 useful species, 68 species occurred across three of the four vegetation types, hence there was much overlap of species and only a few species were unique to each vegetation type. When compared with natural forest, secondary vegetation contained very few unique useful species and all of these occurred in the secondary woodland (Table 1).

The collective UV of natural forest was a third greater than in secondary vegetation. However, lower overall species richness in secondary vegetation meant that the average UV of a species was greater in both naturalised forest (UV = 4.3 per species) and secondary woodland (UV = 3.1 per species) than in mature (UV = 2.6 per species) or regrowth forest (UV = 2.9 species). The species comprising secondary vegetation, therefore, had greater or equal multipurpose value when compared to the suite of species that comprised natural forest. Within secondary vegetation, the UV of species occurring in naturalised forest was slightly greater and more variable ($CV = 0.48$) than in secondary woodland ($CV = 0.21$). Overall, the main differences in UV, NTFP and AFS value were observed between natural and secondary vegetation and not between mature and regrowth forest or between naturalising forest and secondary woodland (Table 1).

Resource value of use-classes across vegetation types

Of the 115 species we assessed the most common NTFP class was medicinal plant products (RV = 63), followed by building material (RV = 46). The NTFP use-classes of food and fuel had an intermediate RV of about 20 species.

Table 1: Comparison of species UV across vegetation types

Variable	Natural forest (n = 50)		Mature forest (n = 28)		Regrowth forest (n = 22)		Secondary vegetation (n = 56)		Naturalised forest (n = 30)		Secondary woodland (n = 26)		Kruskal–Wallis, H	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	Forest vs secondary	Across four vegetation types
Total species richness (trees, shrubs, lianas)	113		93		82		53		46		48			
Number of species with uses	94		71		73		53		41		41			
Number of uniquely occurring species with uses	41		9		12		5		0		2			
Total UV	337		261		273		236		175		193			
UV (all classes per plot)	54.1	(15.49)	55.2^{a}	(16.24)	53.0^{a}	(14.98)	27.2	(9.32)	24.5^{a}	(11.78)	25.6^{a}	(5.15)	**70**	**67**
Sum of NTFP UV	225		172		179		158		116		128			
UV (NTFP per plot)	35.2	(10.36)	36^{a}	(11.28)	34.6^{a}	(9.62)	17.9	(6.05)	18.5^{b}	(3.85)	17.2^{b}	(7.84)	**67**	**67**
Sum of AFS UV	112		91		90		78		62		65			
UV (AFS per plot)	18.3	(5.58)	19.2^{a}	(5.34)	18.4^{a}	(5.84)	8.7	(3.80)	7.2^{b}	(4.31)	5.8^{b}	(2.67)	**67**	**70**

H values in bold type = significant differences of means ($p \le 0.05$) between columns of (i) natural and secondary vegetation, and (ii) individual vegetation types
Different superscripts refer to significant post-hoc differences ($p \le 0.05$) in variables

Spiritual use, gum oil resins, beverages and fibre were least represented (Figure 2). The most common AFS classes were species suited to restoration purposes (RV = 43) and for fodder (RV = 20), while production-specific AFS classes (microclimate manipulation, boundary systems, intercropping and IPM) had about eight species each.

In general, there were more species per use-class category in natural forest (median RV = 18.5) than in secondary vegetation (median RV = 12.5; $T = 8.5$, $Z = 3.2$, $p = 0.001$), however, there was no difference for classes of beverages, fibre and gum oil resin (Figure 2). Secondary vegetation contained species that supported all medicinal ailment classes, while species for about half the medicinal ailment classes namely cardiac, childbirth, ears, gynaecology, infertility, pain, swelling and venereal (Figure 3) were equally available in natural forest and secondary vegetation. The most common medicinal class in secondary vegetation was for gastrointestinal ailments. There were no differences in RV between mature and regrowth forest, nor between naturalised forest and secondary woodland.

Multivariate analysis

The first two PCA axes captured 39% of use-class variance (Figure 4) and showed a clear difference in composition of plant resources between natural forest samples (centroids and convex hulls clustered tightly within the centroid of the ordination) and secondary vegetation samples which were more widely spread. Corresponding with the species composition of naturalised forest, the positive side of the first PCA axis described an increase in use-class composition towards wood products (craft, building and fuel) and gum oil resin products. The converse (negative) direction along the first axis defines an increasing importance of beverages, restoration, IPM and medicinal classes, which corresponds with mature forest, regrowth forest and, to some extent, secondary woodland. The second PCA axis described an increasing importance of the AFS classes of intercropping, N-fixation, microclimate and browse, which were associated with vegetation where legumes were abundant.

Use-class composition could therefore be characterised by three principal components, namely wood products, agroforestry legumes and wellness-restoration classes (Figure 4). A close association was observed between the use-classes of food (fruits) and agroforestry boundary systems. Plots classified as secondary woodland and regrowth forest and plots with high species richness corresponded with an increasing availability of medicinal plants, beverage products and species suited to restoration purposes. See supplementary Tables S2 and S3 for Pearson and Kendall correlations between categories and PCA ordination axes.

IPA analysis

The IPA provided a species-level summary of the relationship between UV and species abundance. Firstly, it highlighted which species contributed to the uniqueness of plant resources in each secondary vegetation type. For example, *Hyphaene coriaceae* was unique to and abundant in the secondary woodland and has a high UV (Figure 5a; Q3), thus this species would provide a distinct value to the secondary woodland by supplying fibre and sap resources. Similarly, *Carissa bispinosa* was unique to and abundant in naturalised forest, thereby adding a distinct value to naturalised forest by providing food (fruits), medicine, fuel and browsing resources (Figure 5b; Q2b).

The second pattern revealed by the IPA related to differences in the abundance of species within each vegetation type. For example, *Strychnos spinosa* exhibited a strong positive response to clear-felled compartments contributing to 7% of abundance in secondary woodland (Figure 5a; Q2a) but less than 1% within naturalised forest (Figure 5b; Q1b). Hence, *S. spinosa* would be better suited to an open canopy and fire-exposed environment than shaded understory conditions.

Third, the IPA distinguished both multipurpose and specialist species which were abundant across secondary vegetation. For example, multipurpose and abundant (Q3) species included *Albizia adianthifolia*, *Apodytes dimidiata*, and *Brachylaena discolor* (Figure 5a, b). These three species accounted for roughly 20% of the composition of secondary vegetation and collectively provided 24 UV options. By contrast, species that were abundant but had few UV options (Q2a species) would have provided an abundant specialist resource to the plantation. The species used in the IPA analysis can be found in Table S4.

Discussion

Implications for the differences of NTFP resources between natural forest and secondary vegetation communities

Accompanying the ongoing transformation of natural vegetation in rural communal areas (Jewitt et al. 2017), a proportion of actively managed agricultural land is expected to become abandoned (Shackleton et al. 2013; Blair et al. 2018). The dynamic between transformation and abandonment, when linked with ecological disturbance-recovery processes, provides insight into the types of NTFP that would be available within the shifting mosaic of abandoned and actively managed agricultural lands. This has implications for the socio-economic resilience in rural landscapes such as Maputaland. In this context, knowing what NTFP species are to be expected in secondary vegetation, and which NTFP products would be supplied across natural and secondary vegetation systems, can inform which NTFP products will be available to the transformed rangelands of the future. For example, Njwaxu and Shackleton (2019) showed that forest successional processes on abandoned cropland had influenced the composition of NTFP species; younger stands provided the highest proportion of medicinal plants and, in older stands, wood, craft and fruit production peaked due to a greater occurrence of woody plants. In our study, some species were unique, or occurred in far greater abundances, to either secondary woodland or abandoned compartments and therefore provided a distinct ‘socio-ecological’ (*sensu* Shackleton et al. 2018) value to each of these environments. The effect that fire had on the species composition of secondary woodland explained this difference. For example, *Hyphaene coriaceae* (‘iLala’), a fire-tolerant palm, introduces the provisioning of fibre and sap resources to secondary woodland, while in natural forest and abandoned

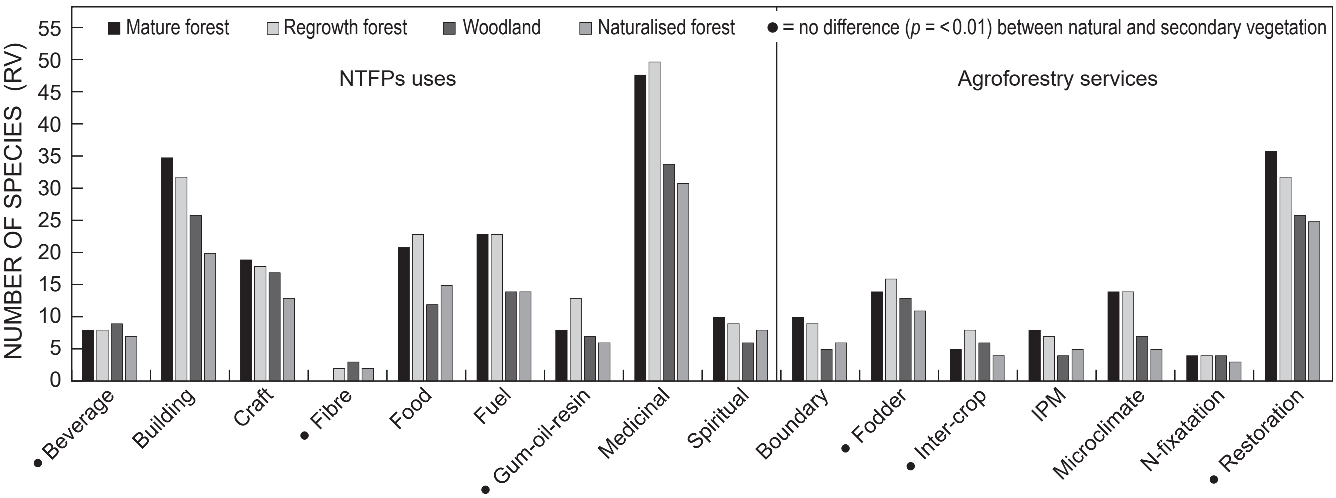

Figure 2: Summary of use-class occurrence across vegetation types

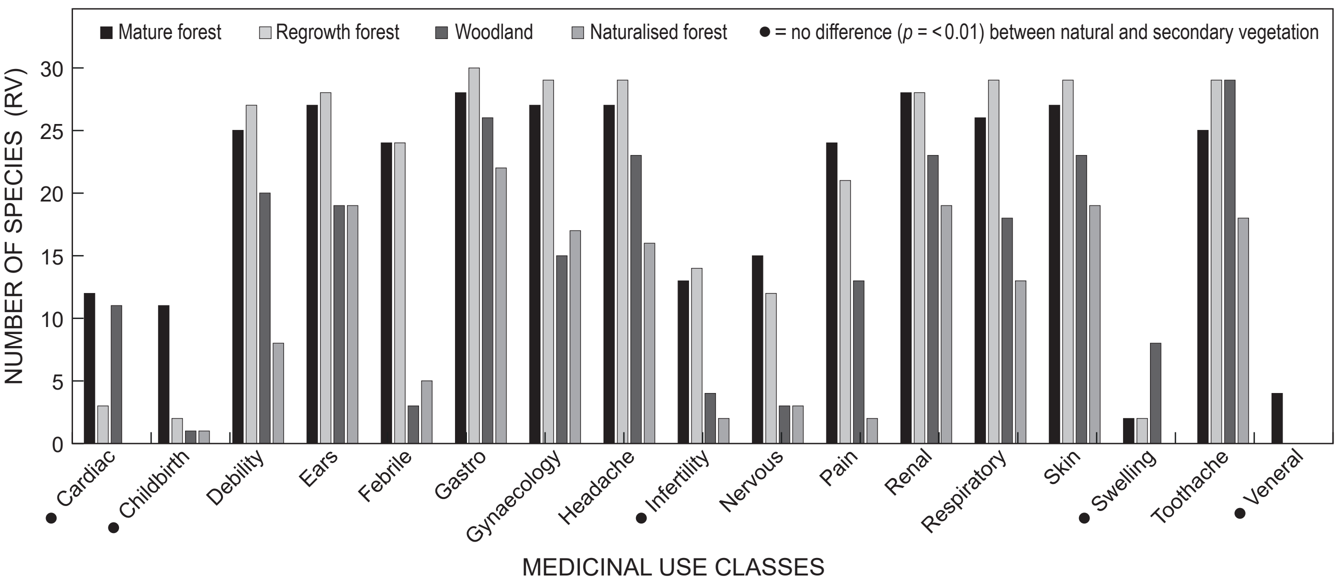

Figure 3: Summary of medicinal use-class occurrence across vegetation types

compartments, *Manilkara discolor* and *Inhambanella henriquesii* (both Sapotaceae) have the potential to supply fruit resources which do not occur in woodland systems.

Secondary vegetation as a reservoir of useful plant species

The high overlap of woody species between mature coastal forest, forest edges and fire-exposed woodlands is a characteristic of vegetation communities on the IOCB (Everard et al.1995; Adie et al. 2023). Similarly, this pattern of species overlap occurs between secondary vegetation communities and naturally occurring forests (Starke et al. 2019). The species that were common and abundant in both natural and secondary vegetation have the potential to supply a typical set of plant resources that would be expected to be delivered from the plantation. Our analysis found that NTFP species that occurred in secondary vegetation provided two-thirds of the total UV of natural forest, supporting the notion that secondary vegetation which has developed in abandoned forestry plantation compartments, can supplement NTFP plant resources of natural forest and woodlands. Specifically, these NTFP species have the potential to provide medicinal, wood, and fruit plant products. Medicinal plant species in secondary vegetation provided resources to treat a diverse selection of health ailments (Figure 3), however, traditional medical practitioners ('iziNyanga') typically employ more than a single species to treat ailments, and this was not accounted for in our analysis. Woody plants in secondary vegetation also provide potential value to traditional practitioners in the form of plants with spiritual uses including species known for their psychoactive properties ('ubulawu' species, e.g. *Landolphia kirkii* and *Pappea capensis*) which

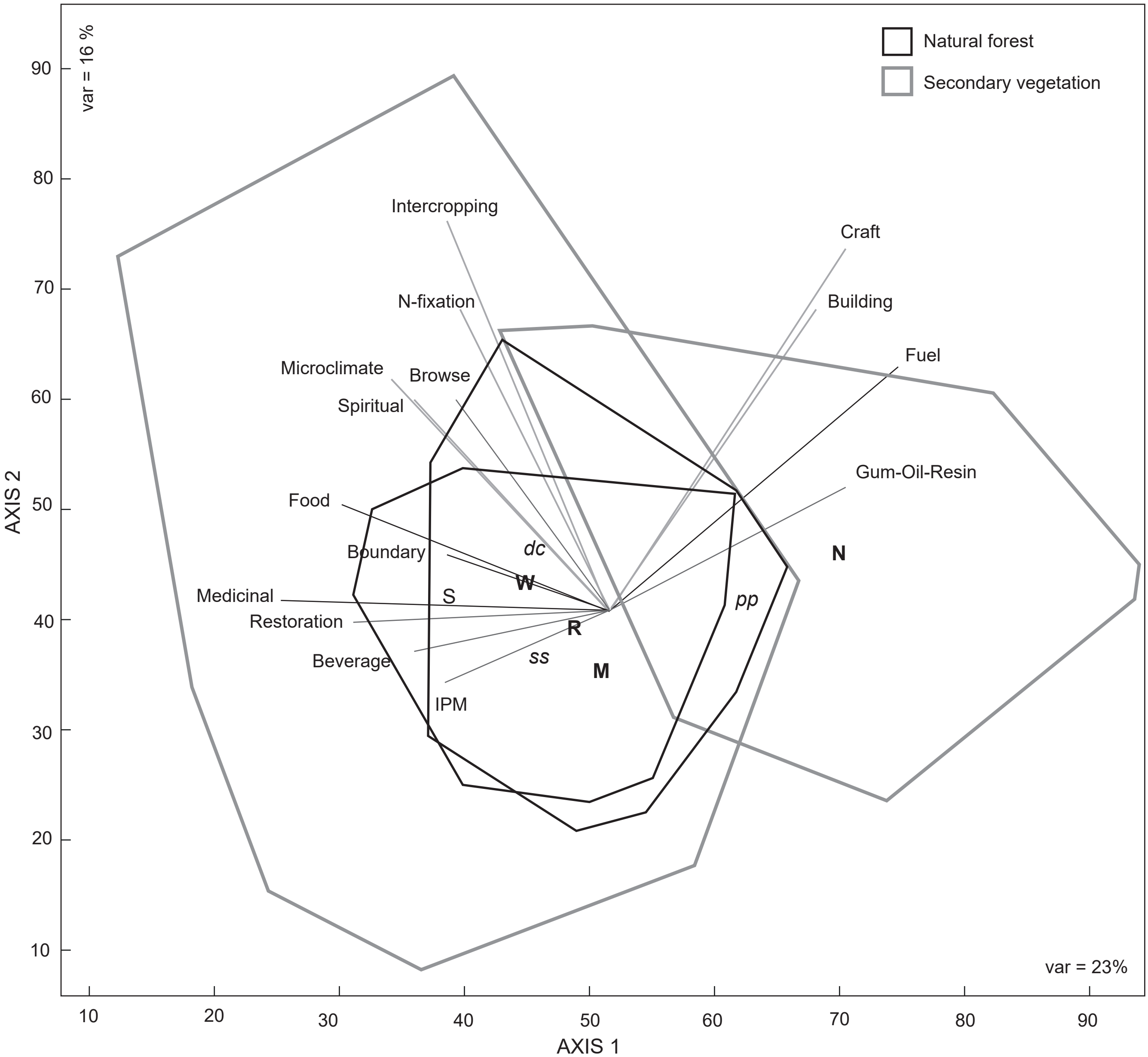

Figure 4: The first two axes of a correlation-type PCA of use-classes (eigenvalues: eigenvalue Axis 1 = 3.77; eigenvalue Axis 2 = 2.56; cumulative eigenvalue = 14.86). Initials of vegetation types are located on their centroids and convex-hulls define the boundaries of the vegetation types (see Appendix 1, Tables 1 and 2 for correlation values) M = mature forest; R = regrowth forest; W = woodland; N = naturalised forest. The strength and direction of Pearson bi-plot correlations with the PCA are represented by species initials (ss = *Strychnos spinosa*, pp = *Pinus elliotii*, dc = *Dichrostachys cinerea*) and S = species richness

are used for training spiritual healers (Bernard and Khumalo 2004; Sobiecki 2006).

Wood products gained from species which readily occurred within secondary vegetation were species that could provide high quality timber used to supply termite-resistant building poles (e.g. *Hymenocardia ulmoides*), as well as species with regional value for carving, such as *Ekebergia capensis*, which are in high demand for curios (Jacobsen 2004). In addition, some wood-producing species, for example, *Trichilia emetica*, are multipurpose, as their wood is used for carving and their seeds are used to produce a local oil which has value as a base product for cosmetic applications (Vermaak et al. 2011).

In rural landscapes, NTFP species that provide edible fruits have been shown to supply micronutrients to local people, such as β-carotene, vitamin A, iodine, iron and zinc (Powell et al. 2015). In addition to *Sclerocarya birrea*, important socially relevant fruiting species which occurred in secondary vegetation included *Annona senegalensis, Strychnos madagascariensis, Strychnos spinosa, Ximena caffra, Carissa bispinosa*, *Vangueria infausta,* and *Dialium schlechteri*. The socio-economic value of secondary vegetation is dependent on the composition of vegetation, which affects the availability of NTFP resources. The distribution of these resources is likely determined across ecological successional

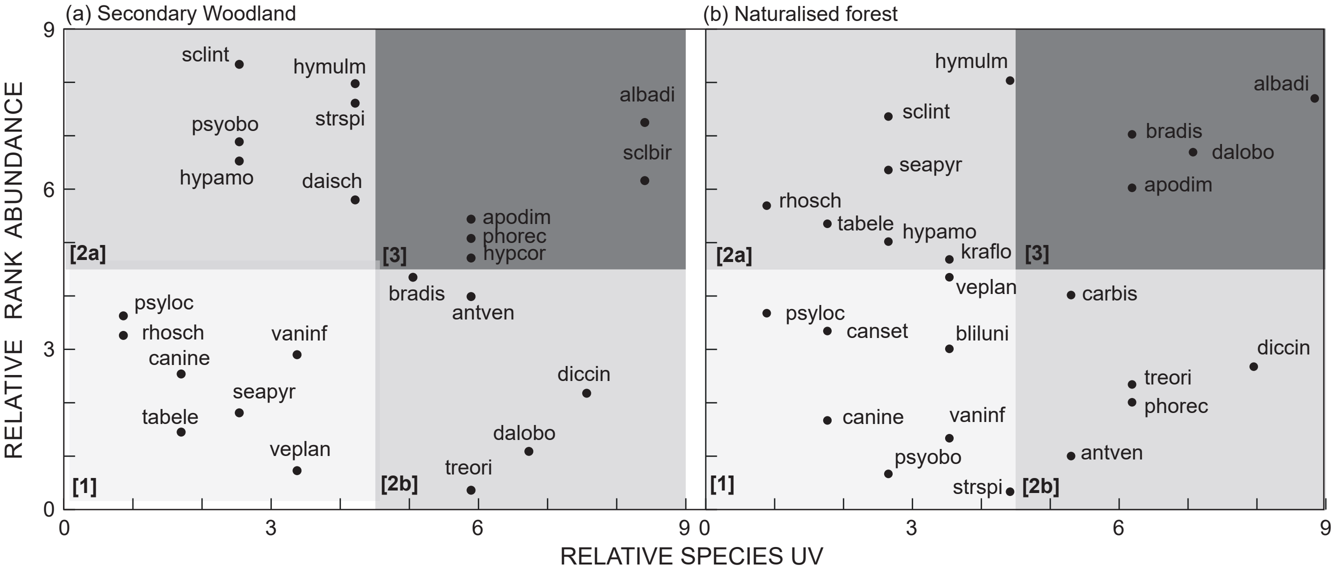

Figure 5: Quadrant analysis of species use values

Key to species

albadi	*Albizia adianthifolia*	diasch	*Dialium schlechteri*	rhosch	*Rhoicissus schlechteri*
antven	*Antidesma venosum*	diccin	*Dichrostachys cinerea*	sclbir	*Sclerocarya birrea*
apodim	*Apodytes dimidiata*	hymulm	*Hymenocardia ulmoides*	sclint	*Sclerocroton integerrimus*
aliunj	*Blighia unijugata*	hypamo	*Hyperacanthus amoenus*	seapyr	*Searsia pyroides*
bradis	*Brachylaena discolor*	hypcor	*Hyphaene coriacea*	strspi	*Strychnos spinosa*
canine	*Canthium inerme*	kraflo	*Kraussia floribunda*	tabele	*Tabernaemontana elegans*
canset	*Canthium setiflorum*	phorec	*Phoenix reclinata*	treori	*Trema orientalis*
carbis	*Carissa bispinosa*	psyloc	*Psydrax locuples*	vaninf	*Vangueria infausta*
dalobo	*Dalbergia obovata*	psyobo	*Psydrax obovata*	veplan	*Vepris lanceolata*

gradients (Njwaxu and Shackleton 2019) and influenced by the type of land abandonment (Figure 4). In this context, large commercial forestry plantations which contain distinctly different vegetation types, such as those which occur in forest-grassland mosaics ecosystems, for example, Manzengwenya estate, can play a crucial role in developing local socio-ecological resilience to support the surrounding landscape. Such plantations may contain significant portions of conserved natural areas, secondary woodland and naturalising forests, which individually provide different sets and quantities of NTFP plant resources. Plantation managers should be aware of these differences if they wish to optimise the socio-ecological value of their management areas. However, there is also potential to optimise NTFP resource provision of forestry plantations by purposefully integrating selected species into agroforestry systems within plantations.

Agroforestry as a means to integrate native woody species into plantation systems

Agroforestry systems have been suggested as an appropriate land use to increase social and environmental resilience to both climatic changes and biodiversity decline in Southern Africa (Sheppard et al. 2020). Utilising native plant species in agroforestry systems is an approach that can add biodiversity and NTFP value to agricultural environments through, for example, the facilitated management of naturally occurring populations in agricultural fields or for silvopastures (Balehegn 2017; Tsegu 2019), cultivation of multipurpose species (Lelamo 2021) and improved breeding of select native plant species (Leakey et al. 2022). Using these approaches, NTFP species could formally be incorporated into forestry plantation systems, and specifically Manzengwenya estate, in three ways. First, as managed NTFP-based silvopastures. This approach would optimise the value provided by the many browse, fruiting and medicinal NTFP species, and forage grasses (Starke et al. 2020) that occur in secondary woodland, and serve to lower the risk to timber compartments from unplanned fires. For example, within compartment buffers at Manzengwenya estate, facilitating populations of *Hyphaene coriacea* (iLala) and *Sclerocarya birrea*, through cultivation or selective management using assisted natural regeneration techniques *sensu* Geldenhuys et al. (2017) would contribute positively to regional fruit, oil, fibre and seed oil products (Cunningham 1985; Mckean 2003; Vermaak et al. 2011). Moreover, given their preference for growing in secondary woodland, other fruit-producing species such as *Strychnos spinosa, Vangueria infausta* and *Annona senegalensis* would also be suited to silvopasture buffer systems. A second use of silvopasture would be to buffer hydrologically sensitive peat wetlands from densely planted high water-use timber compartments. We suggest that silvopasture wetland-buffer systems comprise a mixture of commercially appropriate high-value non-native timber species, locally relevant NTFP species that are not common to secondary vegetation and native forage grasses (Starke et al. 2020). Silvopasture agroforestry would therefore provide benefits for socio-economic conditions, biodiversity and water conservation while functioning as productive compartments for timber and livestock (Everson et al. 2019). At Manzengwenya forestry plantation, such silvopastures could be developed through participatory forest management structures. For example, if local entrepreneurs develop silvopastures on the buffer areas of plantations in partnership with plantation management, this will likely reduce the occurrence of uncontrolled and unplanned fires in timber compartments. This was highlighted in a recent study of community perceptions of reasons for intentionally setting uncontrolled fires in the interface between forestry plantations and communal land (Ramantswana 2021).

Second, with careful design and planning, Liu et al. (2018) have shown that mixed-species timber compartments can be as productive as monoculture stands in terms of stand-level production and carbon storage. Hence, the abundance of the native timber producing species, *Hymenocardia ulmoides,* that occurred within the naturalising forest in unfelled compartments suggests a model of mixed commercial timber and native timber species compartments. The species chosen for mixed species forestry would need to have complementary traits (i.e. they do not compete for the same resources) but would add biodiversity value (Liu et al. 2018) and utilise less water than monoculture compartments (Everson et al. 2019). Third, an approach similar to agroforestry ecobuffers (*sensu* Schroeder 2012) could be developed by planting multispecies hedgerows along roadways, compartment edges, servitudes and loading depots so that these non-productive areas of the plantation could function primarily as a source of NTFP fruiting species; as a reservoir of medicinal plant resources; permanent carbon stock; livestock forage; and biodiversity corridors. The apparent value of shade-tolerant multipurpose species such as *Brachylaena discolor* and *Carissa bispinosa* for such application needs further investigation.

Conclusion

Secondary vegetation communities are ubiquitous within human-disturbed environments. They can be biodiverse and provide a variety of plant-based ecosystem services that are often overlooked. The implications of this study are therefore wider than forestry plantation systems because it is possible to integrate native species agroforestry systems within many models of agriculture. A start may be as simple as collating knowledge of the ecology and NTFP value of the local 'pool' of native species within a given area. Thereafter, one may purposefully interact with stakeholders and direct how the uses of native plant species may be best applied, either within a commercial forestry plantation context, rural commonages or homestead environment.

Acknowledgements — This research was managed and funded by the Water Research Commission (WRC) of South Africa, project no: K5/2554, with co-funding and support provided by the Department of Economic Development, Tourism and Environmental Affairs (EDTEA). We thank the TMM Trust and the Department of Agriculture, Forestry and Fisheries (DAFF) for access to Manzengwenya plantation, and X Ngubane and the Isibusiso-Esihle Science Discovery Centre for support during fieldwork. We also thank an anonymous reviewer for constructive comments which has improved the manuscript.

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