

Exploring tree diversity and stand structure of savanna woodlands in southeastern Sudan post-print

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Abstract

Savanna woodlands in Sudan host great biodiversity, provide a plethora of ecosystem goods and services to local communities, and sustain numerous ecological functions. Although the importance of the Acacia trees in these areas is well known, up-to-date information about these woodlands' diversity is limited and changes in their woody vegetation composition, density, diversity and relative frequency are not monitored over time. This study explored tree diversity and stand stage structure in Nuara Reserved Forest, a typical savanna woodland ecosystem in southeastern Sudan. A total of 638 circular sample plots (1000 m² for each) were established using a systematic sampling grid method. The distance between plots was 200 m. In each plot, all living trees with diameter at breast height (DBH) ≥ 5.00 cm were identified and counted, and their DBH values were recorded. From these data, tree composition, diversity, density and stage structure were assessed. There were 12,259 individual trees representing four species (Acacia seyal, Balanites aegyptiaca, Acacia Senegal and Acacia mellifera) that belong to two families. The dominant species was Acacia seyal. Average tree density was 191 trees/hm² and the Shannon-Weiner index for trees diversity was 0.204. Overall, young trees comprised 86.30% of the forest. The state of tree richness and density in the study area was low compared to other similar environments in the region and around the world. We recommended adoption of a proper management system that includes monitoring of woody vegetation diversity in this forest, and management actions to enhance tree diversity and sustain ecosystem services to local communities. In addition to care for the dominant Acacia seyal stands, more attention and conservation should be devoted to reestablishing Acacia senegal and Acacia mellifera trees because of their high ecological and economic values for local communities.

Full Text

Preamble

Exploring Tree Diversity and Stand Structure of Savanna Woodlands in Southeastern Sudan

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Abstract: Savanna woodlands in Sudan host great biodiversity, provide a plethora of ecosystem goods and services to local communities, and sustain numerous ecological functions. Although the importance of Acacia trees in these areas is well known, up-to-date information about these woodlands' diversity is limited, and changes in their woody vegetation composition, density, diversity, and relative frequency are not monitored over time. This study explored tree diversity and stand stage structure in Nuara Reserved Forest, a typical savanna woodland ecosystem in southeastern Sudan. A total of 638 circular sample plots (1000 m² each) were established using a systematic sampling grid method with 200 m spacing between plots. In each plot, all living trees with diameter at breast height (DBH) ≥ 5.00 cm were identified, counted, and their DBH values recorded. From these data, tree composition, diversity, and species richness were analyzed. The dominant species was *Acacia mellifera* (Fabaceae) belonging to two families. The dominant species was *Acacia seyal* (Fabaceae). Average tree density was 191 trees/hm², and the Shannon-Weiner diversity index was 0.204. Overall, young trees comprised 86.30% of the forest. The state of tree richness and density in the study area was low compared to other similar environments in the region and around the world. We recommend adoption of a proper management system that includes monitoring of woody vegetation diversity in this forest and management actions to enhance tree diversity and sustain ecosystem services to local communities. In addition to caring for the dominant *Acacia seyal* stands, more attention and conservation should be devoted to reestablishing *Acacia senegal* and *Acacia mellifera* trees because of their high ecological and economic values for local communities.

Keywords: species diversity; stand structure; savanna woodland ecosystem; forest monitoring; forest management; ecosystem services; Nuara Reserved Forest

1. Introduction

Forests and savanna woodlands provide ecosystem services such as wildlife habitat, protection against erosion and desertification, soil fertility enhancement, and many others (FAO, 2016). Sudan is characterized by five climatic zones extending from desert in the far north to savanna in the south. Sudan's Fifth

National Report to the Convention on Biological Diversity (HECNR, 2014) and the National Biodiversity Strategy and Action Plan 2015–2020 (NBSAP, 2015) stated that forests cover 11.9% of the country's total area and are rich in ecosystem and species diversity. Forest resources substantially contribute to Sudan's society, economy, and environment (Abdel Nour, 2013; Siddig et al., 2019a). However, forests in Sudan are threatened by deforestation, motivated primarily by energy needs and land clearance for agricultural expansion.

Furthermore, Bakr et al. (2018) noted that the distribution of these resources is unbalanced: the greatest amount of remaining forests is in the south, whereas the northern part is characterized by poor and sparse woody formations despite having higher population concentrations and greater need for forest goods and services. Forest cover has degraded from about 40% to 10% in Sudan over the last 110 years. The Forest National Corporation (Abdel Nour, 2013) reported that desert and semi-desert zones cover about 62.0% of Sudan's land area, of which 88.1% is classified as drylands. In response to this unprecedented decline in vegetation cover and biodiversity, many conservation efforts have been initiated over the last decade, including establishing biodiversity institutions and protected areas, developing the National Biodiversity Strategy and Action Plan 2015–2020, and signing and ratifying several regional and international agreements (Siddig et al., 2019a).

Despite these significant steps toward forest protection, establishing a forest monitoring system remains an essential need. Forest monitoring programs provide information on the status of forests and habitats and are central to applying proper sustainable forest management (Millennium Ecosystem Assessment, 2005). Forest monitoring can rigorously estimate potential ecosystem goods and services. Repeated assessments based on plant responses and changes in species composition can evaluate environmental quality and temporal changes in response to forest management (Ferris-Kaan and Patterson, 1992; Siddig et al., 2016). Vardon and Harris (2017) recognized five indicators of forest ecosystem condition: vegetation, biodiversity, soil, water, and carbon. Furthermore, forest monitoring is regarded as an international commitment. For instance, the Convention on Biological Diversity (CBD) highlighted the necessity of monitoring ecosystems, habitats, species, communities, and genes (Spellerberg, 2005).

Although monitoring is important for proper forest management, it faces many challenges worldwide. In Europe, definitions, approaches, and scope of monitoring present continuous challenges that result in non-uniform and problematic forest information collection, making it difficult to draw conclusions across time and space (Vidal et al., 2016). In China, forest inventory and monitoring programs face difficulties in obtaining information across large areas and high costs (Zhang et al., 2018). Shuaibu and Dagba (2016) stated that in Nigeria, forest monitoring faces challenges such as site access and inadequate technology, equipment, and funds.

Sometimes monitoring is motivated by the economic value of forest products. For example, stands of gum arabic producing trees (GAPTs) (*Acacia senegal*

and *Acacia seyal*) are considered the most important wooded lands in Sudan due to their tremendous economic value to the national economy and local community livelihoods. Consequently, the Forest National Corporation gives these stands special focus, including management, gum production, and threat control. Nevertheless, current reports and field observations indicate a substantial decline in both GAPT abundance and gum production, primarily due to massive expansion of mechanized rain-fed agriculture that converts forests to agricultural lands and recent drought events (Bakr et al., 2018). Moreover, Siddig (2014) warned about potential impacts of instability and conflicts on forest resources in Sudan, particularly in and around the gum arabic belt (Darfur and Kordofan) where vast natural stands of GAPTs exist.

Quantitative knowledge about basic stand diversity and structure, as well as stand health indicators such as canopy health and density of dead standing trees, is required for current efforts toward proper management and use of GAPTs to be successful. Unfortunately, due to the absence of regular, long-term monitoring programs, Sudan currently lacks these vital forest condition indicators in most GAPT stands (Siddig, 2019b). Consequently, management and conservation planning are based on rough estimates. Baillie et al. (2008) stated that to create effective forest management plans, it is obligatory to know which species are present, their relative abundance, species-specific stages, and what factors control their future persistence and dynamics. Clearly, answering these questions requires development and adoption of systematic, regular forest monitoring activities as part of management plans. These programs will not only provide crucial information about current conditions and signals of future trends but also lay the basis for rational and sustainable use of forest ecosystem services and goods.

Therefore, the aim of this study is to assess tree diversity and stage structure in Nuara Reserved Forest (a typical savanna woodland ecosystem in southeastern Sudan), as recommended by Siddig (2014) and Sudan's Fifth National Report to the Convention on Biological Diversity (HECNR, 2014). Specific objectives include: (1) establishing baseline information about the current condition of Nuara Reserved Forest, including species composition, diversity, density, and stage structure; (2) discussing the significance of monitoring results for planning forest utilization, conservation, and management; and (3) developing a protocol for future monitoring programs in Nuara Reserved Forest and other similar natural forests in Sudan.

2.1 Study Area

This study was conducted in Nuara Reserved Forest, located in Sennar State, Sudan, approximately 360 km southeast of the capital, Khartoum (Ahmed et al., 2015). The forest covers an area of $2.56 \times 10^3 \text{ km}^2$ and lies between $12^\circ 20' - 12^\circ 26' \text{ N}$ and $34^\circ 05' - 34^\circ 08' \text{ E}$ (Mohammed, 2018). It is situated in southeastern

Sudan and shares borders with Gezira State to the north, Blue Nile State to the south, Gedaref State to the east, and White Nile State to the west (Fig. 1 [Figure 1: see original paper]). The region's climate is tropical, with the year divided into very humid and rainy autumns, intensely dry winters, and hot summers. Winter months (December and January) are relatively cold, with temperatures ranging from 16°C to 20°C. From March to November, the climate is very hot (temperature range of 35°C–41°C). Precipitation is influenced by South Atlantic and Congo air masses with little or no influence from the Indian Ocean. Precipitation increases in the southeast, with total annual precipitation between 300 and 700 mm. Most precipitation falls between June and October, peaking in August (Gadallah, 2019).

Fig. 1 Sketch maps for the location of Sennar State in southeastern Sudan (a) and the location of Nuara Reserved Forest (study area) in Sennar State (b), as well as the overview of Nuara Reserved Forest (c)

2.2 Study Design and Field Measurement

The data used in this study were provided by the Faculty of Forestry, University of Khartoum, from a student training course on forest management plan formulation conducted in Nuara Reserved Forest. In February 2018, 638 circular sample plots were established in a systematic sampling grid using ArcGIS software (Fig. 2 [Figure 2: see original paper]). The grid consisted of several parallel survey lines spaced 200 m apart. Along each survey line, circular plots were located every 200 m, with each plot covering approximately 1000 m² (radius = 17.84 m). The first plot in each line was located 100 m from the edge to avoid edge effects. All living trees with diameter at breast height (DBH) ≥ 5.00 cm were identified to species and counted. Their DBH and height were measured using calipers and altimeters, respectively.

Fig. 2 Distribution of sample plots in Nuara Reserved Forest

2.3 Data Analyses

Data were organized in a classic site (plot)-by-species table, and species richness, tree diversity, and tree density were computed in R software (version 3.5.1) using the `vegan: Community Ecology Package` (R Core Team, 2015). All analyses were computed at the plot level.

Species richness is the number of tree species in each plot and for the forest overall. Tree diversity was computed using the Shannon-Weiner diversity index (H' ; Eq. 1) (Shannon and Weiner, 1963):

where H' is the Shannon-Wiener diversity index; i is the proportion of individuals belonging to species i ; s is the number of tree species; and p is the

importance value of a species as a proportion of all species i in each sample plot.

DBH values were used to classify trees into different stage classes, which were then computed on the ArcGIS platform. Based on the homogeneity of the study area, we classified tree stages into three categories: young (DBH: 5.00–14.99 cm), pre-mature (DBH: 15.00–24.99 cm), and mature (DBH: ≥ 25.00 cm).

3.1 Species Richness and Diversity

Surveys of 638 sample plots in Nuara Reserved Forest revealed 12,259 living trees representing four species (*Acacia seyal*, *Balanites aegyptiaca*, *Acacia senegal*, and *Acacia mellifera*) belonging to two families: Mimosaceae (three species) and Balanitaceae (one species) (Table 1). *Acacia seyal* was the most abundant and dominant species, with 11,638 individuals. We also identified 577 *Balanites aegyptiaca* trees, 40 *Acacia senegal* trees, and only 4 *Acacia mellifera* trees in the entire forest. The average tree diversity in Nuara Reserved Forest was 0.204 as computed by the Shannon-Wiener diversity index, which was very low.

Table 1 Estimates of tree species composition, relative frequency, number of individuals, and relative density in Nuara Reserved Forest

Species name	Number of plots	Relative frequency (%)	Number of individuals	Relative density (trees/hm ²)
<i>Acacia seyal</i>			11,638	
<i>Balanites aegyptiaca</i>			577	
<i>Acacia senegal</i>			40	
<i>Acacia mellifera</i>			4	
Total			12,259	

Note: n_i , number of sample plots where species present; N , total number of surveyed plots.

3.2 Tree Density and Frequency

Average tree density was 191 trees/hm² across the entire forest. Relative density was highest for *Acacia seyal* (218.34 trees/hm²; Fig. 3 [Figure 3: see original paper]), followed by *Balanites aegyptiaca* (32.78 trees/hm²), *Acacia senegal* (26.60

trees/hm²), and *Acacia mellifera* (20.00 trees/hm²). As shown in Figure 4 [Figure 4: see original paper], the spatial pattern of tree density revealed that more than 90% of the forest area had medium to high tree density (green and red regions), whereas relatively small areas in the northern tip of the forest were characterized by low tree density (yellow regions).

Fig. 3 Photo showing a very dense sample plot dominated by *Acacia seyal* trees in Nuara Reserved Forest

Fig. 4 Spatial distribution of average tree density in Nuara Reserved Forest. The black lines within the figure represent the boundaries of forest compartments.

Species occurrence and distribution in the forest area, as measured by relative frequency, indicated that *Acacia seyal* was the dominant species (Table 1). It occurred in 84.20% of the forest, followed by *Balanites aegyptiaca*, which was distributed in 27.80% of the forest. In contrast, *Acacia senegal* and *Acacia mellifera* were present in only 2.36% and 0.31% of the forest, respectively.

3.3 Tree Stage Structure

We used three diameter classes to describe forest stage structure (Table 2). Trees with DBH ranging from 5.00 to 14.99 cm were classified as young/juvenile stage-class, accounting for 86.30% of forest trees. Pre-mature tree stage-class (DBH: 15.00-24.99 cm) represented 13.35% of total trees. Only 0.34% of total trees had DBH \geq 25.00 cm and were classified as mature stage-class.

Species-specific stage structure indicated that young trees dominated all species. Young stage-class trees comprised 100.00%, 93.10%, 90.00%, and 56.49% of *Acacia mellifera*, *Acacia seyal*, *Acacia senegal*, and *Balanites aegyptiaca* trees, respectively.

Table 2 Percentage of each species in the three tree stand stages in Nuara Reserved Forest

Species	Number of trees	Percentage of species in the stage (%)	
		Young (5.00-14.99 cm)	Pre- Mature mature \geq 25.00 (15.00-24.99 cm)
<i>Acacia seyal</i>	11,638		

Species	Number of trees	Percentage of species in the stage (%)
<i>Balanites aegyptiaca</i>	577	
<i>Acacia senegal</i>	40	
<i>Acacia mellifera</i>	4	
Total	12,259	

4. Discussion

The present study detected only four species, with overwhelming dominance of *Acacia seyal* and notable rarity of *Acacia mellifera*. While this species count is similar to other forests in transitional zones with intermediate precipitation, it is much lower than species richness found in many dry forests in Africa. For instance, the average number of woody species was 28 in Neotropical continental forests, 48 in Beza Mahafaly tropical dry forests in Madagascar, and 110 in Bereku Forest Reserve, Tanzania (Sussman, 1994). Analysis revealed that Nuara Reserved Forest was dominated by a single species (*Acacia seyal*), an indicator of ecosystem state change (Thompson, 2011). This dominance may suppress natural regeneration of other tree species in the area.

Tree density in Nuara Reserved Forest (Table 1) was similar to that in Oban Forest Reserve, Nigeria (306.00 trees/hm²) as reported by Igbiosa and Ejakhe (2015) and lower-altitude Western Himalayan forests, India (235.00 trees/hm²) as reported by Malik and Bhatt (2015). However, our estimates were lower than those in Bereku Forest Reserve, Tanzania (616.00 trees/hm²) (Giliba et al., 2011), higher-altitude Western Himalayan forests, India (505.00 trees/hm²) (Malik and Bhatt, 2015), and tropical forests of Costa Rica (446.00 trees/hm²) (Lieberman et al., 1996). Tree species diversity in Nuara Reserved Forest ($H = 0.204$) was also lower than in other African forests (H ranged from 0.380 in northeastern Nigeria to 4.270 in Bereku Forest Reserve, Tanzania). The lower species diversity in this study could be due to study area size, environmental heterogeneity, and deforestation activities (Suratman, 2012). The low values of tree density and diversity compared to other locations may reflect differences in precipitation, soil characteristics, landscape features, and sampling intensity (Wakawa et al., 2017).

Nuara Reserved Forest greatly contributes to local community livelihoods by providing forest fruits, fallen wood for fuel, forage, crops, and job opportunities (Mohammed, 2018). This study identified ecological information about the

dominant species *Acacia seyal*, which provides significant economic benefits in the region, including charcoal production and gum arabic. It also provides baseline information about current forest condition, including species composition, tree diversity, density, and stage structure, which will help establish rigorous future monitoring programs and inform conservation efforts. Overall, this study provides information and insights to guide forest biodiversity restoration and implement sustainable forest management activities in savanna woodlands.

5. Conclusions and Recommendations

Forest tree diversity, dominant species, tree density, and stage structure are key data needed to design ecosystem management and environmental conservation strategies for a given region. This study showed low tree diversity ($H = 0.204$) in Nuara Reserved Forest of southeastern Sudan. The forest included only four species (*Acacia seyal*, *Balanites aegyptiaca*, *Acacia senegal*, and *Acacia mellifera*) typical of savanna woodlands. *Acacia seyal* was the most abundant species, while *Acacia mellifera* was very rare. Nuara Reserved Forest may be considered a young forest because 86.30% of trees were in the young stage-class (DBH: 5.00–14.99 cm). The state of tree species richness and relative density in the study area was low compared to similar environments worldwide.

To secure a sustainable supply of goods and services from Nuara Reserved Forest to local communities while maintaining the highest forest ecological integrity, we suggest implementing the following management interventions:

1. Prioritize restoration of *Acacia senegal* and *Acacia mellifera* because they are currently rare and at risk of extinction in this area, and because they have high ecological and economic value for local communities;
2. Establish a comprehensive long-term monitoring program through permanent sample plots in this forest to provide time-series data essential for assessing overall ecosystem state and evaluating tree population dynamics and savanna ecosystem changes;
3. Conduct in-depth research focusing on savanna ecosystem resilience to climate change and variability, and on deforestation drivers causing decline of woody vegetation diversity in southeastern Sudan's savanna woodlands.

Since our primary objective was exploratory and we were limited by available data, we recommend that future work focus on revealing relationships and trends of diversity metrics as a function of environmental conditions in the region.

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References

- Abdel Nour, H. O. 2013. The status of Sudan forests and the changes that have occurred during the period 2000–2011. *Nineteenth Annual Forestry Conference “Under the Slogan ‘Towards a Comprehensive Package for the Protection and Reconstruction of Forests’ .”* 24–27 April 2013. Khartoum: FNC (Forests National Corporation).
- Ahmed, K. M. S., Hamid, A. A., & Doka, A. 2015. Investigation of spatial risk factors for RVF disease occurrence using remote sensing & GIS—a case study: Sennar State, Sudan. *Journal of Geographic Information System*, 7(2): 226–257.
- Baillie, J. E. M., Collen, B., Amin, R., et al. 2008. Toward monitoring global biodiversity. *Conservation Letters*, 1(1): 18–26.
- Bakr, A., Siddig, E., & Eltohami, A. 2018. Threats to green gum arabic production in Sudan. *Biomedical Journal of Scientific and Technical Research*, 3(5). BJSTR.MS.ID.000951, doi: 10.26717/BJSTR.2018.03.000951.
- FAO (Food and Agriculture Organization of the United Nations). 2016. *Trees, forests and land use in drylands: The first global assessment*. Rome, Italy: FAO.
- Ferris-Kaan, R., & Patterson, G. S. 1992. Monitoring vegetation changes in conservation management of forests. *Forestry Commission Bulletin*, 108: 31, doi: <https://doi.org/10.4274/npa.y5917>.
- Gadallah, N. A. H. 2019. Assessment of conservative and protective needs for natural forests in drylands: Case of Wad Al-Bashir Forest, Gedaref State, Sudan. MSc Thesis. Khartoum: Desertification and Desert Cultivation Studies Institute, University of Khartoum, 1–100.
- Giliba, R. A., Boon, E. K., Kayombo, C. J., et al. 2011. Species composition, richness and diversity in Miombo Woodland of Bereku Forest Reserve, Tanzania. *Journal of Biodiversity*, 2(1): 1–7.
- HCENR (Higher Council for Environment and Natural Resources). 2014. *Sudan’s Fifth National Report to the Convention on Biological Diversity*. Ministry of Environment, Natural Resources and Physical Development, Sudan. <https://www.cbd.int/doc/world/sd/sd-nr-05-en.pdf>.
- Igbinsosa, H., & Ejakhe, G. 2015. Tree species composition and diversity in Oban forest. *Journal of Agricultural Studies*, 3(1): 10–24.

- Lieberman, D., Lieberman, M., Peralta, R., et al. 1996. Tropical forest structure and composition on a large-scale altitudinal gradient in Costa Rica. *The Journal of Ecology*, 84(2): 137-152.
- Malik, Z. A., & Bhatt, A. B. 2015. Phytosociological analysis of woody species in Kedarnath Wildlife Sanctuary and its adjoining areas in Western Himalaya, India. *Journal of Forest and Environmental Science*, 31(3): 149-163.
- Millennium Ecosystem Assessment. 2005. *Ecosystems and Human Well-being: Synthesis*. Washington, DC: Island Press, 1-137.
- Mohammed, M. 2018. *Decadal working plan for management of riparian forests in Sennar State*. Faculty of Forestry, University of Khartoum. Khartoum, Sudan.
- NBSAP. 2015. *National Biodiversity Strategy and Action Plan 2015-2020*. Ministry of Environment, Natural Resources and Physical Development, Sudan. <https://www.cbd.int/doc/world/sd/sd-nbsap-v2-en.pdf>.
- R Core Team. 2015. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna. <https://www.R-Project.org>.
- Shannon, C. E., & Weiner, W. 1963. *The Mathematical Theory of Communication*. Urbana: University of Illinois Press, 29-125.
- Shuaibu, R. B., & Dagba, B. I. 2013. Challenges of forest inventory and its effects on forest management and planning in Nigeria. *Forestry Association of Nigeria*, 1: 200-206.
- Siddig, A. A. H. 2014. Biodiversity of Sudan: Between the harsh conditions, political instability and civil wars. *Biodiversity Journal*, 5(4): 545-555.
- Siddig, A. A. H., Ellison, A. M., Ochs, A., et al. 2016. How do ecologists select and use indicator species to monitor ecological changes? Insights from 14 years of publication in *Ecological Indicators*. *Ecological Indicators*, 60: 223-230.
- Siddig, A. A. H., Abdel, M. T. D., El-Nasry, H. M., et al. 2019a. Biodiversity of Sudan. In: Pullaiah, T. (Ed.), *Global Biodiversity (Vol. 3): Selected Countries in Africa*. Waretown: Apple Academic Press, 275-294.
- Siddig, A. A. H. 2019b. Why is biodiversity data-deficiency an ongoing conservation dilemma in Africa? *Journal for Nature Conservation*, 50: 125719, doi: 10.1016/j.jnc.2019.125719.
- Suratman, M. N. 2012. Tree species diversity and forest stand structure of Pahang National Park, Malaysia. In: Lameed, G. A. (Ed.), *Biodiversity Enrichment in a Diverse World*. Rijeka: IntechOpen, 473-492.
- Sussman, R. W. 1994. Plant diversity and structural analysis of a tropical dry forest in Southwestern Madagascar. *Biotropica*, 26(3): 342-354.
- Thompson, I. 2011. Biodiversity, ecosystem thresholds, resilience and forest degradation. *Unasylva*, 238: 25-30.

Vardon, M., & Harris, R. 2017. Review of ecosystem condition indicators. Paper for the London Group. https://seea.un.org/sites/seea.un.org/files/lg23_{review}_{of}_{ecosystem}_{condition}_{harris}.pdf.

Vidal, C., Alberdi, I., Redmond, J., et al. 2016. The role of European National Forest Inventories for international forestry reporting. *Annals of Forest Science*, 73(4): 793-806.

Wakawa, L., Suleiman, A., & Adam, L. 2017. Tree species biodiversity of a sahelien ecosystem in North-East Nigeria. *Journal of Bartin Faculty of Forestry*, 19(2): 166-173.

Zhang, Q., Liang, Y., & He, H. S. 2018. Tree-lists estimation for Chinese boreal forests by integrating Weibull diameter distributions with MODIS-based forest attributes from kNN imputation. *Forests*, 9(12): 758, doi: 10.3390/f9120758.

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