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Scattered trees in an oil palm landscape: Density, size and distribution

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A R T I C L E I N F O

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A B S T R A C T

In tropical landscapes dominated by oil palm monocultures, scattered trees can contribute to biodiversity, regulate diverse ecosystem functions and deliver goods and services. However, basic quantitative information about such trees is often lacking. The objectives of our study were to identify the landscape-wide density and distribution patterns of scattered trees in an oil-palm-dominated area of Sumatra (Indonesia), and to estimate their size. The study area with the total of 1120 ha was situated in Jambi province in the lowlands of Sumatra. In 2016, the year of our assessment, 83% of the area was covered by oil palm monocultures including industrial and smallholder plantations; other land-use types included rubber plantations and secondary forests. An earlier land-use classification suggests that oil palm cultivation began before 1990 on 41% of the area. The study area was mapped in 2016 using a fixed-wing drone equipped with red-green-blue and near-infrared cameras. We counted all visible trees in the aerial image. In the entire study region, we detected 10.1 scattered trees/ha. In areas where oil palm plantations were established before 1990, the tree density was 67% lower than in the area where oil palm was introduced later. The median tree crown diameter was 4.5 m, which corresponds to an estimated diameter at breast height of 12 cm; thus, most trees were small-statured. The trees were spatially clustered and often aligned along roads and rivers. In conclusion, we found a considerable number of scattered, mostly small-statured trees. This suggests that most trees were young and disappeared before reaching larger dimensions. To ensure the survival of trees and further provision of related ecosystem services, scattered trees in the oil palm landscape need to be conserved and/or restored.

1. Introduction

Oil palm cultivation has contributed to economic growth, particularly in Southeast Asia, and helps to meet the global demand for vegetable oils (Qaim et al., 2020). However, the significant expansion of oil palm cultivation over the past 20 years is associated with a decline in forest area (FAO, 2019) impairing biodiversity and ecosystem services (Barnes et al., 2014; Bernard et al., 2016; Brühl and

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Eltz, 2010; Chapman et al., 2018; Clough et al., 2016; Danielsen et al., 2009; Dislich et al., 2017; Koh and Wilcove, 2008). The lowlands of Sumatra are a centre of the Southeast Asian palm oil production. Here, land-use transitions from forest to rubber and oil palm monocultures were associated with widespread biodiversity-profit trade-offs, and profit gains came at the expense of big losses in ecosystem functions (Grass et al., 2020). Thus, strategies are required to mitigate negative impacts of oil palm cultivation on decreasing biodiversity and weakening ecosystem functions (Koh et al., 2009; Luke et al., 2020). Such strategies may also contribute to sustaining palm oil production. Trees scattered in the landscape may make a valuable contribution with less impact on the yield, first of all, in extensively managed plantations (Teuscher et al., 2015).

In recent years, scattered trees, that are defined in this article in accordance with the definition of “trees outside forests” sensu FAO (FAO, 2010), were observed to promote biodiversity in different agricultural and urban environments (Clough et al., 2009; Heim et al., 2015; Le Roux et al., 2018; Mellink et al., 2017; Stagoll et al., 2012) with increasing diversity of both forest-specialists and non-specialists within the supported species communities (Prevedello et al., 2018). In particular for oil palm monocultures, it was shown that even young trees can promote birds and invertebrate communities in such areas (Teuscher et al., 2016). In addition to serving as biodiversity refugia and enhancing landscape connectivity, trees have a cooling effect on the atmosphere via transpiration, provide products and goods such as fire wood, timber, fruits, honey, livestock forage (Barrance et al., 2003; Endale et al., 2017; Harvey and Haber, 1998; Tscharntke et al., 2011), enhance pest control (Clough et al., 2009; Guenat et al., 2019) and could contribute to climate change mitigation by storing carbon (Chapman et al., 2020).

Despite the importance of scattered trees, little quantitative information is available, e.g., regarding the density of trees in agricultural landscapes or their size and age distributions (Schnell et al., 2015). Previous studies clearly showed that land management influences these variables as well as the species composition of scattered trees (Augusseau et al., 2006; Barrance et al., 2003; Esquivel et al., 2008; Harvey et al., 2011; Harvey and Haber, 1998; Tambara et al., 2012; Valencia et al., 2015). A brief literature review suggests that there may be an enormous variation ranging from 0.3 trees/ha in a Mexican pasture (Guevara et al., 1994) to 1052 trees/ha in the crop fields of the mid-Zambezi valley of Zimbabwe (Tambara et al., 2012), although the latter study considered woody

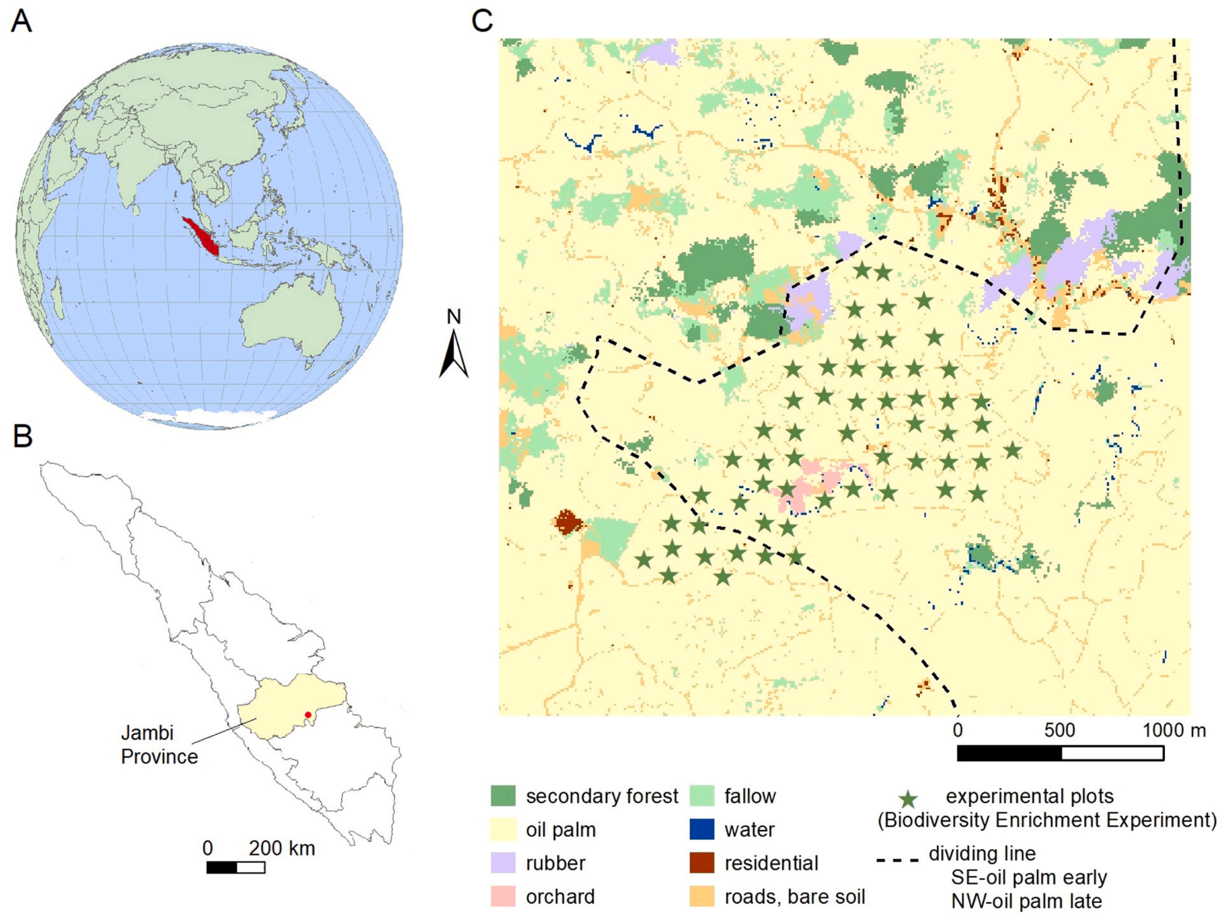

Fig. 1. Sumatra in the world (map: Dianacht, n.d.) (A); Jambi province on Sumatra including the actual study area (red dot) (Source: D-maps.com, 2021, modified) (B); and land use in the study area (2016) (Khokthong, 2019, modified) (C). In the south-eastern part, oil palm was established before 1990 (SE-oil palm early). In the north-western part, oil palm cultivation started after 1990 (NW-oil palm late). Stars indicate plots of the Biodiversity Enrichment Experiment EFForTS-BEE (Teuscher et al., 2016). These plots (2.3 ha in sum) were excluded from our study.

plants of all development stages including seedlings. Studies on tree structure mostly focus on height and diameter at breast height (dbh; Harvey and Haber, 1998; Samuel et al., 2019; Santhyami et al., 2020; Tambara et al., 2012) and sometimes crown size (Endale et al., 2017; Harvey et al., 2011; Nahed-Toral et al., 2013). Spatial distribution of trees is most often studied with respect to tree density in different land-use systems (Endale et al., 2017; Samuel et al., 2019), but rarely regarding the spatial arrangement (Rossi et al., 2016). Overall, little quantitative information is available regarding scattered trees in oil palm landscapes (but see Teuscher et al., 2015).

This study was conducted in an oil palm landscape of Jambi province in lowland Sumatra, Indonesia, using drone-based image acquisition. The study area covered 1120 ha; maps from earlier satellite-based land-use classification (Melati, 2017) suggest that oil palm and rubber cultivation began before 1990 on 41% of this area. Although we know little about the current management practices in the study area and, in particular, about tree-related land management decisions, our aerial images showed extended oil palm monocultures with scattered trees being an integral part of the landscape. The objectives of our study were (1) to identify the density of scattered trees (n/ha) as well as their spatial distribution and (2) to analyse their crown structure. Subsequently, we discussed the influence of land-use history on these characteristics.

2. Methods

2.1. Study region

The study area is situated in Jambi province, Sumatra, Indonesia (Fig. 1A; 1B). The terrain is undulating at an average altitude of 53 m a.s.l. (Naumann, 2015). The mean air temperature is 26.7 °C and the annual precipitation is 2235 mm (Drescher et al., 2016).

The study area was 1120 ha in size. A drone-based assessment from 2016 found that 83% of the area was covered by oil palm plantations (predominantly first generation oil palm); other land-use types were rubber cultivation (2%), secondary forest (4%) and fallow land (6%) (Fig. 1C, Khokthong, 2019). The remaining area (5%) was classified as roads, bare soils, water bodies and residential areas. In lowland Sumatra, there is a mix of large-scale industrial and smallholder oil palm cultivation (InPOP, 2015; Qaim et al., 2020). Our study was conducted in a landscape centered around the industrial-scale plantation PT Humsindo Makmur Sejati with 500 ha bordering on another industrial-scale plantation in the southeast (study area central point: 01.95° S and 103.25° E). The ownership of other plantations in the study area is not known. A part of PT Humusindo harbours the Biodiversity Enrichment Experiment EFForTS-BEE (Teuscher et al., 2016). Here, 56 experimental agroforest islands were established in 2013 by planting up to six native tree species among oil palms. The goal of this experiment is to gain scientific insights into restoring biodiversity and ecosystem functions in oil palm landscapes. The islands cover 2.3 ha cumulatively and were not considered in this study.

Based on maps of Melati (2017), we inferred that the oil palm cultivation started already before 1990 in the southeast of the area (41%), whereas the northwest (59%) was still covered with secondary forest. From now on, these parts will be referred to as “SE-oil palm early” and “NW-oil palm late”, respectively.

2.2. Mapping the landscape

The analysis of scattered tree density and structure was based on drone-derived maps from October 2016. Red-green-blue (RGB, Canon PowerShot SX260 HS) and near-infrared (NIR, same camera type with modified Rosco #2007 filter) images were acquired from a fixed-wing drone (Aero M, 3D Robotics, USA). The flight altitude was 300 m a.s.l. with an image overlap of 50% sideward and 50% forward. Orthophoto generation and georeferencing was done with (Agisoft LLC, 2021). Seamless orthophotos were compiled into a raster of 0.1 m resolution after colour balancing between two overlapping images using the PCI Geomatica software 2017 by PCI Geomatics Enterprises Inc., 2021 (Khokthong, 2019).

Land-use types were assigned by a supervised classification with the maximum likelihood classifier following a pixel-based approach in (Esri Inc., 2021). Training polygons samples were collected based on identification of land use type after ground truthing. Ground truthing with 100 locations was done in a field survey using random sampling. The resulting land use maps contained

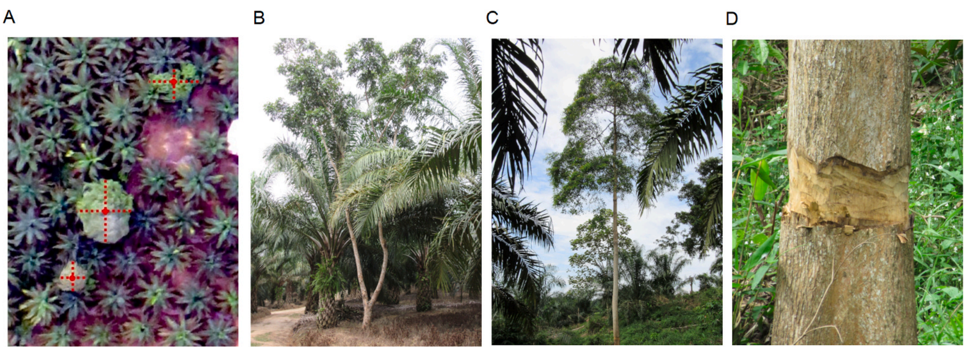

Fig. 2. Scattered trees in the study region: Aerial view with two marked trees and indications of crown diameter measurements (A); a roadside tree in an oil palm plantation (B); a tree from a distance (C); the same tree (as close-up) girdled to be removed (D).

eight classes of land use: Secondary forest, oil palm plantation, rubber plantation, fallow, orchard, water, residential areas, and bare soil. Oil palm plantations were defined as a cultivated area where oil palms should be present and have a canopy size of at least 1 m and be situated in a homogeneous field. Forest was defined as an area covered with trees and larger than 0.5 ha (FAO, 2006), but in our study excluded rubber plantations. The map resolution was decreased to 10 m with the resampling technique in ArcGIS in order to reduce small-scale landscape heterogeneity. An accuracy assessment was performed by creating 504 reference points using equalized stratified random point sampling in ArcGIS (version 10.4) and a confusion matrix approach (Foody, 2002; Müllerová et al., 2017). The overall accuracy was 84% (Khokthong, 2019).

To determine the dividing line between SE-oil palm early and NW-oil palm late, a Landsat based map of the whole Jambi province in the year 1990 was used (Melati, 2017). A rectangular polygon of the same geometry area as the drone maps was applied to clip the raster of the study area using ArcGIS software by (Esri Inc., 2021).

2.3. *Mapping scattered trees*

We particularly focused on scattered trees in the oil palm areas (Fig. 2). We also included trees on fallow lands and in residential areas as well as trees standing along water creeks and roads. However, we did not consider trees in secondary forest patches that were defined as forests according to FAO definition (FAO, 2006), in rubber plantations or in orchards. We neither considered trees in the EFForTS-BEE plots.

2.3.1. *Measuring tree density and structure*

All scattered trees that could be seen in the orthophotos of 0.1 m resolution as described before were counted by visual assessment in (Esri Inc., 2021) and marked as point geometries (Fig. 2A). From all identified trees, 371 (3.5%) were randomly selected to measure crown diameter (Fig. 2A). The sample size was calculated with the function "rsampcalc" in the package "sampler" of the programming language R (Baldassaro, 2019) with a total population size = 10,652 trees and the tolerable margin of error = 5%. The selection process was stratified by percentage area of land-use types (excluding secondary forest, rubber and orchard) and by presumed land-use history (oil palm established before or after 1990; app. A). The crown diameter of each tree on the aerial images was recorded as an average of two perpendicular measurements (north – south, west – east). The minimal measured crown diameter in the sample was 1.9 m. To further assess changes in tree density over oil palm plantation age, we used (Google Earth Pro.Ink., 2020) with relevant images available from the year 2002 and differentiated oil palm plantations aged < 15 or ≥ 15 years at the time of our drone mission in 2016.

2.3.2. *Analysing tree density, structure and distribution*

Tree density was assessed as the number of trees per hectare for the whole study area as well as for previously identified land-use types in the SE-oil palm early and in the NW-oil palm late. These were oil palm areas, fallow lands, residential areas, areas along water creeks and roads, but again without secondary forests, rubber plantations, orchards and the trees of the EFForTS-BEE plots. We performed the statistical analysis in R, version 4.0.2 (R Core Team, 2013). A non-parametric Mann-Whitney-*U*-Test (Mann and Whitney, 1947) was applied to compare the tree crown size in the SE-oil palm early and in the NW-oil palm late. For histograms demonstrating the distribution of crown diameters, the values were rounded to whole numbers. From the crown diameter, we estimated the dbh and the height of trees in the study area by using regression analyses for 126 trees measured for previous studies in the ca. 18 km distant Harapan rainforest (app. B, Ahongshangbam et al., 2020) and in the experimental areas of EFForTS-BEE (app. B, Ahongshangbam et al., 2019). Distribution patterns of scattered trees were analysed with the Average Nearest Neighbour function in ArcGIS where the ratio of observed and expected average distance < 1 indicates a clustered distribution and the ratio of > 1 implies a random one (Esri, 2018).

3. Results

3.1. *Tree density*

For the entire study region, we detected 10,652 scattered trees resulting in a density of 10.1 trees/ha (Table 1). In oil palm plantations, 6631 scattered trees (7.2 trees/ha) were observed. A noticeable large number of scattered trees occurred on the fallow land: 57 trees/ha. Further, 4.6 trees/ha were identified in the landscape part where oil palm was introduced before 1990 (SE-oil palm

Table 1
Tree density in the study area (1050 ha; secondary forests, rubber plantations and orchards excluded) with a total of 10,652 detected trees.

	Study region (entire) (trees ha^{-1})	SE-oil palm early (trees ha^{-1})	NW-oil palm late (trees ha^{-1})
Oil palm	7.2	4.1	9.6
Fallow	56.7	34.7	58.8
Residential	9.7	25	8.8
Road edges, bare soil	6.3	5.1	6.9
Water edges	7.7	9.3	5.4
Total	10.1	4.6	14

Table 2
Distribution patterns of scattered trees. Nearest Neighbour Ratio < 1 indicates clustered spatial patterns; a very low z-score (standing for standard deviation) implies a very low likelihood of the scattered trees being distributed randomly (Esri, 2018).

	Study region (entire)	SE-oil palm early	NW-oil palm late	SE-oil palm early (palm plantations)	NW-oil palm late(palm plantations)
Nearest Neighbour Ratio	0.47	0.44	0.51	0.47	0.56
z-score	- 105.3	- 47.1	- 88.2	- 41.0	-58.8
Random distribution likelihood	< 1%	< 1%	< 1%	< 1%	< 1%

early), whereas 14 trees/ha were detected in the NW-oil palm late. Directly in oil palm plantations, these densities were 4.6 trees/ha for the SE-oil palm early and 9.6 trees/ha for the NW-oil palm late.

From our satellite-based assessment of changes in tree density over oil palm age, we estimated 4.4 trees ha^{-1} in the SE plantations aged < 15 years and 3.5 trees ha^{-1} in the SE plantations aged ≥ 15. For the NW-oil palm late, we found 10.9 trees ha^{-1} in plantations aged < 15 years and 3.2 trees ha^{-1} in plantations aged ≥ 15.

3.2. *Trees distribution patterns*

The Average Nearest Neighbour analysis resulted in an index of 0.47 for the entire study area, with 0.44 for the SE-oil palm early and 0.51 for the NW-oil palm late (Table 2). Staying always < 1, the index suggests a clustered distribution of scattered trees in all cases.

Elongated, meandered patterns were typical for scattered trees distribution in the oil palm plantations (examples in Fig. 3). These linear tree formations only seldomly reached the width of 20 m. A closer inspection of the RGB-images revealed that they were mostly situated along roads and water bodies. Such elongated patterns were more frequently found in the area SE-oil palm early.

3.3. *Tree structure*

Structural measurements of trees in the entire study area as well as in the SE-oil palm early and NW-oil palm late showed right-skewed distributions indicating the prevalence of smaller trees (Fig. 4). Nearly 50% of the scattered trees in the entire study area had a crown diameter < 4 m (Fig. 4A) suggesting a dbh of ≤ 10 cm and a height of ≤ 7 m (app. B). The median of the tree crown diameter in the study area was 4.5 m, which corresponds to a dbh of 12 cm and a height of 7.5 m according to our regression models. Less than 5% of the trees had a crown diameter of > 10 m (Fig. 4A) and, correspondingly, a dbh of > 30 cm and a height of > 25 m (app. B). The median of crown diameter in the oil palm plantations within the SE was 4.6 m, whereas it was 4.4 m in the oil palm plantations within the NW ($p = 0.048$ by confidence interval = 95%). In the oil palm plantations within the SE, the largest measured trees belonged to the crown diameter class of 16 – 18 m (Fig. 4B). In the oil palm areas of the NW-oil palm late, trees with a crown diameter larger than 10 m were absent (Fig. 4C). When it comes to the entire SE and NW including trees in oil palm plantations, fallow lands, residential areas and trees along water creeks and roads, the trend was similar to that within only the respective oil palm plantations. The median crown diameter was 4.6 m in the entire SE-oil palm early and 4.2 m in the entire NW-oil palm late ($p = 0.017$).

4. Discussion

Using drone-based mapping in an oil-palm-dominated landscape of lowland Sumatra (1120 ha), we observed a landscape-wide average density of 10.1 scattered trees/ha. The trees were relatively small-statured with a median crown diameter of 4.5 m and their spatial distribution was clumped or linear.

4.1. *Tree density*

The mean tree density in our study area was 10.1 trees/ha, whereas the oil palm density was found to vary from 120 palms/ha in older to 160 palms/ha in younger plantations (Röll et al., 2015). The resulting relation is 6–8 trees per 100 oil palms. The mean tree density that we observed in our study is less than in a study in other Sumatran oil palm landscapes, in which 27.9 trees/ha were found by a terrestrial sampling (Teuscher et al., 2015). However, Teuscher et al. (2015) ground-based sampling included trees ≥ 2 m height, whereas in our study the smallest tree that could be detected was estimated 5.5 m high. Thus, it is likely that we could not detect smaller trees below the oil palm canopy from our aerial images, so that the differences in the assessment method and this size threshold may cause data discrepancies. In addition, we sampled a much larger area. Our observed values are close to the value of 12 trees/ha reported by farmers during Teuscher et al.'s (2015) interviews in their study region.

Other available data on density of scattered trees in tropical agricultural landscapes also vary enormously, in which the variability can be explained by differing methodological approaches, size thresholds of sampled trees, local site conditions and management. In Central and South America, the range reaches from 0.3 trees/ha in a pasture in Los Tuxtlas (Guevara et al., 1994) to 163 trees/ha in another Mexican pasture in the buffer zone of the biosphere reserve Selva El Ocote (Gómez Castro et al., 2013). In Africa, the density of scattered trees was found to range between 2.6 trees/ha (*Acacia tortilis* in the Central Rift Valley of Ethiopia) or 3.7 trees/ha (*Croton*

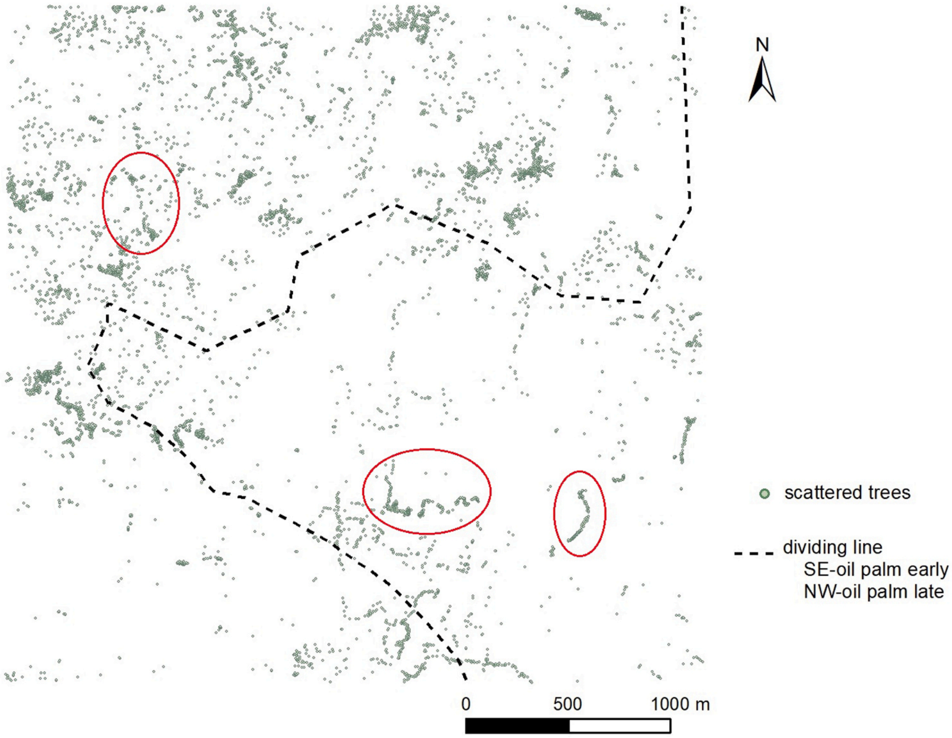

Fig. 3. Scattered trees (n = 6631) in oil palm plantations of the study region. Some linear structures along roads and creeks are indicated by red circles.

macrostachyus in Western Ethiopia) in fields with maize and wheat (Sida, 2018) to 1051.5 trees/ha (different species) in crop fields in the mid-Zambezi Valley of Zimbabwe (Tambara et al., 2012). A cacao agroforestry on Sulawesi in Indonesia had 15 trees/ha (Clough et al., 2009), whereas 1108 trees/ha were found in another cacao cultivation region in Indonesian West Sumatra (the last number incl. cacao plants, cacao stems density = 433 trees/ha) (Santhyami et al., 2020). Apart from methodological differences definitely causing differences in those results, land management decisions were found to be crucial for tree density. Decisions on tree removal and/or supression were driven, e.g., by negative interactions between trees and cultivated crops (Barrance et al., 2003). The species-specific ability of trees to provide certain goods and services like fruits and medicine (Tambara et al., 2012), food and shade (Gómez Castro et al., 2013) was important for tree preservance. Farmers near Monteverde (Costa Rica) named 19 reasons to let trees stay in pastures (Harvey and Haber, 1998).

4.2. Trees distribution patterns

Clumped distribution of trees over the whole study area and inside the oil palm monocultures in the study area indicates that the

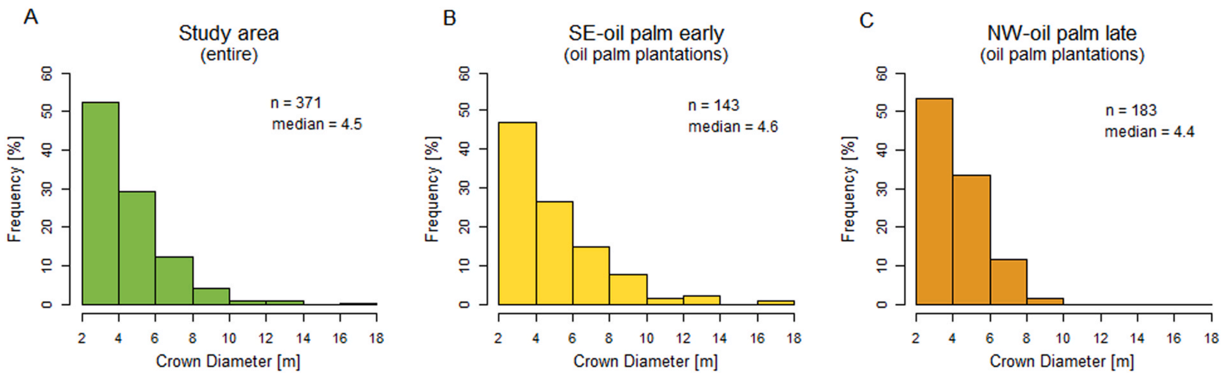

Fig. 4. Crown diameter for n = 371 trees in the entire study area including trees in oil palm plantations, fallow lands, residential areas and trees along water creeks and roads (A); and crown diameter of trees in oil palm plantations only: SE-oil palm early (B) and NW-oil palm late (C).

trees in our study region are highly unevenly distributed. In particular in the SE-oil palm early, trees were scarce within the plantations, but numerous linear tree patterns emerged along roads and water bodies at the edge of the oil palm monocultures. For existing trade-offs between tree density and oil palm yield (Teuscher et al., 2015), the scarcity of trees within the plantations can be attributed to their deliberate removal in course of the plantation management. On the other hand, competition between oil palms and trees is mutual, so that trees grow more slowly nearby oil palms (Zemp et al., 2019). In contrast, at roads or at rivers of the oil palm plantations in our study area, trees are sometimes planted to prevent erosion (Lassen, 2020). In particular in the industrial plantations of PT Humusindo situated in the middle of our study area, trees are kept or planted mostly inside the orchard and along rivers; the species include fruit trees (*Lansium domesticum*, *Archidendron pauciflorum*, *Nephelium lappaceum*) and timber species (*Paraserianthes falcataria, Swietenia macrophylla*) and are used and perceived differently by the various stakeholders (Lassen, 2020). As our study is drone-based, we do not have comprehensive information on tree species identity and usage for the entire study area. However, from oil palm areas in the Batanghari region of Jambi Province, 35 tree species were reported with 19 species being fruit bearing and 15 able to provide timber and rubber (Teuscher et al., 2015). Another positive ecosystem service as an enhanced soil water infiltrability and, thus, a potential contribution to the mitigation of local flooding has been observed on the experimental agroforestry islands of EFForTS-BEE (Merten et al., 2020). Nevertheless, despite potential usefulness of scattered trees, our drone mapping of the SE-oil palm early shows that the interiors of oil plantations barely contain scattered trees.

4.3. Tree structure

The median of the crown diameter of scattered trees in the study area was 4.5 m. Based on a regression analysis (app. B), a median tree was predicted to have a dbh of 12 cm and a height of 7.5 m. Whereas trees $\geq$ 10 cm dbh were abundant in the nearby old-growth forest (nearly 600 trees/ha by Rembold et al., 2017), trees of that size were estimated to only comprise 5.7 individuals per ha in the entire oil palm landscape; and only 5% of all sampled trees were found to have a dbh of $>$ 30 cm and a height of $>$ 25 m. This indicates a dominance of young trees, whereas larger trees would be preferable for biodiversity maintenance (Jones et al., 2018; Le Roux et al., 2016; Lindenmayer, 2017; Slik et al., 2013; Stagoll et al., 2012; Zotarelli et al., 2019). In general, large trees are rather rare in agricultural areas (Endale et al., 2017; Samuel et al., 2019; Santhyami et al., 2020; Tambara et al., 2012). On the other hand, Harvey et al. (2011) report more large than small trees for one pasture combined with different agricultural land use in Cañas, Costa Rica, and interpret that as a signal for a well-represented relict vegetation with rather suppressed regeneration. The study by Nahed-Toral et al. (2013) also emphasizes the majority of scattered trees in another pastoral-agricultural landscape in the watershed of Grijalva River (Mexico) to be forest remnants. The rather small crown diameter in our study area indicates a very scarce presence of forest remnant trees.

4.4. Land-use history

In 1990, the SE-oil palm early was already used for growing oil palm and rubber, whereas the north-western part of the study region was still covered with forest. A considerable part of the NW-oil palm late belongs to the conservation area Taman Hutan Raya Sulthan Thaha Syaifuddin. However, as visible on historical images of Google Earth, also in this area oil palm plantation began no later than 2007 (Google Earth Pro.Ink., 2020). In 2016, at the time of our study, the oil palm plantations in the SE-oil palm early were still more homogeneous than in the NW-oil palm late where they alternated with the remaining patches of secondary forest, rubber and fallow (Fig. 1C). Both parts of the study area differed in densities of scattered trees: 4.6 trees/ha in the SE-oil palm early and 14 trees/ha in NW-oil palm late. A different tree density was also observed if comparing only oil palm land: 4.1 trees/ha in the southeast and 9.6 trees/ha in the northwest. This might mean that an area with a longer use for oil palm cultivation (SE-oil palm early) contains fewer trees. Our satellite-based assessment also would indicate a lower tree density in older palm plantations in both parts of the study area (although, smaller trees under well-developped oil palm canopies might have remained undetected by us). As far as the crown diameter was rather small for both the SE and NW, a lower tree density in the SE oil palm early could hardly result from a more intensive removal of forest remnants. We suppose that the difference between both parts of the area is caused by a more consequent surpression of tree regeneration or a less active tree planting in the SE-oil palm early. However, due to the lacking data on plantations management in the study area, no exact statements are possible thus far.

On the other hand, there is no evidence that the duration of oil palm cultivation and land-use history actually cause differences between tree density in the SE-oil palm early and NW-oil palm late. Alternative explanations include stochastic events (a lightning strike, a fire etc.), environmental differences, differences in management regime and land ownership. Stochastic events are possible and cannot be tested with our dataset. Environmental differences in the landscape occur but, to our knowledge, do not differentiate in the SE-oil palm early and NW-oil palm late. The entire landscape undulates at an altitude of 26–89 m a.s.l. (Naumann, 2015). Upland and well-drained soils are Acrisols with some variation in texture (Drescher et al., 2016), whereas the riparian areas at lower site are more hydromorphic. However, we know little about land ownership and management in this landscape. According to the Indonesian Ministry of Agriculture, about 40% of the oil palm cultivation area in Indonesia is managed by smallholders and about 60% by larger companies and estates (InPOP, 2015; Qaim et al., 2020). However, exact property relationships for our study region are not known. In the centre of the area, there is the medium-sized privately owned company PT Humusindo Makmur Sejati that comprises approximately 500 ha at this site; in the very southeast, there is PT Berkat Sawit Utama, formerly PT Asiatic Persada, a pioneer of oil palm cultivation in the region. For large other areas, we do not know the ownership and potentially associated differences in management type. We also do not know which type of management and ownership would result in which differences in tree density and distribution. Thus, our analyses only give a first hint to the potential role of land-use history for the occurrence of scattered trees. Future and more comprehensive landscape assessments should, therefore, also focus on distances to certain landscape features such as forests and include more precise data on historic and current land use.

A utilitarian approach to natural resources has historically been in confrontation with considerations of tree preservation (Mölder et al., 2020). Declines in tree densities have been observed in many regions of the world for different agricultural land-use types (Gibbons et al., 2008; Harvey and Haber, 1998; Manning et al., 2006). Some management recommendations have been developed (Augusseau et al., 2006; Gibbons et al., 2008; Tscharntke et al., 2011; Grass et al., 2019), and experimental trials show that relatively simple policy instruments like provision of information and high-quality seedlings of native species could enhance land owners ́ willingness to plant trees in their oil palm plantations (Romero et al., 2019; Rudolf et al., 2020). It should be also mentioned that relatively low densities of trees have been shown to benefit biodiversity (Fischer et al., 2010; Gallé et al., 2017) meaning a comparatively small amount of land needed. In EFForTS-BEE, in the first years of the experiment there was no reduction of oil palm yield due to tree establishment (Gérard et al., 2017). Another study indicates that the negative impact of additionally planted trees on the oil palm yield is negligible in extensively managed plantations (Teuscher et al., 2015). Preserving scattered trees becomes even more crucial regarding recent observations of ephemerality (sensu Reid et al., 2018) of secondary forests that, in the light of vanishing old-growth forests, are considered of high value for conserving biodiversity. Reid et al. (2018) found secondary forests often disappearing again before the diversity could recover. Thus, scattered trees obtain a special significance as a supportive diversity refugia in landscapes where secondary forests vanish soon after the reestablishment. In particular, they can improve the landscape matrix to support tree- and forest-depending species in the anthropogenically impacted areas (Arroyo-Rodríguez et al., 2020).

5. Conclusions

At the time of the study, tree density in the entire study area was still considerable. However, in the south-eastern part, where oil palm had been cultivated for longer, fewer trees were found. This might indicate that tree density declines over time in conventional oil palm monocultures. However, the exact reasons for such a decline (a consistent removal of forest remnants, surpression of natural tree regeneration, absence of new plantings) remain unknown and can potentially be uncovered in a more comprehensive and interdisciplinary future landscape assessment. The small crown diameter in the entire study area, nevertheless, suggests, that most trees here were young and disappeared before they reached larger dimensions. To safeguard biodiversity and the multiple ecosystem functions and service that scattered tree provide, it is important to implement conservation management startegies for the promotion and maintenenance of scattered trees in the landscape.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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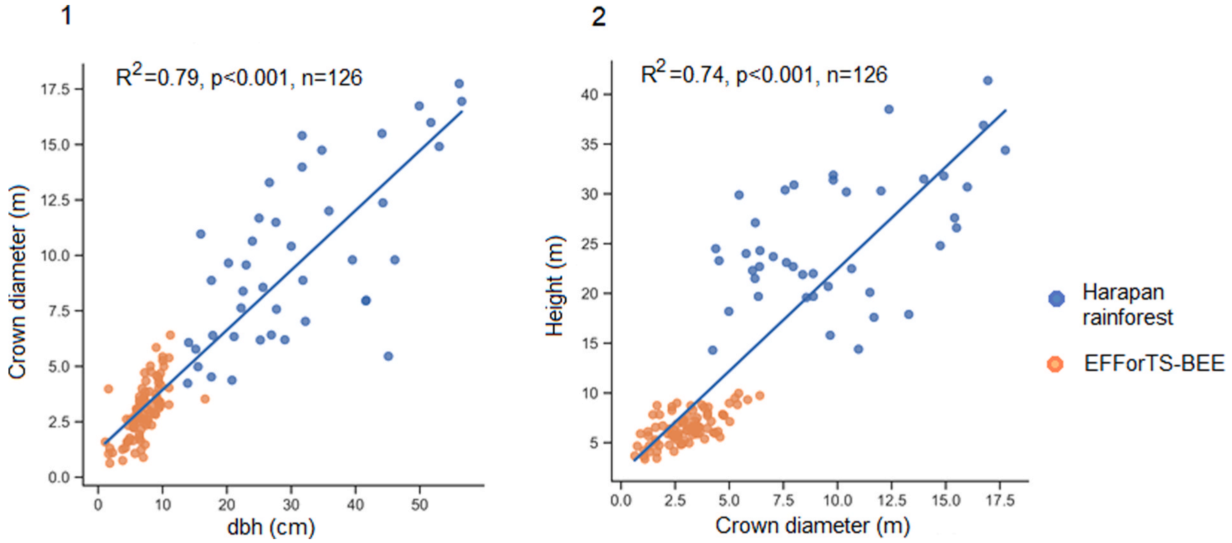
Appendix A. Sample trees for crown diameter assessment

Land use	SE-oil palm early	NW-oil palm late
Oil palm	143	183
Fallow	2	21
Residential areas	0	1
Roads & bare soil	6	14
Water	1	0
Total	152	219

The number of trees measured in each part of the study region was defined according to the proportion of the areas SE-oil palm early and NW-oil palm late as well as to the proportion of each land-use type. The area of the SE-oil palm early takes 41% of the entire study region. Correspondingly, 152 trees (41% of the total sample of 371 trees) were taken from this part. Thereafter, these 152 trees were split up to different land-use types (excluding secondary forest, rubber and orchard). Nearly 94% of the SE-oil palm early is occupied by oil palms, 1.3% by fallow, 4% by roads and bare soil and 0.5% by water bodies. Correspondingly, 94% of all 152 trees measured in the SE-oil palm early come from the oil palm stands (143 trees), 1.3% come from the fallow (2 trees) etc. The same principles work for trees measured in the NW-oil palm late.

Appendix B

Tree stem diameter (dbh) vs. crown diameter (1) and tree height vs. crown diameter (2). Data for small-statured trees, EFForTS-BEE, were assessed on an experimental plot of the Biodiversity Enrichment Experiment located in the center of the area of the present study (dbh from terrestrial measurements; crown diameters and heights were assessed with drone-based imagery; Ahongshangbam et al., 2019). Data for larger forest trees come from the Harapan rainforest which is located ca. 18 km distant from the area of the present study (dbh from terrestrial measurements; crown diameters and heights were assessed with drone-based imagery; Ahongshangbam et al., 2020).



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