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POPULATION STRUCTURE AND PHENOLOGICAL PATTERNS OF MILICIA EXCELSA IN MOIST EVERGREEN AFROMONTANE FORESTS OF SOUTHWESTERN ETHIOPIA

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Knowledge of population structure and phenological patterns is basic to understanding the biological process, impact of disturbance, and forest successional trend. The main objective of this paper is to investigate the population structure and phenology of *Milicia excelsa* for seed production area. This study was conducted in Yayu and Bebeka natural forests, South West Ethiopia. Systematic sampling method was used to collect the data. Ten line transects were laid down along the gradient at each 100 m interval. Sample plots of 20 × 20 m for trees and saplings and 5 × 5 m for seedlings were laid down along transects at 50 m interval. Within the main plots, sub-plots for seedlings were laid out at the four corners and centre. A total of 60 quadrats were sampled at the Kebereta (Bebeka) and Dawe (Yayu) sites. DBH and height of trees were measured from each main plot. Data on phenology study was collected from both primary and secondary sources. The results of the distribution of the population of M. excelsa exhibited almost irregular pattern across the selected natural forests. The regeneration status of *M. excelsa* is 'fair' at the Bebeka site and 'none' at the Yayu site. *M. excelsa* has the highest proportion of individuals in natural forest at the Kebereta site than at the Dawe site; thus, it is more favourable to establish a seed production area there.

Keyword: flower, fruit, regeneration, seed production.

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Tropical forests are one of the richest ecosystems supporting a variety of life forms, and they have a tremendous intrinsic ability for self-maintenance. There are different indigenous timber tree species, and one of the most important one found in tropical forests is Milicia excelsa (Welw.) C.C. Berg, which comes from the genus Milicia of the family Moracae. It contains two species, which are closely related: Milicia excelsa and Milicia regia (A. Chev.) C.C. Berg. Both are among the most useful indigenous tropical rain forest tree species. It has great socioeconomic and cultural importance in the timber industry with a natural distribution that ranges across most parts of Sub-Saharan Africa (West, Central, and East Africa) (Bizoux *et al.,* 2009). It is commonly spread in tropical Africa (Guinea-Bissau east to Ethiopia and south to Angola, Zimbabwe and Mozambique) (Sabu *et al.,* 2018).

M. excelsa is also traded under the names *African teak, kambala, mvule,* and *iroko* and it is the most valuable commercial timber species (Ouinsavi and Sokpon, 2010). It belongs to the most valuable timber trees due to its attractive appearance, durability, stability, and good working properties. It is covering both the dry semi-deciduous forests and the rain forest zones in Africa (Ouinsavi *et al.,* 2005). *M. excelsa* also found in the south-western part of Ethiopia in the natural range of the Moist and Wet Kolla agro-climatic zones of Gambella, Illubabor and Bench-Maji zones (Azene, 2007; field observation). Population structure is the individuals' distribution of each species arbitrarily to provide the overall regeneration profile of the area based on the tree density, frequency, and diameter at breast height, height, basal area and species importance value (Tesfaye *et al.*, 2002, Shibru, Balcha, 2004). Knowledge of phenological patterns is basic to understanding the biological processes of *M. excelsa*.

Understanding the phenological calendars of tree species in response to climate change is therefore important for predicting the amount of carbon stored in forest (Piao *et al.*, 2019), so it's very important to develop mitigation and adaptation strategies. Knowing the phenological calendar of the tree species is also essential for conservation of the ultimate remaining forests in Ethiopia. The information on the reproductive phenology of the tree species gives good indication of the impact of climate change on vegetation structure, terrestrial ecosystems, and human life (Richardson *et al.,* 2013). The arrangement of species within a

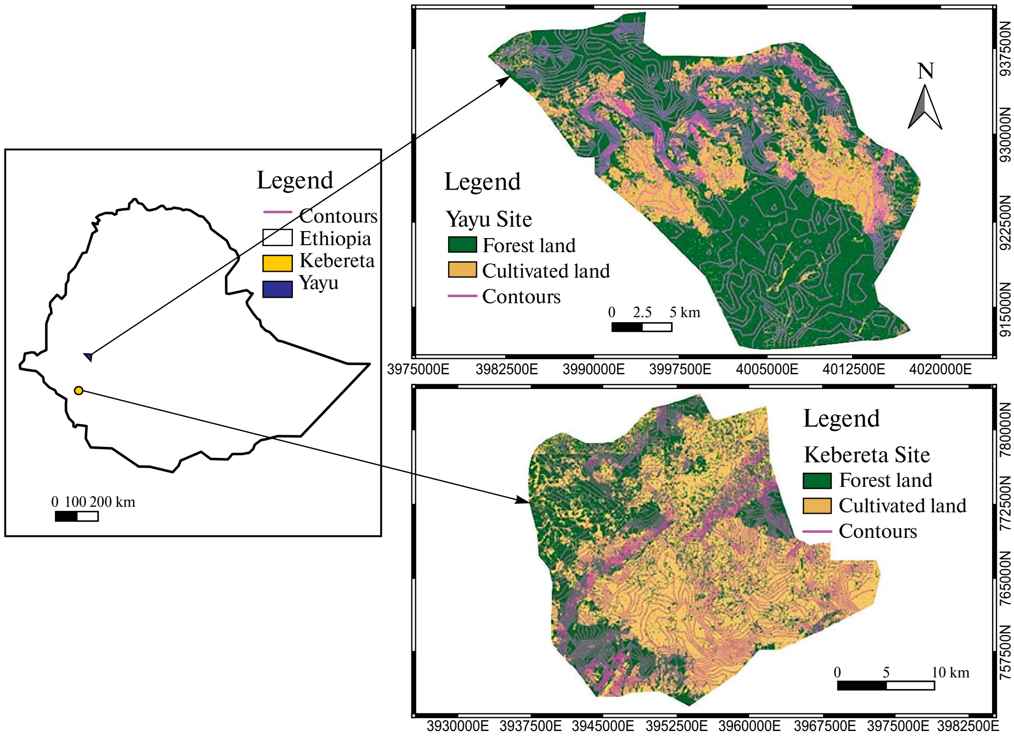

Fig. 1. Map of the study area.

community (community structure) plays a vital role in carbon assessments because it has an impact on the amount of carbon stored in the forests.

According to Ebert's (2004) findings in East Africa, populations of *M. excelsa* have two flowering and fruiting phases per year that correspond to the commencement of the two local rainfall seasons. Seasonal duration or variation of flowering and fruiting mainly determine the phenological behaviour of trees. Studying the phenology of tree species is very important to know the effects of weather and climate on plant life stages, including flowering, fruiting, leafing and defoliation. According to Agroforestry Database 4.0 (Orwa *et al.,* 2009), the date of flowering varies widely according on location, with different regions experiencing flowering at different times of the year. For example, flowering occurs on Kenya's north coast in January or February, while it occurs on the south coast from January through March. Flowering occurs in western Kenya from October to December, as well as in January and February. Individuals of *M. excelsa* flower and produce fruits during the beginning (May–June) and end (September–November) of the dry season in the Southern Democratic Republic of the Congo, where there is a single dry season that lasts 4–5 months (Couralet, 2010). Especially in Ethiopia, knowledge of the seasonal manifestation of the biological phenomenon of leafing, flowering, and fruiting can contribute effectively to the development of strategies for the use and sustainable management of this species because there is illegal logging and deforestation at the selected site. The main objective of this study is to investigate the population structure and phenology of *M. excelsa* in the south-western part of Ethiopia.

OBJECTS AND METHODS

Study area. The study was conducted in the Bebeka and Yayu natural forests in south-western Ethiopia. Bebeka Forest is found in Bench Sheko Zone of Southern Nations, Nationalities and Peoples' Regional States (SNNPRS), and Yayu Forest is located in Illubabor Zone of Oromia National Regional State (Fig. 1). Geographically, Bebeka Forest lies between 07°16' N and 36°15' E longitude (Mihreiu, 2004), whereas Yayu Forest is located between 8°21'–8°26' N latitude and 35°45'–36°3' E longitude (Woldegeorgis and Wube 2012). The altitudinal range of Bebeka and Yayu natural forests is 1,000–1,350 m a.s.l. and 1,200–2,000 m a.s.l., respectively.

Yayu Forest has a mean annual rainfall of 1,900 mm with a minimum and maximum temperature of 7.6°C and 34.7°C (Woldemariam, 2003). As for Bebeka natural forest, the mean annual rainfall is 2,200 mm and the mean annual temperature is about 25°C.

The dominant soil type in Yayu Forest is Nitosols. These types of soils are deep, reddish-brown and clayey, with relatively high organic matter content. Nitosols have a crumb and/or sub-angular structure and are well drained (Arbestain *et al.*, 2008).

Data collection. Data collection was conducted from January to February 2020. For the purpose of this study, the terms 'seedling', 'sapling', and 'tree' were defined.

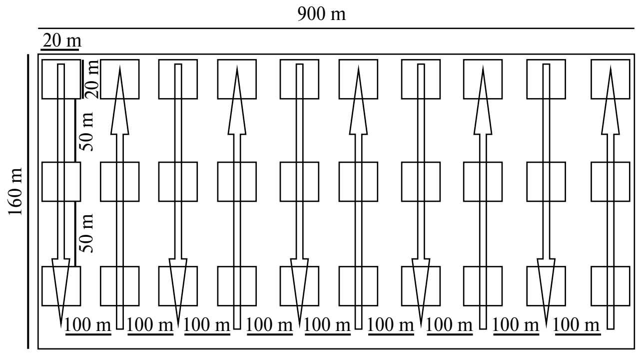

Fig. 2. Sample size of transects and quadrats.

A seedling has a diameter of <3.5 cm and a height of <50 cm; a sapling has a diameter of 3.5–10 cm and a height of > 0.5 m < 2 m; and tree has diameter of >10 cm and a height of ⩾2 m (Dhaulkhandi *et al.*, 2008, Bharali *et al.*, 2012, Gebrehiwot, Hundera, 2014). The study forests were selected by conducting reconnaissance survey based on the area where the target species were found. A systematic sampling method was used to collect the data, and ten line transects were laid down along the gradient at each 100 m interval (Morton *et al.*, 2000) non-systematic sampling in hill country can result in high coefficients of variation (CV 18–55% (Fig. 2). Sample plots were of 20 × 20 m for trees and saplings, and 5 × 5 m for seedlings. Only *M. excelsa* trees were measured on the study plots. There are many tree species found in the areas; other tree species growing on the study plots were not measured. Measuring all tree species would have provided more complete data, but focusing only on *M. excelsa* was appropriate given the aims of this particular study. The sample plots were laid down along transects at 50 m interval. Within the main plots, sub-plots for seedlings of *M. excelsa* were laid out at the four corners and centre. A total of 60 quadrats were sampled at the Kebereta (Bebeka) and Dawe (Yayu) sites. DBH and total height were measured in plots for trees with minimum size of DBH >10 cm and a height of >2 m (Dhaulkhandi *et al.,* 2008, Bharali *et al.,* 2012, Gebrehiwot, Hundera, 2014).

Kebeles (Ethiopian municipalities), which are proximate to the sampled natural forest, were purposively selected for the survey. The selection was made through discussion with experts of Woreda Environmental Protection, Forest and Climate Change Control Office (Woreda EFCC), kebele administrators of respective sites, as well as with the help of field observation by researchers. Data on phenology study was collected from both primary and secondary sources. The primary data were collected through a questionnaire survey at the household level using key informant interview and focus group discussions, while secondary data was collected from reports in government offices of Environment, Forest, and Climate Change Commission (Woreda EFCCC).

In this study, key informants (KI) mean knowledgeable farmers and experts who have deeper knowledge about representative forests and have lived in the area for many years. The key informants were selected with the help of the kebele administrators. Five key informants from each kebele were used for selection of households (HHs). A total of 10 KIs were selected from Achibo Kebele (Yayu Woreda) and 5 from Abeyi (Bebeka). The information taken from key informants was used for the selection and triangulation of HHs surveyed data.

Household Survey. A total of 60 elders (a minimum of 30 elders from each study site) who had lived in the area for many years and knew more about the forest and tree species found in the representative forests were selected for household interview by the help of key informants. The number of HHs selected for the interview is limited to 30 from each study site, because the number of people living within the proximity of selected forests is low. The household interview was conducted to assess the indigenous knowledge of the local community on the phenology of flowers and fruit of *M. excelsa* in each natural forest. The developed questionnaires were presented to the selected households in the local language.

For focus group discussions (FGDs), individuals with a deeper knowledge about representative forests were purposefully selected from the households. Based on the objective of the research, two FGD groups of 7–8 members each were selected from each kebele that is proximate to the selected natural forest. During the focus group meeting, flowering and fruiting season (months) were mainly discussed.

Population structure. All data for *M. excelsa* were entered, organised, and summarised in Microsoft Excel spread sheets and SPSS software.

Diameter at breast height (DBH): the structural data of *M. excelsa* DBH were analysed based on nine DBH classes (i.e., <10 cm, 10.1–20 cm, 20.1–30 cm, 30.1–40 cm, 40.1–50 cm, 50.1–60 cm, 60.1–70 cm, 70.1–80 cm, and >80 cm).

The basal area was calculated in m^2 ha^{-1}.

Density was calculated per hectare (Kent and Coker 1992).

Height: individual trees having a height of more than 2 m and DBH of ⩾10 cm within sampling plots were collected and analysed with disaggregation by seven classes (2–10 m, 10.1–19 m, 19.1–28 m, 28.1–37 m, 37.1–46 m, 46.1–55 m, and >55 m). Population structure was summarised using histograms of diameter size classes. ANOVA was used to test for difference in basal area, DBH, height and number of trees among different natural forest. Finally, both sampled natural forests were compared in terms of their population structure and then the best sample natural forest was recommended for seed production area establishment.

The regeneration status of *M. excelsa* in Kebereta (Bebeka) and Dawe (Yayu) forest habitats were analysed by comparing the population density of seedlings, saplings, and mature trees (Dhaulkhandi

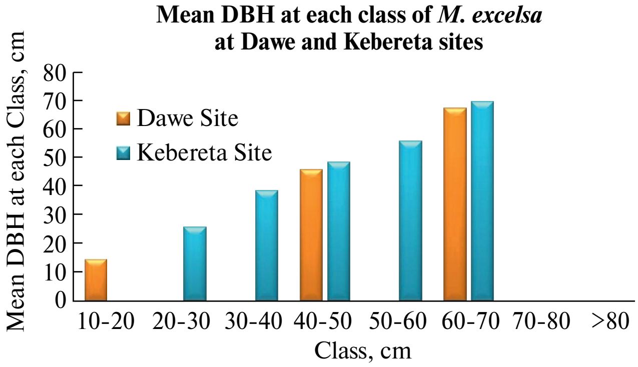

Fig. 3. Mean DBH of *M. excelsa* in the Dawe and Kebereta site natural forests.

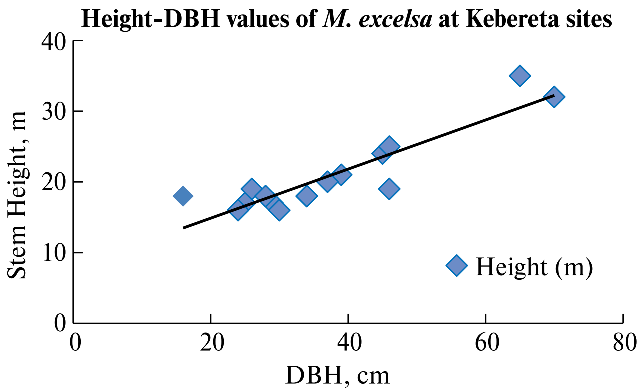

Fig. 4. Population structure of *M. excelsa* in the Dawe and Kebereta site natural forests.

et al., 2008, Gebrehiwot, Hundera, 2014) as follows: 1) 'good' regeneration, if population density of seedlings > saplings > mature trees; 2) 'fair' regeneration, if population density of seedlings > saplings < mature trees; 3) 'poor' regeneration, if a target species survives only in the sapling stage, but not as seedlings; 4) 'none', if a species is absent both in the sapling and seedling stages, but presents as a mature tree; and 5) 'new', if a species is presented only by the sapling and/or seedling stages but not by the mature trees. Both selected sampled natural forests were compared in terms of their regeneration status, and then the best site was recommended for seed production area establishment.

Phenology data collected from primary sources were checked, coded, encoded on a computer, and analysed using descriptive statistics.

RESULTS AND DISCUSSION

A total of 20 individuals of *M. excelsa* trees were observed in 6 plots out of 30 plots in Kebereta natural forests. In the Dawe (Yayu) site natural forest, 6 trees of *M. excelsa* were observed from 4 plots out of 30 plots. The density and DBH of *M. excelsa* trees were significantly higher in the Kebereta (Bebeka) natural forest than in the Dawe (Yayu) site natural forest (Table 1). In Dawe (Yayu) site natural forest, the highest frequency of overall distribution of *M. excelsa* by diameter class was at 10.1–20 cm (Fig. 3), while in Kebereta (Bebeka) natural forest, the highest frequency of *M. excelsa* was at 30.1–40 cm (Fig. 4).

As for the DBH-class distribution, *Milicia excelsa* in the Dawe and Kebereta site natural forests were dispersed differently in almost all classes. Some DBH classes had a large number of individuals while other DBH classes had a small number of individuals; some were even missed, probably due to selective cutting by the local people for construction and firewood. The population structure in the DBH class of *Prunus africana* in Adela site natural forest showed a bell-shape distribution pattern (Fig. 3); this pattern is a type of frequency distribution in which the numbers of individuals are low in the lower and higher diameter classes and high in the middle diameter classes. The closed forest canopy limits germination of the species, thus there is a low number of individuals in the lower DBH classes. In the higher DBH classes, the low number of individuals is due to past harvesting that targets mature trees leaving few reproducing individuals, which leads to a decline in the overall density.

M. excelsa DBH-class were dispersed irregularly in the Dawe and Kebereta site natural forests (since they are distributed differently in almost all classes). Some DBH classes had a large number of individuals while other DBH classes had a small number of individuals and even some were missed (Fig. 4), probably due to selective cutting by the local people for construction and firewood.

Mean DBH, mean density, and basal area of *M. excelsa* at the two sites were found to be significantly different ($p < 0.05$). Stem/ha, mean DBH, and basal area of *M. excelsa* species at the Kebereta (Bebeka) site were greater than those at the Dawe (Yayu) site ($p < 0.05$) (Table 1).

The height distribution patterns of *M. excelsa* in the Dawe site natural forest were characterised by high individuals at the middle stage and lower ones at the lower

Table 1. Density, DBH, height, and basal area of *M. excelsa* among sampled natural forests

Natural forests	Density, ha^{-1} (Mean)	DBH, cm (Mean)	Height, m (Mean)	Basal area, $m^2\ ha^{-1}$
Dawe ($n = 30$)	37.5	37.55	21.58	23.36
Kebereta ($n = 30$)	83.3	44.83	24.39	59.26
p value	0	0.04	0.046	0.033

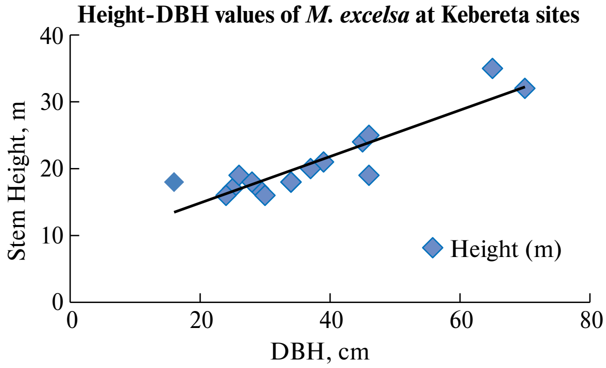

Fig. 5. The linear trend line of height-DBH values of *M. excelsa* at the Kebereta site.

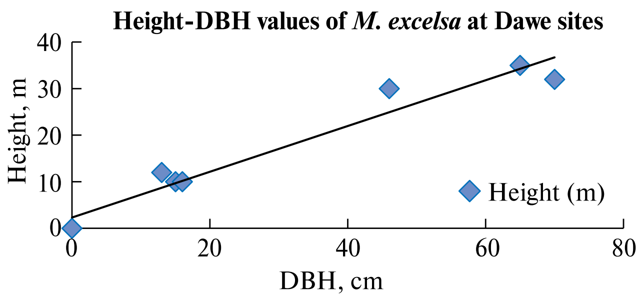

Fig. 6. The linear trend line of height-DBH values of *M. excelsa* at the Dawe site.

stage and among mature populations (Fig. 6). In Kebereta site natural forest, *M. excelsa* were also characterised by individuals higher at the middle stage than those among the young and mature populations (Fig. 5).

The density values of mature trees, saplings, and seedlings of *M. excelsa* trees were varied among all selected natural forests. The density of all age classes was higher in the Kebereta site natural forest than in the Dawe site natural forest. Seedlings and saplings were missing in Yayu sampled natural forest (Fig. 7). Thus, the present study showed that regeneration status of *M. excelsa* at the Kebereta site was at a 'fair' regeneration level because the density of seedlings > saplings < mature trees, while the regeneration status of *M. excelsa* in the Dawe site natural forest is 'none' since both the sapling and seedling stages are absent.

In the Kebereta site natural forest, the number of individuals is as follows: seedlings > saplings < tree/shrub state. This pattern shows 'fair'-type regeneration, namely, poor reproduction and hampered regeneration (Dhaulkhandi *et al.*, 2008). The target species individuals (*M. excelsa*) in the Dawe site natural forest were absent in the seedling and sapling stages, but relatively many individuals were presented in the mature tree stage. It corresponds to the result of the study where it was concluded that it is 'none'-type regeneration.

M. excelsa population structure has the highest proportion of individuals and a fair regeneration status in the Kebereta site natural forest, as compared to the Dawe site natural forest. It is more favourable for seed production area establishment for *M. excelsa* than the existing sampled natural forest. In the Dawe site natural forest, however, number of individuals of *M. excelsa* is low and seedlings and saplings were missing when compared to the Kebereta site natural forest.

Flowering time is fairly short in *M. excelsa*; it takes place at a range of different times but often occurs in January and February (Fig. 8). Fruiting time of *M. excelsa* most of the time ranges from February to March (Fig. 9). Rainfall, moisture, temperature, and photoperiod are the factors that may influence the timing of flowering and fruiting (Gunter *et al.*, 2008), taking into account the data with ranges stated by the respondents. It seems that the pattern of fruiting and flowering in this study may coincide with seasonality due to fluctuations in rainfall, temperature, and moisture. Trees grow when the environmental conditions allow for this. These phenological stages are highly influenced by environmental conditions. The exact duration of flowering and fruiting could be site-specific (Anderson et al., 2005).

Most respondents mentioned February as the month for flower initiation and expansion of *M. excelsa* in both selected sampled natural forest areas. Out of 60 interviewed households, 56.7% from Yayu and 50% from Bebeka respectively named February, 20% and 23.3% of the interviewed HHs from Yayu and Bebeka respectively confirmed January, and the remaining 23.3% of elders from Yayu and 26.7% of elders from Bebeka stated December. The most popular answer in the HH questionnaires showed that the exact fruiting duration of *M. excelsa* was during February since 56.7% and 60% respondents from Yayu and Bebeka respectively confirmed that the event occurred in this month. The other 20% / 23.3% and 23.3% / 16.7% from Yayu / Bebeka stated January and March, respectively.

The respondents from all selected sites in south-western Ethiopia stated almost the same duration (months) for flowering and fruiting. It seems that the pattern of fruiting and flowering in this study may

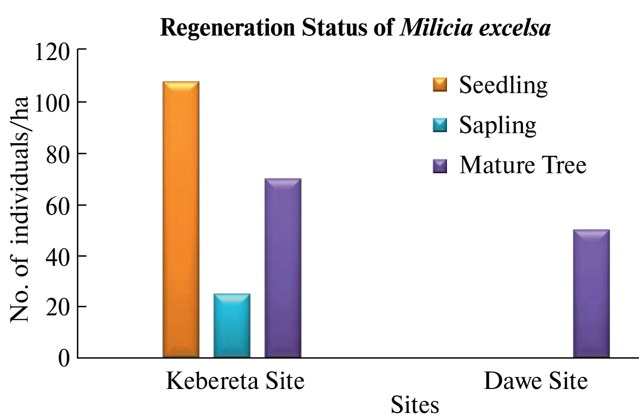

Fig. 7. Regeneration status of *M. excelsa* in the Dawe and Kebereta site natural forest.

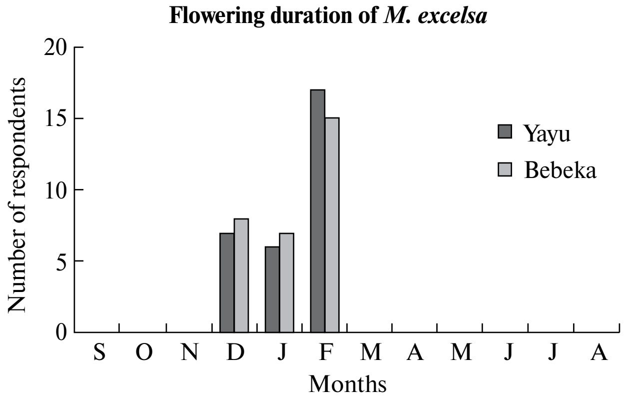

Fig. 8. Flowering duration of *M. excelsa* in the Yayu and Bebeka natural forests as stated by respondents.

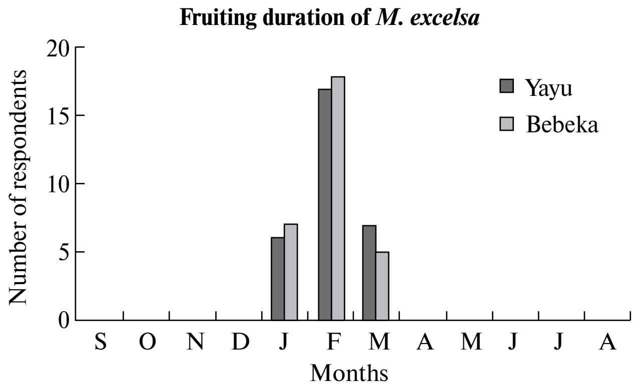

Fig. 9. Fruiting duration *M. excelsa* in the Yayu and Bebeka natural forests as stated by respondents.

coincide with seasonality. Many similarities were recorded in the flowering and fruiting duration of target species among the sampled natural forests.

CONCLUSIONS

Knowledge of tree population structure and phenology is very important for understanding the conditions of recruitment, the impact of disturbance, forest successional trends, and the regeneration of the species. This study assessed the population structure and phenological duration of *M. excelsa* in different natural forests in south-western Ethiopia. The result of these findings also indicates that the population of *M. excelsa* relatively low in both sampled natural forests. Its DBH-class distribution in the Dawe and Kebereta site natural forests was irregular since they are distributed differently in almost all classes.

M. excelsa represented by 'fair'-type regeneration at the Kebereta (Bebeka) site and by 'none'-type regeneration at the Dawe (Yayu) site. 'None' regeneration pattern indicates that the tree species growth, survival, and reproduction potential are at risk in the future, therefore, it needs urgent management and in-situ conservation. Flowering time is fairly short in *M. excelsa*, it takes place at a range of different times but often occurs in January and February. Fruiting time of *M. excelsa* most of the time ranges from February to March. There is a slight variation in phenology among sites and, in some cases, similarity across the inventoried forest sites. The results of the distribution of the population of *M. excelsa* exhibited almost irregular pattern across the selected natural forests. The regeneration status of *M. excelsa* is 'fair' in Bebeka and 'none' in Yayu site. *M. excelsa* has the highest proportion of individuals at the Kebereta site compared to the Dawe site natural forest, thus the Kebereta site is favourable for seed production area establishment.

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СТРУКТУРА ПОПУЛЯЦИИ И ФЕНОЛОГИЧЕСКИЕ ЗАКОНОМЕРНОСТИ *MILICIA EXCELSA* ВО ВЛАЖНЫХ ВЕЧНОЗЕЛЕНЫХ АФРОМОНТАННЫХ ЛЕСАХ ЮГО-ЗАПАДНОЙ ЭФИОПИИ

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Знание структуры популяций и фенологических закономерностей является основным для понимания биологических процессов, влияния нарушений и сукцессионных тенденций в лесу. Основная цель данной работы — изучить структуру популяции и фенологию *Milicia excelsa* для целей семеноводства. Исследование проводилось в природных лесах Яю и Бебека на юго-западе Эфиопии. Для сбора данных использовался метод систематической выборки. Десять линейных трансект были проложены вдоль градиента с интервалом 100 м. Вдоль трансекты с интервалом 50 м были заложены пробные площади размером 20 × 20 м для деревьев и саженцев и 5 × 5 м для саженцев. В пределах основных участков по четырем углам и в центре были заложены подпосевные участки для саженцев. Всего было отобрано 60 квадратов на участках Keберета (Бебека) и Дау (Яю). На каждой основной делянке измеряли DBH и высоту деревьев. Данные по изучению фенологии собирались как из первичных, так и из вторичных источников. Результаты распределения популяции M. excelsa по выбранным природным лесам оказались практически неравномерными. Состояние возобновления *M. excelsa* является "удовлетворительным" на участке Бебека и "никаким" на участке Яю. Доля особей *M. excelsa* в естественном лесу на участке Кеберета выше, чем на участке Дау, поэтому здесь благоприятнее организовать семеноводческий участок.

Ключевые слова: цветок, плод, регенерация, семеноводство.