Tropical Ecology (2019) 60:62–73
https://doi.org/10.1007/s42965-019-00007-2

International Society for Tropical Ecology

RESEARCH ARTICLE

Reproductive period of a sub-montaneous tropical forest: estimation of seed availability for forest restoration in mount Masigit-Kareumbi, Indonesia

Susana P. Dewi[1] · **Endah Sulistyawati**[1] · **Tati Suryati Syamsudin**[1]

Published online: 3 May 2019

Abstract

The ability of local tree species (LTS) to produce seeds is an intrinsic factor that contributes to the success of forest restoration efforts through a natural regeneration process. The aim of this study was to investigate the reproductive period of LTS in order to estimate seed sources availability for the forest restoration process in the sub-montaneous forests. Twenty permanent plots (20 × 20 m) were identified at Mt. Masigit-Kareumbi. Observations regarding flowering and fruiting were conducted on 399 individual LTS (78 species, 29 families) that had a diameter at breast height of more than 10 cm. This activity was done every month: period I was from July 2015 to June 2016, and period II was from July 2016 to June 2017. The results showed that the number of flowering–fruiting trees in period I was higher than it had been in period II. Peak flowering–fruiting occurred in period I (30.1% of the total individuals), and the lowest flowering–fruiting occurred in period II (10.5% of total individuals). 242 individual trees (60.7%) in total, comprising 57 species (73.1%), were flowered–fruited. Most LTS had short durations of reproductive phases. The shortest flowering duration was 0.1–0.8 months (61.7%), the shortest flowering–fruiting duration was 0.1–0.5 months (80.0%), and the shortest fruiting duration was 0.1–1.0 months (59.4%). Flowers and fruits or seeds were always available all year round. To support seed availability for forest restoration, the best time for fruit or seed collection is December to January.

Keywords Duration of reproductive phase · Flowering–fruiting · Local tree species · Plant diversity · Tropical forest

Introduction

The rapid rate of land cover and land use change due to anthropogenic activities on a global scale has led to ecosystem degradation. The conversion of forest areas to different types of land uses and land cover (such as farmland or grassland) is generally associated with deforestation. From 1990 to 2015, the world's forests reduced from 4128 million ha in 1990–3999 million ha in 2015, a rate of loss of 5.2 million ha yr^{-1} (Keenan et al. 2015). Compared with other regions, deforestation in the tropics was the highest (1966 million ha in 1990–1770 million ha in 2015), with a loss rate of 7.8 million ha yr^{-1}. Among the countries in the tropics, Indonesia dominates the loss of tropical forests in Asia, about 684,000 ha yr^{-1} (Keenan et al. 2015). In the highly populated island of Java, deforestation reached 1.38 million ha from 2000 to 2009, and West Java Province was the highest at 596,743 ha (Nahib et al. 2015). A substantial amount of deforestation in Java occurred in montane forests, mainly due to forest encroachment by landless farmers. This was studied by Gunawan and Subiandono (2014) on Mt. Ciremai, by Kamilia and Nawiyanto (2015) on Mt. Lamongan, and Sulistyawati et al. (2008) on Mt. Papandayan.

The reduction of rainforest cover around the world contributes to the extensive loss of biodiversity and an increase in carbon dioxide emissions—more than 12% (van der Werf et al. 2009; Holl and Aide 2011). The existence and functioning of tropical rainforest ecosystems are highly threatened by a high rate of deforestation and forest degradation globally because they lead to a decrease in forests' capacity to provide ecosystem services, such as decreasing biodiversity, storing carbon, preventing soil erosion, and maintaining habitat connectivity and soil nutrient dynamics (Corbin

✉ Tati Suryati Syamsudin
tati@sith.itb.ac.id

1 School of Life Sciences and Technology, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, West Java, Indonesia

and Holl 2012). To restore biodiversity and ecosystem services at their optimal level, recovery efforts through passive as well as active restorations are required. Restoration is a process that aims to assist in the recovery of degraded, damaged, or destroyed ecosystems. It specifically aims to form a diverse ecosystem that is relatively similar to that of the closest undisturbed forest (Gann and Lamb 2006; Reis et al. 2010).

Efforts to naturally restore degraded forests require knowledge of the potential and characteristics of local tree species (LTS) regeneration, including their seed supply at a particular site. The preference for LTS in restoration activities is based on the assumption that genetically they have adapted well to the condition of the restoration target site (FORRU 2008) and that they are comprised of the natural vegetation of that land prior to degradation. Forest regeneration can be done vegetatively by using scions growing on the stumps (coppice) that already have strong and established root systems (FORRU 2008). Meanwhile, generative regeneration is possible when seed rain, seed bank, and seeds from LTS are available. Wang et al. (2010) explained that seed rain and seed banks provide important support to seed quantity and composition, which are crucial in the regeneration of vegetation.

The potential for the generative natural regeneration of forests is related to the ability of LTS to produce fruits or seeds. The availability of fruits or seeds in the forest can be examined through phenological studies of LTS that grow in the adjacent forest. According to Somasundaram and Vijayan (2010), a phenological event can be divided into two phases: vegetative and reproductive. The reproductive phase includes the flowering and fruiting phases. These phases are distinctive among regions as a result of different altitudes and various climatic factors (rainfall, photoperiod, radiation, and extreme weather). In a montane forest, for example, the flowering and fruiting phenology of each area differ (Gunter et al. 2008; Somasundaram and Vijayan 2010; Zhang et al. 2010; Sulistyawati et al. 2012) and have been found to have a strong correlation with rainfall and temperature at the different direction of association (positive/negative) among species (Kebede and Isotalo 2016). Other studies report that changes in rainfall pattern affect the fruiting phenology in Madagascar (Dunham et al. 2018). In a tropical deciduous forest, drought conditions influence the flowering phase by creating a strong association between the flowering and vegetative phases in relation to the allocation of photosynthates for the duration of the deciduous period (Singh and Kushwaha 2006).

The study of phenological events can provide an overview of the flowering and fruiting periods at the community and species level and of the appropriate time for collecting seeds to support seedling production in nurseries. It also supports the success of direct seeding programs that form part of intensive forest restoration efforts (Somasundaram and Vijayan 2010; Cole et al. 2011; Sulistyawati et al. 2012). The study of the phenological events of LTS is critical to maintain the continuity of seed supply for forest restoration programs. The results of such a study can contribute to specific steps of forest restoration, namely, identifying the appropriate times for fruit or seed availability in the adjacent forest to the restoration target area, the duration of the reproductive phases, and local factors that affect the flowering–fruiting phase. With this information, the appropriate times for fruit or seed collection can be predicted (Elliott et al. 1994; Buisson et al. 2016).

Moreover, knowledge of the timing of flowering and fruiting can also be useful to support the implementation of the applied nucleation approach in forest restoration. The critical factor in applied nucleation is the selection of a combination of local tree species to be planted in nuclei. Planting tree species that produce abundant seeds for a long period can increase the chances of seeds dispersing to the surrounding areas, thus accelerating natural regeneration. Mohandass et al. (2016) found that species selection for planting the open area can be highly important in the proper management of shading, grazing, composting, weed controlling, and regular watering. It can facilitate germination, regeneration, and the establishment of local tree species. Furthermore, according to Osuri et al. (2017), limitation of seed dispersal can alter the density and richness of sapling natural regeneration at the community level.

Mount Masigit-Kareumbi Reserve (MKR) is a nature conservation area situated in the lower montane forest ecosystem with an altitude range between 1000 and 1400 m asl. MKR's forest has been subject to deforestation. Even though there is no official account of the deforestation rate of MKR, the signs of forest encroachment by farmers was noticeable in the field. This condition was widely observed in other montane forests in Java (e.g. Mt. Lamongan, Mt. Ciremai and Mt. Papandayan). Given the importance of the forest ecosystem function provided by MKR, forest restoration seems to be urgently required for restoring forest cover, protecting biodiversity, and restoring ecosystem services to a certain level. This forest restoration program must be supported by adequate knowledge of plant phenology (FORRU 2006), i.e., the reproductive patterns of local trees grown in MKR. The specific objectives of this study were to: (1) determine the pattern of the flowering–fruiting period; (2) determine the reproductive period among individuals and species of LTS; (3) examine the durations of the reproductive phases among species, and (4) examine how the reproductive period is correlated with climatic conditions. We hypothesize that reproductive period of LTS will vary among times, number of individuals and number of species.

Materials and methods

Study area

This study was conducted in the conservation zone of MKR (6°51′31″–7°00′12″S and 107°50′30″–108°1′30″E), located in Sumedang Regency. MKR is under the management of the Natural Resources Conservation Bureau of West Java Province. MKR covers an area of 12,420.70 ha, with 64.41% of the MKR belonging to Sumedang Regency and the remainder belonging to Garut and Bandung Regency (Fig. 1).

The part of MKR that was examined in this study is located at a block that is locally known as Mt. Rengganis. Our preliminary study revealed that the tree community at Mt. Rengganis is dominated by a member of the following families: Lauraceae, Moraceae, Fagaceae, Malvaceae, Rubiaceae, and Phyllantaceae. Meanwhile, the dominant trees include: saninten (*Castanopsis argentea*), kiminyak (*Itea macrophylla*), sobsi (*Maesopsis eminii*), puspa (*Schima wallichii*), jaranak (*Castanopsis accuminatissima*), tangogo (*Lhitocarpus elegans*), rasamala (*Altingia excelsa*), and huru picung (*Ostodes paniculata*). Kileho (*Saurauia microphylla*), which is an endemic flora of Java Island and listed under the IUCN Red List of Threatened Species 2016 (World Conservation Monitoring Center 1998) was also found.

Flowering–fruiting period

The study was conducted at 1000–1300 m asl. Observation plots (20 × 20 m) were set following Sutherland (2006) at every 100m interval of altitude, purposively. Twenty plots in total were set across all study sites (Fig. 2). Each observation plot was required to comply with the following criteria: it should be covered by natural vegetation (not planted), should be accessible, should have at least five species of trees present inside the plot, and should not be prone to landslides. To minimize human interference, the location of each plot was expected to be moderately accessible (based on topographic conditions). Individual trees in an observation plot were selected based on their diameter at breast height (dbh). Trees with a dbh of more than 10 cm were assumed to have entered the reproductive phase. Each selected tree was numbered so that it could be identified, so that it could be identified. When the number of tree species in a prospective plot was less than five, the location of the plot was moved to another spot at the same altitude.

For each plot, the reproductive phases (flowering, flowering–fruiting, and fruiting) were observed, following Somasundaram and Vijayan (2010) with some modifications. Observations were conducted by recording the presence of flowers (Flo), flowers and fruits (Flo–Fru), and fruits (Fru) of LTS every month simultaneously during two time periods. Period I was from July 2015 to June 2016 and period II was from July 2016 to June 2017. The duration of the reproductive phase for each LTS was calculated according to the status of each reproductive stage in every observation (Elliott

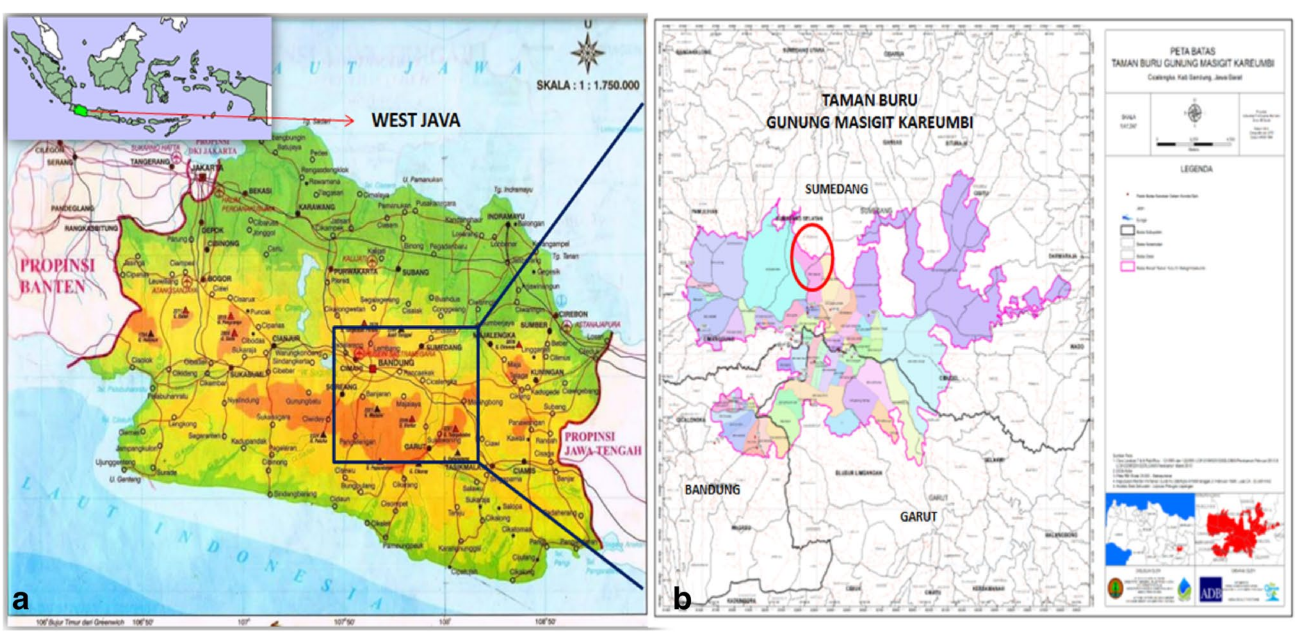

Fig. 1 The study area in West Java Province, Sumedang District. **a** West Java Province: blue rectangles represent Bandung, Garut, and Sumedang Regency; **b** Mount Masigit-Kareumbi Reserve: red circle is study area, Resort Kareumbi Timur in Sumedang District

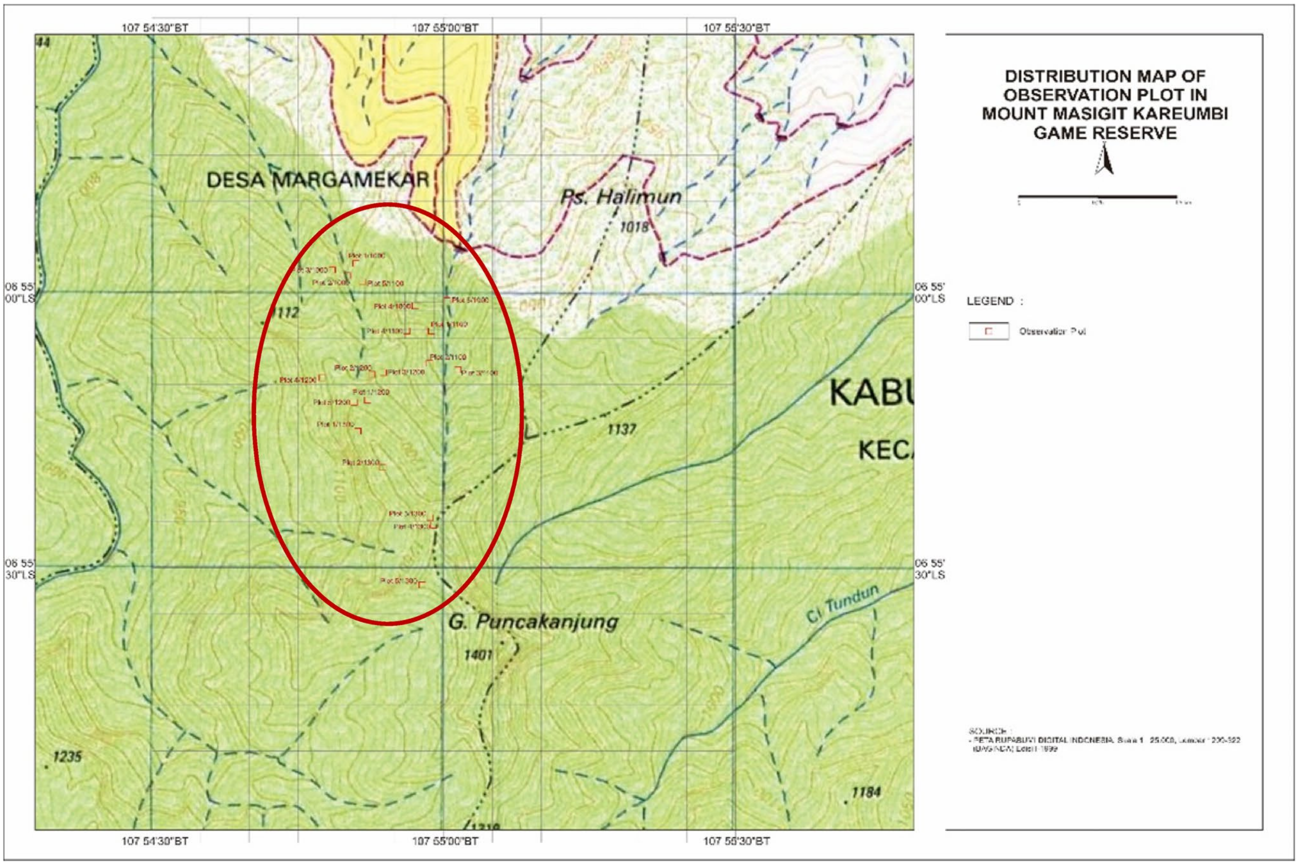

Fig. 2 Observations plots in Mount Masigit-Kareumbi Reserve (MKR)

et al. 1994). For the analysis of the reproductive phase duration, only tree species with at least three individuals were included. Furthermore, the duration of each reproductive phase was clustered in several classes of frequency distribution following the Sturge rule (Kumar and Chaudhary 2010). Data on climatic conditions was obtained from the nearest weather station at Cimalaka Sumedang District. The correlation between the climatic variables and reproductive phases of the LTS was analyzed by Pearson's correlation using Minitab16.

Results

Flowering–fruiting *pattern of LTS*

During the observation periods, 399 individual trees (with a dbh of more than 10 cm) in total were recorded. They consisted of 78 species, belonging to 29 families. Fifty-seven species, or 60.7% of the total number of species, had flowered or fruited at least in one observation. The flowering–fruiting pattern among tree individuals was unsynchronized (Fig. 3). Indication of an unsynchronized flowering–fruiting pattern is that during the 24-month observation period, the maximum number of individual trees that flowered–fruited was only 30% (December 2015). This study also reveals that flowers and fruits were always available the whole year because a minimum of 10% of individual trees flowered and/or fruited every month.

In general, the number of individual flowered–fruited trees in period I (July 2015–June 2016) was higher than in period II (July 2016–June 2017), except in July 2016. During period I, the percentage of individuals that were flowering–fruiting gradually increased until the peak was reached in December 2015 (30.1%). This was then followed by a gradual decrease until the end of period I in June 2016. In contrast, the percentage of flowering–fruiting individuals in period II fluctuated with no clear pattern. At the beginning of period II, the percentage of individuals that flowered–fruited was 15.8% (July 2016). The highest percentage of flowering–fruiting was in January 2017 (21.1%) and the lowest percentage was in August 2016 (10.5%).

During two successive years of observations, the peak seasons of the flowering–fruiting period shifted from December 2015 in period I to January 2017 in period II (Fig. 3). The percentage of individuals that flowered–fruited

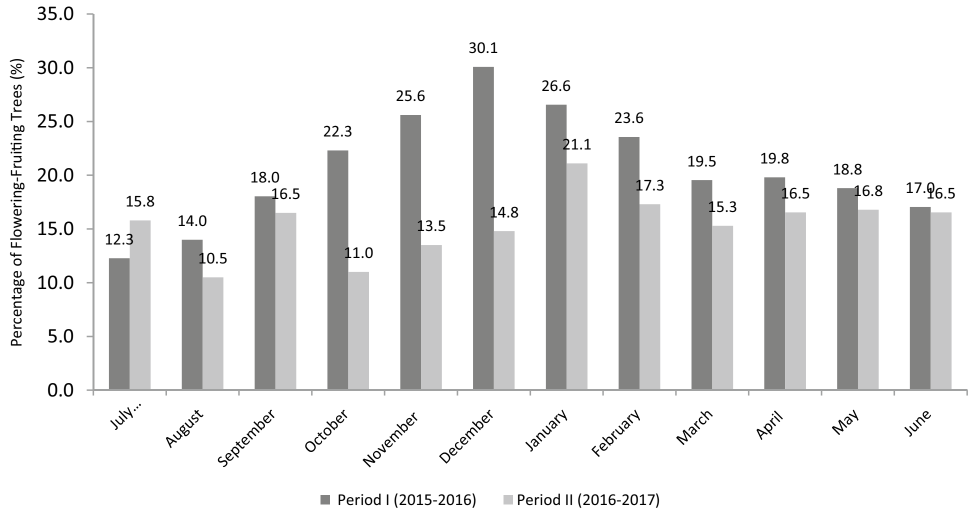

Fig. 3 Flowering–fruiting pattern of local trees species in MKR (399 trees belong to 78 species)

each month during period II was also lower than in the same month of period I. The largest decrease occurred between December 2015 and December 2016, when the number of flowered–fruited trees decreased by 50.8%.

Reproductive period

The flowering (Flo) or fruiting (Fru) phase is a phenomenon according to which either flowers or fruits predominate during observations. Meanwhile, the flowering and fruiting (Flo–Fru) phase finds flowers (Flo) and fruits (Fru) together at the time of observation. For some species, the three phases can be distinguished easily, but in some other species, this is more difficult, especially the flowering–fruiting (Flo–Fru) phase.

In period I, the number of individuals in the flowering phase during July-December 2015 was higher than in January–June 2016. Meanwhile, during this time, the number of individuals in the fruiting phase was higher than in the flowering phase. This suggests a rather apparent transition from the flowering to fruiting phase in period I. Unlike in period I, there was no clear pattern in the transition from the flowering to fruiting phase in period II (Fig. 4).

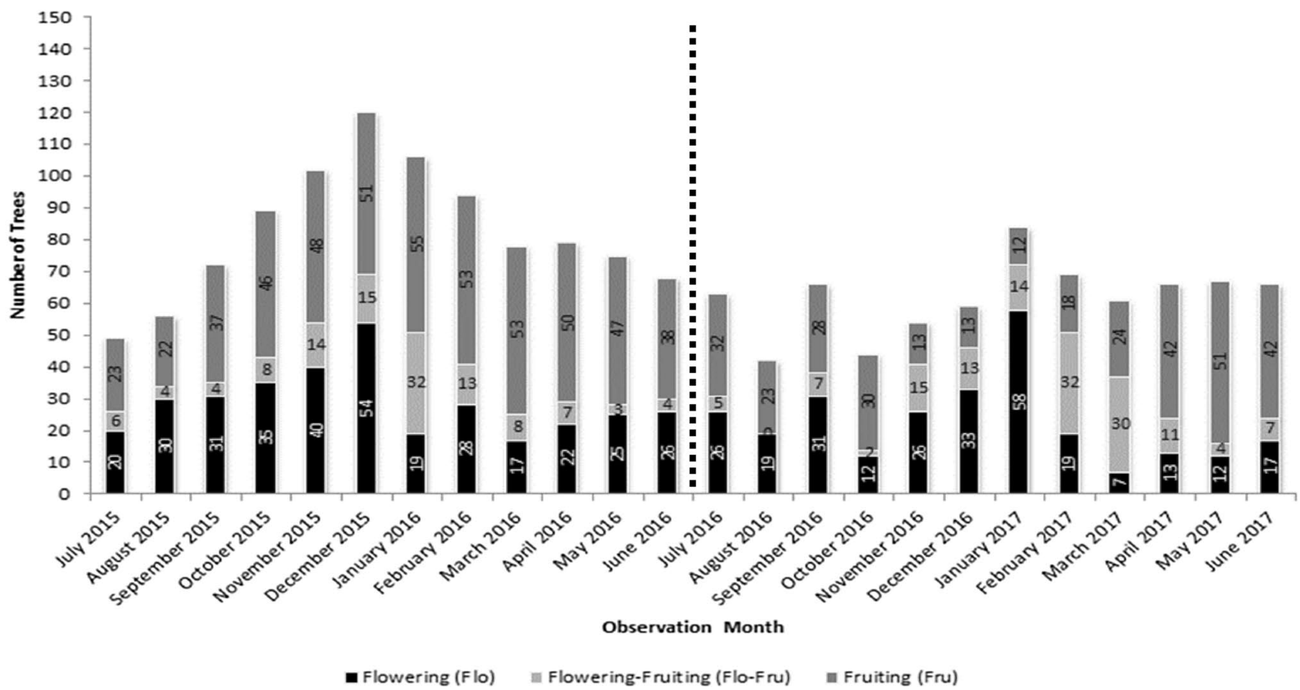

Fig. 4 Number of trees in reproductive phases at Mount Kareumbi Reserved (MKR)

In terms of reproductive phases by species (Fig. 5), the highest number of species flowering (Flo) during period I was found in August and October 2015, whereas in period II, it was not found in the same month, i.e., January 2017. Similarly, the highest number of species fruiting (Fru) during period I was found in January 2016, whereas in period II, it was not found in the same month, i.e., July 2016 and September 2016. Compared with the pattern at the individual level, as shown previously in Fig. 4, a similarly clear transition from the flowering to fruiting phases was also found at the species level.

Duration of reproductive phases

The durations of the reproductive phases of each species in the forest provided an indication of the availability of fruit and seed resources. This data may be useful for forest restoration programs. Observations of the durations of the reproductive phases were conducted on 78 LTS, but only 37 tree species were used to estimate the durations of the reproductive phase because the remaining 41 species were less than three individuals. The duration of the flowering (Flo) of 34 species was 0.1–4.4 months; the duration of the flowering–fruiting (Flo–Fru) of 15 species was 0.1–2.4 months; and the fruiting (Fru) of 32 species was 0.1–5.7 months (Fig. 6). For *Saurauia microphylla*, the longest duration was recorded: flowering (Flo) was 4.4 months and flowering–fruiting (Flo–Fru) was 2.4 months. The longest duration of fruiting (Fru) was recorded for *Ficus obscura* (5.7 months). Meanwhile, *Sloanea sigun* (Blume) K. Schum., *Sterculia oblongata* R.Br., and *Brassica rugosa* had the shortest durations of all the reproductive phases (Fig. 6). During the two years of observation, no records of the reproductive phases for *Casearia flavovirens* Blume were found. Meanwhile, *Ficus variegata* was only found during the fruiting phase.

In terms of the species, the durations of the reproductive phases were varied (Fig. 7). Most species (21 out of 34) were found to be flowering (Flo) for a short duration (0.1–0.8 months, Fig. 7a). Similarly, 19 out of 32 species were found to be fruiting (Fru) for 0.1–1.0 months (Fig. 7c). Meanwhile, most species (12 out of 15) were found to be flowering–fruiting (Flo–Fru) for a short duration (0.1–0.5 months; Fig. 7b). Therefore, in general, most species had a short duration of reproductive phases. Information on the reproductive phase duration is essential for determining the appropriate time for collecting fruits or seeds to be used in nurseries of local trees to support forest restoration activities.

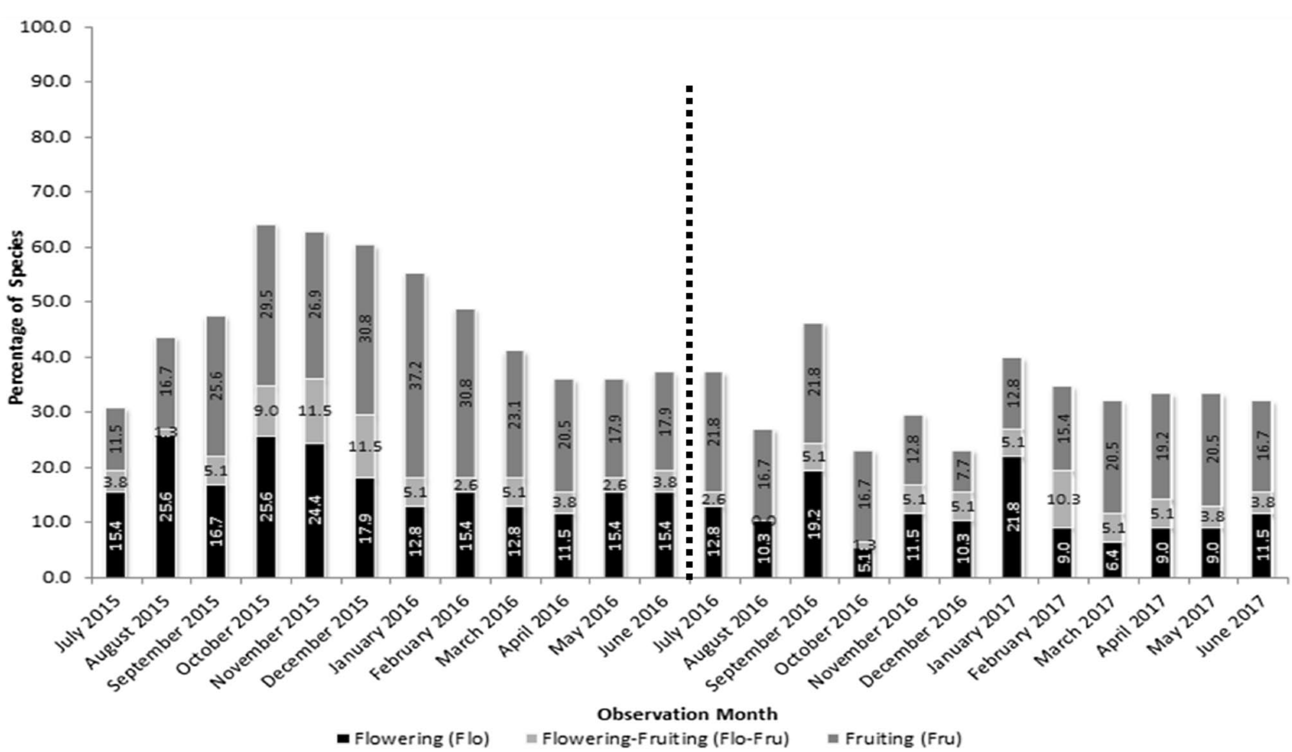

Fig. 5 Number of species in reproductive phases at Mount Kareumbi Reserved (MKR)

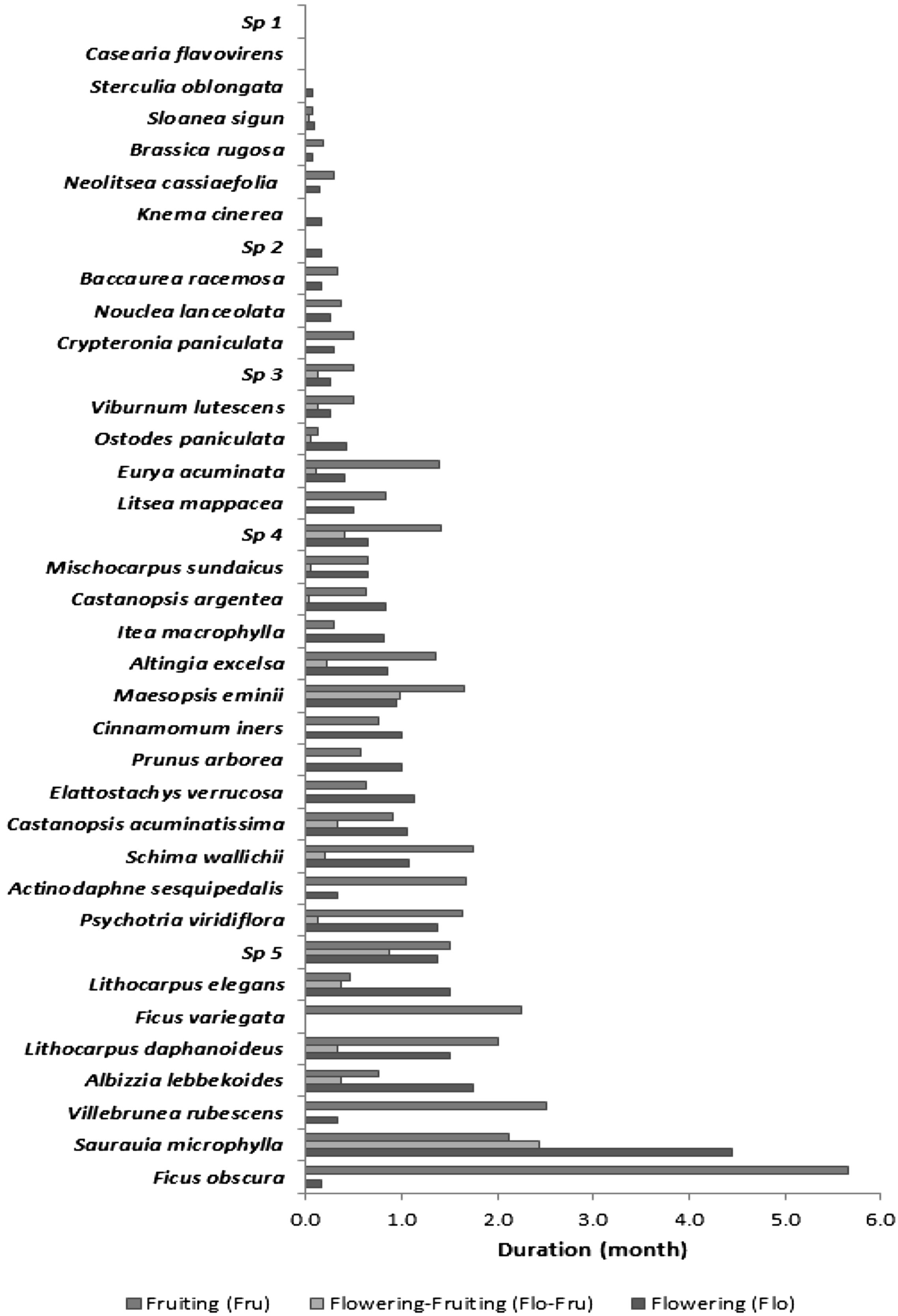

Fig. 6 Duration of reproductive phases of each local tree species in Mt. Masigit-Kareumbi Reserve (MKR)

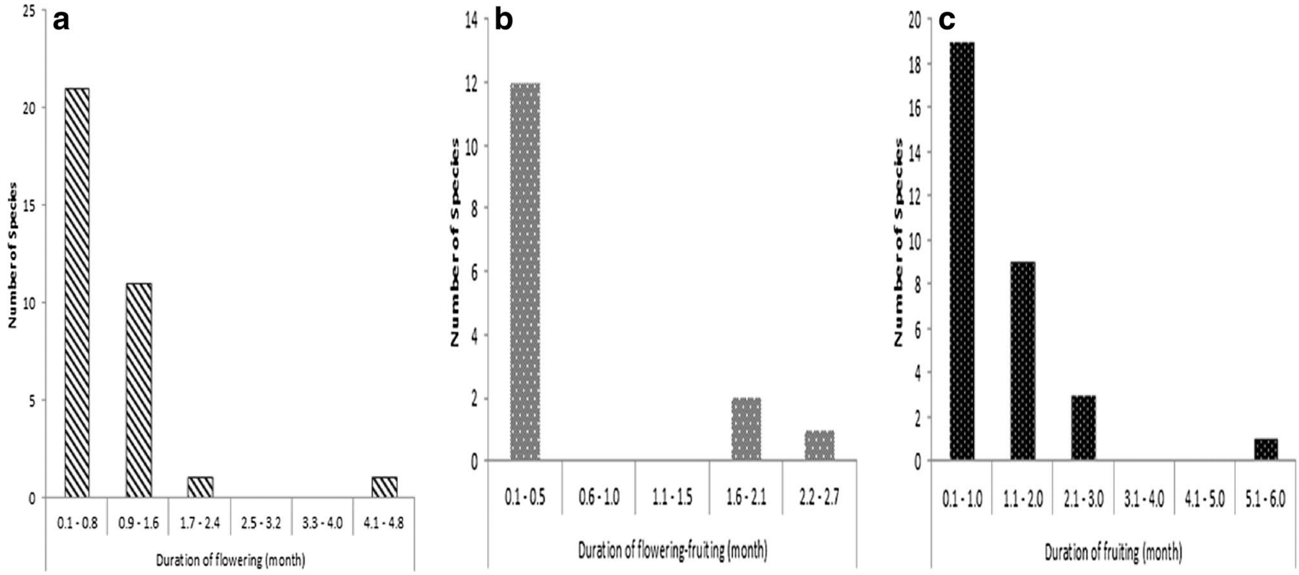

Fig. 7 Clustering of reproductive phase duration of local tree species in MKR. **a** Flowering (Flo) phase, **b** Flowering–fruiting (Flo–Fru) phase, **c** Fruiting (Fru) phase

Table 1 Correlation between reproductive and climatic variables at MKR

Variables	Wind Velocity (m s^{-1})	Relative Humidity (%)	Solar Radiation (watt m^{-2})	Temperature (°C)	Rainfall (mm)
1. Number of indivuals flowering and fruiting per month	– 0.42*	0.157	0.006	0.544**	– 0.105
2. Number of individuals flowering (Flo) per month	– 0.18	– 0.147	0.256	0.173	– 0.135
3. Number of individuals fruiting (Fru) per month	– 0.46*	0.137	– 0.056	0.38	– 0.075
4. Number of species flowering (Flo) per month	– 0.49*	– 0.493*	0.429*	0.061	– 0.139
5. Number of species fruiting (Fru) per month	– 0.61**	– 0.028	0.132	0.304	– 0.227

Climatic variables were based on monthly data for 24 months of observation

*Correlation is significant at the 0.05 level ($p < \alpha_{0.05}$)

**Correlation is significant at the 0.01 level ($p < \alpha_{0.01}$)

The reproductive period and climatic conditions

The occurrence of flowering (Flo), flowering–fruiting (Flo–Fru), fruiting (Fru) trees in period I was higher than in period II (Fig. 3). The correlation between reproductive periods and climatic factors (wind velocity, relative humidity, solar radiation, temperature and rainfall) showed strong correlation with the number of reproductive phase of the trees and species (Table 1).

The number of species that undergo the reproductive phase responds sensitively to climatic conditions. Based on the reproductive period, the total number of trees that were flowering and/or fruiting has a strong correlation with wind velocity (r = -0.42) and temperature (r = 0.54). The number of individuals that were fruiting (Fru) is strongly correlated with wind velocity (r = - 0.46), but no correlation was found between the number of individuals that were flowering (Flo) with all climatic variables (Table 1). The number of species undergoing the reproductive period showed a strong correlation with several climatic factors. The number of species that were flowering (Flo) are strongly correlated with wind velocity (r = – 0.50), relative humidity (r = – 0.49) and solar radiation (r = 0.43). The number of fruiting (Fru) species only has a strong correlation with wind velocity (r = – 0.61). The correlation analysis suggests that wind velocity is strongly correlated with many reproductive variables. Furthermore, the number of species that were flowering (Flo) is strongly correlated with more climatic variables than other reproductive variables. This can be taken as an indication that the number of species that were flowering (Flo) responded sensitively to climatic conditions.

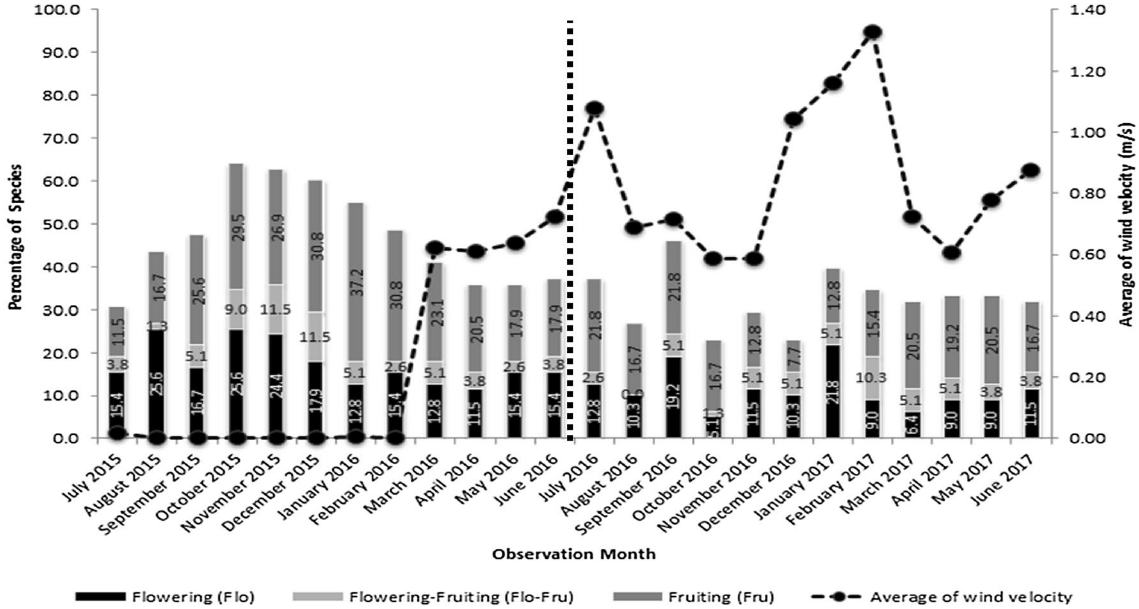

Fig. 8 Correlation between wind velocity and the number of species during observation periods at Mt. Masigit-Kareumbi Reserve

In general, the occurrences of flowering, flowering–fruiting, and fruiting individuals were lower in period II than in period I (Fig. 3). Despite occurring at a lower quantity, all the reproductive phases (flowering [Flo], flowering–fruitings [Flo–Fru], fruitings [Fru]) were recorded in each month of period II. One possible explanation for this phenomenon is that flowering and fruiting occurred, but there was a condition that caused a significant number of flowers and fruits to fall out during that period. The impact of strong winds during period II was likely the reason, as presented in Fig. 8. In general, wind velocities in the months of period II were generally higher than those in period I. These higher wind velocities correspond with the lower number (than in period I) of species flowering (Flo), flowering–fruiting (Flo–Fru), and fruiting (Fru) in period II. It appears that stronger winds caused many flowers and fruits that had been set to fall to the ground. This notion was supported by visual observations in which many flowers and fruits were found on the ground during periods of strong wind.

Discussion

Flowering periodicity is an important factor because it is associated with the flowering season, when the production of fruits or seeds can be predicted. The study of the plant re productive phase also provides great opportunities for each tree to cross-breed (outcrossing) so that inbreeding can be minimized. Based on these conditions, Schmidt (2000) suggested that observations should be made for more than one flowering–fruiting season. In this study, two periods of flowering–fruiting seasons were examined. The peak flowering–fruiting in period I was in December 2015. A total of 120 trees were flowering–fruiting (30% of 399 individuals). Fifty-four individual trees were recorded to be in the flowering (Flo) phase, i.e., 14 species (17.9%); 15 individuals were in the flowering–fruiting (Flo–Fru) phase, i.e., 9 species (11.5%); and 51 individuals were in the fruiting (Fru) phase, i.e., 24 species (30.8%). However, in period II, the amount of flowering–fruiting was lower than in period I. In August 2016 (period II), only 42 trees (10.5%) were flowering–fruiting. In that time period, 23 individuals were fruiting (Fru), i.e., 17 species (21.8%); 19 individuals were flowering (Flo), i.e., 8 species (10.3%); and no trees were flowering–fruiting (Flo–Fru) (Figs. 3, 4, and 5).

The flowering–fruiting peak season for tree communities has been discussed in several studies. A study of tree communities in Mt. Papandayan-Indonesia found that the peak flowering–fruiting period was in July 2010 and that the period of the lowest flowering–fruiting was in October 2009 (Sulistyawati et al. 2012). Another study in the montane wet temperate forests of India found that the peak fruiting period for 23 species of fleshy fruit trees was in July 2003, and the period of lowest flowering–fruiting was in June 2002 (Somasundaram and Vijayan 2010). In MKR, this study founds that the peak flowering–fruiting was in December 2015, and the period of lowest flowering–fruiting was in August 2016. Interestingly, even though Mt. Papandayan and MKR are relatively close (about 100 km apart), the peak times for their flowering–fruiting periods are different. Observations of the two flowering–fruiting seasons successively could not obtain similar patterns, despite that the same observation methods were used in the same month of the Julian calendar.

The observation of the flowering (Flo)–flowering–fruiting (Flo–Fru)–fruiting (Fru) phase (reproductive phases) of each individual tree in a species was rather difficult due to some general limitations: short flower cycles, a very low number of flowers produced, uncertain flowering cycles, and a high dependency on seasons (Schmidt 2000). Some of the obstacles that may cause flowering data collection to be underestimated are as follows: the location of flowers that are difficult to observe, unfavorable weather, and tree height or size (Sulistyawati et al. 2012). Experiences during field observations, such as sudden fog conditions, rain, strong winds, crown density, height of trees, and small flower sizes and their position on the exterior of tree canopies contribute to the difficulties in recording reproductive phases.

The flowering–fruiting periods and reproductive phases of plant communities might exhibit different patterns during certain seasons. Some of the factors that strongly influence the flowering–fruiting period are rainfall, humidity, temperature, radiation, photoperiod and biotic factors (Singh and Kushwaha 2006; Gunter et al. 2008; Zhang et al. 2010; Sulistyawati et al. 2012). In this study, the effects of climatic factors on the reproductive behavior of trees can be observed from the decreasing number of individual trees that flowered–fruited during period II compared to period I (Fig. 4). This decline was influenced by wind velocity (negative correlation, $r = -0.42$) and temperature (positive correlation, $r = 0.54$) (Table 1).

Other climatic factors, such as the intensity of sunlight that was often blocked by fog, the length of the dry season, and fairly strong winds influenced the flowering–fruiting pattern of individual trees. Seasonal variations in rainforests are diverse and tend to fluctuate erratically compared to the variations in dry climates (Schmidt 2000). Increased photoperiods in the dry season tend to stimulate flowering (Wright and Cornejo 1990). The flowering signals of tree species in tropical montane forests are often attenuated by the influence of cloud cover, which decreases solar radiation and shortens the duration of daytime, allowing for different seasonal patterns of flowering–fruiting phases (Gunter et al. 2008). In this study, solar radiation had a positive correlation with the reproductive period, as indicated by the number of flowering species ($r = 0.43$). This means that solar radiation also influences the number of flowering species. Wind velocity is negatively correlated with the number of species that flower and fruit, and with the number of trees that fruited in general (Table 1).

In this study, the reproductive behavior of the tree community that underwent flowering–fruiting was generally unsynchronized. The study of the flowering–fruiting of dipterocarp in a tropical rainforest showed that peak flowering and fruiting of mature trees was only 40–50%. However, the reproductive behavior at the community and individual levels was different (Schmidt 2000), in line with the results of Kebede and Isotalo (2016) study that flowering phenology is varied at the population level. Therefore, differences in reproductive behavior created different phenological events at the community or population level and individual or tree species level (Schmidt 2000; Somasundaram and Vijayan 2010).

Generally, the reproductive phase was approached based on the age of the trees, but determining the reproductive phase in natural forests was not easy. Therefore, in this study, the reproductive phase was approached using dbh size and by assuming that trees with a dbh of more than 10 cm have entered the reproductive phase. However, this did not seem to be entirely appropriate for some species.

Seed production can be expected based on some important indicators, such as the duration of the reproductive phase. Elliott et al. (1994) explained that duration is the average length of the flowering–fruiting period (in weeks or months) for each individual tree and the average of all individual tree species observed. However, Zhang et al. (2010) considered the duration of the flowering period as the length of time from flower initiation to the end of the flowering period. Their study of an alpine forest (Mt. Qomolangma, Mt. Everest) indicated that there is a considerable variation among the flowering durations of plant species (ranging from 27 to 93 days). In this study, the durations of the reproductive phases of LTS also varied, and most trees had a short duration of reproductive phase (the duration of flowering [Flo] ranging from 0.1–0.8 months or 3–24 days; the duration of fruiting [Fru] from 0.1–1.0 months or 3–30 days; and the duration of flowering–fruiting [Flo–Fru] from 0.1–0.5 months or 3–15 days), as shown in Fig. 7. Our observations confirmed that the reproductive phase is affected by extrinsic factors (climatic) but the durations of the reproductive phases were influenced more by intrinsic factors, such as ecological pollination syndrome (Zhang et al. 2010).

The flowering phenomenon in tropical forests is also influenced by biotic factors, such as the presence of animals with different roles. The reproductive phase can provide the resources (flower) needed by pollinators to assist the pollination and fruits for frugivores and animals that act as dispersal agents of fruits or seeds. According to Rey (2011), the existence and management of frugivorous bird species should be a priority for conservation areas because they can act as seed dispersal agents through their eating behaviors and digestive systems. Potential pollinators seem to react to periodical patterns in seasonal forests compared to wet forests (Gunter et al. 2008).

The study of the reproductive periods of LTS can make important contributions to every step of the forest restoration program, as explained by Buisson et al. (2016). They stated that the key steps in a restoration program are (1) establishing a reference, (2) ensuring the availability of seeds and seedlings, (3) implementing the selected restoration method, (4) setting up permanent monitoring, and (5) implementing adaptive management. The flowering–fruiting period and the periodicity of the reproductive phases of LTS can be used to estimate the fruit production and seed availability in MKR as a reference site. According to Chazdon (2008), the management of the restoration target area is highly dependent on the level of degradation of forested ecosystems. The stages of restoration activities were carried out to reach the optimal levels of biodiversity and ecosystem services, among others, through the planting of local tree species.

In the early stages of the forest restoration program, the availability of fruit or seeds at the reference site can contribute to the availability of target LTS seedlings. Meanwhile, the peak period of fruiting is considered to be the best time for fruit or seed collection and can affect the seed germination quality and seedling quality. Thus, the quantity and quality of seedling production can be optimized. The process of seed collection and seed handling until the nursery stage must be conducted quickly because most of the LTS in MKR have a very short duration of fruiting phase. Although the reproductive periods in MKR varied, the highest availability of fruit or seeds was in December and January, so the site managers can obtain a sufficient number of seeds from different species.

Conclusions

The reproductive pattern (flowering–fruiting periods) of local tree species in the sub-montaneous tropical forests of MKR were unsynchronized, but flowers and fruits or seeds were always available all year round. Wind velocity is the most important ecological factor that correlated with the tree reproductive phase. Most of the local tree species have a short duration of reproductive phase. To support seed availability for forest restoration, the best time for fruit or seed collection was found to be December to January.

Acknowledgements Part of this study was funded by Domestic Postgraduate Education Scholarship (BPP-DN) of Directorate General of Higher Education, Ministry of Research, Technology and Higher Education Republic of Indonesia to the first author. We would like to express our sincere appreciation to Natural Resources Conservation Bureau (BBKSDA) of West Java Province who was given the opportunity to perform long-term research at Mt. Masigit Kareumbi Reserve. We also express our appreciation to Head of Resort Kareumbi Timur and staff for supporting our research in the field. In particular, we would like to thank local community of Mt. Masigit Kareumbi, especially Pak Awo and Pak Ahin who made this research possible. I would also like to thank the management of the School of Life Sciences and Technology, Institut Teknologi Bandung (ITB) which has given first author the opportunity to continue studies during doctoral program in biology, ITB.

References

Buisson E, Alvarado ST, Le Stradic S, Morellato LPC (2016) Plant phenological research enhances ecological restoration. Restor Ecol 25(2):164–171

Chazdon RL (2008) Beyond deforestation: restoring forests and ecosystem services on degraded lands. Science 320:1458–1460

Cole RJ, Holl KD, Keene CL, Zahawi RA (2011) Direct seeding of late-successional trees to restore tropical montane forest. For Ecol Manage 261:1590–1597

Corbin JD, Holl KD (2012) Patient-reported outcomes in child and adolescent mental health services (CAMHS): Use of idiographic and standardized measures. J Ment Health 21(2):165–46

Dunham AE, Razafindratsima OH, Rakotonirina P, Wright PC (2018) Fruiting phenology is linked to rainfall variability in a tropical rain forest. Biotropica 50(3):396–404

Elliott S, Promkutkaew S, Maxwell JF (1994) The phenology of flowering and seed production of dry tropical forest trees in Northern Thailand. In: Proceedings internationl symposium on genetic conservation and production of tropical forest tree seed, ASEAN-Canada Forest Tree Seed Project, pp 52–62

Forest Restoration Research Unit (FORRU) 2006 How to plant a forest: the principles and practice of restoring tropical forests. Biology Department Science Faculty, Chiang Mai University, Thailand

Forest Restoration Research Unit (FORRU) 2008 Research for restoring tropical forest ecosystem: a practical guide. Biology Department Science Faculty, Chiang Mai University, Thailand

Gann GD, Lamb D (2006) Ecological restoration: a mean of conserving biodiversity and sustaining livelihoods. Society for Ecological Restoration International, Tucson, Arizona

Gunawan H, Subiandono E (2014) Desain ruang restorasi ekosistem terderadasi di Taman NasionalNasional Gunung Ciremai, Jawa Barat [Spatial design for restoration of degraded ecosystem inMount Ciremai National Park, West Java]. Indones For Rehabil J 2(1):67–78 (Text in Indonesian)

Gunter S, Stimm B, Cabrera M, Diaz ML, Lojan M, Ordonez E, Richter M, Weber M (2008) Tree phenology in montane forests of southern Equador can be explained by precipitation, radiation and phoperiodic control. J Trop Ecol 24:247–258

Holl KD, Aide TM (2011) When and where to actively restore ecosystem? For Ecol Manage 261:1558–1563

Kamilia I, Nawiyanto. (2015) Kerusakan hutan dan munculnya gerakan konservasi di lereng Gunung Lamongan, Klakah 1999–2003 [Forest damage and the emergence of conservation movements on 18 the slopes of Mount Lamongan, Klakah 1999–2013]. Publika Budaya 1(3):72–85 (Text inIndonesian)

Kebede M, Isotalo J (2016) Flowering and fruiting phenology and floral visitation of four native tree species in the remnant moist Afromontane forest of Wondo Genet, south central Ethiopia. Trop Ecol 57(2):299–311

Keenan RJ, Reams GA, Achard F, de Freites JV, Grainger A, Lindquist E (2015) Dynamic of global forest area: result from the FAO global forest assessment 2015. For Ecol Manag 352:9–20

Kumar A, Chaudhary A (2010) Descriptive statistics (statistical methods) 4th edition. Krishna Prakashan Media (P) Ltd., Meerut

Mohandass D, Chhabra T, Pannu RS, Beng KC (2016) Recruitment of sapling in active tea plantation of the Nilgiri Mountain: implication for restoration ecology. Trop Ecol 57(1):101–118

Nahib I, Turmudi, Suwarno Y (2015) Pemodelan spasial deforestasi di kabupaten Tasikmalaya,provinsi Jawa Barat [Spatial deforestation modeling in Tasikmalaya district, West Java Province]. Majalah Ilmiah Globe 17(2):155–164 (Text in Indonesian)

Natural Resources Conservation Bureau of West Java (2013) Rencana pengelolaan jangka panjang Taman Buru Gunung Masigit-Kareumbi periode 2014-2039 [Long-term management plan for Mount Masigit-Kareumbi Reserve for the period 2014-2039]. Ministry of Forestry, Directorate General of PHKA, Bandung. (Text in Indonesian)

Osuri AM, Chakravarthy D, Mudappa D, Raman TRS, Ayyappan N, Muthuramkumar S, Parthasarathy N (2017) Successional status, seed dispersal mode and overstorey species influence tree regeneration in tropical rain forest fragment in Western Ghats India. J Trop Ecol 33(4):270–284

Reis A, Bechara FC, Tres DR (2010) Nucleation in tropical ecological restoration. Scientia Agricola 67:244–250

Rey PJ (2011) Preserving frugivorous birds in agroecosystems: lessons from Spanish olive orchards. J Appl Ecol 48:228–237

Schmidt L (2000) Guide to handling of tropical and subtropical forest seed. DANIDA Forest Seed Centre, Humlebaek, Denmark, pp Xxi+511. http://www.dfsc.dk/Guidechapters.htm

Singh KP, Kushwaha CP (2006) Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Ann Bot 97:265–276

Somasundaram S, Vijayan L (2010) Plant diversity and phenological pattern in the montane wet temperate forests of the Southern Western Ghats, India. For Stud China 12(3):116–125

Sulistyawati E, Mashita N, Setiawan NN, Choesin DN, Suryana P (2012) Flowering and fruiting phenology of tree species in mount papandayan nature reserve, West Java, Indonesia. Trop Life Sci Res 23(2):81–95

Sulistyawati, E., Y. I. Ulumudin & M. Zuhri. 2008. Land-use change in Mount Papandayan: its associated impact on biodiversity and carbon stock. International Conference on Environmental Research and Technology. pp 463–467

Sutherland WJ (2006) Ecological census techniques a handbook. Cambridge University Press, New York

Van der Werf GR, Morton DC, DeFries RS, Olivier JGJ, Kasibhatla PS, Jackson RB, Collatz GJ, Randerson JT (2009) CO2 emission from forest loss. Nat Geosci 2:737–738

Wang J, Li D, Ren H, Yang L (2010) Seed supply and the regeneration potential for plantation and shrubland in southern china. For Ecol Manage 259:2390–2398

World Conservation Monitoring Centre. 1998. Saurauia microphylla. The IUCN Red List of Threatened Species 1998: e.T37404A10050108.

Wright SJ, Cornejo FH (1990) Seasonal drought and the timing of flowering and leaf fall in a Neotropical forest plants. In: K. S. Bawa & M. Hadley (eds.) Man and the biosphere series. Unesco and The Parthenon Publ. Grp. Vol.7, pp 49–61

Zhang L, Turkington R, Tang Y (2010) Flowering and fruiting phenology of 24 plant species on the North Slope of Mt. Qomolangma (Mt. Everest). J Mt Sci 7:45–54