Running title: *Phlegmariurus* Migration and loss

Migration and Loss of *Phlegmariurus* (Lycopodiaceae) at Southern Slope of Mt. Slamet Indonesia

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Abstract

Phlegmariurus is a genus of lycophyte plants in the family Lycopodiaceae which is sensitive to climate change. In the past, there were four species namely 1) *Phlegmariurus phlegmaria*, 2) *P. nummulariifolius*, 3) *P. carinatus*, and 4) *P. squarrosus* found as epiphytic clubmosses on many trees such as pines and *Agathis* on the southern slope of Mt. Slamet. During 42 years there has been a significant loss of *Phlegmariurus* at the slope which covers approximately 15,000 ha rain forest covering the subdistrict of Cilongok in the west, Baturraden in the middle, and Sumbang in the east. Some surveys that had been conducted from 1978 to 2020 showed that the presence frequency of the plant decreased. We correlated the temperature increase data from NOAA and precipitaion data from the local meteorology and geophysics data to the frequency of the plants. Furthermore, we also interviewed ten nurseries which sold the *Phlegmariurus* of approximately 60 nurseries (Figure 6). The information we gathered showed that the location of the plant sources was above the previous locations. We also observed the cultivated *Phlegmariurus* at different altitudes namely at 95-97 m, 300-400 m, and 600-800 m a.s.l. The result of this study showed that in the past there were a lot of *Phlegmariurus* spp. However, in 2020 *Phlegmariurus* were absent in most areas at the southern slope of Mt. Slamet. We proposed three causes of the migration and loss of *Phlegmariurus* at the southern part of Mt. Slamet namely: 1) The increase of temperature, the decrease of precipitation, and 3) commercial hunting.

Keywords: climate change, dynamics, epiphyte, Java, Lycopodiaceae, *Phlegmariurus,* Mt. Slamet.

Introduction

Phlegmariurus is a type of fern which is included in the family Lycopodiaceae which is an old family of vascular plants, including all of the core clubmosses, comprising 16 accepted genera (PPG I, 2016), and ca 400 known species (Christenhusz & Byng, 2016). This family originated about 380 million years ago in the early Devonian, though the diversity within the family has been much more recent (Judd et al., 2015). The rate of species extinction since 1600 was, until recently, 50-100 times the historical rate tracked by scientifically analyzed fossil records. Alarmingly this extinction rate is now expected to accelerate to between 1,000-10,000 times the natural rate by 2020 (JICA 2010).

In the past, *Phlegmariurus* was found a lot on the slope of Mt. Slamet at the altitude from 500-700 m a.s.l. In 2020, they were absent in the same location. Beside over exploitation, it seems to be affected by this climate change, because in the past they were found a lot there, however in from 2014-2020 there has been almost nothing on southern slope of Mt. Slamet. This phenomenon may be caused by the increase of temperature, the decrease of precipitation so that it is not suitable anymore for *Phlegmariurus*. In fact overall annual rainfall has decreased by 2-3% since 1990 (BMKG 2020, CCKP 2020). The decrease of precipitation in the surrounding area can be seen in Figure 2. On the other hand, many farmers have tried to cultivate some *Phlegmariurus* for business and ornamental purposes.

Climate change could lead to decline in more than 50% of common plants including *Phlegmariurus*. If nothing is done to reduce the amount of global warming, this plant may be extinct immediately. This means that geographic ranges of common plants will shrink globally and biodiversity will go down almost everywhere. The link between climate change and biodiversity has long been established. Climate change has strong indirect effects on plant diversity in plantation forests via changes in forest management actions (Pawson et al. 2013). Although throughout Earth's history the climate has always changed with ecosystems and species coming and going, rapid climate change affects ecosystems and species ability to adapt and so biodiversity loss increases. Ecosystems are already showing negative impacts under current levels of climate change which is modest compared to future projected changes. In addition to warming temperatures, more frequent extreme weather events and changing patterns of rainfall and drought can be expected to have significant impacts on biodiversity (Secretariat of the Convention on Biological Diversity, 2010).

Southern slope of Mt. Slamet has a tropical climate, with average annual rainfall of 2,000 meters, and an average temperature of 21-32 ° C. Areas with high rainfall are mainly found in western Nusakambangan, and along the North Serayu Mountains. Areas with low rainfall and frequent drought in the dry season are in Blora and surrounding areas and in the southern part of Wonogiri regency. A study on the trend and pattern of rainfall over Java (Siswanto & Supari 2015) showed that for the period of 1981-2010 the the extreme rainfall event over Java Island especially around the research area namely Cilacap showed an increasing trend.

Mean annual temperature has increased by about 0.3°C, overall annual precipitation has decreased by 2 to 3%, there has been a decline in annual rainfall in the southern regions in Indonesia (Hulme & Sheard, 1999; Boer & Faqih, 2004). Decreased rainfall during critical times of the year may translate into high drought risk (Wang et al., 2006). These changes may have affected the presence and migration of some plant species including the clubmosses.

The southern slope of Mt. Slamet is very long namely ca. 30 km long, it ranges from Ajibarang highland to Purbalingga highland. The area consists of hills and valeys with very various slope angles. On the map it seems to be only approximately 15 km straight, however, the actual land distance may reach 30 km. In the past, it had a lot of rare plants which grow very well. However, fires and grazing may have reduced its diversity. In addition, daily grazing which has been done by many local people may have caused the decrease of the diversity.

Mt. Slamet is an area with high rainfall which is mainly part of western Central Java, and along the North Serayu Mountains. In general, Central Java has a tropical climate, with average annual rainfall of 2,000 meters, and an average temperature of 21-32°C the rain fall mainly in the afternoon (BPS 2019). The mountains are more humid than the lowland and the rainfall may reach 400 mm per year. While areas with low rainfall and frequent drought in the dry season are in east and south east Central Java.

The distribution of *Phlegmariurus* depends on environmental conditions in combination with other factors which play a key role in defining the function. Changes in long term environmental conditions that can be collectively coined climate change are known to have had enormous impacts on plant diversity patterns in the past and are seen as having significant current impacts (Sahney et al 2010). The climate change will be one of the major drivers of biodiversity patterns in the future. It has been shown that past climatic change has been a major driver of the processes of speciation and extinction (Sahney et al 2010). Current research is focus on identifying the impacts of climate change on biodiversity, and predicting these effects into the future.

Climate change occurring in Indonesia is generally characterized by changes in daily average temperature, rainfall pattern, sea level, and climate variability e.g. El Niño and La Niña, Indian Dipole, etc. Climate change has many consequences for plants for exampple the increasing temperatures directly affect plant growth, reproduction, and resilience (Eisenach 2019). These changes have serious impacts on various sectors in Indonesia suach as agriculture including plant adaptation and crop losses. Some studies, both from within and outside the country, show that the climate in Indonesia has changed since 1960, although scientific analysis and data are still limited.

The linear temperature increase is about 2.6° C per hundred years for Malang (East Java) based on the data analysis of the last 25 years (KLH, 2012). The increase of daily mean temperature significantly influences the rainfall pattern which is generally determined by Asian and Australian monsoon circulation. With the monsoon circulation, Indonesia has two major seasons that change every half year namely rainy and dry season. There is a trend in air temperature in Semarang City by 0.0279 °C per year, from year 1980-2016 (Suryadi et al. 2018).

The UK Met Office has recorded severe droughts and floods from 1997 to 2009. In the period of 2003-2008 there had been an increased chance of extreme rainfall events, especially in western Indonesia namely in Java, Sumatra and Kalimantan. One of the phenomena that confirm the occurrence of temperature increase in Indonesia is melted ice in Puncak Jayawijaya, Papua. This ongoing climate change is a reality that our earth must face. WWF research shows that 33% of the world's habitats are threatened, even some of the plants and animal species have faced extinction (WWF 2000).

Increases in atmospheric CO_2 concentration has affected photosynthesise process in plants, resulting in increases water use efficiency in plant, enhanced photosynthetic capacity and increased growth (Steffen & Canadell, 2005). Increased CO_2 can also lead to increased Carbon : Nitrogen ratios in the leaves of plants or in other aspects of leaf chemistry, possibly changing herbivore nutrition (Gleadow et al. 1998). There are differential responses to elevated atmospheric CO_2 between major ‘functional types’ of plant, such as C3 and C4 plants, or more or less woody species; which has the potential among other things to alter competition between these groups (Dukes and Mooney 1999).

It is not easy to predict the extinction risk of plant species, because it takes long time. However, estimations from particular periods of rapid climatic change in the past have shown relatively little species extinction in some regions, for example (Botkin et al. 2007). Here I found a preliminary fact that Lycopodiaceae which were abundant in 1992 (Muljani et al 1993), become rare in 2014. Knowledge of how species may adapt or persist in the face of rapid change is still relatively limited thus this fact needs verification.

Climate change is a change in the state of the climate which can be identified for example using statistical tests by changes in the average or the variability of temperature, humidity and rainfall, and that persists for a long period of time. The global mean land surface has warmed 0.27 °C per decade since 1979 (Intergovernmental Panel on Climate Change 2007), but it is unclear whether this change has caused widespread shifts in plant distribution (Parmesan 2006). We compared the local climate and diversity of *Phlegmariurus* in 1993, 2014, 2017, 2018, and 2020.

The climate change detection in Mt. Slamet were defined in the TAR (IPCC, 2001; Mitchell et al., 2001). Detection is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change. This year the dry season in Mt. Slamet and its surrounding areas delayed from the begining of June to the beginning of July 2020. One of the reasons for the delay of dry season is that this June sea water tempaerature is still high, so that the evaporation is high and the cloud is thick causing the rain.

There is already evidence that plant species are shifting their ranges in altitude and latitude as a response to changing regional climates (Parmesan & Yohe 2003), (Walther et al. 2002). In fact, there were four species of *Phlegmariurus* in Baturraden agathis forest at the altitude of 600 700 m in 1993 (Muljani et al 1993). However, in 2014, there is an indication that these *Phlegmariurus* became rare at the same area and altitude. *Phlegmariurus* may be a type of genus which may be used as climate change indicator.

Material and methods

Plant species

Phlegmariurus, a family member of clubmosses found as epiphytic plant on some trees of Agathis and *Pinus*. This ferns are widely branched, erect, prostrate or creeping stems, with small, simple, needle-like or scale-like leaves that cover the stem and branches thickly. The leaves contain a single, unbranched vascular strand and are called microphylls. Sporangia kidney-shaped or reniform containing spores of one kind only (homosporous) and are borne on the upper surface of the leaf blade of specialized leaves called sporophylls which are arranged in a cone-like strobilus at the end of upright stems.

Survey material

Phlegmariurus were collected from five mountainous areas (geographical positions extends from 7°15'07" S - 7°17'50"S, 109°07'13"E - 109°14'48"E, approximately 15 km long straight distance or 25 – 35 km land distance from Cilongok to Sumbang Banyumas Central Java. These areas are typical fluctuation zones along rivers with elevation ranging from 500 to 2,500 m and little disturbed by human activity. In each area, plants were collected randomly from two different plant habitats namely on the groud (terrestrial plants) and on trees (epiphytic plants). These plants were taken for herbarium and planted on low land areas in Purwokerto. After a few days planted in the lowlands, the plant showed suboptimal growth, many of its leaves were dry.

Results

Survey agenda

In the year 1978 to1980s our seniors and lecturers collected *Phlegmariurus* from some areas in Baturraden which is located at the southern slope of Mt. Slamet. They found many specimens and some were stored in the Herbarium Fakultas Biologi Universitas Jenderal Soedirman (PUNS).

A total of four species were recorded from 1993–2020. In 1990s many of these species were found at elevations between 600 – 700 m a.s.l. All *Phlegmariurus* were found as epiphytic plants on *Agathis* and pine trees. In the year 1992 Muljani, Titi and myself collected *Phlegmariurus* as a very abundant epiphytic plant. On the 10th September 2011 we found *Phlegmariurus squarrosus* at an altitude of ca 2100 m a.s.l.

In the year 2012 we resurvey the plants on the altitude of 600-800 m a.s.l., however, there has been no *Phlegmariurus* in the location we sampled 22 years before. Then, in the year 2014 we surveyed again in the areas of Wanawisata Baturraden, and the resuls showed nothing. In the same year we searched in the eastern part and we found it cultivated as an ornamental plant in Purbalingga Regency.

In April 2018 we search for 6 days five night on the western part of southern slope on the altitude of 1300 to 1500 m a.s.l. and there was no *Phlegmariurus* at all. Then in the year 2019 we tried to search again in the western part of southern slope of Mt. Slamet namely in Curug Cipendok, however, there was no *Phlegmariurus* anymore. We search from the altitude of 600 – 800 m a.s.l.

In the year 2020 we resurvey the areas with the transect rises from 300 m to 2,560 m over 30 km ranged from Curug Cipendok to Serang Purbalingga, driving along the small road, walking and climbing through pine woodland, agathis woodland, grassland and tropical rain forest and we found no *Phlegmariurus*.

Regression Analysis

1. Climate change

Climate change is one of some factors affecting the presence of *Phlegmariurus* at Southern Slope of Mt. Slamet. We compare the NOAA data of temperature increase from 1978 – 2020 to the frequency of *Phlegmariurus* from the same years (Figure 1). In addition, we also compare the local data of climate change from BMKG (Body of Meteorology and Climatology, and Geophysics) especially for the precipitation. The regression results of frequency of *Phlegmeriurus* vs temperature anomaly were summarized in Table 1 and Figure 4.

2. Habitat elevation

Previously, in 1990s there were a lot of *Phlegmariurus* at an altitude of 600 – 700 m a.s.l. However since 2012 there has been nothing at those habitats (Figure 5). Some informations showed that those plants had moved to the higher altitudes. *Phlegmariurus phlegmaria*, *P. carinatus*, and *P. squarrosus* migrated from altitude of 600-900 m alt to 1200-1500 m alt, while *P. nummulariifolius* lost (Figure 8).

3. Commercial hunting

An increase of commercial hunting on the *Phlegmariurus* has also been recorded. There has been an increase of commercial hunting of *Phlegmariurus* around Mt. Slamet. In the year 2012 there were only 2 (6.7%) of approximately 30 nurseries in the southern slope of Mt. Slamet. However, in 2020 there were aproximately 10 (16.7%) of 60 nurseries selling *Phlegmariurus* (Figure 6).

Discussion

There are some factors affecting the presence of *Phlegmariurus* at Southern Slope of Mt. Slamet namely climate change and hunting for business. *Phlegmariurus* is a genus of Lycophyte plant which is interesting for ornament and sensitive to environmental factors such as air temperature, altitude, precipitations, and climate. A small experiment by giving treatment on different altitudinal locations showed that most *Phlegmariurus* cultivated at lowland would die sooner than those cultivated on higher locations. The frequency of *Phlegmariurus* had been decreasing since 2012 (Figure 3). On the other hand, in 2011, this plant was found on higher altitude namely ca 1800 m a.s.l. (Figure 4).

Phlegmariurus phlegmaria (Figure 7), commonly known as either coarse tassel fern or common tassel fern, is an epiphytic (Rusea et al 2009) species native to rainforests in Madagascar, some islands in the Indian Ocean, Asia, Australasia and many Pacific Islands. *P. phlegmaria* is commonly found in moist forests and rainforsests at high altitudes, in and amongst mosses and other epiphytes. In the past, it was found a lot as epiphytic fern on pine and agathis trees on Wanawisata Baturraden which is on the southern slope of Mt. Slamet. But now it cannot be seen on the previous locations. It is for sale in at 10 of approximately 60 nurseries. The nursery owners said that it can still be orderred from Mt. Slamet at higher altitude.

Phlegmariurus carinatus (Figure 7) is an epiphytic plant closely related to ferns and mosses. This plant were usually found on tree trunks or rocks in dense forests of ridges, valleys, and hills. They prefer warm to cool conditions but won't tolerate frost. This plant seems to be adaptable to wider altitude because this can still grow well and produce more offspring better than any other *Phlegmariurus*. Our collections of this clubmoss cultivated at an altitude of 97 m a.s.l. can grow well only for some months. This plants are distributed widely in China, Taiwan, Cambodia, India, Japan, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam; Indonesia and Pacific islands (USDA). Now this plant has become rare and the conservation status (IUCN) of this plant is VU (Fraser-Jenkins 2012).

Phlegmariurus squarrosus (Figure 7) or rock tassel fern is a kind of epiphytic or lithophytic tassel fern with pendulous or erect tufted branches, but arched to nodding towards the end. The branches may be undivided or branched one to several times and reach 30-75 cm long. The sterile portion (lacking spores) of the branch is 1.5-3cm in diameter, including the leaves (DEWHA 2008). The sterile leaves are spirally arranged around the stem, angled at 60-90 degrees and twisted near the base. They are thin but firm, linear to lance-shaped, 10-20 mm long by 1.2mm wide, and pale green to yellowish-green coloured. This plant is threatened due to collection for cultivation.

Phlegmariurus nummulariifolius (Figure 8), an extremely rare fern, with flattened leaves appressed to the thin, wiry stems. Each stem branches frequently resulting in a magnificent cascade. The plants are normally cultivated in pots. In other countries such as Australia the conservation status is least concern (LC), howerver, in Indonesia it may be threatened as the climate is getting warmer. This plant contains alkaloids which are important for inhibiting tumor development in human (Nakayama et al 2018).

The overall climate on souther slope of Mt. Slamet is wet, with predominantly daily high precipitation. The annual precipitation, proportion of precipitation falling as showers, and probability of rain increase with increasing elevation, and the annual mean temperature and interannual precipitation variability decrease with increasing elevation. The climate change has affected the occurences of *Phlegmariurus*. This finding is almost like those reported by

Wang et al. (2019). The plant facing climate warming may migrate to find their seasonal climate niche and to track favourable conditions in time (Hereford et al. 2017).

The migration and loss of *Phlegmariurus* (Fig. 5) can be summarized as follows: 1) Three *Phlegmariurus* (*P. phlegmaria*, *P. carinatus*, and *P. squarrosus*) in 1980-2010 occurred abundantly at 600-800 m a.s.l. (Figure 7); 2) In 2012 they occurred at higher altitude ca 1800 m a.s.l. and they were also found domesticated as ornament. 3) The plants at higher altitude may survive 4) There are two possibilities for the domesticated ones namely those which are cultivated at high land may survive, on the other hand those which are cultivated at lowland may axtinct. 5) *Phlegmariurus nummularifolius* is the most sensitive to envirnmental changes (Figure 8). It was present abundantly in 1990s, however, in 2012 it lost and can not be found anylonger including those in the nurseries (Figure 9).

In 2014, almost all of *Phlegmariurus* migrated or lost. In fact, according to the local Meteorology, Climatology, and Geophysics Body (BMKG) the year 2014 was the hottest year followed by 2015, 2016, and 2017 (BPS 2017). This situation might have caused the loss or migration of *Phlegmariurus* at the southern slope of Mt. Slamet. In fact, *P. nummularifolius* has lost, while three other *Phlegmariurus* namely *P. phlegmaria, P. carinatus, and P. squarrosus* have moved to higher altitude (Figure 9).

Human activities by domesticating the plant is not the major cause of extinction because the spores of *Phlegmariurus* may still be present around the host plant, however the environment may be unfavourable anymore. As a result, the spores which can grow well are those only on the higher altitude. So, climate change may be another cause of the migration of the plant to higher altitude where the environmental factors such as temperature and rainfall are suitable.

Conclusions

There is a trend that *Phlegmariurus* are moving from low land to higher which may due to 1) the increase of air temperature in the area, 2) the decrease of precipitaion, 3) the exploitation for collection and business may also have caused the loss of the plant. In the past, *Phlegmariurus* was found abundant on the southern slope Mt. Slamet at the altitude of 600-800 m a.s.l. However, they are absent and were found at higher altitude namely form 800-2100 m a.s.l. and not abundant any longer. Plant domestication and climate change interacted to affect species occurrences and colonization.

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Data Accessibility Statement

We agree that the data supporting the results in this paper to be archived in an appropriate public archive.

1. Climate data files: Dryad
2. Sampling locations, morphological data: Dryad

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Tables here (if there is any)

Table 1. Regression analysis for *Phlegmariurus* vs anomalies

Table 1. Regression analysis for *Phlegmariurus* vs anomalies

No	Species	Statistical significancy	Fitted line plot
1	*P. nummularifolius*	Not statistically significant ($p>0.05$).	$Y = 2{,}742 – 2{,}334\ X$ (Figure 4.1.)
2	*P. phlegmaria*	Not statistically significant ($p>0.05$).	$Y = 8{,}526 – 6{,}677\ X$ (Figure 4.2.)
3	*P. squarrosus*	Statistically significant ($p<0.05$).	$Y = 5{,}731 – 25{,}25\ X + 40{,}16\ X^2 – 19{,}87\ X^3$ (Figure 4.3.)
4	*P. carinatus*	Not statistically significant ($p>0.05$).	$Y = 2{,}027 – 0{,}5285\ X$. (Figure 4.4.)

Figure legends

Figure 1. Temparature increase (C) from 1978 to 2020. Source: NOAA

Figure 2. The average precipitation per decade in Cilacap Meteorogical Station (BMKG 2020)

Figure 3. Frequency of *Phlegmariurus* from 1978 – 2020

Figure 4. Fitted line plots for linear and cubic models for *Phlegmariusus carinatus*, *P. nummularifolius*, *P. phlegmaria* (linear models), and *P. squarrosus* (cubic model) vs anomalies

Figure 5. Migration of *Phlegmeriurus* from 1990s to 2020

Figure 6. The increase of nursery number which selling *Phlegmariurus*

Figure 7. The survive ferns *Phlegmariurus carinata*, *P. squarrosus*, & *P. phlegmaria*

Figure 8. The lost ferns *Phlegmariurus nummulariifolius*

Figure 9. Prediction for occurence of *Phlegmariurus* on the slope of Mt. Slamet

Figure 1. Temparature increase (C) from 1978 to 2020. Source: NOAA

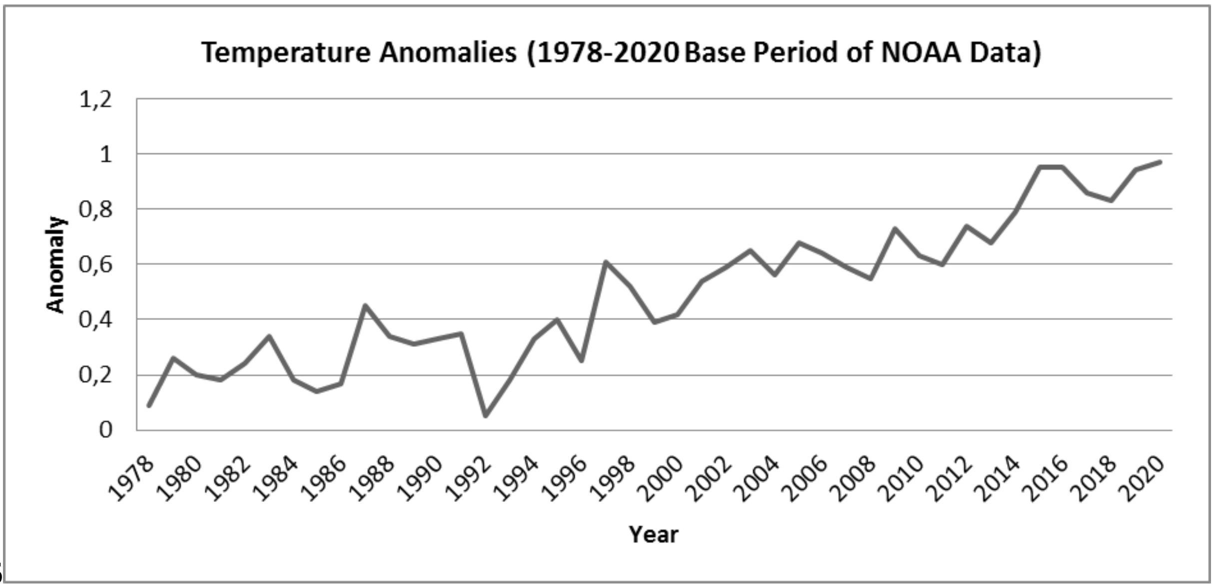


Figure 2. The average precipitation per decade in Cilacap Meteorogical Station (BMKG 2020)

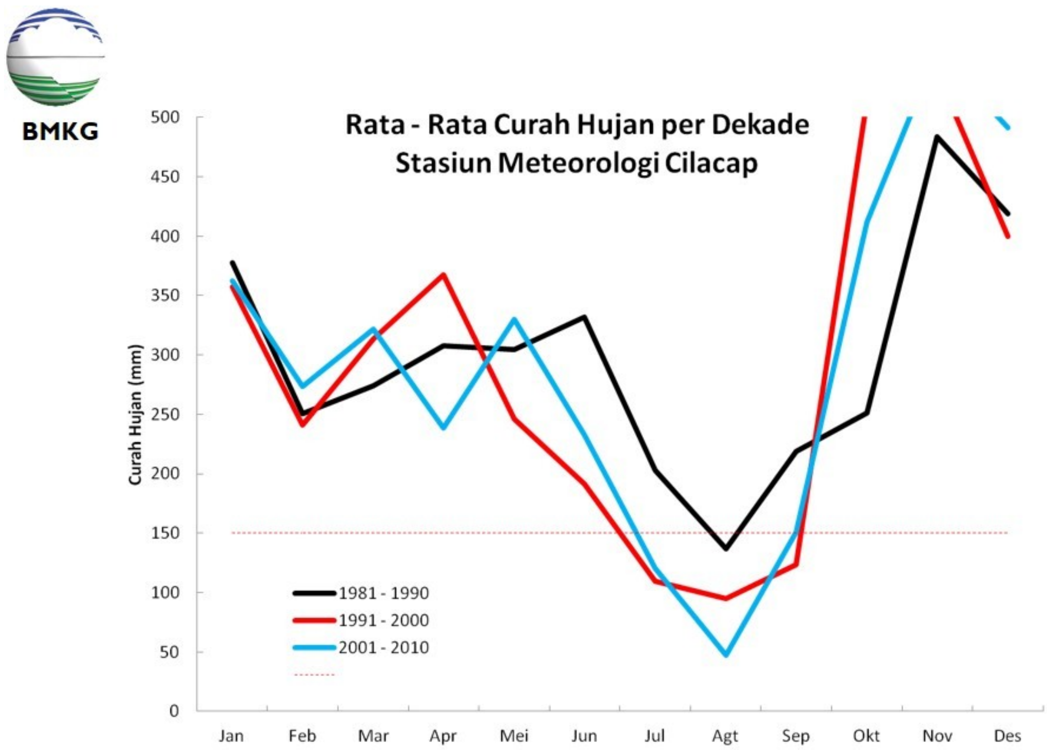


Figure 3. Frequency of *Phlegmariurus* from 1978 - 2020

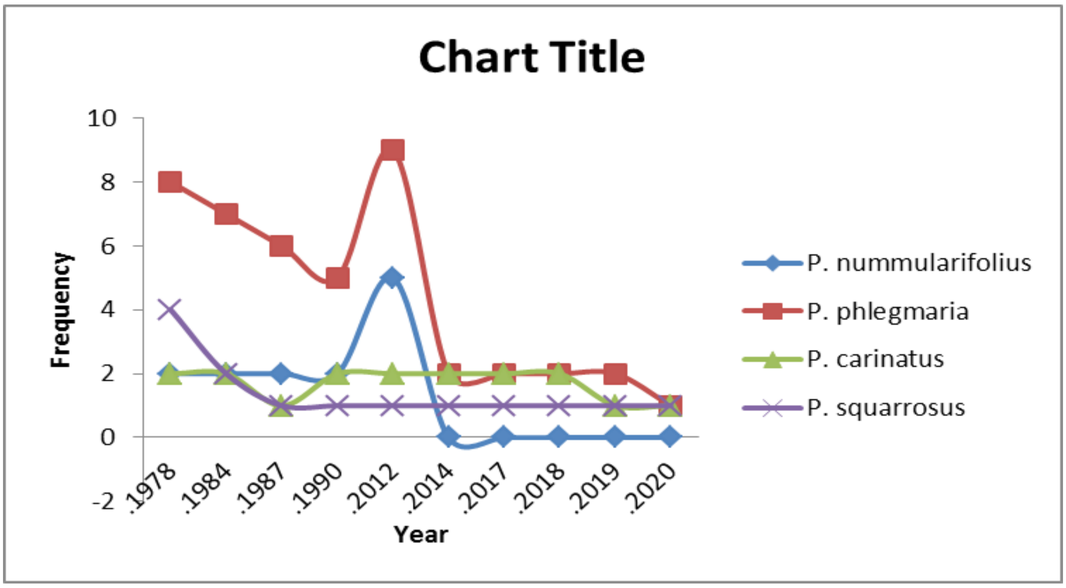


Figure 4. Fitted line plots for linear and cubic models for *Phlegmariusus carinatus*, *P. nummularifolius*, *P. phlegmaria* (linear models), and *P. squarrosus* (cubic model) vs anomalies

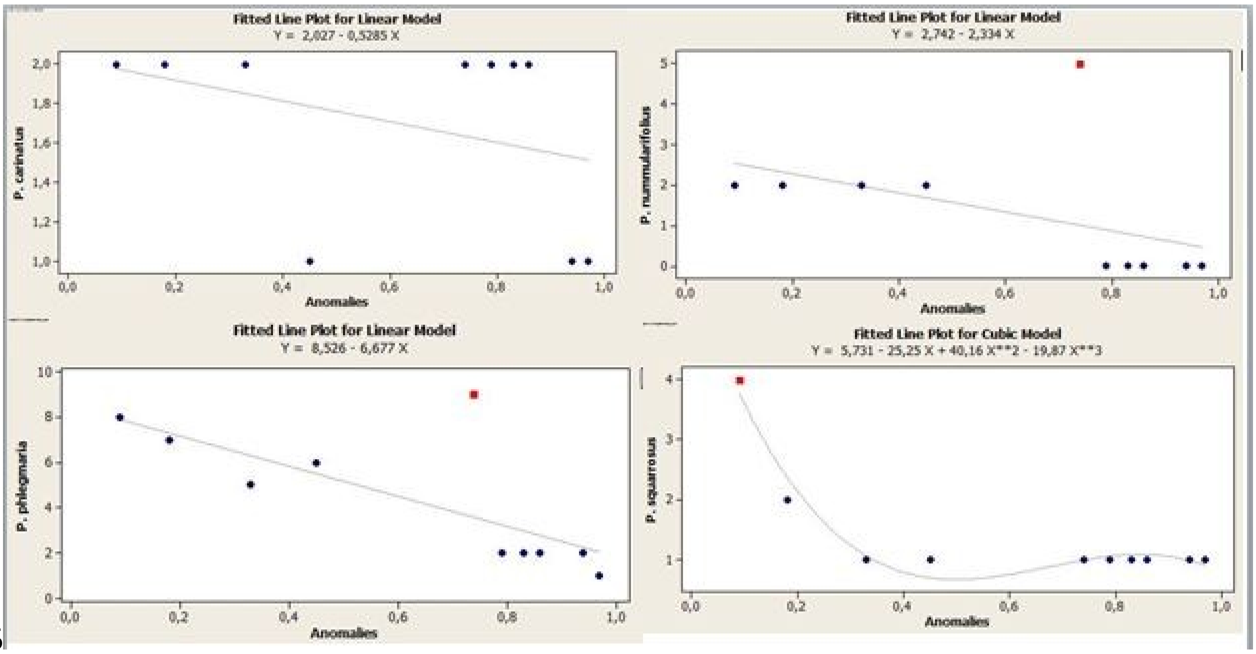


Figure 5. Migration of *Phlegmeriurus* from 1990s to 2020

Figure 6. The increase of nursery number selling *Phlegmariurus*

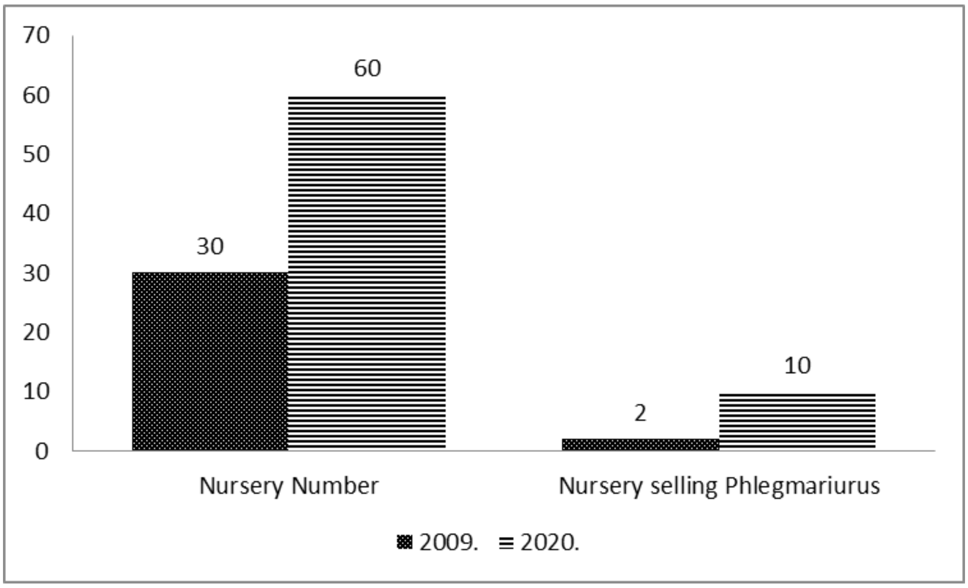


Figure 7. The survive ferns: *Phlegmariurus carinata*, *P. squarrosus*, & *P. phlegmaria*

Figure 8. The lost ferns *Phlegmariurus nummulariifolius*

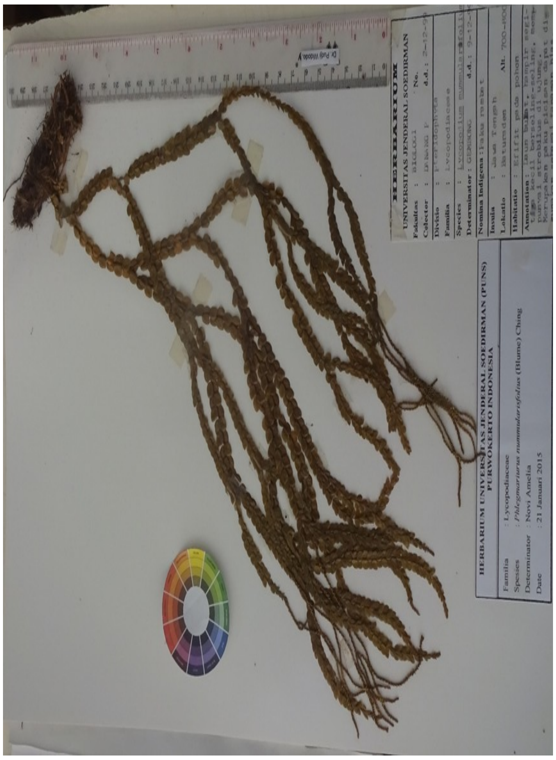
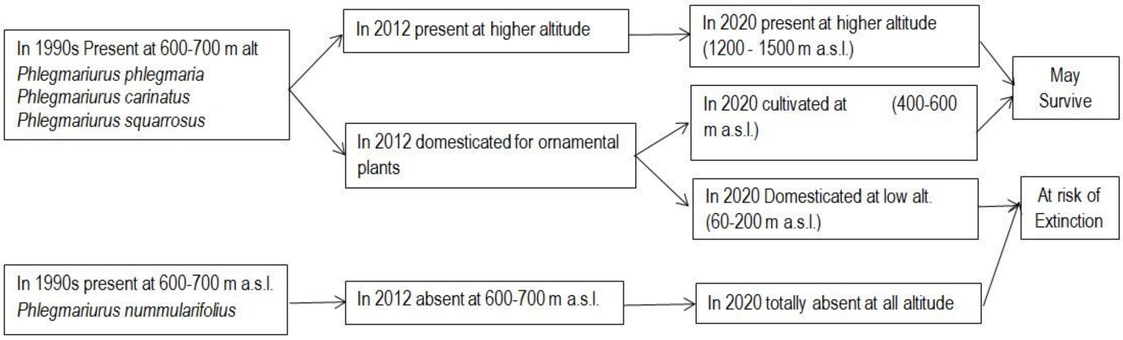


Figure 9. Prediction for occurence of *Phlegmariurus* on the slope of Mt. Slamet


In 1990s Present at 600-700 m alt
Phlegmariurus phlegmaria
Phlegmariurus carinatus
Phlegmariurus squarrosus
In 2012 present at higher altitude
In 2012 domesticated for ornamental plants
In 2020 present at higher altitude (1200 - 1500 m a.s.l.)
In 2020 cultivated at (400-600 m a.s.l.)
In 2020 Domesticated at low alt. (60-200 m a.s.l.)
May Survive
At risk of Extinction
In 1990s present at 600-700 m a.s.l.
Phlegmariurus nummularifolius
In 2012 absent at 600-700 m a.s.l.
In 2020 totally absent at all altitude