Review

Bagworms in Indonesian Plantation Forests: Species Composition, Pest Status, and Factors That Contribute to Outbreaks

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Abstract: The role of plantation forests will become more important in the future, along with the increasing demand for wood. However, pest infestation problems may represent significant obstacles to the development of sustainable forest plantations. Bagworms are one of the most important pests in Indonesian plantation forests. Outbreaks of bagworms have occurred in different tree species for wood or non-wood resources. This paper presents the first review of bagworms in Indonesian plantation forests. This review presents the diversity of bagworms, their pest status, and the factors affecting the outbreaks. More than 70 bagworm species were recorded in Indonesia, which is higher than the species richness recorded in neighboring countries. The subfamily Oiketicinae has the highest number of species, followed by Typhoniinae and Taleporiinae. The highest bagworm richness has been recorded in Western Indonesia, except for Papua, where many new species have recently been described. More than 10 species of bagworms have been reported as pests in Indonesian forest trees. *Pteroma plagiophleps* is currently considered the most important pest in the forestry sector because of the wide range of forest trees used as hosts. Bagworm outbreaks have been reported in forest trees since 1924. The first outbreak occurred only in pines in Sumatra. Currently, outbreaks occur in more host plants and on other islands. Bagworm outbreaks are influenced by multiple factors, such as the biology of the bagworms, their host plants and natural enemies, climate, and silvicultural practices.

Keywords: host plant; infestations; Oiketicinae; sustainable forest plantation; Taleporiinae; Typhoniinae

1. Introduction

Indonesia has 125.9 million hectares (ha) of forests, comprising 68.8 million ha of production forests (54.6%), 27.4 million ha of conservation forests (21.8%), and 29.7 million ha of protected forests (23.6%) [1]. Based on the Law of the Republic of Indonesia Number 41 (year 1999), a protected forest is defined as a forest area with the main functions of regulating water systems, preventing flooding, controlling erosion, preventing seawater intrusion, and maintaining soil fertility. By contrast, a conservation forest is defined as a forest area with the main function of preserving plant and animal diversity and their ecosystems. Other than being managed as natural forests, production forests are also managed as plantation forests.
forests, including industrial and state-owned forests. Industrial plantations cover an area of 7.07 million hectares, and state-owned plantations cover an area of 2.23 million ha [2]. Farmers have established another type of forest plantation in the form of small-holder forestry. Small-holder forestry comprises plantation forests built and managed by individuals on private land. Generally, it is managed as an agroforestry system by combining trees with crops to support livelihood needs. The indicative area of small-holder forestry using Landsat images in Java and Madura is 2.58 million ha [3]. Fast-growing species dominate plantation forests in Indonesia, especially in industrial and small-holder plantations [2]. Meanwhile, slow-growing species, such as teak, pine, and mahogany, dominate the state-owned forests [2]. Acacias and eucalyptus are the two most widely used species in industrial plantations, and sengon (Falcataria moluccana (Miq.) Barneby & J.W. Grimes), teak, acacia, and mahogany are the most common species in small-holder plantations [2,4]. The role of forest plantations is becoming increasingly important, as the Government of Indonesia has targeted a significant increase in timber production from plantation forests [5]. Therefore, sustainable forest plantation management is a key factor in achieving these targets.

Currently, pests are one of the major problems in managing forest plantations. Lepidoptera are among the most important forest and agricultural pests [6]. This order includes butterflies, skippers, and moths, with at least 150,000 described species [7,8]. In Indonesian forests, many lepidopteran pests significantly affect plantations and cause economic losses. Several important recorded pests are found in Indonesian forest plantations. An outbreak of bagworms (Pteroma plagioleps Hampson, 1893; Lepidoptera: Psychidae) caused the severe defoliation of hundreds of hectares of F. moluccana plantations in Central Java [9]. The teak defoliator caterpillar (Hyblaea puera Cramer, 1777; Lepidoptera: Hyblaeidae) and the mahogany shoot borer (Hypsipyla robusta Moore, 1886; Lepidoptera: Pyralidae) also caused significant damage to their host plants [10,11].

Recently, many Indonesian researchers have been interested in studying bagworms in forest trees. In addition to the fact that many species are economic pests, there are several interesting reasons to study these pests in plantation forests. Bagworms have a unique morphological character that makes them easy to recognize and distinguish from other insect groups. As indicated by their name, these pests are equipped with a bag to protect their bodies. The bag serves as adequate protection against natural predators and unfavorable environmental conditions, such as extreme temperatures [12–16]. The bag essentially consists of silk fiber produced by the larvae and covered by plant material (such as leaves, twigs, branches, and flowers), algae, lichens, stones, and dead insects [13,17,18]. The moths are small to medium in size, with the male always fully winged; the female can be fully winged, brachypterous, apterous, or vermiform, with all body appendages vestigial or lost [19,20]. As in other Lepidoptera, most bagworms are herbivores, and a few are predators [21–24].

Bagworms are polyphagous, with many hosts; for example, the defoliator P. plagioleps was found feeding on 22 plant families [19], in annual crops and perennial trees [19,25–28]. Bagworm infestations occur not only in plantation forests but also in natural forests [10,29–31]. In many cases, the dynamics of a pest infestation are not well understood. For example, in India, P. plagioleps, previously known as an insignificant pest of Tamarindus indica L., was involved in outbreaks in 1977 in F. moluccana, followed by Delonix regia (Hook.) Raf. and Acacia nilotica (L.) Delile [32,33]. Understanding the diversity of bagworms and the factors that influence their development are important for sustainable plantation forest management. Therefore, this paper reviews the importance of bagworm pests in Indonesia, including the diversity of the species, pest status, and factors affecting the outbreaks. This information provides the basis of knowledge in managing bagworm pests in Indonesian plantation forests.
2. Species Composition of Bagworms in Indonesia

Bagworms (Lepidoptera: Psychidae) are one of the six members of the superfamily Tineoidea, the most plesiomorphic group of ditrysian Lepidoptera [20]. According to Sobczyk [17], a total of 1324 species of bagworms from 236 genera have been described worldwide. However, hundreds still have not been described. The Palearctic region displays the highest numbers of bagworm species (approximately 37%). In the Oriental region, including Indonesia, the number of bagworm species is 229 (16%). Furthermore, Sobczyk [17] classified the Psychidae into ten subfamilies, namely: Epichnopteriginae Tutt, 1900; Metisinae Dietl, 1971; Naryciinae Tutt, 1900; Oiketicinae Herrich-Schäffer, 1855; Placodominae Sauter and Hättenschwiler, 1991; Pseudarbelinae Clench, 1959; Psychinae Boisduval, 1840; Scoriodytinae Hättenschwiler, 1989; Taleporiinae Herrich-Schäffer, 1857; and Typhoniinae Lederer, 1853. At least 1035 species were described in 10 subfamilies, and the rest have still not been assigned [17].

Only six subfamilies out of ten were recorded in Indonesia [9,17,25,34–37]. Epichnopteriginae, Naryciinae, Placodominae, and Scoriodytinae were not recorded in Indonesia, although some of them, such as Epichnopteriginae, have a wide distribution, including the Oriental region [17]. Oiketicinae, Typhoniine, and Taleporiinae are the richest subfamilies in Indonesia [17,34–36]. These three subfamilies also dominate worldwide (Figure 1). However, Malaysia lacks Taleporiinae, and Papua New Guinea lacks both Taleporiinae and Typhoniine. Indonesia lacks Naryciinae, which exist in Malaysia and Papua New Guinea.

In Indonesia, 69 bagworm species have been described in 6 subfamilies, and 2 species have still not been assigned to any subfamily (Figure 1) [9,17,25,34–37]. The subfamily Oiketicinae has the highest number of species (40 species), followed by Typhoniinae with 13 species. The number of bagworm species in Indonesia is approximately 31% of the number of species recorded in the Oriental region, or approximately 5.4% of all bagworm species worldwide [17]. This species number is greater than the number recorded in countries directly bordering Indonesia, namely, Malaysia and Papua New Guinea. In Malaysia, 19 bagworm species have been described in four subfamilies, and in Papua,
40 bagworm species have been described in four subfamilies [17,34–36]. In Indonesia and Malaysia, several species, such as *Pteroma pendula* (Joannis, 1929), *Mahasena corbetti* Tams, 1928, and *Metisa plana* Walker, 1855, were found to be important pests in oil palm and forestry crops [28,34–38–45]. *Pteroma planigrapheps* Hampson, 1893, previously distributed in Sri Lanka and India [17], is now widely distributed in Java and Sumatra [8,25,26,37]. In Papua New Guinea, three new bagworm species, *Amatissa nava* Hättenschwiler, 2013, and *Manatha conglacia* Hättenschwiler, 2013, have been reported as new bagworm pests in oil palm [35]. *Amatissa sentaniensis* Sobczyk, 2020, another species similar to *M. conglacia* [36], was introduced to Indonesia in 2021, in Central Kalimantan [46].

Bagworms are mostly concentrated in Western Indonesia, whereas they are less widespread in Eastern Indonesia, except for Papua, where many new species have been recently described (Figure 2). There is the possibility of a bias toward conducting research in Western Indonesia rather than in Eastern Indonesia. Today, approximately 16 species of bagworms are reported in Papua, whereas neighboring Papua New Guinea (same island) has around 40 species [17,36]. There are likely many species that have not yet been described in Papua.

![Figure 2. Distribution of bagworm species in Indonesia. Different colors represent different Islands. Data source [9,17,25,34–37].](image)

Bagworm biodiversity in Indonesia is quite high, including species that are not found on other islands (Table 1) [9,17,25,34–37]. Almost all islands have than 50% unique species, with the highest being Papua, except for Kalimantan, where the number of unique species is around 26%. Several species, such as *Eumeta variegatus* (Snellen, 1879), *Pagodiella heckmeyeri* (Heylaerts, 1885), and *M. plana*, were found in both Western and Eastern Indonesia. New bagworm species in Eastern Indonesia (eleven in Papua and two species in the Moluccas) have not been reported in Western Indonesia (Figure 2) [36].
Table 1. Species composition of bagworms species in Indonesia.

<table>
<thead>
<tr>
<th>Islands</th>
<th>No. of Total Species</th>
<th>No. of Endemic Species</th>
<th>Percentage of Specific Species (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sumatra</td>
<td>33</td>
<td>18</td>
<td>54.5</td>
</tr>
<tr>
<td>Java</td>
<td>22</td>
<td>13</td>
<td>59.1</td>
</tr>
<tr>
<td>Kalimantan</td>
<td>23</td>
<td>6</td>
<td>26.1</td>
</tr>
<tr>
<td>Sulawesi</td>
<td>3</td>
<td>1</td>
<td>33.3</td>
</tr>
<tr>
<td>East Nusa Tenggara</td>
<td>1</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Moluccas</td>
<td>4</td>
<td>3</td>
<td>75.0</td>
</tr>
<tr>
<td>Papua</td>
<td>16</td>
<td>12</td>
<td>75.0</td>
</tr>
</tbody>
</table>

Data source [9,17,25,34–37].

Most bagworms are herbivores and are reportedly associated with various plant species, such as ornamental, estate, and forest plants. Several ornamental plants, such as flamboyant, rose, orchid, Asoka, bougainvillea, hibiscus, euphorbia, Palmae, roselle, and allamanda, have been reported as infested by bagworms [47,48]. For estate crops other than oil palm, bagworm infestation has been reported in *Psidium guajava* L. and *Rutealis trisperma* (Blanco) Airy Shaw [49,50].

3. Pest Status of Bagworms in Indonesian Plantation Forests

Bagworm species associated with forest trees in Indonesia are presented in Table 2. All these species belong to the subfamilies Metisinae, Psychinae, and Oiketicinae. Their pest status in forest trees varies. Most bagworms are categorized as minor pests. However, some species, such as *P. plagiophleps* on *F. moluccana* (Figure 3a) and *Acanthopsyche* sp. on *Shorea leprosula* Miq., are major pests [8,51].

Figure 3. Some common bagworm species associated with Indonesian forest trees. Larvae are equipped with a bag as a morphologically unique feature: (a) *Falcataria moluccana* infested by *Pteroma plagiophleps*; (b) *Falcataria moluccana* infested by *Amatissa* sp.; (c) *Falcataria moluccana* infested by *Cryptothelea* sp.; (d) *Shorea balangeran* infested by *Pteroma* sp.; (e) *Shorea balangeran* infested by *Cryptothelea* sp.; (f) Mangrove infested by *Pagodiella* sp.

The infestation of bagworms on forest trees has mainly occurred in Fabaceae (especially *F. moluccana*), Dipterocarpaceae, and mangroves (Table 2). Early symptoms show small feeding holes on the leaves. The color of the leaves turns brown, with leaves eventually drying out completely. The infestation can cause the plant to become partially defoliated and weakened. In cases of severe infestation, complete defoliation may also occur, even...
following an infestation of the bark [52,53]. On the other hand, bagworms are rarely reported as major pests of eucalyptus and acacia, despite these two commodities being the most dominant species in Indonesian industrial forest plantations [2]. Several reports on bagworm infestations on \textit{Acacia mangium} Willd. only indicated minor attacks [37,54].

\textit{Pteroma plagiophleps}, as a member of Metisinae, is considered the most important pest in the forestry sector due to the wide range of forest trees used as hosts. Around 14 forest tree species are recorded as its host (Table 2). Severe infestation of \textit{P. plagiophleps} occurred on \textit{Pinus merkusii} Jungh. & de Vriese, \textit{F. moluccana} (Figure 4a), \textit{S. leprosula}, and \textit{Rhizophora} sp. The first record of a \textit{P. plagiophleps} outbreak was on the natural stands of \textit{P. merkusii} in North Sumatra in 1924, 1933, and throughout 1934 to 1938 (Figure 5) [11,30,31]. The outbreaks affected approximately 100,000 ha of natural pine stands and caused severe defoliation that continued for months during the outbreak, affecting resin production, especially in the most severely attacked sites [11,31].

Other outbreaks of \textit{P. plagiophleps} were then reported in other forest trees in different regions in Indonesia, mostly in plantation forests (Figure 5). \textit{Pteroma plagiophleps} outbreaks occurred in an industrial forest plantation in South Sumatra from 1994 to 1997 [31,55]. It attacked a five-year-old \textit{F. moluccana} plantation and caused severe defoliation [31,55]. In Java, \textit{P. plagiophleps} was considered a minor pest until the first outbreak reported in 1997 in \textit{F. moluccana} and \textit{A. mangium} plantations in West Java and Banten [37]. A \textit{P. plagiophleps} outbreak in \textit{F. moluccana} was then recorded in Central Java in 2008 [8]. Outbreaks affected hundreds of hectares in the \textit{F. moluccana} plantations, causing severe attacks and plant death [8]. In 2019, infestations continued to occur in Central and West Java [25]. Bagworm outbreaks in Central Java’s \textit{F. moluccana} plantations are becoming more frequent. Previously, outbreaks only occurred occasionally, but they have become more frequent every year [25].
In S. leprosula, severe infestations of *P. plagiophleps* were reported over 2–7 years in South Kalimantan [51]. Meanwhile, in mangrove tree *Rhizophora* sp., severe infestation of *P. plagiophleps* also occurred on the seedling in Aceh [56]. *Pteroma plagiophleps* infestations result from unsuccessful factors in mangrove planting, both in natural reforestation and plantation forests [29,56].

Minor infestations of *P. plagiophleps* were recorded in at least five species of dipterocarp. An infestation of *P. plagiophleps* on the seedling and plantation of *Shorea balangeran* Burck was reported in South Sumatra with low severity [57,58]. In West Kalimantan, infestation of *P. plagiophleps* was reported in *S. leprosula* with low–moderate severity [59]. In Java, minor infestations of *P. plagiophleps* were reported in *Shorea macrophylla macrophylla* (de Vriese) P.S. Ashton, *Shorea stenoptera* Burk., and *Anisoptera* sp. seedlings [60]. Furthermore, *P. plagiophleps* infestations of minor incidence and severity were also reported in other forest trees, such as *Azadirachta excelsa* (Jack) Jacobs in Bengkulu and South Sumatra [26,58,61], *Neolamarckia cadamba* (Roxb.) Bosser and *Maesopsis eminii* Engl. in Lampung [56], and *A. mangium* in West Java [37,62,63].

Outbreaks of *P. plagiophleps* in forest trees were also reported in India. The first outbreak of *P. plagiophleps* in India occurred in 1977 on *F. moluccana*, *D. regia*, and *A. nilotica* [31–33]. Infestations of *P. plagiophleps* were also reported on mangroves [64,65]. Another *Pteroma* species, *P. pendula*, has also been considered an important pest. Similar to *P. plagiophleps*, it has a wide host range [19]. It is the second most destructive bagworm pest of oil palm (*Elaeis guineensis* Jacq.) in Malaysia and Indonesia [66–68]. However, there are no reports of infestation in Indonesian forest trees, although, in Malaysia, it has been reported to infest *A. mangium* [67].

Other bagworms that cause severe infestation in Indonesian forest trees are *Acanthopsycha* and *Cryptothelea*. Akbar [51] reported an outbreak of *Acanthopsycha* sp. on *S. leprosula* in South Kalimantan. This species infested 2–7-year-old trees of *S. leprosula* and caused severe defoliation. An infestation of *Acanthopsycha* sp., together with *Pagodella* sp., in *Avicennia alba* Blume and *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff. caused severe defoliation in sapling levels in West Kalimantan [29].

Figure 5. Bagworm outbreaks recorded in Indonesia. Most of these cases occurred in Western Indonesia. Different colors indicate the province where the outbreak of bagworms was reported.
Cryptothelea is also an important bagworm infesting forest trees. This species is larger than Pteroma sp. or other species of bagworms (Figure 3). This species is commonly found in plantations rather than nurseries. The forest trees recorded as hosts are F. moluccana, Shorea selanica (Lam.) Blume, and S. balangeran. Generally, these bagworms are found in low population densities with other bagworm species [8,37]. Cryptothelea infestation in S. balangeran on peatland in Sumatra showed low severity [28]. However, repeated attacks can exacerbate the severity [57]. Attacks of Cryptothelea are also known in Avicennia sp. and Bruguiera sp. in Riau [69]. In pines, the outbreak of Cryptothelea variegata Snellen (1879) has been reported in a few instances [31].

Pagoda bagworms, Pagodiella sp., are often found in mangrove trees, both in nurseries and plantations (Figure 3) [27,70]. Pagodiella sp. sometimes causes severe damage to mangrove trees (Figure 4b). The attacks of Pagodiella sp. in West Kalimantan caused moderate–severe damage [29]. In Malaysia, Pagodiella sp. was also reported to cause severe defoliation [71]. Other forest trees that can host Pagodiella sp. are N. cadamba, A. excelsa, and Michelia champaca L. The level of infestation and severity is still relatively low [72]. Pagodiella sp. was also considered a severe pest of oil palm in Malaysia [73]. This pest has also attacked the Myrtaceae family [30].

<table>
<thead>
<tr>
<th>Bagworm Species</th>
<th>Host Plant</th>
<th>Host Stage</th>
<th>Level of Damage</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falcatoria moluccana</td>
<td>seedling, tree</td>
<td>minor–severe</td>
<td>Java, Sumatra</td>
<td>[8,25,33,56,74]</td>
<td></td>
</tr>
<tr>
<td>Acacia mangium</td>
<td>tree</td>
<td>minor</td>
<td>Java, Sumatra</td>
<td>[37,62,63]</td>
<td></td>
</tr>
<tr>
<td>Rhizophora sp.</td>
<td>tree</td>
<td>severe</td>
<td>Sumatra</td>
<td>[75]</td>
<td></td>
</tr>
<tr>
<td>Saterinia caseolaris</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[76]</td>
<td></td>
</tr>
<tr>
<td>Shorea leprosula</td>
<td>seedling, tree</td>
<td>minor–severe</td>
<td>Java, Kalimantan,</td>
<td>[58,59]</td>
<td></td>
</tr>
<tr>
<td>Shorea balangeran</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[57]</td>
<td></td>
</tr>
<tr>
<td>Shorea macrophylla</td>
<td>seedling</td>
<td>minor</td>
<td>Java</td>
<td>[60]</td>
<td></td>
</tr>
<tr>
<td>Shorea stenoptera</td>
<td>seedling</td>
<td>minor</td>
<td>Java</td>
<td>[60]</td>
<td></td>
</tr>
<tr>
<td>Anisoptera sp.</td>
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<td>minor</td>
<td>Java</td>
<td>[60]</td>
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</tr>
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<td>seedling, tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[26,58]</td>
<td></td>
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<tr>
<td>Neolamarckia cadamba</td>
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<td>minor</td>
<td>Sumatra</td>
<td>[56]</td>
<td></td>
</tr>
<tr>
<td>Maesaopsis eminii</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[56]</td>
<td></td>
</tr>
<tr>
<td>Pinus merkusi</td>
<td>tree</td>
<td>severe</td>
<td>Sumatra</td>
<td>[10,30,31]</td>
<td></td>
</tr>
<tr>
<td>Acanthopsyche sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Avicennia alba, Bruguiera parvifolia</td>
<td>tree</td>
<td>minor–moderate</td>
<td>Kalimantan</td>
<td>[29]</td>
<td></td>
</tr>
<tr>
<td>Shorea leprosula</td>
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<td>moderate–severe</td>
<td>Kalimantan</td>
<td>[61]</td>
<td></td>
</tr>
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<td>Clania sp.</td>
<td>Falcatoria moluccana</td>
<td>Seedling, tree</td>
<td>minor–severe</td>
<td>Java, Kalimantan</td>
<td>[25,77,78]</td>
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<td>Cryptothelea sp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Falcatoria moluccana</td>
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<td>minor–severe</td>
<td>Java</td>
<td>[8,25,77,78]</td>
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<td>Pinus merkusi</td>
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<td>severe</td>
<td>Sumatra</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shorea selanica</td>
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<td>minor</td>
<td>Kalimantan</td>
<td>[79]</td>
<td></td>
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<td>Avicennia sp.</td>
<td>tree</td>
<td>n.a.</td>
<td>Sumatra</td>
<td>[69]</td>
<td></td>
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<tr>
<td>Bruguiera sp.</td>
<td>tree</td>
<td>n.a.</td>
<td>Sumatra</td>
<td>[69]</td>
<td></td>
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<tr>
<td>Shorea balangeran</td>
<td>seedling, tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[27,57]</td>
<td></td>
</tr>
<tr>
<td>Mahasena corbetti</td>
<td>Neolamarckia cadamba</td>
<td>tree</td>
<td>moderate</td>
<td>Sumatra</td>
<td>[44]</td>
</tr>
<tr>
<td>Metisa plana</td>
<td>Shorea balangeran</td>
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<td>minor</td>
<td>Sumatra</td>
<td>[27,57]</td>
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<td>Anisoptera marginata</td>
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<td>minor</td>
<td>Sumatra</td>
<td>[80]</td>
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</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>Bagworm Species</th>
<th>Host Plant</th>
<th>Host Stage</th>
<th>Level of Damage</th>
<th>Location</th>
<th>Reference</th>
</tr>
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<tbody>
<tr>
<td>Pagodiella sp.</td>
<td>Avicennia alba, Bruguiera parviflora</td>
<td>tree</td>
<td>minor–moderate</td>
<td>Kalimantan</td>
<td>[29]</td>
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<tr>
<td>Rhizophora apiculata</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra, Sulawesi</td>
<td>[27,70]</td>
<td></td>
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<tr>
<td>Neolamarckia cadamba</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[72]</td>
<td></td>
</tr>
<tr>
<td>Azadirachta excelsa</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[72]</td>
<td></td>
</tr>
<tr>
<td>Michelia champaca</td>
<td>tree</td>
<td>minor</td>
<td>Sumatra</td>
<td>[72]</td>
<td></td>
</tr>
<tr>
<td>Amatissa sp.</td>
<td>Falcataria moluccana</td>
<td>seedling, tree</td>
<td>minor–severe</td>
<td>Java, Kalimantan</td>
<td>[8,37,77,78]</td>
</tr>
<tr>
<td>Chalia javana</td>
<td>Falcataria moluccana</td>
<td>tree</td>
<td>minor</td>
<td>Java</td>
<td>[25]</td>
</tr>
<tr>
<td>Kophene cuprea</td>
<td>Falcataria moluccana</td>
<td>tree</td>
<td>minor</td>
<td>Java</td>
<td>[25]</td>
</tr>
<tr>
<td>Psyche sp.</td>
<td>Falcataria moluccana</td>
<td>tree</td>
<td>severe</td>
<td>Java</td>
<td>[37]</td>
</tr>
<tr>
<td>Acacia mangium</td>
<td>tree</td>
<td>n.a.</td>
<td>Java</td>
<td>[37]</td>
<td></td>
</tr>
</tbody>
</table>

Remark: n.a: not assessed.

Three major bagworm pests (M. plana, P. pendula, and M. corbetti) in oil palm [38–44,73] were also found in Indonesian forest trees. However, infestation was still at a minor–moderate level. Infestation of M. plana was reported in S. balangeran in South Sumatra at a minor to moderate level [28]. Metisa plana has been found in the dipterocarp Anisoptera marginata Korth nursery and caused moderate damage [80]. Similarly, M. corbetti has attacked N. cadamba stands with moderate damage in Sumatra [44]. The diffusion of this bagworm should be monitored because forest trees around oil palm plantations can act as alternative hosts [34].

In addition to the bagworm species mentioned previously, several other bagworm species, including Amatissa sp., Chalia javana Heylaerts, 1885, Kophene cuprea Moore, 1879, and Psyche sp., were reported to be associated with F. moluccana plants, except Psyche, which is also found in A. mangium [8,25,37,63,78]. An unidentified bagworm was also reported in Shorea spp. in East Kalimantan and specifically on S. leprosula and S. selanica in West Java [10,81].

In Indonesia, bagworm outbreaks on forest trees have been recorded on three main islands: Java, Sumatra, and Kalimantan (Figure 5). This may relate to the distribution of plantation forests, which are mostly concentrated on these three islands [2]. Other bagworm attacks have occurred in mangrove stands in Sulawesi [70]. Outbreaks of bagworms are no less important than those of other pests. Although no economic loss data have been reported on Indonesian forest trees, reports on oil palm plantations can provide an overview of the impact of bagworm outbreaks. Wood et al. [82] reported crop losses in oil palm up to 40–50% due to severe defoliation caused by bagworms in Malaysia. Another study on oil palm also reported that approximately 40% of crop losses were due to bagworm outbreaks [83,84].

4. The Key Factors That Lead to Bagworm Outbreaks in Indonesian Plantation Forests

The population dynamics of bagworms are not fully understood. Populations are usually maintained at a low level, but they can increase sharply in a short time under particular conditions. Nair and Mathew [33] categorized the level of bagworm infestation into three types: (1) sparse infestations (bagworm infestations that occur with a low number of bagworm populations in most host plants); (2) dense infestations (bagworm infestations that occur in isolated and individual plants); and (3) heavy outbreaks (large-scale bagworm infestations that affect many plants in a patch, e.g., in F. moluccana and A. nilotica). Outbreaks can also occur in other tree species that are not a primary host of bagworm. For instance, a bagworm outbreak occurred in Eucalyptus tereticornis Sm. in a location polluted by sulfur dioxide, despite this tree not being the primary host of the bagworm [3]. Therefore, host stress has been indicated as a predisposing factor for bagworm outbreaks [31].
This review emphasizes that the emergence of bagworm outbreaks is influenced by multiple factors: bagworm biology, host plants, natural enemies, climate, and silvicultural practices. The interaction among these factors significantly influences the incidence of bagworm outbreaks.

4.1. Reproductive Strategy and Mode of Dispersal

The life cycle and fecundity of bagworms significantly influence the occurrence of bagworm outbreaks [19,85,86]. The fecundity of bagworms varies greatly depending on the species. Small-sized bagworms such as *Psyche*, *Pterona*, and *M. plana* produce fewer eggs than large-sized species, such as *Eumeta variegata* (Snellen, 1879) and *Eumeta crameri* (Westwood), 1854. However, *M. corbetti*, categorized as a smaller-sized bagworm, produces a large number of eggs [19].

The body size and the developmental phase of the bagworms affect the preferences of natural enemies in finding hosts. Parasitoids avoid small and early stage bagworms [87]. Some large parasitoids, such as *Xanthopympla* sp., and tachinid flies prefer *Cryptothelea crameri* (Westwood), 1854 as a host compared to other smaller bagworms, such as *P. plagiophleps* [25]. In Java, outbreaks of *P. plagiophleps* in *F. moluccana* are more common than *Cryptothelea*. The *Cryptothelea* population affecting *F. moluccana* is always low, even though the fecundity is high. Furthermore, *P. plagiophleps* outbreaks often occur, even though their fecundity is lower [19,25].

The short life cycle significantly influences the incidence of bagworm outbreaks. For instance, outbreaks can occur more easily in *P. pendula* than in *M. plana*; this is due to the shorter life cycle of *P. pendula* compared with *M. plana*. The life cycles of *P. pendula* and *M. plana* range from 48 to 50 days and 92 to 97 days, respectively, whereas their number of generations is eight and three, respectively [86].

Dispersal strongly impacts population dynamics, and it is the most important factor influencing population size [88,89]. The different dispersal modes among bagworm species influence the incidence of outbreaks [85].

The neonate larvae of *P. pendula* crawl immediately to the host plant. Furthermore, the neonate larvae of *M. plana* disperse through a long silk thread in a process called ballooning. The differences in dispersal mode are probably related to the number of neonate larvae produced by each species. Ballooning is the primary dispersal method for low-density larvae, with wind assisting. The ballooning of *M. plana* larvae in oil palm trees is greater for females than males [88]. The relatively uniform distribution of *M. plana* in oil palm plantations results from a density-dependent dispersal, by simultaneously stabilizing populations in heavily infested palms and redistributing larvae in lightly infested palms. There is another mode of dispersal that allows bagworms to spread further. Phylogeographic analysis on *M. plana* in oil palm plantations indicated the occurrence of gene flow between populations due to its ability to fly further or be accidentally transported and spread by human activities [90].

4.2. Climate

Climatic factors affecting the development of bagworms are temperature and rainfall. Increasing temperature accelerates the rate of pest consumption, development, and mobility, as well as fecundity, survival, generation time, population density, and geographic range [91]. Pest metabolism tends to increase twofold with an increase in temperature of 10 °C [91]. An increase of 2 °C can cause pests to experience five life cycles per year [91]. Temperature affects the development time of reproduction and the fecundity of the bagworm *Thyridopteryx ephemeraeformis* (Haworth, 1803) [92,93]. An increase in air temperature over the usual values induces a shorter life cycle and higher fecundity in *T. ephemeraeformis* [92–94].

Rainfall also affects the behavior and survival of bagworms. Rainfall had a more deleterious effect on the population of *M. plana* than *P. pendula* due to the greater ballooning habits of neonate larvae [95]; this explains why *P. pendula* is more resistant to wet weather
and can initiate outbreaks early in dry periods [94]. In the case of bagworm outbreaks in *F. moluccana* stands in Java, rainfall significantly influences their population dynamics [25]. When the rainfall is high during the rainy season, the bagworm population decreases because the heavy rain causes the bagworms attached to *F. moluccana* leaves to fall away [25].

The diversity, abundance, and distribution of natural enemy populations affect bagworm populations [84,96]. Environmental factors such as light intensity, temperature, and relative humidity affect the diversity and activity of bagworms’ natural enemies. Natural enemies (hymenopterous parasitoids and reduviid predatory insects) of bagworms in oil palm plantations are significantly more active under conditions of moderate light intensity (<8000 fc), medium humidity levels (50–69%), and medium temperatures (30–34 °C) [95].

*Pteroma plagiophleps* has 4–6 generations per year; however, population peaks only occur one to two times during the dry season [31]. Higher temperatures during the dry season enhance the development rate of bagworms [96]. In this situation, the rate of entomopathogenic attacks also decreases [85]. Bagworm attacks on *F. moluccana* are reported annually by field workers in many locations in Java, with fluctuating rates of infestation [54].

### 4.3. Monoculture Plantation

There are two management forms in small-holder forest plantations, a complex agroforestry system and a monoculture system [97]. The first form of agroforestry combines forest trees with some fruit trees, creating a mixed-species plantation. The second form of agroforestry combines forest trees with crops/horticulture and crops. Referring to species composition, the second form is a mixed-species plantation; however, its stand structure is classified as a monoculture.

The presence and abundance of host plants are supporting factors for bagworm outbreaks. The monoculture pattern is considered an efficient cultivation practice to increase productivity. However, monoculture also increases the risk of pest population outbreaks [88]. Large-scale monoculture stands provide an abundant food source to support large bagworm populations. Low plant species diversity in monocultures encourages the development of pest populations [98]. Host abundance and low natural enemy abundance in monoculture patterns, accompanied by host suitability, are more likely to trigger outbreaks [99].

Host plants influence the biological performance of bagworms, such as the outbreak of *P. plagiophleps* on *F. moluccana* plants in several areas of Java (Figure 6). Although polyphagous, *P. plagiophleps* shows differences in life cycle performance in other hosts. Other research has shown how food quality and environmental conditions affect the rate of bagworm development [25,100]. In addition, the quality of the host plant changes the insect’s reproductive strategy, through factors such as size, egg quality, and oviposition behavior [101].

The simplified ecosystem in plantation forests appears sensitive to natural disturbance [102]. Therefore, using mixed species in plantation forests may be an attractive alternative to achieve sustainability goals. Previous research showed that the disturbance caused by insect pests in forestry systems is lower in more diversified ecosystems than in simplified ecosystems [103–108].
Two classic hypotheses have been proposed to explain the mechanism of decreasing insect pest populations in diversified ecosystems [109–112]. The first mechanism, the so-called “resource concentration hypothesis”, explains that a decreasing insect pest population is caused by decreasing pest immigration and increasing pest emigration. A diversified ecosystem with non-host trees causes signal disruption of visual and olfactory cues and triggers the pest to leave. The second mechanism, known as the “enemies hypothesis”, postulates that a decreasing insect pest population occurs due to increasing natural enemies. A diversified ecosystem provides better shelter opportunities and prey resources for natural enemies. Some previous studies showed that the diversity and abundance of natural enemies in mixed plantations are higher than in monocultures [113,114].

4.4. Cultivation Practices

Cultivation practices affecting bagworm outbreaks include planting patterns and insecticide application. Monocultures can cause outbreaks, as described above. The use of chemical insecticides directly affects the potential for outbreaks in bagworms. Inappropriate use of synthetic chemical insecticides with a broad spectrum negatively impacts natural enemies as they are more susceptible to insecticides [85]. Chemical control should only be conducted if the bagworm population reaches the threshold; if the bagworm’s life cycle is known, the control will be effective. Furthermore, the application should be performed with the correct dose, at the appropriate time [85].

Understory vegetation indirectly affects bagworm outbreaks. Total weeding, without leaving any refugia, around F. moluccana plantations in Java can reduce the populations of natural enemies. The destruction of ground vegetation was reported to cause food deprivation and shelter for parasitoids, leading to bagworm outbreaks in oil palm plantations [86].

4.5. Natural Enemies

The presence of natural enemies plays an important role in controlling bagworm populations in oil palm plantations [86,115]. Predators, parasitoids, and some entomopathogenic fungi significantly contribute to the mortality of P. pendula and M. plana in oil palm plantations [68,86,115,116]. Four species of parasitoids were recorded attacking P. pendula in an oil palm plantation, namely, Pediobius imbrues Walker (1846) (Hymenoptera: Eulophidae), Pediobius elasmi (Ashmead, 1904) (Hymenoptera: Eulophidae), Dolichogenidea metesae (Krombh.) (Hymenoptera: Eulophidae), and

![Diagram](image-url)
In M. plana, the recorded parasitoids were D. metesae (Hymenoptera: Braconidae), Apanteles aluaella (Nixon, 1967) (Hymenoptera: Braconidae), Aulosaphes psychidivorus Muesebeck, 1935 (Hymenoptera: Braconidae), Buysmania oxymora (Tosquinet, 1903) (Hymenoptera: Ichneumonidae), Elasmus sp. (Hymenoptera: Eulophidae), Sympiesis sp. (Hymenoptera: Eulophidae), and Tetristachus sp. (Hymenoptera: Eulophidae) [87]. Callimerus arcufer Chapin, 1919 (Coleoptera: Cleridae) larvae and Cosmolestes picticeps (Stal, 1859) (Hemiptera: Reduviidae) were common predators found to attack P. pendula [86]. Two species of entomopathogenic fungi affected bagworm populations in oil palm plantations, namely, Paecilomyces fumosoroseus (Wize) A.H.S. Br. & G. Sm. (1957) and Metarhizium anisopliae (Metschn.) Sorokin (1883) [68, 86].

Natural enemies were also reported to significantly influence bagworm populations in Indonesia’s oil palm plantations. Parasitoids Brachymeria sp. (Hymenoptera: Chalcididae), Eurytoma sp. (Hymenoptera: Eurytomidae), Tetrastichus sp. (Hymenoptera: Eulophidae), and D. metesae (Hymenoptera: Braconidae) were reported to suppress M. plana populations in oil palm plantations [114, 117]. Oecophylla smaragdina (Fabricius, 1775) (Hymenoptera: Formicidae) was the most common predator attacking M. plana in oil palm plantations [118].

In Indonesian forest trees, some species of parasitoids and entomopathogenic fungi were also recorded attacking P. plagiophelps, C. javana, and C. crameri in an F. moluccana plantation in Java [25]. The recorded parasitoids were Goryphus sp. (Hymenoptera: Ichneumonidae), Sympiesis sp. (Hymenoptera: Eulophidae), Elasmus sp. (Hymenoptera: Eulophidae), Spathius sp. (Hymenoptera: Braconidae), Brachymeria carinata Joseph, Narendran & Joy, 1970 (Hymenoptera: Chalcididae), Trichogramma sp. (Hymenoptera: Trichogrammatidae), D. metesae (Hymenoptera: Braconidae), Xanthopympla sp. (Hymenoptera: Ichneumonidae), Pedioius sp. (Hymenoptera: Eulophidae), and Eurytoma sp. (Hymenoptera: Eurytomidae). The recorded entomopathogenic fungi were Paecilomyces sp. and Beauveria bassiana (Bals.-Criv.) Vuill. (1912).

5. Bagworm Outbreak in Falcataria moluccana Plantation: Case in Java

If a favorable climate, decreasing natural enemies, and bagworm biology lead to outbreaks, why do outbreaks only occur in F. moluccana? It is challenging to answer this question. However, we can assume the cause by identifying the difference between F. moluccana and other species. As illustrated in Figure 6, in addition to the unexplained preference of pests for certain host species, outbreaks in F. moluccana are most likely influenced by cultivation patterns, such as agroforestry with monocultures, lack of management capacity, and the lack of a pest monitoring system.

Falcataria moluccana is the most popular tree in small-holder plantations, especially in Java. The population of F. moluccana in Java constitutes almost 50% of the total forest tree species in small-holder forests [4]. The massive planting of F. moluccana in Java began in the 1970s with a reforestation program initiated by the government of Indonesia and accelerated by the “sengonisi” (planting F. moluccana) program from 1988 to 1993 [119]. Public interest in planting this species continues every year. Over ten years, between 2003 and 2013, the population of this tree increased by 448% [120]. As previously stated, an outbreak of bagworms, identified as P. plagiophelps, was reported in 1997 in West Java and Banten [37] when the population of F. moluccana was increasing. Furthermore, hundreds of hectares of an F. moluccana plantation were affected by a bagworm outbreak reported in Central Java in 2008 [8]. Bagworm outbreaks were widespread, causing severe attacks and plant death. From these two events, we assume that the bagworm outbreak in F. moluccana was associated with a rapid increase in the host population.

Falcataria moluccana plantations are generally located in the areas surrounding agricultural fields. In these fields, the practice of controlling pests and diseases using chemical pesticides is highly prevalent [121]. Pesticides are used in massive and continuous quan-
tities, with inappropriate pesticides being prevalent in many areas [121,122]. The use of pesticides with a broad spectrum poses a high risk to natural enemies [123]. Although there has been no report in this regard in Java, population reduction in bagworm natural enemies may also occur, so it becomes one factor that plays a role in outbreaks.

Another factor contributing to bagworm outbreaks is the lack of management capacity. A farmer’s knowledge and awareness of well-managed forest tree cultivation is key to the success of pest management [124–127]. Farmers apply minimal or even no fertilizer to forest tree plantations. Fertilization amendment and stand composition management are two silviculture practices most related to stand resistance for pest infestations. Fertilization is important to ensure and provide nutrients for plants and to ensure their vigor [128–130]. Most farmers also have limited knowledge about forest pests and diseases, including bagworms. Although farmers can discern from the symptoms that there is a pest attack, they cannot identify the type of pest that is causing it. Little or no control is taken when pest infestation occurs; therefore, it is difficult to control and prevent bagworms from spreading.

Monitoring is the key to reducing the spread of the outbreaks. Since plantation forests cover large and remote areas, remote sensing is needed to identify and map plant distribution [131]. Dispersal patterns are determined by monitoring pests using species traceability [132]. Information about plant damage is collected from field reports from farmers or field workers. Remote sensing technology can be used to map pest attacks among plants [133,134]. An early warning system should involve multiple parties and requires commitment. The government should build a network, provide research and technology facilities, and formulate policies to control the system [133]. Meanwhile, scientific panels consisting of research institutions, universities, and scientific communities should perform basic and applied research, the compilation of databases, and the development of models and control systems [134]. Farmers and field officers should be actively involved in reporting incidents and implementing policies at the field level. Although there are government regulations governing forest protection, unfortunately, monitoring systems for forest pests are not as advanced as in agriculture.

6. Conclusions

This review describes the diversity of bagworms, their pest status, and the factors contributing to outbreaks in Indonesia. Approximately 71 bagworm species were recorded in Indonesia, comprising approximately 31% of the species recorded in the Oriental region and more than 5% of all bagworm species in the world. Bagworm species are mostly found in Western Indonesia, whereas there are fewer species in Eastern Indonesia, except for Papua, where many new species have recently been described. More than ten species of bagworms have been reported as pests in Indonesian forest trees. *Pteroma plagiophleps* is considered the most important bagworm pest in Indonesian plantation forests, followed by *Pagodiella* sp. and *Acanthopsyche* sp. Bagworms infest many forest tree species. However, bagworm outbreaks have only occurred in pines, *Shorea* spp., mangroves, and *Falcataria moluccana*. These pest outbreaks cause severe damage and even plant death. Bagworm outbreaks are influenced by multiple factors, such as the biology of bagworms, their hosts and natural enemies, climate, and silvicultural practices. This review provides comprehensive information about bagworms that is important in supporting sustainable plantation forests. Further studies should be performed to better understand bagworm infestations in Indonesian forest plantations, for example with more extensive use of molecular approaches, which are still limited. Species identification by molecular approaches would be particularly useful to increase our knowledge of bagworm diversity and conservation and to relate their population distribution and genetic variation with outbreaks.

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