UNIVERSITAS INDONESIA

THE FIG WASPS OF EX-SITU CONSERVATION AREAS OF DEPOK AND BOGOR: SYMBIOSIS REVISITED

THESIS

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FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
PROGRAM STUDI BIOLOGI
PROGRAM PASCASARJANA
DEPOK
JULY 2011

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Submitted as a requirement for the Master of Science degree

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Tanda Tangan	**:**
Tanggal	**: 15 Juli 2011**

HALAMAN PENGESAHAN

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Program Studi : Biologi

Judul Tesis : THE FIG WASPS OF EX-SITU CONSERVATION AREAS OF DEPOK AND BOGOR: SYMBIOSIS REVISITED

Telah berhasil dipertahankan di hadapan Dewan Penguji dan diterima sebagai bagian persyaratan yang diperlukan untuk memperoleh gelar Magister Sains pada Program Studi Biologi Program Pascasarjana, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia.

DEWAN PENGUJI

Pembimbing : Dr. Rosichon Ubaidillah, M.Sc. ( )

Pembimbing : Dr. Adi Basukriadi, M.Sc. ( )

Penguji : Andrio Adiwibowo, M.Sc. ( )

Penguji : Mega Atria, M.Si. ( )

Ditetapkan di : Depok

Tanggal : 15 Juli 2011

FOREWORDS

Alhamdulillahirobbil'alamin. Praise ALLAH, the creator of this magnificent universe filled with rainbows that would only increase our awe when un-weaved by science. *Shalawat* and *Salam* are to the prophet Muhammad S.A.W. who had brought forth the light of truth that honors the search of truth. The author would like to thank the following:

(1) Dr. Rosichon Ubaidillah M.Sc. and Dr. Adi Basukriadi M.Sc. as the author's advisors for this research project and also for their knowledge of entomology and ecology;

(2) Andrio Adiwibowo M.Sc. and Mega Atria M.Si. as this research project's assessors, for their comments, inputs, and discussions;

(3) Pak Uyung, Mas Anto, and Mba' Fatimah for their help while preserving and identifying the specimens in LIPI;

(4) The author's mom, Ibu Sumatri, and dad, Bapak Suhanto, for without them, and their genes, the author would not be here. To all my brothers, sisters, cousins, nieces and nephews, thanks for making the author's life at home worthwhile; and

(5) All of the specimens of this research, and all other specimens that the author had made his entire life, for their sacrifice as the author hone his scientific skills.

The author realized that this thesis would be far from perfect but still hoped that it could be useful, especially for the management of UI and KRB, and to all that read it.

The author

2011

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ABSTRACT

Name : Nugroho Ponco Sumanto

Study program: Master Program, Conservation Biology

Title : FIG WASPS (Hymenoptera; Chalcidoidea) OF TREE AND LARGE SHRUB-FORMING FIGS IN THE EX-SITU CONSERVATION AREAS OF THE UNIVERSITAS INDONESIA (UI) DEPOK AND KEBUN RAYA BOGOR (KRB), WEST JAVA, INDONESIA

A research to know the fig wasps of the Universitas Indonesia (UI) and Kebun Raya Bogor (KRB) has been done from January 2010 until December 2010. This research was aimed to record the pollinating and non-pollinating fig wasps of UI and KRB, to later compare the result with reports from previous researches. This research would also confirm whether symbiotic breakdown occurs in the research areas. A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) were chosen to be sampled. From those trees and shrubs, 10 *sycone* were taken. The wasps were then reared inside the *sycone* to later be preserved using the method of Noyes (1982). After identification, 7 wasp species were found. *Ceratosolen marchali* Mayr, *Ceratosolen fusciceps* Mayr, *Liporrhopalum tentacularis* Grandi, *Philotrypesis pilosa* Mayr, *Boučeka percaudata* Bouček, *Apocrytophagus testaceus* Mayr, and *Apocrypta bakeri* Joseph were found. From those wasps, 3 species are pollinators and the rest are non-pollinating fig wasps (NPFW). The wasps were found from *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana* and *Ficus glomerata*. Some differences between the specimens of this research with the descriptions from other research were explained. Using Krukal-Wallis analysis, this research discovered that the head width (HW) and front femur length (FFL) of *Ceratosolen marchali* that were found in *Ficus glomerata* were smaller than the ones found in other fig species (p HW same = 0.0002; p FFL same = 0.0002), while the ovipositor length (OvL) were the same (p OvL same = 1). Though still statistically smaller, the HW and FFL value of the *Ceratosolen marchali* found in *Ficus glomerata* were closer to that of *Ceratosolen fusciceps*. The result of the research also shows that the one-to-one symbiosis between *Ceratosolen marchali* and its host (*Ficus hispida*) has been broken. In this research, *Ceratosolen marchali* were found pollinating *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, and even *Ficus glomerata*. For *Ficus montana* and *Ficus glomerata*, it seems that their symbiosis with their pollinators were still maintained.

Key words: Chalcids; Ficus*; Figs; Kebun Raya Bogor; Non Pollinating Fig Wasps; Pollinators; Symbiosis; Symbiotic breakdown; Universitas Indonesia*.

ABSTRAK

Nama : Nugroho Ponco Sumanto
Program studi : S2-Biologi
Judul : TAWON *Ficus* (Hymenoptera; Chalcidoidea) DARI *Ficus* HABITUS POHON DAN SEMAK BESAR PADA DAERAH KONSERVASI EX-SITU DI UNIVERSITAS INDONESIA (UI) KAMPUS DEPOK DAN KEBUN RAYA BOGOR (KRB), JAWA BARAT, INDONESIA

Telah dilakukan penelitian untuk mengetahui tawon *Ficus* Universitas Indonesia (UI) dan Kebun Raya Bogor (KRB) telah dilakukan dari Januari 2010 sampai dengan Desember 2010. Penelitian bertujuan untuk melihat tawon *Ficus* penyerbuk dan bukan penyerbuk UI dan KRB, untuk kemudian dibandingkan dengan hasil laporan dari penelitian sebelumnya. Penelitian ini juga akan mengkonfirmasi apakah keruntuhan simbiosis terjadi di daerah penelitian. Sebanyak 56 *Ficus habitus* pohon dan semak belukar (dari 9 spesies *Ficus*) di UI dan 34 *Ficus habitus* pohon dan semak belukar (dari 34 spesies *Ficus*) dipilih sebagai sampel. Dari pohon dan semak tersebut, 10 sycone diambil. Tawon tersebut kemudian dipelihara di dalam *sycone* untuk kemudian diawetkan dengan menggunakan metode Noyes (1982). Setelah identifikasi, 7 spesies tawon ditemukan. *Ceratosolen marchali* Mayr, *Ceratosolen fusciceps* Mayr, *Liporrhopalum tentacularis* Grandi, *Philotrypesis Agrimonia* Mayr, *Boučeka percaudata* Bouček, *Apocrytophagus testaceus* Mayr, dan *Apocrypta bakeri* Yusuf ditemukan dalam penelitian. Dari tawon-tawon tersebut, 3 spesies merupakan penyerbuk dan sisanya adalah tawon bukan penyerbuk / *non-pollinating fig wasps* (NPFW). Tawon-tawon tersebut ditemukan di *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana* dan *Ficus glomerata*. Beberapa perbedaan antara spesimen penelitian ini dengan deskripsi dari penelitian lainnya kemudian dijelaskan. Dari hasil analisis Krukal-Wallis, penelitian ini menemukan bahwa lebar kepala / *head width* (HW) dan panjang *femur* bagian depan / *front femur length* (FFL) dari *Ceratosolen marchali* yang ditemukan di *Ficus glomerata* lebih kecil dibandingkan dengan yang ditemukan pada spesies *Ficus* lainnya [p (sama) HW = 0,0002; p (sama) FFL = 0,0002], sedangkan panjang ovipositor / *ovipositor length* (OvL) yang sama [p (sama) OvL = 1]. Meskipun lebih kecil secara statistik, nilai HW dan FFL dari *Ceratosolen marchali* ditemukan di *Ficus glomerata* lebih dekat dengan *Ceratosolen fusciceps*. Hasil penelitian juga menunjukkan bahwa simbiosis "one-to-one" antara *Ceratosolen marchali* dan inang tawon tersebut (*Ficus hispida*) telah rusak. Dalam penelitian ini, *Ceratosolen marchali* ditemukan menyerbuki *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, dan bahkan *Ficus glomerata*. Untuk *Ficus montana* dan *Ficus glomerata*, tampaknya simbiosis mereka dengan penyerbuk mereka masih dipertahankan.

Kata kunci: Chalcid; *Ficus*; Kebun Raya Bogor; Keruntuhan simbiosis; Penyerbuk; Simbiosis; Tawon *Ficus* bukan penyerbuk; Universitas Indonesia.

ABSTRACT

Name : Nugroho Ponco Sumanto

Study program: Master Program, Conservation Biology

Title : COMPARING UNIVERSITAS INDONESIA (UI) DEPOK AND KEBUN RAYA BOGOR (KRB), WEST JAVA, INDONESIA, FROM THEIR FIG WASPS OF TREE AND LARGE SHRUB-FORMING FIGS: WITH A SPECIAL VIEW TOWARDS THE EFFECTS OF FRAGMENTATION TO THE FIG WASP COMMUNITY

A research concerning the fig wasp community of UI and KRB was done in August–September 2010. The research was aimed to find out and compare the fig wasp diversity of UI and KRB. Fragmentation was chosen as a view topic for this research because fragmentation could trigger decay in the fig-fig wasp community. *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana*, and *Ficus glomerata* was chosen to be compared. From those trees and shrubs, 10 *sycone* were taken. The wasps were then reared inside the *sycone* to later be preserved using the method of Noyes (1982). Using PAST software, a cluster analysis with single linkage algorithm, using Morisita's similarity index was done to depict the similarity between the fig species and also between the wasp species. The mean value of the wasp community was used to calculate the Shannon (H) and evenness indices. From the analysis done, it's known that the fig species in UI may not have a similar wasp community with their KRB counterpart. Though the three pollinator wasp species has a different host preference, it was found that a symbiotic breakdown might have occurred in both UI and KRB. It was found that *Ficus glomerata* of KRB and *Ficus hispida* var. *badiostrigosa* of UI has the biggest diversity value. The proportions of the pollinators against the non-pollinating fig wasps (NPFW) were also calculated to compare UI and KRB based on their fragmentation level. This comparison would only compare *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica*. From the comparisons, *Ficus hispida* var. *badiostrigosa* and *Ficus septica* shows that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.2396 & 0.1416]. For *Ficus hispida* var. *hispida* however, the result shows that pollinator proportion would be higher in areas with higher fragmentation level [p (uncorr) = 0.0637]. This pattern was possibly the result of the symbiotic breakdown that happened to the 3 fig species. After compiling the proportion data for the 3 fig species, it shows that that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.4349]. This research shows that though fragmentation affects the pollinator-NPFW proportion, symbiotic breakdown could change the relationship pattern between fragmentation and pollinator-NPFW proportion.

Key words: Diversity value; Fig; Fig wasp; Fragmentation; Host preference; Non pollinating fig wasp; Pollinator wasp; Symbiotic breakdown.

ABSTRAK

Nama : Nugroho Ponco Sumanto

Program studi : S2-Biologi

Judul : MEMBANDINGKAN UNIVERSITAS INDONESIA (UI) KAMPUS DEPOK DENGAN KEBUN RAYA BOGOR (KRB), JAWA BARAT, INDONESIA, MENGGUNAKAN TAWON *Ficus* DARI *Ficus* HABITUS POHON DAN SEMAK BESAR YANG ADA DI KEDUA DAERAH: DENGAN PANDANGAN MENGENAI EFEK FRAGMENTASI KEPADA KOMUNITAS TAWON *Ficus*

Sebuah penelitian mengenai komunitas tawon *Ficus* UI dan KRB dilakukan pada bulan Agustus-September 2010. Penelitian bertujuan untuk mengetahui dan membandingkan keanekaragaman tawon *Ficus* UI dan KRB. Fragmentasi dipilih sebagai topik penelitian ini karena fragmentasi dapat memicu peluruhan di masyarakat tawon *Ficus*. *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana*, dan *Ficus glomerata* dipilih untuk dibandingkan. Dari *Ficus habitus* pohon dan semak, 10 *sycone* diambil. Tawon kemudian dipelihara di dalam sycone untuk kemudian diawetkan dengan menggunakan metode Noyes (1982). Menggunakan perangkat lunak PAST, analisis cluster dengan algoritma *single linkage*, menggunakan indeks kesamaan Morisita dilakukan untuk menggambarkan kesamaan antara spesies *Ficus* dan juga antara spesies tawon. Nilai rata-rata masyarakat tawon digunakan untuk menghitung indeks Shannon (H) dan indeks kemerataan. Dari analisis yang dilakukan, diketahui bahwa spesies *Ficus* di UI mungkin tidak memiliki pola komunitas tawon yang sama dengan mitra KRB mereka. Meskipun ketiga spesies tawon penyerbuk memiliki preferensi inang yang berbeda, ditemukan bahwa keruntuhan simbiosis mungkin terjadi di UI dan KRB. Ditemukan bahwa *Ficus glomerata* di KRB dan *Ficus hispida* var. *badiostrigosa* di UI memiliki nilai keanekaragaman terbesar. Proporsi dari tawon penyerbuk terhadap tawon *Ficus* bukan penyerbuk / non-pollinating fig wasp (NPFW) juga dihitung untuk membandingkan UI dan KRB berdasarkan tingkat fragmentasi. Perbandingan tersebut hanya membandingkan *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, dan *Ficus septica*. Dari perbandingan, *Ficus hispida* var. *badiostrigosa* dan *Ficus septica* menunjukkan bahwa proporsi penyerbuk akan lebih rendah di daerah yang mempunyai tingkat fragmentasi lebih tinggi [p (uncorr) = 0,2396 & 0,1416]. Namun, hasil untuk *Ficus hispida* var. *hispida* menunjukkan bahwa proporsi penyerbuk akan lebih tinggi di daerah dengan tingkat fragmentasi tinggi [p (uncorr) = 0,0637]. Pola tersebut mungkin adalah hasil dari keruntuhan simbiosis yang terjadi pada ketiga spesies ara. Setelah data proporsi kompilasi untuk ketiga spesies ara dianalisis, hasilnya menunjukkan bahwa proporsi penyerbuk akan lebih rendah di daerah dengan tingkat fragmentasi tinggi [p (uncorr) = 0,4349]. Penelitian ini menunjukkan bahwa meskipun fragmentasi mempengaruhi proporsi penyerbuk-NPFW, keruntuhan simbiosis dapat mengubah pola hubungan antara fragmentasi dan proporsi penyerbuk-NPFW.

Kata kunci: *Ficus*; Fragmentasi; Keanekaragaman; Keruntuhan simbiosis; Preferensi inang; Tawon *Ficus*; Tawon *Ficus* bukan penyerbuk; Tawon penyerbuk.

CONTENTS

Name: Nugroho Ponco Sumanto (0806420386) Date:

Title : THE FIG WASPS OF EX-SITU CONSERVATION AREAS OF DEPOK AND BOGOR: SYMBIOSIS REVISITED

Thesis Supervisors: Dr. Rosichon Ubaidillah.
Dr. Adi Basukriadi.

SUMMARY

As sanctuaries, the Universitas Indonesia (UI) Depok and Kebun Raya Bogor (KRB) should maintain the diverse animals and plants inside their territories. The genus *Ficus*, or better known as figs, that could be found in UI and KRB would be an important resource as well as being a group of species that should be maintained due to the sanctuary function of those areas. To maintain the figs, we should maintain their pollinators. The problem is that there are only a few researches about the fig wasps of KRB and probably none about the ones in UI. In addition, we did not know whether the symbiosis of the fig-fig wasps still exists or not.

This research was done from January 2010 until December 2010. A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) were chosen to be sampled. Each month, 10 *sycone* were taken from each trees and shrubs. After the *sycone* were collected, they were put inside collecting bags and reared until the wasps emerged from the *sycone*. The rearing was done in a dark place to induce the male wasps to come out of the *sycone*, enabling the male wasps to be collected without having to cut open the *sycone*.

The ecological analysis was done with PAST software. A cluster analysis with single linkage algorithm, using Morisita's similarity index was done to depict the similarity between the fig species and also between the wasp species. The mean value of the wasp community was used to calculate the Shannon (H) and evenness indices. Diversity t tests were done to know whether the wasp diversity of each fig species between the two areas were different. The proportions of the

pollinators against the NPFW were also calculated to compare the effect of fragmentation level towards pollinator-NPFW proportion in UI and KRB using a Spearman's correlation analysis.

A total of 3 pollinator wasp species were found. *Ceratosolen marchali* has a symbiotic relationship with *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* in UI and KRB. The wasp species were also found in *Ficus glomerata* in KRB. *Ceratosolen fusciceps* has a symbiotic relationship with *Ficus glomerata* in KRB. *Liporrhopalum tentacularis* has a symbiotic relationship with *Ficus montana* in UI, but none were found in the *Ficus montana* of KRB. The pollinators of *Ficus benjamina*, *Ficus microcarpa*, and *Ficus elastica* were not found, but since the seedlings of said fig species could be found in UI and KRB, there must be some pollinator wasps in UI and KRB. No pollinators found in the introduced fig species nor were any seedlings of such fig species found in UI and KRB.

A total of 4 NPFW species found. The NPFW does not seem to have a restriction toward choosing their host. The NPFW found were *Philotrypesis pilosa*, *Bouček*a *percaudata*, *Apocrytophagus testaceus*, and *Apocrypta bakeri*.

The "one-to-one rule" has been broken both in UI and KRB for some fig species. Though *Ceratosolen marchali* still maintain their symbiotic relationship with *Ficus hispida*, the wasp species were found to be functioning as pollinators for *Ficus septica* as well, and even perhaps for *Ficus glomerata*. The symbiotic relationship between *Ficus montana* and its pollinator wasp seems to still be holding up. Though disturbed by *Ceratosolen marchali,* the symbiotic relationship between *Ficus glomerata* and its pollinator wasp seems to be holding up.

Ficus hispida var *badiostrigosa* has the biggest wasp diversity in UI and *Ficus glomerata* has the biggest wasp diversity in KRB. Ficus montana has the lowest wasp diversity in both UI and KRB. From the correlation analysis, it shows that pollinator would most likely have a higher proportion in areas with low fragmentation compared to areas with high fragmentation. The opposite applies for the NPFW. This research also shows that though fragmentation affects the pollinator-NPFW proportion, symbiotic breakdown could change the relationship pattern between fragmentation and pollinator-NPFW proportion.

From the results of this research, most figs of UI could support their fig wasp community. The wasp community of *Ficus montana* in UI could be facing a threat since that specific fig has a very low wasp count. The wasp community of KRB could face some difficulties from fragmentation since it seems that the wasps there still move from one area to another. This research shows that symbiotic breakdown was strongly correlated with fragmentation level. This shows that fragmentation effects symbiotic breakdown and symbiotic breakdown could change some ecological patterns affected by fragmentation.

In addition, this research found out that the flowering time pattern of the figs of UI shows the figs there produced *sycone* in a succession, while the ones in KRB produced *sycone* simultaneously. From the flowering time pattern, it seems that the figs of UI would stand a greater chance against fragmentation and isolation. The fig wasps seem to always be present in UI, while in KRB the wasps are sometimes absent. There is a possibility that the wasps moved to another fig population outside of KRB. The other arthropods that were found in this research come from two classes, Arachnida and Insecta. The insects found are members of the order Coleoptera, Hymenoptera, Diptera, Lepidoptera, Heteroptera or Homoptera, and Thysanoptera. The arachnid was found parasitizing *Philotrypesis pilosa*.

xvii + 84 pp; figures; tables
Bibl.: 35 (1940–2010)

GENERAL INTRODUCTION

The genus *Ficus*, or better known as figs, are commonly known as a very important group of species in the tropical forest (Sastrapradja & Afriastini 1984; Gautier-Hion & Michaloud 1989). Long have mankind known and used this plant species. Some civilization even considered the fruit (the *sycone*) of this species as the fruit of heaven (Chhetri 2010). The figs are often known as keystone species that provides food source for herbivores all year long. This is possible because there are usually more than one species of fig in a single patch of tropical forest (Goodman *et al.* 1997; Kaspari 2000; Bleher & Bőhning-Gaese 2001). Some species may bear fruit at the same time when others may produce fruit in a succession (Cook & Rasplus 2003).

Birds and also flying and arboreal mammals usually use the canopies of big fig trees as shelter and as a place to build their nests. But vertebrates are not the only animal group that utilized fig trees as shelter and nesting spot. Insects also use the tree and the fruit as a place to rear their young (Kaspari 2000; Ridwan 2001; Hilaluddin *et al.* 2003; Nugroho *et al.* 2005; Lok & Lee 2009). One group of insects has taken the animal-nesting place relationship into a whole new level.

The figs are known to have a special relationship with their pollinator. Usually we know this as the “one-to-one rule” that stated that one species of fig would only have one species of pollinator, and vice-versa. Those pollinator are a member of a group of wasps (order Hymenoptera) known as chalcids (Super-family Chalcidoidea). And along with the pollinator, other chalcids also depend on the fig’s syconia as a nursery ground. These other chalcids are usually known as parasites and they may not be bound to the “one-to-one rule”. The parasites are usually more flexible on picking their host fig species (Corner 1940; Hill 1967b; Boucek 1997; Gullan & Cranston 2005).

However, the one-to-one rule gives crucial limitations, which was that there should always be a fig tree of the same species nearby bearing flowers when one tree is not bearing any. Another limitation is that there should not be any habitat fragmentation affecting the fig population. The fragmentation mentioned here is one that could become a barrier to the movement of the pollinators from one tree, or group of trees, to another. Due to the short living nature of the chalcids, they live on an average of 2 weeks reared in a laboratory, it's very important for a pollinator to find another flower bearing tree, and fast. Habitat fragmentation could hinder the effort of a pollinator to get to another flower bearing tree before it dies. To put it short, there should always be a succession of reachable flower bearing trees in a population of fig in order to sustain the population of the pollinators and in the end, the figs (Condit & Swingle 1947; Hill 1967a; Michaloud *et al.* 1996; Gullan & Cranston 2005).

Though the "one-to-one rule" used to be well known, it is now known that there could be more than one species, or subspecies, of fig that could be pollinated by one species of chalcid, and vice versa. This knowledge forced us to look at the fig-pollinator community as a complex one. The relationship that works in the ecosystem of a given area may work differently in another. If habitat fragmentation and introduced species were to be added in, the scenario would be even more complex. Some researchers have even report of a symbiotic breakdown, where the "one-to-one rule" between figs and their pollinators cease to exist. When a breakdown occurs, the pollinator of one fig species could also be pollinating other fig species. If a breakdown happened, then hybridization between species could occur. This hybridization has been observed in Java. That could mean that maybe a symbiotic breakdown had occurred before in Java. The reason for the occurrence of a symbiotic breakdown is still uncertain, but some suggest that fragmentation and environmental stress to be partly responsible (Michaloud *et al.* 1985; Ware & Compton 1992; Parrish *et al.* 2003).

Other important factors to the survivability of figs in an area are the availability of seed dispersers, suitable environment to ensure germination, and lastly, enough protection from herbivores and cutting. From the factors that influence the survivability of figs and all the correlating problems, the survivability of a fig population in a specific area seems fragile. From this, we would expect to see that there would just be a few fig species in the world, but this didn't happen. Now we could see various fig species, especially in the tropics (Corner 1940; Hill 1967a).

Situated in the tropical region, Indonesia also has a high diversity of figs, even in urban areas. In the urban areas of Indonesia, an open vegetated area concept was adopted. The Universitas Indonesia, Depok (henceforth shall be referred to as UI Depok or UI) and the Kebun Raya Bogor (henceforth shall be referred to as KRB) are two examples of such open vegetated areas in Jakarta, Depok, Bogor, Tanggerang, and Bekasi (henceforth shall be referred to as Jadebotabek). Both open vegetated areas have similar goals despite their different backgrounds, histories, and problems. KRB an UI's main goal is to be more than just a vegetated area, but also to become a collection area for plant species, especially native ones. Their other goal is to become a sanctuary for the animal community inside and around them (Taqyudin *et al.* 1997; Kirmanto 2008; Anonym 2009).

The goal of being a sanctuary is apparent judging from the initial vegetation chosen to be planted in UI and KRB. In those areas, we could find vegetations that provide shelter, shades, fruits, and flowers. But through the course of time, and alongside changes in managements, UI and KRB could wind up rather differently. While KRB tends to change very little concerning the vegetation composition and coverage, UI tend to change a lot. The information concerning the chalcid species for figs in UI are also seriously lacking compared to KRB. The knowledge and information about the chalcids and the changes that are happening to them could serve as a mean to monitor the effects of our development (Arumasari 1989; Rasidi *et al.* 1989; Taqyudin *et al.* 1997; Priantomo 2007). The knowledge and information could also give an early warning of the emergence of habitat fragmentation in and around UI and KRB.

Though it seems that there is more environmental stress in UI rather than KRB, UI has one advantage over KRB. And that advantage would be size. UI as a whole is larger than KRB and that would mean that UI could sustain more fig species and larger populations than KRB. Though the more species part did not happen, UI has a larger population per fig species compared to KRB. The reason that KRB has bigger species richness is that there are a lot of introduced fig species. The introduction of alien fig species to KRB means that it is important to know whether the pollinators were introduced along with the figs. This information is important to assess whether the introduced species could be invasive or not. The comparison of the chalcid's biodiversity could also shed light which chalcid population would be more sustainable, UI's or KRB's.

This thesis aims to obtain the much needed primary information of the chalcids in UI and the changes to the chalcids of KRB. The chalcid community that would be the research focus would be the ones that exploit the *sycone* of large shrub and tree forming fig species. The reason for this arbitrary limitation is that the large shrub and tree forming figs has more ecological importance compared to other forms. This would be due to the fact that there would be more niches available in large shrub and tree forming figs compared to other forms. This thesis would try to answer some questions, amongst those questions are:

1. What chalcid species have a symbiotic relationship with the large shrub and tree forming figs of UI and KRB and does the introduced fig species has a pollinator?
2. Would the "one-to-one rule" still exist in UI and KRB?
3. What species of fig, and where, could accommodate the most wasp diversity?
4. Would there be any difference between the pollinator proportions of UI and KRB?
5. Could the fig community of UI and KRB support the sustainability of their pollinators and other chalcids that utilized the figs?

Hopefully this thesis would provide an input to the management policy of UI, KRB, and perhaps other open vegetated area in the urban areas of Jadebotabek.

This thesis would be divided in two main papers, the first paper would be entitled:" Fig Wasps (Hymenoptera; Chalcidoidea) of Tree and Large Shrub-forming Figs in the Ex-situ Conservation Areas of the Universitas Indonesia (UI) Depok and Kebun Raya Bogor (KRB), West Java, Indonesia", and the second paper would be entitled:"Comparing Universitas Indonesia (UI) Depok and Kebun Raya Bogor (KRB), West Java, Indonesia, From Their Fig Wasps of Tree and Large Shrub-forming Figs: With a special view towards the effects of fragmentation to the fig wasp community". The appendix part would be turned into a note paper, placed between the main papers.

Paper I

FIG WASPS (Hymenoptera; Chalcidoidea) OF TREE AND LARGE SHRUB-FORMING FIGS IN THE EX-SITU CONSERVATION AREAS OF THE UNIVERSITAS INDONESIA (UI) DEPOK AND KEBUN RAYA BOGOR (KRB), WEST JAVA, INDONESIA

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ABSTRACT

A research to know the fig wasps of the Universitas Indonesia (UI) and Kebun Raya Bogor (KRB) has been done from January 2010 until December 2010. This research was aimed to record the pollinating and non-pollinating fig wasps of UI and KRB, to later compare the result with reports from previous researches. This research would also confirm whether symbiotic breakdown occurs in the research areas. A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) were chosen to be sampled. From those trees and shrubs, 10 *sycone* were taken. The wasps were then reared inside the *sycone* to later be preserved using the method of Noyes (1982). After identification, 7 wasp species were found. *Ceratosolen marchali* Mayr, *Ceratosolen fusciceps* Mayr, *Liporrhopalum tentacularis* Grandi, *Philotrypesis pilosa* Mayr, *Boučeka percaudata* Bouček, *Apocrytophagus testaceus* Mayr, and *Apocrypta bakeri* Joseph were found. From those wasps, 3 species are pollinators and the rest are non-pollinating fig wasps (NPFW). The wasps were found from *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana* and *Ficus glomerata*. Some differences between the specimens of this research with the descriptions from other research were explained. Using Krukal-Wallis analysis, this research discovered that the head width (HW) and front femur length (FFL) of *Ceratosolen marchali* that were found in *Ficus glomerata*

were smaller than the ones found in other fig species (p HW same = 0.0002; p FFL same = 0.0002), while the ovipositor length (OvL) were the same (p OvL same = 1). Though still statistically smaller, the HW and FFL value of the *Ceratosolen marchali* found in *Ficus glomerata* were closer to that of *Ceratosolen fusciceps*. The result of the research also shows that the one-to-one symbiosis between *Ceratosolen marchali* and its host (*Ficus hispida*) has been broken. In this research, *Ceratosolen marchali* were found pollinating *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, and even *Ficus glomerata*. For *Ficus montana* and *Ficus glomerata*, it seems that their symbiosis with their pollinators were still maintained.

Key words: Chalcids; Ficus*; Figs; Kebun Raya Bogor; Non Pollinating Fig Wasps; Pollinators; Symbiosis; Symbiotic breakdown; Universitas Indonesia.*

INTRODUCTION

It has been known that fig and chalcids has a unique relationship. Some chalcids were even specialized to depend on the gal flowers of figs to lay their eggs in; these chalcids are known as fig wasps. A part of those chalcids has even taken the relationship a level higher, these species became pollinators for the fig species in which they lay their eggs in. Many researches have been done by Wiebes, Hill, and other researchers in the Indo-Malayan region to find the pollinators and parasites of the area's fig species. The initial researches show the famed "one-to-one rule".

Though the "one-to-one rule" has been proven to be true, in 1985 Michaloud *et al.* stated that there could be more than one pollinating species for a fig species in an area. In 1992, Ware and Compton proved that a breakdown in the "one-to-one rule" could happen. Both researches were done in Africa, but in 2003 Parrish *et al.* proved that there has been natural hybridizations between species of dioecious figs in the Krakatau islands and western Java. For natural hybridization to occur in figs, a breakdown in pollinator specificity must first happen. This makes it interesting to find out whether the result of Parrish *et al.* (2003) means that symbiotic breakdowns may not be rare in western Java.

UI and KRB were chosen as research locations because both places are open vegetated areas that acts as sanctuaries for the animal community inside and around them (Taqyudin *et al.* 1997; Anonym 2009). As a sanctuary, figs could prove to be a useful resource for food or shelter (Gautier-Hion & Michaloud 1989). Both wild and introduced species of figs could be found in UI and KRB. The total tree and large shrub-forming fig species that could be found in KRB outnumbered UI. This is because there are a lot more introduced species in KRB than in UI.

The existence of introduced species in UI and KRB rendered it important to know whether the native pollinators of the introduced figs were also introduced with the figs. Is would also be important to know whether the pollinator species of UI and KRB utilize the introduced figs, and whether those wasps managed to pollinate the introduced fig species. This knowledge would be useful to figure out whether the introduced figs pose a threat of becoming invasive or not. It would also be interesting to know whether the parasite wasps, better known as non-pollinating fig wasps (NPFW), could use the *sycone* of the introduced figs.

This research has three aims: (i) To know the pollinator wasps of native and introduced tree and large shrub-forming figs in UI and KRB; (ii) To know the NPFW of native and introduced tree and large shrub-forming figs in UI and KRB; (iii) To compare the results of this research with the results of previous researches; (iv) To confirm whether symbiotic breakdown occurs in the research areas.

MATERIALS AND METHODS

A. LOCATION AND TIME OF RESEARCH

This research was done in UI and KRB from January 2010 until December 2010. UI is situated in the town of Depok and KRB is situated in Bogor. Both research sites are situated in the Province of West Java. Spanning from 6° 20'

45.75"–6° 22' 33.84" S and 106° 49' 8.42"–106° 49' 58.60" E (Neave 2009), UI encompasses around 300 hectare of land (Taqyuddin *et al.* 1997). Compared to UI, KRB has a much smaller area. The 87 hectare (Anonym 2009) area of KRB spans from 6° 35' 28.90"–6° 36' 16.08" S and 106° 47' 36.93"–106° 48' 18.09" E (Neave 2009). The complete map of both research areas could be seen in Figure 1.

Both UI and KRB could be classified as open vegetated areas. But the two areas were design to be sanctuaries for flora and faunas, especially native ones (Taqyuddin *et al.* 1997; Anonym 2009). The goal of being a sanctuary is apparent judging from the initial vegetation chosen to be planted in the UI urban forest and KRB. In those areas, we could find vegetations that provide shelter, shades, fruits, and flowers. While KRB is a mixture of sanctuary-tourism spot, UI is a mixture of sanctuary-campus-human activity spot. Not to mention UI's future plans on adding tourism spot to the existing mix. Compared to KRB, the potential for environmental disturbance would be bigger in UI.

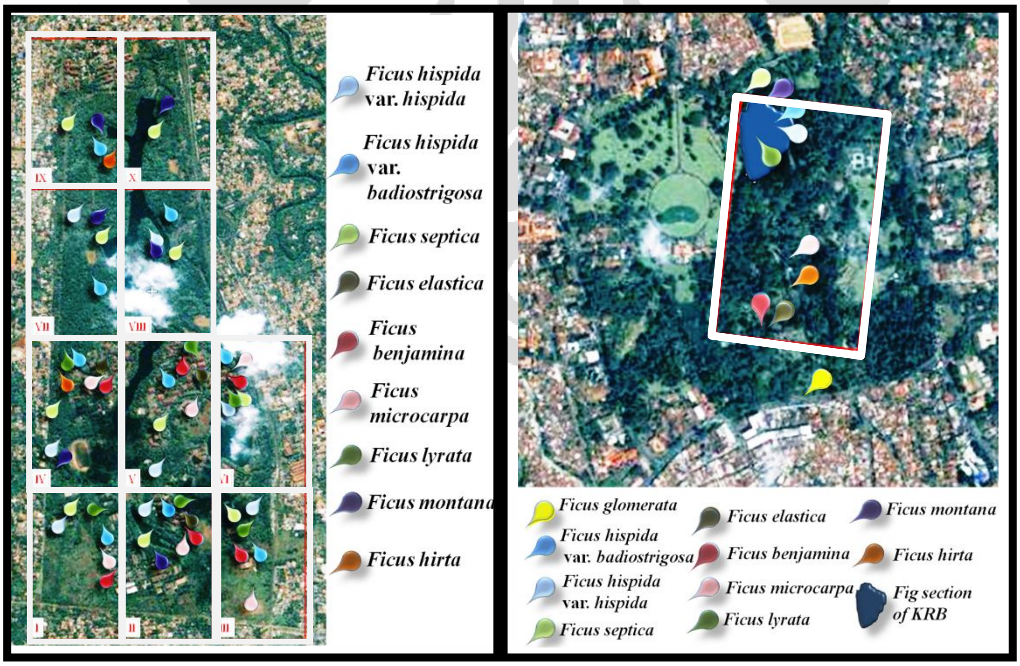

Figure 1. Map of the research areas. Left: UI; Right: KRB. The white boxes represent sampling areas of the same size
(Source of map: Flash Earth© Neave 2009).

B. COLLECTING THE WASPS

The research area of UI was divided into ten sectors while KRB was not divided. The reason for that action was because the figs of KRB are relatively concentrated in an area equivalent to one sector in UI. From each of those sectors, one tree of each tree and large shrub-forming fig species was chosen randomly. The sample for *Ficus glomerata* of KRB was an exception, since the trees inside the sampling areas yield no wasps.

A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) in KRB were chosen to be sampled. The identification of the fig trees was done using Flora of Java vol. II (Backer & Brink 1965). Each month, 10 *sycone* were taken from each trees and shrubs. After the *sycone* were collected, they were put into collecting bags and reared until the wasps emerged from the *sycone*. The rearing was done in a dark place to induce the male wasps to come out of the *sycone*, enabling the male wasps to be collected without having to cut open the *sycone*.

C. PRESERVATION, IDENTIFICATION, AND SIZE MEASUREMENT

Upon collection, the wasps were killed using etil acetate and are preserved using 70% alcohol. A few specimens were separated to be mounted the day after. The mounting and preservation procedure used in this research follows that of Noyes (1982). The identification of the specimens was done in the Entomology lab of the Zoology Museum of The Indonesian Institute of Sciences (LIPI). The identification of the wasp would be based on Mayr (1906), Grandi (1926), Joseph (1952), Hill (1967), Bouček (1988), Wiebes (1989), Wiebes (1993), Wiebes (1994), and Zhen *et al.* (2005).

From the specimens, 10 (or less) individual of wasps would be photographed using DINO Digital Microscope (AM-451). To complete the identification information, the head width (HW), front femur length (FFL), and ovipositor length (OvL) of the wasps were calculated using ImageJ image analysis program. HW, FFL, and OvL were chosen because the size of those parts determines whether the wasp would manage to successfully deposit their eggs (Wiebes 1989; Cook & Rasplus 2003; Liu *et al.* 2011). Size comparison analyses were done using PAST software (Hammer *et al.* 2001).

D. SYMBIOTIC BREAKDOWN

To determine whether symbiotic breakdown occurred in UI and KRB, the pollinated fig species of each pollinator were recorded. *Ceratosolen marchali* was considered as a pollinator in *Ficus glomerata* because, in this research, the wasps were found carrying the pollen of *Ficus glomerata* (Jousselin *et al.* 2003; Jandér & Herre 2010). The mean values of pollinated fig species per-month and per-sector were compared with the "one-to-one rule" to examine whether symbiotic breakdown really happened or just a random incident.

RESULTS AND DISCUSSIONS

Table 1. The wasps found in the *sycone* of figs in UI and KRB.

Wasps	**Found in *sycone* of**	**Location (UI/KRB)**	**Role**
Ceratosolen marchali Mayr	*Ficus hispida* var. *hispida*	Both	Pollinator
	Ficus hispida var. *badiostrigosa*	Both	Pollinator
	Ficus septica	Both	Pollinator
	Ficus glomerata	KRB	Pollinator
Ceratosolen fusciceps Mayr	*Ficus glomerata*	KRB	Pollinator
Liporrhopalum tentacularis Grandi	*Ficus montana*	UI	Pollinator
Philotrypesis pilosa Mayr	*Ficus hispida* var. *hispida*	Both	NPFW
	Ficus hispida var. *badiostrigosa*	Both	NPFW
	Ficus septica	Both	NPFW
Boučeka percaudata Bouček	*Ficus montana*	UI	NPFW
	Ficus glomerata	KRB	NPFW
Apocrytophagus testaceus Mayr	*Ficus hispida* var. *badiostrigosa*	UI	NPFW
	Ficus glomerata	KRB	NPFW
Apocrypta bakeri Joseph	*Ficus hispida* var. *badiostrigosa*	UI	NPFW
	Ficus glomerata	KRB	NPFW

This research resulted in a total of 7 wasp species found in UI and KRB. Those wasp species were *Ceratosolen marchali* Mayr, *Ceratosolen fusciceps* Mayr, *Liporrhopalum tentacularis* Grandi, *Philotrypesis pilosa* Mayr, *Boučeka percaudata* Bouček, *Apocrytophagus testaceus* Mayr, and *Apocrypta bakeri* Joseph. Out of the 7, *Ceratosolen fusciceps* are only found in KRB and *Liporrhopalum tentacularis* are only found in UI. That means 5 shared wasp species existed both in UI and KRB. The complete list of wasp species, their host figs, and their function could be seen in table 1.

A. FIG WASPS

1. How to Recognize a Fig Wasp

To recognize a fig wasp is to recognize a chalcid. Chalcids could be differentiated from other hymenopteran by a few features, such as: The veins of all chalcid wasps are greatly reduced, generally forming one linear vein, without a closed cell; Chalcids have a set of prepectus. The prepectus is a sub-triangular sclerite between the lateral panel of the pronotum and the tegula; The mesothoracic spiracle of a chalcid could be found at the dorso-lateral margin of the mesoscutum; And one or more proximal segments of a chalcid's flagellum are often reduced into an anelli. The antennae of a chalcid are usually elbowed, strongly or not, between the scapus and the rest (Bouček 1988). Fig wasps are the known term to group the chalcids that needs the *sycone* of a fig to rear their eggs and young.

There are two forms of male fig wasps, the winged form and the wingless or brachypterous form. In this research, only the wingless or brachypterous form was found. Therefore the male and female wasp of UI and KRB could be differentiated by the presence or absence of wings.

2. Identification

The keys and classifications here are based on Bouček (1988), Rasplus *et al.* (1998), and Campbell *et al.* (2000), with a little modification to fit the genera of UI and KRB's fig wasps.

Key to genera

1. A. Fully winged (macropterous)…………………………………..…………… **2**
   B. Apterous or brachypterous, in latter case wing stumps not exceeding middle of gaster; Body mostly yellowish and without eyes or with unusually small eyes…………………………………………………..……………………… **7**

Female wasps

2. A. Mandibles with conspicuous flat appendages which bear distinct transverse ridges and adhere to the underside of head; Ovipositor usually simple, thin, shorter than body; **AGAONIDAE**, **Agaoninae**……..………..………….. **3**
   B. Mandibles normal, without appendages; Ovipositor long, forming a tail that is longer than the body……………………………………….....…………… **4**
3. A. Antennae hardly clavate or, if moderately clavate, ovipositor shorter than body; Antennae never reaches the abdomen if pulled back; Head slightly longer than broad; Spiracles of sixth tergite surrounded by concaved and elongated peritremal areas…………………………….....***Ceratosolen* Mayr.**
   B. Antennae not clavate; Antennae very long, they could sometimes reaches the abdomen if pulled back; Head just as long as it is broad; Spiracles of sixth tergite not surrounded by concaved and elongated peritremal areas…………………..……………………….. ***Liporrhopalum* Waterston**
4. A. Tail formed only by ovipositor and its sheaths (valvulae), not by terminal tergite……………………………………..………………………….....…. **5**
   B. Tail sheathed by tubular extension of one or two terminal tergites…….......**6**
5. A. Scutellum in dorsal view simple, without any lateral grooves; Gaster compressed, has great capability of telescoping; **PTEROMALIDAE**, **Sycoryctinae**, **Apocryptini**………………………….. ***Apocrypta* Coquerel**

B. Scutellum in dorsal view shows lateral grooves; Gaster not compressed, has no capability of telescoping; **Sycophaginae**….***Apocryptophagus*** **Cocquerel**

6. A. Gastral tail consisting of two or three parts; Tergite sheath only encapsulate the basal half of the tail; **PTEROMALIDAE**, **Sycoryctinae**, **Phylotrypesini**………... ***Philotrypesis*** **Förster**

B. Gastral tail only consists of one part; Tergite sheath encapsulate the entire tail; **PTEROMALIDAE**, **Sycoryctinae**, **Sycoryctini**…………………....….
…………………………………………..........***Boučeka*** **Koçak&Kemal**

Male wasps

7. A. Posterior gastral segments soft, long, and narrow, telescoping, usually turned in U-shape forward under the body; Fore and hind femora enlarged………………….…………………………………………………….**8**

B. Posterior gastral segments not as above; Femora of similar size, either enlarged or slim…………………………………………………………….**9**

8. A. Antennae slender, placed in deep channels which are anteriorly separated by a triangular raised area………………………………...***Ceratosolen*** **Mayr**

B. Antennae not slender or, if slender, not inserted in deep channels separated by a triangular raised area………………………***Liporrhopalum*** **Waterston**

9. A. Head sub-cylindrical, very long, bare with antennal toruli close to each other in one broad cavity………………………………***Apocrypta*** **Coquerel**

B. Head more or less flattened, different from above……..............................**10**

10.A. Antennae not in common cavity; Head strongly elongated; Abdomen ribbon-like, sometimes with horn-like extensions present on sixth tergite………………………………………..***Apocryptophagus*** **Ashmead**

B. Both antennae in a common cavity; Head not or only slightly elongate; Abdomen isosceles-triangle-like, no extensions present on sixth tergite………………………………………………… ***Philotrypesis*** **Förster**

B. DESCRIPTION OF THE SPECIES FOUND

1. *Ceratosolen marchali* Mayr

Found in the *sycone* of *Ficus hispida* var. *hispida*, F. *hispida* var. *badiostrigosa*, and F. *septica* of UI and KRB. It was also found in the *sycone* of *Ficus glomerata* in KRB. It could be found in the same *sycone* that also contained *Ceratosolen fusciceps* Mayr. Wiebes (1966a) reported that *Ceratosolen marchali* acts as one of the pollinating wasp species for *Ficus hispida*. *Ceratosolen marchali* was also known as *Ceratosolen solmsi marchali* Mayr. Wiebes (1963) used the name *Ceratosolen marchali* because he proposed for *Ceratosolen solmsi marchali and Ceratosolen solmsi solmsi* Mayr to be put into *Ceratosolen solmsi* group and treated as two different species.

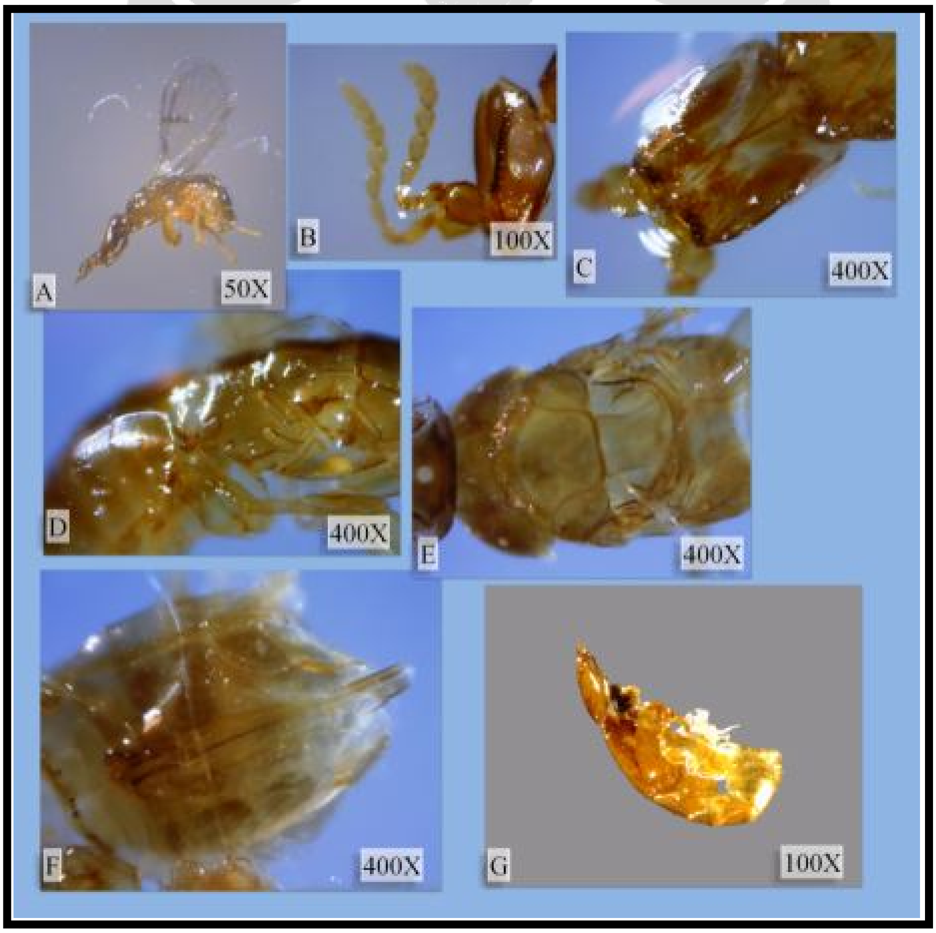

Figure 2. *Ceratosolen marchali* Mayr.

It has been known that in Java both *Ceratosolen solmsi* and *Ceratosolen marchali* could be found in the same individual of *Ficus hispida*, but there was only one *Ceratosolen* species found in this research. The characters of the specimens found in this research were closer to that of *Ceratosolen marchali* rather than *Ceratosolen solmsi*, based on the descriptions in Grandi (1928) and Wiebes (1963). There are a few differences between the descriptions of Grandi (1928) and the specimens found in this research. The first difference is that the eleventh antennal segment's longer than the tenth (Fig. 2B), just like a *Ceratosolen solmsi*. The other is that there seems to be no cerci in the male genitalia (Fig. 2C). However, this is in accordance with the report from Wiebes (1963) that also could not found the cerci within the specimens of Java Island. The descriptions for the male correspond to that of Hill (1967).

The average size of *Creatosolen marchali* wasps that were found in *Ficus glomerata* were different with the ones that were found in the other figs. The results of Kruskal-Wallis test were as follow: (i) p (same) values for the head width (HW) and front femur length (FFL) were 0.0002; (ii) p (same) value for the ovipositor length (Ovl) was 1. The average size of HW for the *Ceratosolen marchali* found in *Ficus glomerata* was 0.4052±0.0018 mm; FFL was 0.2269±0.0036 mm; and OvL was 1.1556±0.0012 mm. While the average size of HW for the *Ceratosolen marchali* found in other fig species was 0.4591±0.0236 mm; FFL was 0.3671±0.0026 mm; and OvL was 1.1556±0.0009 mm. The overall results shows that aside from the ovipositor length the *Ceratosolen marchali* that were found in *Ficus glomerata* were smaller than those found in the other fig species.

2. *Ceratosolen fusciceps* Mayr

Found in the *sycone* of *Ficus glomerata* in KRB. In this research, it was found that *Ceratosolen fusciceps* is capable of sharing *sycone* with *Ceratosolen marchali*.

During this research, *Ceratosolen fusciceps* (Fig. 3) was once misidentified as *Ceratosolen marchali*. This was because the two species could be found in the same *sycone* and there are only a few differences between the two.

Figure 3. *Ceratosolen fusciceps* Mayr.

The first is the bacilliform process that is hard to see before the specimen was treated with KOH. *Ceratosolen fusciceps* does not have a bacilliform process. Besides the bacilliform process, the mandibular process in *Ceratosolen fusciceps* has 5 ridges.

The characters that have been described are the same with the characters of *Ceratosolen fusciceps* by Wiebes (1989). There is only one slight difference between the descriptions of Wiebes (1989) with the specimens found in this research. The ovipositor of the specimens of this research could reach around 1.75 times the length of the abdomen, opposed to the one and a half times abdomen length described by Wiebes (1989). Though the ovipositor to abdomen length ratio differs a little from that described by Wiebes (1989), the average length ratio is still not far from one and a half. The other characteristics of the *Ceratosolen fusciceps* found in this research match those of Wiebes (1989) and Wiebes (1963). The average size of *Ceratosolen fusciceps* HW found in this research was 0.4044±0.0022 mm; FFL found in this research was 0.2244±0.0025 mm; and OvL found in this research was 1.1649±0.0014 mm.

3. *Liporrhopalum tentacularis* Grandi

Found in the *sycone* of *Ficus montana* of UI, specifically the F. *montana* that grows in the UI urban forest. None were found outside of the urban forest. Were once known as *Blastophaga tentacularis* and *Ceratosolen tentacularis*, Wiebes (1993) proposed that it should be moved into the genus *Liporrhophalum* Waterston due to the elongated antennal segments of *Liporrhopalum tentacularis*.

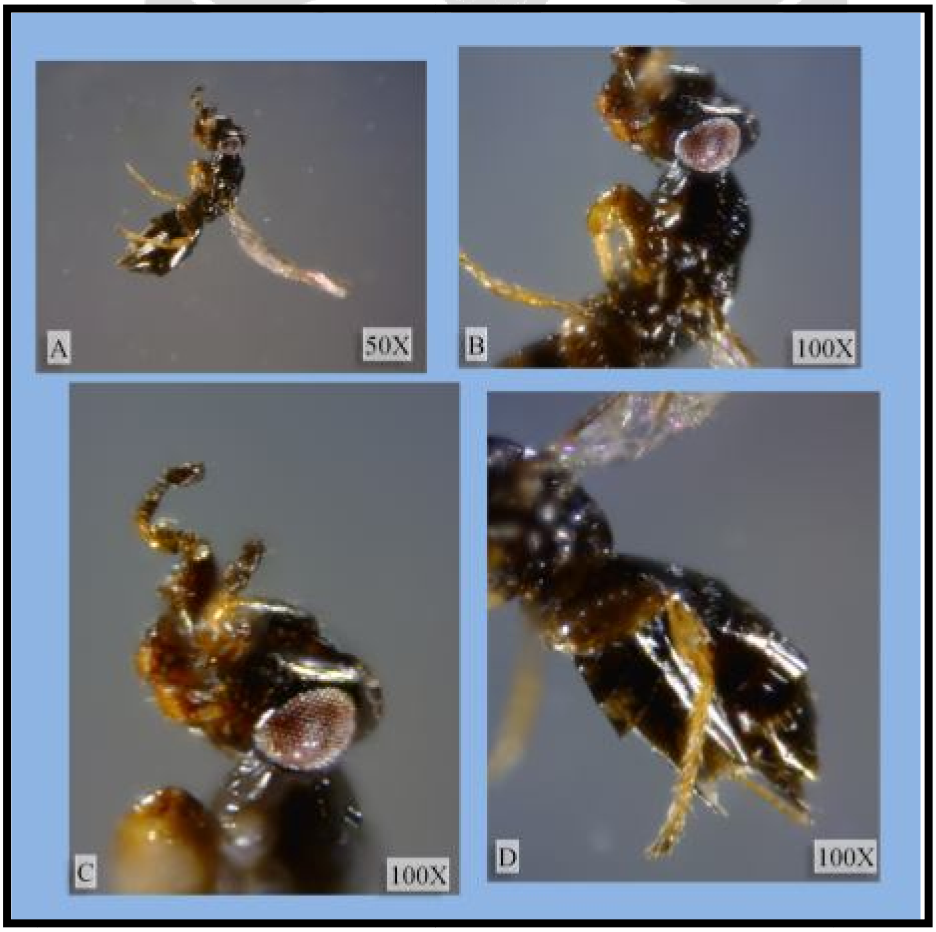

Figure 4. *Liporrhopalum tentacularis* Grandi.

Liporrhopalum tentacularis (Fig. 4) differs with the other species of the same genus upon the presence of a bacilliform process on its maxilla. The bacilliform process of the *Liporrhopalum* species found in this research is only one third of the length of the maxilla. In the description of Bouček (1988), the genus *Liporrhopalum* has a non-pigmented vein on the fore wings. Most specimens found in UI have a moderately to almost strongly pigmented vein. The pigmentation is more or less even from the base up to the apex of the vein. Other characters are similar with the description of Grandi (1926) and Wiebes (1994). The average size of *Liporrhopalum tentacularis* HW found in this research was 0.4511±0.0016 mm; FFL found in this research was 0.4988±0.0014 mm; and OvL found in this research was 0.3266±0.0009 mm.

4. *Philotrypesis pilosa* Mayr

Found in the *sycone* of *Ficus hispida* var. *hispida*, F. *hispida* var. *badiostrigosa*, and F. *septica* of UI and KRB. *Philotrypesis pilosa* is considered one of the NPFW species, they deposits their eggs from outside of the *sycone*. *Philotrypesis pilosa* was recorded to inhabit the *sycone* of *Ficus hispida* and is a parasitoid of *Ceratosolen solmsi* (Wiebes 1966a; Jiang *et al.* 2006). In this research, it seems that *Philotrypesis pilosa* could be found in the same individual of fig but not in the same *sycone* with *Apocrytophagus testaceus* Mayr.

There seems to be more than one color pattern of the female body found in the specimens of this research. The same phenomenon was observed by Jiang *et al.* (2006), they reported that *Philotrypesis pilosa* could change host and has a diverse female color pattern, though there was no completely black female in the specimens of this research. *Philotrypesis pilosa* may have similar color patterns with *Apocrytophagus testaceus*. The difference between the two species lies in the thorax and ovipositor. The thorax of *Philotrypesis pilosa* is simple and almost smooth. The head and thorax color are similar. The ovipositors of *Philotrypesis pilosa* are sheathed by the last two tergites, forming a capsule that covers the basal half of the ovipositor. This caused the tail of *Philotrypesis pilosa* to form a branch starting form halfway down the tail (Fig. 5F–G). Aside from the color pattern character, the specimens found in this research seem to fit the description of Mayr (1906). The average size of *Philotrypesis pilosa* HW found in this research was 0.4958±0.0122 mm; FFL found in this research was 0.4369±0.0138 mm; and OvL found in this research was 8.9428±0.0081 mm.

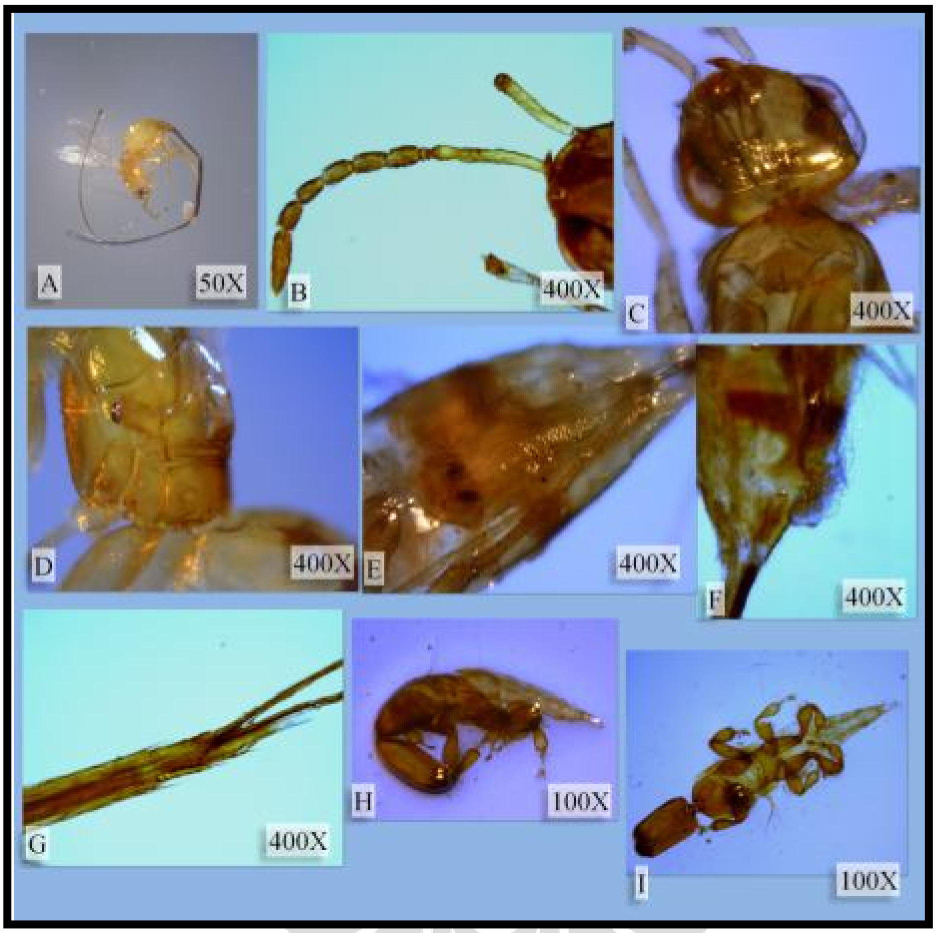

Figure 5. *Philotrypesis pilosa* Mayr.

5. *Boučeka percaudata* Bouček

Found in the *sycone* of *Ficus montana* in UI and *Ficus glomerata* in KRB. *Boučeka percaudata* was once known as *Tenka percaudata* Bouček. The genus *Tenka* was later on replaced by *Boučeka* Koçak&Kemal because it is a junior homonym of *Tenka* Barrande (Bivalvia: Lunulacardiidae) (Özdikmen & Darılmaz 2010).

On first glance, the appearance of a female *Boučeka percaudata* looks a bit like the all black female *Philotrypesis pilosa* of Jiang *et al.* (2006). The difference between the two species lies in the ovipositor's tergite sheath. The

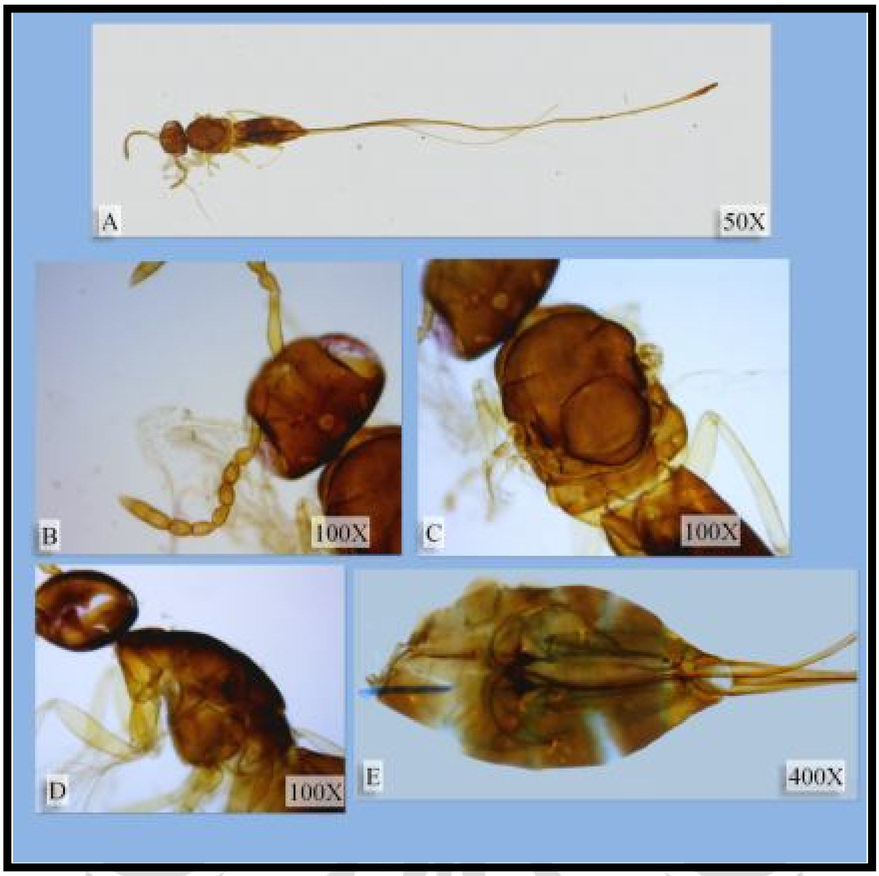

Figure 6. *Boučeka percaudata* Bouček.

tergite sheath of *Boučeka percaudata* covers the whole length of the ovipositor, opposed to the tergite sheath of *Philotrypesis pilosa* that only covers half the length of its ovipositor. Another difference of the two still concerns the ovipositor tergite sheath. While the tergite sheath of *Philotrypesis pilosa* is a complete tube from the base to its end, the tergite sheath of *Boučeka percaudata* is opened at the base and forms a complete tube nearing its end. The tergite sheath of *Boučeka percaudata* looks like a vagina of a leaf (Fig. 6E). The tail length of *Boučeka percaudata* has a larger ratio to body length (Fig. 6A) compared to *Philotrypesis pilosa*. Another difference is that the pronotum of *Boučeka percaudata* is very narrow (Fig. 6C) compared to the wider pronotum of *Philotrypesis pilosa*. The difference between the two species was confirmed after the specimens are treated with KOH. The gonads of the two species are clearly different. Bouček (1988) has a complete description of the species. The specimens found in this research have no notable difference with that of Bouček's. The average size of *Boučeka percaudata* HW found in this research was 0.4226±0.0010 mm; FFL found in this research was 0.2315±0.0009 mm; and OvL found in this research was 12.5281 ±0.0036 mm.

6. *Apocrytophagus testaceus* Mayr

Found in the *sycone* of *Ficus hispida* var. *badiostrigosa* in UI and *Ficus glomerata* in KRB. *Apocrytophagus testaceus* were also known as *Tetragonaspis testaceus* Mayr or *Eukoebelea testaceus* Mayr (Mayr 1906, Wiebes 1966b, Wiebes 1968). According to Wiebes (1966a), the species is a NPFW of *Ficus glomerata* in Java. In this research, *Apocrytophagus testaceus* were never found in the same *sycone* with *Philotrypesis pilosa*.

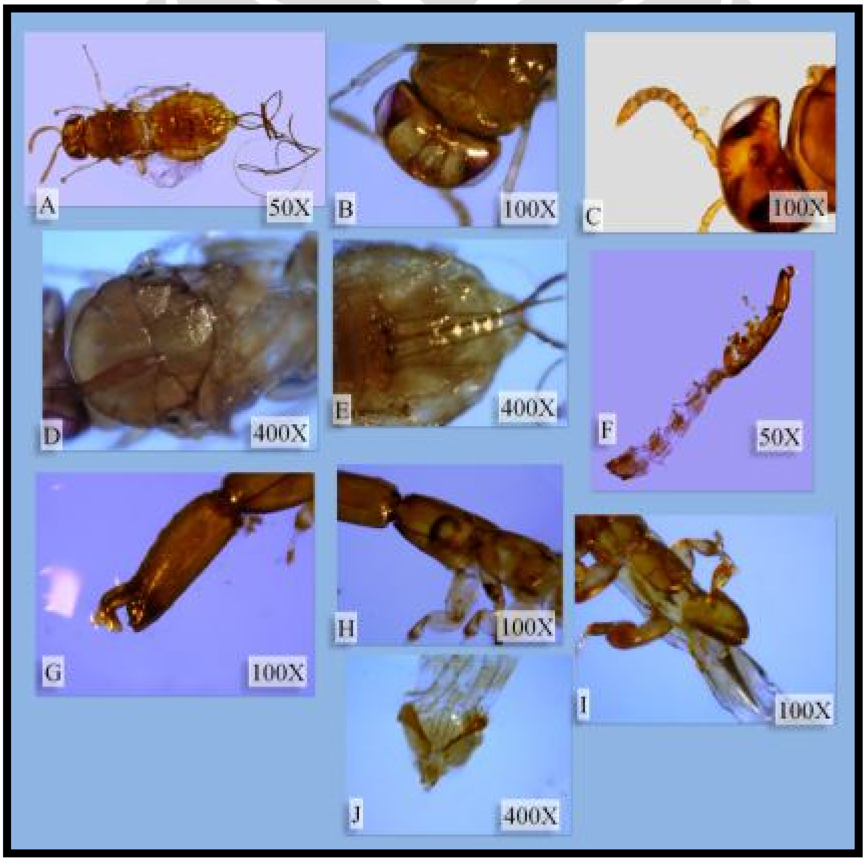

Figure 7. *Apocrytophagus testaceus* Mayr.

The female *Apocrytophagus testaceus* found in this research has a color pattern similar to that of some of the female *Philotrypesis pilosa* found. A notable difference between the two is that *Apocrytophagus testaceus* would be bulky as opposed to the slender *Philotrypesis pilosa*. Another difference is that the thorax of *Apocrytophagus testaceus* has curves on its sides (Fig. 7D). The curves were not very conspicuous in the specimens found in this research, before they were treated with KOH. The most striking difference is that the ovipositors of Apocrytophagus testaceus were only sheathed by their valvulae (Fig. 7E) and not by the last segments of the abdominal tergites. This will cause the tail of *Apocrytophagus testaceus* to be forked from the base, though sometimes the two ovipositors cling together. Other characters are similar to those observed by Mayr (1906) and Wiebes (1966b). The average size of *Apocrytophagus testaceus* HW found in this research was 0.4226±0.0010 mm; FFL found in this research was 0.2315±0.0009 mm; and OvL found in this research was 12.5281±0.0036 mm.

7. *Apocrypta bakeri* Joseph

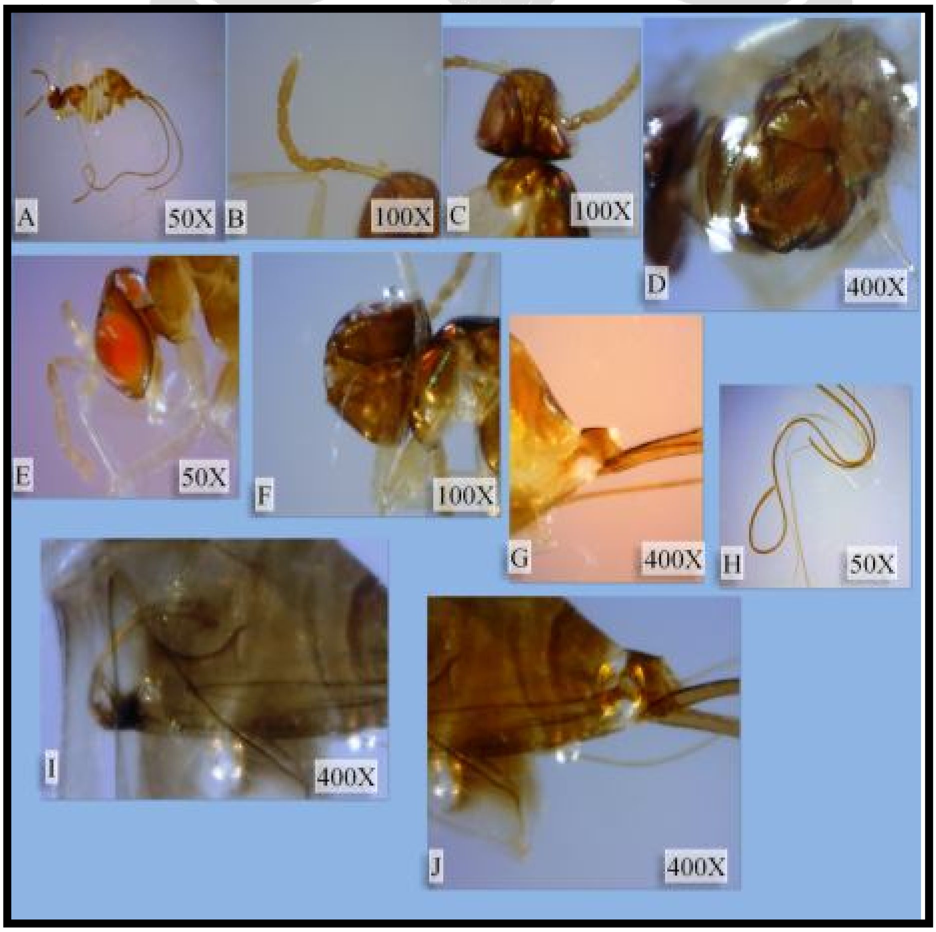

Figure 8. *Apocrypta bakeri* Joseph.

Found in the *sycone* of *Ficus hispida* var. *badiostrigosa* in UI and *Ficus glomerata* in KRB. *Apocrypta bakeri* was also known as *Lipothymus bakeri* Joseph (Joseph 1952). *Apocrypta bakeri* was recorded to inhabit the *sycone* of *Ficus hispida* and is a parasitoid of *Ceratosolen solmsi* (Wiebes 1966a; Jiang *et al.* 2006).

The female of the genus *Apocrypta* Coquerel was the easiest genus to identify among the specimens found in this research. This genus has a striking feature which is a telescopic proximal gastral segments (Fig. 8A). Those segments are used to stabilize the long ovipositor and perhaps help to add pressure when the wasp's trying to penetrate the *syconial* wall (Joseph 1952, Wiebes 1966a). Based on the description of Joseph (1952) and Zhen *et al.* (2005), the specimens found in this research belong to *Apocrypta bakeri*. Though there seems to be a few differences between the specimens found by Zhen *et al.* (2005) and the ones found in this research. The differences lie in the mean length of the legs. The ones found in this research seem to have longer legs. Aside from the length of the legs, there seems to be no other difference especially concerning the length of the ovipositors and their valvulae. The average size of *Apocrypta bakeri* HW found in this research was 0.4745±0.0034 mm; FFL found in this research was 0.3342±0.0218 mm; and OvL found in this research was 9.2005±0.0080 mm.

C. SYMBIOTIC BREAKDOWN

In this research, *Ceratosolen marchali* were found in 3 fig species in UI and 4 fig species in KRB. This finding suggested that a symbiotic breakdown has occurred in both UI and KRB. To confirm whether the result of this research points to symbiotic breakdown or just an abnormal pattern, the mean pollinated fig species of all pollinator wasps (*Ceratosolen marchali*, *Ceratosolen fusciceps*, and *Liporrhopalum tentacularis*) in UI and KRB was compared with each other and with the "one-to-one rule". The comparison would be based on sectors and months. This was meant to see whether symbiotic breakdown happens in all research areas and whether it happens all the time.

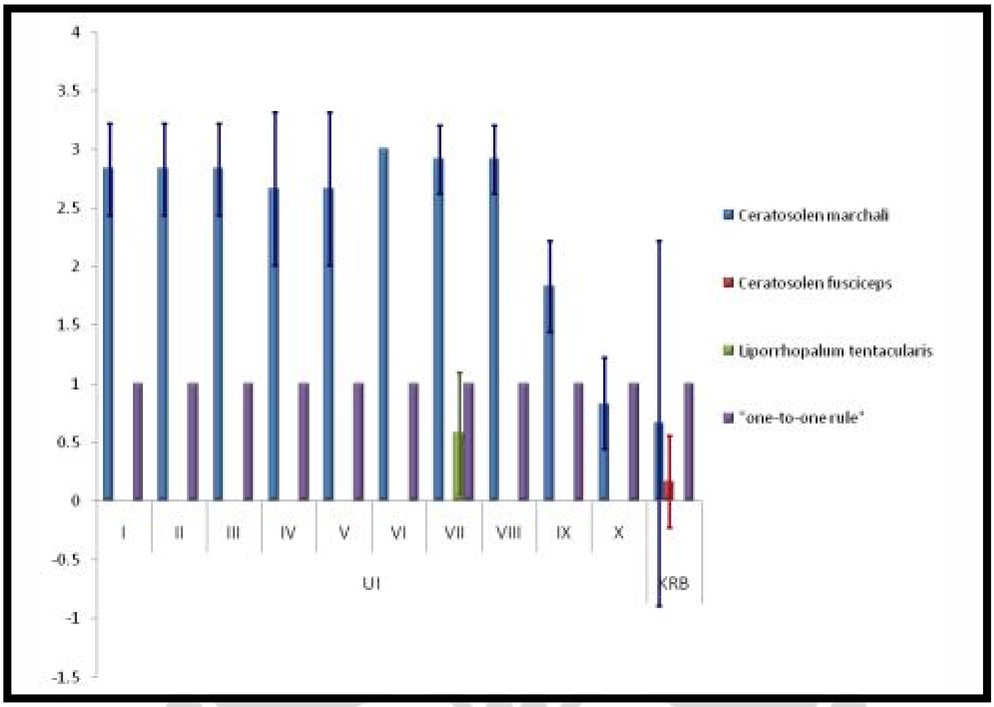

Figure 9. Mean pollinated fig species of each pollinator wasp per-sector.

The result of the analysis where the pollinators were compared per-sector (Figure 9) shows that the mean value of the pollinated figs for *Ceratosolen marchali* exceeded that of the "one-to-one rule" pattern in almost all sectors. Though sector X in UI and the sector in KRB shows that the mean value of the pollinated figs was below the "one-to-one rule" pattern, does not mean that symbiotic breakdown did not happened in those two sectors. From the mean and mean+SD value (1.2226) of sector X in UI, we could see that the *Ceratosolen marchali* only pollinated 1 fig species on several months during the research. This result may points to the "one-to-one rule", but the fig pollinated by *Ceratosolen marchali* in sector X was *Ficus septica* instead of *Ficus hispida* as reported by Wiebes (1966a). It should also be noted that *Ficus septica* was the only tree and large shrub-forming fig that could be found in sector X. As for KRB, the below 1 mean (0.6667) and large SD value (1.557) was the result of the absence of *Ceratosolen marchali* in KRB for the whole year except in August and September. During those months, *Ceratosolen marchali* pollinated 4 fig species in KRB. In conclusion, the overall result indicates that symbiotic breakdown has occurred for *Ceratosolen marchali* in all sectors in UI and KRB.

The result for the other two pollinator species shows that *Ceratosolen fusciceps* and *Liporrhopalum tentacularis* still retained their relationship with their respected host figs. As for the mean values of the pollinated figs for those wasps were below the "one-to-one rule" was the result of the absence of the wasps for a few months during the research. It was recorded that *Liporrhopalum tentacularis* was absent for 5 month from the whole 12 months of research, while *Ceratosolen fusciceps* were present only in August and September. A better view of when the wasps are present and absent and how many fig species were pollinated by a particular wasp could be seen in Figure 10.

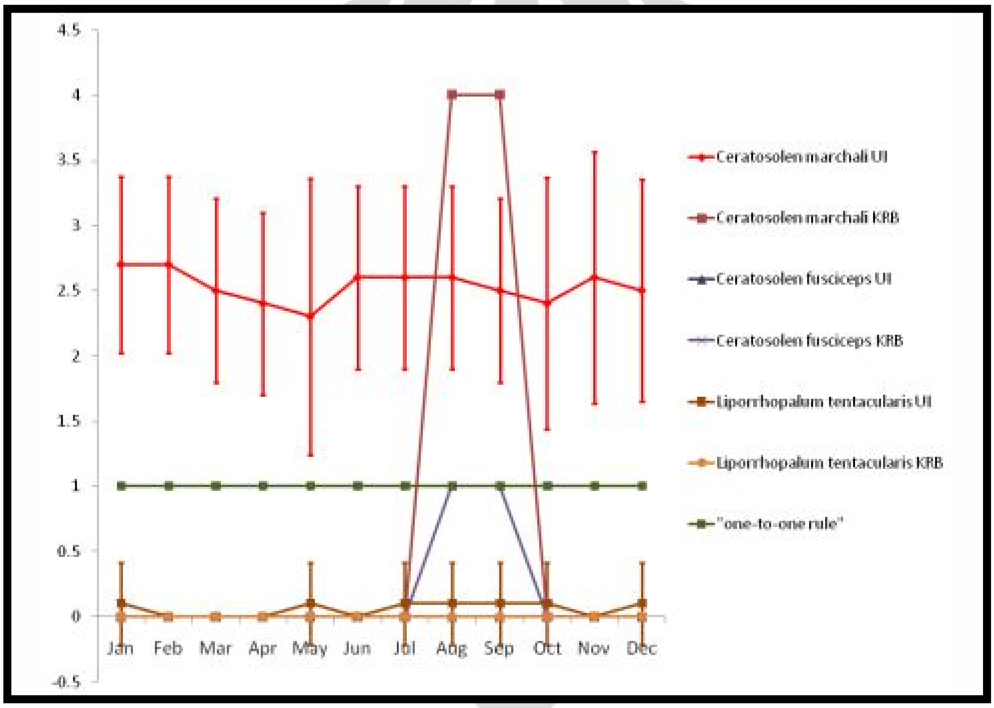

Figure 10. Mean pollinated fig species of each pollinator wasp per-month.

The result of the analysis where the pollinators were compared per-month (Figure 10) shows that *Ceratosolen marchali* has broken free of their exclusive symbiosis with their host fig (*Ficus hispida*). The graph shows that the mean (2.3–2.7) and mean-SD (1.2407–2.0251) value of the pollinated figs for *Ceratosolen marchali* in UI was above the "one-to-one rule" line in all months. This result indicates that *Ceratosolen marchali* was always present and pollinates more than 1 species of fig in all, or most of, the sectors in UI. As for the Ceratosolen marchali in KRB, the wasp species was only present in August and September. During their presence, they pollinated 4 fig species. In conclusion, the overall result indicates that symbiotic breakdown has occurred for *Ceratosolen marchali* for the whole research time in UI and when the wasp was present in KRB.

The result for the other two pollinator species shows that *Ceratosolen fusciceps* and *Liporrhopalum tentacularis* still retained their relationship with their respected host figs during the research. The result for *Ceratosolen fusciceps* shows that the wasp species were only found in August and September in KRB. During that time they only pollinate *Ficus glomerata*, the wasp's host fig species according to Wiebes (1966a). No *Ceratosolen fusciceps*, and *Ficus glomerata* for that matter, were found in UI. The result for *Liporrhopalum tentacularis* shows that the wasp species were found pollinating *Ficus montana* except for the 5 months it was not found in UI. Though *Ficus montana* could be found in KRB, *Liporrhopalum tentacularis* were never found there during the research.

In overall, the result of the analysis confirmed that symbiotic breakdown occurred in all research areas and in all months. This indicates that the result of Parrish *et al.* (2003) was caused by a symbiotic breakdown of *Ceratosolen marchali-Ficus hispida* prior to natural hybridization. The results of the analysis also suggest that symbiosis breakdown was not a rare occasion in western Java, especially in UI and KRB. From the results of this research, it seems that for *Ceratosolen marchali* the "one-to-one rule" does not apply.

CONCLUSIONS

Seven species of fig wasps were found in this research. Three species was considered as pollinator wasps and four others are considered as NPFW. All those wasps were found in the *sycone* of native fig species, while no wasp were found inside the *sycone* of introduced fig species.

For the pollinating wasp species, *Liporrhopalum tentacularis* Grandi and *Ceratosolen fusciceps* Mayr was found in the same fig species as recorded by Wiebes (1966a). *Ceratosolen marchali* Mayr was found in *Ficus septica* and *Ficus glomerata* as well as the two variant of *Ficus hispida* in UI and KRB. This result shows that *Ceratosolen marchali* has changed their host preference compared to the report of Wiebes (1966a). It was also discovered that the size of the *Ceratosolen marchali* wasps found in *Ficus glomerata* were smaller than those found in the other fig species.

For the NPFW, *Philotrypesis pilosa* Mayr was found in the *sycone* of both variant of *Ficus hispida* as well as *Ficus septica*. *Apocrypta bakeri* Joseph was found in the *sycone* of *Ficus hispida* var. *badiostrigosa* and *Ficus glomerata*. According to Wiebes (1966a), *Philotrypesis pilosa* and *Apocrypta bakeri* were only found in *Ficus hispida*. *Boučeka percaudata* Bouček was found in the *sycone* of *Ficus montana* and *Ficus glomerata*. *Apocrytophagus testaceus* Mayr was found in the *sycone* of *Ficus hispida* var. *badiostrigosa* and *Ficus glomerata*. The author found no clear record for the fig hosts of *Boučeka percaudata* and *Apocrytophagus testaceus*.

Symbiotic breakdown was confirmed to happen to *Ceratosolen marchali*. The wasp species was observed pollinating 4 fig species in UI and KRB. From the analysis, it was shown that the symbiotic breakdown happened in all research areas for the whole research time. This result might explain the natural hybridization between Ficus hispida and Ficus septica observed by Parrish *et al.* (2003). For the other pollinating wasp species, their exclusive symbiotic relationship with their host fig species were still retained.

ACKNOWLEDGEMENTS

The author is indebted to Dr. Rosichon Ubaidillah, M.Sc. and Dr. Adi Basukriadi, M.Sc. as the author's advisors for this research project and also for their knowledge of entomology and ecology. The author would also like to thank Andrio Adiwibowo, M.Sc. and Mega Atria, M.Si. as this research project's assessors, for their comments, inputs, and discussions. Special thanks to Pak Uyung, Mas Anto, and Mba' Fatimah for their help while preserving and identifying the specimens in LIPI.

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Note Paper

ON THE FIG AND FIG WASPS OF TREE AND LARGE SHRUB-FORMING FIGS IN UNIVERSITAS INDONESIA (UI) DEPOK AND KEBUN RAYA BOGOR (KRB), WEST JAVA, INDONESIA: THE FLOWERING TIME PATTERN OF THE FIGS, THE OCCURRENCE OF THE WASPS, AND OTHER ARTHROPODS FOUND WITHIN THE *SYCONE*

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ABSTRACT

A research regarding the chalcids of the Universitas Indonesia (UI) and Kebun Raya Bogor (KRB) has been done from January 2010 until December 2010. This research was aimed to know the flowering time patterns of the figs in UI and KRB, to discuss the occurrence of the fig wasps, and to know other arthropods that also use the *sycone* of the figs. A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) were chosen to be sampled. Each week, the stages of the sycone were noted for the flowering time pattern. From each trees and shrubs, 10 *sycone* were taken. The wasps were then reared inside the *sycone* to later be preserved using the method of Noyes (1982). The *sycone* were then cut open to collect other arthropods inside the *sycone* that haven't emerged for the *sycone*. The other arthropods were preserved inside 70% alcohol. The flowering time pattern of the figs of UI shows that the figs there produced *sycone* in a succession, while the ones in KRB produced *sycone* simultaneously. From the flowering time pattern, it seems that the figs of UI would stand a greater chance against fragmentation and isolation. The fig wasps seem to always be present in UI, while in KRB the wasps are sometimes absent. There is a possibility that the wasps moved to another fig population outside of KRB and haven't returned when the samples were taken.

The *Ceratosolen marchali* found in *Ficus glomerata* have a body size more similar to those of *Ceratosolen fusciceps* compared to *Ceratosolen marchali* found in other fig species. The other arthropods that were found in this research were members of two classes, Arachnida and Insecta. The insects found are members of the order Coleoptera, Hymenoptera, Diptera, Lepidoptera, Heteroptera, Homoptera, and Thysanoptera.

Key words: Arachnida; Arthropods; Fig population; Fig wasps; Figs; Flowering time pattern; Fragmentation; Insects; Isolation; Produced sycone in a succession; Produced sycone simultaneously.

INTRODUCTION

It is not rare for figs to be considered as an important or even keystone species in the area that they are found. Aside from the fig wasps, the *sycone* of a fig has high value to other arthropods. Those arthropods used the *sycone* for various reasons and in various ways. Some used the *sycone*'s cavity to rear their offspring; some consume nutrition from the *sycone*; and some prey on the wasps and other insect larvae that are in the *sycone* (Sastrapradja & Afriastini 1984; Gautier-Hion & Michaloud 1989; Kaspari 2000; Ridwan 2001; Hilaluddin *et al.* 2003; Nugroho *et al.* 2005; Lok & Lee 2009). The knowledge concerning the other arthropod species that utilized the *sycone* of the figs would shed light into how valuable the *sycone* of the figs for the arthropods, the occurrence of the wasps, and other animals, of an area.

In order for the chalcids of a particular area to survive, there should be at least one receptive fig within days. This is because the life expectancy of a chalcid wasp is very short, around 2 weeks reared in a laboratory (Hill 1967b). Though chalcids are reported to be able to ride wind currents, the fact that they are poor fliers makes it important for the wasps to find receptive figs that are close by.

Some figs produce *sycone* simultaneously in one population, and some in succession. For the figs that produced *sycone* simultaneously, the wasps must be able to move from one population to another. For the figs that produced *sycone* in succession, the wasps could afford not moving to another fig population. From the two patterns of producing *sycone*, the figs that produced *sycone* in succession should survive if they were cut off from other fig populations (Cook & Rasplus 2003; Jia *et al.* 2007). For that matter, the information on the flowering time pattern of the fig population would be important. It is important to know whether the fig population of an area could survive if in the future a fragmentation occurred.

This note was made to give additional information that was not given in the paper "Chalcids (Order Hymenoptera; Super-family Chalcidoidea) of tree and large shrub-forming Figs in Universitas Indonesia (UI) Depok and Kebun Raya Bogor (KRB)". The information would include the flowering time pattern of the figs and other arthropods found within the *sycone*.

This research has three aims: (i) To know the flowering time pattern of native and introduced tree and large shrub-forming figs in UI and KRB; (ii) To discuss the occurrence, and un-occurrence, of the wasps in the native and introduced tree and large shrub-forming figs; (iii) To obtain information regarding other arthropods that could be found inside the sycone of native and introduced tree and large shrub-forming figs in UI and KRB.

MATERIALS AND METHODS

A. LOCATION AND TIME OF RESEARCH

This research was done in UI and KRB from January 2010 until December 2010.. UI is situated in the town of Depok and KRB is situated in Bogor. Both research sites are situated in the Province of West Java. Spanning from 6° 20' 45.75''–6° 22' 33.84'' S and 106° 49' 8.42''–106° 49' 58.60'' E (Neave 2009), UI encompasses around 300 hectare of land (Taqyuddin *et al.* 1997). Compared to UI, KRB has a much smaller area. The 87 hectare (Anonym 2009) area of KRB spans from 6° 35' 28.90''–6° 36' 16.08'' S and 106° 47' 36.93''–106° 48' 18.09'' E (Neave 2009). The complete map of both research areas could be seen in Figure 1.

Both UI and KRB could be classified as open vegetated areas. But the two areas were design to be sanctuaries for flora and faunas, especially native ones (Taqyuddin *et al.* 1997; Anonym 2009). The goal of being a sanctuary is apparent judging from the initial vegetation chosen to be planted in the UI urban forest and KRB. In those areas, we could find vegetations that provide shelter, shades, fruits, and flowers. While KRB is a mixture of sanctuary-tourism spot, UI is a mixture of sanctuary-campus-human activity spot. Not to mention UI's future plans on adding tourism spot to the existing mix. Compared to KRB, the potential for environmental disturbance would be bigger in UI.

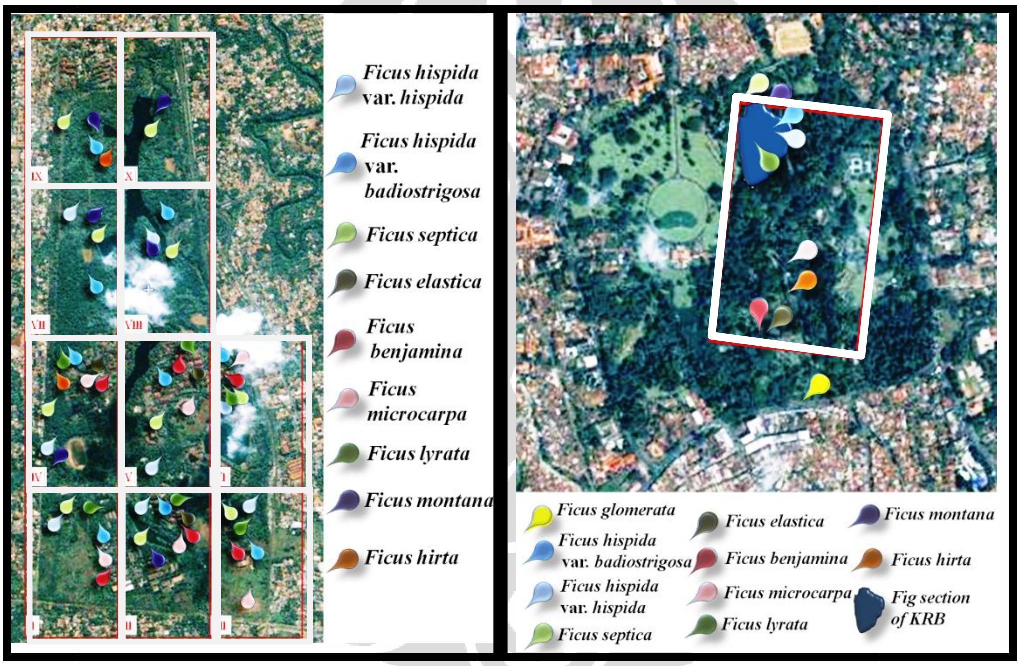

Figure 1. Map of the research areas. Left: UI; Right: KRB. The white boxes represent sampling areas of the same size
(Source of map: Flash Earth© Neave 2009).

B. COLLECTING THE WASPS AND OTHER ARTHROPODS

The research area of UI was divided into ten sectors while KRB was not divided. The reason for that action was because the figs of KRB are relatively concentrated in an area equivalent to one sector in UI. From each of those sectors, one tree of each tree and large shrub-forming fig species was chosen randomly. The sample for *Ficus glomerata* of KRB was an exception, since the trees inside the sampling areas yield no wasps.

A total of 56 fig trees and shrubs (from 9 species of fig) in UI and 34 fig trees and shrubs (from 34 species of fig) in KRB were chosen to be sampled. The identification of the fig trees was done using Flora of Java vol. II (Backer & Brink 1965). Each month, 10 *sycone* were taken from each trees and shrubs. On the moment of the collection, all arthropods that were found utilizing the *sycone*, or the wasps, were also collected and their behavior noted. After the *sycone* were collected, they were put into collecting bags and reared until the wasps emerged from the *sycone*. The rearing was done in a dark place to induce the male wasps to come out of the *sycone*, enabling the male wasps to be collected without having to cut open the *sycone*. After the wasps have been collected, then the *sycone* were dissected to observe the other arthropods that didn't came out during the rearing.

C. RECORDING THE FLOWERING TIME PATTERN OF THE FIGS

The flowering time pattern of each sampled tree was taken every week to know the monthly fluctuation of the flowering time of the figs. The phases of the *sycone* were classified into 4 stages. Stage I being the occurrence of the bud; stage II being the female phase; stage III being the male stage; and stage IV would be the stage where the *sycone* and the seeds ripened. The *sycone* are usually receptive for the fig wasps in stage II and the waps would emerge from the *sycone* in stage III. The result of the flowering time patterns would be presented in the form of Tables (table 1 and 2).

D. PRESERVATION, IDENTIFICATION, AND SIZE MEASUREMENT

Upon collection, the wasps and other arthropods were killed using etil acetate and are preserved using 70% alcohol. A few wasp specimens were separated to be mounted the day after. The mounting and preservation procedure used in this research follows that of Noyes (1982). The specimens of the other arthropods were kept inside 70% alcohol in a freezer.

The identification of the specimens was done in the Entomology lab of the Zoology Museum of The Indonesian Institute of Sciences (LIPI). The identification of the wasp would be based on Mayr (1906), Grandi (1926), Joseph (1952), Hill (1967a), Bouček (1988), Wiebes (1989), Wiebes (1993), Wiebes (1994), and Zhen *et al.* (2005). The identification of the ants is based on Budianggoro (2005) and the other insects are based on Romoser & Stoffolano (1998).

From the wasp specimens, 10 individual of *Ceratosolen marchali* found in *Ficus glomerata* [Cm(G)], the *Ceratosolen marchali* found in other fig species [Cm(NG)], and the *Ceratosolen fusciceps* (Cf) would be photographed using DINO Digital Microscope (AM-451). To complete the identification information, the head width (HW), front femur length (FFL), and ovipositor length (OvL) of the wasps were calculated using ImageJ image analysis program. HW, FFL, and OvL were chosen because the size of those parts determines whether the wasp would manage to successfully deposit their eggs (Wiebes 1989; Cook & Rasplus 2003; Liu *et al.* 2011). Size comparison analyses were done using PAST software (Hammer *et al.* 2001). The comparisons were meant to distinguish any similarities, or dissimilarities, in body part sizes between the 3 wasp groups.

RESULTS AND DISCUSSIONS

A. THE FLOWERING TIME PATTERN OF THE FIGS

The figs of UI and KRB were observed once every week to obtain their flowering time patterns. It was found that in UI, the figs produced their *sycone* in a succession. In KRB, the figs produced their *sycone* simultaneously. It should be known that UI is a lot larger than KRB. UI has a total area of almost 300 hectare while KRB only has a total area of around 87 hectare (Taqyuddin *et al.* 1997; Anonym 2009). The pattern that was observed could mainly be because of this size difference. If the areas around KRB (until the total area would be close to 300 hectare) were also included, there would be a possibility that the observed

Table 1. Flowering time pattern of the figs in KRB.

Table 2. Flowering time pattern of the figs in UI.

pattern of KRB is similar to that of UI. The complete flowering time pattern of the figs could be seen in Table 1 and 2.

One interesting pattern was shown by the male figs on the bank of Lake Agathis in UI (Sector II). The male figs that consist of *Ficus hispida* var. *hispida* and *Ficus hispida* var. *badiostrigosa* have a strong intra-tree asynchrony in producing their *sycone*. This asynchrony makes it possible for one tree to always be receptive all year long. This phenomenon was also observed by Jia *et.al* (2007) in the Ficus Garden of the South China Botanical Garden. This particular pattern was only observed in UI. The male *Ficus hispida* in KRB does not seem to have such a strong intra-tree asynchrony. The male figs there still have a few days of un-receptive phase.

From the flowering time patterns, the fig wasps of UI would stand a greater chance if someday faced with fragmentation or isolation. In other words, the figs of UI should also be more resilient to fragmentation and isolation without the need of human help.

B. THE OCCURRENCE OF THE FIG WASPS

The data concerning the figs wasps are collected twice, once in February–March and once in August–September 2010. From those two collecting time, there's a difference in occurrence between the fig wasps in UI and those of KRB. Except for the wasps of *Ficus montana*, the wasps of UI seem to always be present, while the wasps of KRB are only found in August–September. This pattern of occurrence could be correlated with the movement of the fig wasps. Harrison (2003) stated that the fig wasps have the tendency to move from one fig tree or population to the other. This is mainly because most figs might not be receptive all year round. Therefore the wasps must move and find a receptive tree after they've come out of the *sycone*.

The Flowering time pattern of the male figs of *Ficus hispida* in KRB would contribute to the absence of the fig wasps. The male figs in KRB do not have a strong intra-tree asynchrony. The male figs there still have a few days of un-receptive phase. Those few days would be enough to force the wasps to search for a receptive fig outside of KRB.

Another factor might be the abnormal weather pattern of 2010 in western Java. There's practically no real dry season in Western Java throughout 2010. Though Bronstein & Hossaert-McKey (1995) reported that the fig-fig wasp community of Florida could withstand Hurricane Andrews in 1992, there's no guarantee that the fig-fig wasp community could survive a prolonged abnormality in the weather pattern or even a change in the local climate. The local extinction and possible breakdown of mutualism in the fig-fig wasp community caused by a long change of weather pattern has been reported by Harrison (2000). He reported that the drought caused by El Niño in 1998 caused a local extinction of the local fig pollinator at Lambir Hills National Park, Sarawak, Malaysia. Though the abnormal weather observed by Harrison (2000) are not the same with the one observed in this research, the result could just be the same. Harrison (2003) shows that the fig wasps depend on wind current and they could not fly against strong wind, therefore a change in the wind current could cause a barrier for the fig wasps. Heavy rain could also cause a barrier for the fig wasps, cause like most insects they could not fly through heavy rain. Though there should be a more throughout research regarding this matter, there is a possibility that the abnormal weather of 2010 hinders the movements of the fig wasps into KRB.

The reason why the fig wasps of UI could always be present could be caused by the successive flowering time pattern of the figs and the strong intra-tree asynchrony that the male *Ficus hispida* has. Since according to the paper "Chalcids (Order Hymenoptera; Super-family Chalcidoidea) of tree and large shrub-forming Figs in Universitas Indonesia (UI) Depok and Kebun Raya Bogor (KRB)" the fig wasps of *Ficus hispida* and *Ficus septica* are the same, the male *Ficus hispida* could act as a refuge for most of the fig wasps. *Ficus hispida* as a refuge does not apply to the fig wasps of *Ficus montana* because their wasps are different. And that, added with the possibility that the fig wasps of *Ficus montana* search for receptive figs outside of UI, would be the reason why the fig wasps of Ficus montana are only found in the August–September data collection.

In this research, it was found that only one species of pollinator wasp (*Ceratosolen marchali*) lived in the sycone of *Ficus septica* and *Ficus hispida* in UI and KRB. Since the seedlings of the two species were found all around UI and KRB, both species must have been pollinated. *Ceratosolen marchali* are supposed to pollinate *Ficus hispida* (Wiebes 1966a), further researches are in order to figure out whether the species acts as a pollinator for *Ficus septica* as well. If this is the case, then it seems a symbiotic breakdown has occurred in UI and perhaps KRB. This would not be so surprising since Parrish *et al.* (2003) reported that in Indonesia *Ficus septica* and *Ficus hispida* might have gone through natural hybridization with one another. For a natural hybridization to occur there should be at least one species of agaonid wasp that were able to enter the *sycone* of both fig species and cross-pollinate them. It must be noted though, that there is always a possibility that the pollinator of *Ficus septica* existed in UI and KRB, but was not found in this research.

Ceratosolen marchali poses another problem since the species could be found in the same sycone with *Ceratosolen fusciceps* in *Ficus glomerata* of KRB. It would also be interesting, and important, to see the role of *Ceratosolen marchali* in *Ficus glomerata*. In this research, some *Ceratosolen marchali* individual that were found in *Ficus glomerata* were carrying the pollen of the fig. This indicates that there's a chance for *Ceratosolen marchali* to help the pollination of *Ficus glomerata* (Jousselin *et al.* 2003; Jandér & Herre 2010).

The body part sizes [head width (HW), front femur length (FFL), ovipositor length (OvL)] of *Ceratosolen marchali* found in *Ficus glomerata*, *Ceratosolen marchali* found in other fig species, and *Ceratosolen fusciceps*. These comparisons were done to discern whether there's a difference between the 3 groups to explain the appearance of *Ceratosolen marchali* in the *sycone* of *Ficus glomerata*. After comparing the body part sizes of the 3 groups of wasps with a kruskal-wallis analysis, it was known that the HW and FFL value of all 3 groups of wasps were different. The HW and FFL of the *Ceratosolen marchali* found in *Ficus glomerata* were significantly smaller than the *Ceratosolen marchali* found in other fig species [p (same) = 0.0002]. The HW and FFL of the *Ceratosolen marchali* found in *Ficus glomerata* were larger than *Ceratosolen fusciceps* [p (same) = 0.273]. The p (same) values of the HW and FFL size analysis shows that the HW and FFL of the *Ceratosolen marchali* found in *Ficus glomerata* were more similar with that of *Ceratosolen fusciceps* than that of *Ceratosolen marchali* found in other fig species. This shows that one of the reasons why *Ceratosolen marchali* had been found in *Ficus glomerata* was that the wasp has individuals with a body size small enough to pass through the *ostiole* of *Ficus glomerata* (Cook & Rasplus 2003; Liu *et al.* 2011). Though these results could explain why *Ceratosolen marchali* could enter the *sycone* of *Ficus glomerata*, the reason why the wasp could recognize the volatile of *Ficus glomerata* should be studied.

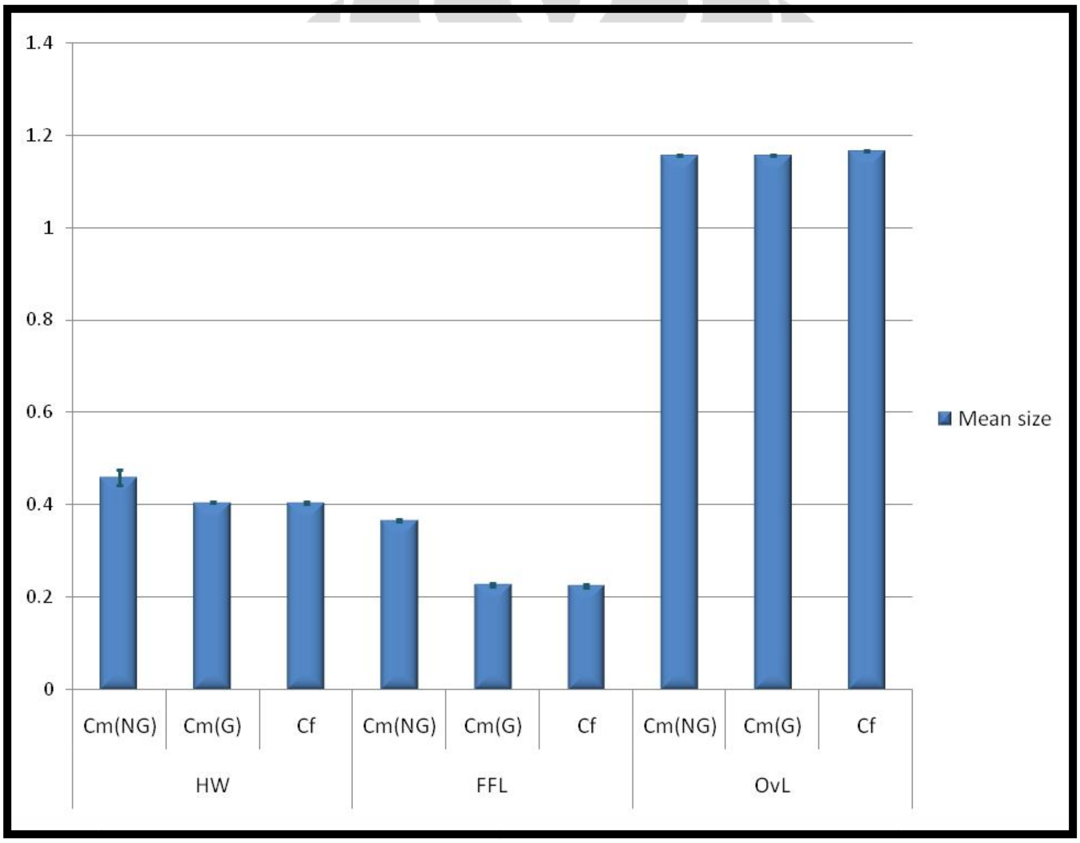

Figure 2. The mean size of head width (HW), front femur length (FFL), and ovipositor length (OvL) of *Ceratosolen marchali* found in *Ficus glomerata* [Cm(G)], *Ceratosolen marchali* found in other fig species [Cm(NG)], and *Ceratosolen fusciceps* (Cf).

The OvL of the *Ceratosolen marchali* found in *Ficus glomerata* were the same with the *Ceratosolen marchali* found in other fig species [p (same) = 1]. The OvL of the *Ceratosolen marchali* found in *Ficus glomerata* significantly smaller than *Ceratosolen fusciceps* [p (same) = 0.0002]. The p (same) values of the OvL size analysis shows that the OvL of the *Ceratosolen marchali* found in *Ficus glomerata* were similar with that of *Ceratosolen marchali* found in other fig species than that of *Ceratosolen fusciceps*. The fact that *Ceratosolen marchali* could deposit their eggs in *Ficus glomerata* would mean that the OvL of those wasps were long enough to pass the *stylus* of the female flowers (Wiebes 1989; Cook & Rasplus 2003).

No pollinators were found in this research for *Ficus benjamina* and *Ficus microcarpa*, and no NPFW were found for both fig species either. Though the pollinators of both figs were not found, there are a lot of fig seedlings from the sub-genus *Urostigma* in UI and KRB. One reason why there were no pollinators found might be because of insufficient collecting of the *sycone* done in this research. Another reason may involve the possibility that the population of the wasps move from one fig population to another (Harrison 2003). The phenomenon happened to *Ficus elastica* in KRB as well. For the ones in UI, it

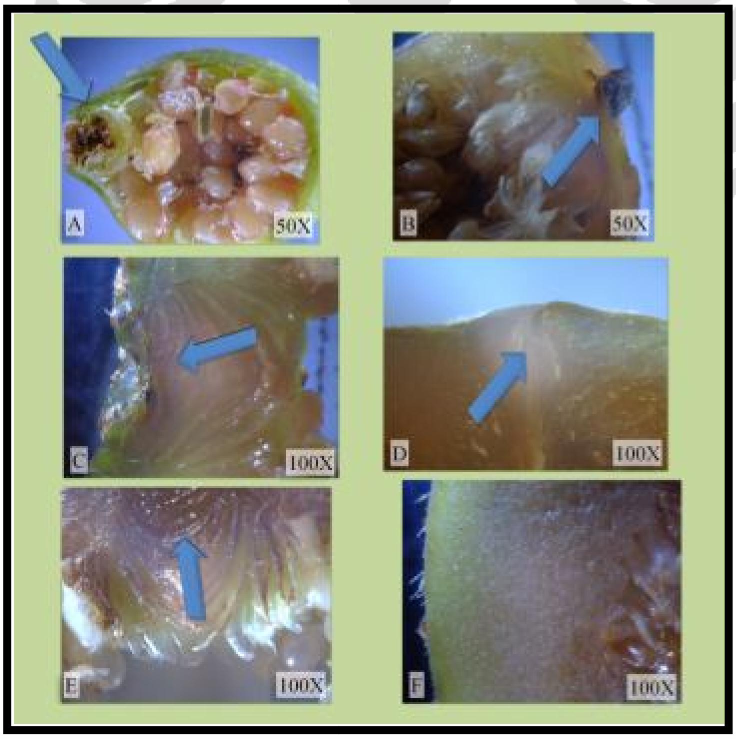

Figure 3. Sycone of figs. (A) *Ficus montana*; (B) *Ficus benjamina*; (C) *Ficus septica*; (D) *Ficus lyrata*; (E–F) *Ficus hispida*. The arrows are pointing at the *ostiole* of the *sycone*.

seems that the *Ficus elastica* trees have not produced any fruit for the whole year. So there's a possibility that the seedlings in UI came from trees outside of UI.

The pollinators of all introduced figs such as *Ficus lyrata* and *Ficus ampelas* were not found. Since the seedlings of all introduced fig species were not found in and around UI and KRB, it seems that there are no pollinators for the introduced species, whether it's their native pollinator or a new one from UI and KRB. One thing to note concerning the introduced figs is that there are no NPFW species that made use of their *sycone*. This could occur because the wasps of UI and KRB cannot recognize the *sycone* of the introduced figs, or the wasps cannot penetrate the *syconial* wall or *ostiole* of the figs. Ware *et al.* (1993) reported the function of volatiles produced by the *sycone* of figs to attract pollinators. It is very much possible that the wasps of UI and KRB did not recognize the volatile of the introduced fig species. In addition, for the introduced species from Africa, it seems that the *syconial* walls of those figs are harder and the *ostiole* narrow (Fig. 3D). The hard wall and narrow *ostiole* would make it hard for any agaonids and NPFW to deposit their eggs in the *sycone*.

C. OTHER ARTHROPODS FOUND IN THE *SYCONE*

The insects found are members of the order Coleoptera, Hymenoptera, Diptera, Lepidoptera, Heteroptera, Homoptera, and Thysanoptera. There were two species of ants (Class Insecta Order Hymenoptera Family Formicidae) found in and on the *sycone* of *Ficus septica*, *Ficus hispida*, *Ficus glomerata*, *Ficus nekbudu*, and *Ficus lyrata*. One species is a member of the Sub-family Myrmicinae (Fig.4E), and the other one is a member of the Sub-family Cerapachyinae (Fig. 4F). The ants did not live inside the *sycone*; they simply entered the *sycone* via holes made by other insects, and leave through the same manner after preying on the wasps.

Though there are no fig wasps found in the *sycone* of *Ficus lyrata*, one species of fungus beetle from the Class Insecta; Order Coleoptera; Family Endomychidae (Fig. 4C–D) were found there. A lot of aphids (order Homoptera) were found feeding on the *sycone* of *Ficus nekbudu*, and in the end the aphids were exploited by ants.

Figure 4. Other arthropods found in the *sycone* of the figs of UI and KRB (1).

Figure 5. Other arthropods found in the *sycone* of the figs of UI and KRB (2).

The larvae of a fly species (Order Diptera Family Phoridae) manages to exploit the decaying *sycone* of *Ficus septica*, *Ficus hispida*, and *Ficus glomerata* as a food source, and the adults (Fig 4A) fly out through the holes made by the chalcids. One species of Lepidoptera (Fig. 5E–F) seems to be able to make use of the *sycone* and the flowers of *Ficus septica* and *Ficus hispida* as a food source and shelter for their larvae. A few pupae (Fig. 5B & 5D) of a true bug (either Order Heteroptera or Homoptera) were also found inside the *sycone* of *Ficus glomerata*. It is still unclear whether the larvae reside inside the *sycone* or not. There are some Thysanoptera (Fig. 5A & 5C) found inside the *sycone* of a few *Ficus septica* in UI. These Thysanopteras are usually found on leafs, but in this research they're found inside the *sycone*.

One species of mite (Fig 4B) is found. The mites (Class Arachnida) found were parasites of the chalcid *Philotrypesis pilosa* Mayr. The mites are usually found beneath the abdominal tergites of the fig wasp. In this research, the mites are not found in other wasp species.

CONCLUSIONS

The various arthropods that was found inside the *sycone* of the figs in UI and KRB shows that the fig, and fig wasp, species of both areas are important resources, at least for the arthropods. Most of the arthropods found in the *sycone* of the figs either exploit the fig wasps or the *sycone* itself. The reason for the occurrence of some Thysanoptera in the sycone of a few *Ficus septica* in UI is unknown. For the introduced fig species, especially the ones from Africa, it seems that only beetles and aphids were able to exploit the *sycone* of those figs.

The head width (HW) and front femur length (FFL) of *Ceratosolen marchali* found were varied. The wasps found in *Ficus glomerata* have a body size more similar to those of *Ceratosolen fusciceps*. This result explained why *Ceratosolen marchali* could enter the *sycone* of *Ficus glomerata*. The Ovl of the *Ceratosolen marchali* found in any figs seems to be the same.

The simultaneous flowering time pattern of the figs in KRB could pose a threat to the figs of KRB. If an area has simultaneous flowering time pattern for all fig species in that area, it means that the area would need fig populations from adjacent areas to sustain the population of their fig wasps. The fig wasps of KRB could face a serious problem if the figs of KRB were to be isolated from their adjacent populations.

The strong intra-tree asynchrony shown by a group of male *Ficus hispida* trees in UI might just be the reason why the wasps that could be found in Ficus hispida in UI were found all year round. Those trees provided the needed nursing ground for the wasps to grow in. Of course, the said trees could not help the wasp population that could not utilize the *sycone* of *Ficus hispida*. These strong intra-tree asynchronies were only discovered in UI, which made the fig community of KRB even more fragile because the figs of KRB really have to depend on adjacent fig populations.

ACKNOWLEDGEMENTS

The author is indebted to Dr. Rosichon Ubaidillah, M.Sc. and Dr. Adi Basukriadi, M.Sc. as the author's advisors for this research project and also for their knowledge of entomology and ecology. The author would also like to thank Andrio Adiwibowo, M.Sc. and Mega Atria, M.Si. as this research project's assessors, for their comments, inputs, and discussions. Special thanks to Pak Uyung, Mas Anto, and Mba' Fatimah for their help while preserving and identifying the specimens in LIPI.

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Paper II

COMPARING UNIVERSITAS INDONESIA (UI) DEPOK AND KEBUN RAYA BOGOR (KRB), WEST JAVA, INDONESIA, FROM THEIR FIG WASPS OF TREE AND LARGE SHRUB-FORMING FIGS: WITH A SPECIAL VIEW TOWARDS THE EFFECTS OF FRAGMENTATION TO THE FIG WASP COMMUNITY

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ABSTRACT

A research concerning the fig wasp community of UI and KRB was done in August–September 2010. The research was aimed to find out and compare the fig wasp diversity of UI and KRB. Fragmentation was chosen as a view topic for this research because fragmentation could trigger decay in the fig-fig wasp community. *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana*, and *Ficus glomerata* was chosen to be compared. From those trees and shrubs, 10 *sycone* were taken. The wasps were then reared inside the *sycone* to later be preserved using the method of Noyes (1982). Using PAST software, a cluster analysis with single linkage algorithm, using Morisita's similarity index was done to depict the similarity between the fig species and also between the wasp species. The mean value of the wasp community was used to calculate the Shannon (H) and evenness indices. From the analysis done, it's known that the fig species in UI may not have a similar wasp community with their KRB counterpart. Though the three pollinator wasp species has a different host preference, it was found that a symbiotic breakdown might have occurred in both UI and KRB. It was found that *Ficus glomerata* of KRB and *Ficus hispida* var. *badiostrigosa* of UI has the biggest diversity value. The proportions of the pollinators against the non-pollinating fig wasps (NPFW) were also calculated to compare UI and KRB based on their fragmentation level. This comparison would

only compare *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica*. From the comparisons, *Ficus hispida* var. *badiostrigosa* and *Ficus septica* shows that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.2396 & 0.1416]. For *Ficus hispida* var. *hispida* however, the result shows that pollinator proportion would be higher in areas with higher fragmentation level [p (uncorr) = 0.0637]. This pattern was possibly the result of the symbiotic breakdown that happened to the 3 fig species. After compiling the proportion data for the 3 fig species, it shows that that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.4349]. This research shows that though fragmentation affects the pollinator-NPFW proportion, symbiotic breakdown could change the relationship pattern between fragmentation and pollinator-NPFW proportion.

Key words: Diversity value; Fig; Fig wasp; Fragmentation; Host preference; Non pollinating fig wasp; Pollinator wasp; Symbiotic breakdown.

INTRODUCTION

Figs and their fig wasps have long been known to have a special relationship. Some fig wasps have even built a symbiotic relationship with their fig. Those wasps have become pollinators for their figs. Besides the pollinators, other fig wasps utilize the *sycone* of figs. These wasps are usually known as the parasites or non-pollinating fig wasps (NPFW). Both the pollinators and the NPFW needed to find a viable tree as soon as they emerge from their previous *sycone* (Corner 1940; Hill 1967b; Boucek 1997; Gullan & Cranston 2005). As they must find a viable tree within their 2 weeks live, habitat fragmentation would be a major problem for the wasps. Since the wasps depend on the wind for long range travels, any change in the wind current pattern of an area could create a barrier for the wasps (Condit & Swingle 1947; Hill 1967a; Michaloud *et al.* 1996; Harrison 2003; Gullan & Cranston 2005).

Changes in the habitat and climate could cause an area to be fragmented or even isolated in the point of view of the fig wasps. Fragmentation could change the community attributes in an area. On early stages, the abundance of each species would change. On latter stages, the species composition itself would change (Wilcox & Murphy 1985; Andrén 1994). In the fig-fig wasp community, a change in species abundance and composition could lead to symbiotic breakdown, pollinator extinction, and even the extinction of the figs (Michaloud *et al.* 1985; Ware & Compton 1992; Wang *et al.* 2005).

UI and KRB were chosen as research locations because both places are open vegetated areas that acts as sanctuaries for the animal community inside and around them (Taqyudin *et al.* 1997; Anonym 2009). As a sanctuary, figs could prove to be a useful resource for food or shelter (Gautier-Hion & Michaloud 1989; Prihantomo 2007), therefore the survivability of the fig community would be crucial. The areas in and around UI and KRB are prone to changes, UI a bit more than KRB, therefore researches that views on habitat changes and fragmentation would be important. The information collected by those researches could be a valuable input for the management of UI and KRB so they could maintain the sanctuary function of both areas.

This research has four aims: (i) Comparing the figs of UI and KRB based on their wasp community; (ii) Knowing the fig preference of the fig wasps; (iii) Comparing the diversity of the fig wasps of each fig species in UI and KRB; and (iv) Comparing the pollinator-NPFW proportion of *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa,* and *Ficus septica* in UI and KRB based on the fragmentation level of the two areas.

MATERIALS AND METHODS

A. LOCATION AND TIME OF RESEARCH

This research was done in UI and KRB. UI is situated in the town of Depok and KRB is situated in Bogor. Both research sites are situated in the Province of West Java. Spanning from 6° 20' 45.75''–6° 22' 33.84'' S and 106° 49' 8.42''–106° 49' 58.60'' E (Neave 2009), UI encompasses around 300 hectare of land (Taqyuddin *et al.* 1997). Compared to UI, KRB has a much smaller area.

The 87 hectare (Anonym 2009) area of KRB spans from 6° 35' 28.90"–6° 36' 16.08" S and 106° 47' 36.93"–106° 48' 18.09" E (Neave 2009). The complete map of both research areas could be seen in Figure 1.

Both UI and KRB could be classified as open vegetated areas. But the two areas were design to be sanctuaries for flora and faunas, especially native ones (Taqyuddin *et al.* 1997; Anonym 2009). The goal of being a sanctuary is apparent judging from the initial vegetation chosen to be planted in the UI urban forest and KRB. In those areas, we could find vegetations that provide shelter, shades, fruits, and flowers. While KRB is a mixture of sanctuary-tourism spot, UI is a mixture of sanctuary-campus-human activity spot. Not to mention UI's future plans on adding tourism spot to the existing mix. Compared to KRB, the potential for environmental disturbance would be bigger in UI.

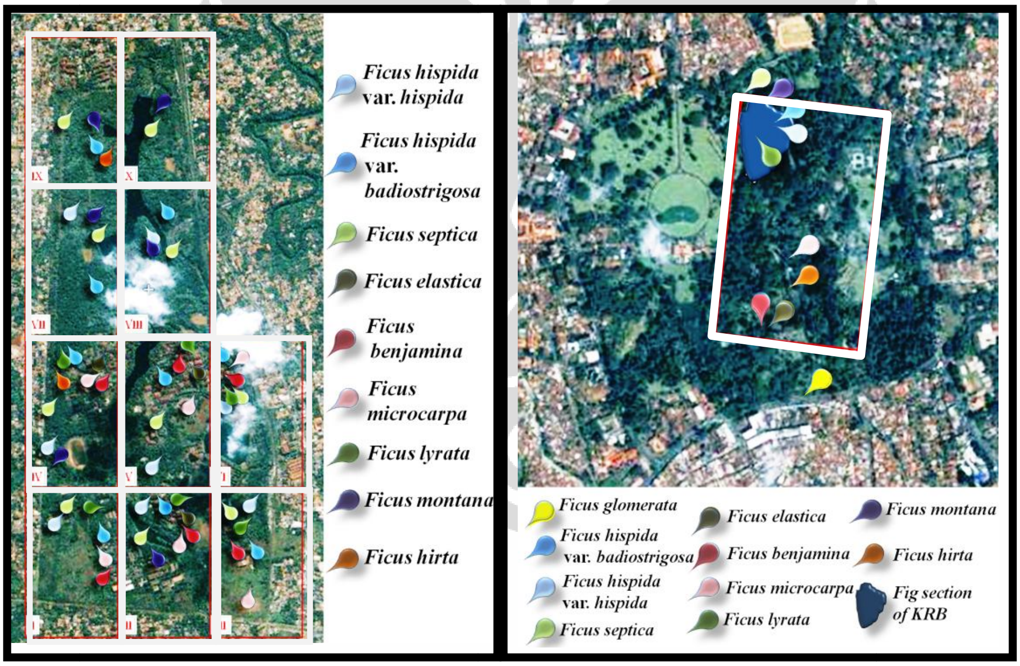

Figure 1. Map of the research areas. Left: UI; Right: KRB. The white boxes represent sampling areas of the same size (Source of map: Flash Earth© Neave 2009).

This research was carried out in February–March and August–September 2010. The overall weather of 2010 could be considered as abnormal. This was because there seems to be no dry season what so ever in the research areas on that year. The dry season, which usually occurred between June–September, was laden with heavy rainfall and wind.

B. COLLECTING THE WASPS

For objectivity sake, the research area of UI was divided into ten sectors while KRB was not divided. The reason for that action was because the figs of KRB are relatively concentrated in an area equivalent to one sector in UI. From each of those sectors, one tree of each tree and large shrub-forming fig species was chosen randomly. The sample for *Ficus glomerata* of KRB was an exception, since the trees inside the sampling areas yield no wasps.

The identification of the fig trees was done using Flora of Java vol. II (Backer & Brink 1965). During the sampling, 10 *sycone* were taken from each trees and shrubs. After the *sycone* were collected, they were put into collecting bags and reared until the wasps emerged from the *sycone*. The data that were calculated was only from the female wasps.

C. PRESERVATION AND IDENTIFICATION

Upon collection, the wasps were killed using etil acetate and are preserved using 70% alcohol. A few specimens were separated to be mounted the day after. The mounting and preservation procedure used in this research follows that of Noyes (1982). The identification of the specimens was done in the Entomology lab of the Zoology Museum of The Indonesian Institute of Sciences (LIPI).

D. DATA ANALYSIS

The ecological analysis was done with PAST software (Hammer *et al.* 2001). A cluster analysis with single linkage algorithm, using Morisita's similarity index was done to depict the similarity between the fig species and also between the wasp species. The mean value of the wasp community was used to calculate the Shannon (H) and evenness indices. Diversity t tests were done to know whether the wasp diversity of each fig species between the two areas were different. *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, *Ficus montana*, and *Ficus glomerata* was chosen to be compared in this part of the analysis. Those five species was chosen because from all the fig species in UI and KRB, only the wasps of those five species were found.

The proportions of the pollinators against the NPFW were also calculated to be compared based on the fragmentation level of UI and KRB. *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* were chosen to be compared. The 3 fig species were chosen because wasps were found in the *sycone* of those species in all research areas. In this research, four fragmentation levels were used. Those fragmentation levels were:

- None (0) = Vegetation coverage more than 54.513%, fig trees are still in groups or abundant.
- Low (1) = Vegetation coverage more than 54.513%, fig trees are not in groups or scarce.
- Medium (2) = Vegetation coverage less than 54.513%, fig trees are still in groups or abundant.
- High (3) = Vegetation coverage less than 54.513%, fig trees are not in groups or scarce.

The levels were modified from Franklin *et al.* (2002) and Wang *et al.* (2005). The vegetation coverage limit of 54.513% were the mean vegetation coverage of the sectors in UI and KRB in this research. Using PAST software (Hammer *et al.* 2001), a Spearman correlation analysis was done to determine whether there's a correlation between fragmentation level and pollinator-NPFW proportion.

RESULTS AND DISCUSSIONS

From the data collection, only the collection of August–September 2010 yield any result for KRB. There seems to be no fig wasps to be found in KRB in the February–March collection. Interestingly, the same did not happen in UI. Except for *Ficus montana*, there are no difference in the fig wasp composition and abundance in UI. For that reason, the author decided to only compare the UI-KRB data of August–September 2010.

Ceratosolen marchali Mayr, *Ceratosolen fusciceps* Mayr, *Liporrhopalum tentacularis* Grandi, *Philotrypesis pilosa* Mayr, *Boučeka percaudata* Bouček, *Apocrytophagus testaceus* Mayr, and *Apocrypta bakeri* Joseph were found. From those wasps, 3 species are pollinators and the rest are NPFW. The wasps were found from *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, and *Ficus montana* in UI and from *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, *Ficus septica*, and *Ficus glomerata* in KRB. The mean value of the fig wasps found in this research could be seen in Table 1.

A. THE FIGS OF UI AND KRB: A Comparison Based on Their Wasp Community and the Host Preference of the Fig Wasps

Table 1. Arithmetic mean of all found wasp species in their respective figs at UI and KRB.

Wasp species	Arithmetic mean number of individual and proportion of fig wasp in *Ficus*								
	hispida var. *hispida*		*hispida* var. *badiostrigosa*		*septica*		*montana*		*glomerata*
	UI	KRB	UI	KRB	UI	KRB	UI	KRB	KRB
Ceratosolen marchali	104.75±1.97*	24±4.58*	121.11±2.82*	59±5.49*	108.6±2.52*	75±5.52*	0±0	0±0	21±2.47*
Ceratosolen fusciceps	0±0	0±0	0±0	0±0	0±0	0±0	0±0	0±0	41±4.25*
Liporrhopalum tentacularis	0±0	0±0	0±0	0±0	0±0	0±0	1.33±0.22*	0±0	0±0
Apocrypta bakeri	0±0	0±0	11.11±0.97	0±0	0±0	0±0	0±0	0±0	87±5.33
Philotrypesis pilosa	109±1.26	72±4.37	161.67±2.74	68±5.90	165.2±2.71	65±4.84	0±0	0±0	0±0
Bouceka percaudata	0±0	0±0	0±0	0±0	0±0	0±0	1.33±0.19	0±0	27±3.43
Apocryptophagus testaceus	0±0	0±0	20.78±1.74	0±0	0±0	0±0	0±0	0±0	58±4.61

* Suspected as pollinating wasps

From the data of Table 1, a cluster analysis with single linkage algorithm, using Morisita's similarity index was done to depict the similarity between the fig species (Waite 2000). This was done to know which fig species is more similar from the wasps' point of view. The result could be seen in Figure 2. A transpose data from Table 1 was used to depict the similarity between the wasp species based on their preference of fig host. The result could be seen in Figure 3.

From Figure 2, it could be seen that the same species of fig could have different wasp composition. The *Ficus montana* of KRB is the most different one

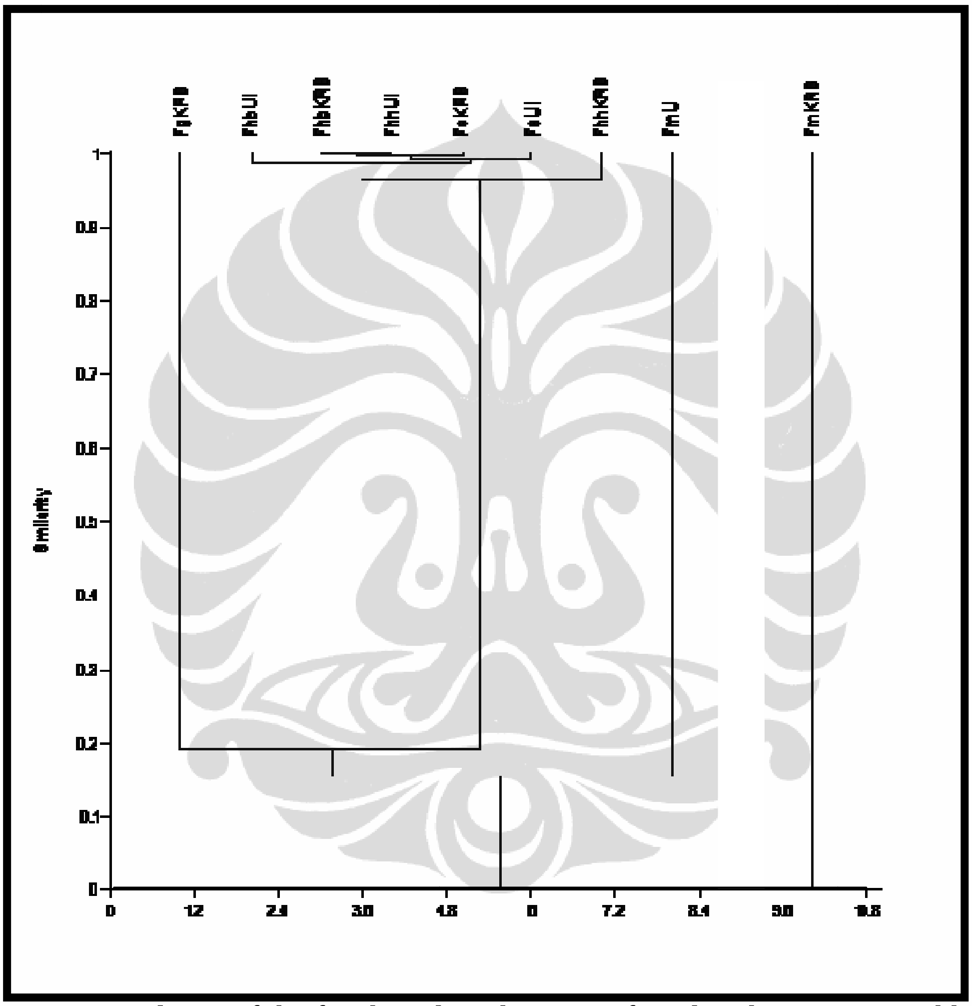

Figure 2. Similarity of the figs based on the wasps found in their *sycone*. Fhh= *Ficus hispida* var. *hispida*; Fhb= *Ficus hispida* var. *badiostrigosa*; Fs= *Ficus septica*; Fm= *Ficus montana*; and Fg= *Ficus glomerata*.

since there was no wasp to be found in the sycone of said species. The absence of wasps from the *Ficus montana* of KRB could be because of the tendency of the fig wasps to move from one fig population to another, as observed by Harrison (2003). But this tendency, if coupled with habitat fragmentation, could do harm to the survivorship of the fig wasps of Ficus montana in KRB and in the end, the fig itself (Aizen & Feinsinger 1994; Murren 2002; Wang *et al.* 2005). From the research, it was also discovered that compared to the other figs, the wasp community of *Ficus montana* seems to be a bit more specialized than the others. The pollinator species of *Ficus montana* (*Liporrhopalum tentacularis*) are still very specialized in choosing their host, this would make the fig prone to population decline and even extinction because of fragmentation (Pianka 1983; Cunningham 2000; Fahrig 2003; Wang *et al.* 2005). The NPFW of *Ficus montana* in UI (*Bouček percaudata*) seems to prefer *Ficus glomerata* more in KRB (Table 1 & Fig. 3). This shows that unlike the pollinators, NPFW would not be limited to one host.

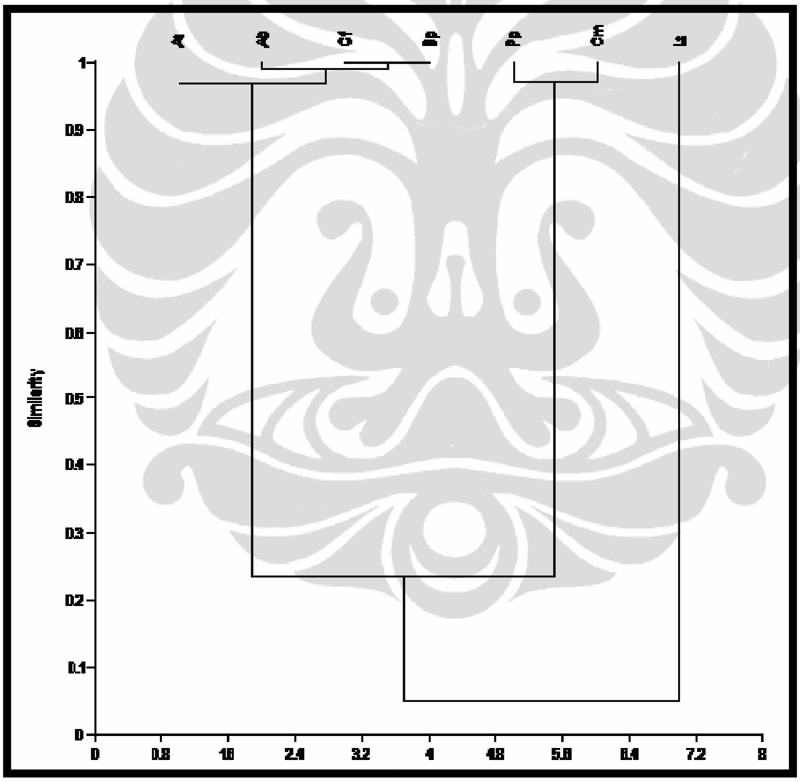

Figure 3. Similarity of the fig wasps based on their preference of their fig host(s). Cm= *Ceratosolen marchali* Mayr; Lt= *Liporrhopalum tentacularis* Grandi; Pp= *Philotrypesis pilosa* Mayr; Bp= *Bouček percaudata* Bouček; At= *Apocrytophagus testaceus* Mayr; Ab= *Apocrypta bakeri*; and Cf= *Ceratosolen fusciceps* Mayr.

The next most dissimilar fig species would be the *Ficus glomerata* which was only found in KRB. The pollinator species of *Ficus glomerata* (*Ceratosolen fusciceps*) was still specialized in their host selection (Table 1 and Fig. 3). The problem is the presence of *Ceratosolen marchali* in the sycone of *Ficus glomerata*. In this research, the *Ceratosolen marchali* in *Ficus glomerata* was found carrying the fig's pollen. This suggested that in *Ficus glomerata*, Ceratosolen marchali acts as a pollinator (Jousselin *et al.* 2003; Jandér & Herre 2010).

For the other fig species (*Ficus hispida* var. *hispida, Ficus hispida* var. *badiostrigosa*, and *Ficus septica*), the similarity based on the wasp community is very high. From Table 1 and Figure 2, we could see that the wasp species that occupied the Sycone of those species are the same except for the *Ficus hispida* var. *badiostrigosa* of UI. The pollinator wasps of those fig species are the same, which is *Ceratosolen marchali*. This result suggests the possibility of a symbiotic breakdown.

B. THE DIVERSITY OF THE FIG WASPS OF EACH FIG SPECIES IN UI AND KRB

From the data of Table 1, an analysis of the fig wasp diversity was done. The value of Shannon (H) index and evenness was calculated to depict the diversity of the fig wasp communities of the figs. The complete result could be seen in Table 3. The diversity indices were also compared to determine whether the value of a fig species different with another species, this comparison was done with the diversity t test. The result of this calculation could be seen in Table 4. The reason for this diversity analysis was to decide which species of figs sustain the most diverse wasp community. This information would be important for the management of UI and KRB.

From this research, the *Ficus glomerata* of KRB has the largest diversity value (H= 1.484), followed by the *Ficus hispida* var. *badiostrigosa* of UI (H= 1.007). This conclusion was taken after seeing that the Shannon (H) value of the two species was the highest and the diversity t tests shows that their diversity values were significantly different from the other fig species (Table 3 & Table 4). Combined with the data in table1, it seems that *Ficus glomerata* could sustain a diverse array of fig wasp species, including the wasps of other fig species. But this doesn’t necessarily signify that *Ficus glomerata* could be the host of all fig wasp species. It seems that *Ficus glomerata* are able to attract a wide range of NPFW. The presence of *Ceratosolen marchali* in the *sycone* of *Ficus glomerata* could be caused by the symbiotic breakdown between *Ceratosolen marchali* and *Ficus hispida* (Michaloud *et al.* 1985; Michaloud *et al.* 1996; Parish *et al.* 2003). This information could be useful for the management of UI and KRB, because *Ficus glomerata* could function as a “refuge species” in this research.

Table 3. Shannon Diversity Index and Evenness Index value of the wasps in the figs of UI and KRB.

Indices	*Ficus*								
	hispida var. *hispida*		*hispida* var. *badiostrigosa*		*septica*		*montana*		*glomerata*
	UI	KRB	UI	KRB	UI	KRB	UI	KRB	KRB
Shannon (H)	0.6919	0.5623	1.007	0.6906	0.6707	0.6906	0.5406	0	1.484
Evenness	0.9987	0.8774	0.6845	0.9975	0.9778	0.9975	0.8585	0	0.8824

Table 4. P value (Diversity t method) comparing the fig wasps diversity of each fig species in UI and KRB.

P (same)			*Ficus*								
			hispida var. *hispida*		*hispida* var. *badiostrigosa*		*septica*		*montana*		*glomerata*
			UI	KRB	UI	KRB	UI	KRB	UI	KRB	KRB
Ficus	*hispida* var. *hispida*	UI	1	8.35 E-3*	4.36 E-15*	7.46 E-1	1.05 E-1*	7.61 E-1	3.12 E-1*	0*	2.41 E-66*
		KRB		1	1.05 E-11*	1.07 E-2*	2.96 E-2*	1.04 E-2*	4.66 E-1*	0*	1.34 E-35*
	hispida var. *badiostrigosa*	UI			1	7.35 E-15*	1.15 E-15*	6.80 E-15*	1.37 E-1*	0*	5.40 E-20*
		KRB				1	2.36 E-10*	9.77 E-1	3.14 E-1*	0*	2.17 E-67*
	septica	UI					1	2.19 E-1*	3.31 E-1*	0*	8.79 E-70*
		KRB						1	3.14 E-1*	0*	2.58 E-67*
	montana	UI							1	0*	5.60 E-2*
		KRB								1	0*
	glomerata	KRB									1

* Significantly different at α 0.05

The fate of *Ficus montana* would also be important since their pollinator wasps (*Liporrhopalum tentacularis*) are still specialized. This species of fig also has the lowest value of diversity (H= 0.5406 in UI; H= 0 in KRB). The survivorship of the pollinators should be of concern to ensure the survivorship of the fig. Their NPFW should not be of too much concern because the wasp *Bouček*a *percaudata* could use the *sycone* of *Ficus glomerata* to sustain its population.

C. COMPARING UI AND KRB BASED ON FRAGMENTATION LEVEL

The research of Wang *et al.* (2005) shows that the fragmentation level of an area could affect the proportion of pollinator-NPFW. In their research, they concluded that the proportion of NPFW would be higher in a more fragmented area. The opposite applied for the pollinators. The more fragmented the area, the lower the proportion of the pollinators. In this research, *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* were compared based on the correlation between pollinator-NPFW proportions and fragmentation level.

1. Results for *Ficus hispida* var. *hispida, Ficus hispida* var. *badiostrigosa*, and *Ficus septica*

Table 5. Fragmentation level for *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* in UI and KRB.

Fig species	UI										KRB
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Ficus hispida var. hispida	3	2	3	2	1	3	1	1	1	1	0
Ficus hispida var. badiostrigosa	3	2	3	2	1	3	1	1	1	1	0
Ficus septica	2	2	2	2	1	3	0	1	1	1	0

Based on the criteria of fragmentation level used in this research, the fragmentation level for *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* in UI and KRB could be seen in Table 5. The fragmentation level for *Ficus hispida* var. *hispida* and *Ficus hispida* var. *badiostrigosa* were the same, while *Ficus septica* were different. The fragmentation level for Ficus septica was lower in some sectors in UI compared to the other fig species.

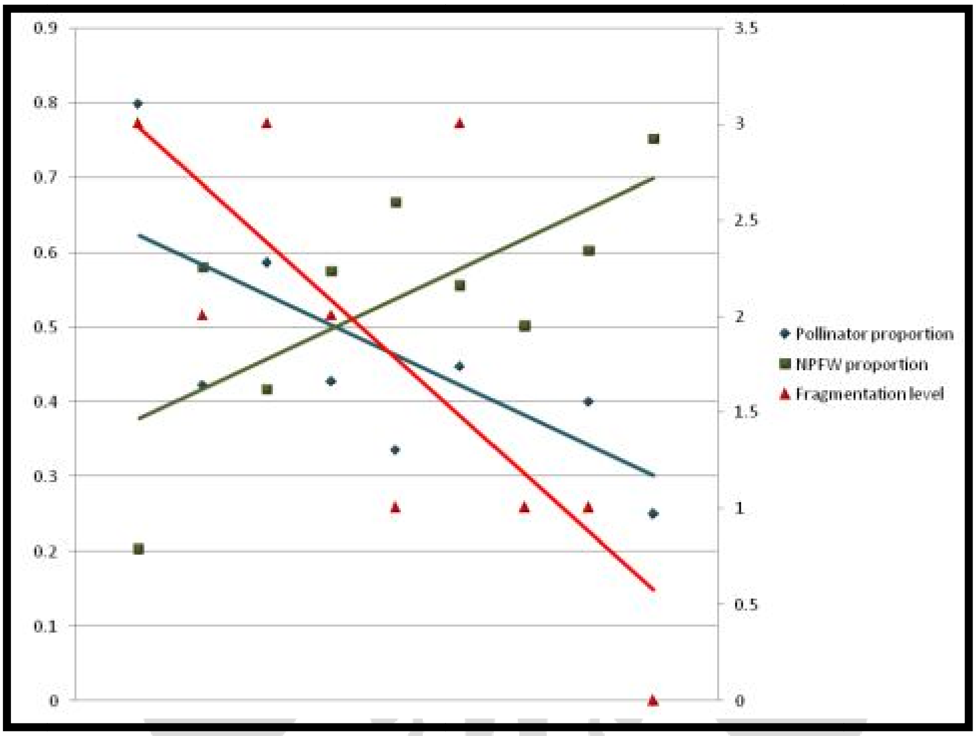

Figure 4. Comparison of pollinator and NPFW proportion compared with fragmentation level for *Ficus hispida* var. *hispida*.

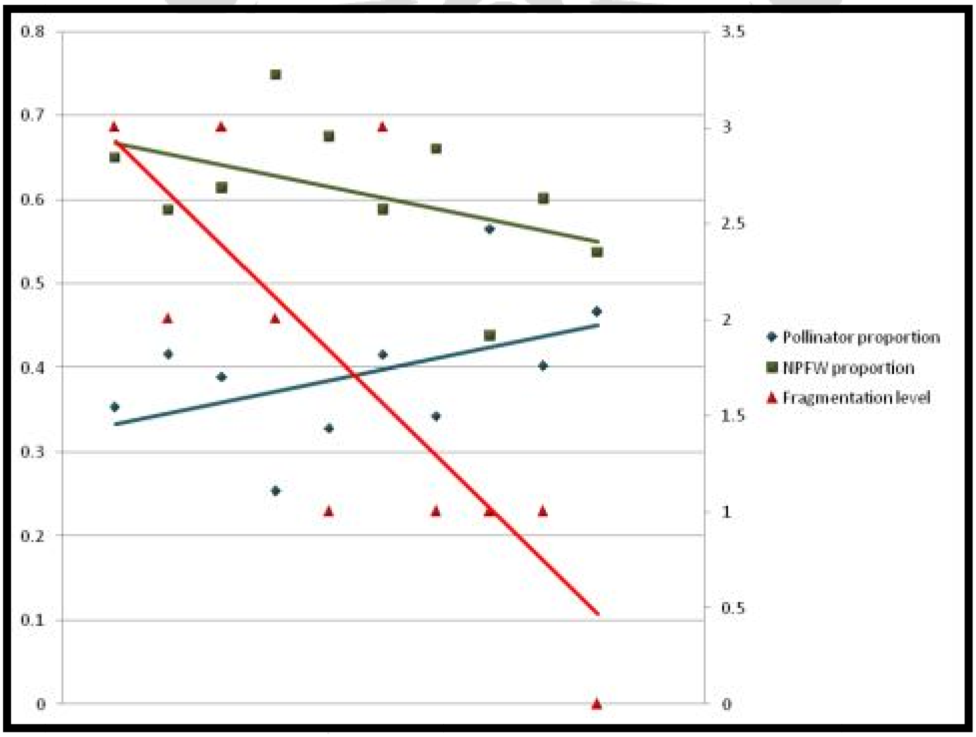

Figure 5. Comparison of pollinator and NPFW proportion compared with fragmentation level for *Ficus hispida* var. *badiostrigosa*.

For *Ficus hispida* var. *hispida*, the analysis result shows that pollinator and NPFW proportion are correlated with the fragmentation level [p (uncorr) = 0.0637]. The analysis also shows that pollinator proportion was positively correlated with fragmentation level and NPFW proportion was negatively correlated with fragmentation level (Fig. 4). These results were different with that of Wang *et al.* (2005).

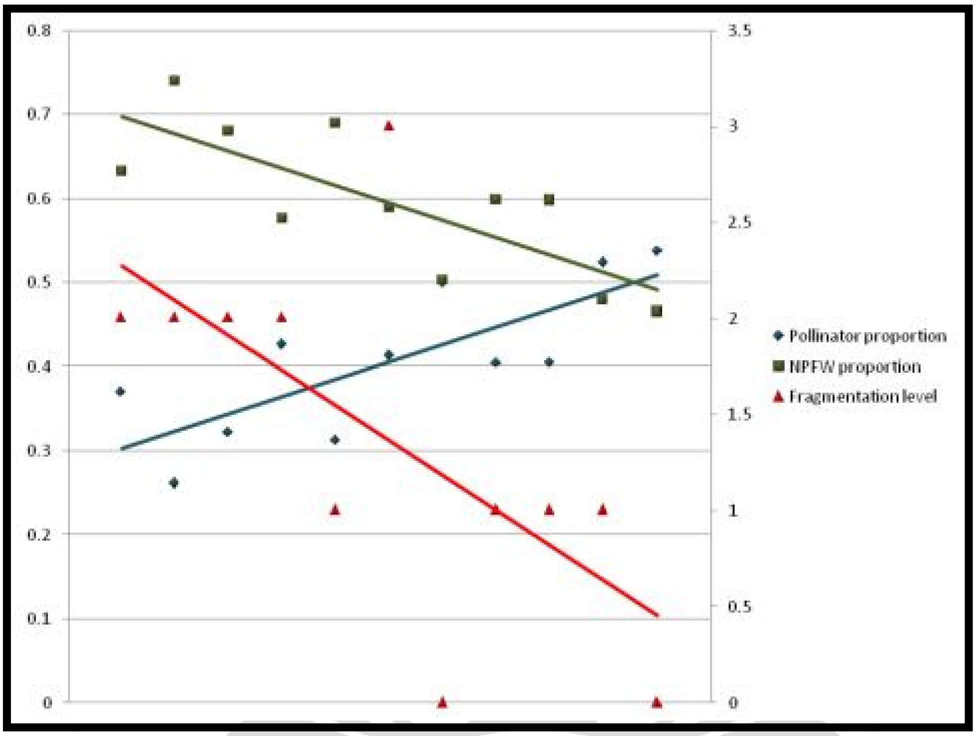

Figure 6. Comparison of pollinator and NPFW proportion compared with fragmentation level for *Ficus septica*.

For *Ficus hispida* var. *badiostrigosa*, the analysis result shows that pollinator and NPFW proportion are correlated with the fragmentation level [p (uncorr) = 0.2396]. The analysis also shows that pollinator proportion was negatively correlated with fragmentation level and NPFW proportion was positively correlated with fragmentation level (Fig. 5). These results were coherent with that of Wang *et al.* (2005).

For *Ficus septica*, the analysis result shows that pollinator and NPFW proportion are correlated with the fragmentation level [p (uncorr) = 0.1416]. The analysis also shows that pollinator proportion was negatively correlated with fragmentation level and NPFW proportion was positively correlated with fragmentation level (Fig. 6). These results were again consistent with that of Wang *et al.* (2005).

In overall, aside from the *Ficus hispida* var. *hispida* result, KRB has a larger pollinator to NPFW proportion compared to most sectors of UI. This was caused by the low fragmentation level of KRB (0), compared to most of the sectors in UI. But even so, it would still be possible for areas with higher fragmentation level to have a large pollinator to NPFW proportion.

A different pattern was observed in *Ficus hispida* var. *hispida*. KRB has a smaller pollinator to NPFW proportion compared to most sectors of UI. These results, which contradicts the results of Wang *et al.* (2005) and the results of the other fig species in this research, seems to indicate that the pollinator of *Ficus hispida* var. *hispida* species thrive better in fragmented habitats compared to the pollinator of the other fig species.

2. Pollinator-NPFW Proportion Affected by Symbiotic Breakdown

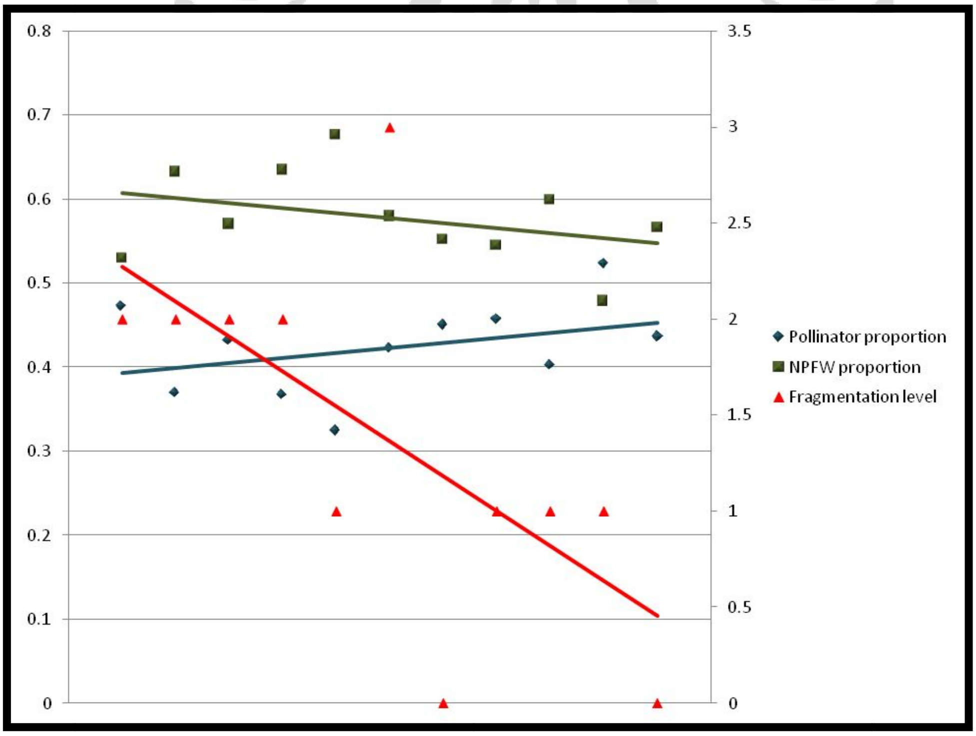

Figure 7. Comparison of pollinator and NPFW proportion compared with fragmentation level for combined fig species.

In this research, it should be noted that for *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica*, a symbiotic breakdown have occurred. Those fig species were all pollinated by *Ceratosolen marchali*. In this segment of the paper, the author would try to change the point of view for the effect of habitat fragmentation to the pollinator-NPFW proportion from fig species based to wasp species based and compare the results with that of Wang *et al.* (2005). Based on this notion, the wasp count of all pollinator and NPFW found in *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* were summarized as if the 3 fig species were considered as a single species and the mean value of each wasp species were calculated. A combined pollinator-NPFW proportion was calculated using that summarized mean value. The fragmentation level of each sectors in UI and KRB were determined with the same concept. After a re-analysis of the fragmentation level, the conclusion was the fragmentation level for the combined species was the same with the fragmentation level for *Ficus septica* (Table 5).

From the Spearman correlation analysis, it shows that the proportion of pollinator wasps in UI and KRB were correlated with the fragmentation level [p (uncorr) = 0.4349]. The analysis also shows that the correlation were negative. The large p (uncorr) value indicates that the correlations between habitat fragmentation with pollinator and NPFW proportions were weak. It also suggests that even if it's more probable for low fragmented areas to have a higher pollinator proportion, it's still possible for areas with higher fragmentation level to have high pollinator proportion. Such case happened in this research where sector X and VIII of UI has a higher pollinator proportion compared to KRB and sector VII of UI. Compared to the results of Wang *et al.* (2005), there is a possibility that symbiosis breakdown could change the relationship pattern between fragmentation and pollinator-NPFW proportion.

CONCLUSIONS

From the wasp community, it was discovered that *Ficus montana* is the most unique of all the fig species. The second most unique fig was *Ficus* *glomerata* that was only found in KRB. *Ceratosolen fusciceps* and *Liporrhopalum tentacularis* were found to still function as pollinators for their respective figs. *Ceratosolen marchali* seems to have broken free from its symbiotic relationship with *Ficus hispida*. The wasp species were found to also be pollinating *Ficus septica* and were found in the sycone of *Ficus glomerata*. The fig species that has the largest diversity was *Ficus glomerata* in KRB and *Ficus hispida* var. *badiostrigosa* in UI. The fig species that has the lowest diversity was *Ficus montana*, both in UI and KRB.

From the comparison of pollinator-NPFW proportion with fragmentation level, *Ficus hispida* var. *badiostrigosa* and *Ficus septica* shows that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.2396 & 0.1416]. This indicates that low fragmented areas such as KRB would have a high proportion of pollinators and low proportion of NPFW compared to areas with higher fragmentation level. The results for *Ficus hispida* var. *hispida* differs with the results of the other fig species. The result shows that pollinator proportion would be higher in areas with higher fragmentation level [p (uncorr) = 0.0637]. This pattern indicates that low fragmented areas such as KRB would have a low proportion of pollinators and high proportion of NPFW compared to areas with higher fragmentation level. It also suggests that the pollinator of *Ficus hispida* var. *hispida* thrive better in fragmented habitats compared to the pollinator of the other fig species.

After compiling the proportion data for the 3 fig species, it shows that that pollinator proportion would be lower in areas with higher fragmentation level [p (uncorr) = 0.4349]. The large p (uncorr) value suggests that even if it’s more probable for low fragmented areas to have a higher pollinator proportion, it’s still possible for areas with higher fragmentation level to have high pollinator proportion. This shows that though fragmentation affects the pollinator-NPFW proportion, symbiotic breakdown could change the relationship pattern between fragmentation and pollinator-NPFW proportion.

ACKNOWLEDGEMENTS

The author is indebted to Dr. Rosichon Ubaidillah, M.Sc. and Dr. Adi Basukriadi, M.Sc. as the author's advisors for this research project and also for their knowledge of entomology and ecology. The author would also like to thank Andrio Adiwibowo, M.Sc. and Mega Atria, M.Si. as this research project's assessors, for their comments, inputs, and discussions. Special thanks to Andrio for introducing the author to PAST and to Pak Uyung, Mas Anto, and Mba' Fatimah for their help while preserving and identifying the specimens in LIPI.

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GENERAL DISCUSSION

The importance of figs in UI and KRB for insects and other arthropods has been observed during the research needed to assemble this thesis. As we could see in the first paper, a total of 7 fig wasp species were found. Those wasps were members of the sub-families Agaoninae, Sycoryctinae, and Sycophaginae (Bouček 1988; Rasplus *et al.* 1998; Campbell *et al.* 2000). From the 7 wasp species, 3 were pollinators and 4 were non-pollinating fig wasps (NPFW). Those wasps were found from 4 native fig species, one of which has two variants. There were no wasps, not pollinator nor NPFW, found in the *sycone* of the introduced figs. This might be caused by the inability of the native wasps to identify the *sycone* of the introduced fig species or the ability to penetrate the *syconial* wall or *ostiole* of the figs.

An interesting thing is that a beetle species from the Endomychidae family was found boring their way inside the *sycone* of *Ficus lyrata*, a fig species introduced from Africa. From this discovery, it seems that the absence of the fig wasps, especially the NPFW, would be caused more by the inability of the wasps to recognize the *sycone* of the introduced figs. This based on the observation of Compton *et al.* (2009) that shows that a fig wasp could utilize holes made by other fig wasp. Therefore, if the wasps could recognize the Sycone of *Ficus lyrata*, then they would have been able to use the holes made by the beetles. Although there are always the possibility that the wasps simply haven't learned to do so just yet. In short, since there were no pollinators and no seedling belonging to the introduced fig species found, there seems to be no threat that the introduced figs would become invasive.

Aside from the beetle found in *Ficus lyrata*, the other arthropods worth mentioning would be the two species of ants that prey on the fig wasps. Those ants made use of the holes bored by the wasps and perhaps other insects to go in and out of the *sycone*. Ants aren't the only one that considered fig wasps as a food source. One species of were found to be parasitizing the wasp *Philotrypesis pilosa*. This mite could be found both in UI and KRB and were not found in other wasp species during the research. It is unknown whether the mite has a preference towards *Philotrypesis pilosa* or not.

From the fig-fig wasp interaction, a symbiotic breakdown has been observed in UI and KRB. The wasp *Ceratosolen marchali* was able to pollinate *Ficus hispida* var. *hispida*, *Ficus hispida* var. *badiostrigosa*, and *Ficus septica* in UI and KRB. This finding is coherent with the findings of Parrish *et al.* (2003) that stated that the *Ficus hispida* and *Ficus septica* of Western Java has undergone natural hybridization with one another. A research replicating the work or Parrish *et al.* (2003) would be useful to find out whether a symbiotic breakdown really happened and how long the breakdown has happened.

Ceratosolen marchali was also found in the *sycone* of *Ficus glomerata* in KRB. Judging from the rather small proportion of *Ceratosolen marchali* compared to the other fig wasps (0.09±0.11) and the result that the host preference of *Ceratosolen marchali* and *Ceratosolen fusciceps* were different, it's possible that the wasp was not the main pollinator of the fig. The work of Jousselin *et al.* (2001) shows that the parasite wasps that deposit their eggs by entering the *sycone* of a fig could function as pollinators. Probably this is the case with *Ceratosolen marchali*. Since Ware *et al.* (1993) stated that the aganionids (the pollinators) identify the *sycone* of the figs by means of volatiles, it would be interesting to know whether the natural hybridization caused the volatiles of *Ficus septica* and *Ficus hispida* to change. It would also be interesting whether the "one-to-one rule" was ever really functioning in western Java. The symbiotic breakdown was not observed in the other fig species of UI and KRB.

A symbiotic breakdown could be caused by many reasons. Amongst those reasons would be fragmentation. Fragmentation could cause changes in the abundance of some species, and even change the species composition. Fragmentation could also cause ecosystem decay and extinction (Wilcox & Murphy 1985; Andrén 1994; Wang *et al.* 2005). To depict whether fragmentation level and symbiotic breakdown has any relationship with one another, a Spearman's correlation analysis was done using the mean pollinated fig species of *Ceratosolen marchali* (per-sector) from paper I with the fragmentation level of the sectors in UI and KRB (combined fig species) from paper II. A graph showing the comparison could be seen in figure 1.

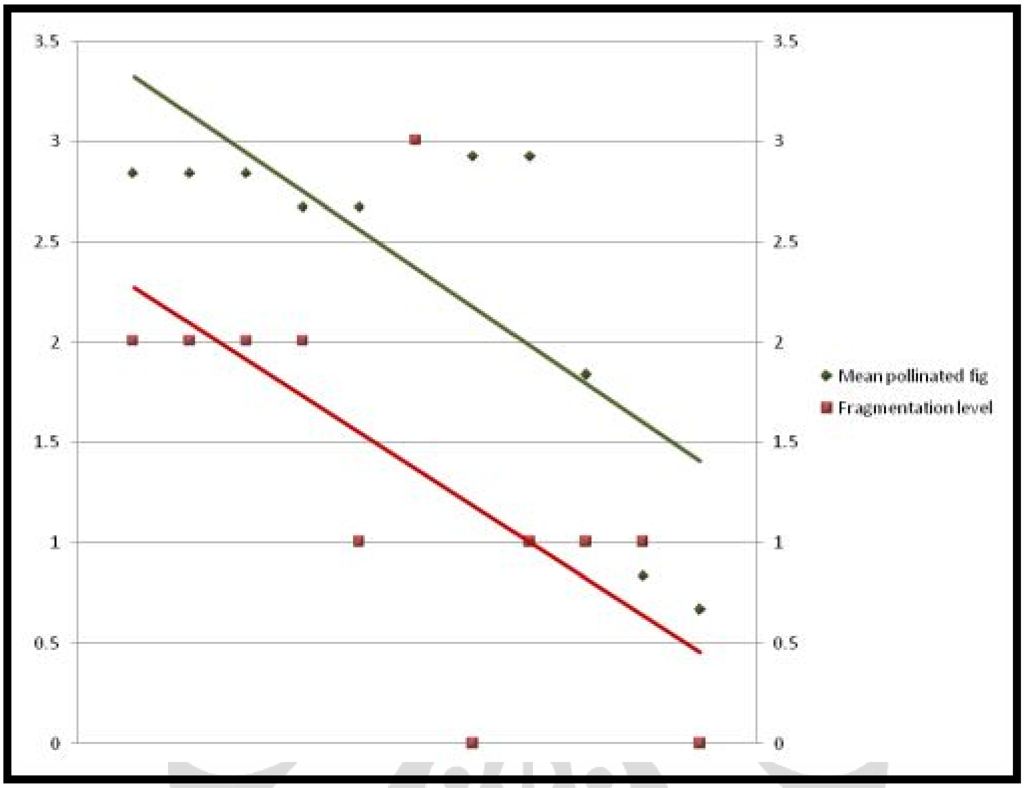

Figure 1. Comparison between mean pollinated figs of *Ceratosolen marchali* with the fragmentation level of the sectors in UI and KRB (combined fig species).

The Spearman correlation analysis result and Figure 1 shows that there's a positive correlation between the mean pollinated figs of *Ceratosolen marchali* (per-sector) and the fragmentation level of the figs pollinated by the wasp. The p (uncorr) value was 0.2023; this shows that the correlation was a strong one. Since the mean pollinated figs per-sector which was above the "one-to-one rule" line depicts the occurrence of symbiotic breakdown, the correlation analysis would also indicate that fragmentation level was correlated with symbiotic breakdown. This result seems to support the notion that symbiotic breakdown was caused by fragmentation (Wilcox & Murphy 1985; Andrén 1994; Wang *et al.* 2005), but the fact that a symbiotic breakdown also happens in sectors that was not fragmented (fragmentation value =0) suggest that the relationship between fragmentation and symbiotic breakdown would not be a simple one.

With the strong intra-tree asynchrony happening to a group of *Ficus hispida* var. *hispida* and *Ficus hispida* var. *badiostrigosa* in UI, the fig wasps would always have a receptive fig tree as their host. KRB does not have such trees. This asynchrony would help the *Ficus hispida* and *Ficus septica* population in UI because the two fig species has the same pollinating wasp species. The asynchrony would not help the *Ficus montana* population in UI, because the pollinator of *Ficus montana* (*Liporrhopalum tentacularis*) could not utilize the *sycone* of *Ficus hispida*. *Ficus montana* seemed to be the species that could be hit most hard by the fragmentation in UI and KRB. *Ficus montana* has the lowest species diversity value in UI and KRB. The pollinator wasp has a very low population size, which is very unnerving due to the prospect of local extinction.

Ficus glomerata has the largest diversity value in KRB and *Ficus hispida* var. *badiostrigosa* holds that record in UI. It would be interesting to know the reason why *Ficus hispida* var. *badiostrigosa*, and not *Ficus hispida* var. *hispida* that has the larget diversity value. It would also be interesting to know why the diversity of *Ficus hispida* var. *badiostrigosa* was just the same with *Ficus hispida* var. *hispida* in KRB where there were *Ficus glomerata*. The reason why there were no *Ficus glomerata* to be found in UI while the fig could be found on the bank of a nearby river would also be interesting to figure out.

From Arumasari (1989), Prihantomo (2007), and up until this research, cutting and rooting of the large shrub-forming figs and the fig seedlings was done routinely. It seems that the management of UI thinks of shrub-forming figs and fig seedlings as weeds. This constant cutting and rooting could make the effects of fragmentation worse, because it could disturb the natural succession flowering between the fig populations. The author did not know if the same happened in the areas surrounding KRB in Bogor.

CONCLUSIONS, SUGGESTIONS, AND IDEAS FOR FURTHER RESEARCHES

A. CONCLUSIONS

1. Fig wasps and other arthropods utilized the *sycone* of figs as a place to rear their young. Some arthropods prey on and parasitize the wasps.
2. A total of 3 pollinator wasp species were found; they were *Ceratosolen marchali*, *Ceratosolen fusciceps*, and *Liporrhopalum tentacularis*; *Ceratosolen fusciceps* were only found in KRB and *Liporrhopalum tentacularis* were only found in UI.
3. A total of 4 NPFW species found; they were *Philotrypesis pilosa*, *Boučeka percaudata*, *Apocrytophagus testaceus*, and *Apocrypta bakeri*.
4. The "one-to-one rule" has been broken both in UI and KRB for some fig species; the symbiosis of *Ficus glomerata* and *Ficus montana* with their respected pollinators were still retained.
5. *Ficus hispida* var *badiostrigosa* has the biggest wasp diversity in UI and *Ficus glomerata* has the biggest wasp diversity in KRB; Ficus montana has the lowest wasp diversity in both UI and KRB.
6. The proportion of pollinator wasp was negatively correlated with fragmentation level; though due to symbiotic breakdown, a different pattern might be observed if the analysis was done according to the fig species and not the wasp species.
7. Symbiotic breakdown was found to be positively correlated with fragmentation level, though the relationship seems to not be a simple one.
8. Most figs of UI could support their fig wasp community, while the ones in KRB might need help from the surrounding areas.

B. SUGGESTIONS

1. The management of UI should try to refrain from cutting and rooting to much *Ficus montana* and *Ficus septica* shrub.

2. The group of male *Ficus hispida* that has strong intra-tree asynchrony on the bank of Lake Agathis should be maintained and never be cut down. Moving the trees might still be possible. If there's any way to obtain more of such male trees, attaining more would be advisable.
3. Should the management of UI desired to add the fig species collection of UI, *Ficus glomerata* would be a good choice.
4. The management of KRB should create an understanding with the government of Bogor that the figs of KRB would not survive if the figs of Bogor and adjacent areas are gone.
5. It would be beneficial should the management of KRB able to acquire some male *Ficus hispida* trees that has strong intra-tree asynchrony.
6. There should be routine checks on the fig wasps of UI and KRB, especially the pollinators.

C. IDEAS FOR FURTHER RESEARCHES

1. There should be a research on the subject of whether the *Ficus hispida* and *Ficus septica* of UI and KRB has undergo hybridization or not, for further proof of a symbiotic breakdown.
2. There should be a research concerning the real role of *Ceratosolen marchali* in *Ficus glomerata*. If the wasp could function as a pollinator, a research concerning the effectiveness of the wasp compared to the fig's original pollinator.
3. There should be a research on the natural movement pattern of the fig wasps that encompasses UI and KRB.
4. There should be a research on the subject of the objects and forces that could act as barriers for the movement of the fig wasps.
5. There should be a research on the subject of the effects of weather abnormalities and even climate change to the fig wasp community, especially in western Java.

6. There should be a research concerning the minimum population size of the fig wasps before a total collapse and extinction happens.
7. There should be more researches regarding the functions and potentials, preferably ones with economical value, of the native figs as leverage to persuade the management of UI to conserve those figs.

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