Effects of habitat enhancement on bird diversity in Kaeng Khoi district, Saraburi province

Mrs. Dijan Sunar Rukmi

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy in Biological Sciences
Common Course
Faculty of Science
Chulalongkorn University
Academic Year 2018

ผลของการเสริมถิ่นที่อยู่ต่อความหลากหลายของนกในอำเภอแก่งคอย จังหวัดสระบุรี

นางดิจาน ซุนาร์ ลัคมิ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาวิทยาศาสตร์ชีวภาพ ไม่สังกัดภาควิชา/เทียบเท่า
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2561

Thesis Title	Effects of habitat enhancement on bird diversity in Kaeng Khoi district, Saraburi province
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ดิจาน ซุนาร์ ลัคมิ : ผลของการเสริมถิ่นที่อยู่ต่อความหลากหลายของนกในอำเภอแก่งคอย จังหวัดสระบุรี . (Effects of habitat enhancement on bird diversity in Kaeng Khoi district, Saraburi province) อ.ที่ปรึกษาหลัก : ชัชวาล ใจซื่อกุล, อ.ที่ปรึกษาร่วม : นิพาดา เรือนแก้ว ดิษยทัต

การเสริมถิ่นที่อยู่หลากหลายวิธีการได้ถูกนำมาใช้ในการเพิ่มคุณภาพของถิ่นที่อยู่และมีผลในการเพิ่มความหลากหลายทางชีวภาพและบำรุงรักษาการบริการในระบบนิเวศ การศึกษาในครั้งนี้มีวัตถุประสงค์เพื่อประเมินผลจากการเสริมถิ่นที่อยู่ด้วยพืชอื่นนอกเหนือจากพืชปลูกที่มีต่อความหลากหลายของนก โครงสร้างกลุ่มเชิงนิเวศของนก และแบบแผนการใช้พื้นที่ของนก โดยทำการสำรวจนก สังเกตกิจกรรมการใช้พื้นที่ของนก และการสำรวจสัตว์ขาปล้องในแปลงทดลองระดับภูมิภาพ (landscape-scale: LS) และแปลงปลูกสัก (teak reforestation: TR) ที่เสริมด้วยทานตะวันและปอเทืองในฤดูแล้งและฤดูฝนในปี พ.ศ. 2558-2559 ผลการศึกษาพบว่าแปลงที่เสริมด้วยทานตะวัน (LS: 28, TR: 19) มีนกหลากชนิดมากกว่าแปลงที่เสริมด้วยปอเทือง (LS: 25, TR: 15) แต่การปรากฏของนกในแปลงศึกษาแปรผันตามทรัพยากรในแปลง กลุ่มนกที่กินแมลงเป็นอาหารเป็นกลุ่มเชิงนิเวศเด่นในทุกกลุ่มการทดลองและมีความชุกชุมสูงในแปลงที่มีการปลูกปอเทืองแต่แปลงที่ปลูกทานตะวันพบนกกินเมล็ดเป็นกลุ่มสำคัญ โดยรวมแล้วนกมีการตอบสนองที่แตกต่างกันอันเนื่องมาจากขนาดของแปลงหรือทรัพยากรที่มีในแปลงทำให้เกิดโครงสร้างกลุ่มเชิงนิเวศที่แตกต่างกัน ในขณะที่กลุ่มนกที่กินแมลงเป็นอาหารและนกกินเมล็ดเป็นกลุ่มเด่นในแปลงระดับภูมิภาพ นกที่กินทั้งพืชและสัตว์แทนตำแหน่งของนกกินเมล็ดในแปลงปลูกสัก การหาอาหารเป็นกิจกรรมหลักในทุกกลุ่มการทดลองตามด้วยการเกาะพัก การพบกลุ่มนกที่กินแมลงเป็นอาหารในปริมาณที่มากในแปลงที่มีปอเทืองสอดคล้องกับการพบความชุกชุมที่สูงของแมลงกินพืชซึ่งอาจเป็นอาหารของกลุ่มนกที่กินแมลงเป็นอาหารเหล่านี้ซึ่งอาจให้การบริการในการควบคุมแมลงศัตรูพืชได้ นอกเหนือจากการที่ทานตะวันเป็นแหล่งอาหารให้กับนกกินเมล็ดแล้วในแปลงทานตะวันยังพบกลุ่มผู้ล่าขนาดกลางที่หลากหลาย ดังนั้นพืชทั้งสองชนิดนี้ให้ประโยชน์ในการอนุรักษ์ต่อนกและสัตว์ขาปล้องที่เป็นประโยชน์รวมทั้งส่งผลในการควบคุมทางชีววิธีในภูมิภาพการเกษตร

สาขาวิชา	วิทยาศาสตร์ชีวภาพ	ลายมือชื่อนิสิต ....
ปีการศึกษา	2561	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5672812023 : MAJOR BIOLOGICAL SCIENCES

KEYWORD: bird, sunflower, sunn hemp, guild, habitat enhancement, intercropping

Dijan Sunar Rukmi : Effects of habitat enhancement on bird diversity in Kaeng Khoi district, Saraburi province. Advisor: Asst. Prof. CHATCHAWAN CHAISUEKUL, Ph.D. Co-advisor: Asst. Prof. NIPADA RUANKAEW DISYATAT, Ph.D.

Various techniques of habitat enhancement have been used to increase the habitat quality, consequently enriching biodiversity and maintaining ecosystem services. This study aims to assess the effects of habitat enhancement on bird diversity, guild composition and bird usage pattern by conducting bird censuses and observations as well as arthropod samplings in the landscape-scale (LS) experiment plots and in the teak reforestation (TR) enhanced with sunflower and sunn hemp species over dry and wet seasons of 2015-2016. Sunflower treatment attracted more bird species (LS: 28, TR: 19) than sunn hemp treatment (LS: 25, TR: 15), but bird occurrence was varied based on resources. Insectivorous were the dominant guild across all treatments with higher occurrence in sunn hemp treatment. Otherwise, sunflower treatment likely supports the granivorous birds. Overall, bird responded differently based on the plot size or because of resource availability, creating different guild composition. While insectivores and granivores dominantly occurred in landscape-scale, omnivores substituted granivores in teak reforestation. Foraging was the major activity in all treatments followed by perching. This explained the high occurrence of insectivorous birds in the sunn hemp treatment, corresponding with the high abundance of herbivorous insects which could be potential prey for insectivorous birds, so these birds are offering pest control services. Besides providing food for granivores, sunflower also attracts diversed groups of mesopredators. In conclusion, both non-crop plants provide differential benefits for bird and conservation of beneficial arthropods and biological control in the agricultural landscape.

Field of Study: Biological Sciences
Academic Year: 2018

Student's Signature ....
Advisor's Signature ....
Co-advisor's Signature ....

ACKNOWLEDGEMENTS

Thank you Allah SWT., the almighty, the most gracious and merciful, over the blessings and wonderful life that have been given to me.

I would like to express my sincere gratitude to my advisor, Assistant Pofessor Chatchawan Chaisuekul. Ph.D and my co-advisor, Assistant Professor Nipada Ruankaew Disyatat, Ph.D. They have supported and encouraged me to do the best I could to overcome any obstacles and keep my spirit up. I admired their advice, guidance and patience. The thesis would not have been possible without them.

I also want to express my appreciation to all of committee members: Assistant Professor Noppadon Kitana, Ph.D., Associate Professor Sasitorn Poungparn, Ph.D., Assistant Professor Pongchai Harnyuttanakorn, Ph.D. and Associate Professor Kumthorn Thirakhupt, Ph.D. for their time, advice and suggestion for better thesis presentation.

I also want to thank Assistant Professor Natapot Warrit, Ph.D. and Professor Donald L. J. Quicke for kindly helping in bees and wasps identification, respectively.

I truly thank all staff member of Biological Sciences program and Biology Department for their assistance during my time studying at Chulalongkorn University. I also want to thank Dr. Anusorn Pansook, Ms. Suttinee Lhaotaew and all staff member of Chulalongkorn University – Center of Learning Network for the Region Saraburi (CU-CLNR) for the assistance and accommodation during field works.

I want to thank all funding agencies: CU-ASEAN scholarship, Beasiswa Kaltim Cemerlang and the 90th Anniversary of Chulalongkorn University Fund (GCUGR1125582028D) for supporting my Ph.D. enrollment, tuition, allowance and research scholarship.

Most of all, I would like to thank my husband, Dr. Medi Hendra, for his love, support, patience and understanding during I was being away from him. Last but not least, I also appreciate my parents and family for unconditional love and support; and all my friends for togetherness and mutual support during Ph.D. studies.

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CHAPTER I

INTRODUCTION

Demands for natural resources have been increasing along with the human population growth and its effects to land-use conversion. Terrestrial ecosystems have been converted to agriculture (Foley et al., 2011), forest plantations and human settlements to meet the needs of mankind (Pimentel et al., 1992). Extensive land conversion and intensification of land use result in increasing yield and productivity, but a simplification of an ecosystem is likely to threaten natural habitats and biodiversity. Even so, biodiversity in agriculture landscape is intrinsically valuable and provides ecosystem services. Agricultural expansion and intensification tend to reduce diversity of various taxa, including birds.

Birds provide important ecosystem services, such as pollination, seed dispersion and control of herbivorous insect populations in natural and agricultural ecosystems. Bird abundance and diversity have been used to monitor ecosystem health. Since alteration of structure and composition of vegetation determine diversity and abundance of bird species across feeding guilds, a decrease of bird diversity can result in changes in trophic structure and further reduce direct and indirect benefits to human society (Díaz, Fargione, Chapin III, & Tilman, 2006; Peters & Greenberg, 2013; Sekercioglu, 2006; Whelan, Şekercioğlu, & Wenny, 2015). Therefore, it will be necessary to manage agricultural practices so that complex habitats that resemble the natural conditions could be maintained, providing resources for birds and species.

Improving habitat conditions can be achieved through enhancements. Various techniques have been applied to improve habitat quality for birds and subsequently increase bird diversity. These included intercropping (Jones & Sieving, 2006; Stallman & Best, 1996), conservation patches (Chang, Quan, & Wang, 2013; Fischer & Lindenmayer, 2002), field margins (Giacomo & Casenave, 2010), hedgerows (Muñoz-Sáez, Perez-Quezada, & Estades, 2017), filter strips (Blank, Dively, Gill, & Rewa, 2011), and supplementary food (Peters & Greenberg, 2013). Some of these techniques increase habitat heterogeneity and complexity of vegetation, therefore determining diversity and abundance of birds (Deikumah, McAlpine, & Maron, 2013; Van Bael, Bichier, Ochoa, & Greenberg, 2007; Waltert, Mardiastuti, & Mühlenberg, 2004). Habitat enhancement aims to counter the negative effects caused by simplified system by increasing plant diversity.

Intercropping is one of the techniques that can be readily applied to enhance the monoculture cropping system. Intercropping plants were inserted between rows of existing crop plants, giving benefits such as increasing diversity and productivity, controlling insect pests and reducing pesticide usage (Jankowska, Poniedziałek, & Jedrszczyk, 2009). Several plant species can be used in enhancement. The common practice is enhancing with crop plants species, for example, cassava and cacao, in order to increase economic values or fulfill daily consumption (Haggar, Rheingans, Arroyo, & Alvarado, 2003; Santosa, Sugiyama, Hikosaka, Takano, & Kubota, 2005).

Using non-crop plants is a common strategy of enhancing biodiversity in agriculture landscape due to the rapid growth of these species and low investment (Amaral, 2014). Lately, non-crop plants, such as sunflower (*Helianthus annus*) and sunn hemp (*Crotalaria juncea*) were widely planted for its aesthetic value or its ability to improving soil condition. Sunflower was reported in several studies as a cover crop and intercropping plant to attract birds, subsequently increasing species richness and abundance (Jones & Gillett, 2005; Jones & Sieving, 2006). Meanwhile, little is known about the impact of sunn hemp on birds. Moreover, both plants are known for good adaptation to dry conditions (Kaya, Jocic, & Miladinovic, 2012; Mannetje, 2012; Putnam et al., 1990).

Additional information regarding the enhancement plants used in various habitats, including agricultural lands or tree plantations, would increase the understanding of habitat enhancement as well as broaden their applications. In order to maximize the advantages provided by planting sunflower and sunn hemp, both plants were used as cover crops and intercropping plants in the landscape-scale, enhancing fallow vegetation, and as intercropping plants in a teak reforestation. Non-crop plants could provide additional resources to increase bird diversity and occurrence, as well as increase their habitat usages. However, the effects of sunn hemp on bird diversity have not been reported elsewhere. Moreover, the underlying explanation of usage patterns by bird of non-crop plants have been rarely studied.

Biological control of insect pest is one off the common uses of habitat enhancement in agriculture landscape, and in this work arthropods would be sampled as they represent are potential food resources for the insectivorous birds (Hollander, Titeux, Walsdorff, Martinage, & Van Dyck, 2015; Muñoz, Ippi, Celis, Salinas, & Armesto, 2017; Philpott et al., 2009; Razeng & Watson, 2015). Thus, evaluating the composition and distribution of arthropods is a key to understand the ecological processes in the enhanced habitats. Manipulation of producers may also affect subsequent trophic interactions among feeding guilds of the community (Landis, Wratten, & Gurr, 2000; Nilsson, Porcel, Swiergiel, & Wivstad, 2016).

Information about the impacts of habitat enhancement to bird diversity in agriculture and reforestation area is limited, particularly in the tropics probably due to complex species interactions in the biotic community. Diverse systems encourage complex food webs that entangle more interactions among vegetation, pest and natural enemies. This condition provides resources for a more diverse groups of organisms. An ecosystem with higher diversity tends to be more stable and less fluctuating in pest and disease (Altieri & Nicholls, 2004). Therefore, there is a need to increase or enhance habitat complexity in order to increase biodiversity.

The objectives of this study are:

(1) to study diversity of birds in an enhanced reforestation system

(2) to study habitat usages and ecological guilds of birds in the enhanced reforestation system.

In addition, ecological guilds of insects in the reforestation area will also be explored to determine the relationship between structure and composition of plants, arthropods and birds. The outcome from this work will lead to additional knowledge and establish management using enhancement techniques that may be suitable for bird conservation, and biological control of insect pests in the reforestation area.

Conceptual framework of this research can be seen in Figure 1.1.

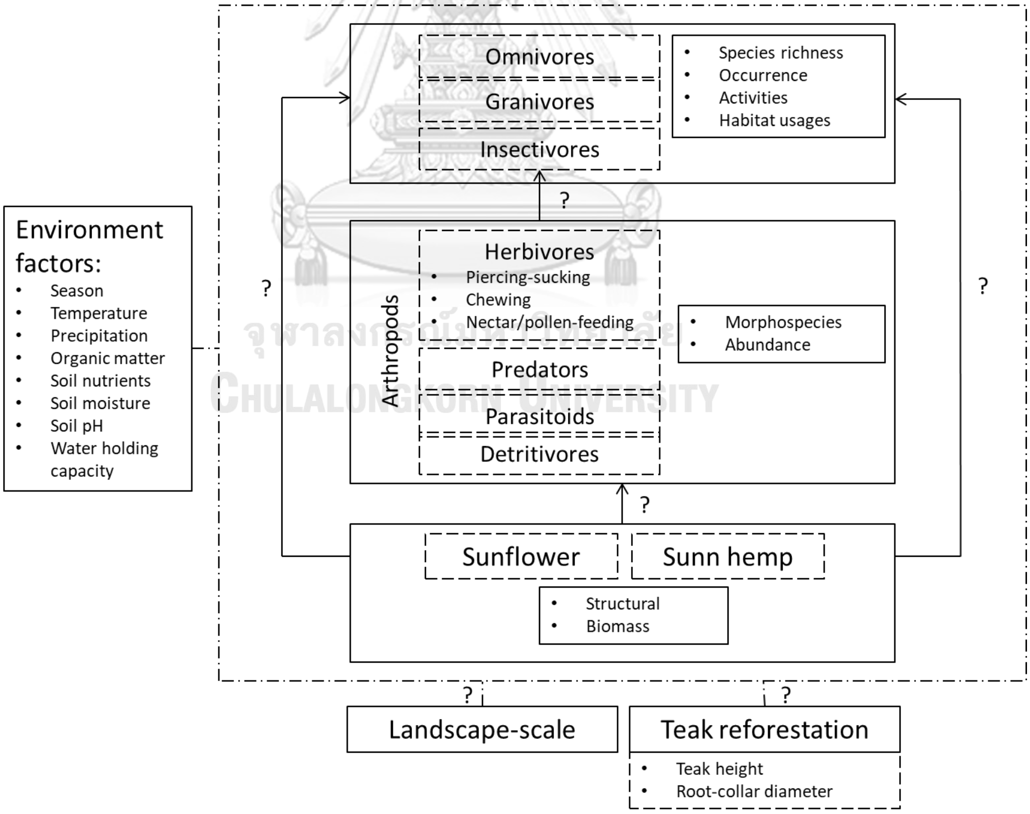

Figure 1.1 Conceptual framework of the research

CHAPTER II

LITERATURE REVIEW

2.1 Bird diversity and ecosystem services

Birds are known as excellent indicators of habitat quality and conditions because of their ability to respond quickly to changes in the environment. They are easier to observe than other types of wildlife because they are widespread, generally active during the day, visually conspicuous, highly vocal and taxonomically stable (Koskimies, 1989; Sekercioglu, 2006).

Ecosystem services are the direct and indirect contributions of ecosystems that benefit humans (Figure 2.1). Birds provide ecosystem services, such as:

(1) Provisioning services: Birds provide natural products that are directly used by human, include meat for food, down for garment, and guano for fertilizer.

(2) Regulating services: Birds act as regulators with functions such as dispersing seeds, pollinating flowers, controlling invertebrate and vertebrate pests, and scavenging carcass and waste.

(3) Cultural services: Birds provide recreational chances for aesthetic and spiritual values, including the cash spent on birdwatching.

(4) Supporting services: Birds are involved in nutrient cycling and soil formation, which eventually provide habitats for species and maintenance of genetic diversity (Díaz et al., 2006; Sekercioglu, 2006; Wenny et al., 2011).

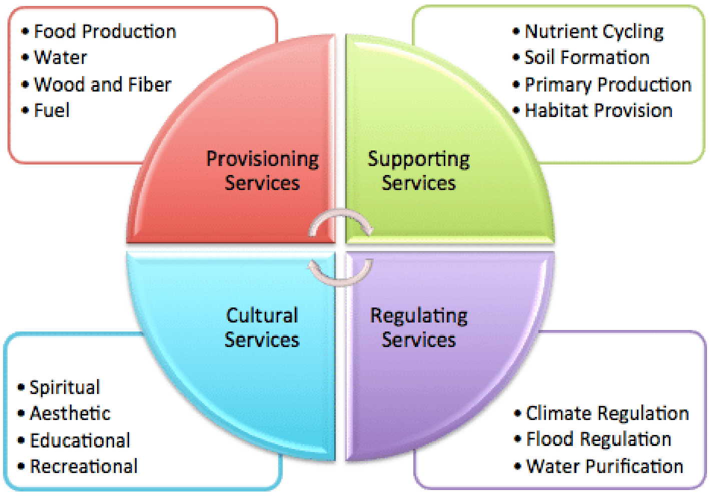

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Figure 2.1 Ecosystem services

Some studies reported that bird richness declines as a result of the forest conversion to production forest and agriculture (Aratrakorn, Thunhikorn, & Donald, 2006; Dawson et al., 2011; Kofron & Chapman, 1995; Waltert et al., 2004). Furthermore, bird species composition changes gradually as habitats are altered from forests, secondary forests, agroforestry system to annual cultures (Waltert et al., 2004). Different community structure and composition of birds between land use types have been described in relation to vegetation complexity. For example, dramatic changes in species composition and decreased bird species number were observed in adjacent deforested areas compared to undisturbed rain forests in Liberia (Kofron & Chapman, 1995). Bird species richness was higher in young-growth forests than old-growth forests in Costa Rica (Blake & Loiselle, 2001). Bird species richness and diversity was higher in three different forest types than agricultural habitats in Papua New Guinea (Dawson et al., 2011). Variable food availability, in terms of abundance and constancy, could explain different bird diversity in tropical habitats (Peters, Mordecai, Carroll, Cooper, & Greenberg, 2010).

Biodiversity encompasses number of species, relative abundance, composition, spatial distribution and interaction of genotypes, populations, species, functional types and traits, and landscape units in a system. Biodiversity influences ecosystem process and services, which are affected by habitat change and disturbance to the certain level (Díaz et al., 2006; Peters & Greenberg, 2013; Sekercioglu, 2006). In other words, ecosystems require a certain proportion of organisms, since species have different roles and differ in the need to survive (Díaz et al., 2006).

As biodiversity affects the stability of an ecosystem, organisms can be distinguished by their role or functions and therefore belong to functional groups or guilds. Commonly, classification of guilds is based on the usage of food resources and specific habitat structures (Blaum, Mosner, Schwager, & Jeltsch, 2011). Birds can be grouped into granivores, frugivores, insectivores, carnivores, nectarivores and omnivores. According to Dhindsa and Saini (1994), all functional types of birds can be found in agricultural areas, but they may different in structure and composition among places as a result of food availability in the area.

Insectivorous birds are more responsive to delicate changes. Different from fruits, flowers, and seeds, invertebrate prey species actively refrain insectivores and, as a result, insectivorous birds have evolved into many specific niches and seek prey in particular microhabitats. Finally, according to the limited dispersal hypothesis, understory insectivores, which have relatively inactive habits and possible restraint of clearings, may not disperse into more favorable habitats and easily vanish from fragments as a result of negative results of fragmentation (Stouffer & Bierregaard Jr, 1995). In addition, food limitation may be apparent in the quantity and composition of invertebrates in the diets of birds.

Human modification of natural areas leads to changes in abundance and richness of bird species. Information about species richness and abundance cannot completely describe the functional composition of communities or functional response of bird species to habitat changes. Bird species could be arranged into groups that represent similar ecological roles (Coelho, Raniero, Silva, & Hasui, 2016). Functional diversity describes how species behave, obtain food and use the natural resources of an ecosystem. A species-rich ecosystem is generally presumed to have high functional diversity, due to potentially different requirements of diverse species. However, species richness alone could not properly explain functional diversity due to its assumption of neutrality of species without consideration of similarities or differences in the functional traits of the species (Hooper, 2002). Each species is independently contributes to functional diversity (Petchey, Hector, & Gaston, 2004). Reduction or addition of species with certain functional traits may raises an impact, and likely to be affected by different species and functional groups (Tilman et al., 1997). In many circumstances, functional diversity of birds is lost faster than species diversity if disturbance occurs (Flynn et al., 2009).

Functional redundancy describes how some species perform identical roles in communities and ecosystems, and therefore can be replaced with little impact on ecosystem processes (Rosenfeld, 2002). Redundancy of species is a result of small changes in species composition within functional groups. Species redundancy is also predicted to enhance ecosystem resilience (Naeem, 1998).

Understanding functional diversity and species redundancy of an ecosystem can help to understand a food web or ecological niches that might be useful to conserve or restore the ecosystems. With the knowledge of the roles and behaviors of species, several bird conservation measures are possible, starting with efforts to increase species richness and abundance (Pywell et al., 2012) and to improve habitat quality (Chandler & King, 2011; Stevens, Holland, Clarke, Cooke, & Bennett, 2015).

2.2 Habitat enhancement

Habitat enhancement can be defined as any changes made to a habitat that serves to improve its value and ability to meet the requirements of one or more organisms (Vaughn et al., 2010). Enhancement with plants is one of the common approaches. Plant species can be incorporated in several ways, as monoculture, such as cover crops (Balkcom & Reeves, 2005; Hinds, Wang, Marahatta, Meyer, & Hooks, 2013; Manandhar, Hooks, & Wright, 2009; Mansoer, Reeves, & Wood, 1997; Wang, Sipes, Hooks, & Leary, 2011), field margins (Hatt et al., 2015), hedgerows (Morandin, Long, & Kremen, 2014) or intercropped with other crop plants (Cruse, Erbach, Barnhart, Owen, & Wedin, 1992; Elba, Suárez, Lenardis, & Poggio, 2014; HansPetersen, McSorley, & Liburd, 2010; Jones & Gillett, 2005; Jones & Sieving, 2006; Tajmiri, Fathi, Golizadeh, & Nouri-Ganbalani, 2017). Two or more interacting plant species may create a more complex habitat that can support a wider variety of organisms.

Selection of enhancement technique should be appropriate for ecological functions needed as well as the selection of plants that are used. Increasing vegetation diversity through the addition of plants that provide specific functions can help to increase the diversity or abundance of natural enemies. Diversification of plant species, such as intercropping, can increase habitat heterogeneity and associated with biodiversity and agroecosystem (Elba et al., 2014).

Non-crop plants are often used for biodiversity conservation (Feltham, Park, Minderman, & Goulson, 2015), soil improvement (Balkcom & Reeves, 2005; Mansoer et al., 1997), as well as pest management (HansPetersen et al., 2010; Hatt et al., 2015; Z.-X. Lu et al., 2014). Numerous non-crop plants, such as alfalfa (Putnam et al., 2001; Tajmiri et al., 2017), sunflower, marigold, red clover, wildflower (Blaauw & Isaacs, 2014; Braman, Pendley, & Corley, 2002; Feltham et al., 2015; Hatt et al., 2015; Pywell et al., 2011; Rundlöf, Persson, Smith, & Bommarco, 2014) and sunn hemp (legumes) (Manandhar et al., 2009; Mansoer et al., 1997), are often used as enhancement plants in monoculture or intercropped with crop plants. Non-crop plants can provide food directly for birds, such as nectar (Dhindsa & Saini, 1994), fruits (Peters et al., 2010) and seeds (Dhindsa & Saini, 1994; Schäckermann, Weiss, von Wehrden, & Klein, 2014). Some non-crop species increased the abundance of arthropods which served as food resources for insectivorous birds (Dhindsa & Saini, 1994; Feltham et al., 2015; Giffard, Barbaro, Jactel, & Corcket, 2013; Jones & Gillett, 2005; Jones & Sieving, 2006; Manandhar, 2013). Alfalfa, a widely cultivated forage crop, offered food sources for granivorous birds and microhabitats of invertebrate prey for insectivorous birds (Hartman & Kyle, 2010). Plots enhanced with alfalfa and soybean could attract similar levels of bird species richness, but a higher bird density was observed in the alfalfa-enhanced plots than the soybean-enhanced plots (Giacomo & Casenave, 2010).

Sunflower, *Helianthus annuus* L., is an annual plant that grows to 3 m or more. Sunflower bears one or more wide, terminal capitula (flower head), with bright yellow ray florets at the outside and yellow disc florets inside. The rough and hairy stem is branched in the upper part in wild plants, but the stem is usually unbranched in domesticated cultivars. Sunflower is commercially grown for use as cut flowers, human and animal food. It is also a reliable enhancement species due to its ability to support birds, offering food resources, as well as providing plant structure as predator refugia (Jones & Sieving, 2006). Sunflower is reportedly successful to attract insects on several researches (Jones & Gillett, 2005; Royer & Walgenbach, 1991).

Sunn hemp, *Crotalaria juncea* L., is an erect, branching, annual legume that grows rapidly, reaching a height of over 1.2 m in 60 days in favorable conditions. It can achieve a height of over 1.8 m in approximately 90 days. The pea-type flowers are bright yellow. Its seed pods are cylindrical, about 2–3 cm long, and 5–10 mm. It is normally cross-pollinated by bees and self-pollinated if stigmas are manipulated by insects or human. Plants are usually unbranched from the ground to 60 cm and many branches develop above this height. Sunn hemp provides natural fiber and fodder (Rotar & Joy, 1983; Valenzuela & Smith, 2002). Moreover, it has been widely used as green manure (Mansoer et al., 1997; Oliveira et al., 2007), nematodes suppression (Hinds et al., 2013; Hooks, Chandara, Fallon, Wang, & Manandhar, 2007; Jourand, Rapior, Fargette, & Mateille, 2004; Sheahan, 2012; Wang, McSorley, Marshall, & Gallaher, 2004) and soil conservation (Balkcom & Reeves, 2005; Mansoer et al., 1997; Rotar & Joy, 1983; Sheahan, 2012). The effects of sunn hemp on arthropod or bird communities have not been thoroughly explored.

Sunflower and sunn hemp are common species that have been used as rotational non-crop plants in intercropped systems (Jones & Sieving, 2006; Mansoer et al., 1997; Wang et al., 2011). In addition, non-crop plants could be used to increase the complexity of vegetation structure and composition and the structure of non-crop plants could provide microhabitats that birds can use for shelters and nesting sites.

2.3 Effects of habitat enhancement on birds

Several reports showed that there were positive results of enhancing habitat on bird species richness (Beecher, Johnson, Brandle, Case, & Young, 2002) and bird abundance (Beecher et al., 2002; Jones & Sieving, 2006; Peters & Greenberg, 2013; Stallman & Best, 1996). Resources needed in habitat enhancement are mentioned as shelter, pollen, nectar, and alternative prey (Nilsson et al., 2016).

Perches or perching sites are efficient for attracting birds. Perches provide stopping and resting places for birds to regurgitate and expel seeds. Bird perches can be natural or artificial. Natural perches, such as remnant trees, live fences and dead trees, provide food and shelter for birds. While artificial perches, such as wood or bamboo poles can also be used to attract birds. Higher perches may provide better visibility for insectivorous birds, predatory birds and seed dispersers (Athiê & Dias, 2016; Gopali, Raju, Mannur, & Suhas, 2009).

2. 4 Effects of habitat enhancement on arthropods

Habitat enhancement can attract and maintain a higher species richness and abundance of certain arthropod species and natural enemies (Andow, 1991; Cai, You, & Lin, 2010; Jones & Gillett, 2005; H. Li et al., 2018; Pywell et al., 2012; Pywell et al., 2011; Root, 1973; Tajmiri et al., 2017), increase yield in several crops (C. Li et al., 2009; Stoltz & Nadeau, 2014), and maintaining ecosystem services (Landis et al., 2000; Sidhu & Joshi, 2016; Wratten, Gillespie, Decourtye, Mader, & Desneux, 2012).

Arthropods have several roles in ecosystem, such as pollination, decomposition, biological control and food sources (Losey & Vaughan, 2006; Spafford & Lortie, 2013). Arthropods are abundant small organisms with high protein content that provide resources for insectivorous birds, especially for breeding birds (Hollander et al., 2015; Razeng & Watson, 2015).

Based on ecological guilds, arthropods can be divided as herbivores (piercing-sucking, chewing and nectar/pollen feeding), parasitoids, predators and detritivores (Novotny et al., 2010). Some arthropods are meso-predators, positioning in the middle of the trophic structure and feeding on smaller arthropods, which are usually herbivorous species. Meso-predator species often vary in ecosystem, depends on the food web.

Arthropod community is influenced by vegetation in their habitats (Andow, 1991; Jones & Gillett, 2005; Kaiser et al., 2017). Vegetation is functioning as a direct resource, offering water and nectar, and also provides a physical refuge (e.g. trichomes, shelter) from disadvantageous weather conditions and higher trophic level of predators (Kaiser et al., 2017). Different taxonomic or ecological groups of arthropods require distinct resources and their diversity and composition may be altered by changes in their habitats.

Interactions among plants, arthropods and birds are part of intrinsic relationships among multiple trophic levels within an ecosystem. Arthropods occupy vegetation at all stages of life because these plants serve as habitats for living, breeding and feeding their offspring. Presence of arthropods can be potentially harmful to the plants, inhibiting growth and even causing death. Although birds sometimes forage in reforestation area, the role is still need to be further exposed. Johnson et al. (1996)

mentioned that several bird species were found as predators feeding on pests in several agriculture and forested areas and therefore beneficially help to provide more income for farmers. Some other studies also showed the positive relationships between birds and insects (Giffard et al., 2013; Sipura, 1999). On the contrary, other studies stated that birds were not significantly useful in reducing pests (Peters & Greenberg, 2013). The difference performances make it as very encouraging topic to study to gain more information.

Suitable estimation of the communities composition is an important element in solving ecological problems. Arthropods are key elements of the ecosystems and represent a diverse and highly abundant groups in terrestrial environments.

2.5 Reforestation

Reforestation tries to restore degraded lands to forested areas. Reforestation efforts are usually carried out on low productive lands or low soil fertility that are unsuitable for agriculture (Piotto, 2007). Forest plantation is one of the techniques used in reforestation, usually with commercial purposes. From the aspect of biodiversity, conventional plantations tend to be monoculture and associated with low bird diversity. Alteration of forest structure and composition into a monoculture agricultural farm or plantation would reduce biodiversity (Aratrakorn et al., 2006; Dawson et al., 2011; Kofron & Chapman, 1995; Waltert et al., 2004). Limited seed dispersal is one of the main forest regeneration barriers. Seed disperser-birds can help in accelerating the process of ecological succession in sites to be restored/contributing to the dynamics of ecological succession (Athiê & Dias, 2016).

Monoculture plantations have limited availability of food resources, nesting sites, vegetation complexity and microhabitat structures (Dhindsa & Saini, 1994; Peters et al., 2010; Van Bael et al., 2007). Reforestation areas can become habitats for birds if properly managed. To increase the value of reforestation areas, several approaches can be done, such as habitat enhancement.

CHAPTER III
METHODOLOGY

3.1 Study site

The study was conducted at Chulalongkorn University Center of Learning Network for the Region (CU-CLNR) (14°32’N to 14°30’N and 101°0’E to 101°3’E) at Kaeng Khoi District, Saraburi Province. The area was surrounded by tropical deciduous forest fragments on low elevation hills (approximately 60-120 m above the sea level). Some areas were abandoned agricultural fields, previously planted with rice, cassava and corn until 2004-2005.

The average annual temperature was 29°C in both 2015 and 2016 with the minimum of 25.4°C in January 2015 and maximum of 31.3°C in May of 2015, while the minimum 26.5°C in January of 2016 and the maximum of 32.4°C in April of 2016. The annual precipitation of the area in 2015 and 2016 were 99 mm and 94 mm, respectively. The minimum precipitation of 6.2 mm in January and the maximum of 296.9 mm in September of 2015; while the minimum of 0 mm in February and the maximum of 309 mm in July of 2016.

The climatic conditions of the study areas were determined by constructing a climograph of average monthly air temperature and rainfall. The dry seasons were designated during March to June 2015, with monthly air temperature were ranging from 29.7-31.3°C and 14.9-126.9 mm monthly precipitation; and January to April 2016, with monthly air temperature were ranging from 26.5-32.4°C and 0-54.8 mm monthly precipitation. The wet seasons were during July to October 2015°C monthly air temperature was ranging from 28.3-30.1°C and 72.7-296.9 mm monthly precipitation and June to September 2016°C monthly air temperature was ranging from 28.6-29.8°C and 129.2-309 mm monthly precipitation (Appendix 1).

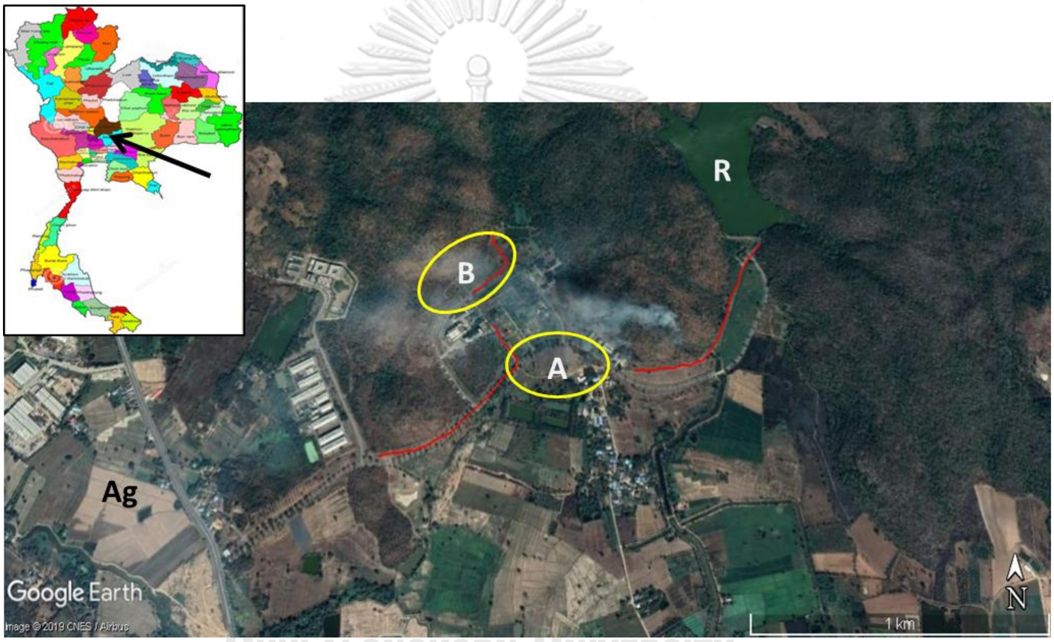


Figure 3.1 Map of experiment plots in the area of Chulalongkorn University Center of Learning Network for the Region Saraburi A. Landscape-scale plots, B. Teak reforestation

Note: R is reservoir, Ag is agriculture area, and transect line (red) for surrounding area bird observation.

There were two spatial levels of enhancement in experiment plots: (1) as plots interspersed in the patches (larger spatial scale) and (2) as intercropping strips in a 2-year-old teak reforestation stand (Figure 3.1). The distance between landscape-scale plots and the teak reforestation site was around 450 m. Landscape-scale plots were surrounded by some natural and planted trees, open grassy areas with ponds and a reservoir, villages and small roads. Experiment plots in the teak plantation were surrounded by hilly forests in the northwest side, several ponds and dipterocarp reforestation area in other sides. Experiments were held during March to June 2015 and January to April 2016 (dry seasons) and July to October 2015 and June to September 2016 (wet seasons) based on historical data and verified with the climograph.

3.2 Plot preparation

3.2.1 Landscape scale

Three adjacent 40m x 30m rectangular plots were designated as the experiment plots, with 5m buffer between plots. Each plot was arranged in 18 rows of 1m x 40m with about 1m space between rows (Figure 3.2). Planting of sunflower, sunn hemp and intercropping of both species was repeated for 4 growing seasons of 2015 and 2016. The experiment plots were plowed and set aside for 2 weeks, then plowed again before seed sowing. Due to the presence of other vegetation in the plots in the first year, a fallow plot was added during the dry and wet seasons of 2016. Consisting of natural vegetation in the area, without enhanced practice, the fallow plot was mainly covered with herbaceous plants in the Poaceae in combination with other plants in Mimosaceae, Malvaceae and Convovulaceae. The fallow plot was left untreated after being plowed. During the dry season of 2016, the vegetation in the fallow plot was cut in the middle of observation period, but no management was applied during the wet season of 2016 (Figure 3.3).

Seeds were taken from the same source in order to get the genetically homogenous seedlings. Seeds of sunflower were put in seedling trays and kept under shading. Seedlings were transplanted into plots after two true leaves appeared. Manual transplantation was performed unless there was an insect infestation during seedling stage; direct seeding of sunflower seeds into holes dug directly in the plots was applied instead. The largest disturbance happened when grasshoppers infested sunflower seedling trays at the beginning of the wet season of 2016. Alternate planting in the landscape scale plots required sowing seeds directly in holes and then covering sunflower seedlings with 65% black paranet and sprayed twice with a mixture of neem (*Azadirachta indica*) leaf and lemon grass (*Cymbopogon* sp.) extracts (modification from the SAPP project, http://projects.nri.org/aspp/Azadirachta_indica.htm). Sunn hemp seeds were sown directly in the 1 x 40m rows in the landscape scale plots. Weeding was not conducted during a growing season. Plants in landscape-scale plots were watered manually.

Sunflower seeds (27 seeds/m^2) and sunn hemp seeds (600 seeds/m^2) were sown in 1m-wide rows at the beginning of each growing season. In the intercropping plots, sunflowers and sunn hemp were planted in alternate rows. The densities (mean ± SE) of sunflower and sunn hemp in landscape scale plot were 10 ± 3 plants/m^2 and

250 ± 62 plants/m^2, respectively. Herbaceous plant species growing unintendedly in the landscape plots were assigned as other vegetation, including *Mimosa* spp. (Mimosaceae), *Hibiscus sabdariffa* (Malvaceae), *Ipomoea aquatica* (Convolvulaceae) and grasses (Poaceae), which are common in farming areas of the region (Radanachaless & Maxwell, 1994).

Figure 3.2 Experiment plots in landscape scale: fallow plot (Fal), sunflower plot (SF), sunn hemp plot (SH) and intercropping plot (Int)

A.

B.

C.

D.

E.

Figure 3.3 Landscape-scale plots, A. Prior to experiment, B. Sunflower, C. Sunn hemp, D, Intercropping, E. Fallow

3.2.2 Teak reforestation

Sunflower and sunn hemp were planted between rows of teak saplings in the 2-year-old plantation. The teak plantation plots were arranged with a randomized block design (RBD) consisting of three blocks, each with three rectangular plots of 20m x 20m each with 10m distance between plots, representing the treatments. Distance between the blocks was 20m in width. the distance between individual teak *Tectona grandis* seedlings and saplings was 4m. One plot consisted of 5 teak rows with 1m-width row of enhancement plants intercropped between teak rows. Three treatments were arranged as (1) teak intercropped with sunflower, (2) teak intercropped with sunn hemp, and (3) homogenous teak, with no manipulation was performed on the plots, functioning as a control plot (Figure 3.4). The experiment plots were plowed and set aside for 2 weeks, then plowed again before seed sowing. Meanwhile, the control plot was maintained following regular practice in the area, with monthly cutting of ground vegetation between teak trees. The teak reforestation plots were shown in Figure 3.5.

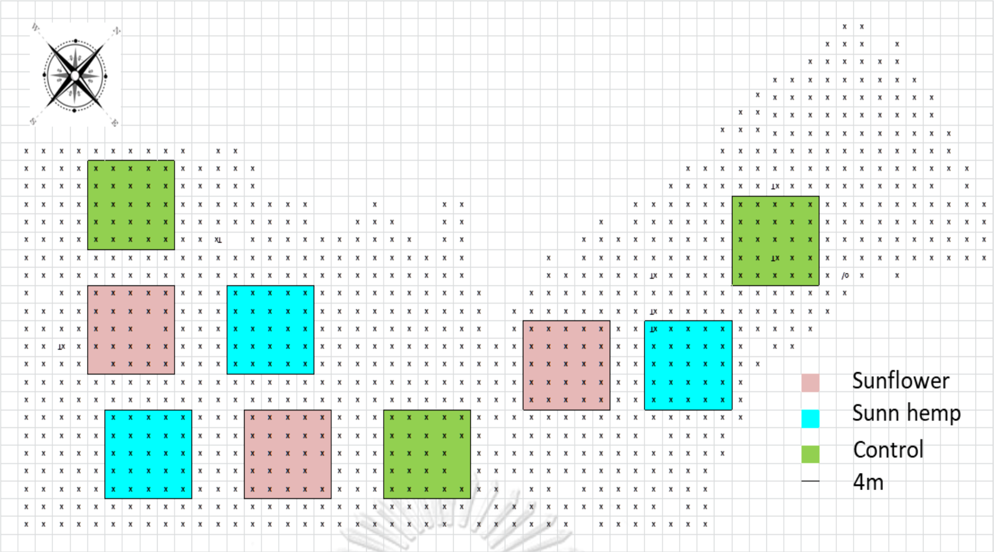


Figure 3.4 Plots arrangement in teak reforestation during dry and wet season of 2015-2016

Sunflower seedlings were prepared and transplanted as explained above. During the grasshopper infestation at the beginning of the wet season of 2016, sunflower seeds were sown in holes in between rows of teaks, with the application of neem spray as described above but without the paranet cover. Sunn hemp seeds were sown directly in the intercropping rows in the teak reforestation plots.

Weeding was not conducted during a growing season but grass cutting and teak pruning was done bimonthly, according to the existing teak maintenance plan. Plants in teak reforestation plots watered using an irrigation system for two seasons and then watered manually for the next two seasons.

Figure 3.5 Teak reforestation plots. A. Sunflower, B. Sunn hemp, C. Control

Sunflower intercropped density in teak reforestation was 7 ± 4 plants/m^2, with short and small flower during the experiment. Sunn hemp density was 180 ± 29 plants/m^2. Herbaceous plant species growing unintendedly in the rows between teak trees were of the same species as seen in the landscape plots; these plants were designated as other vegetation.

3.3 Bird surveys

Bird surveys were conducted between the period of an hour after sunrise and 11 AM on windless, clear days. Birds were observed using an 8 x 42 binocular and identified to species according to “A Guide to the Birds of Thailand” (Lekagul & Round, 1991; Nabhitabhata, Lekagul, & Sanguansimbat, 2012). Birds were censused on experiment plots during the four growing seasons, started on the third week after sunflower and sunn hemp planting. Then the observations were conducted weekly in each of the growing seasons for bird species and abundance.

Species names and taxonomic groups were updated following Boyd (2017). Birds flying over or across the plots were noted but not included in the analyses. Species presence and occurrence were recorded.

Landscape scale plots

Two observation posts were located 5 m from the perimeter of each plot, covered with vegetation or under tree shade to provide camouflage during bird observation. Bird observation began 5 minutes after the arrival of the observer and switched halfway between the two observation posts to cover the whole plot area. All birds seen in each experiment plot during 40-minute period were noted for their species and occurrence.

Teak plantation plots

An observation post was located 5m from the perimeter of each plot, covered with vegetation or under a shade tree to provide camouflage during bird observations. The 15-minute bird observation started 5 minutes after the arrival of the observer at the post. Bird species and occurrence were recorded as described above.

Surrounding area

Bird diversity in the surrounding area adjacent to the experiment plots was documented as supporting data. Bird surveys using distance sampling along a 2km line transect with 50m distance on either side (red lines in Figure 3.1). The line transect sampling was performed once every two weeks during the study period to obtain local species pool of available birds. Species name and number of individuals were recorded. All birds visible within the 50m-distance of the line were counted, excluding birds flying overhead (Bibby, Burgess, & Hill, 1992).

Bird activities and habitat usages

When a bird was observed in a plot, its activity and microhabitat where it was observed were recorded. The activities were classified based on Stallman and Best (1996) and Yang et al. (2015). Bird activities were defined as: (1) foraging, if birds were observed searching widely for food, pecking or eating insects, seeds, or plants; (2)

perching, when birds remained stationary on a substrate, such as vegetation or staying on the ground; and (3) other activities, include preening, threatening, playing, and walking. Nesting was not included in the analysis of bird activity due to its rarity. If a bird moved to another row or left the observation plot and returned later to the same or different row, it would be recorded as a separate observation. Birds flying over experiment plots were excluded, except for several species feeding on aerial invertebrates directly over vegetation (Boutin, Freemark, & Kirk, 1999).

Habitat usages in the teak reforestation were grouped based on the locations where birds were observed into enhancement plants (sunflower or sunn hemp), teak trees and the ground (vegetation above ground or bare soil out of teak or enhancement plants). Microhabitats where bird activities were observed in a landscape plot were classified into stems, flowers and leaves of sunflower and sunn hemp, other vegetation and bare ground. In addition, teak stems, leaves and treetop were added as microhabitats for teak trees. The frequencies of activity types when birds were observed directly in the plot and using microhabitats were tabulated for each 40-minute observation in landscape plot and for each 15-minute observation in the teak reforestation plot.

3.4 Arthropod sampling and identification

Arthropods in the experiment plots were sampled biweekly using sweep-net collection during each of the 4-month growing seasons. Sweeping is the best way to obtain greater quantity and variety of insects, usually used in general assessment of arthropods community (Triplehorn & Johnson, 2005). Sweep-netting was used due to the reliability, consistency and efficiency in sampling invertebrates that fly or sit on low vegetation (Spafford & Lortie, 2013; Sutherland, 2006). Sampling began on the third week after planting. Sampling was conducted in the morning, between 9 am and 12 pm on the day without rain and strong wind. In each plot, three 1x1 m^2 quadrats in different rows were randomly selected to reduce repetition in the landscape scale. Meanwhile, a quadrat was randomly applied in each plot in teak reforestation plots. A 35 cm-diameter sweep net was swept back and forth for five times across the sampling area. The trapped arthropods were placed in a plastic bag and preserved in 70% ethanol for later identification.

All arthropods were classified into order, family and morphospecies, following Triplehorn and Johnson (2005). Morphospecies were conservatively identified based on differences in morphological characters to distinguish species. In other words, if there were two specimens that could not be definitely differentiated, they were considered as belonging to a single morphospecies. In contrast, specimens with differences in patterns or body part shape were assumed as different morphospecies. For example: *Acanthoscelides* sp 1 and sp 2 had different serrate antennae. Anthicidae-1 had darker color in body and 2-tone color legs, while Anthicidae-2 had a single tone and lighter color of legs.

Arthropod species richness was reported as the accumulated number of morphospecies over each year. Arthropod abundance was presented as an average number of individuals caught in each sampling. Unidentified larval specimens were excluded from arthropod richness analysis.

3.5 Ecological guilds

3.5.1 Bird guilds

Birds observed in the experiment plots and the surrounding area were then classified into feeding guilds using actual observations and secondary sources (Cummins & O'Halloran, 2002; del Hoyo, 2015; Garrick, 1981; Sivakumaran & Rahmani, 2005). In this research, birds were divided in four groups of feeding guilds, namely insectivores, omnivores, granivores and others (these included frugivores, piscivores, and carnivores).

3.5.2 Arthropod guilds

The arthropod specimens were classified based on feeding guilds by family level identification. Larval specimens were included in feeding guild analysis. The arthropod specimens were assigned as herbivores, predators, parasitoids and detritivores. Some arthropods species that feed on other arthropod are considered as predatory species. Furthermore, based on the examination of mouth parts, herbivorous arthropods were further separated into piercing-sucking herbivores, chewing herbivores, and nectar/pollen-feeding herbivores (Dilling, Lambdin, Grant, & Buck, 2007; Novotny et al., 2010).

3.6 Functional diversity

In addition to species diversity, the bird species and occurrence data was analyzed for their functional diversity, using mostly species resource use patterns (Petchey & Gaston, 2006). The functional diversity analysis used traits of species as the foundation and estimated some component of the dispersion of species in the corresponding trait space. Dispersion was estimated as the total branch length of the functional dendrogram that result from clustering the species in the trait space (Petchey & Gaston, 2002). Traits were used to create a distance matrix among the bird species, which was then used to construct a dendrogram representing functional similarity/dissimilarity among the bird species (Petchey, Evans, Fishburn, & Gaston, 2007; Petchey & Gaston, 2007).

For the landscape bird data, the traits used were: enhanced type (sunflower, sunn hemp, intercropping and fallow), feeding guilds (insectivores, granivores, omnivores and other) and activity strata (ground, sunflower, sunn hemp and other vegetation) from the observation in the landscape-scale enhanced plots. Meanwhile, for the teak reforestation dataset the traits consisted of enhanced type (sunflower, sunn hemp, control) feeding guilds (insectivores, granivores and omnivores) and activity strata (ground, sunflower, sunn hemp and teak). Bird species abbreviations were composed of the first 3 letters from the generic name and the first 4 letters from its specific epithet. For examples: Col_livi, Pri_inor and Myr_eryt refer to *Columba livia*, *Prinia inornata* and *Mirafra erythrocephala*, respectively. Functional diversity analysis was performed using picante and ade4 packages in R program version 3.3.2, following instructions by Petchey and Gaston (2002).

Species redundancy arises due to the compensative capacity of species in a functional group. Redundancy was shown through numbers of tips arising from the same branch in the dendrogram. Some groups may be highly redundant, but generally most functional groups are presented by only a few species (Coelho et al., 2016; Naeem, 1998).

3.7 Supporting data

3.7.1 Biological factors

Five 1x1 m^2 subplots were prepared in the landscape-scale, while one 1x1 m^2 subplots were applied in each in the teak reforestation at the end of each growing season to measure plant density and dry plant biomass. Plant biomass was collected, cut slightly above ground when vegetation was still in the seeding phase, weighed and followed with drying process in 80°C using oven until the weight was stable. The biomass of sunflower and sunn hemp biomass was separated from other vegetation in all treatments.

Since sunflower and sunn hemp reportedly are able to improve soil, it was additionally interesting to observe teak growth by measuring tree height (m) and root collar diameter (cm) before and after treatment. Tree height was measured with a tape measure when the height was reachable and then using rangefinder (Nikon Laser Forestry Pro). Root-collar diameter was measured using a vernier caliper.

3.7.2 Physical factors

Soil pH, soil moisture, water holding capacity and soil nutrients were measured at the end of each growing season as supporting data. Soil samples were sent to the Central Laboratory and Greenhouse Complex (Kasetsart University, Kamphaeng Saen Campus) for analysis of some nutrients, such as nitrogen (KCl extraction and distillation), phosphorus (Bray II extraction and spectroscopy) and potassium (K) (NH_4OAc extraction and atomic spectroscopy) (Appendix 2).

3.8 Data Analysis

3.8.1 Bird species richness and occurrence

Bird species richness was estimated as cumulative number of species detected at each experiment plot from 4 growing seasons. Species accumulative curves were constructed using BiodiversityR package through R program version 3.3.2 (Kindt & Coe, 2005). Bird species richness was then compared among the experiment plots and with the surrounding area.

Bird occurrence was tabulated as number of individuals observed per each 40-minute observation in the landscape-scale plots and per each 15-minute observation in the teak reforestation plots. Relative occurrence was calculated from the proportion of each species to the total occurrence.

Shannon-Wiener diversity index and Pielou's evenness index were calculated for each treatment. Sorensen's Similarity Index (Magurran, 2013) was calculated to determine the resemblance of bird species composition between the experiment plots.

The Kruskal-Wallis test was used to determine differences in bird occurrence among experiment plots, and Mann-Whitney U-test was used to determine differences between the pairs of plots.

The frequencies of bird usage activities were compared among microhabitats in the experiment plots. Activities of birds belonging to different guilds were analyzed separately. Chi-square test was used to determine whether the proportions of various bird guilds differed between plots and to compare the frequencies of each type of activity among microhabitats.

3.8.2 Arthropods

The impact of enhancement treatments was assessed as the comparison of arthropod morphospecies richness and mean abundance between treatments. Species accumulation curves were constructed based on yearly species richness for each treatment and presented by year using BiodiversityR package through R program version 3.5.1 (Kindt & Coe, 2005). Estimators of species richness (Chao2 and ICE) were calculated using SpadeR package (Chao, Ma, Hsieh, & Chiu, 2016). Kruskal-Wallis was used to determine differences among arthropod richness and abundance and only performed with the data from the landscape-scale plots. Mann-Whitney U-test was used to determine differences between the pairs of treatments. Chi-square test was used to determine whether the proportions of various arthropod guilds differed between treatments. Relationships among trophic levels were determined using Spearman rank correlation analysis (IBM SPSS Statistic 22).

CHAPTER IV

BIRDS AND ARTHROPODS IN THE LANDSCAPE-SCALE PLOTS

4.1 Bird diversity and composition in the landscape-scale experiment plots

A total of 2785 individuals from 38 bird species, classified into 22 families, were observed in the experiment plots planted with sunflower, sunn hemp, and a mixture of both plant species. Thirty-one (89%) of the bird species in the experiment plots were resident species, such as *Prinia inornata, Prinia hodgsoni, Columba livia, Spilopelia chinensis, Geopelia striata* and *Lonchura punctulata*, all of which were commonly observed in all growing seasons. A few bird species were winter visitors, such as *Bubulcus coromandus, Lanius cristatus* and *Saxicola stejnegeri*. The bird species observed in the experiment plots represented 40% of the local bird species (96 species) observed in the surrounding area during the time of study (Appendix 3).

Twenty-eight, 25, 25 and 19 bird species were recorded in the sunflower, sunn hemp, intercropping and fallow plots, respectively. Different numbers of bird species among treatments were presented yearly (Figure 4.1), with average of 14-15 species per plot per season (Table 4.1). The Shannon-Wiener diversity index was higher in the surrounding area than those of the experiment plots. Among the experiment plots, Shannon-Wiener index was highest in the sunn hemp plots in 2015, but in 2016 bird diversity was highest in the sunflower plots. The Pielou’s evenness indices resembled the pattern of Shannon-Wiener indices (Table 4.2). The bird species composition was similar among the experiment plots with 18 species (51%) shared among all landscape-scale experiment plots (Figure 4.2). The values of Sorensen's similarity (SS) indices varied between 0.53-0.84 among the experiment plots. Species similarity was also high between years (SS = 0.68) and seasons (SS = 0.77).

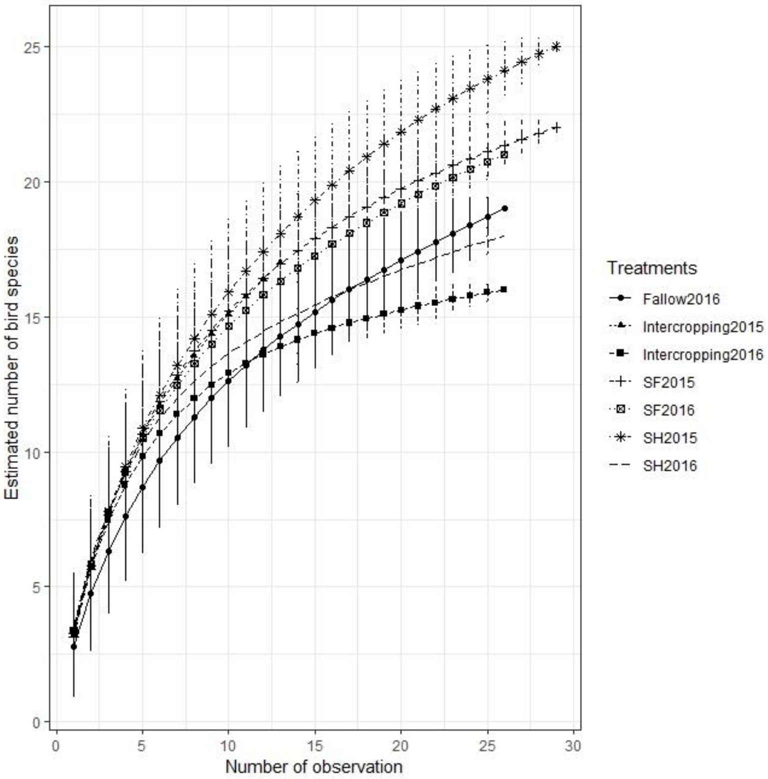


Figure 4.1 Species accumulation curves of the bird species in the landscape-scale experiment plots in 2015-2016

Note: plots were enhanced with sunflower, sunn hemp, intercropping of both species during 2015-2016 and fallow plots only in 2016. Error bars are standard deviation of the mean. Intercropping 2015 was appeared in a half due to difficulties in discriminate with sunflower 2015 for overlapping data.

Table 4.1 Number of bird species per season in the landscape-scale experiment plots in 2015-2016

Season	Sunflower	Sunn hemp	Intercropping	Fallow
Dry 2015	16	18	16	-
Wet 2015	14	18	17	-
Dry 2016	13	16	13	12
Wet 2016	14	10	11	10
Average	14.25	15.50	14.25	11.00
SE	0.63	1.89	1.38	1.00

Note: plots were enhanced with sunflower, sunn hemp, intercropping of both species during 2015-2016 and fallow plots only in 2016.

Table 4.2 Species diversity indices of birds observed in landscape-scale experiment plots and the surrounding area during dry and wet seasons of 2015-2016

Index	Dry 2015	Wet 2015	Dry 2016	Wet 2016	Overall
Shannon-Weiner diversity Index					
Sunflower	2.06	1.9	1.94	2.05	2.36
Sunn hemp	2.29	2.24	1.73	1.76	2.3
Intercropping	2.06	2.15	1.38	1.70	2.2
Fallow	-	-	1.98	1.48	1.94
Surrounding area	3.41	3.38	3.14	3.45	3.49
Pielou's evenness index					
Sunflower	0.74	0.72	0.76	0.78	0.71
Sunn hemp	0.79	0.77	0.63	0.76	0.71
Intercropping	0.74	0.76	0.54	0.71	0.68
Fallow	-	-	0.8	0.64	0.66
Surrounding area	0.79	0.80	0.73	0.83	0.76

Note: plots were enhanced with sunflower, sunn hemp, intercropping of both species and fallow plots.

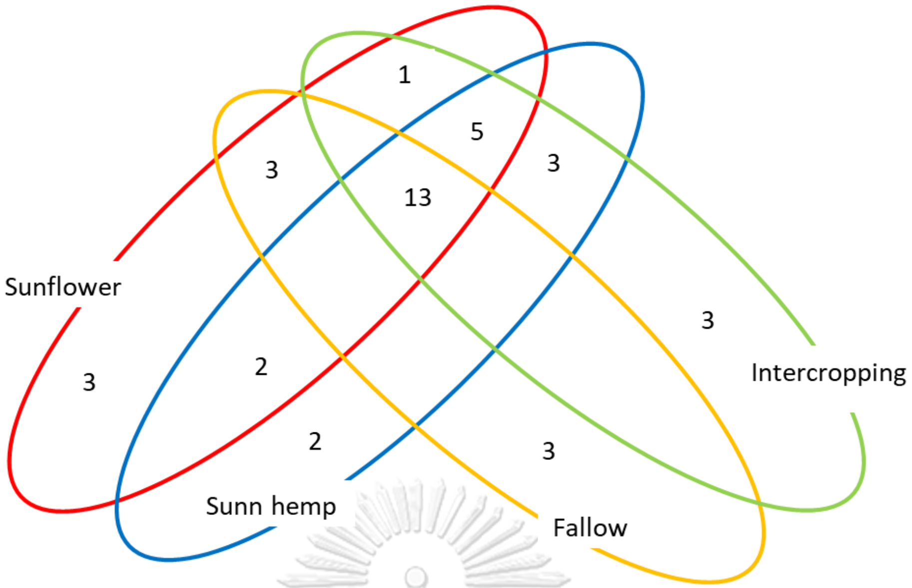


Figure 4.2 Number of bird species observed in landscape-scale experiment plots in 2015-2016

Note: plots were enhanced with sunflower, sunn hemp, intercropping of both species during 2015-2016 and fallow plots only in 2016.

Average bird occurrence was not significantly different among treatments ($\chi^2_2 = 6.659$, $n_1 = 54$, $n_2 = 54$, $n_3 = 54$, $n_4 = 25$, $p = 0.084$), between seasons ($U = 3913.5$, $n_1 = 108$, $n_2 = 79$, $p = 0.174$) and between years ($U = 4085$, $n_1 = 87$, $n_2 = 100$, $p = 0.248$). Bird species with the highest occurrence were resident species and their ranks differed in the experiment plots. *Lonchura punctulata* was the most frequently observed species in all experiment plots. *Columba livia* was almost of equal occurrence with *L. punctulata* in the sunflower plot while *P. inornata* was the second rank in sunn hemp and intercropping plots. The other commonly observed species were *Corydalla* sp., *Geopelia striata* and *C. livia*. Overall, these species made up approximately 62%

of the total occurrence of birds observed in this study. Some of bird species were observed exclusively in each of the experiment plots, such as *Caprimulgus macrurus* and *Lonchura striata* in sunflower plot; *Pycnonotus aurigaster* and *Leucocirca javanica* in sunn hemp plot; and *Anastomus oscitans* and *Chaptia aenea* in intercropping plot. Most of them were observed only once during the study period (Table 4.3).

Table 4.3 Bird occurrence in landscape-scale experiment plots enhanced with sunflower, sunn hemp, intercropping of both species and fallow plots during 2015-2016

Species	Guild	Sunflower		Sunn hemp		Intercropping		Fallow	
		Occ	Rel. occ	Occ	Rel. Occ	Occ	Rel. Occ	Occ	Rel. Occ
Lonchura punctulata	G	4.09	0.243	4.07	0.316	6.39	0.345	1.16	0.16
Prinia inornata	I	1.02	0.061	2.83	0.220	2.33	0.126	3.00	0.42
Columba livia	G	4.07	0.242	0.09	0.007	2.13	0.115	-	-
Geopelia striata	G	0.80	0.047	0.80	0.062	2.13	0.115	-	-
Spilopelia chinensis	G	1.30	0.077	0.31	0.024	1.15	0.062	0.32	0.44
Corydalla sp.	I	1.39	0.083	0.67	0.052	0.83	0.045	0.16	0.02
Mirafra erythrocephala	O	0.85	0.051	0.22	0.017	0.30	0.016	1.04	0.14
Cisticola exilis	I	0.80	0.047	0.78	0.060	0.15	0.008	0.12	0.02
Prinia hodgsoni	I	0.30	0.018	0.50	0.039	0.76	0.041	0.20	0.03
Merops orientalis	I	0.43	0.025	0.65	0.050	0.39	0.021	-	-
Edolius macrocercus	I	0.20	0.012	0.48	0.037	0.19	0.010	0.28	0.04
Passer flaveolus	O	0.09	0.006	0.26	0.020	0.61	0.033	-	-
Streptopelia tranquebarica	G	0.26	0.015	0.04	0.003	0.57	0.031	0.04	0.01
Vanelus indicus	O	0.31	0.019	0.17	0.013	0.09	0.005	0.12	0.02
Saxicola stejnegeri	I	0.09	0.006	0.17	0.013	0.07	0.004	0.24	0.03

Species	Guild	Sunflower		Sunn hemp		Intercropping		Fallow	
		Occ	Rel. occ	Occ	Rel. Occ	Occ	Rel. Occ	Occ	Rel. Occ
*Bubulcus coromandus**	I	0.37	0.022	0.04	0.003	-	-	-	-
Cacomantis merulinus	I	-	-	0.37	0.029	0.04	0.002	-	-
Chrysomma sinense	I	0.02	0.001	0.15	0.011	0.07	0.004	0.04	0.01
*Lanius cristatus**	I	0.11	0.007	0.06	0.004	0.06	0.003	0.04	0.01
Centropus sinensis	O	-	-	-	-	-	-	0.20	0.03
Prinia rufescens	I	0.02	0.001	0.06	0.004	0.07	0.004	-	-
Caprimulgus macrurus	I	0.07	0.004	-	-	-	-	0.04	0.01
Acridotheres tristis	O	0.04	0.002	0.06	0.004	0.02	0.001	-	-
Coracias benghalensis	I	-	-	-	-	-	-	0.08	0.01
Halcyon smyrnensis	O	-	-	0.06	0.004	0.02	0.001	-	-
Lonchura striata	G	0.07	0.004	-	-	-	-	-	-
Anastomus oscitans	P	-	-	-	-	0.07	0.004	-	-
Ploceus hypoxanthus	G	0.02	0.001	-	-	-	-	0.04	0.01
*Muscicapa latirostris**	I	0.02	0.001	-	-	-	-	0.04	0.01
*Saxicola caprata**	I	0.02	0.001	0.04	0.003	-	-	-	-

Species	Guild	Sunflower		Sunn hemp		Intercropping		Fallow	
		Occ	Rel. occ	Occ	Rel. Occ	Occ	Rel. Occ	Occ	Rel. Occ
Gracupica nigricollis	O	-	-	-	-	-	-	0.04	0.01
Passer montanus	O	0.02	0.001	-	-	0.02	0.001	-	-
Acridotheres grandis	O	0.04	0.002	-	-	-	-	-	-
Pycnonotus aurigaster	O	-	-	0.04	0.003	-	-	-	-
Ploceus philippinus	G	0.02	0.001	-	-	-	-	-	-
Leucocirca javanica	I	-	-	0.02	0.001	-	-	-	-
Chaptia aenea	I	-	-	-	-	0.02	0.001	-	-
Merops philippinus	I	-	-	-	-	0.02	0.001	-	-

Occurrence (Occ) is average number of individuals per observation. Relative occurrence (Rel. occ) is the proportion of each species to total occurrence. Species are ranked by their overall occurrence. Feeding guilds are assigned as granivore (G), insectivore (I), omnivore (O), and piscivore (P). * indicates status as winter visitor.

Overall, insectivorous species (>50% of all species) dominated the bird species composition in the experiment plots, followed by granivores and omnivores (Table 4.4, Figure 4.3). Relative proportion of guilds was similar among the experiment plots but differed from that of the surrounding area of which insectivores were less than 50% of all species. Particularly, the relative proportion of the granivores was significantly higher in the experiment plots than in the surrounding area ($\chi 2 = 93.83$, $p < 0.001$). On the other hand, omnivores and other guild (piscivores) were observed at lower proportions in the experiment plots than the surrounding area. Common insectivorous species were *P. inornata, Corydalla* sp. and *C. exilis*. Common granivorous species were *L. punctulata*, *C. livia, S. chinensis* and *G. striata*. Common omnivorous species were *Mirafra erythrocephala* and *Passer flaveolus* (Table 4.3, Figure 4.4).

Table 4.4 Number of bird species in the landscape-scale experiment plots classified by guild during 2015-2016

Guild	Sunflower	Sunn hemp	Intercropping	Fallow	Surrounding area
Insectivores	14	14	13	11	41
Omnivores	6	6	6	4	28
Granivores	8	5	5	4	8
Others	0	0	1	0	19
Total	28	25	25	19	96

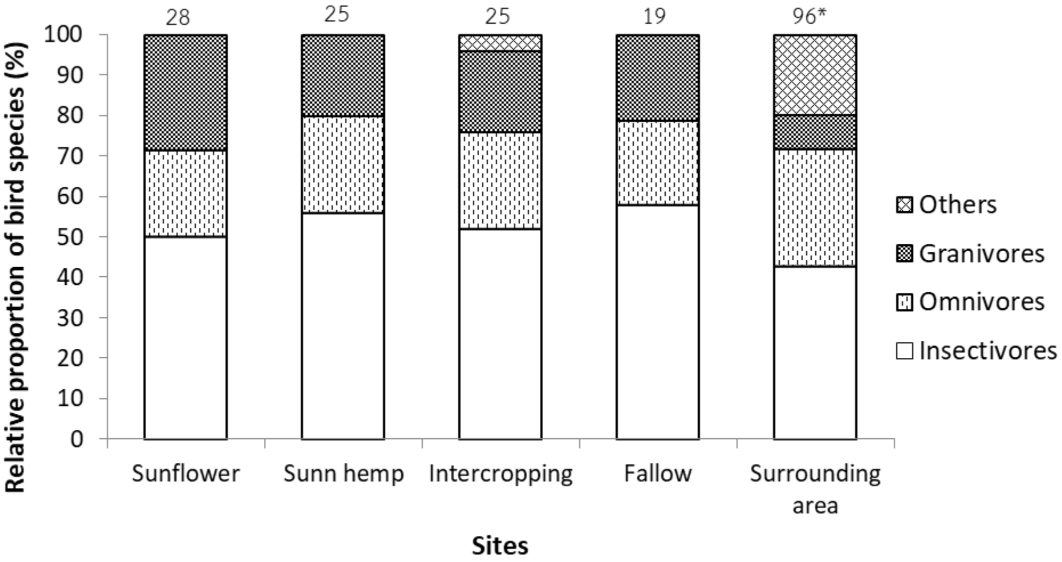


Figure 4.3 Relative proportion of bird feeding guilds observed in the landscape-scale experiment plots and the surrounding area during 2015-2016

Note: the experiment plots were enhanced with sunflower, sunn hemp, intercropping of both species and fallow plots. Numbers above represent the species richness. (*) Birds were observed using the line-transect method in the surrounding area.

The average occurrence of insectivores was slightly different among treatments, with the highest occurrence observed in the sunn hemp treatment. Average occurrence of granivores were significantly different among treatments with the high occurrence in the sunflower and intercropping treatments. While 5-7 individuals per observation of insectivores were observed in all treatments, the occurrence of granivores varied between 5-12 individuals per observation. Only a few omnivorous species (1 individual per observation) were observed across all treatments and all seasons (Figure 4.5).

Lonchura punctulata *Prinia inornata*

Mirafra erythrocephala *Corydalla* sp.

Passer flaveolus *Columba livia*

Figure 4.4 Most abundant bird species in the landscape-scale experiment plots enhanced with sunflower, sunn hemp, intercropping of both species and fallow plots during dry and wet seasons of 2015-2016

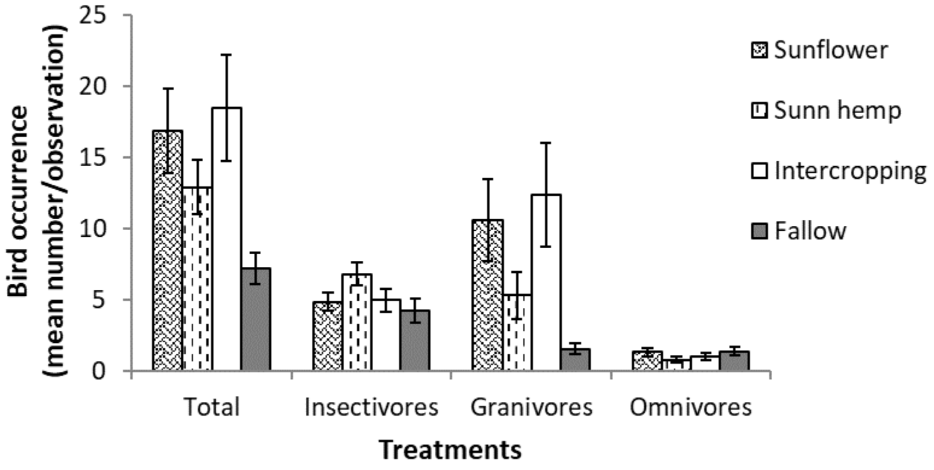


Figure 4.5 Bird occurrence of feeding guilds in the landscape-scale experiment plots during 2015 and 2016
Note: the experiment plots were enhanced with sunflower, sunn hemp, intercropping of both species and fallow plots during dry and wet seasons

Functional diversity values ranged between 1.11-1.18. Birds in the enhanced landscape-scale plots showed clear grouping based on the feeding guilds, followed by similar usages of treatment plots. Similar species function in the experiment plots was formed by branch arrangement, showed species redundancy. Most of them showed two bird species in the same branch, such as *L. striata* and *P. philippinus*, *C. livia* and *G. striata, L. cristatus* and *C. exilis, P. inornata* and *E. macrocercus,* while *V. indicus* and *M. erythrocephala* were also shared similar function ecologically (Figure 4.6).

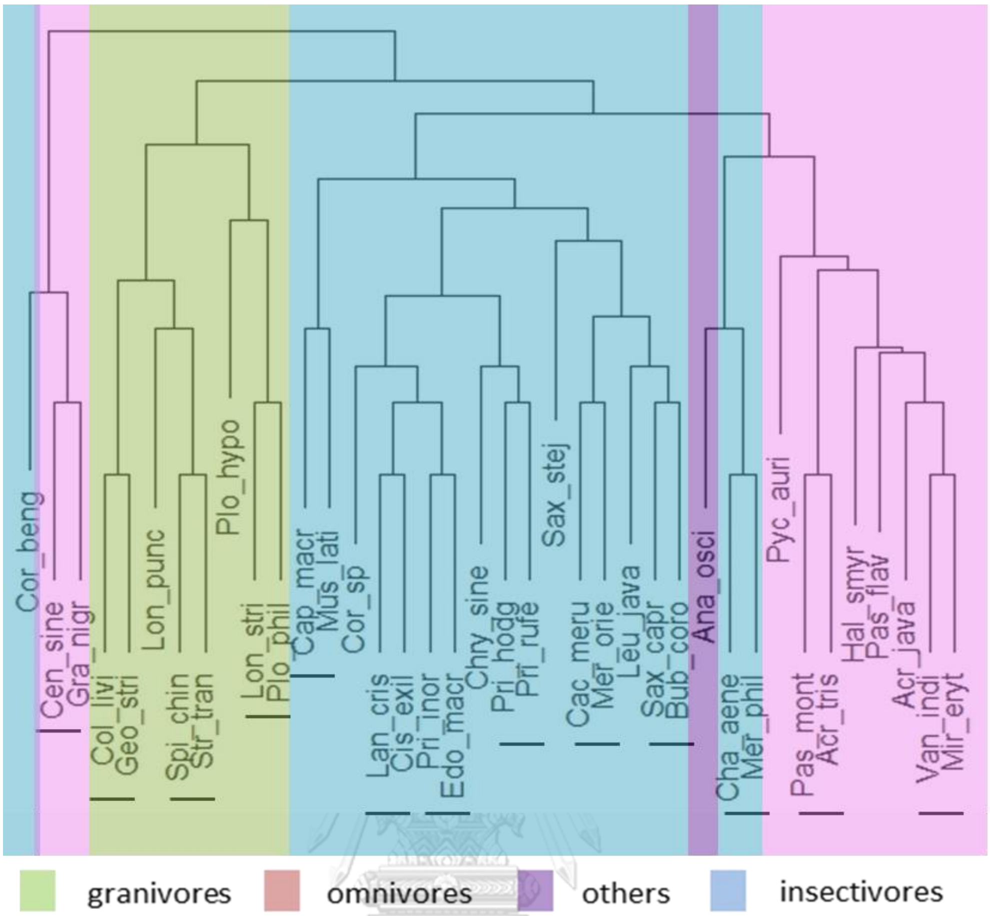


Figure 4.6 Functional dendrogram among 38 bird species that observed in the landscape-scale experiment plots enhanced with sunflower, sunn hemp and intercropping of both species and fallow plots at Kaeng Khoi district, Saraburi province, during dry and wet seasons of 2015-2016

Note: species are abbreviated for first 3 letters from generic name and the first 4 letters from its specific epithet. Bar below species name showed species from the same branch and assumed could replace each other function ecologically.

4.2 Bird activities and habitat usages

Overall, foraging (52%) and perching (37%) were the most frequently observed activities in the experiment plots (Figure 4.7). In the sunn hemp, intercropping and fallow plots, foraging and perching showed similar proportions while birds were seen more frequently foraging than perching in the sunflower plot.

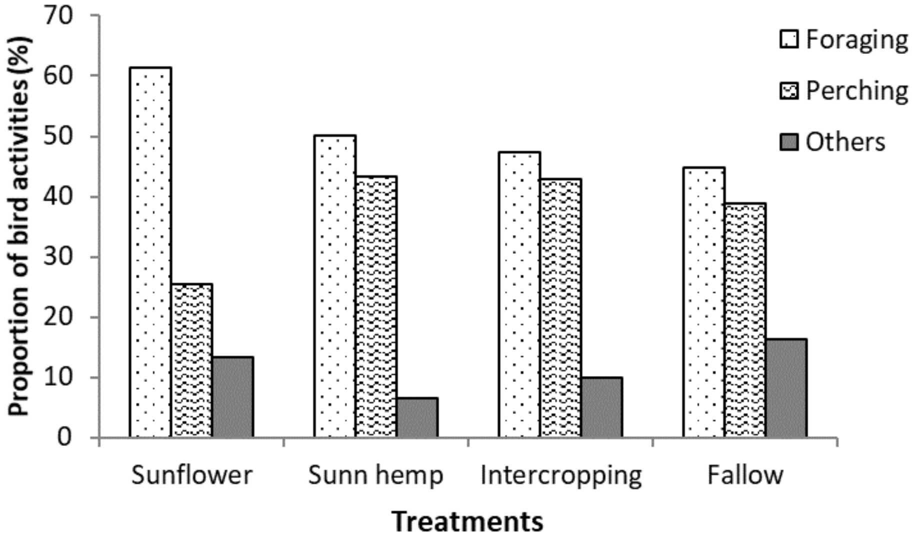


Figure 4.7 Proportion of bird activities in the landscape-scale experiment plots during 2015-2016

Bird usages of habitat strata were grouped into ground, enhancement plants, and other vegetation; only ground and other vegetation strata were included in the data from the fallow plot. The proportion of ground usages was higher than the usages of enhancement plants in the sunflower treatment, while the opposite pattern was observed in the sunn hemp and intercropping treatments (Figure 4.8). In the fallow plot, more birds were observed using the other vegetation than the ground.

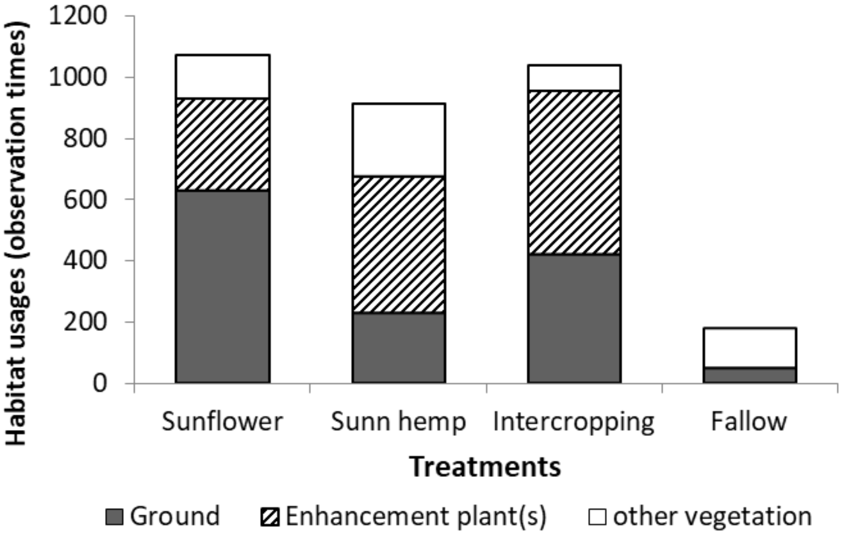
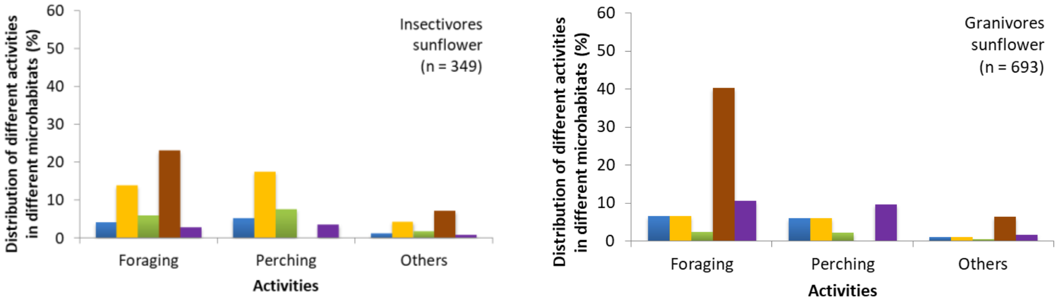


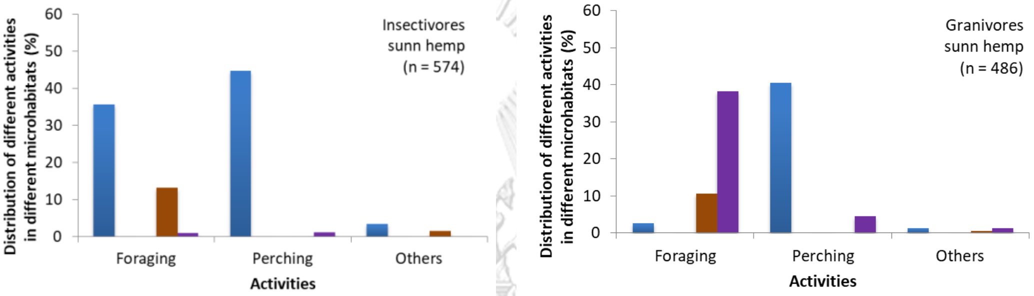
Figure 4.8 Habitat usages by bird in the landscape-scale experiment plots during 2015-2016

Generally, birds from each guild were using the treatment plots rather differently. Because granivores and insectivores were the dominant guilds in all plots, only their activities in different microhabitats are reported here. The overall results showed that granivores and insectivores differently used various microhabitats created by planting sunflower and sunn hemp in the experiment plots (Figure 4.9). Insectivorous birds mostly foraged on sunn hemp stems in both sunn hemp and intercropping plots, while they foraged on the ground in the sunflower plot. They also perched on the stems in the sunn hemp and intercropping plots while perched on sunflower heads in the sunflower plot. Similar patterns of microhabitat usages for foraging and perching were observed in the sunn hemp and in the intercropping plots (foraging: χ^2 = 5.01 p = 0.29; perching: χ^2 = 6.44, p = 0.09). Meanwhile, granivorous birds mostly foraged on the ground in the sunflower and intercropping plots, but they foraged on other vegetation in the sunn hemp plots. They perched on sunn hemp stems in both sunn hemp and intercropping plots, but rarely perched in the sunflower plot (Figure 4.9).

(a) Sunflower plot



(b) Sunn hemp plot



(c) Intercropping plot

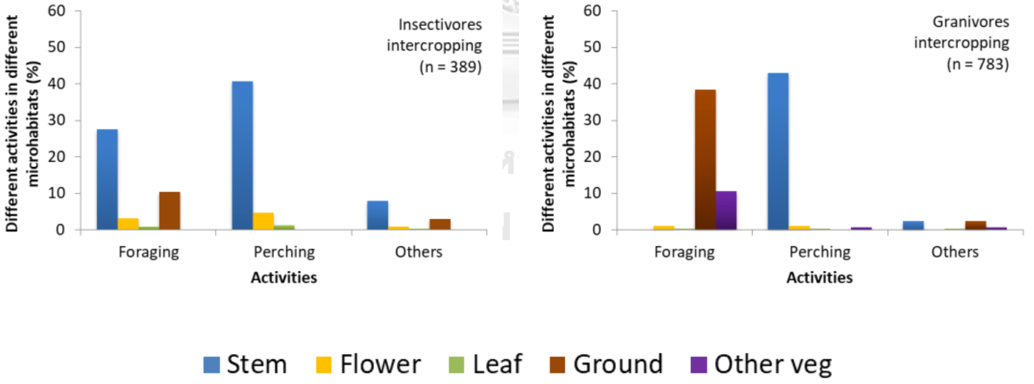


Figure 4.9 Distribution of different activity types in different microhabitats in (a) Sunflower plot, (b) Sunn hemp plot, (c) Intercropping plot

Note: other activities consist of preening, resting, playing and walking

4.3 Arthropods in the landscape-scale experiment plots

A total of 6671 individuals from 161 arthropod morphospecies, classified into 93 families, were observed in the experiment plots. Overall, slightly more arthropod species were observed in the 2016 than 2015 and within each year the species richness was comparable (Figure 4.10). Intercropping with sunn hemp and sunflower did not consistently result in a higher number of arthropod species. Meanwhile, the fallow plot without enhancement plants showed the similar level of species richness with the other experiment plots in 2016. Chao2 and ICE estimators also showed similar values, with no significant difference among treatments (Table 4.5).

Forty-eight arthropod morphospecies (30%) and 39 families (42%) were commonly shared among all experiment plots. Several arthropod families were uniquely found in each treatment, mostly just once and in a small number. Meanwhile, certain arthropod groups, such as spiders (Araneidae, Oxyophidae, Salticidae, and Thomisidae), beetles (Anthicidae, Chrysomelidae, Coccinellidae), leafhoppers (Cicadellidae), plant bugs (Miridae), bees (Apidae, Halictidae) and grasshoppers (Acrididae) were commonly observed in all treatments and seasons (Appendix 4).

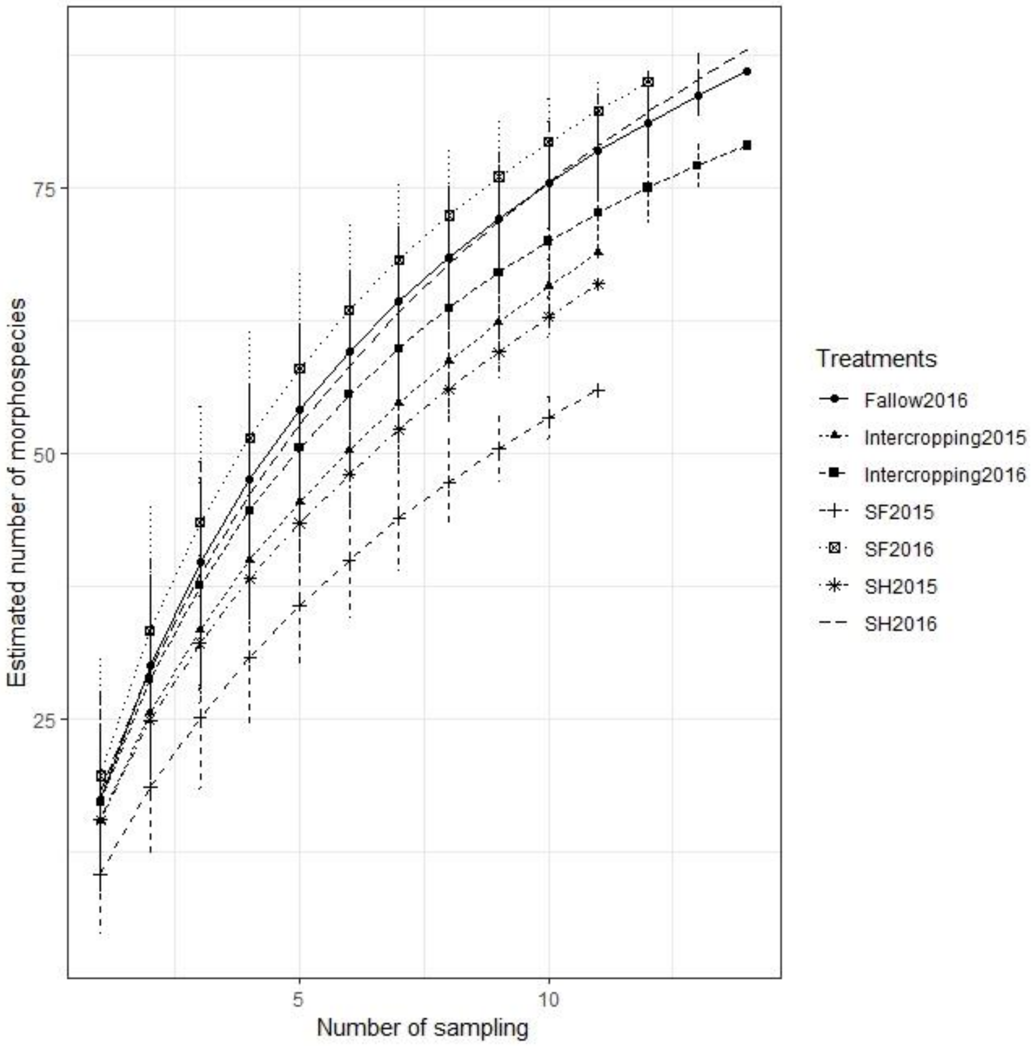


Figure 4.10 Species accumulation curves of arthropods in landscape-scale experiment plots in 2015-2016

Note: plots were enhanced with sunflower, sunn hemp and intercropping of both species during 2015–2016 and fallow plots only in 2016. Error bars are standard deviations

Table 4.5 Number of arthropod morphospecies and family sampled in landscape-scale experiment plots in 2015-2016

	2015			2016		
	Observed	Chao2	ICE	Observed	Chao2	ICE
Number of arthropod morphospecies						
Sunflower	56	85.4	91.9	85	111.1	115.3
Sunn hemp	66	113.8	124.5	88	129.5	135.4
Intercropping	69	111.8	123.1	79	93.3	100.9
Fallow	-	-	-	86	111.0	115.2
Number of arthropod families						
Sunflower	45	72.5	72.1	55	64.0	67.5
Sunn hemp	48	76.6	75.7	53	78.1	70.6
Intercropping	52	68.7	78.1	53	60.8	62.7
Fallow	-	-	-	57	73.7	73.8

Note: plots were enhanced with sunflower, sunn hemp, intercropping of both species during dry and wet seasons of 2015-2016, and fallow plot during dry and wet seasons of 2016

Average species richness was not significantly different among the treatments, while the arthropod abundance differed significantly among the treatments for several guilds (Table 4.6). Arthropod abundance was highest in the sunn hemp treatment, followed by the intercropping. The abundance of arthropods was similar between the sunflower and fallow plots (Table 4.6, Figure 4.11). Seasonally, arthropod average richness and abundance was higher in the wet season than the dry season for most arthropod feeding guilds (Table 4.6).

Table 4.6 Arthropod species richness and abundance in landscape-scale experiment plots in 2015-2016

	Sunflower	Sunn hemp	Intercropping	Fallow	P	
					Treatments	Seasons
Morphospecies richness						
Total	15.2 ± 2.1	17.1 ± 1.5	16.5 ± 1.5	17.3 ± 1.8	ns	< 0.001
Herbivores	8.0 ± 1.1	9.8 ± 0.8	8.8 ± 0.7	8.8 ± 1.3	ns	< 0.001
- Piercing-sucking herbivores	5.5 ± 0.8	5.6 ± 0.6	5.4 ± 0.7	5.2 ± 0.9	ns	< 0.001
- Chewing herbivores	1.5 ± 0.3	2.5 ± 0.3	2.2 ± 0.3	2.3 ± 0.4	ns	< 0.001
- Nectar/pollen-feeding herbivores	1.0 ± 0.2	1.7 ± 0.3	1.2 ± 0.2	1.3 ± 0.4	ns	ns
Predators	4.2 ± 0.6	4.8 ± 0.5	4.8 ± 0.4	5.9 ± 0.6	ns	< 0.001
Parasitoids	1.7 ± 0.4	1.4 ± 0.3	1.6 ± 0.4	1.9 ± 0.3	ns	< 0.001
Detritivores	1.3 ± 0.3	1.1 ± 0.2	1.3 ± 0.2	0.7 ± 0.2	ns	< 0.001
Abundance						
Total	15.3 ± 3.3a	36.8 ± 8.2b	30.3 ±7.6ab	14.4 ± 2.2a	0.008	< 0.001
Herbivores	7.6 ± 1.9a	31.6 ± 8.2b	22.2 ± 7.1ab	6.5 ± 1.1a	< 0.001	< 0.001
- Piercing-sucking herbivores	6.1 ± 1.6a	25.1 ± 7.9b	19.4 ± 7.1ab	5.0 ± 0.7a	< 0.001	< 0.001
- Chewing herbivores	1.1 ± 0.4a	5.5 ± 0.9b	2.2 ± 0.5ab	1.0 ± 0.2a	< 0.001	0.041
- Nectar/pollen-feeding herbivores	0.3 ± 0.1a	0.9 ± 0.2b	0.6 ± 0.1a	0.5 ± 0.1a	0.031	ns
Predators	3.5 ± 0.8	3.1 ± 0.4	3.3 ± 0.3	4.7 ± 0.5	ns	< 0.001
Parasitoids	2.6 ± 0.6	1.1 ± 0.2	3.4 ± 0.7	2.8 ± 1.0	ns	< 0.001
Detritivores	1.5 ± 0.4	1.0 ± 0.2	1.4 ± 0.4	0.4 ± 0.1	ns	< 0.001

Note: plots were enhanced with sunflower, sunn hemp, intercropping of sunflower and sunn hemp plots during 2015-2016, and fallow plot during 2016. Values are presented as mean ± SE. Arthropod morphospecies were classified based on feeding groups. Herbivores values are composed from piercing-sucking, chewing and nectar/pollen-feeding herbivores values. Different letters are indicate significant different between abundance among treatments based on Kruskal-Wallis test (p<0.05).

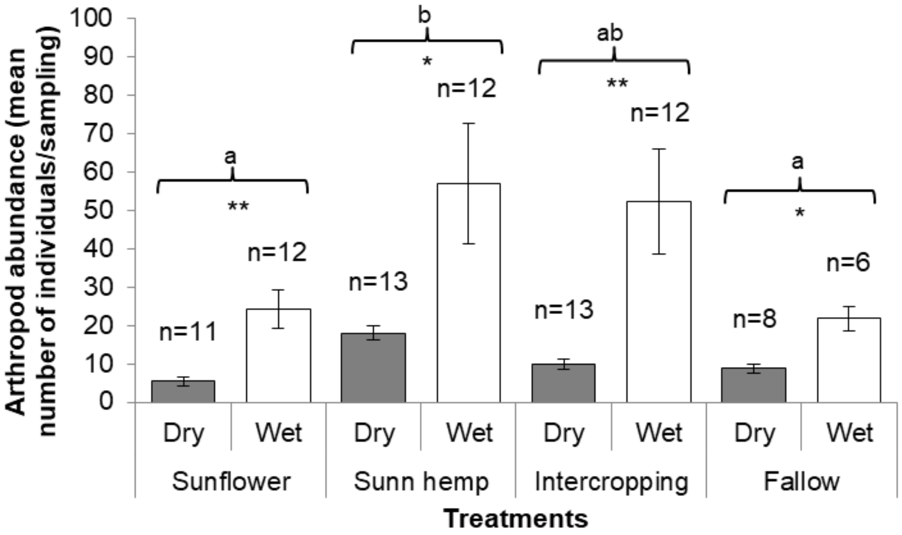


Figure 4.11 Mean arthropod abundance in the landscape-scale experiment plots in 2015-2016

Note: plots were enhanced with sunflower, sunn hemp, and intercropping of both species during the dry and wet seasons of 2015 and 2016 and the fallow plot during the dry and wet seasons of 2016. Error bars are standard errors of the mean. Different letters above brackets showed significantly differed at P≤0.05 among treatments. Different asterisks (*/**) above error bars showed significantly difference at P≤0.05 and P≤0.001 between seasons of each treatment.

Herbivores were the most common arthropod guild found in all treatments followed by predators, parasitoids and detritivores (Table 4.6). The guild proportion of arthropod morphospecies was similar in all treatments (χ^2 = 7.031, p = 0.957) (Figure 4.12A). However, arthropod abundance by guild was significantly different among treatments (χ^2 = 63.418, p < 0.001). Similar proportion of arthropod abundance was observed between the sunflower and fallow plots (χ^2 = 7.481, p = 0.187), and between the sunn hemp and intercropping plots (χ^2 = 7.266, p = 0.122) (Figure 4.12B).

Piercing-sucking herbivores, chewing herbivores and nectar/pollen-feeding herbivores were found in a higher abundance in the sunn hemp treatment, followed by the intercropping, sunflower and fallow treatments, respectively. Piercing-sucking herbivores were the dominant guild among treatments, and their abundance was highest in the sunn hemp and intercropping treatments. Meanwhile, the abundance of predators, parasitoids and detritivores was not significantly different among treatments (Table 4.6). Relatively, a high proportion of predators was observed from the sunflower and fallow treatments.

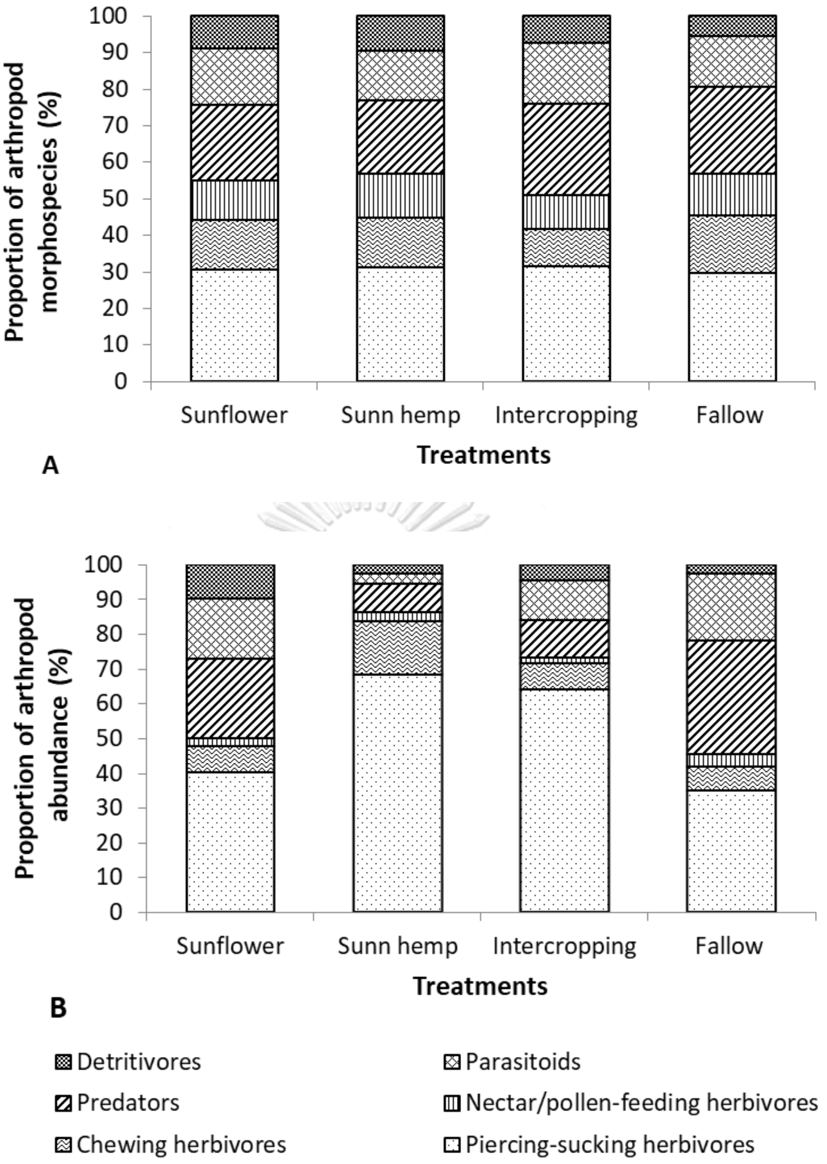


Figure 4.12 A. Proportion of arthropod morphospecies B. Proportion of arthropod abundance based on guilds in the treatment plots of sunflower, sunn hemp, intercropping during 2015-2016 and fallow only in 2016

Although a high similarity of arthropod species and ecological guilds was observed in the experiment, a relatively unique arthropod composition was observed in each treatment, as a result of different levels of dominance, or relative abundance, at the family, species and guild levels. Half of the arthropods observed in the sunflower treatment were dominated by parasitoids and piercing-sucking herbivores, while piercing-sucking herbivores and chewing herbivores were the most abundant guilds in the sunn hemp treatment. The composition of arthropods in the intercropping and fallow treatments was dominated by piercing-sucking herbivores and parasitoids. Even though the piercing-sucking herbivores was observed in all treatments, the dominant families were different between the sunflower and sunn hemp treatments while similar dominant families were observed between the sunflower and fallow treatments.

Different arthropod morphospecies composition was observed in each of the ecological guilds. Among the piercing-sucking herbivores, Mirid bugs were the most common piercing-sucking herbivores and their abundance was significantly higher in the treatments with sunn hemp than the other treatments without sunn hemp ($U = 0.001$, $n_1 = 8$, $n_2 = 6$, $p = 0.002$). Leafhoppers (Cicadellidae) and planthopper (Delphacidae) were abundant in the sunflower treatment, while thrips (Thripidae) and Cicadellidae were the dominant families in the fallow. Common chewing herbivores, leaf beetles (Chrysomelidae) and grasshoppers (Acrididae) were the most abundant chewing herbivores in the sunflower treatment, while Chrysomelidae (*Longitarsus* sp.) dominated the sunn hemp and intercropping treatment (Figure 4.13 A, B).

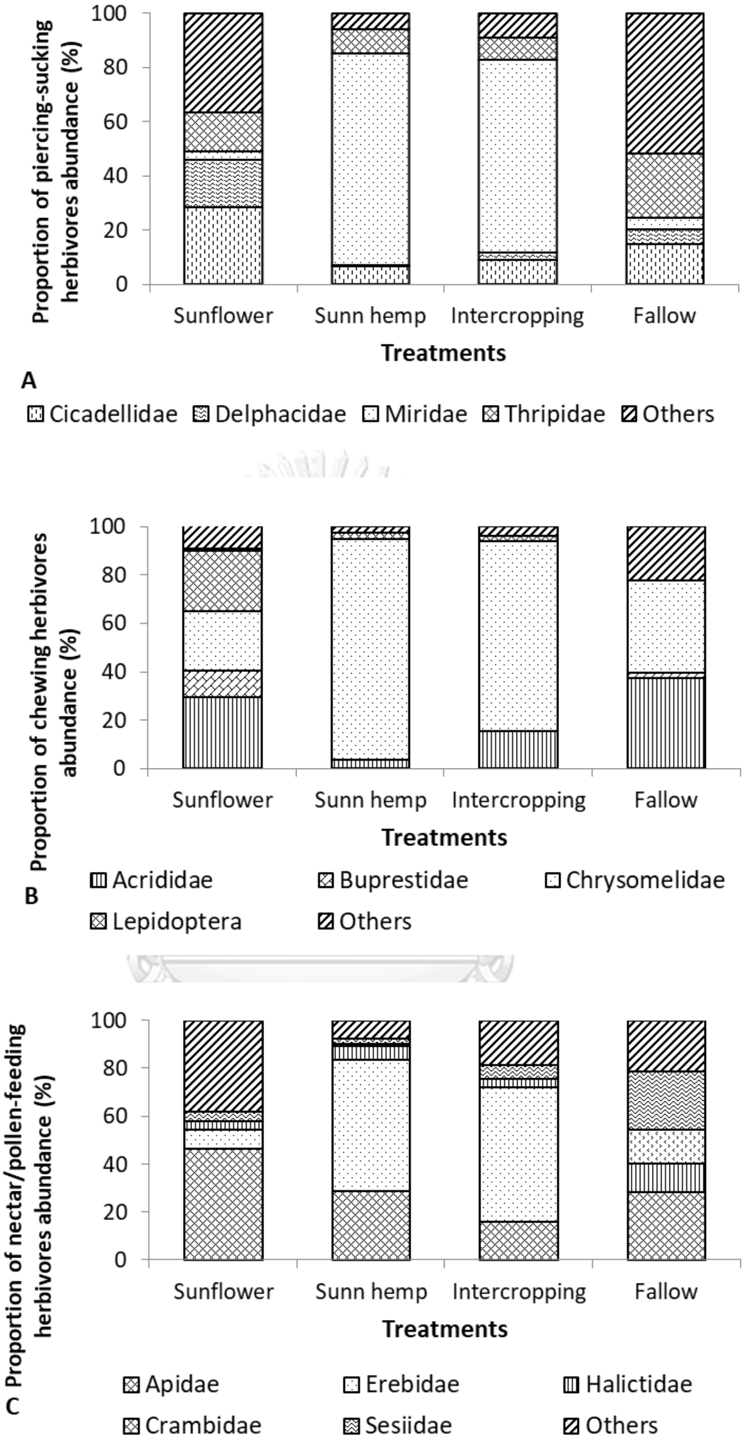


Figure 4.13 Composition of arthropod families in herbivorous guilds: A. piercing-sucking herbivores, B. chewing herbivores, C. nectar/pollen-feeding herbivores

Note: Families abundance lower than 10% was grouped as others

Nectar/pollen-feeding herbivores were collected in a very low number in all treatments throughout the seasons and represented by green metallic bees, *Ceratina (Pithitis) smaragdula* (Apidae) and salt-and- pepper moth, *Utetheisa lotrix* (Erebidae). Apidae, was dominant in the sunflower treatment, but commonly found in all treatments with different proportions. Erebidae was the dominant nectar/pollen-feeding in the sunn hemp and intercropping treatments, while Apidae, Sesiidae, Crambidae and Halictidae showed comparable proportion in the fallow (Figure 4.13C).

Even the predator species and abundance were comparable between treatments, the proportion of predatory family differed among treatments. Predators in the sunflower treatment were distributed evenly among Formicidae, Coccinellidae, and Oxyopidae, while Anthicidae and Oxypidae dominated the guild in the sunn hemp and intercropping treatments. Formicidae and Coccinellidae were the dominant predator taxa in the fallow treatment. Unique morphospecies composition of the spiders was observed for each treatment. Relatively more Oxyopidae spiders were observed in the sunn hemp and intercropping treatments. On the other hand, Araneidae was most abundant in the sunflower treatment, in which the least number of Thomisidae spiders were present (Figure 4.14A).

Parasitoids from the Eurytomidae were the most common taxa, comprising more than 40% of all parasitoids in all treatments. Relatively higher proportions of Braconidae and Torymidae parasitoids were observed in the sunn hemp treatment (Figure 4.14B). Among the detritivores, Diptera was the dominant taxa in all treatments while Latrididae was present in all treatments except the fallow (Figure 4.14C). Several common arthropod taxa found in the landscape-scale experimental plots as seen in Figure 4.15.

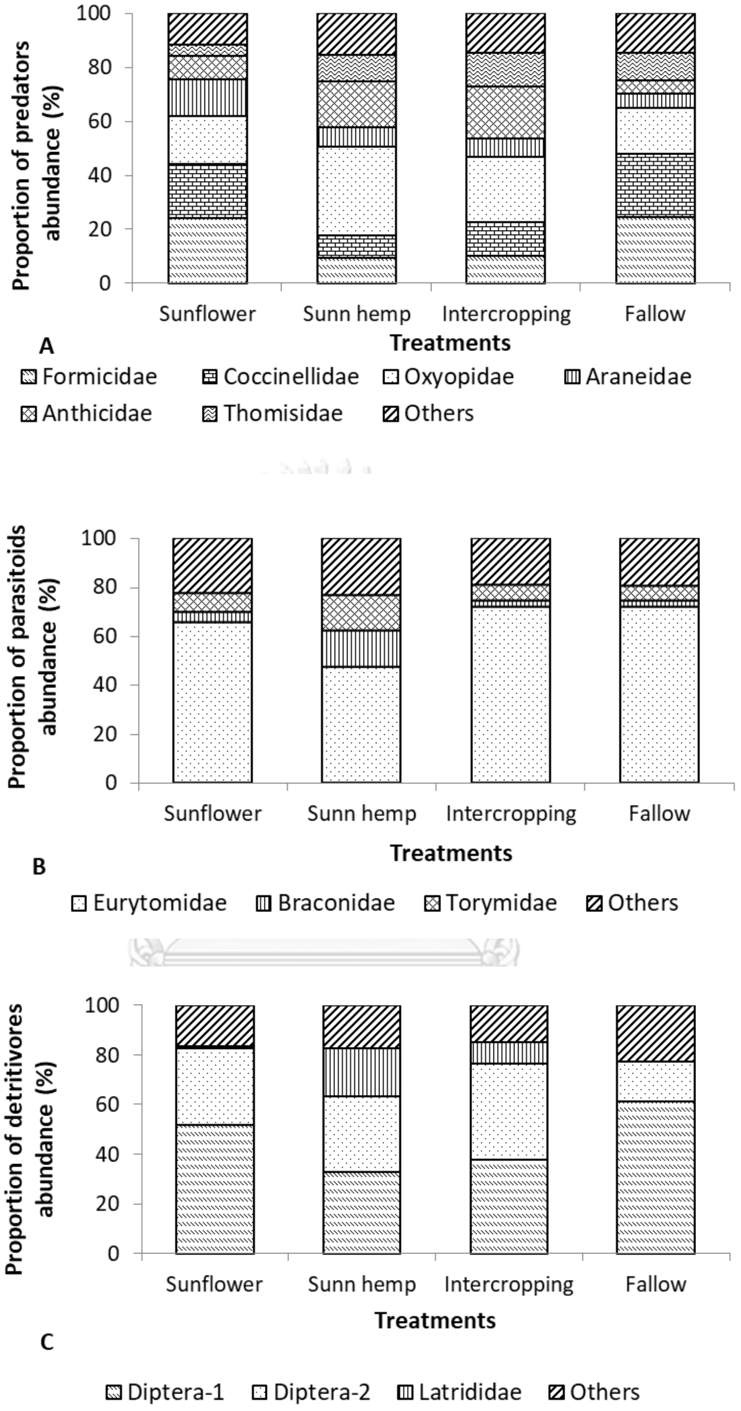


Figure 4.14 Composition of arthropod families in A. predators, B. parasitoids. C. detritivores

Note: families abundance lower than 10% were grouped as ‘Others’

Oxyopidae

Miridae

Apidae

Ceratina (Pithitis) smaragdula

Formicidae

Iridomyrmex anceps

Chrysomelidae

Eurytomidae

Figure 4.15 Common taxa of arthropods in the landscape-scale plots enhanced with sunflower, sunn hemp and intercropping of both species during 2015 – 2016 and fallow plots only in 2016

4.4 Relationship among vegetation, arthropods and birds in the landscape-scale experiment plots

The total dry plant biomass in all treatments was higher in the wet seasons than the dry seasons ($U = 0.001$, $n_1 = 7$, $n_2 = 7$, $p = 0.002$) but did not differ among treatments ($\chi^2_2 = 0.05$, $n_1 = 4$, $n_2 = 4$, $n_3 = 4$, $n_4 = 2$, $p = 0.919$) (Figure 4.16). The biomass of sun hemp and sunflower in the plots with single enhanced plant species and intercropping plots did not differ significantly ($p > 0.05$). The proportion of other vegetation biomass was higher in the wet than dry seasons ($U = 1.00$, $n_1 = 7$, $n_2 = 7$, $p = 0.003$). The proportion of other vegetation was relatively less in the sunn hemp plot than the sunflower and intercropping plots ($\chi^2 = 31.66$, $p < 0.001$).

The overall arthropod abundance increased as overall plant biomass increased ($r = 0.811$, $p < 0.001$). The abundance of herbivorous arthropods was correlated with the sunn hemp biomass ($r = 0.606$, $p = 0.022$). The biomass of other vegetation was correlated with predatory arthropods and detritivores. Insectivorous birds were correlated with the abundance of herbivorous arthropods (Figure 4.17).

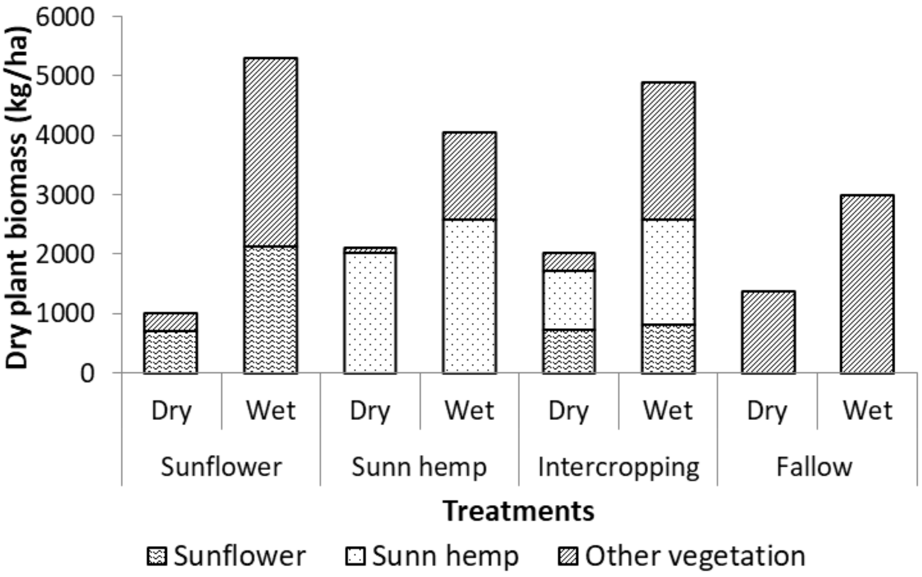


Figure 4.16 Dry plant biomass in the landscape scale plots enhanced with sunflower and sunn hemp during the dry and wet seasons of 2015-2016

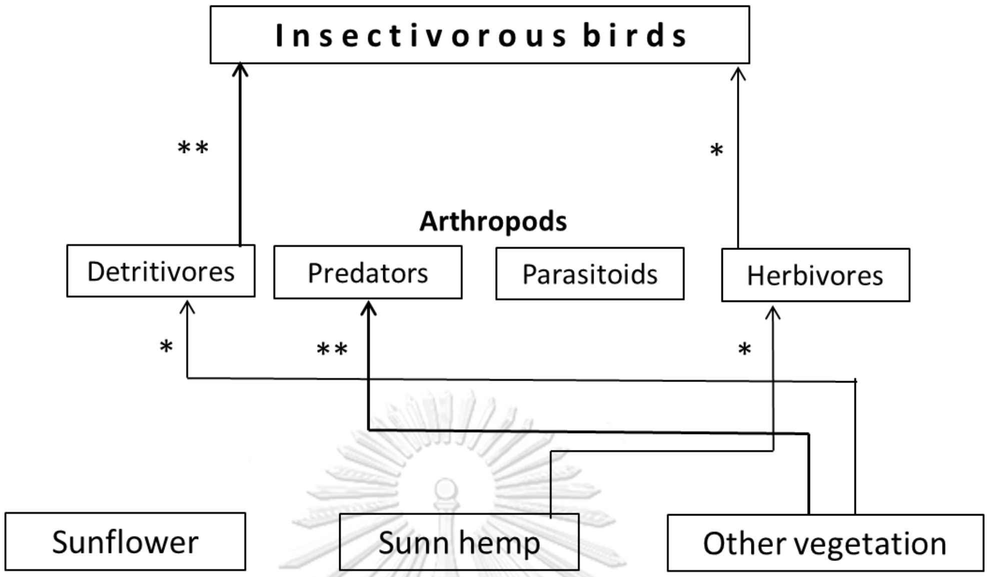


Figure 4.17 Relationship among vegetation, arthropod guilds and insectivorous birds Note: arrows showed significant positive correlation. Different asterisks (*/**) showed correlation was significantly difference at p≤0.05 and p≤0.01.

4.5 Discussion

Only some bird species from the local species pool were observed in the experiment plots. When resources were abundant elsewhere, such as rice paddies in the vicinity and nearby forest, birds were less likely to come to the experiment plots. Some bird species, such as *A. oscitans* and *Halcyon smyrnensis*, were rare visitors to the experiment plots because they used the plots as a stopover or utilized temporary resources, such as water puddles, frogs, crabs, and snails, which were occasionally available in several parts of the experiment plots during the wet seasons. All granivorous species from the surrounding area were observed in the experiment plots. The experiment plots attracted a high occurrence of granivorous birds because of more resources, such as food, perching sites and bare ground, were offered by planting sunflower and sunn hemp.

However, carnivores, several insectivores and omnivores were not observed using the experiment plots. Carnivores were not observed using the plot probably because of the lack of suitable prey. Some insectivores and omnivores, particularly large size birds, were rarely observed in the experiment plot due to lack of feeding and perching sites. For example, *Coracias benghalensis* was a common insectivore which was often seen perched on 3-10m-tall trees or overhead electricity wires and flying down catch insect prey on the open ground. Most bulbuls (Family Pycnonotidae), common omnivores in the surrounding area, perched and foraged mostly from trees taller than 3m, while the height of sunflower and sunn hemp plants were shorter than 2m.

Bird species in surrounding area were comparable to previous observations in the same area by Vasinopas in 2008 (103 species) and by Ekeurmanee in 2012-2013 (80 species). Changes of the land use in the area from mostly natural condition (forests) to human-made environment (buildings, roads), affected bird species richness and composition. Several species were no longer observed during the period of this study. In addition, some birds showed ambiguous characters which were not easily recognized, and this could also affect the identification. For example, pond heron

(*Ardeola* sp.), was observed in a juvenile form that was difficult to distinguished from *A. bachus* and *A. speciosa* in the previous studies. Other than that, the observations in the previous studies in this area were conducted on natural trails going through several different habitats, such as through the forests, grassland, alongside a reservoir and residential area, while the observations in this current study were done mostly along the road sides.

The fact that all bird species in the experiment plots belonged to the local species pool and the high similarity between the bird species that used all of the experiment plots reflected the relatively unrestricted movement of birds in the area, but the different patterns of bird composition in each treatment and the surrounding area underlined the variability of resource abundance at each location. Most birds in the experiment plots and the surrounding area were insectivorous birds but the higher proportion was observed in the experiment plots because sunflower and sunn hemp could potentially provide more arthropods as food resources. Insectivorous birds offer an important ecological function of pest control as they feed on various arthropod pests (Giffard et al., 2013; Jones & Sieving, 2006; Komar, 2006; Sekercioglu, 2006). In this study, sunn hemp could support a bird guild assemblage similar to that of sunflower in which a wide guild assemblages, including insectivores, granivores and omnivores have been reported (Hagy, Linz, & Bleier, 2007, 2010; Linz, Homan, Werner, Hagy, & Bleier, 2011).

Functional redundancy was observed in our experiment plots even though the degree was not as high as in the forest birds (Coelho et al., 2016). If some species play similar roles in the community and ecosystem, species could be substituted. For example, insectivores within the same genus, *P. hodgsoni* was observed when *P rufescens* did not appear, while another example observed as *V. indicus* and *M. erythrocephala* were observed in one branch, showed possibility in replacing each other roles.

Despite their similar species composition, bird guilds showed different usage patterns on microhabitats in the experiment plots. Insectivorous birds used the experiment plots mainly as foraging sites, as they were seen searching and feeding in the plots. Some of the insectivores were observed with arthropods in their bills. Some of birds were purely insectivores, such as *Corydalla* sp., *Prinia* spp., and *S. stejnegeri* (Cummins & O'Halloran, 2002; Garrick, 1981), which were frequently observed in the experiment plots. Bare ground is an important component of habitat for ground-foraging insectivorous birds (Schaub et al., 2010), and *Corydalla* sp., a ground-insectivore species, was observed using the ground between rows of plants. Granivores are commonly observed in small fragments and forest edge (Donoso, Grez, & Simonetti, 2004) and their abundance is affected by grain availability, seed size and preference (Turček, 2010). Small granivores mostly foraged on grass seeds, but larger granivores picked larger-size seeds from the ground and on sunflower heads. Seed size diversity could increase granivores diversity (Thompson & Lawton, 1983), and abundance of some granivores was associated with a high number of weed seeds and a larger proportion of bare soil (Moorcroft, Whittingham, Bradbury, & Wilson, 2002). Some granivorous birds, such as *L. punctulata,* foraged in a large flock, resulting in a high variation in occurrence in the experiment plots.

Vegetation external appearance, growth forms and structural heterogeneity may create different microhabitats and niches for a wide variety of bird species (Mulwa, Böhning-Gaese, & Schleuning, 2012; Tews et al., 2004). Structural complexity, rather than plant species diversity, was highly influential to bird composition (Müller, Stadler, & Brandl, 2010) and bird species richness (Munro et al., 2011). Even though the intercropping plot did not attract more bird species than the plots enhanced with a single plant species, different structures of sunflower and sunn hemp allowed birds to use microhabitats for different activities. The mixture of sunflower and sunn hemp may have some additive effects on the usage patterns by granivorous birds, showing different activities on complementary microhabitats from both plant species. On the other hand, such additive effects were not observed with insectivorous birds as their activities in the intercropping plots resembled that of the sunn hemp plots. Individual bird species in the same functional group may exhibit diverse responses due to habitat heterogeneity (de Bonilla, León-Cortés, & Rangel-Salazar, 2012). Some guilds contain several species that could potentially replace one another functionally (Coelho et al., 2016). The different usages were consequences of species specific requirements for resources, reflecting functional differences among species in the community (Petchey & Gaston, 2002).

In addition to the food resources, non-crop plants such as sunflower and sunn hemp provide microhabitats which serve as refugia, perching and nesting sites. Overall, vegetation structure provided (1) perching sites with high visibility on prey encounter, (2) cover for aerial predator avoidance and (3) corridors for cryptic species (Jones & Sieving, 2006). *M. erythrocephala* were observed hiding in the sunflower plots when attacked by *Elanus axillaris*. As predator refugia, vegetative structure of sunflower was suitable as escape cover to avoid aerial predators (Jones & Sieving, 2006). As nesting sites, *C. macrurus* was observed laying eggs on the ground under sunflower plants in the sunflower plot during the dry season of 2016. *P. hodgsoni* was laying 4 eggs in a nest of grass placed between sunflower leaves sewn together in the intercropping plot during the wet season of 2016. Also, in the wet season of 2016, male individuals of *C. exilis* were observed bringing food into the sunflower plot, sometimes from the sunn hemp plot, suggesting that the nests were in the sunflower plot. Breeding times were from July until October for *P. hodgsoni* and during wet season (April to September) for *C. exilis* (del Hoyo, 2015). Several studies also reported nesting birds in non-crop plants (Giacomo & Casenave, 2010; Jones & Sieving, 2006).

Ecosystem services are crucial part of biodiversity conservation (Dıaz et al., 2005; Kremen & Miles, 2012; Power, 1992). Enhancing habitats with non-crop plants would increase ecosystem services provided by birds, which mostly are the results of foraging behavior (Jones & Sieving, 2006; Stallman & Best, 1996). Controlling arthropod communities, plant pollination and seed dispersal were common ecological services provided by birds (Wenny et al., 2011; Whelan, Wenny, & Marquis, 2008). Higher crop yield was achieved in the presence of insectivorous birds (Gras et al., 2016; Mols & Visser, 2002), making them favorable in most agroecosystems. Meanwhile, granivorous birds were perceived as agriculture pests in several studies, but their function as weed controllers was reported in few studies (Wenny et al., 2011). Large ground-foraging granivorous birds in family Columbidae may feed on grains during the sowing and seeding periods of grain crops while small granivorous birds, such as *Lonchura* spp., commonly feed on grass seeds and potentially offering weed controlling. Enhancement should provide resources for birds to maximize benefits from conservation of bird diversity and management of agriculture landscape.

An arthropod community is influenced by vegetation in their habitats (Andow, 1991; Jones & Gillett, 2005; Kaiser et al., 2017). Several factors, such as biotic (competition, predation) and abiotic (plant resources availability, environmental heterogeneity), may influence arthropod communities during growing seasons. Seasonal variation of physical factors may affect plant growth and the interactions between host plants and herbivorous insects (Tauber, Tauber, & Masaki, 1986).

Using the plant biomass as a proxy for plant yield, sunflower and sunn hemp was able to suppress the growth of other plant species within the treatments and their weed suppression was more effective in the dry seasons. Planting both sunflower and sunn hemp, however, did not seem to offer additional weed suppression in the intercropping treatment. The presence of other plant species within the treatments gave rise to the floristic diversity of the vegetation, although the composition of the plant species could differ with the presence of different enhancement species (Elba et al., 2014). Differences in the plant communities could have an impact on the relative abundance and composition of the arthropod communities. Vegetation offers direct resources, providing food or prey, shelter and other supports that may benefit arthropods in different ways. As habitats become more diverse with wild or cultivated plants and weeds, provide more alternative resources, shelter and suitable microhabitats, higher arthropod abundance could be supported.

Intercropping was expected support more arthropods due to higher plant diversity than the single species enhancement plots. However, our results were not as expected. Intercropping with one or two species would increase the species richness and abundance with suitable intercropping plants. Meanwhile, more diverse habitat (7 species) showed higher arthropod in species richness but may lower the arthropod abundance (Bennett & Gratton, 2013; Cai et al., 2010). Co-occurrence of plant species may alter biological and physical conditions, resulted in species fitness that the dominant plant species can attract more arthropod (Bennett & Gratton, 2013). Arthropod species richness was similar among the treatments likely because the species found within the experiment plots came from the regional species pool within the surrounding landscape, as the flow of organisms across systems are commonly occurred (Tscharntke, Rand, & Bianchi, 2005).

Enhancement plants influence arthropod presence on plants. Certain plant traits, such as relatively smooth surface of sunn hemp stems and leaves allow more herbivores on sunn hemp than sunflower, which has hairy leaves and trichomes (Kaiser et al., 2017). Extremely high abundance of herbivorous arthropods, specifically Miridae (Hemiptera), was observed in the sunn hemp treatments. Miridae, commonly found on herbs, shrubs and trees in high abundance (Wheeler, 2001), was not serious pests in agriculture, but they were reported to become serious pest lately in *bt*-cotton and some other plants in China (Y. Lu & Wu, 2011). On the other hand, mirid bugs were also used as biological control agents on whiteflies, spider mites and/or thrips in tomato (Castañé, Arnó, Gabarra, & Alomar, 2011). Opposite to a previous study (Kaiser et al., 2017), hairy leaves and stems of sunflower did not restrict predator presence.

Floral resources, such as nectar and pollen, are crucial for some arthropods, including bees (Sidhu & Joshi, 2016), coccinellids (Patt, Hamilton, & Lashomb, 1997), parasitoids (Landis et al., 2000) and spiders (Knauer, Bakhtiari, & Schiestl, 2018; Nyffeler, Olson, & Symondson, 2016). The flower shape of sunflower is more accessible than sunn hemp, attracting a higher proportion of nectar/pollen-feeding and parasitoids. In addition, plants also provide nesting sites or refugee sites for the predators of herbivorous insects (Finch & Collier, 2000; Fürstenberg-Hägg, Zagrobelny, & Bak, 2013; Kaiser et al., 2017). Based on the observation, fast growth and sequential flowering of sunn hemp could attract more nectar/pollen-feeding herbivores. Sunflower could also increase the abundance and visitation of pollinators (Jadhav, Sreedevi, & Prasad, 2011), including *Ceratina* spp. (Apidae), reported as one of sunflower pollinators, perhaps due to its small body size (less than 8mm) (Kasina, Nderitu, Nyamasyo, & Oronje, 2007). On the other hand, bigger nectar/pollen-feeding herbivores, such as carpenter bees *Xylocopa* sp. (Apidae), have been reported as more common pollinators in sunn hemp (Krueger, Wang, McSorley, & Gallaher, 2008; Mosjidis & Wang, 2011).

Arthropod guild composition differed among treatments. In the intercropping treatments, additive and synergistic effects were observed in several taxa. Arthropods from Cicadellidae and Oxyopidae showed additive effects and synergistic effects were apparent in Miridae and Thomisidae. However, no additive effects were detected in Araneidae and Coccinellidae. Intercropping sunflower with sunn hemp affected to arthropod differently, as seen in composition of spiders (Araneidae, Oxyopidae, and Thomisidae), showed combination effect of sunflower and sunn hemp.

Fallow vegetation can be a stable habitat allowing the presence of many predators, such as spiders and coccinellid beetles, commonly considered as generalist predators because their presence are related to prey abundance (Basappa, 2011). Abundance of predators and parasitoids corresponded to their ability in switch and feed on the greater variation of herbivores at different times during the growing season which allows for maintaining stability in predator-prey and parasitoid-host interaction.

Presence of more host plants in diverse habitat can theoretically be utilized and support greater variety of insect prey (Andow, 1991; Root, 1973).

In addition to the influence of vegetation structure on the diversity and abundance of arthropods, seasonality also played a role. The overall arthropod abundance was similar across treatments, but the higher abundance was observed in the wet seasons than the dry seasons. Insects in the tropic experience changes in abundance seasonally due to the dry and wet seasons alteration (Silva, Frizzas, & Oliveira, 2011; Wolda, 1988). Seasonal attributes, mainly temperature and precipitation, affect vegetation directly through biomass forming and subsequently support herbivorous insects. Higher prey abundance would increase predatory arthropods as shown in the correlations between the dry plant biomass and arthropod abundance. Other vegetation, which included weedy grass and herbaceous species, was apparently more affected by the seasons than sunflower or sunn hemp showing wider fluctuations of dry biomass throughout the study period.

Suppression of weedy vegetation, especially during the dry seasons, showed that sunflower and sunn hemp could potentially be used as cover crop or intercrop species. Sunn hemp planted at a moderate density (20-50 individual/m^2) could reduce more than 50% of weed biomass (Mosjidis & Wehtje, 2011). Sunflower is allelopathic and could potentially inhibit other plant growth and development (Rawat, Maikhuri, Bahuguna, Jha, & Phondani, 2017).

All treatments could support various guilds of arthropods. The presence of piercing-sucking and chewing herbivores may not be beneficial for crop plants as they can potentially become insect pests; this should be taken into consideration when using enhancement plants. While nectar/pollen-feeding herbivores offer direct services to plants, indirect benefits are derived from predators, parasitoids and detritivores. Increasing habitat diversity may limit the proliferation of some group of arthropods, especially piercing-sucking herbivores, through the limited resource availability and the control from different group of higher trophic level. Interguild interaction is continuously fluctuating, depend on supply and control. The abundance of herbivorous arthropods in sunn hemp would increase food sources for higher-level predators, both predatory arthropods and insectivorous birds. Herbivores were in a vulnerable position because of regulated by bottom-up and top-down control (Memmott, Martinez, & Cohen, 2000; Power, 1992).

4.6 Conclusion

Bird species richness and occurrence were comparable in both sunflower and sunn hemp plots. Sunflower and sunn hemp uniquely provided habitats and resources for some birds in particular functional groups, so both non-crop plants could potentially be used efficiently as single-species enhancement or intercropping to support bird conservation.

Planting sunflower and sunn hemp could accommodate herbivorous arthropods and subsequently their predators. Arthropods responded differently to species enhancements depending on their taxa. Within-guild species composition and relative abundance of major guilds varies across the treatments. As sunn hemp supported more herbivores, sunflower supported more predators and parasitoids. Meanwhile, intercropping had combination proportion of both enhancement plants. Additional benefit was in suppression of weeds, although more detailed experiments are needed. Sequential planting might be applied to increase and prolong the presence of herbivorous arthropods, because they can move around based on plant stage preference. With the slight difference in their impacts on arthropod and bird communities, sunflower and sunn hemp can be used in various ways. Sunflower can be applied in pest management as conservation of biological control by predatory arthropods, while sunn hemp can be applied in conservation of insectivorous birds.

CHAPTER V

BIRDS AND ARTHROPODS IN THE ENHANCED TEAK REFORESTATION

5.1 Bird diversity and composition in the enhanced teak reforestation

A total of 686 individuals from 24 bird species, classified into 18 families were recorded on the treatment plots in the teak reforestation area during the dry and wet seasons of 2015-2016. Twenty (83%) of the bird species in the treatment plots were resident species, such as *Prinia inornata*, *Corydalla* sp. and *Mirafra erythrocephala*, and commonly found during observation. Meanwhile, *Lanius colluroides*, *L. cristatus*, *Bubulcus coromandus* and *Saxicola stejnegeri* were winter visitors.

Nineteen, 15 and 16 bird species were observed in the teak plots intercropped with sunflower, sunn hemp and control (no intercrop plants), respectively. Numbers of bird species per year were comparable among treatments, with the average of 7-9 species per season (Figure 5.1, Table 5.1). Shannon-Wiener diversity indices varied among treatments and seasons, and the highest value was observed in the teak plots intercropped with sunflower. The Pielou’s evenness index values were similar in the teak plots intercropped with sunflower and without intercropping plants (control) (Table 5.2). The bird species composition was similar among treatment plots, with 10 species (42 %) shared among all treatment plots (Figure 5.2). The values of Sorensen’s similarity index were between 0.65-0.77. The bird species similarity was high between years (S_S = 0.79) and seasons (S_S = 0.81).

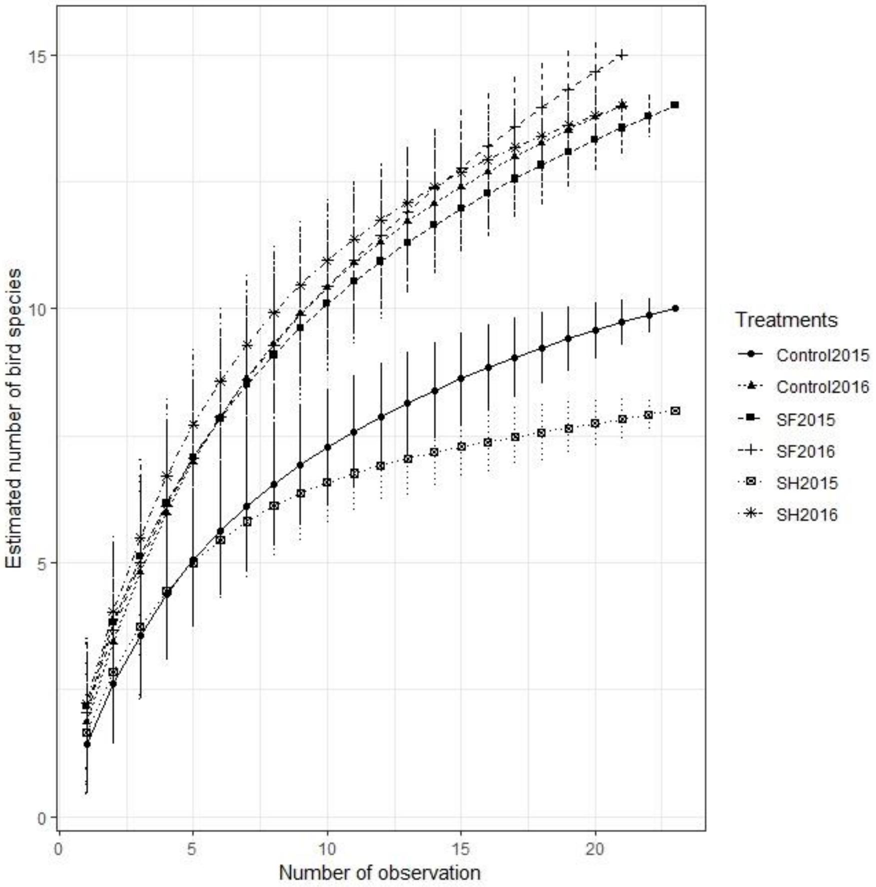


Figure 5.1 Species accumulation curves of birds in teak reforestation enhanced with sunflower, sunn hemp and control plots during 2015 – 2016

Note: error bars are standard deviations.

Table 5.1 Average number of bird species per-season in teak reforestation

Season	Sunflower	Sunn hemp	Control
Dry 2015	8	5	4
Wet 2015	9	7	8
Dry 2016	10	8	9
Wet 2016	9	9	7
Average	9	7.25	7
SE	0.41	0.85	1.08

Table 5.2 Bird diversity indices in the teak reforestation area during dry and wet seasons of 2015 and 2016, in Chulalongkorn University - Center of Learning Network Region Saraburi, Thailand

Index	Dry 2015	Wet 2015	Dry 2016	Wet 2016	Overall
Shannon-Wiener diversity index					
Sunflower	1.10	1.95	1.72	1.78	2.31
Sunn hemp	1.08	1.08	1.78	1.45	2.00
Control	0.78	1.83	1.73	1.59	2.31
Pielou's evenness index					
Sunflower	0.53	0.89	0.75	0.81	0.79
Sunn hemp	0.55	0.55	0.85	0.66	0.74
Control	0.57	0.88	0.79	0.81	0.83

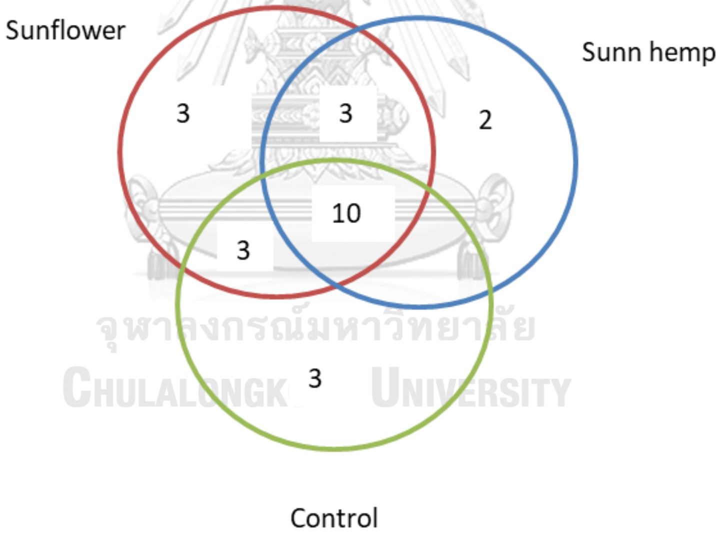


Figure 5.2 Number of bird species observed in sunflower-enhanced plots, sunn hemp-enhanced plots and control plots in teak reforestation during dry and wet seasons of 2015-2016

Average bird occurrence was not significantly different among the treatments ($\chi^2_2 = 2.39$, $n_1 = 44$, $n_2 = 44$, $n_3 = 44$, $p = 0.302$), seasons ($U = 1785.00$, $n_1 = 23$, $n_2 = 21$, p = 0.075) and years ($U = 2159.00$, $n_1 = 24$, $n_2 = 20$, $p = 0.947$). The species with higher occurrence were different among treatment plots. *Corydalla* sp., and *Mirafra erythrocephala* were common species and observed in a high frequency in all plots. *Pycnonotus aurigaster* was also frequently observed in the sunflower plots, and *Vanellus indicus* in the control plots. *Prinia* spp. was observed with the highest frequency in the sunn hemp plots. Several bird species were observed exclusively in each treatment, such as *C. jugularis, S. tranquebarica* and *D. vagabunda* in the sunflower plots; *C. bengalensis* and *C. sinense* in the sunn hemp plots; while *A. tipia, B. coromandus* and *S. stejnegeri* in the control plots (Table 5.3).

Table 5.3 Bird species and occurrence as observed in the teak reforestation area during dry and wet seasons of 2015 and 2016, in Chulalongkorn University - Center of Learning Network Region Saraburi, Thailand

Species	Guild	Sunflower		Sunn hemp		Control	
		Occ	Rel. occ	Occ	Rel. Occ	Occ	Rel. Occ
Prinia inornata	I	0.24	0.14	0.73	0.35	0.15	0.11
Prinia hodgsonii	I	0.08	0.05	0.40	0.19	0.11	0.08
Corydalla sp.	I	0.33	0.19	0.23	0.11	0.27	0.20
Mirafra erythrocephala	O	0.26	0.15	0.23	0.11	0.23	0.17
Pycnonotus aurigaster	O	0.30	0.17	0.17	0.08	0.15	0.11
Geopelia striata	G	0.08	0.05	0.08	0.04	-	-
Spilopelia chinensis	G	0.21	0.12	0.05	0.03	0.01	0.01
Vanellus indicus	O	0.05	0.03	0.04	0.02	0.17	0.12
Lonchura punctulata	G	0.02	0.01	0.03	0.01	-	-
Cisticola exilis	I	0.05	0.03	0.03	0.01	0.05	0.04
*Lanius collurioides**	I	0.01	0.00	0.03	0.01	0.02	0.02
Edolius macrocercus	I	0.03	0.02	0.02	0.01	0.07	0.05
Pycnonotus blanfordi	O	0.01	0.00	0.02	0.01	-	-
Centropus bengalensis	I	-	-	0.01	0.00	-	-
Chrysomma sinense	I	-	-	0.01	0.00	-	-
Streptopelia tranquebarica	G	0.04	0.02	-	-	-	-
Aegithina tipia	I	-	-	-	-	0.01	0.01
*Bubulcus coromandus**	I	-	-	-	-	0.07	0.05
*Lanius cristatus**	I	0.01	0.00	-	-	0.01	0.01
Merops orientalis	I	0.01	0.00	-	-	0.01	0.01
*Saxicola stejnegeri**	I	-	-	-	-	0.02	0.02
Dendrocitta vagabunda	O	0.02	0.01	-	-	-	-
Cinnyris jugularis	O	0.01	0.00	-	-	-	-
Passer flaveolus	O	0.02	0.01	-	-	0.02	0.01

Note: the experiment plots were enhanced with sunflower, sunn hemp and plot without enhancement plants as control. Birds are assigned guilds as granivores (G), insectivores (I), omnivores (O). Occurrence is average occurrence from total observation. (*) indicates status as winter visitor.

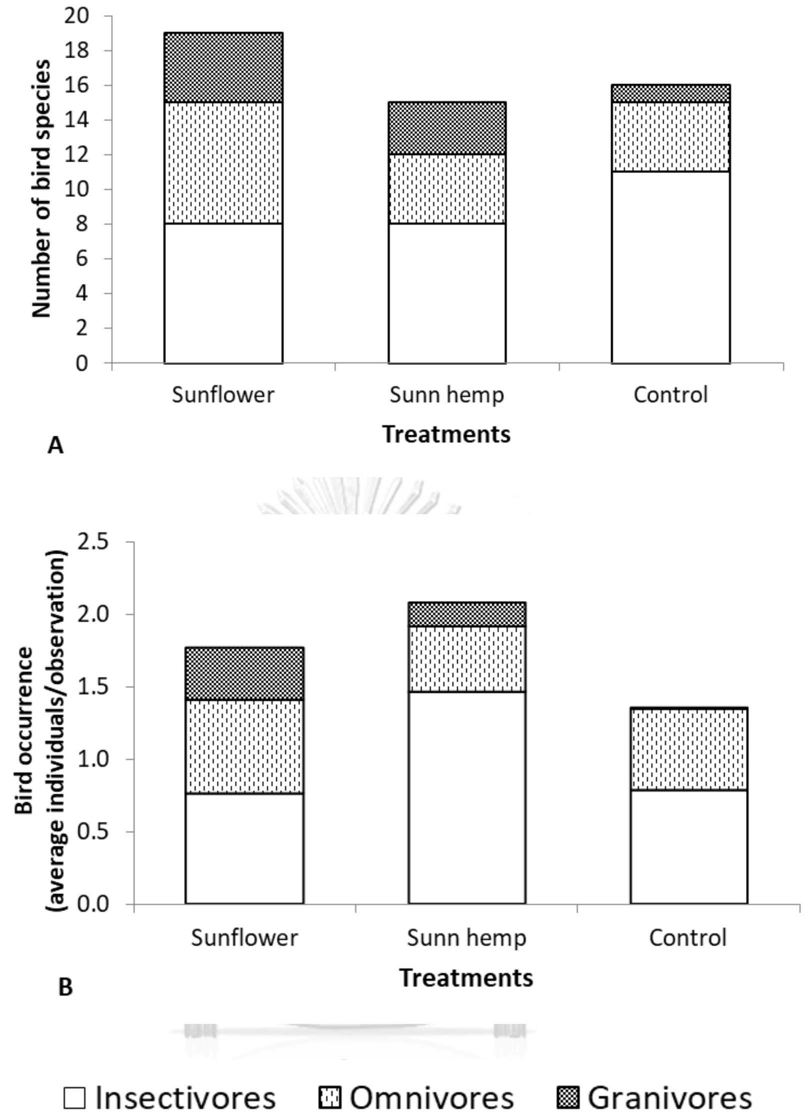


Figure 5.3 A. Number of bird species by ecological guilds, B. Bird occurrence by ecological guilds, in the enhanced teak reforestation during dry and wet seasons of 2015-2016

Insectivorous bird species (> 50%) dominated the species composition. Common insectivores were *Prinia inornata, P. hodgsoni* and *Corydalla* sp. Common omnivores were *M. erythrocephala, P. aurigaster* and *V. indicus*. The most common granivore was *S. chinensis* (Table 5.3). Approximately the same numbers of insectivorous bird species were observed in the teak plots enhanced with sunflower and sunn hemp, but the occurrence was higher in the sunn hemp treatment than the sunflower treatment. Meanwhile, the number of insectivorous species was higher in the control treatment with less occurrence than that of the sunflower and sunn hemp treatments. The higher number of omnivorous and granivorous species were observed in the sunflower treatment than that other treatments (Figure 5.3). Species similarity was high among treatments, but different relative occurrence led to different composition of bird species. The sunflower and control treatments were dominated by *Corydalla* sp., while the sunn hemp treatment was dominated by *P. inornata*. Both species were insectivores. While total bird occurrence was not different among treatments, the occurrence of insectivorous birds was higher in the sunn hemp treatment (Figure 5.4).

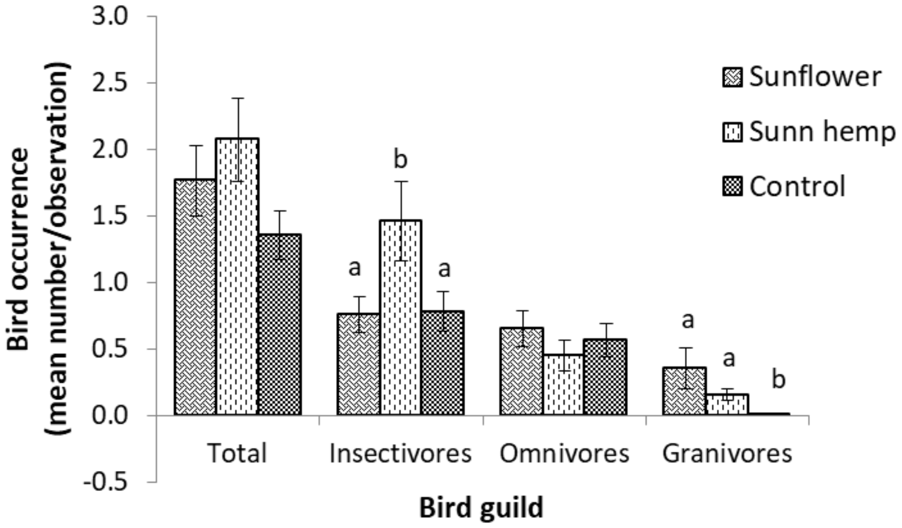


Figure 5.4 Bird occurrence in the teak reforestation during dry and wet seasons of 2015-2016

Note: error bars are standard errors of the mean. Different letters above error bars showed significantly different at p≤0.005 among treatments.

Species composition, described as the ratio of number of insectivores: omnivores: granivores, differed among treatments, with 8:7:4 in the sunflower plot, 8:4:3 in the sunn hemp plot and 11:4:1 in the control plot. The proportion of bird species in teak intercropped with sunflower and sunn hemp plots differed significantly with control plots (χ^2 = 84.81, p < 0.001) (Figure 5.5A). The proportion of bird occurrence in the teak plots intercropped with sunflower and sunn hemp differed significantly with the control plots (χ^2 = 795.68, p < 0.001) (Figure 5.5B).

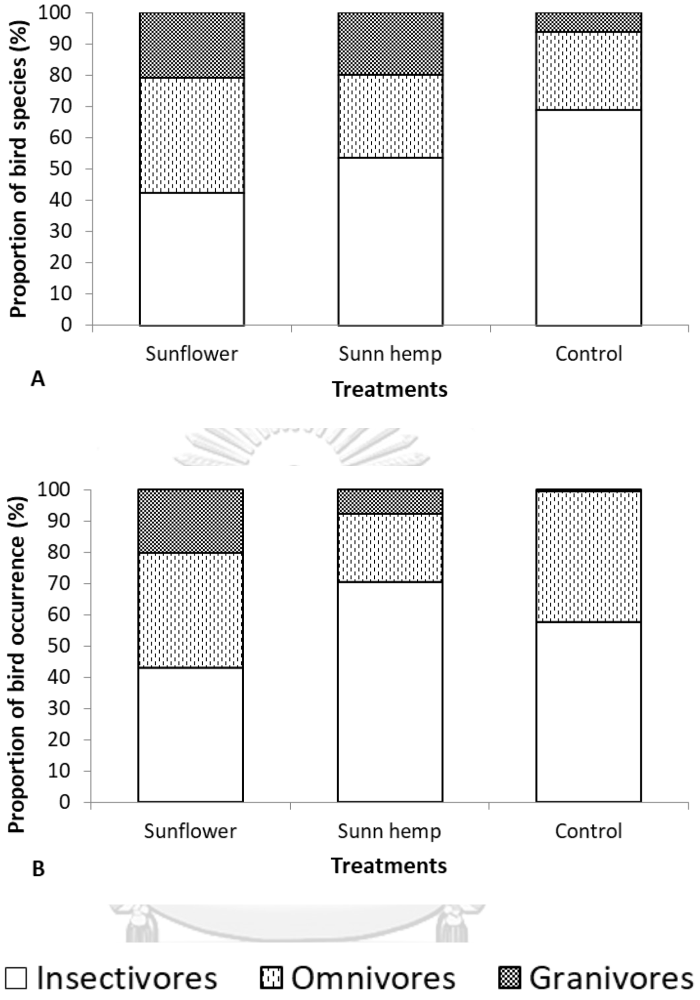


Figure 5.5 A Proportion of bird species, B. Proportion of bird occurrence in the enhanced reforestation during dry and wet seasons of 2015-2016

Low values of functional diversity (0.70 – 1.35) were affected by the low number of bird species observed in the treatments. The bird species in the enhanced teak reforestation showed clear grouping based on the feeding guilds. Functional redundancy was observed in the experiment plots, as several species have similar ecological functions, as shown by the branch arrangement on the dendrogram. Most branches showed two bird species in the same branch, such as *D. vagabunda* and *C. jugularis*, *M. erythrocephala* and *P. flaveolus, G. striata* and *L. punctulata, C. bengalensis* and *C. sinense, C. exilis* and *Corydalla* sp., *P. hodgsoni* and *E. macrocercus*, *A. tipia* and *S. stejnegeri*, and *L. colluroides* and *L. cristatus* (Figure 5.6).

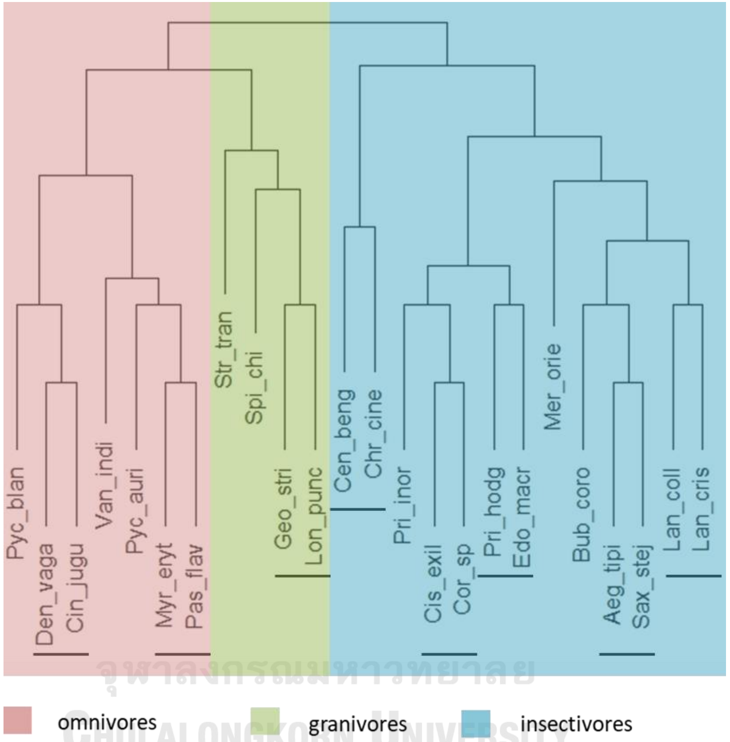


Figure 5.6 Functional relationship among 24 bird species that observed in the teak reforestation enhanced with sunflower, sunn hemp and control plots at Kaeng Khoi district, Saraburi province during dry and wet seasons of 2015-2016

Note: species are abbreviated for first 3 letters from generic name and the first 4 letters from its specific epithet. Bar below species name showed species from the same branch and assumed could replace each other function ecologically.

Prinia inornata *Pycnonotus goiavier*

Corydalla sp. *Mirafra erythrocephala*

Spilopelia chinensis

Figure 5.7 Most abundant bird species observed in the teak reforestation plots at Kaeng Khoi district, Saraburi province during 2015-2016

5.2 Bird activities and habitat usages

Foraging (55%) and perching (40%) were the most frequently observed activities in the teak experiment plots (Figure 5.8). Overall observation showed that each guild was using the treatment plots differently. Insectivores were observed foraging and perching more in the sunn hemp plot than the sunflower and control plots. Omnivores were using all treatment plots equally for foraging and perching. Meanwhile, granivores were observed using the sunflower plot more than the other plots (Figure 5.9).

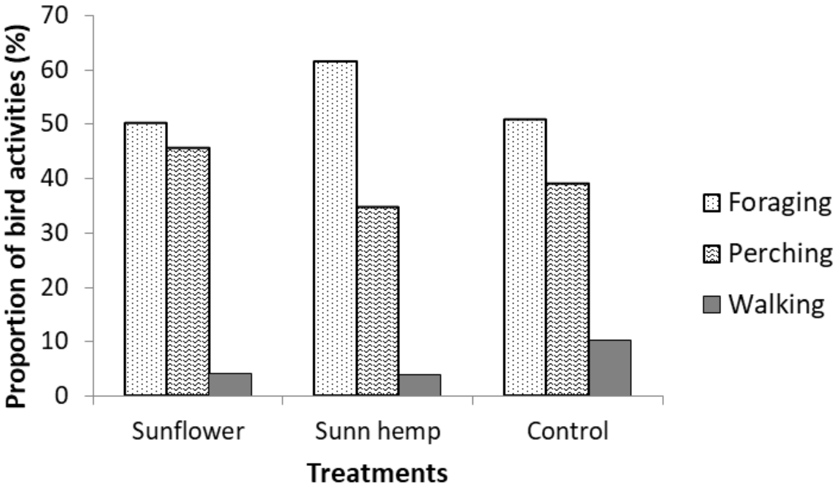


Figure 5.8 Proportion of bird activities in the enhanced teak reforestation plots in 2015-2016

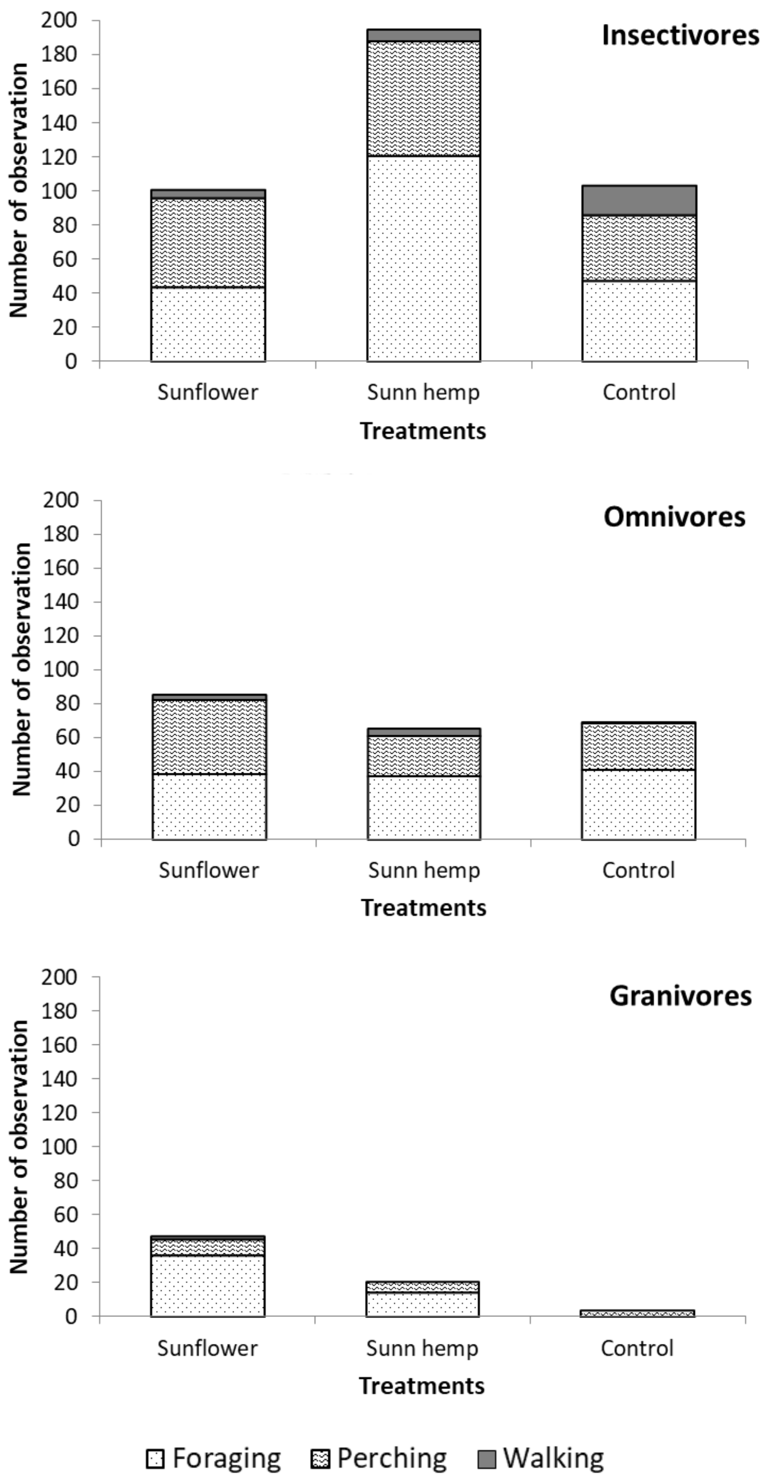


Figure 5.9 Activities of bird guilds in the enhanced teak reforestation plots in 2015-2016

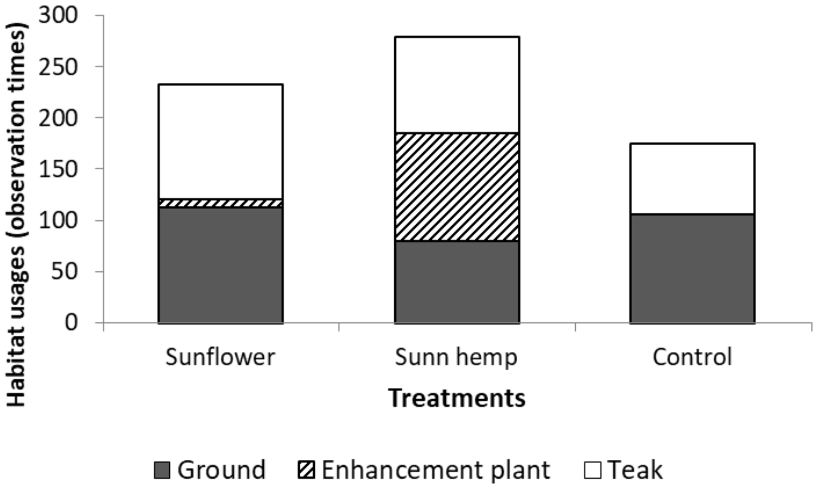


Figure 5.10 Habitat usages by bird in the enhanced teak reforestation plots in 2015-2016

Habitat strata were divided into ground, enhancement plants, and teak trees. The proportion of usages of ground, enhancement plant, and teak trees in all treatments were significantly different (χ^2 = 78.08, $p < 0.001$). Birds mostly used ground and teak trees for various activities, as seen in the sunflower and control plots even though without difference in proportions (χ^2 = 5.87, p = 0.053) (Figure 5.10).

In all treatment plots, foraging was mostly observed on the ground and perching was on the teak trees. Insectivores foraged mostly in the sunn hemp treatment, while some granivores perched in the sunflower treatment. Meanwhile, omnivores were not observed using the enhancement plants (sunflower/sunn hemp) (Figure 5.11, Figure 5.12, Figure 5.13).

Moreover, birds used microhabitats differently. Foraging was observed mostly on ground in the sunflower treatment and control, while bird foraged mostly on sunn hemp stems in the sunn hemp treatment. In addition, perching was mostly observed on the top parts and leaves of the teak trees in all plots.

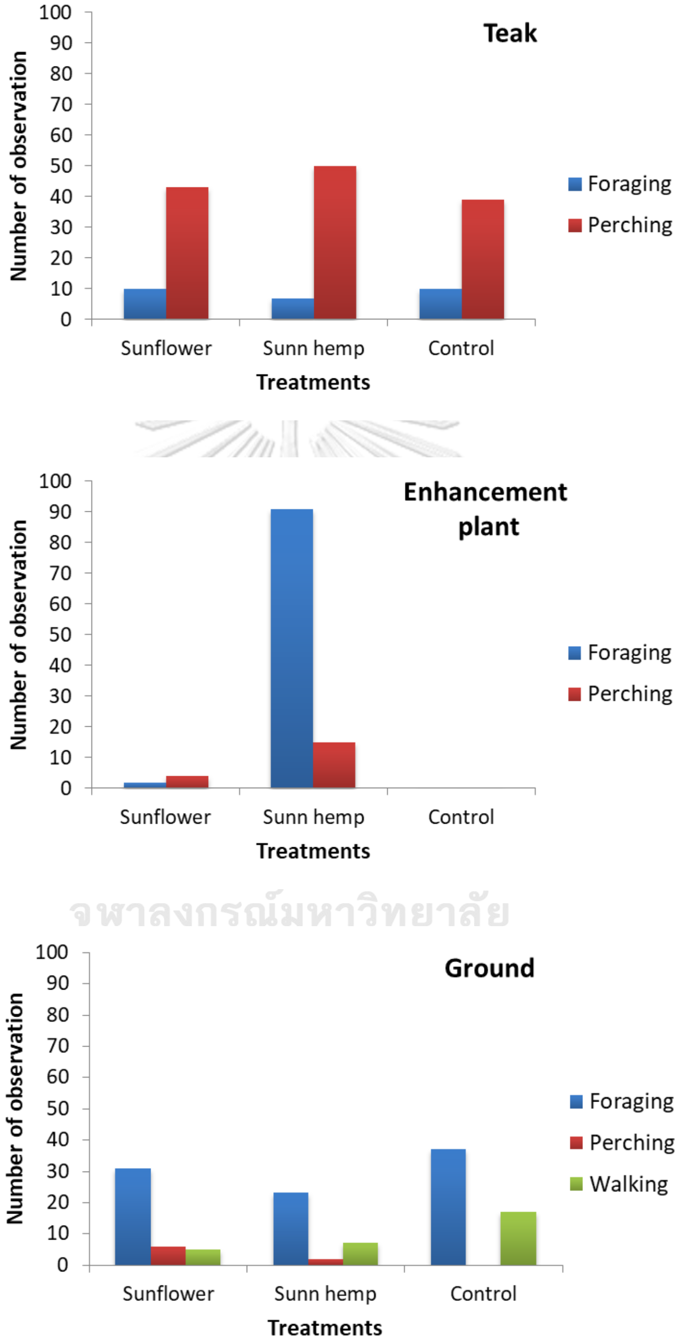
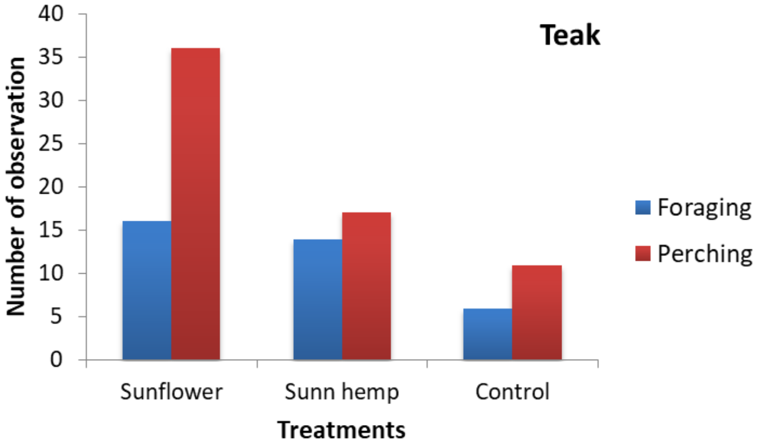


Figure 5.11 Habitat usages of insectivores in each treatment plots based on bird activities in the enhanced teak reforestation plots in 2015-2016



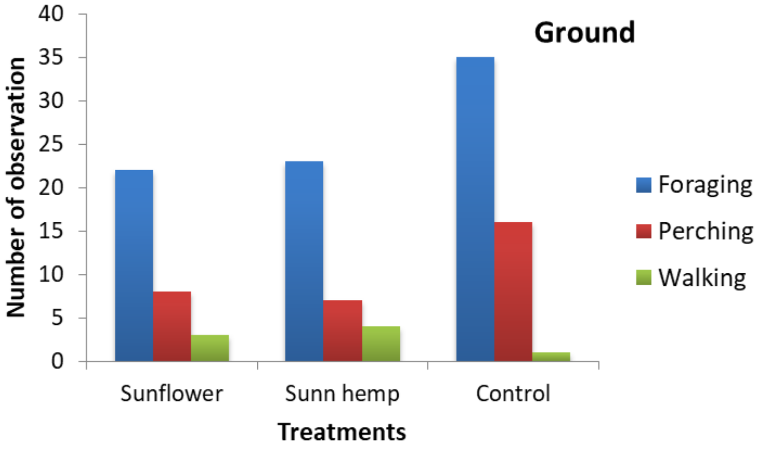


Figure 5.12 Habitat usages of omnivores in each treatment plots based on bird activities in the enhanced teak reforestation plots in 2015-2016

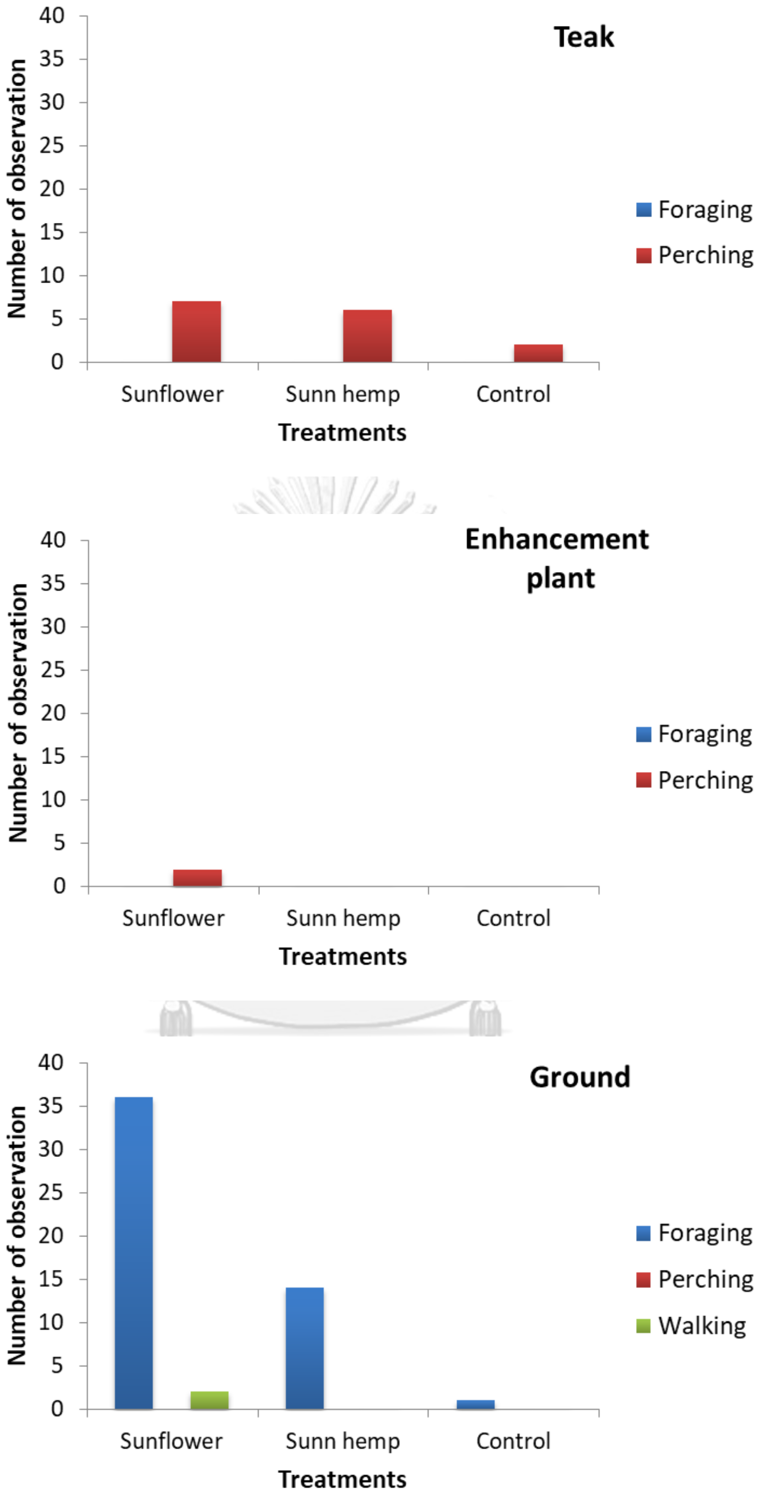


Figure 5.13 Habitat usages of granivores in each treatment plots based on bird activities in the enhanced teak reforestation plots in 2015-2016

5.3 Arthropod diversity and abundance in the enhanced teak reforestation

A total of 3209 individuals from 141 morphospecies, classified into 88 families were observed in the experiment plots (Table 5.4). Species accumulation curves showed similarly increasing tendency in all treatments (Figure 5.14).

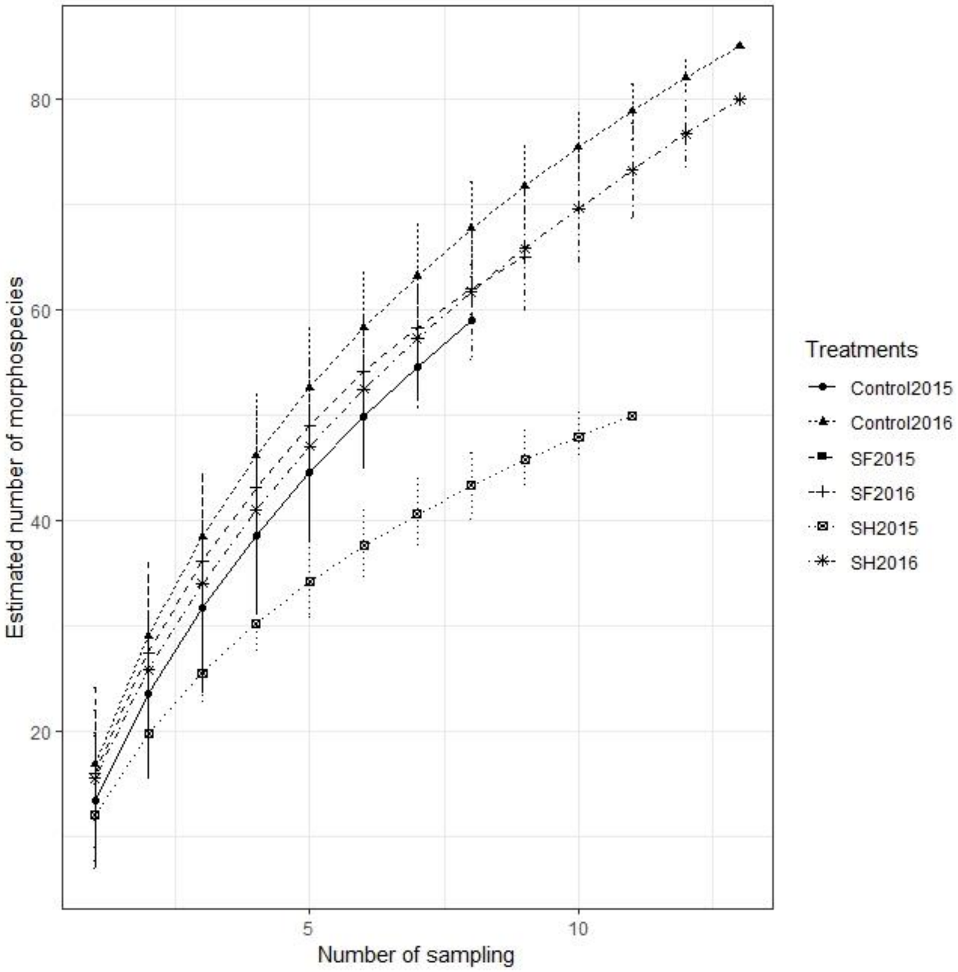


Figure 5.14 Species accumulation curves of arthropods in experiment plots enhanced with sunflower, sunn hemp and control plots during 2015 – 2016
Note: error bars are standard deviations.

Table 5.4 Number of arthropod taxa in the enhanced teak reforestation during dry and wet season of 2015-2016

Taxa	Sunflower		Sunn hemp		Control		Total	
	Families	Morphospecies	Families	Morphospecies	Families	Morphospecies	Families	Morphospecies
Araneae	5	6	5	8	4	7	5	9
Coleoptera	8	12	11	18	11	19	15	29
Diptera	6	6	7	8	6	7	10	11
Hemiptera								
- Heteroptera	8	11	10	17	10	13	12	22
- Homoptera	6	11	6	8	7	9	11	15
Hymenoptera	13	23	12	19	17	28	18	34
Lepidoptera	4	5	4	4	6	7	7	9
Odonata	0	0	1	1	2	2	2	2
Orthoptera	3	5	2	3	3	5	3	5
Others	4	4	3	3	3	3	5	5
	57	83	61	89	69	100	88	141

Total arthropod abundance was significantly different among treatments (χ^2_2 = 9.502, n_1 = 17, n_2 = 24, n_3 = 21, p = 0.009) and between years (U = 328.5, n_1 = 17, n_2 = 24, n_3 = 21, p = 0.038), but not between seasons (U = 371.0, n_1 = 17, n_2 = 24, n_3 = 21, p = 0.166).

Table 5.5 Arthropod species richness and abundance in the teak experiment plots enhanced with sunflower, sunn hemp, and control plots during 2015-2016

	Sunflower	Sunn hemp	Control	P	
				Treatments	Seasons
Morphospecies richness					
Total	13.24±1.66	13.83±0.81	16.14±1.42	ns	0.02
Herbivores	7.06±0.96	7.75±0.41	8.67±0.82	ns	0.01
- Piercing-sucking herbivores	4.47±0.61	4.54±0.35	4.43±0.53	ns	ns
- Chewing herbivores	1.65±0.32	2.17±0.24	2.67±0.37	ns	0.02
- Nectar/pollen-feeding herbivores	0.94±0.28	1.04±0.14	1.57±0.30	ns	0.01
Predators	3.76±0.36	4.50±0.46	4.57±0.41	ns	ns
Parasitoids	1.76±0.45	1.17±0.25	2.14±0.40	ns	< 0.001
Detritivores	0.65±0.23	0.42±0.13	0.76±0.25	ns	< 0.001
Abundance					
Total	11.10±2.31a	24.71±4.93b	13.71±1.83a	0.009	ns
Herbivores	3.98±0.27a	20.35±2.10c	9.27±0.81b	< 0.001	ns
- Piercing-sucking herbivores	2.65±0.49a	15.88±5.00c	5.98±1.43b	0.001	ns
- Chewing herbivores	0.96±0.20	3.82±1.15	2.29±0.57	ns	0.019
- Nectar/pollen-feeding herbivores	0.37±0.12	0.65±0.15	0.98±0.43	ns	0.011
Predators	2.86±0.47	3.14±0.43	2.57±0.32	ns	ns
Parasitoids	3.31±1.26	0.89±0.28	1.17±0.30	ns	< 0.001
Detritivores	0.94±0.53	0.33±0.21	0.71±0.26	ns	< 0.001

Note: values are presented as mean ± SE. Arthropod morphospecies were classified based on feeding groups. Herbivores values are composed from piercing-sucking, chewing and nectar/pollen-feeding herbivores values. Different letters are indicate significant different between abundance among treatments based on Kruskal-Wallis test ($p < 0.05$).

The average arthropod species richness was not significantly different among treatments, but significantly different between season ($p < 0.005$) except for piercing-sucking herbivores and predators. Only the abundance of piercing-sucking herbivores differed significantly among treatments ($p<0.05$), while other guilds were significantly different between seasons. The abundance of predators was not different between treatments and seasons (Table 5.5). The arthropod abundance was highest in the sunn hemp treatment, contributed by the high abundance of herbivorous arthropods.

Meanwhile, the abundance of arthropods was similar between the sunflower and control plots, but the proportions of herbivorous arthropods differed between these plots. Many arthropod feeding guilds showed higher average species richness and abundance of arthropods in the wet season than the dry season (Table 5.5, Figure 5.15A).

Dry plant biomass varied seasonally with more biomass during the wet season. The biomass of the other vegetation contributed crucially to the total dry plant biomass. Intercropping with sunflower and sunn hemp in the teak plots increased plant biomass more than in the control plots (Figure 5.12).

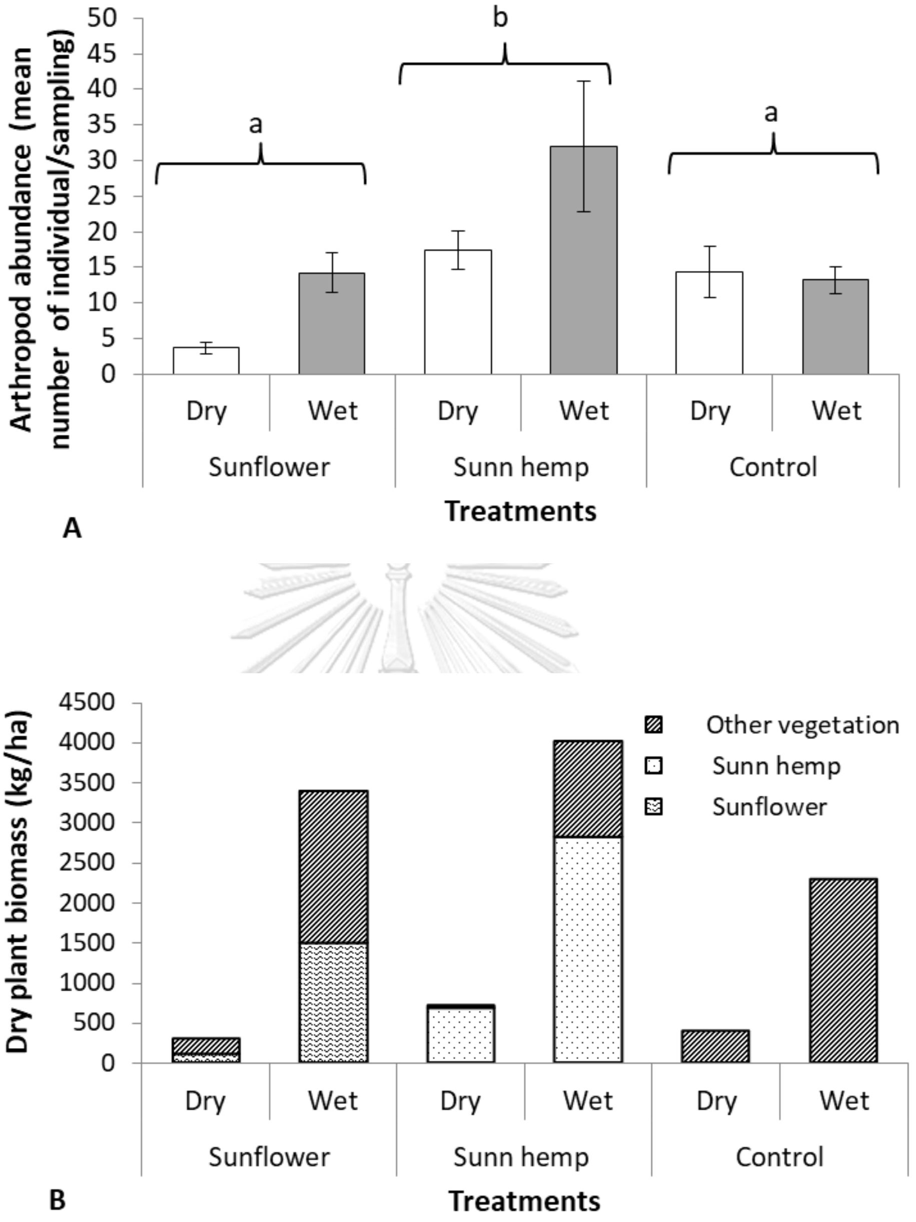


Figure 5.15 A. Mean arthropod abundance in the teak experiment plots enhanced with sunflower, sunn hemp, and control plots during 2015-2016

Note: error bars are standard errors of the mean. Different letters above brackets showed significantly differed at p≤0.05 among treatments. B. Dry plant biomass in treatment plots, enhanced with sunflower and sunn hemp during the dry and wet seasons of 2015-2016.

Herbivorous arthropods were the most common guild found in all treatments followed by predators, parasitoids and detritivores (Table 5.5, Figure 5.16). Guild proportion of arthropod morphospecies was similar in all treatments ($\chi^2 = 4.99$, $p = 0.89$) (Fig. 5.17A). However, the proportion of arthropod abundance by guild was significantly different among treatments ($\chi^2 = 53.17$, $p < 0.001$). (Figure 5.17B).

Oxyopidae Miridae Thripidae

Formicidae Acrididae Eurytomidae

Iridomyrmex anceps

Figure 5.16 Common taxa of arthropods in the enhanced teak reforestation during 2015-2016

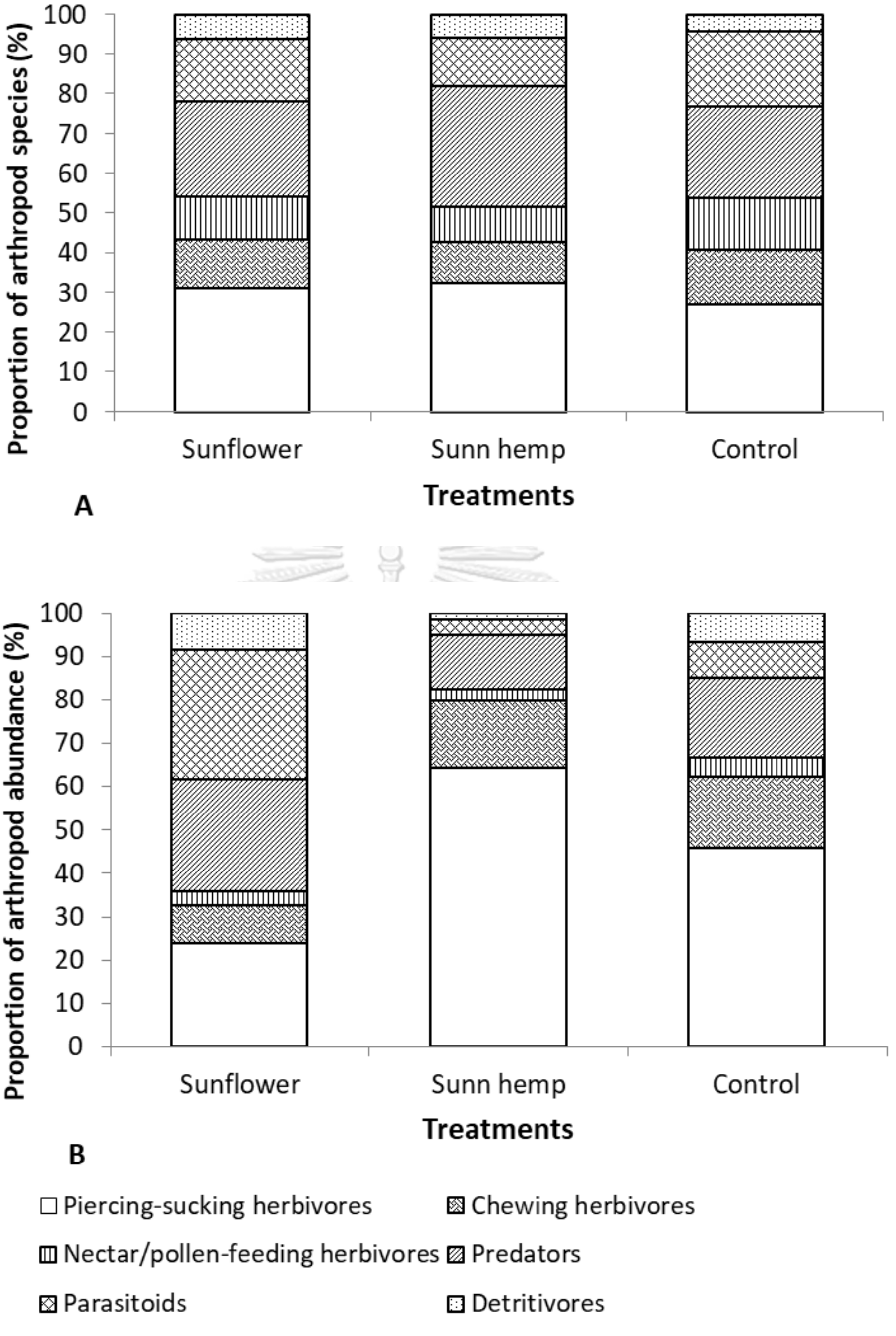


Figure 5.17 A. Proportion of arthropod morphospecies B. Proportion of arthropod abundance based on guilds in the treatment plots of sunflower, sunn hemp, and control plots during 2015-2016

While the sunn hemp treatment could support more herbivorous arthropods, the treatment with sunflower contained more meso-predators (Figure 5.18). The relative abundance of herbivores, meso-predators and detritivores was significantly different among treatments ($\chi^2 = 44.92$, $p < 0.001$).

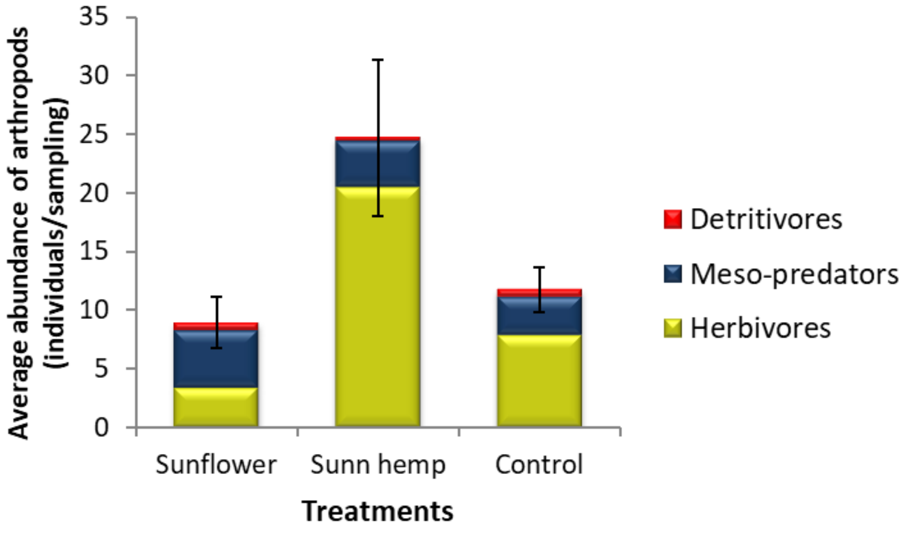


Figure 5.18 Arthropod abundance in the teak reforestation during dry and wet seasons of 2015-2016

Arthropod species and ecological guilds in the teak reforestation showed high similarity among treatments. Even though, different dominance or relative abundance at the family, species and guild levels created distinctive arthropod composition in each treatment. Predators and parasitoids were proportionally dominant arthropod guilds in the sunflower treatment, while piercing-sucking herbivores were the most abundant guild in the sunn hemp and control treatments.

Each ecological guild showed different composition of arthropod morphospecies. Mirid bugs were the most common piercing-sucking herbivores and dominant in the sunn hemp treatment. Leafhoppers (Cicadellidae) and thrips (Thripidae) was abundant in the sunflower treatment while Cicadellidae and Rhyparochromidae were the dominant families in the control. Common chewing herbivores, leaf beetles (Chrysomelidae) and grasshoppers (Acrididae) were the most abundant chewing herbivores in the sunflower and control treatment, while Chrysomelidae dominated the sunn hemp intercropping treatment (Figure 5.19A, B).

Nectar/pollen-feeding herbivores were rarely obtained in all treatments throughout the study period. Apidae was dominant in sunflower and sunn hemp treatment, while Sesiidae was dominant in control treatment. Apidae in sunn hemp was mostly represented by green metallic bees, *Ceratina (Pithitis) smaragdula* (Figure 5.19C).

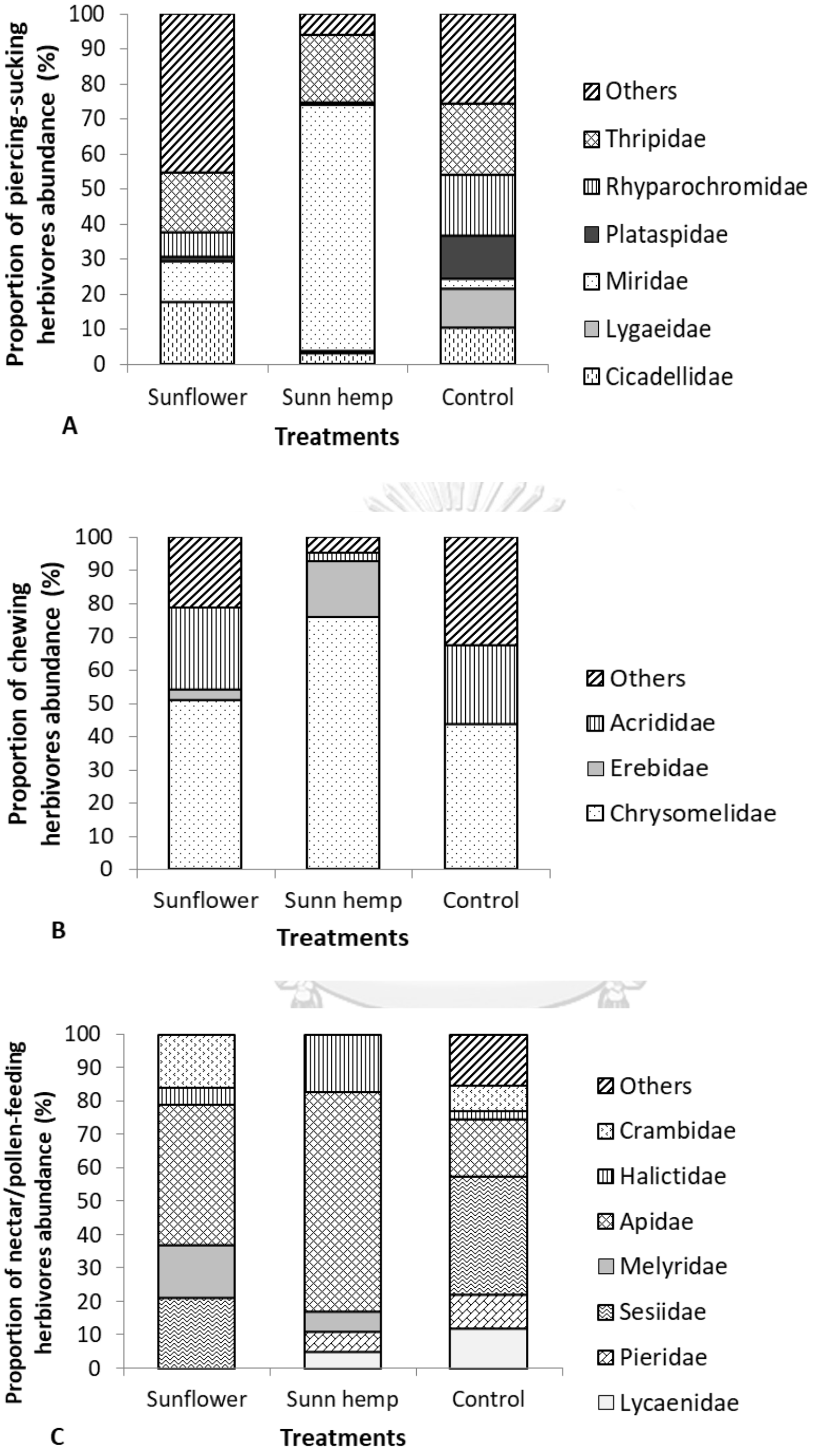


Figure 5.19 Composition of arthropod families in herbivorous guilds. A. piercing-sucking herbivores. B. chewing herbivores, C. nectar/pollen-feeding herbivores

Note: families abundance lower than 10% were grouped as "Others".

Predator abundance was higher in sunflower than other treatments, and the proportion of predatory family differed among treatments. While Formicidae were dominant in sunflower, Formicidae and Oxyopidae were observed in similar proportion in sunn hemp and in control treatment (Figure 5.20A).

Parasitoids from the Eurytomidae were the most abundant in sunflower treatment, comprising more than 50% of all parasitoids in sunflower treatments. Meanwhile, Erythraeidae and Eurytomidae were abundant in sunn hemp treatment. Even Eurytomidae showed higher proportion in control treatment, other families were relatively equal in proportions. Scelionidae was found only in sunflower treatment and Mutilidae was found only in sunn hemp treatment, but both families were found in control treatment (Figure 5.20B). Among the detritivores, Diptera was the dominant taxa in all treatments (Figure 5.20C).

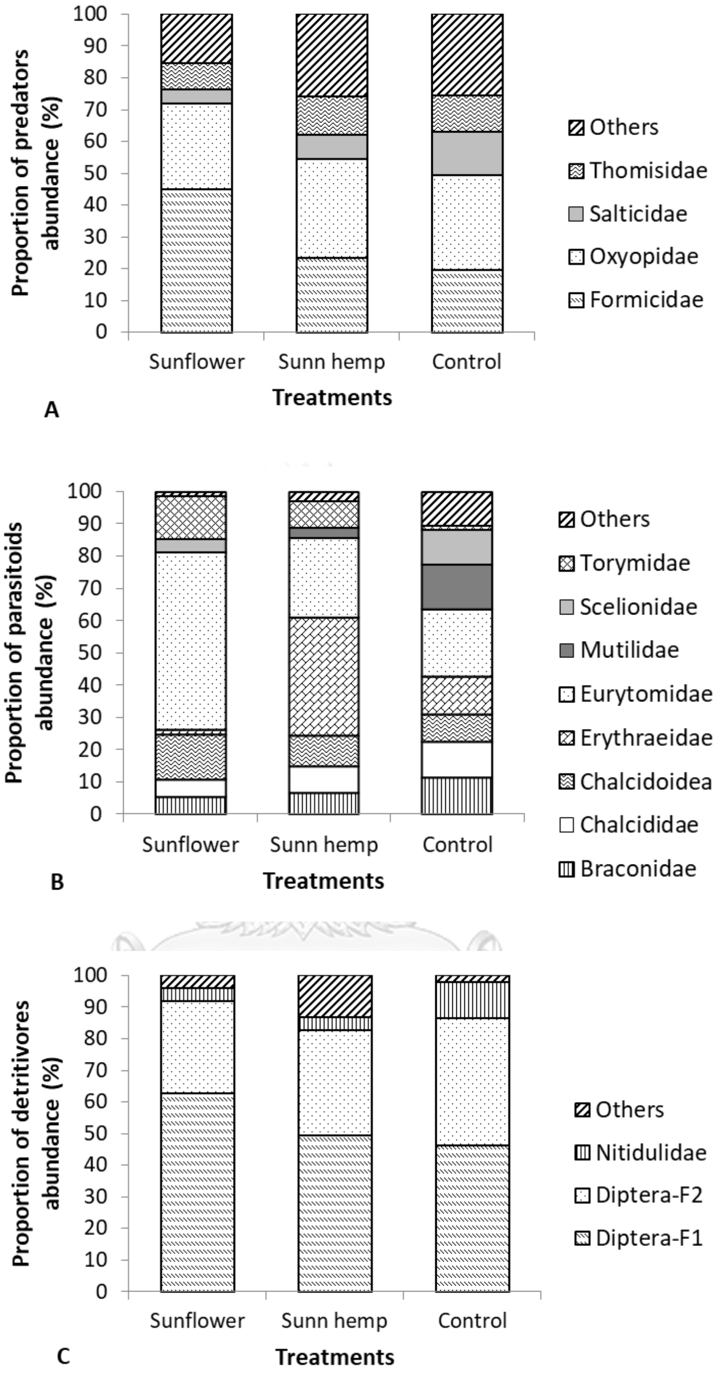


Figure 5.20 Composition of arthropod families in A. predators, B. parasitoids. C. detritivores

Note: families abundance lower than 10% were grouped as “Others”

5.4 Relationship among treatments, arthropods and birds

Sunflower, sunn hemp and teak trees were support both birds and arthropods directly and indirectly. Directly by providing perching sites, food (for granivorous birds), coverage from predator. Indirectly through creating suitable habitat for arthropods that would be food source for birds (Figure 5.21). Sunn hemp biomass was assumed in supporting availability of herbivorous arthropods ($r = 0.724$, $p < 0.0001$). Sunn hemp biomass affected bird activities in foraging ($r = 0.907$, $p < 0.0001$) and perching ($r = 0.774$, $p = 0.003$). Higher insectivorous bird occurrence in sunn hemp intercropped affected in foraging ($r = 0.716$, $p = 0.009$) and perching ($r = 0.650$, $p = 0.22$) activities. While foraging on sunn hemp correlated to herbivorous arthropod availability, foraging on teak tree was related to non-herbivorous arthropod presence ($r = 0.709$, $p = 0.010$).

Teak growth in the enhancement treatments was higher than the control treatment showing increasing height ($r = 0.71^{**}$) and enlarging root-collar diameter of teak (Figure 5.22, Figure 5.23). Even though, teak height did not correlate to foraging and perching activities of birds ($p > 0.05$).

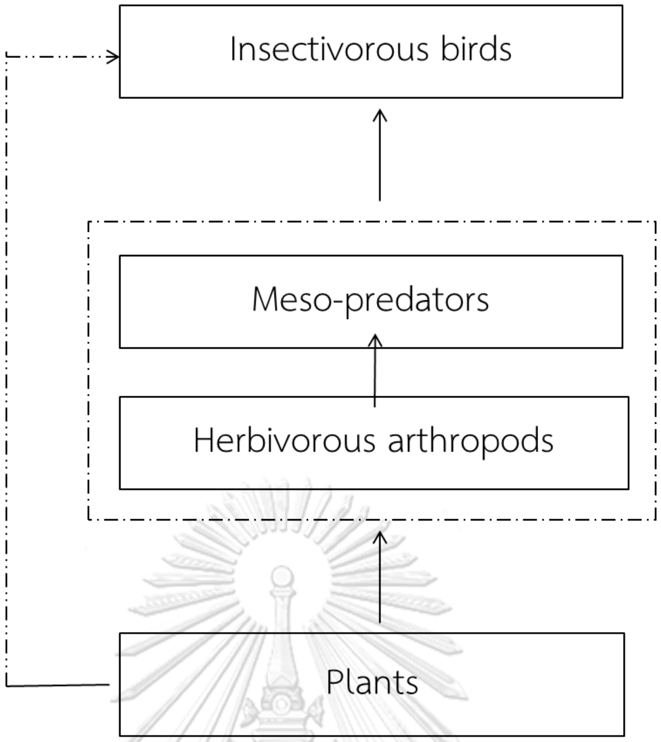


Figure 5.21 Schematic relationship among plants, arthropods and insectivorous birds

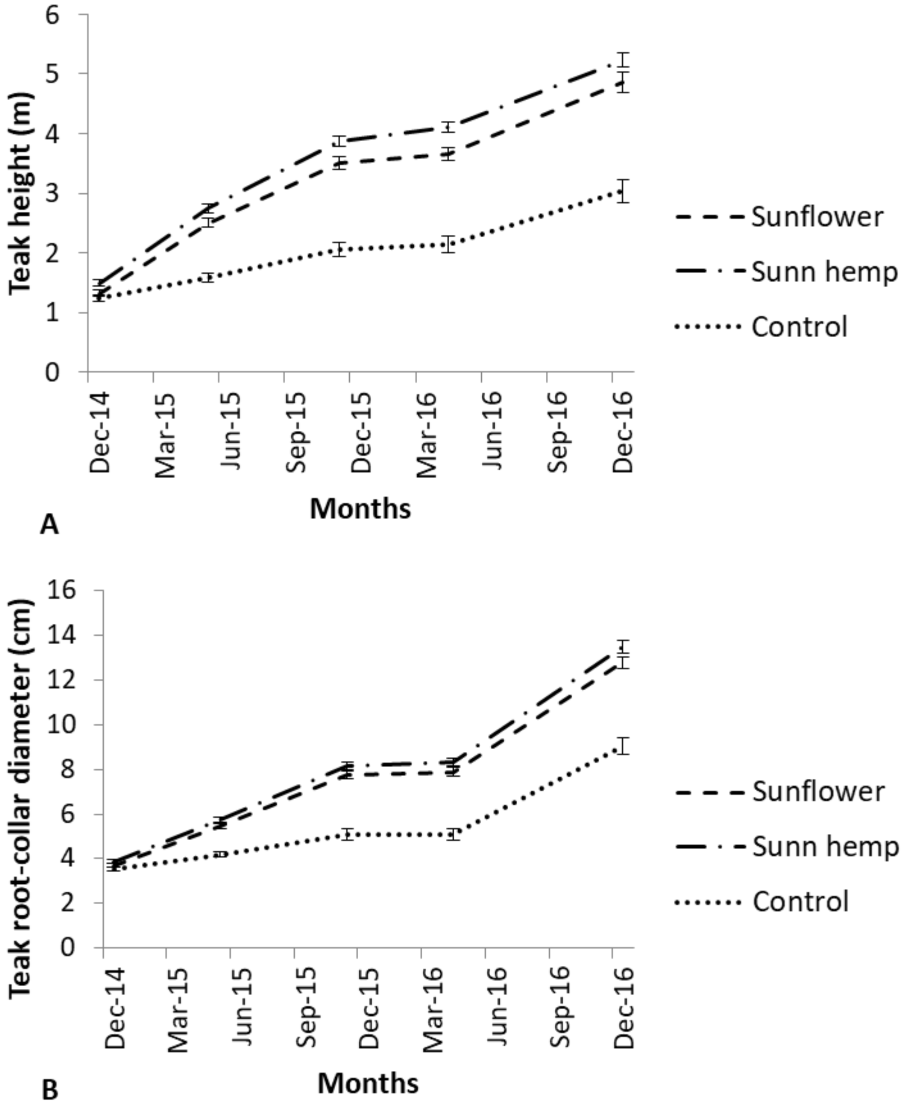


Figure 5.22 Teak growth in teak reforestation area during dry and wet seasons of 2015-2016. A. Teak height, B. Root-collar diameter of teak

Figure 5.23 Teak reforestation in the beginning and in the end of enhancement experiments

5.5 Discussion

Intercropping non-crop plant species in teak reforestation showed effects on bird species richness and occurrence. It may not significantly different, but there was tendency of plant species supported bird differently. Intercropping with sunflower increased bird species richness, meanwhile sunn hemp was responsible to increase the bird occurrence. Enhancement does not always affect all guilds, it may only affect specific guild according to what is offered. Species richness of the guild did not constantly associate with the relative abundance. The most fruitful habitats for birds are those offering resources variety which can support foraging groups diversity (Clough, Putra, Pitopang, & Tscharntke, 2009).

Enhanced plots offered more arthropods as food sources, attracting insectivorous birds. Previous researches mentioned that many herbivorous arthropods are mainly found and remained on the host plants that are growing in dense stands, mentioned as resources theory concentration (Finch & Collier, 2000; Root, 1973). Sunn hemp showed higher abundance of herbivorous arthropod that may become prey for higher level predator, such as meso-predators and insectivorous birds. Meanwhile, sunflower did not grow as good as sunn hemp, resulted in inability to meet the needs of herbivorous insects. Moreover, sunflower morphology with erect, rough-hairy leaves and stems may become barrier for most of herbivorous insects, but not for predatory insects, making meso-predators can occupy sunflower (Kaiser et al., 2017). Abundant meso-predators can affect to herbivorous insect presence. The experiment plots provide arthropods as food source for bird, apply optimal foraging theory. Bird did not need to spend more energy to find a food source that are further away, fulfilled the criteria of optimal foraging theory.

In reforestation area, teak tree provided place and food source which can support several bird guilds. Instead of the enhancement plants, bird using teak for activity. Teak height may attract different bird species to perch on top of teak trees. Different plant structures between teak and enhancement plants created different microhabitat, that suitable for different arthropod and birds. They also provide covers and shelters under big leaves or among dense stands. Live perching site provide by teak and sunn hemp may increase probability of pest control (Gopali et al., 2009).

Reforestation areas with thin soil layer with low nutrients are hardly supportive of plant growth, resulting in plants having different strategies to adapt on extreme condition. Teak trees tend to grow vertically as a survival strategy in competition, resulted in fast growing in teak tree height, while sunflower tend to flowering or reach reproductive stage faster than usual. Sunflower biomass was very low due to hard-to-grow sunflower during observation, allowing occupancy by other vegetation. Instead of easily manage, sunn hemp can adapt better than sunflower to the soil condition in reforestation area. Sunn hemp, also reduced other vegetation growth better than sunflower, as grows in a solid stand can be effective in weed suppression (Warren, Wilson, & Edwards, 2014).

Relationship among plants, arthropods and birds are not as simple as it is. Interaction between species in the same trophic level will show output that affects other levels differently. Many factors collaborated in the teak reforestation will create complexity. As arthropod sampling was excluded arthropod in the teak trees, we assumed that samples were arthropod inhabitant in enhancement plants or other vegetation. Our arthropod was not included as potential pest for teak. Several birds observed using teak only and categorized as tree inhabitant birds. Instead of species diversity, functional diversity may help to recognize redundancy in a habitat. Functional redundancy was observed due to some species perform similar roles in the community and ecosystem, create the substitutable function among species, even our results were not highly redundant, just between 2 species, in contrast with forest birds (Coelho et al., 2016). The number of redundant species will help for habitat management. Redundancy will maintain the ecological function.

Since simplification in reforestation area could be worrisome, a good management process and intensification is required to prevent biodiversity and ecosystem service decline. Without integration of practice that fix nitrogen, make efficient usage of nutrient and build soil fertility is resulting in purchase and apply synthetic fertilizers. Practices that not promote diverse communities of natural enemies will require pesticides purchase and application. The chemicals could be contributed to environmental and social harm instead of high financial cost, create social-economic impact that affect the competition ability of small-scale farmers in global market (Kremen & Miles, 2012).

5.6 Conclusion

Sunflower treatment had more bird species than sunn hemp treatment, but sunn hemp support more insectivorous bird occurrence than sunflower. Sunflower and sunn hemp uniquely support bird guild differently. Sunn hemp supported herbivorous arthropods that may function as food sources for insectivorous birds. Sunn hemp was better option for enhancement in the teak reforestation due to its easy maintenance. Presence of teak trees were affected to habitat usages, as teak also provided resources for some birds in specific functional groups.

CHAPTER VI
CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Enhancement habitat with sunflower and sunn hemp affected several guilds of birds. Within each bird guild, species composition and relative abundance of major guilds varies across the treatments. Not only the enhancement affected on bird species richness and composition, it also affected on bird activities and habitat usages (Table 6.1).

Bird species in landscape-scale and in teak experiments represented 40% and 25% of surrounding area bird species, respectively. Enhancing with sunflower and sunn hemp in landscape-scale and in teak experiment plots showed tendency in increasing proportion of insectivorous and granivorous birds species compared to bird species pool in the areas surround experiment plots. Similarity in bird guild and species was high due to bird in landscape-scale and teak reforestation came from the same species pool. High similarity also observed among treatments due to short distance between the experiment plots. Sunflower treatment attracted more bird species, but sunn hemp attracted more occurrence. Sunflower treatment attracted granivorous birds, while sunn hemp supported insectivorous birds probably because of different available food resources (Figure 6.1, Figure 6.2). Even though, plot size and plant growth condition can be affected in differences in species richness.

Table 6.1 Summary of effects of enhancement sunflower and sunn hemp on birds

	Landscape	Teak
Bird species	● Highest in sunflower treatment ● Mostly insectivores	● Highest in sunflower treatment ● Mostly insectivores
Bird occurrence	● Occurrence was not significantly different among treatments ● High occurrence of insectivores in sunn hemp treatment ● High occurrence of granivores in sunflower and intercropping treatments ● High occurrence species: *Lonchura punctulata* (granivores), *Prinia inornata* (insectivores), *Spilopelia chinensis* (granivores)	● Occurrence was not significantly different among treatments ● High occurrence of insectivores in sunn hemp treatment ● High occurrence species: *Prinia inornata* (insectivores) in sunn hemp treatment, while *Corydalla* sp. (insectivores) in sunflower and control treatments
Bird activities	● Foraging was the most observed in all treatments ● Perching, mostly in sunn hemp stems	● Foraging was the most observed in sunn hemp treatment ● Perching, mostly in teak and sunn hemp treatment
Habitat usages	● Sunn hemp for perching and foraging by insectivores ● Ground for foraging by granivores ● Microhabitats: - Flower head and leaves of sunflower for foraging and perching - Stems of sunn hemp for foraging and perching	● Teak for perching ● Sunn hemp for foraging by insectivores ● Ground for foraging by all guilds

Enhancing habitat with sunflower and sunn hemp provided additional resources for birds. Food resources, cover, perching and nesting sites were offered to support bird species richness and occurrence. Insectivorous bird was the dominant guild in all treatments. Sunflower in the landscape-scale directly provide resources for granivorous bird, but this was not observed in the teak reforestation. On the other hand, sunn hemp treatment in both landscape-scale and teak reforestation showed similar trend in supporting insectivorous birds (Figure 6.2).

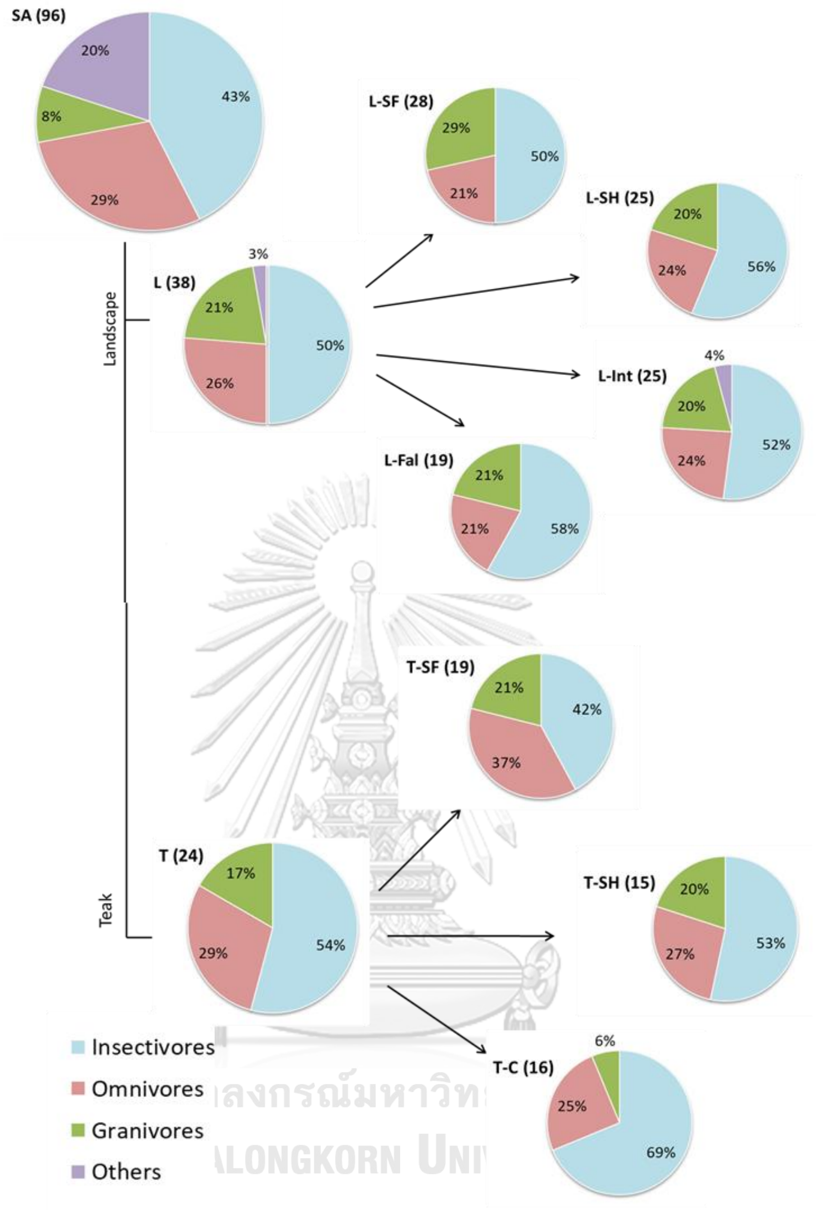


Figure 6.1 Diagram of bird species of various guilds in the landscape-scale and in the teak reforestation experiment plots at Kaeng Khoi District, Saraburi Province during 2015-2016

Note: sites of observation were assigned as surrounding area (SA), landscape-scale plots (L), and teak plots (T). Treatments were showed as sunflower treatment (SF), sunn hemp treatment (SH), intercropping (Int), fallow (Fal) and control (C). Numbers in the parentheses were species richness.

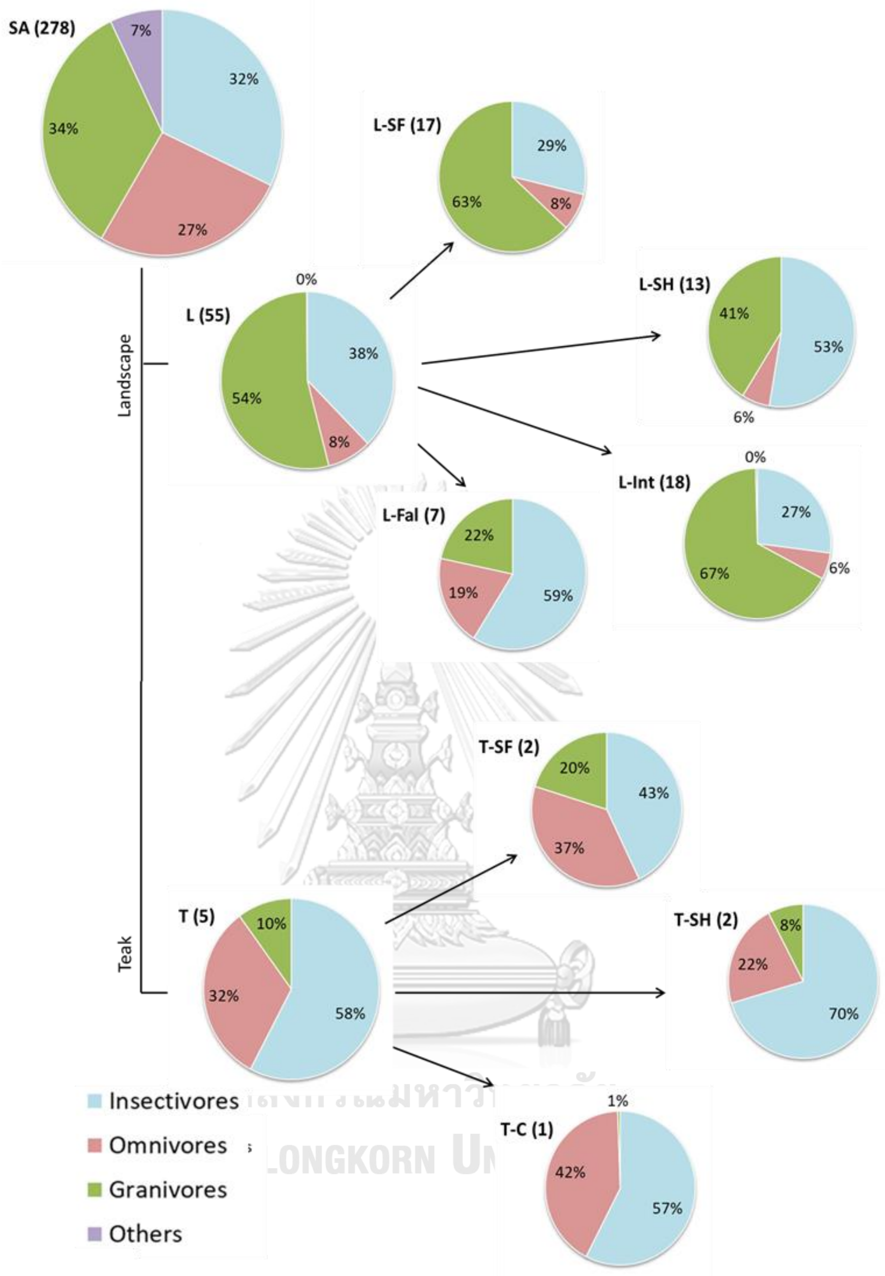


Figure 6.2 Diagram of bird occurrence of various guilds in the landscape-scale and in the teak reforestation experiment plots at Kaeng Khoi District, Saraburi Province during 2015-2016

Note: sites of observation were assigned as surrounding area (SA), landscape-scale plots (L), and teak plots (T). Treatments were showed as sunflower treatment (SF), sunn hemp treatment (SH), intercropping (Int), fallow (Fal) and control (C). Numbers in the parentheses showed bird average occurrence per observation.

Foraging was the most observed activity across all treatments during 4 cropping seasons, followed by perching. While sunflower treatment provided flower head and ground for foraging, sunn hemp treatment provides stems for foraging and perching. In the reforestation, the usage of sunn hemp stems as perching sites was replaced by teak trees and the enhancement plant functioned mostly as foraging sites. Implementation of enhancement could affect bird community and increase bird potential as pest controllers.

Enhancing habitat with sunflower and sunn hemp could assist the presence of herbivorous arthropods and consequently their predators, both predatory arthropods and birds. Herbivorous arthropod species were more than other guilds in all treatments (Figure 6.3). Meanwhile, high proportion of herbivore abundance was observed in sunn hemp treatment. Arthropods in sunflower treatment showed consistency in abundance, with the proportion of meso-predators were higher than herbivores. Sunn hemp treatment in both landscape-scale and teak reforestation showed similar trend in supporting herbivorous insects (Table 6.2, Figure 6.4).

Table 6.2 Summary on effects of enhancement sunflower and sunn hemp on arthropod community

	Landscape	Teak
Arthropods	● Most abundance guilds: - Piercing-sucking herbivores: Miridae in sunn hemp and intercropping, Cicadellidae in sunflower treatment - Predators in fallow plot ● Proportion of predators was higher in sunflower treatment and fallow plot than in sunn hemp and intercropping treatments	● Most abundance guilds: - Piercing-sucking herbivores: Miridae in sunn hemp treatment while Thripidae in control plot - Parasitoids in sunflower treatment ● Proportion of predators and parasitoids was higher in sunflower treatment than other treatments

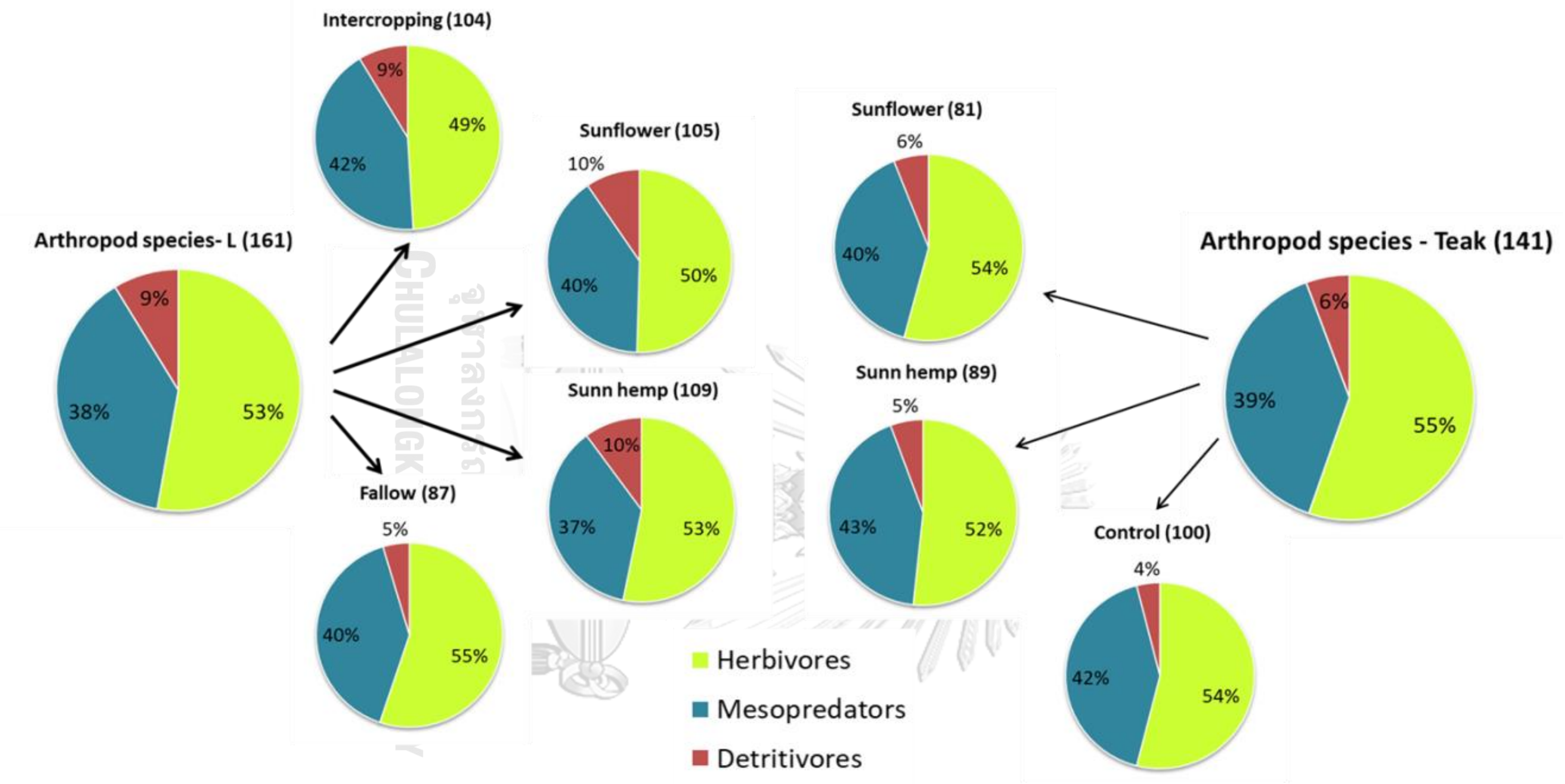


Figure 6.3 Diagram of arthropod morphospecies proportion in the landscape-scale and in the teak reforestation experiment plots at Kaeng Khoi District, Saraburi Province during 2015-2016

Note: sites of observation were assigned as landscape-scale plots (L), and teak plots (T). Numbers in the parentheses were numbers of arthropod morphospecies.

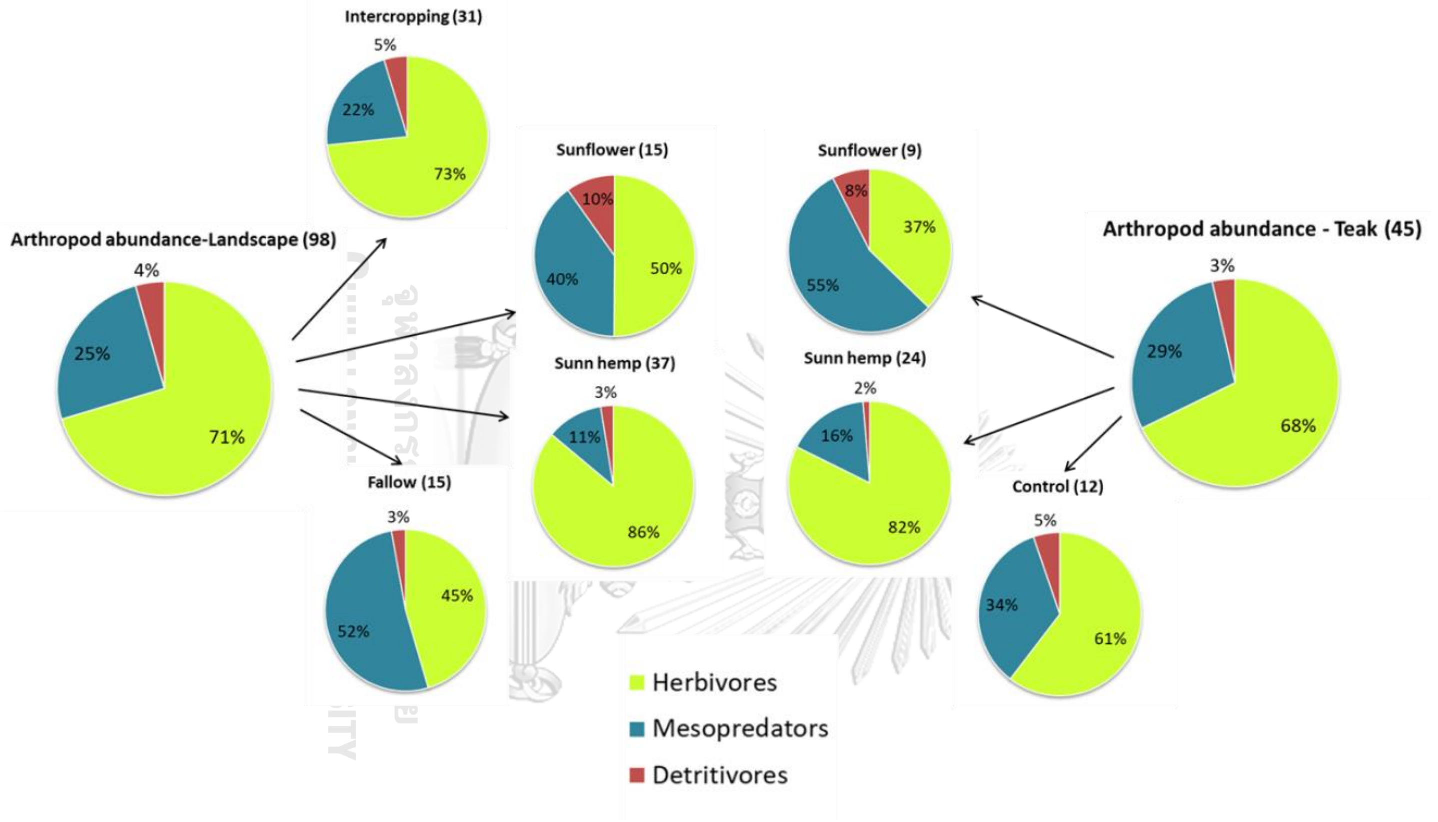
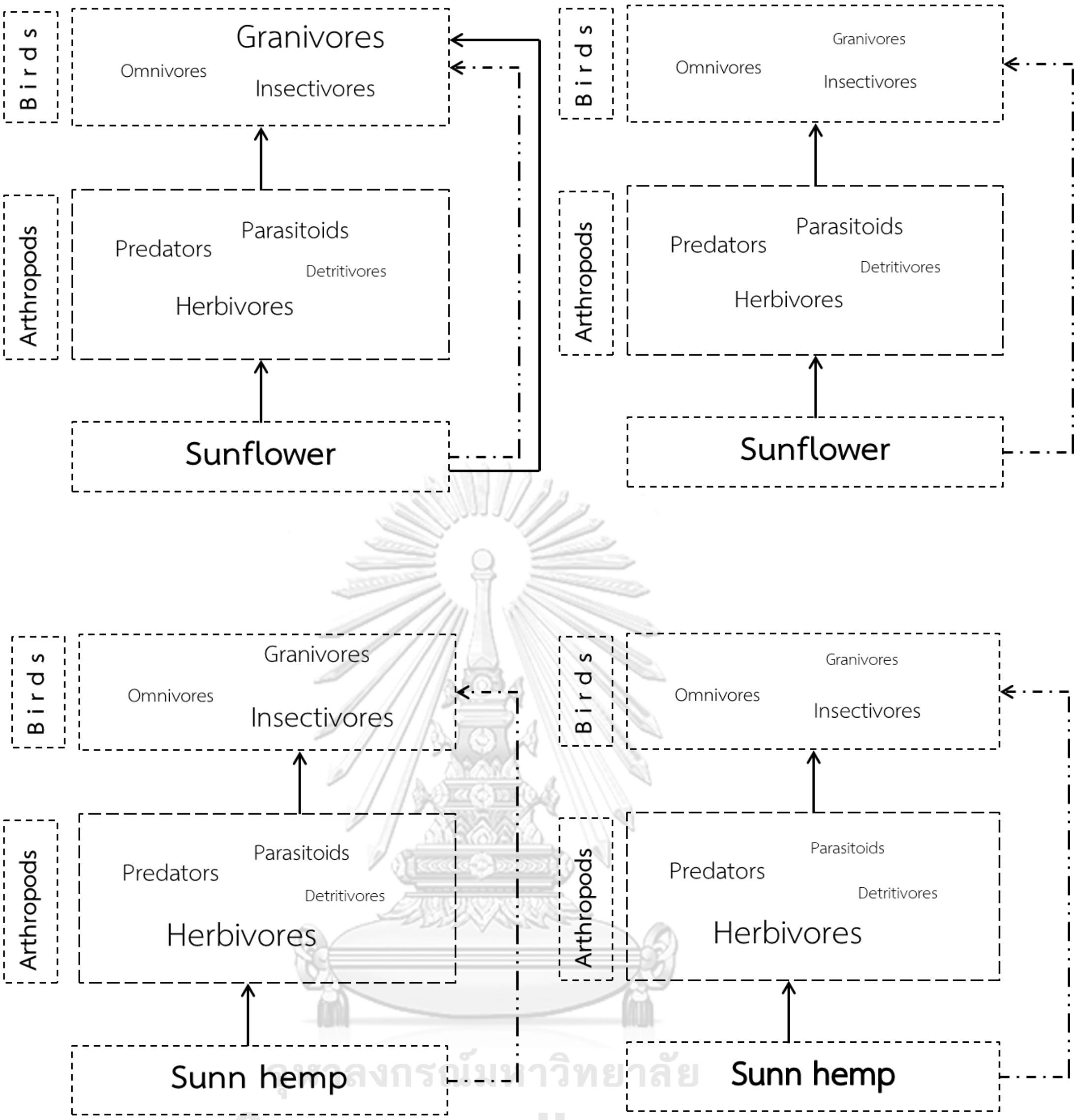


Figure 6.4 Diagram of arthropod abundance proportion in the landscape-scale and in the teak reforestation experiment plots at Kaeng Khoi District, Saraburi Province during 2015-2016

Note: Numbers in the parentheses were average abundance of arthropod morphospecies per sampling.
]

Observation in the landscape-scale and teak reforestation plots indicated that sunflower could support parasitoids, predators and herbivores as food resources for insectivorous birds, but inconsistently showed direct support for granivorous birds. Meanwhile, sunn hemp was consistently supported herbivorous arthropods and insectivorous birds (Figure 6.5). Birds used habitats differently but foraging and perching were the most observed activities in experiment plots. Priority of habitat usages by birds may be shifted due to resources availability. For example, sunn hemp stems were common sites for perching, but in the teak reforestation, the perching location mostly occurred on teak trees and sunn hemp mainly functioned as foraging sites.



Landscape-scale

Teak reforestation

Figure 6.5 Schematic diagrams of relationship among enhancement plant with ecological guilds of arthropod and bird.

Note: solid arrows showed direct effects (food resources) and dashes arrows showed indirect effects (structural supports). Different sizes of feeding guilds in the boxes related to abundance, bigger size showed more abundance than smaller one.

Different plant architecture and plant density between sunflower and sunn hemp treatments affected weeds presence. More space in sunflower treatment allowed weeds growing faster than in dense sunn hemp treatment (Table 6.3), but additional benefit of sunflower and sunn hemp in suppression of weeds need more detailed experiments.

Table 6.3 Summary on effects of enhancement sunflower and sunn hemp on dry plant biomass

	Landscape	Teak
Dry plant biomass	● More biomass in wet season than dry season ● More other vegetation in sunflower treatment than in sunn hemp and intercropping treatments	● More biomass in wet season than dry season ● More other vegetation in sunflower treatment than in sunn hemp treatment

Based on enhancement effects in both landscape-scale and teak reforestation to bird and arthropod community, comparison of the effects of enhanced with sunflower and sunn hemp were as mentioned in Table 6.4.

Table 6.4 Comparison on effects of enhancement with sunflower and sunn hemp in the landscape-scale and in the teak reforestation

	Sunflower	Sunn hemp
Bird species	● Higher than in sunn hemp treatment ● More granivorous and omnivorous species than sunn hemp treatment	
Bird occurrence	● Higher than sunn hemp in landscape-scale, but lower in teak reforestation ● Higher granivores occurrence than other guilds in landscape-scale, but higher insectivores in teak reforestation ● Dominant species in landscape-scale: *L. punctulata* (G) - dominant insectivores (I): *Corydalla* sp. - dominant omnivores (O): *M.erythrocephala* ● Dominant species in teak reforestation: *Corydalla* sp. (I) - dominant omnivores (O): *P.aurigaster* and *M.erythrocephala* - dominant granivores (G): *S.chinensis*	● Lower than sunflower in landscape-scale, but higher in teak reforestation ● Higher insectivores than other guilds ● Dominant species in landscape-scale: *L. punctulata* (G) - dominant insectivores (I): *P.inornata* - dominant omnivores (O): *P.flaveolus* and *M.erythrocephala* ● Dominant species in teak reforestation: *P. inornata* (I) - dominant omnivores (O): *M.erythrocephala* and *P.aurigaster* - dominant granivores (G): *S.chinensis*
Habitat usages	● Foraging in landscape-scale	● Foraging and perching
Arthropods	● Most abundance: piercing-sucking herbivores (Cicadellidae) ● Higher proportion of predator and parasitoid than in sunn hemp	● Most abundance: piercing-sucking herbivores (Miridae)
Dry plant biomass	● More proportion of other vegetation than in sunn hemp	

In term of bird conservation, enhancement plants provide several benefits, direct and indirect, to the habitat. Floral resources may provide direct sources (grain, nectars) and indirect sources (as a proxy of arthropod presence) while plant structures provided as cover for predator and as perching sites, and covered ground by enhancement plant provided foraging space and cover for ground bird species. Enhancement may affect to system differently, depends on application conditions, including biological and physical factors interactions. Trophic level interaction was not as simple as producer and consumer scheme. More food web complexity related to direct and indirect interactions within trophic levels and also presence of omnivorous species that concurrently spread across multiple trophic levels.

Even without enhancement plants, fallow vegetations in landscape-scale and control plots in the teak reforestation plot were also supported several guild of birds and arthropods, though with fewer species richness and occurrence/abundance. Enhancing habitat will add more value to the fallow vegetation in support conservation, such as improving soil condition will related to plant fitness and subsequently increase habitat quality to support herbivorous arthropods and their higher level predators.

6.2 Recommendations

The application of non-crop plants should consider the effects of plants on crop plantation and also enhancement plant fitness. Based on this research, sunflower provides many beneficial aspects in agricultural setting, but it was not applicable in poor soil condition (rocky and thin layer) as commonly used for reforestation, due to difficulty in management while sunn hemp would be suitable in both reforestation and agriculture.

Further research into actual resources provided by the enhancement plants, how birds utilize them, as well as the impact of enhancements and birds on the ecosystem should be explored so that the insights can be applied to agriculture and habitat restoration. Providing perching sites and exclusion cage are important for better understanding of insectivorous birds and arthropods interaction. Sequential planting might be applied to increase and prolong herbivorous insect presence.

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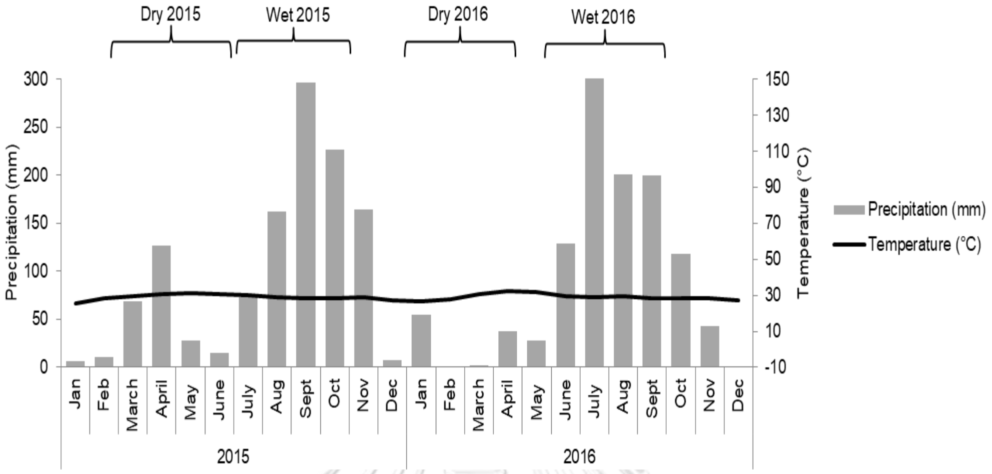
APPENDIX

Appendix 1. Monthly precipitation and monthly temperature for the study site covering 4 growing seasons from January 2015 to December 2016 (Data source: Lopburi station. The Office of Hydrology Irrigation Center for Central Region).



Appendix 2. Physical factors measured in the landscape-scale plots and teak reforestation in Kaeng Khoi District, Saraburi Province during dry and wet seasons of 2015-2016. Organic matter, soil nutrients, pH, moisture and water holding capacity were presented as (average ± SD)

Landscape-scale plots

	Sunflower	Sunn hemp	Intercropping	Fallow
Organic matter (%)	2.52 ± 0.14	2.09 ± 0.14	2.21 ± 0.20	2.58 ± 0.52
Soil nutrient (mg/kg)				
N	36.42 ± 23.63	37.01 ± 22.89	31.98 ± 16.69	16.58 ± 0.00
P	3.64 ± 0.68	5.06 ± 0.70	5.48 ± 0.59	4.14 ± 1.44
K	84.63 ± 40.02	63.44 ± 22.85	64.27 ± 21.07	93.31 ± 47.19
pH	5.77 ± 0.30	5.58 ± 0.19	5.34 ± 0.19	5.61 ± 0.19
Moisture (%)	15.08 ± 13.87	13.74 ± 10.52	16.94 ± 12.29	19.44 ± 17.01
Water holding capacity (%)	47.27 ± 2.88	45.46 ± 1.91	43.06 ± 2.61	49.01 ± 4.03

Teak reforestation

	Sunflower	Sunn hemp	Control
Organic matter (%)	3.08 ± 0.65	3.33 ± 0.50	3.21 ± 0.13
Soil nutrient (mg/kg)			
N	21.62 ± 12.69	23.09 ± 9.88	18.36 ± 8.00
P	3.92 ± 1.73	5.05 ± 1.52	4.19 ± 0.74
K	98.28 ± 60.47	127.05 ± 35.08	99.63 ± 48.18
pH	6.39 ± 0.18	6.31 ± 0.16	6.41 ± 0.30
Moisture (%)	10.64 ± 7.53	10.78 ± 6.94	12.66 ± 6.99
Water holding capacity (%)	40.13 ± 3.04	39.40 ± 2.48	41.41 ± 2.19

Appendix 3. Bird species in the surrounding area during the experiment in 2015 and 2016. Most species are resident birds, and some are winter visitor (*) and passage migrant (°). Feeding guilds are assigned as carnivore (C), frugivore (F), granivore (G), insectivore (I), omnivore (O), and piscivore (P). √ shows presence of bird species in the enhanced landscape-scale and in the enhanced teak reforestation plots.

Family	Scientific name	Common name	Guild	Landscape	Teak
Accipitridae	*Elanus caeruleus*	Black-winged Kite	C		
	Pernis ptilorhyncus	Crested-honey Buzzard	C		
	Tachyspiza badia	Shikra	C		
Aegithinidae	*Aegithina tipia*	Common Iora	I		√
Alaudidae	*Mirafra erythrocephala*	Indochinese Bushlark	O	√	√
Alcedinidae	*Ceryle rudis*	Pied Kingfisher	P		
	Halcyon smyrnensis	White-throated Kingfisher	O	√	
Anatidae	*Dendrocygna javanica*	Lesser Whistling-duck	O		
Apodidae	*Cypsiurus balasiensis*	Asian Palm-swift	I		
Ardeidae	*Ardeola* sp.	Pond heron	C		
	Bubulcus coromandus	Eastern Cattle Egret	I	√	√
	Egretta garzetta	Little Egret	C		
	Ixobrychus cinnamomeus	Cinnamon Bittern	C		
	Ixobrychus sinensis	Yellow Bittern	C		
	Mesophoyx intermedia*	Intermediate Egret	C		
Artamidae	*Artamus fuscus*	Ashy Wood-swallow	I		
Campephagidae	_Pericrocotus divaricatus*_	Ashy Minivet	I		
Caprimulgidae	*Caprimulgus macrurus*	Long-tailed Nightjar	I	√	
Charadriidae	*Vanellus indicus*	Red-wattled Lapwing	O	√	√
Ciconiidae	*Anastomus oscitans*	Asian Openbill	P	√	
Cisticolidae	*Cisticola exilis*	Bright-headed Cisticola	I	√	√
	Cisticola juncidis	Zitting Cisticola	I		
	Orthotomus atrogularis	Dark-necked Tailorbird	I		
	Orthotomus sutorius	Common Tailorbird	I		
	Prinia hodgsonii	Gray-breasted Prinia	I	√	√
	Prinia inornata	Plain Prinia	I	√	√
	Prinia rufescens	Rufescent Prinia	I	√	

Appendix 3. (continuous)

Family	Scientific name	Common name	Guild	Landscape	Teak
Columbidae	_Columba livia_	Rock Pigeon	G	√	
	Geopelia striata	Zebra Dove	G	√	√
	Spilopelia chinensis	Spotted Dove	G	√	√
	Streptopelia tranquebarica	Red Turtle-Dove	G	√	√
Coraciidae	_Coracias benghalensis_	Indian Roller	I	√	
Corvidae	_Corvus levaillantii_	Eastern Jungle-Crow	O		
	Crypsirina temia	Racket-tailed Treepie	O		
	Dendrocitta vagabunda	Rufous Treepie	O		√
Cuculidae	_Cacomantis merulinus_	Plaintive Cuckoo	I	√	
	Centropus bengalensis	Lesser Coucal	I		√
	Centropus sinensis	Greater Coucal	O	√	
	Eudynamys scolopaceus	Asian Koel	F		
	Phaenicophaeus tristis	Green-billed Malkoha	I		
Dicaeidae	_Dicaeum cruentatum_	Scarlet-backed Flowerpecker	F		
	Dicaeum minullum	Plain Flowerpecker	F		
Dicruridae	_Chaptia aenea_	Bronzed Drongo	I	√	
	Dicrurus annectans°	Crow-billed Drongo	I		
	Dicrurus hottentottus	Hair-crested Drongo	I		
	Dicrurus paradiseus	Greater Racket-tailed Drongo	I		
	_Edolius leucophaeus_*	Ashy Drongo	I		
	Edolius macrocercus	Black Drongo	I	√	√
Estrildidae	_Lonchura punctulata_	Scaly-breasted Munia	G	√	√
	Lonchura striata	White-rumped Munia	G	√	
Hirundinidae	_Hirundo rustica_*	Barn Swallow	I		
Laniidae	_Lanius collurioides_*	Burmese Shrike	I		√
	_Lanius cristatus_*	Brown Shrike	I	√	√
Megalaimidae	_Psilopogon haemacephalus_	Coppersmith Barbet	F		
	Psilopogon lineatus	Lineated Barbet	F		
Meropidae	_Merops leschenaulti_	Chesnut-headed Bee-eater	I		
	Merops orientalis	Green Bee-eater	I	√	√
	Merops philippinus	Blue-tailed Bee-eater	I	√	
Monarchidae	_Hypothymis azurea_*	Black-naped Monarch	I		
Motacillidae	_Corydalla sp._	Pipit	I	√	√

Appendix 3. (continuous)

Family	Scientific name	Common name	Guild	Landscape	Teak
Muscicapidae	*Copsychus saularis*	Oriental Magpie-robin	I		
	*Ficedula albicilla**	Taiga Flycatcher	I		
	*Monticola solitarius**	Blue Rock-thrush	I		
	*Muscicapa latirostris**	Asian Brown Flycatcher	I	√	
	Saxicola caprata	Pied Buschat	I	√	
	*Saxicola stejnegeri**	Stejneger's Stonechat	I	√	√
Nectariniidae	*Anthreptes malacensis*	Brown-throated Sunbird	O		
	Cinnyris jugularis	Olive-backed Sunbird	O		√
Oriolidae	*Oriolus chinensis**	Black-naped Oriole	F		
Paradoxornithidae	*Chrysomma sinense*	Yellow-eyed Babbler	I	√	√
Passeridae	*Passer flaveolus*	Plain-backed Sparrow	O	√	√
	Passer montanus	Eurasian Tree-sparrow	O	√	
Phalacrocoracidae	*Microcarbo niger*	Little Cormorant	P		
Phasianidae	*Francolinus pintadeanus*	Chinese Francolin	O		
	Gallus gallus	Red Junglefowl	O		
Picidae	*Dendrocopos analis*	Freckle-breasted Woodpecker	I		
Ploceidae	*Ploceus hypoxanthus*	Asian Golden Weaver	G	√	
	Ploceus philippinus	Baya Weaver	G	√	
Pycnonotidae	*Microtarsus atriceps*	Black-headed Bulbul	O		
	Pycnonotus aurigaster	Sooty-headed Bulbul	O	√	√
	Pycnonotus blanfordi	Streak-eared Bulbul	O		√
	Pycnonotus finlaysoni	Stripe-throated Bulbul	O		
	Pycnonotus goiavier	Yellow-vented Bulbul	O		
	Rubigula flaviventris	Black-crested Bulbul	O		
Rallidae	*Amaurornis phoenicurus*	White-breasted Waterhen	O		
Recurvirostridae	*Himantopus himantopus**	Black-winged Stilt	C		
Rhipiduridae	*Leucocirca javanica*	Malaysian Pied-Fantail	I	√	
Scolopacidae	*Gallinago* sp.*	Snipe	O		
	*Tringa glareola**	Wood Sandpiper	O		

Appendix 3. (continuous)

Family	Scientific name	Common name	Guild	Landscape	Teak
Sturnidae	*Acridotheres grandis*	Great Myna	O	√	
	Acridotheres tristis	Common Myna	O	√	
	Gracupica contra	Pied Myna	O		
	Gracupica nigricollis	Black-collared Starling	O	√	
	*Sturnus sinensis**	White-shouldered Starling	O		
Turnicidae	*Turnix* sp.	Buttonquail	O		
Upupidae	*Upupa epops*	Hoopoe	I		
		Species richness	96	38	24

Appendix 4. Average abundance of arthropods in the landscape-scale experiment plots enhanced with sunflower, sunn hemp, intercropping of sunflower and sunn hemp in 2015-2016, and fallow plot in 2016

Guild designations are as follows: H-ps: herbivore-piercing sucking. H-ch: herbivore-chewing, H-npf: herbivore-nectar/pollen-feeding, Pre: predator, Par: parasitoid, and Det: detritivore.

Taxa	Morphospecies/species	Guild	Average abundance (number of individuals/sampling)			
			Sunflower	Sunn hemp	Intercropping	Fallow
Coleoptera						
Attelabidae	*Apoderus notatus*	H-ps	-	0.02	-	-
Brentidae	Brentidae-1	H-ps	-	-	0.01	-
Curculionidae	*Hypomeces squamosus*	H-ps	0.13	-	-	-
	Magdalinae-1	H-ps	0.09	-	-	-
	Curculionidae-3	H-ps	-	0.02	0.03	-
	Dryophthorinae-1	H-ps	0.03	0.03	-	-
	Curculionidae-8	H-ps	0.02	-	-	0.09
Diptera						
Culicidae	Culicidae-1	H-ps	0.06	0.10	0.09	0.08
Muscidae	Muscidae-1	H-ps	-	-	0.04	0.03
Mycetophilidae	Mycetophilidae-1	H-ps	0.38	0.14	0.09	0.03
	Mycetophilidae-2	H-ps	0.07	0.10	0.13	-
Tephritidae	Tephritidae-1	H-ps	0.03	0.01	-	-
	Tephritidae-3	H-ps	0.01	-	-	-
Hemiptera						
Alydidae	*Riptortus linearis*	H-ps	-	0.04	0.03	0.03
	Megatotomus sp.	H-ps	-	0.02	0.03	0.06
Aphididae	Aphididae-1	H-ps	0.32	0.04	0.34	0.49
Berytidae (Neididae)	Berytidae (Neididae)	H-ps	-	0.02	-	-
Cercopidae	*Cercopus* sp.	H-ps	-	-	0.01	-
Cicadellidae	Cicadellidae-1	H-ps	0.17	0.16	0.16	0.12
	Cicadellidae-2	H-ps	0.11	0.85	0.06	0.02
	Bothrogonia sp.	H-ps	0.02	-	-	-
	Cicadellidae-4	H-ps	1.37	0.74	1.63	0.66

Appendix 4. (continuous)

Taxa	Morphospecies/species	Guild	Average abundance (number of individuals/sampling)			
			Sunflower	Sunn hemp	Intercropping	Fallow
Cixiidae	Cixiidae-1	H-ps	0.03	0.03	-	-
	Melanoliarus sp.	H-ps	-	-	0.02	0.03
Coreidae	*Eutochtha* sp.	H-ps	0.01	-	0.02	-
	Gonocerus sp.	H-ps	0.06	0.06	0.07	0.17
	Coreidae-2	H-ps	-	0.03	0.03	-
Delphacidae	Delphacidae-1	H-ps	1.03	0.05	0.54	0.30
Dictyopharidae	Dictyopharidae-1	H-ps	0.03	0.03	-	-
Dinidoridae	*Megymenum* sp.	H-ps	-	0.01	-	-
Lygaeidae	Lygaeidae-1	H-ps	0.46	0.11	0.17	0.11
	Spilostethus hospes	H-ps	-	0.01	0.03	0.25
	Spilostethus pandurus	H-ps	-	0.24	-	-
Hemiptera						
Lygaeoidea	Lygaeoidea-1	H-ps	0.01	0.02	-	0.03
Machaerotidae	Machaerotidae	H-ps	0.01	-	-	-
Miridae	Miridae-1	H-ps	0.20	19.95	14.21	0.23
	Miridae-2	H-ps	-	0.03	0.01	-
Monophlebidae	Monophlebidae-1	H-ps	-	-	0.03	-
Pentatomidae	*Euchistus* sp.	H-ps	0.03	0.10	0.17	0.31
	Nezara viridula	H-ps	-	0.14	0.04	0.14
	Eysarcoris guttiger	H-ps	-	0.05	0.02	0.03
	Eurydema sp.	H-ps	0.01	-	0.02	-
Plataspidae	Plataspidae-1	H-ps	0.03	0.07	0.14	0.49
Rhyparochromidae	Rhyparochromidae-1	H-ps	0.06	0.04	0.04	0.11
	Rhyparochromidae-2	H-ps	0.04	0.02	0.04	0.03
Tingidae	Tingidae-1	H-ps	0.07	0.04	0.10	0.21
Thysanoptera						
Phlaeothripidae	Phlaeothripidae	H-ps	0.03	-	0.05	-
Thripidae	Thripidae	H-ps	0.83	2.27	1.65	1.29
Coleoptera						
Buprestidae	Buprestidae-1	H-ch	0.12	-	-	0.02
Chrysomelidae	*Monolepta signata*	H-ch	0.25	0.29	0.22	0.17
	Acanthoscelides sp1	H-ch	-	-	-	0.02
	Acanthoscelides sp2	H-ch	-	-	0.01	0.04