STUDY ON DIVERSITY OF FIREFLY POPULATIONS IN HIGHLAND AND LOWLAND HABITATS

ANCHANA THANCHAROEN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

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(ENVIRONMENTAL BIOLOGY)

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MAHIDOL UNIVERSITY

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A field study of the diversity of firefly populations was carried out in habitats at 2 different altitude levels—highland and lowland habitats. The two purposes of the study were to survey firefly diversity and ecology, and to investigate the effects of climatic and moonlight factors on firefly abundance. Monthly monitoring of firefly abundance was carried out for 18 months (June 1998-November 1999), and hourly and moon phase monitoring were conducted in 3 moon cycles from March through May 2000.

Firefly diversity was greater in the highland habitat than in the lowland habitats. Eleven species in 7 genera were found in the highland, whereas only 3 species in 2 genera were found in lowlands. There was a higher diversity of highland fireflies in the wet period (H' = 1.191) than in the dry period (H' = 0.082). Seasonal occurrence of fireflies in both habitats showed a similar trend; the density was low in winter and gradually increased during the rainy season. Fluctuation in climatic factors was the major factor influencing firefly abundance in different habitats. The moonlight factor influenced the abundance of fireflies in the first half of the night in the highland habitat. Highland species showed temporal flashing activities, which were important characteristics that could be used for isolating species in the same habitat. Larvae of different species also utilized different niches to reduce competition and avoid predators. The males and females of adult fireflies showed different behavior. Both sexes spent most of their lives flying around, especially the males. The females stayed near the ground, more often than the males due to their oviposition activity.

In conclusion, it was found that the climatic factors and moonlight influenced firefly diversity and abundance.

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การศึกษาความหลากหลายของประชากรหิ่งห้อยในพื้นที่ที่มีระดับความสูงแตกต่างกัน คือ บริเวณที่สูงและที่ราบต่ำ โดยมีวัตถุประสงค์ในการศึกษาความหลากหลายของชนิด ลักษณะนิเวศ วิทยา และศึกษาผลกระทบของปัจจัยทางกายภาพและแสงจันทร์ต่อความชุกชุมของหิ่งห้อยที่พบ การศึกษาแบ่งออกเป็น 2 ช่วง คือ การติดตามผลความชุกชุมทุกเดือน เป็นเวลา 18 เดือน ตั้งแต่ มิถุนายน 2541 ถึง พฤศจิกายน 2542 และการติดตามผลความชุกชุมทุกชั่วโมงตลอดคืน พร้อมทั้ง ศึกษาอิทธิพลของแสงจันทร์ เป็นเวลา 3 เดือน ตั้งแต่เดือนมีนาคม ถึง พฤษภาคม 2543

หิ่งห้อยในบริเวณที่สูงมีความหลากหลายของชนิดสูงกว่าบริเวณที่ราบ ในบริเวณที่สูงพบ หิ่งห้อย 13 สปีชีส์ จาก 7 สกุล ในขณะที่ในบริเวณที่ราบต่ำพบเพียง 3 สปีชีส์ จาก 2 สกุล จะพบ ความหลากหลายของชนิดหิ่งห้อยในฤดูฝน (H'=1.191) สูงกว่าในฤดูแล้ง (H'=0.082) การศึกษาฤดู กาลของหิ่งห้อยในทั้งสองพื้นที่วิจัยให้ผลที่คล้ายกัน คือ มีประชากรสูงในช่วงฤดูฝนและแนวโน้ม ค่อยๆลดลงเมื่อเข้าสู่ฤดูแล้ง ปัจจัยกายภาพส่งผลต่อแนวโน้มของประชากรหิ่งห้อยในทั้งสองพื้นที่วิจัยแตกต่างกัน นอกจากนี้อิทธิพลของแสงจากดวงจันทร์มีผลต่อการประชากรหิ่งห้อยในทั้งสองพื้นที่มีหิ่งห้อยหลายชนิดในบริเวณเดียวกัน ดังเช่นในบริเวณที่สูง หิ่งห้อยแต่ละชนิดมีช่วงเวลาในการออกกระพริบแสงแตกต่างกัน เพื่อเพิ่มประสิทธิภาพในการหาคู่ผสมพันธุ์ ตัวอ่อนของหิ่งห้อยในบริเวณที่สูงก็มีการแบ่งแยกพื้นที่อาศัยเช่นกันเพื่อลดการแก่งแย่งอาหารและศัตรู หิ่งห้อยเพศผู้และเพศเมียมีพฤติกรรมที่แตกต่างกัน ทั้งสองเพศใช้ชีวิตส่วนใหญ่ในการบิน แต่เพศผู้มีสัดส่วนของพฤติกรรมบินสูงกว่าเพศเมีย ในขณะที่เพศเมียมีสัดส่วนการดำรงชีวิตอยู่ใกล้พื้นดินมากกว่าในเพศผู้อาจเป็นผลเนื่องมาจากเพศเมียด้องทำหน้าที่วางไข่

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CHAPTER I

INTRODUCTION

Fireflies are nocturnal insects belonging to the family Lampyridae, order Coleoptera. They are light producing insects that is their dominant characteristic. Their lights are produced from luminous organ at the tip of their abdomen (Carlson and Copeland, 1978). The fireflies flash lights at night searching for their mates; therefore, the flashes are mating signal. A male firefly flashes a specific pattern of light and waits for response flashes from the same species of females. Each species of fireflies flashes specific patterns, frequencies, and colors of light. Besides these, they probably show different flight patterns and temporal activity (Matthews and Matthews, 1978; Tweit, 1999). Fireflies are found in lowland, freshwater and brackish ecosystem, up to highland. Within any habitat types, there are food sources—snails soften body insects and earthworms—available for the larvae. In the past, fireflies were easily found throughout Thailand but now fireflies have disappeared from many areas because of their habitat are destroyed by developments including human settlements, streets, construction of electricity network and etc. Light from electricity, in particular, showed great effects. Furthermore, contamination of agricultural pesticide, chemical substances from industries in rivers has reduced firefly populations. The reduction of firefly populations in any habitats indicates the destruction of and ecosystem that arises from human activities. Besides making a night beautiful, fireflies are useful for medical, agricultural and genetical research as well as an area of attraction sightseeing (Anonymous, 1996). They play important role in controlling snails that are the intermediate hosts of human and animal parasites

(Chunram and Lewvanich, 1996). Some species of firefly larvae serve as biological control agent, for instance, predator of cherry snail larvae (*Pomacea canaliculata*) that are important pests of rice field; therefore, they are very useful for agriculture. Moreover luminescent genes are used in genetical and biochemical research using luciferase genes as reporter genes. The recent medical study shows that some species of fireflies can produce defensive chemical substance—lucibufagin—which is cardiotonic steroid (Eisner, 1997).

The fireflies show strong habitat specificity, there are different species in various parts of the world. Although biology and ecology of several species have been studied but little work has been done on Thai fireflies. Such information lags, there are addressed here:

Species diversity of fireflies

- 1. What is species diversity of fireflies of the highland and the lowland habitats? Are they same or different species? What is the dominant species in each habitat?
 - 2. Are there any differences in external morphologies among species?

Ecology of fireflies

- 3. Are species diversity and abundance fluctuated by seasons?
- 4. What are the temporal flashing activities by different species?
- 5. What are the ecology of adult and larval fireflies?

Factor affecting firefly abundance

- 6. Is environmental luminosity an important factor in determining firefly abundance?
- 7. Which physical environmental factors play an important role in occurrence of fireflies?

CHAPTER II

LITERATURE REVIEW

Firefly Distribution

Fireflies occur in most regions of the temperate and tropical zones of the earth except deserts and high mountains (Buck and Buck, 1976). Worldwide, there are over 1,900 species that have been given scientific names and there may be many species yet to be discovered (Anonymous, 1996). The highest species diversity of fireflies is found in Tropical Asia and Central and South America where are the warm and humid areas of the world (Branham and Greenfield, 1996). Although some species are found in very arid regions of the world, their abundance are related to the rains. Synchronous flashing is an amazing phenomenon (Buck and Buck, 1976) that is found in the specific regions from East India and South East Asia to the Philippines and New Guinea.

Life Cycle and Ecology

The life cycle of firefly is typical of a coleopteran that involves four stages. It begins with the egg stage, followed by several instars of larva, then pupate and emerge as an adult.

1. Egg

Eggs are usually smooth, spherical, and may be dull creamy white, pale yellow, or colorless. They are deposited singly or in groups (20-100 eggs) in or on the soil or

at the base of grasses. The egg masses contact together with a transparent secretion. Several species of fireflies show egg luminosity. Buschman (1984) observed that *Pyractomena lucifera* eggs from mated females began emitting light 2 or 3 days after they were laid and continued until they hatched. The numbers of the laid eggs were related to weight of the female pupae; the larger females laid nearly twice as many as the small ones. Egg sizes are normally in range 0.5-1 mm in diameter (Buschman, 1984; Chunram and Lewvanich, 1996). The size of *Luciola cruciata* eggs is related to the size of larvae (Yuma, 1986). According to Yuma (1984), the mean egg weight decreased with the age of a female and also decreased seasonally through the oviposited period that led to decrease size and tolerance of newly hatched larvae in *L. cruciata*. The incubation period lasts from 13 to 27 days (LaBella and Lloyd, 1991).

2. Larva

Lampyrid larvae are generally found in damp environment. The terrestrial larval species, *Photuris* and *Photinus*, are found under stones, in ground depression, under leaf litter. Many species in Asia such as *L. cruciata* (Suzuki, 1997; Yuma and Hori, 1981), *L. owadai* (Suzuki, 1997), *L. japonica* (Lloyd *et al.*, 1989b), *Luciola* sp. (Chunram and Lewvanich, 1996) are aquatic lives that occur in freshwater marches, flooded grasslands, rice paddies, and ponds. Another larval species, *Pristolycus*, is not completely adapted to the water because they have no tracheal gill. Similarly, *P. lucifera* have ability to survive under water by absorption of oxygen through the membranous cuticle or through the caudal grasping organ (Buschman, 1984). They are semiaquatic larvae. The firefly larvae were found with other organisms may be due to an overlap in habitats. An exception is *Pleotomodes needhami* coexists with

ants—fungus farming (*Trachymrmex septentrionalis*) and predaceous (*Odontomacnus clarus*)—in order to reduce predation by regard in ant' nests (Sivinski *et al.*, 1998).

All lampyrid larvae are predaceous. The terrestrial larvae feed on land snails and other soft-bodied insects. *Photinus* larvae may specialize on earthworms (LaBella and Lloyd, 1991), larvae of *Stenocladius* also feed on earthworms, and those of *Rhagopthalamus* feed on diplopods (Suzuki, 1997), while the larvae of aquatic and semiaquatic fireflies prey on snails, freshwater limpets, other aquatic insects and their larvae (Buschman, 1984; Chunram and Lewvanich, 1996). Sodeman *et al.* (1980) investigated that lampyrid larvae play a role of natural predators of *Schistosome* vector snails—*Biomphalaria pfeifferi* and *Bulinus globosus*—in Liberia. The lampyrid larva attacks a snail by climbing onto the shell, injecting a toxin from its falcate (hollowed mandibles) and begins feeding when the snail was immobilized (Buschman, 1984; LaBella and Lloyd, 1991). After consuming prey, larva cleans its head and mouthpart with a specialized organ at the tail end, called holdfast organ or caudal grasping organ. Besides cleaning, the organ is used for locomotion and attaching body to the substrate during molting and the pupal stage (Archangelsky and Branham, 1998).

The larval fireflies can also emit light in steady glow that differs from their adults that have a precisely controlled flash pattern. A larval firefly has a bilateral pair of light organ on the ventral side of the eighth abdominal segment. Larval luminescence is an ancestral characteristic that is important for biological meaning and adaptation in evolution. The behavioral function of larval light has been proposed several theories. The larvae sometime glow when mechanically stimulated by touching or vibration or photically with a flashlight or the flash of adult fireflies (Lloyd, 1978). The function of their lights is related to their predatory behavior. They attract preys with their light.

The larvae of some species may use the glow as call other to join their preys because they sometimes hunt large snails or other preys. Each larva has a limited poison reserve for paralyzing preys and could not possibly eat a big snail by itself. Several larvae are found feeding on the same prey. Underwood *et al.* (1997) investigated the hypothesis that bioluminescence in firefly larvae function as "an aposematic display" or predator avoidance. The nocturnal predator can learn the glow for avoiding distasteful (defensive) chemical in prey bodies. When they are disturbed, intensity and frequency of their glow also increase.

3. Pupa

Pupae are exarate. Species of *Photinus* and *Photuris* pupate underground in an excavated cell, in natural cavities in dead logs called "subterranean pupation" (Ross, 1965). Pupae of *Pyractomena* unlike other lampyrids, they climb up on vegetation to pupate called "aerial/arboreal pupation" (Fig. 1) (Buschman, 1984; Lloyd, 1997), probably as a result of their semiaquatic habitat. Lloyd (1997) suggested that Pyractomena borealis shows directional orientation in their pupation site on the trees by using sunlight, height on tree bark coarseness and bark thickness of trees for balancing body temperature in various seasons. Pupae are generally milk white with a little yellow or pink pigmentation but the pupae of Pyractomena differ from other lampyrids, they become cryptically pigmented and do not glow when are disturbed (Buschman, 1984). An anonymous (1996) suggested that the lack of pigment in terrestrial pupae (*Photuris*) might be adaptive in 2 respects. Firstly, the translucent tissue shows entire animal glows when it is touched. This light may deter predators that may break into the chamber and damage the transformer. Secondly, pigmentation may use expensive energy. Pupal duration varies about a week (Pyropyga,

Pyractomena, and Luciola) to 2, 3 or more (Photuris) (Buschman, 1984; Chunram and Lewvanich, 1996; LaBella and Lloyd, 1991). The pupal stage of P. lucifera is significantly longer in males than in females (T-test, $p \le 0.05$); therefore, the females emerge firstly (Buschman, 1984). The size of mature larvae is a character concerned with survival during pupal stage and related to temperature (Yuma and Hori, 1981).

4. Adult

Most adult fireflies are typical soft-bodied beetles with size from 1/5 to 1 inch (5 to 25 millimeters) with the pronotum extending forward over the head. The males have developed wings. The female of some species is short-winged (brachypterous), wingless (apterous), or larviform (pleotomous) (LaBella and Lloyd, 1991) that is often called "glowworm". The male has large eyes and two segments of light producing organ at the tip of the abdomen while the female has only one segment.

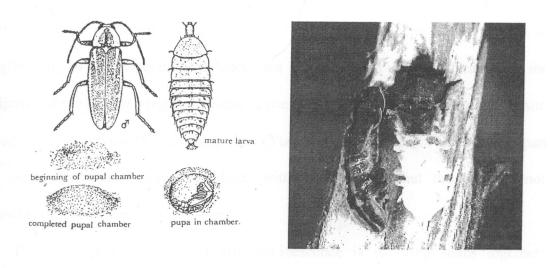


Fig. 1. Pupation of fireflies; a) subterranean pupation of *Photurus pennsylvanicus* under ground (Ross, 1965), b) arboreal pupation of *Pyractomena borealis* (Lloyd, 1997).

Emerged season of each species is different. In Japan, adult males of *L. cruciata* appear from early June to early July and females emerge about a week after the males (Yuma and Hori, 1981) while the common English glowworms, *Lampyris noctiluca*, emerge in April or May. Chunram and Lewvanich (1996) suggested that many *Luciola* adults appeared in early rainy season.

Yuma and Hori (1990) investigated that adult of *L. cruciata* with different ages showed different behaviors. Most virgin females were found near the ground because they emerged from the pupal cell under ground. Flying females were individuals searching for oviposition sites along the riverbank when they increased age gradually, they changed their resting sites from the ground, onto broad-leaves trees. About 99.99% of visible flashes are from males because females turn their attention to lay eggs after mating (Tweit, 1999). The females choose moist oviposition sites because of mortality due to dehydration. In *L. cruciata*, females congregate for oviposition at a particular site, this phenomenon will be called "gregarious oviposition" that consists in a glow of 10-30 ovipositing females that attracts other females searching for ovipositing sites. The gregarious habit is useful to find a favorable oviposition site along rivers by saving the searching time (Yuma and Hori, 1981). Female life span (*P. lucifera*) is significantly correlated with pupal weight but the male is not (Buschman, 1984).

The main purpose of the firefly luminescence is to bring sexes together; therefore, the flashes of light are used for sexual communication. The coding of flashes may be varied to produce species-specific signals that are color, brightness, frequency of emission, shape and size of light organ. These differences are important in reproductively isolating species that are active in same habitat and same temporal

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activity (Lloyd, 1973). In places with only one species of fireflies, the mate matching communication is simple. In some places, two or more species live together, each species has developed their specific courtship pattern to prevent interbreeding. The males fly at different heights and different flight patterns to show glowing curves. Flashes of some species differ in length, number of pulses per flash, and sometime in color or intensity of the light (Fig. 2) (Matthews and Matthews, 1978; Tweit, 1999). The beginning time of flashing activity is a factor that prevents interbreeding because it correlates with the colors or wavelength of firefly light. The early-starting (duskactive) species emit yellow light, beginning flashing activity after sunset while the late-starting (dark-active) species emit green light, beginning later. This phenomenon comes from an adaptation of dusk active species to maximize sensitivity in circumstances with high green foliage-reflected light intensity (Lall et al., 1980). In Pteroptyx fireflies, the males have a special structure, which may prevent other males from taking over a receptive female that is the hooked elytra tips. The *Pteroptyx* males use it to clamp the female during mating (Wing et al., 1983).

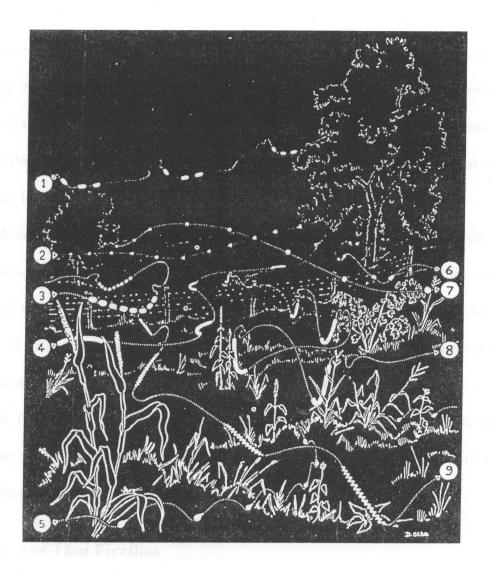


Fig. 2. Patterns of light flashes of 9 species of *Photinus* fireflies, illustrating differences in habitats and flash parameters which help to maintain reproductive isolation between the species: (1) *Photinus consimilis* (slow pulse), (2) *P. brimleyi*, (3) *P. consimilis* (fast pulse) and *P. carolinus*, (4) *P. collustrans*, (5) *P. marginellus*, (6) *P. consanguineus*, (7) *P. ignitus*, (8) *P. pyralis*, and (9) *P. granulatus* (Matthews and Matthews, 1978).

Taxonomy of Fireflies

Taxonomic studies of adult fireflies have been revised by many entomologists since the half of 18th century and in 1964, McDermott (Suzuki, 1997) made the clear outline revision of taxonomy of the fireflies of the world. Ballentyne has revised the Australian and Asian fireflies and made keys for identify them (Ballantyne and Buck, 1979; Ballantyne and McLean, 1970; Ballantyne, 1987). Those are useful to classify fireflies in Thailand.

Although the biology and behavior of adult fireflies have received much attention, the description of the immature stages is very brief because they are very difficult to rear in laboratory. Only 8 of 18 genera of Nearctic fireflies were described and 4 of them were described in Europe and Brazil. Recently, larval description of *Pyractomena borealis* was described by Archangelsky and Branham (1998).

In Thailand, the morphology of adults and their larvae has been poorly studied and has not yet published any publication. Hopefully, this study will light up the identification of some Thai fireflies.

Reviews of Thai Fireflies

Synchronous flashing fireflies in South East Asia have been reported more than two hundred years ago. The unison flashes of *Pteroptyx* species is an amazing phenomenon, which occurs only in some tropical areas. The first observation of Thai fireflies along Chao Phraya River in Bangkok was reported by Smith in 1935 and after that the biology of synchronous fireflies was investigated (Buck and Buck, 1966; 1976). In 1969, rearing *Luciola circumdata* Mots. was started on the basic study of fireflies in laboratory that could explain their life cycle, development, and structure of

light organ (Therapat, 1969). Because of the interesting behavior of synchronous fireflies, many entomologists investigated them. Wing et al. (1983) suggested that the strange morphology of elytral tips of *Pteroptyx* fireflies is used to clamp the female during mating to prevent interbreeding as well as being the major character for identifying the genus *Pteroptyx* from other genera. Two common congregating species of Thai synchronous fireflies are *P. malaccae* and *P. valida*. Both species are commonly found in the same habitat. Their ecology, flashes and behavior were explained and compared by Lloyd et al. (1989a). *Luciola* fireflies are commonly found throughout the year. Their ecology and flashing behavior were observed by Lloyd et al. (1989b) and were reared for their life cycle study (Chunram and Lewvanich, 1996).

In 1997, the research program entitled "A study of diversity of fireflies in Thailand" was launched by Her Majesty Queen Sirikit with the participation of various universities for conservation purposes. A story of the fireflies was then published in many Thai popular magazines (จินคาแสง, 1997, Suntivutimetee, 1998) and known as an indicator of healthy natural environment.

CHAPTER III

STUDY AREAS AND METHODS

Study Areas

The research was carried out to quantify the effect of elevation on diversity of fireflies in two different elevation habitat types, highland and lowland habitats.

1. Highland habitat

Khao Yai National Park was selected for the highland study site. The park is located about 200 km northeast of Bangkok and lies between 14° 05′ and 15° 15′ N and 101° 05′ and 101° 50′ E. The park covers an area of 2,168 km² in 4 provinces: Nakhon Ratchasima, Nakhon Nayok, Sara Buri, and Prachin Buri. The park is mountainous and is the watershed area of important rivers, Lam Takhong, NaKhon Nayok river, and etc. Khao Yai had been regarded as one of the best conservation management areas in the world at a world conference on National Parks in 1972. Nineteen years later, the Royal Thai government proposed Khao Yai as a UNESCO World Heritage Site (Srikosamatara and Hansel, 1996). Therefore, Khao Yai National Park is an important wildlife conservation area in Thailand.

The climate of Khao Yai National Park is influenced by monsoons. The annual precipitation is about 2,270 mm. There are 3 distinct seasons: winter, summer, and rain. The winter season, November-February, is rather dry with an average temperature of 17 °C. The summer has an average temperature of 28 °C, which occurs in March-May. The longest season, rainy season, occurs from June to October. An average humidity is about 86 percent (Srikosamatara and Hansel, 1996).

Pha Kluai Mai waterfall (Fig. 1) is one from over 20 waterfalls in Khao Yai National Park. Its origin is Lum Taklong river branch. That is located about 7 km from the park headquarters. At this site, a trail leads to Haew Suwat waterfall with 3 km long, the trailhead is located at the far end of the camping area. This trail is along the Lam Taklong and passes tropical rain forest (Fig. 2-3) with high humidity. The site is a comfortable trail and safe from dangerous nocturnal wildlife. Therefore, a part of this trail was selected for my study site. This area is about 680 m high from sea level. The distance of study site is about 300 m.

2. Lowland habitat

The lowland habitat was classified in two characters depending on salinity of water—freshwater area and brackish water area.

2.1 Freshwater area

The freshwater area is a habitat where water has no salinity property. The middle pond behind the gymnasium in Salaya campus, Mahidol University (Fig. 4) in Nakhon Pathom province was selected for the study site. The pond's size is 200 X 300 m² of standing water. The pond is close to the road; therefore, it is annoyed with the yellow light from road at night. There are many trees around the pond that can shed a part of the road light. This habitat has many various aquatic vegetation such as cattail (*Typha angustifolia*), *Brachiaria mutica*, water hyacinth (*Eichhornia crassipes*), *Pistia stratiotes*, *Lemna minor*, and *Wolfia* sp., and etc (Fig. 5). Many aquatic faunas—fishes, snails, and aquatic insects—were found abundantly. The quality of water had zero percent of salinity and pH = 7.0.

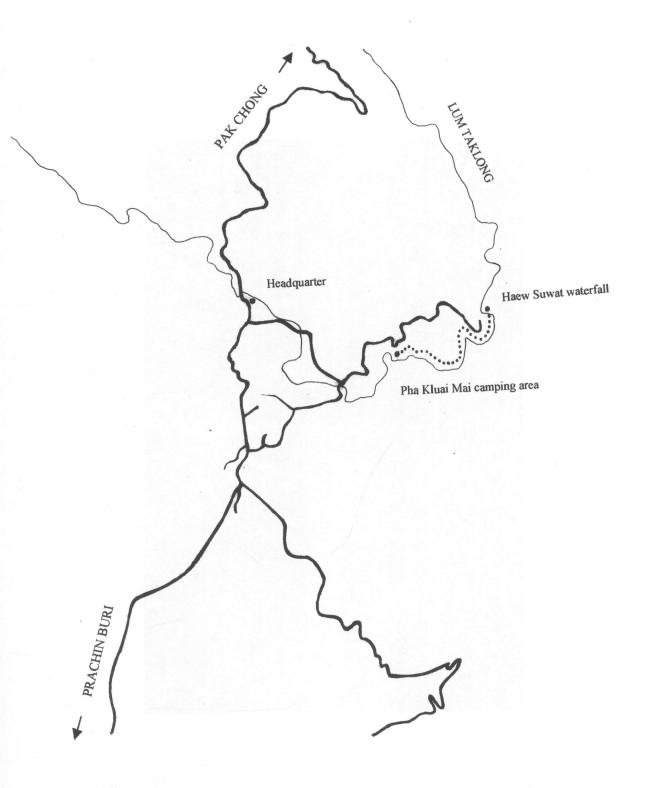


Fig. 1. Map of highland habitat, Pha Kluai Mai Waterfall in Khao Yai National Park; doted line represent trail to Haew Suwat waterfall



Fig. 2. The characteristic of highland habitat in Pha Kluai Mai waterfall



Fig. 3. The study trail along the Lum Taklong

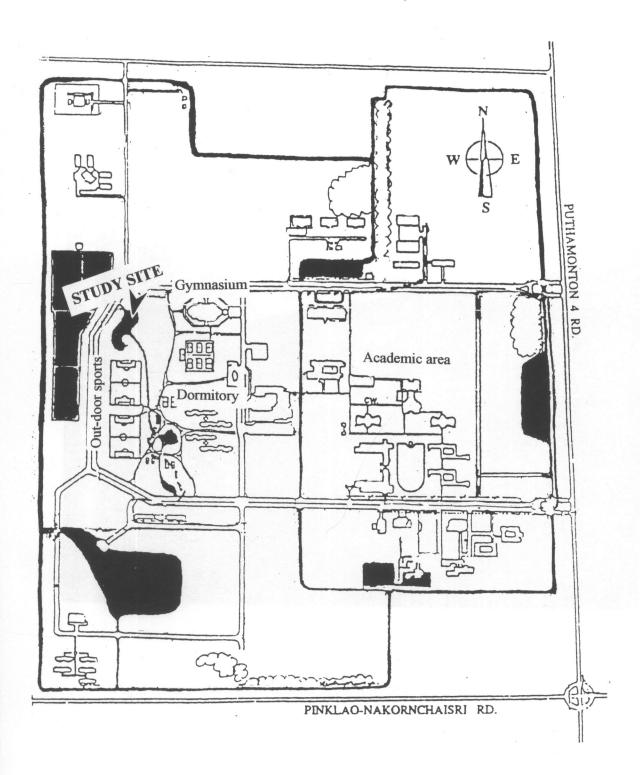


Fig. 4. Map of freshwater area in Salaya campus, Mahidol University



Fig. 5. Freshwater area in Salaya campus, Nakhon Pathom province

2.2 Brackish water area

In a brackish water area, the salinity of water is changeable that is under tidal influence depending on moon factor. The brackish water areas are found along the estuarine rivers with many kinds of mangrove trees where occur congregations of fireflies. In lowland regions of Thailand are found many brackish water areas along many rivers—the Chao Phraya, Tha Chin, and Mee Klong river.

2.2.1 The Mee Klong riverbank in Samut Songkram

The study site was settled in a part of Klong Sunak Hon (Fig. 6-7) which is a branch of Mee Klong river. The distance of study site is about 3 km. At the site, the mangrove vegetation was dominated by *Sonneratia caseolalis* (Lum Poo) where were found congregation of fireflies. This canal is large and used for water transportation and rearing freshwater shrimps. The fireflies are observed from a small boat. The salinity of water at the study site was in range 0-9% that will naturally vary depending upon season, tidal, and rainfall. The pH of water is equal 7.0.

The destruction of the study site comes from construction of dwelling places. The light from houses and rearing freshwater shrimp containers affects the number of fireflies in the site.

2.2.2 The Chao Phraya riverbank in Samut Prakarn

A part of Amphoe Phra Phradaeng, Samut Prakarn province, is almost surrounded with the Chao Phraya river, be called "Krapor Mu" (Fig. 8) because it looks like the pig's stomach. This area is very interesting because it still conserves nature and is close to Bangkok. Most of the area is used for agriculture and living.

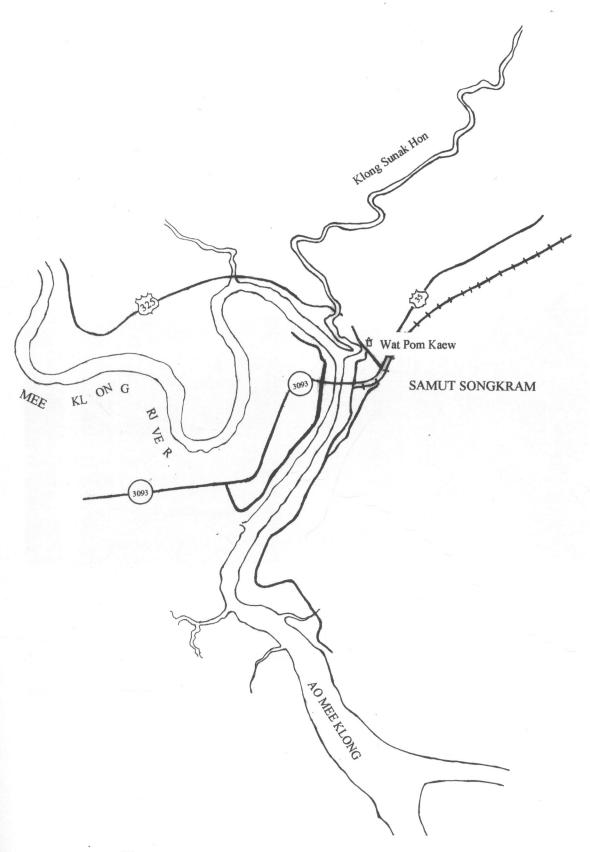


Fig. 6. Map of brackish water area in Samut Songkram



Fig.7. The Brackish water area is in Klong Sunak Hon, Mae Klong river in Samut Songkram province.

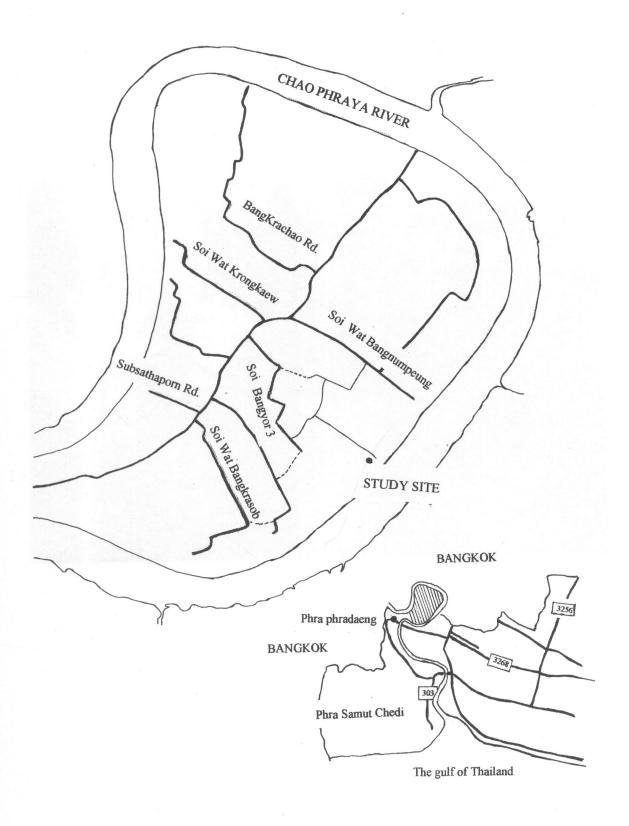


Fig. 8. Map of brackish water area in Samut Prakarn



Fig.9. The brackish water area, the Chao Phraya riverbank in Samut Prakarn province.

The climate is similar to Bangkok. The elevation from sea level is less 1 m. The study site is in the east of Khrapor Mu with 200 X 200 m² (Fig. 11.) where stand many kinds of mangrove trees such as *Sonneratia caseolaris*, *Acanthus ebracteatus*, *Nypa fruiticans* (Chak), and etc.

The disadvantage of this study site come from the road light that occurred after setting the research. That affects directly the occurrence of fireflies.

Field Activities

Two types of surveys were carried out as follows:

1. To study diversity and seasonal abundance of fireflies were carried out for 18 months (June 1998-November 1999). This was conducted in 4 habitats, Nakhon Ratchasima, Nakhon Pathom, Samut Songkram, and Samut Prakarn. The methods for estimating firefly population were different. The collections of highland adults were carried out by the roadside count method, walking along the waterfall trail, while the lowland fireflies used total count method.

The field activity began at sunset time and observed for 2 hours. At night, it is difficult to see the path; therefore torchlight is very necessary. But the white light may affect the firefly behavior; therefore, the red filter is useful to reduce wavelength into red light that less affects the vision of insects (Chapman, 1998). Adult fireflies can clearly be observed their flashing lights from their abdomen. They were captured by sweeping nets and collected individually in 2.5 cm diameter and 5.5 cm in height of plastic boxes for clearly identifying species and sexes. The captured fireflies were released after counting and identifying except for few samples of some species that were difficult to identify. The location and activity of fireflies were recorded in 4

categories: resting near ground (on ground or grass below 10 cm), resting on shrub, resting on tree, and flying.

The firefly larvae are in damp and concealing habitats but they will present themselves by steady light from their abdomen. Although their lights are little, they can be seen clearly at night. In highland habitat, there are several kinds of larvae that they are very difficult to identify in the field. Therefore, they were classified in different groups by morphology and recorded their microhabitats in 2 categories: on ground or resting on shrub. Larval positions on shrub were measured.

The climatic data, including daily minimum and maximum temperature (°C), daily minimum and maximum relative humidity (%), and rainfall (mm) were obtained from the weather station of Khao Yai National Park and Computer Sub-division, Climatology Division, Meteorological Department.

2. To study temporal activity and the effect of moonlight were conducted in Khao Yai National Park to investigate time activity of each species and to quantify the effect of moon cycles on firefly abundance. The waterfall trail was divided into 2 sites with 50 m in length. The study were carried out in 2 moon phases—new moon and full moon—that covered 3 moon cycles in March to May 2000 and each phase consisted of 3 nights. The fireflies were hourly captured overnight from 18.30 p.m. to 05.30 a.m. in the first 40 min of each hour with the same technique in monthly monitoring. The firefly samples were counted, identified, and released at each study site. In this study, the fireflies can be reset for 15 min in each period.

Physical environments study for the effects on firefly abundance, minimum and maximum temperature (°C), minimum and maximum relative humidity (%), and luminosity (lux) were hourly recorded.

Laboratory Investigation

Adult fireflies were collected from the field observation and were kept in plastic boxes with diameter of 13 cm with moist cotton and allowed to oviposit eggs. The oviposited eggs were daily removed, counted, and measured the diameter (in millimeter) then waited for hatching into larval stages. Newly emerged larvae were removed in new plastic boxes and supplied daily with land snails or earthworms. The rearing containers were daily cleaned to avoid growing of fungus and depositing of insect excrements. The developmental duration was recorded.

The unidentified specimens were preserved in 70% ethyl alcohol and pinned for further identification.

Data Analysis

The species diversity of fireflies was calculated using Shannon index, H', in Shannon-Weiner equation. The number of species and the number of individual in each species must be calculated (Krebs, 1989).

$$S$$

$$H' = -\sum_{i=1}^{\infty} p_i \log_2 p_i$$

H' = Index of species diversity (bit)

S =Number of species

pi = Proportion of total sample belonging to ith species

It should be noted that any base of logarithms can be used for this index, since they are all convertible to one another by a constant multiplier: H' (the base is 2) = 3.321928 H' (the base is 10)

H' (the base is e) = 2.302585 H' (the base is 10)

The most commonly used index of evenness in the literature is based on the Shannon-Weiner function

$$J' = H'/H'_{MAX}$$

J' = Evenness measure or equitability (range 0-1)

H' = Shannon-Weiner function

 $H'_{MAX} = Maximum value of H' = log_2S$

A greater number of species increases species diversity, and a more even or equitable distribution among species will also increase species diversity that can be measured by the Shannon-Weiner function (Krebs, 1989).

Multiple linear regression (Kleinbaum *et al.*, 1998, Sokal and Rohlf, 1969) was used to determine the linear relationship between the dependent variable (the number of fireflies) and the independent variables (hourly climatic factors—relative humidity, minimum temperature and maximum temperature. The numbers of fireflies were transformed by square root to linearlize. The multiple regression analysis was used to determine the linear relationship between monthly climatic factors (20 days before observing in highland and 10 days before observing in lowland) and the number of fireflies. The logarithm transformation was used on the number of fireflies in freshwater habitat and the number of fireflies/tree in brackish water habitat to linearize. Correlations between each independent variable were calculated to determine the indirect factors.

Nonparametric method, Kruskal-Wallis test, was used to compare the difference of firefly occurrence between full moon and new moon nights. These tests are performed with SPSS 10.0.5 for window program.

CHAPTER IV

RESULTS

Species Diversity of Fireflies

The firefly species were recorded from June 1998 through May 2000. They consisted of 14 species in 8 genera—*Diaphanes* (2 species), *Lamprigera* (1 species), *Luciola* (5 species), *Pyrocoelia* (1 species), *Pteroptyx* (2 species), Unknown genus A (1 species), Unknown genus B (1 species) and Unknown genus C (1 species) (Fig. 1). Eleven species in 7 genera of fireflies were collected from the highland habitat and only 3 species in 2 genera were collected from lowland habitat.

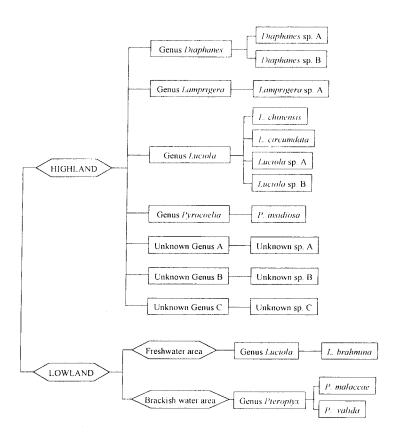


Fig. 1. The diversity of firefly species in highland and lowland habitat

1. Description of firefly species by morphology

The firefly species were characterized by their morphology. Ballantyne and Buck (1979) and Ballantyne and McLean (1970) assigned the morphological features.

Taxonomic consideration

Length of pronotum (L) = longitudinal measuring at the median length of the pronotum

Width of pronotum (W) = measuring at the broadest region of the pronotum Average ratio of pronotal width/length = W/L ratio

The length of entire specimen (LS) = length of elytron + length of pronotum G Greatest head width (GHW) = measuring horizontally across and including the eyes

MFC = metathoracic femoral comb

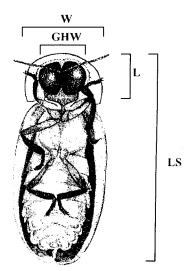


Fig. 2. The taxonomic consideration shows length of pronotum (L), width of pronotum (W), greatest head width (GHW), length of entire specimen (LS).

1.1 Diaphanes sp. A

Description of male (Fig. 3a) — Length: 10.2-10.3 mm.

Head:

Head covered by pronotum in withdrawn condition, contain the large eyes, GHW 2.3-2.4 mm, has a circle ridge around eyes, filiform antennae; dark brown to black; 1.8 mm long, neck red.

Pronotum:

2.4-2.5 mm long, 3.7-3.9 mm wide, W/L = 1.52, dirty dingy yellow, anterior margin rounded, lateral margins slightly arcuate, posterior margin not indented, anterolateral areas with transparent areas.

Elytra:

7.8 mm long, 2.6 mm wide, brown bordered laterally with yellow.

Abdominal segments: White to light brown acute projections on postero-lateral corner, basal abdominal sternites light brown, legs brown with tarsi and tibia dark brown to black.

Light organ:

Filling in sternites 6 and 7 with bean shape white plates.

Description of larva (Fig. 3b)

Thorax:

Three segments, pronotum subrectangular wider at base, little convex at the apex, contain retracted head, meso-metathorax subrectangular not wider than prothorax, thoracic tergites subdivided by a sagittal line, sternites contain color pattern.

Abdomen:

Segments, 1-8 similar in shape, becoming narrower toward end, each tergite subrectangular divided by a sagittal line with a small lateral projection on each side point, segment 8 carrying light organs in ventral.

1.2 Diaphanes sp. B

Description of male (Fig. 3c) — Length: 10 mm.

Head:

Head covered by pronotum in withdrawn condition, contain the large eyes, GHW 2.1 mm, has a circle ridge around eyes, large eyes, filiform antennae; dark brown to black; 2.0 mm long, mouthparts dark brown to black, neck red.

Pronotum:

2.6 mm long, 3.3 mm wide, W/L = 1.27, anterior margin rounded, lateral margins slightly arcuate, posterior margin not indented, dirty dingy yellow, anterolateral with transparent areas.

Elytra:

7.4 mm long, 2.2 mm wide, elytra dingy yellow with apical dark brown.

Abdominal segments: Basal abdominal sternites light brown, acute projections on postero-lateral corner, legs brown with tarsi and tibia dark brown to black.

Light organ:

Filling in sternites 6 and 7 with bean shape white plates.

1.3 Lamprigera sp. A

Description of male (Fig. 4a) — Length: 15-16 mm.

Head:

Head covered by pronotum in withdrawn condition, moderately depressed between eyes, GHW 4-4.2 mm, head black, densely hairly filiform antennae with brown to black; 2-2.5 mm long, mouthparts dark.

Pronotum:

3.6 mm long, 6.9 mm wide, W/L = 1.9, anterior margin barely produced, lateral margins rounded, light brown with median black marking on disc, anterolateral areas with light brown band.

Elytra:

13.2 mm long, 4.2 mm wide, brown, shorter than abdomen.

Abdominal segments: With black acute projections on postero-lateral corner, legs black, basal abdominal sternites black.

Light organ:

Occupying entirely sternites 6 and 7.

Description of female (Fig. 4b)

Thorax:

Three segments, pronotum subtriangular; orange, mesometathorax subrectangular with antero-lateral margins rounded; black with lateral margins orange.

Abdomen:

Similar in shape and color with meso-metathorax, becoming narrower toward, except tergite 6-8 orange.

1.4 Luciola brahmina

Description of male (Fig. 5a) — Length: 8.6-8.7 mm.

Head:

Head not covered by pronotum in withdrawn condition, moderately depressed between eyes, GHW 2.1 mm, head black, fliliform antennae; black; 2.1 mm long, mouthparts dark brown to black.

Pronotum:

1.6 mm long, 2.8-2.9 mm wide, W/L = 1.85, anterior margin barely produced, lateral margins slightly arcuate, posterior margin shallowly trisinuate, light brown with 2 dark brown pionts on disc.

Elytra:

7.2 mm long, 1.9 mm wide, dark brown with apical dark brown, dark brown at the bases of elytra, edges of elytra with light brown.

Abdominal segments: Sternites dingy yellow except sternite 5 black, black, legs yellow to yellow-brown with tarsi and tibia dark brown.

Light organ:

Occupying entirely sternites 6 and 7, sternite 7 of simple outline with median posterior projection round.

Description of larva (Fig. 5b)

Thorax:

Pronotum subtriangular, narrowed anteriorly, and metathorax subrectangular, dark brown.

Abdomen:

Each tergite subrectangular, segment 8 carrying light organs in ventral, dark brown.

1.5 Luciola chinensis

Description of male (Fig. 5c) — Length: 0.91±0.56 cm. (female is bigger than male). The life cycle of L. chinensis see in Appendix A-1.

Head:

Head not covered by pronotum in withdrawn condition, moderately depressed between eyes, GHW 1.3-1.9 mm, head black, filiform antennae; black; 3-4 mm long, mouthparts dark brown to black.

Pronotum:

1.2-1.6 mm long; 2.2-2.5 mm wide; W/L = 1.68; anterior margin barely produced; lateral margins slightly arcuate, posterior margin shallowly trisinuate, pronotum dirty dingy yellow.

Elytra:

6.6-7.2 mm long, 1.5-2 mm wide, dingy yellow to yellow-orange with apical dark brown.

Abdominal segments: Basal abdominal sternites black, legs yellow to yellow-brown with tarsi and tibia dark brown.

Light organ:

Occupying entirely sternites 6 and 7, sternite 7 of simple outline with median posterior projection round.

Description of larva (Fig. 5d) — dorsoventrally flattened, dirty white to cream with black dorsal shields on all segments and dirty white legs.

Thorax:

Three segments, prothorax subtriangular, meso and metathorax subrectangular narrower than prothorax, lateral margins arcute, posterior margin shallowly trisanuate, depressed area in midlateral area of disc.

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Abdomen:

Similar in shape with meso and metathorax, becoming narrower

toward end.

1.6 Luciola circumdata

Description of male (Fig. 5e) — Length: 10.5-10.9 mm.

Head:

Head not covered by pronotum in withdrawn condition, small with large eyes, moderately depressed between eyes, GHW 2.3-2.4 mm, filiform antennae; dark brown to black; 3.3-3.8 mm long, mouthparts black.

Pronotum.

2.1-2.3 mm long, 3.9-4.0 mm wide, W/L = 1.74-1.86, large subtriangular covering head, anterior margin produced, lateral margins rounded, posterior margin indented, orange.

Elytrra:

8.4-8.7 mm long, 2.5-2.8 mm wide, cover fitting abdomen, black bordered laterally with orange.

Abdominal segments: Basal abdominal sternites black, legs orange with tarsi and tibia dark brown to black.

Light organ:

Filling sternites 6 and 7 of simple outline with median posterior projection round.

Description of larva (Fig. 5f) — onisciform almost all black except for dingy yellow prothorax tergum and lateral yellow marking.

Thorax:

Three segments, prothorax subtriangular, little convex at the apex, meso and metathorax subrectangular narrower than prothorax.

Abdomen:

Similar in shape with meso and metathorax, becoming narrower toward end.

1.7 Luciola sp. A

Description of male (Fig. 5g) — Length: 9.8-10.0 mm.

Head: Head not covered by pronotum in withdrawn condition, deeply

excavated between eyes, GHW 1.9-2.0 mm, black, filiform

antennae; black; 3.8-4.1 mm long, mouthparts black.

Pronotum: 1.3-1.7 mm long, 3.2-3.4 mm wide, W/L = 2.0-2.46, anterior

margin barely produced, lateral margins slightly arcuate,

posterior margin shallowly trisinuate, dirty dingy yellow.

Elytra: 8.5-8.6 mm long, 1.8-2.0 mm wide, dingy yellow to brown with

apical black.

Abdominal segments: Basal abdominal sternites black, legs yellow to yellow-brown

with tarsi and tibia dark brown.

Light organ: Filling sternites 6 and 7, sternite 7 of simple outline with

median posterior projection truncate.

1.8 Luciola sp.B

Description of male (Fig. 5h) — Length: 6 mm.

Head: Head not covered by pronotum in withdrawn condition, deeply

excavated between eyes, GHW 1.5 mm, black, filiform

antennae; black; 2.1 mm long.

Pronotum: 0.84 mm long, 1.5 mm wide, W/L = 1.79; with median dark

brown markings, midanterior margin rounded; lateral margins

slightly arcuate, orange to brown.

Elytra: 5.16 mm long, 0.9 mm wide, dark brown.

Abdominal segments: Basal abdominal sternites dark brown, legs dingy yellow with

anterior femur, tibiae and tarsi dark brown.

Light organ: Filling sternites 6 and 7, sternite 7 of simple outline with

median posterior projection round.

1.9 Pteroptyx malaccae

Description of male (Fig. 6a) — Length: 6.42 mm.

Head not covered by pronotum in withdrawn condition, deeply

excavated between large eyes, GHW 1.44 mm, head black,

filiform antennae; brown; 3.6 mm long mouthparts dark brown.

Pronotum: 0.9 mm long, 2.2 mm wide, W/L = 2.4, mid anterior margin

produced, lateral margins slightly arcute, posterior margin

shallowly trisinuate, yellow-orange.

Elytra: 5.8-6.0 mm long, 1.3-1.4 mm wide, deflexed apex bluntly

triangilar, cream to ochreous with apical dark brown.

Abdominal segments: Abdominal sternites yellow, legs yellow to yellow-brown with

tarsi and anterior tibial surfaces dark brown.

Light organ: Filling sternites 6-7 each with a pair of posterolateral projection.

1.10 Pteroptyx valida

Description of male (Fig. 6b) — Length: 10.8 mm, MFC present.

Head:

Head not covered by pronotum in withdrawn condition, moderately excavated between eyes; eye large; GHW 2.3 mm, yellow to light brown, darker at vertex, filiform antennae; brown; 4.2 mm long mouthparts dark brown except labrum yellow.

Pronotum:

1.6 mm long, 3.5 mm wide; W/L=2.19; midanterior margin produced angularly; posterior margin shallowly trisinuate; lateral margins slightly arcute, yellow-orange.

Elytra:

9.2 mm long, 1.9 mm wide, tip of deflexed apex smoothly truncate, brownish-yellow, apices dark brown.

Abdominal segments: Abdominal sternites yellow, legs yellow to yellow-brown with brown tarsi and anterior tibial surfaces dark brown.

Light organ:

Filling sternites 6 and 7; lateral corners not projecting posteriorly; median posterior projection very broad.

1.11 Pyrocoelia insidiosa

Description of male (Fig. 7a) — Length: 14 mm.

Head:

Head covered by pronotum in withdrawn condition, very small with small eyes, GHW 1.8 mm, head brown, serrate antennae; dark brown; 5.1 mm long, mouthparts brown.

Pronotum:

3 mm long, 4.6 mm wide, W/L = 1.53, large subtriangular covering head, anterior margin produced, lateral margins rounded, posterior margin indented, anterolateral areas with transparent areas, yellow to orange.

Elytra:

11 mm long, 3.1 mm wide, cover longer than abdomen, dingy yellow to yellow-orange bordered laterally with orange.

Abdominal segments: Wider than long, becoming narrower after tergites 3, with brown acute projections on postero-lateral corner, basal abdominal sternites dark brown, legs yellow to yellow-brown with tarsi and tibiae dark brown.

Light organ:

Filling sternites 6 and 7.

Description of larva (Fig. 7b)

Thorax:

Three segments, prothorax subrectangular wider at base, little convex at the apex, containing retracted head when larva in response, meso and metathorax subrectangular wider than prothorax, tergites subdivided by a sagittal line, sternites containing color pattern.

Abdomen:

Segments 1-8 similar in shape, becoming narrower toward end, each tergite subrectangular divided by a sagittal line with a small lateral projection on each side point, segment 8 carrying light organs in ventral, tergites subdivided by a sagittal line, sternites divided by 2 lines.

1.12 Unknown sp. A

Description of male (Fig. 8a) — Length: 5.7 mm.

Head:

Head covered by pronotum in withdrawn condition, moderately excavated between large eyes, GHW 1.1 mm, filiform antennae; dark brown; 2.3 mm long, mouthparts brown.

Pronotum:

 $1.0\,$ mm long, $1.6\,$ mm wide, W/L=1.6, large subtriangular covering head, anterior margin round, lateral margins rounded, yellow to orange.

Elytron:

4.7 mm long, 1.1 mm wide, cover longer than abdomen, black bordered laterally with orange.

Abdominal segments:

Wider than long, becoming narrower after tergite 3, abdominal sternites dark brown, legs yellow to yellow-brown with tarsi and tibiae dark brown, has projecting on the posterior margin of sternite 7.

Light organ:

Filling sternites 6 and 7, sternite 7 has projection.

1.13 Unknown sp. B

Description of male (Fig. 8b) — Length: 8 mm.

Head:

Head covered by pronotum in withdrawn condition, contain the

large eyes, GHW 1.4 mm, has a circle ridge around eyes,

moniliform antennae; brown; 2 mm long, mouthparts brown.

Pronotum:

1.0 mm long, 1.7 mm wide, W/L = 0.59, anterior margin

rounded, lateral margins slightly arcuate, posterior margin not

indented, yellow to ochre.

Elytra:

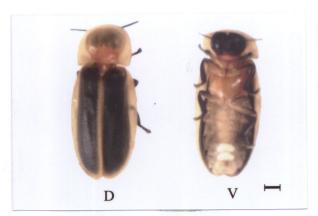
6.5 mm long, 1.2 mm wide, cream to ochreous.

Abdominal segments: With no acute projections on postero-lateral corner, abdominal

sternites dark brown, legs brown.

Light organ:

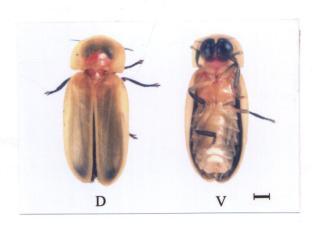
filling in the middle sternites 6 and 7.





a)

b)

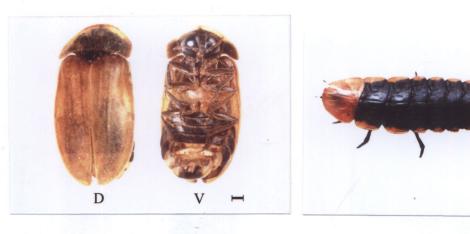


c)

(Scale number in mm)

Fig. 3. *Diaphanes* spp.,

- a) Diaphanes sp. A (adult male), b) Diaphanes sp. A (larva),
- c) Diaphanes sp. B (adult male)





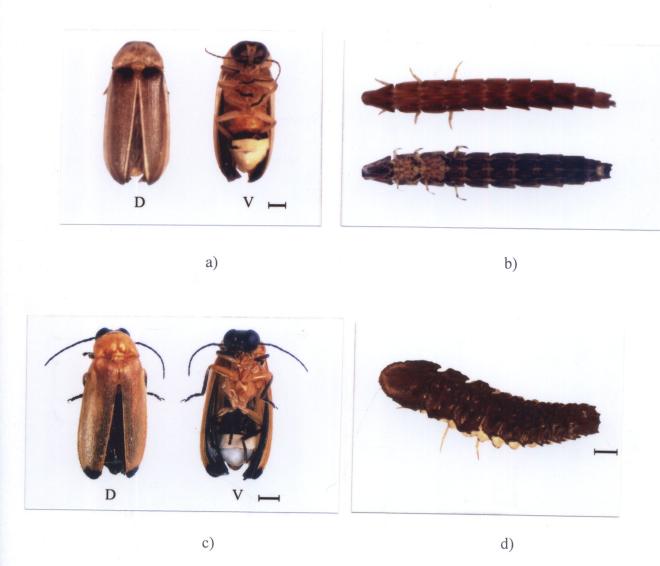
a)

b)

(Scale number in mm)

Fig. 4. Lamprigera sp. A,

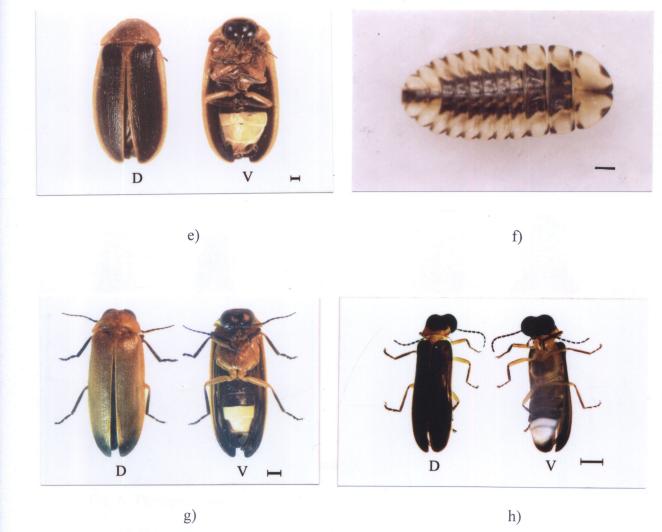
a) Lamprigera sp. A (adult male), b) Lamprigera sp. A (larva);



(Scale number in mm)

Fig. 5. Luciola spp.,

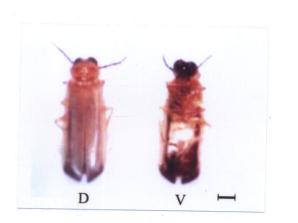
- a) Luciola brahmina (adult male), b) Luciola brahmina (larva),
- c) Luciola chinensis (adult male), d) Luciola chinensis (larva);

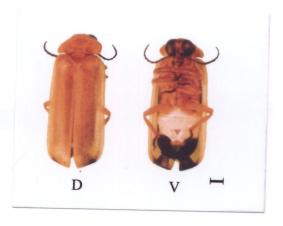


(Scale number in mm)

Fig. 5. Luciola spp.,

- e) Luciola circumdata (adult male), f) Luciola circumdata (larva),
- g) Luciola sp. A (adult female and male), h) Luciola sp. B (adult male)





a)

b)

(Scale number in mm)

Fig. 6. Pteroptyx spp.,

a) Pteroptyx malaccae (adult male), b) Pteroptyx valida (adult male);

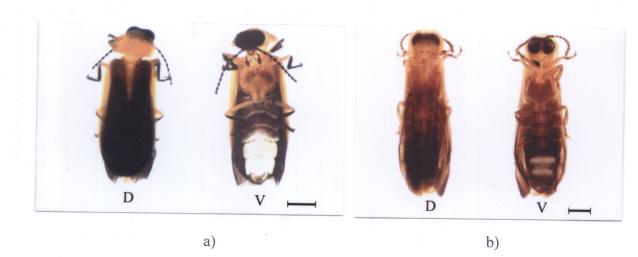


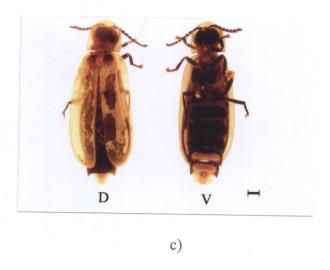


a) b)

(Scale number in mm for adult and cm for larva)

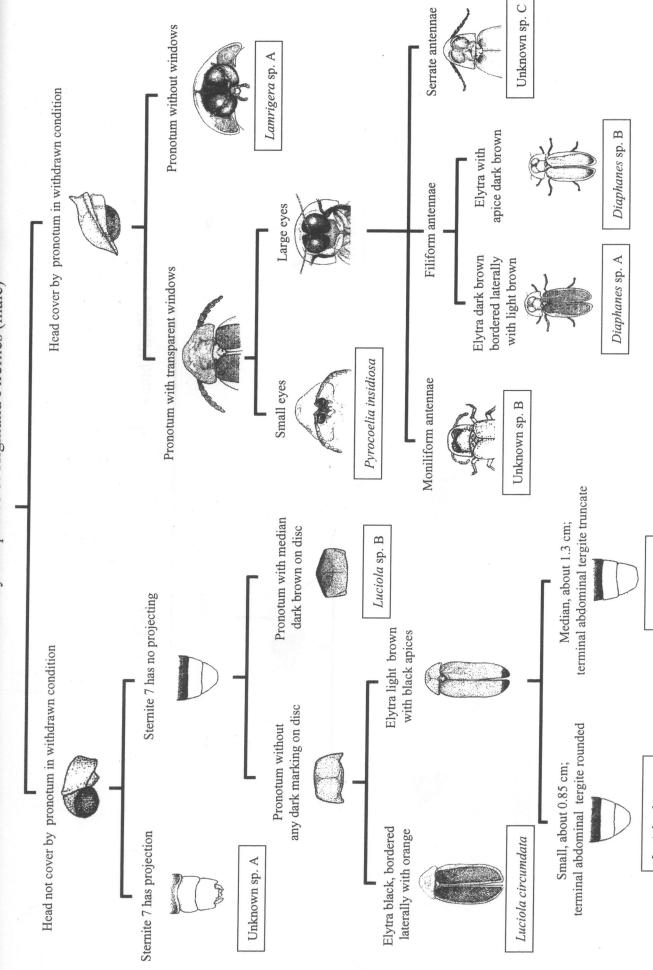
Fig. 7. *Pyrocoelia insidiosa*, a) adult male, b) larva;

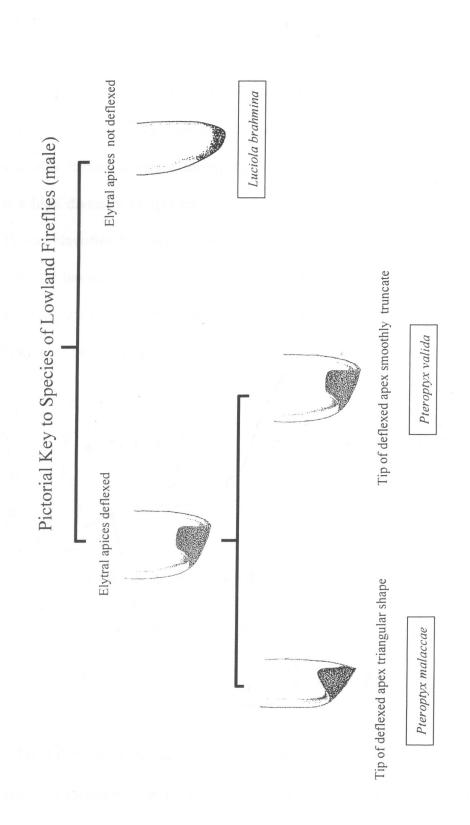




(Scale number in mm)

Fig. 8. **Unknown species** (adult male),
a) Unknown sp. A, b) Unknown sp. B, c) Unknown sp. C





The Ecology of Fireflies

1. Seasonal abundance of fireflies

1.1 Highland habitat

The monthly surveys of fireflies in Khao Yai National Park were used to investigate the long-term seasonal activity patterns of fireflies. The presence of fireflies in this habitat occurred throughout the year with fluctuation in numbers. There is a high diversity of species in this area. An average monthly climatic data (Fig. 11) was classified by quantity of rainfall into 2 periods—wet and dry periods. The wet period has more diversity than the dry period (Table 1, See Appendix A-2). From my observation, the greatest diversity was in May 1999. There were 9 species of fireflies in this period of time.

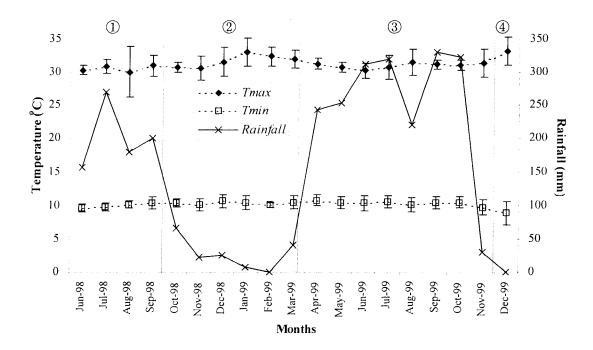


Fig. 11. Average monthly climatic data in Khao Yai National Park

(June 1998-December 1999); ①, ③ = wet periods and ②, ④ = dry periods

	Periods			Wet Period	eriod					Dry Period	eriod		
Firefly	Firefly Species	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Larvae	Diaphanes spp.			×	×	×	×	×	×		×	×	
	Luciola chinensis	×	×	×	×	×	×	×	×	×	×	×	×
,	Luciola circumdata						×						
	Pyrocoelia sp.	×	×	×	×	×	×	×	×				,
Adults	Diaphanes sp. A	: - 	×	×	×	×							
	Diaphanes sp. B		×	×	×		•••••						
	Lamprigera sp. A (male)					×	••••••						
	Lamprigera sp. A (female)	×	×	×	×						×		×
	Luciola chinensis	×	×	×	×	×	×	×	×	×	×	×	×
	Luciola circumdata	×	×	×									
	Luciola sp. A	×	×				•••••						
	Luciola sp. B	×	×										
	Unknown sp. A		×				********						
	Unknown sp. B									×			
	Unknown sp. C										×		
	Species Diversity	9	6	9	5	4	2	2	2	2	2	1	2

Table 2. The occurrence of fireflies in highland habitat (during May 1998-November 1999, Mar-May 2000)

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Table 1. The diversity of firefly species in highland habitat in wet and dry periods

Weather	<i>H</i> ′	H'max	J'
Wet	1.191	3.000	0.397
Dry	0.082	1.585	0.052

Each species of fireflies occurred in different seasons (Figs. 12, 13 and Table 2). Seasonal abundance of highland fireflies showed that firefly abundance was low during winter (November 1998-January 1999 and September-November 1999) and increased after winter. The dominant species of fireflies in Khao Yai National Park, *Luciola chinensis*, were easily found in all seasons. The peak of adult abundance occurred in 2 peaks in a cycle of year, in October 1998 and February 1999 (Fig. 12), that were in the beginning and the end of winter. The numbers of them decreased in winter. The *L. circumdata* adults occurred in short period of summer, April to June, that is the same duration with *Luciola* sp. A, and *Luciola* sp. B (Fig. 12). The two species of *Diaphanes* fireflies, *Diaphanes* sp. A and *Diaphanes* sp. B, were found together in the same period, during May to July. The flying males of *Lamprigera* sp. were found only once in August. The rare species of fireflies—Unknown sp. B, Unknown sp. C, and *Luciola* sp. B—were found in a short period and in less number.

The seasonal abundance of terrestrial larvae is related with adults (Fig. 13). The *L. chinensis* larvae are the most common, and were easily found on the ground. The peak of their abundance was in the end of rainy season (September-October), and was slightly decreased into the winter. The *Pyrocoelia* larvae were found in few numbers. Their abundance occurred in rainy season (April-September) that was overlapped with



Fig. 12. The seasonal abundance of adult fireflies in highland habitat (during June 1998-November 1999)

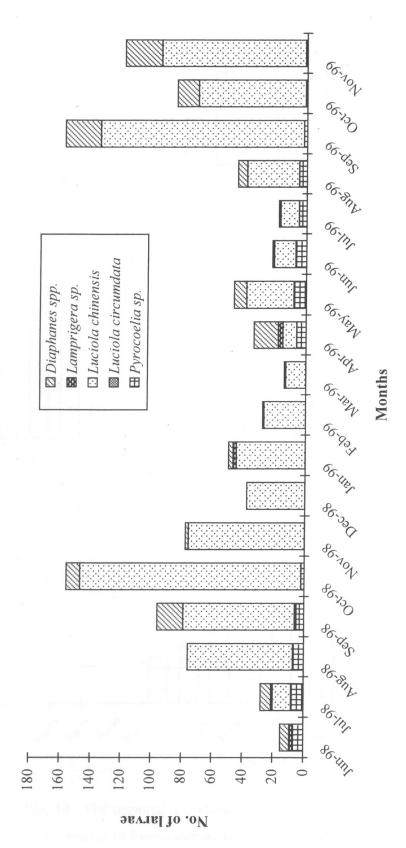


Fig. 13. The seasonal abundance of larval fireflies in highland habitat (during June 1998-November 1999).

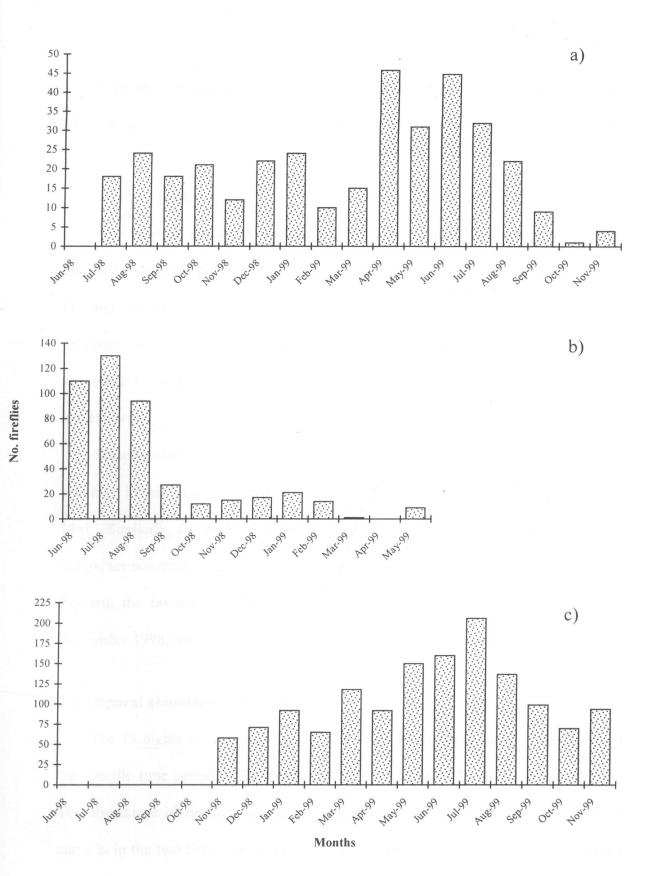


Fig. 14. The seasonal abundance of fireflies in lowland habitats; a) *Luciola brahmina* in freshwater area, Nakhon Pathom, b) *Pteroptyx malaccae* in brackish water area, Samut Prakarn and c) *P. malaccae* in Samut Songkram

the *Diaphanes* abundance (June-November). The *L. circumdata* larvae and larviform of *Lamprigera* females were found in less number that can not clearly explain their seasons.

1.2 Lowland habitat

The seasonal activity of lowland fireflies also occurred throughout the year but there was only one species of fireflies in each habitat. Two different characters of the lowland habitat—freshwater and brackish water areas—showed the existence of different species of fireflies. The population of *L. brahmina* occurred in freshwater area while *P. malaccae* congregated in large population in mangrove trees along rivers and estuaries.

Seasonal abundance of *L. brahmina* in freshwater area showed that its abundance was high in rainy season (April 1999-Auguest 1999) and was low in the winter (Fig. 14a). Similarly, the peak of *P. malaccae* abundance in Samut Prakarn and Samut Songkram occurred in rainy season (Figs. 14b, 14c). In brackish water area in Samut Prakarn, the favorable habitat was changed by the electric light from road since September 1998, led to decrease the fireflies' population permanently (Fig. 14b).

2. Temporal abundance of fireflies

The 13 nights of observations surveyed from the highland habitat that described the specific time period of flashing activities of fireflies in Khao Yai National Park. The abundance of fireflies was high in the first half of the night and their peak of curve is in the two first hour of the night. Each species of fireflies has different time activity. The dominant species of highland fireflies, *L. chinensis*, occurred throughout the night and slightly decreased until sunrise (Fig. 15a).

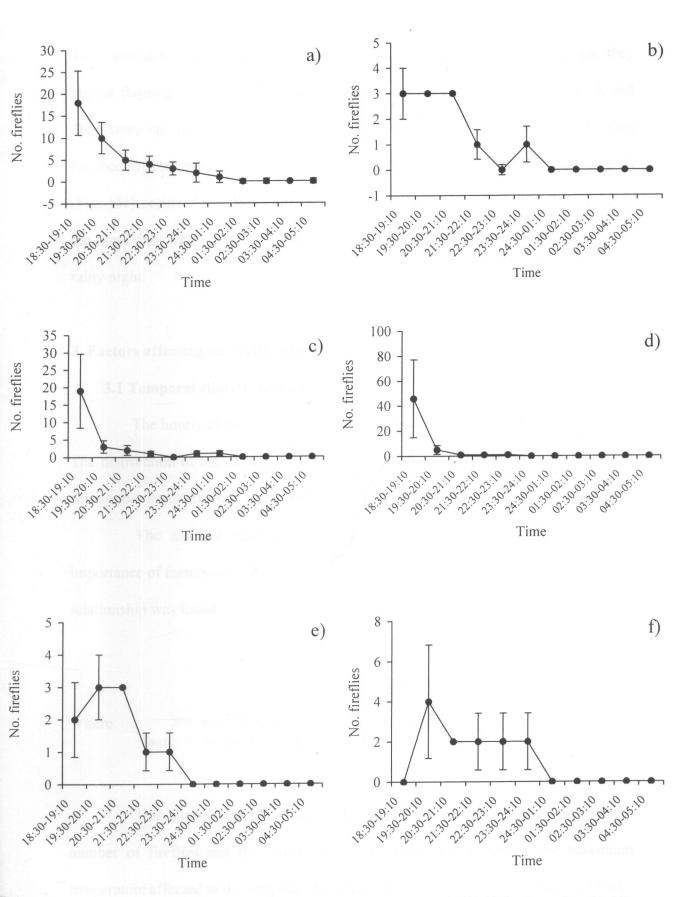


Fig. 15. Temporal activity of each species of fireflies a) Luciola chinensis (N=43), b) L. circumdata (N=11) c) Diaphanes sp. A (N=27), d) Diaphanes sp. B (N=54), e) Luciola sp. A (N=10), f) Unknown sp. A (N=12)

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Their abundant peak is in the first hour after sunset. From my observations, they started flashing before sunset, approximately 10-20 min while *Diaphanes* sp. A and *Diaphanes* sp. B started flashing suddenly after sunset. The *Diaphanes* fireflies finished their activities in 3-4 hours. (Figs. 15c, 15d). The active time of *Luciola* sp. A (Fig. 15e) occurred in 2 hours after sunset and the peak was in the second hour that is the same time with Unknown sp. A (Fig. 15f). The firefly abundance was reduced on rainy night.

3. Factors affecting on firefly activity

3.1 Temporal climatic factors

The hourly climatic data may affect the occurrence of adult fireflies at night.

The distribution of the number of fireflies tends to be Poisson distribution; therefore, square root transformation is the suitable method to linearize the dependent variable.

The multiple regression analysis (Fig. 16) is the best to describe the importance of factors affecting firefly abundance. The following equation indicate the relationship was found (See Appendix A-3):

$$\sqrt{Y} = 0.711 Tmax - 13.465$$

$$R^2 = 0.385, P < 0.05$$

Where

Y = average number of fireflies/site/night,
 Tmax = maximum temperature (°C)

This model describes the relationship between the square root average number of fireflies and the direct factor, maximum temperature. The maximum temperature affected to the temporal abundance of fireflies in Khao Yai National Park.

Other climatic factors may also affect on the temporal abundance of adult fireflies. The correlation between the climatic factors—maximum-minimum temperature and maximum-minimum relative humidity—were calculated in table 2

Table 3. The Pearson correlation coefficients between number of fireflies and hourly climatic factors.

	Ттах	Tmin	RHmax	RHmin
Tmax	(49)	(49)	(48)	(48)
Tmin	0.850*	(49)	(48)	(48)
RHmax	-0.639*	-0.561*	(48)	(48)
RHmin	-0.830*	-0.608*	0.871*	(48)

^{*} Correlation is significant at the 0.05 level, (N)

Tmin = minimum temperature (°C),

 $Tmax = maximum temperature (^{\circ}C),$

RHmin = minimum relative humidity (%),

RHmax = maximum relative humidity (%).

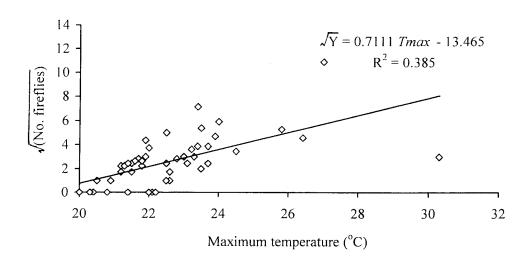


Fig. 16. The regression plot in temporal climatic factor analysis

The correlation between maximum temperature and other climatic factors are strong relationships at the 95% confidence level. The maximum temperature and minimum temperature is a positive correlation (r = 0.850), while the relationships between the maximum temperature and minimum-maximum relative humidity are negative correlation (r = -0.830, -0.639). Therefore, the minimum temperature and the minimum-maximum relative humidity are indirect factors influencing the firefly abundance.

3.2 Seasonal climatic factors

3.2.1 Highland habitat

The average minimum temperature 20 days before observing ($Tmin_{20}$) was the dominant environmental factor influencing the total number of fireflies (adults and larvae) in highland habitat (Fig. 17). Linear regression describes the climatic factors affecting monthly firefly abundance in Khao Yai National Park. The following equation indicates the relationship was found (See Appendix A-4, Fig. 18):

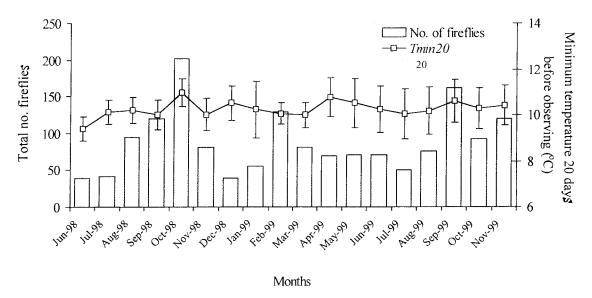


Fig. 17. The relationship between total number of fireflies and average minimum temperature 20 days before observing, throughout the year.

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$$Y = 88.688 \ Tmin_{20} - 817.883$$
$$R^2 = 0.291, \ P < 0.05$$

Where

Y = total number of fireflies in each month $Tmin_{20} = \text{average minimum temperature 20 days before observing (°C)}$

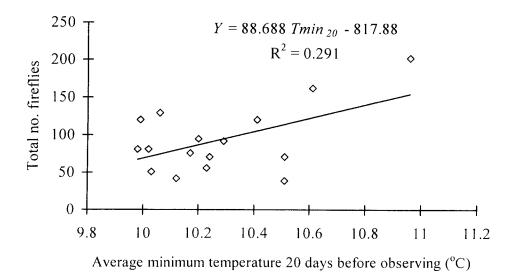


Fig. 18. The regression plot in seasonal climatic factor analysis of highland fireflies

Similarly, the average minimum temperature 20 days before observing ($Tmin_{20}$) also affected to the abundance of firefly larvae. The equation that fits the best for larvae (See Appendix A-5, Fig. 19):

$$Y = 110.972 \ Tmin_{20} - 1075.505$$
$$R^2 = 0.448, \ P < 0.05$$

Where

Y = number of larvae in each month $Tmin_{20} =$ average minimum temperature 20 days before observing (°C)

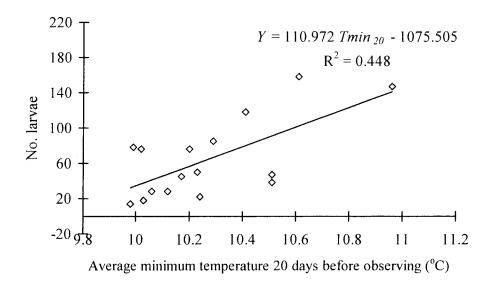


Fig. 19. The regression plot in seasonal climatic factor analysis of highland larvae

The correlation between the other factors are not statistical significant (table 3); therefore, there is only one climatic factor ($Tmin_{20}$) affecting on the firefly abundance.

Table 4. The Pearson correlation coefficients between average seasonal climatic factors 20 days before observing (Khao Yai National Park).

	Tmax ₂₀	Tmin ₂₀	RHmax ₂₀	Rain ₂₀
$Tmax_{20}$	(16)	(16)	(16)	(16)
$Tmin_{20}$	0.089	(16)	(16)	(16)
$RHmax_{20}$	-0.566*	0.047	(16)	(16)
$Rain_{20}$	-0.559*	-0.060	0.510*	(16)

^{*} Correlation is significant at the 0.05 level, (N)

*Tmin*₂₀ = average minimum temperature (°C) 20 days before observing,

 $Tmax_{20}$ = average maximum temperature (°C) 20 days before observing,

 $RHmax_{20}$ = average relative humidity (%) 20 days before observing,

 $Rain_{20}$ = quantity of rainfall (mm) 20 days before observing.

Remark: there is no data of *RHmin*₂₀

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3.2.2 Lowland habitat

The seasonal climatic factors in lowland habitat were not extremely different. The dominant factors influencing their abundance were relative humidity (%). In freshwater area in Nakhon Pathom province, the average maximum relative humidity 10 days before observing ($Hmax_{10}$) influencing the fluctuation of logarithm number of fireflies. Linear regression describes the importance of $Hmax_{10}$ with this equation (See Appendix A-6, Fig. 20):

$$\log Y = 11.708-0.110 RHmax_{10}$$
$$R^2 = 0.266, P < 0.05$$

Where

Y = number of fireflies in each month $RHmax_{I0}$ = average maximum relative humidity 10 days before observing (%)

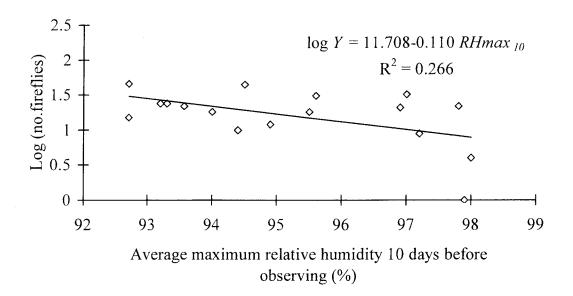


Fig. 20. The regression plot in average seasonal climatic factor analysis of *Luciola brahmina* in Nakhon Pathom

The correlation analysis (table 4) shows a statistical significance indicating a strong relationship between average maximum and average minimum relative humidity (r = 0.738). Therefore, average minimum relative humidity 10 days before observing is an indirect factor.

Table 5. The Pearson correlation coefficients between average seasonal climatic factors 10 days before observing (Nakhon Pathom).

	Tmax ₁₀	$Tmin_{10}$	RHmax ₁₀	RHmin ₁₀	Rain ₁₀
$Tmax_{10}$	(17)	(17)	(17)	(17)	(17)
$Tmin_{10}$	0.575*	(17)	(17)	(17)	(17)
RHmax ₁₀	-0.196	0.230	(17)	(17)	(17)
$RHmin_{10}$	-0.415*	0.402	0.738*	(17)	(17)
Rain ₁₀	0.117	0.579*	0.096	0.477	(17)

^{*} Correlation is significant at the 0.05 level, (N)

 $Tmin_{10}$ = average minimum temperature (°C) 10 days before observing,

 $Tmax_{10}$ = average maximum temperature (°C) 10 days before observing,

RHmin₁₀ = average minimum relative humidity (%) 10 days before observing,

 $RHmax_{10}$ = average maximum relative humidity (%) 10 days before observing,

 $Rain_{10}$ = quantity of rainfall (mm) 10 days before observing.

The brackish water area in Samut Songkram province, P. malaccae congregated in mangrove trees, are called "firefly tree". The distributions of firefly trees are changeable. The numbers of fireflies/tree were transformed with logarithm to linearize. Linear regression on $RHmin_{10}$ is showed in this model (See Appendix A-7, Fig. 21):

$$log (Y / tree) = 1.919-0.018 RHmin_{10}$$

 $R^2 = 0.375, P < 0.05$

Where Y = number of fireflies / trees $RHmin_{10}$ = average minimum relative humidity 10 days before observing (%) Anchana Thancharoen Results / 72

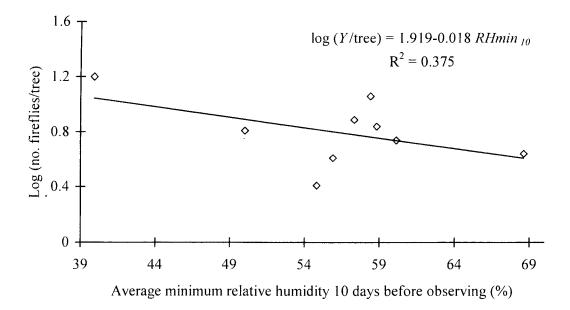


Fig. 21. The regression plot in seasonal climatic factor analysis of *Pteroptyx malaccae* in Samut Songkram

The correlation analysis in table 5 shows that the average maximum temperature and the quantity of rainfall 10 days before observing are statistical significant relationship at 95% confidence level (r = -0.649, 0.652). Therefore, both of the climatic factors are indirect factors affecting on the *Pteroptyx* fireflies in Samut Songkram.

Table 6. The Pearson correlation coefficients between average seasonal climatic factors 10 days before observing (Samut Songkram).

	$Tmax_{10}$	$Tmin_{10}$	$RHmax_{10}$	$RHmin_{10}$	$Rain_{10}$
Tmax ₁₀	(13)	(13)	(11)	(11)	(13)
$Tmin_{10}$	0.492*	(13)	(11)	(11)	(13)
$RHmax_{10}$	-0.101	0.499	(11)	(11)	(11)
$RHmin_{10}$	-0.649*	0.210	0.407	(11)	(11)
$Rain_{10}$	-0.090	0.415	0.368	0.652*	(13)

* Correlation is significant at the 0.05 level, (N)

 $Tmin_{10}$ = average minimum temperature ($^{\circ}$ C) 10 days before observing,

 $Tmax_{10}$ = average maximum temperature (°C) 10 days before observing,

 $RHmin_{10}$ = average minimum relative humidity (%) 10 days before observing,

 $RHmax_{10}$ = average maximum relative humidity (%) 10 days before observing,

 $Rain_{10}$ = quantity of rainfall (mm) 10 days before observing.

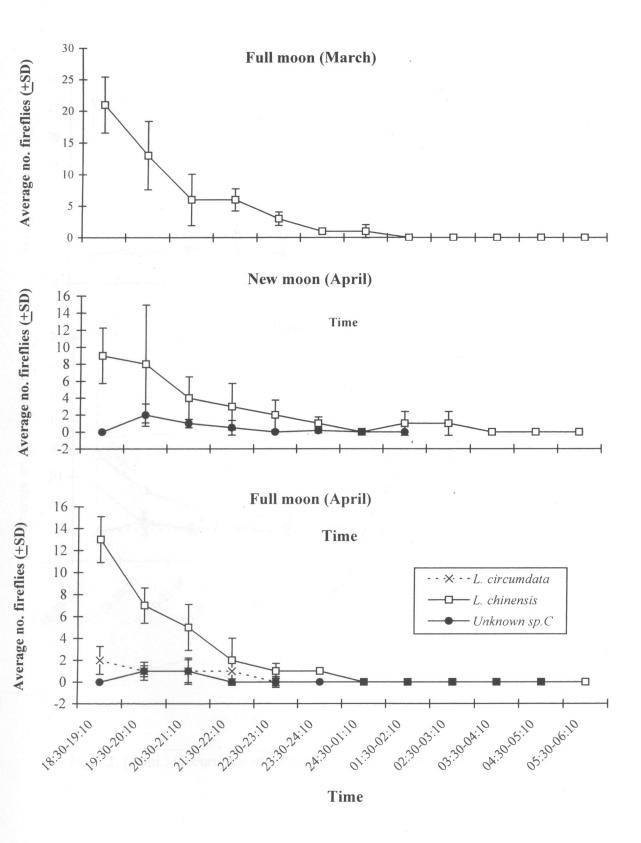


Fig. 22. Occurrence of each firefly species in different moon phase

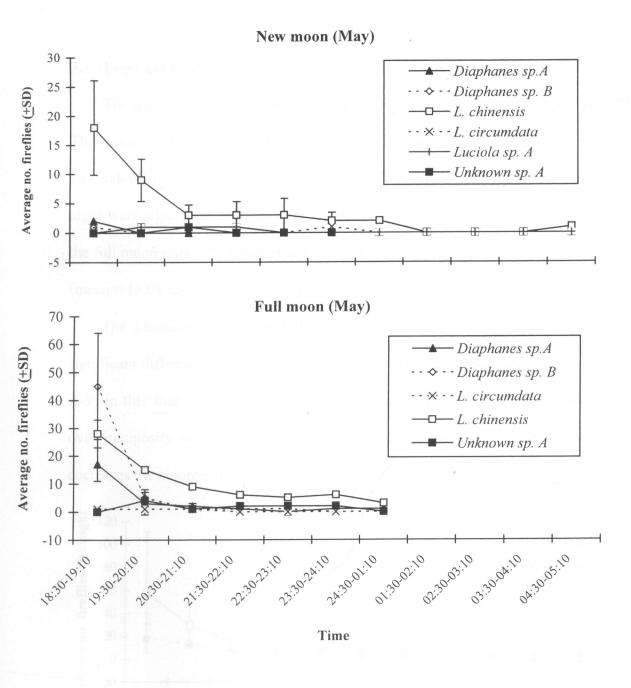


Fig. 22. (Cont.) Occurrence of each firefly species in different moon phase

3.3 Moonlight factor

The occurrence of each species in different moon effects is showed in figure 22. The moon phase influenced firefly abundance during 18.30-24.10, as indicated by Kruskal-Wallis Test. The means of number of fireflies in full moon and new moon night were significant difference (H = 6.055, df = 1, P < 0.05; See Appendix A-8). In the full moon night, the mean of number of fireflies is higher than in new moon night (mean = 16.04 and 8.96 respectively; Fig. 23).

The illumination (lux) in full moon and new moon night was not statistical significant difference and it did not influence on the firefly abundance (See Appendix A-9) in this study. Other environmental illuminations such as sky light, may cause over luminosity in new moon night. Besides cloud cover is a major factor which decreases the moonlight.

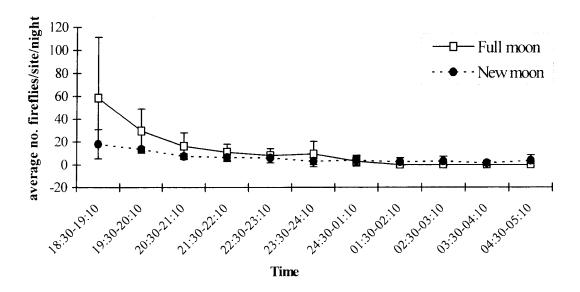


Fig. 23. Average number of fireflies/site/night in different moon phases (13 nights running average)

4. Habitat utilization of fireflies

In highland habitat, the firefly larvae are terrestrial which can be clearly seen from their steady lights. Larval identification in species level is complicate; therefore, the larvae are classified in 4 categories in the genera level. That is *Luciola*, *Lamprigera*, *Pyrocoelia*, and *Diaphanes*. Each kind of larvae has different habitat utilization (Fig 24, See Appendix A-9).

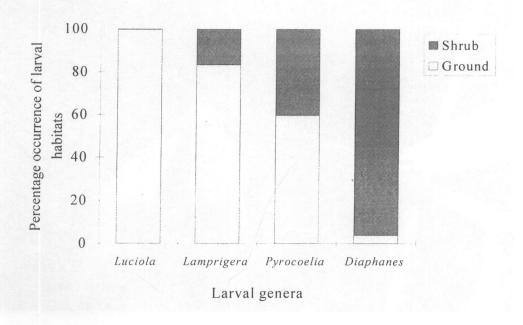


Fig. 24. The habitat utilization of firefly larvae in highland habitat.

All of *Luciola* larvae were found on the ground forest under leaf litter while *Diaphanes* larvae spent their lives on the shrub (Fig. 25). The larvae of *Lamprigera* and *Pyrocoelia* (Fig. 26) lived in both habitats but in different proportion.



Fig. 25. The *Diaphanes* larva on shrub



Fig. 26. The *Pyrocoelia* larva climb on dry branch

The vertical distribution on vegetation of *Diaphanes* larvae showed different heights (Fig. 27). In a sample of 106 larvae, the preferred niche was approximately 51-100 cm of vegetation height.

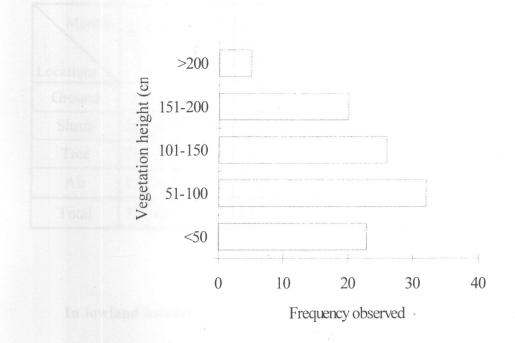


Fig. 27. The vegetation height of Diaphanes larvae

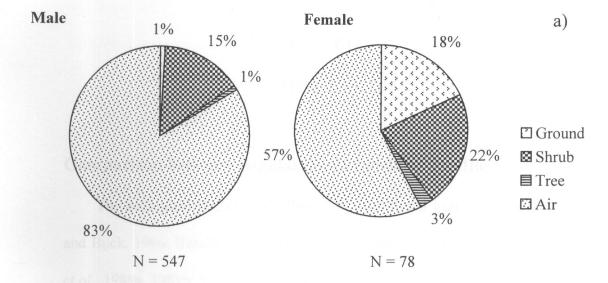
Figure 28a shows habitat utilization of male and female adults in different situations—resting near ground, resting on shrubs, resting on trees, and flying in air. Approximately 83% of males were flying and a few were resting (17%) while 57% of females were flying. The adult females were resting in a much larger proportion (43%) than the males, especially near the ground.

The seasonal change in the location of adult firefly showed in table 6. The fireflies were resting near ground, on shrubs, and on trees during rainy season and showed flying activity in a large number in winter period.

Table 7. The seasonal changes in the location of fireflies in highland habitat

														* *		1		
		Vet p	perio	d		Ι	Ory p	perio	d				\	Vet p	perio	d		
Months	Jun-98	Jul-98	Aug-98	Sep-98	Oct-98	Nov-98	Dec-98	Jan-99	Feb-99	Mar-99	Apr-99	May-99	96-unf	Jul-99	Aug-99	Sep-99	Oct-99	Nov-99
Ground	3	5	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0
Shrub	14	12	0	3	0	0	0	0	7	0	0	3	15	13	4	0	0	1
Tree	28	7	0	61	30	0	0	0	0	0	0	60	0	0	0	0	0	0
Air	27	21	24	32	53	5	0	12	150	114	15	28	58	19	19	5	7	0
Total	72	45	24	96	83	5	0	12	157	114	15	92	73	34	23	5	7	1

In lowland habitat, freshwater area in Nakhon Pathom, the habitat utilization of adults is shown in figure 28b. The main activity of males was flying above the pond (71%), and only approximately 29% were for resting while the females were resting near the ground in a larger proportion (39%).



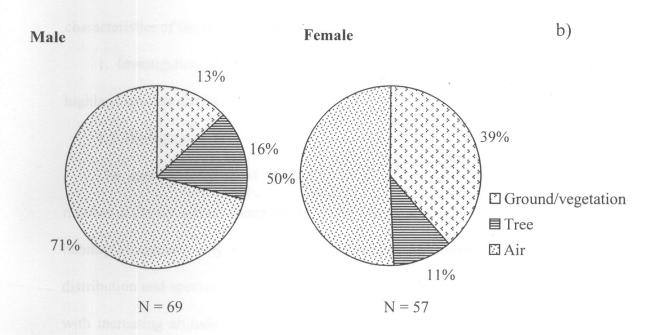


Fig. 28. The habitat utilization of adult fireflies—males and females, a) in highland habitat, b) in freshwater area, Nakhon Pathom province

CHAPTER V

DISCUSSION

Comparison between Highland and Lowland Fireflies

The ecological studies of fireflies have been found in previous studies (i.e. Buck and Buck, 1966; Buschman, 1984; Lall *et al.*, 1980; Lloyd, 1997; Lloyd, 1998; Lloyd *et al.*, 1989a, 1989b; Yuma *et al.*, 1981; Yuma *et al.*, 1990). Most of them occurred in temperate regions. Moreover, habitat specificity causes difference in ecological characteristics of the firefly population.

1. Investigation of the difference of firefly populations between lowland and highland habitats shows that:

1.1 Biological factors

The species diversity of fireflies in these observations indicated that the total number of firefly species found are 14, more abundant species were found in highland habitat (11 species), only 3 species were in lowlands. According to Hanski (1983), the distribution and species richness of dung and carrion beetles is supposed to decrease with increasing altitude. Conversely in my observation, the destruction of suitable habitats for fireflies, which probably leads to smaller areas and isolation of habitats especially in lowland areas. There was a high diversity of highland firefly species in wet period (H' = 1.191) more than during the dry period (H' = 0.082). These may be cause low quality and quantity of food resource in dry period, which lead to low species richness. The occurrence of *Luciola* fireflies in both habitats (highland and freshwater areas) differs from other genera. Lowland habitat showed extreme habitat

specificity of firefly species. There was only one species, *Luciola brahmina* in freshwater area that is same result with Chunram and Lewvanich (1996). The *Pteroptyx* fireflies in brackish water were found in tidal areas at less than 0.5 m above sea level that agree with Lloyd *et al.* (1989a).

The highland habitat presented diverse species of fireflies that have similar niche requirements. The several species may complete for food and space (Hedrick, 1984); therefore, the competition in highland habitat was higher than in lowland habitats.

1.2 Physical factors

The fluctuation in climatic factors is important to firefly abundance. The seasonal climatic factors in highland habitat were extremely different. The temperature was the major factor influencing on their abundance. Yuma (1984) and Yuma and Hori (1981) suggested that temperature affected to survival of eggs, the tolerance and starvation of newly hatch larvae, and survival during pupal stage of Luciola cruciata in Japan. While, the lowland habitats had low stress of climatic pressure that was more suitable. The terrestrial larvae in highland habitat spend long time during larval stage under influencing of temperature; therefore, they select to live under leaf litter, in ground depression, in dead log at noon. That differs from freshwater larvae, which don't be directly forced by climatic factors. The humidity is the most important factor influencing on lowland firefly abundance. The moisture levels are important in limiting the distribution of many invertebrates; however, the amount of moisture available was determined by the interaction of temperature and rainfall (Hadrick, 1984).

2. Investigation of the similarity of firefly population in lowland and highland habitats shows that:

2.1 The seasonal occurrence of fireflies

The seasonal fluctuation of fireflies in lowland and highland occurred in the same trend. The peak of firefly occurrence was high in rainy season and the number of population decreased in winter. Yuma (1986) suggested the amount of food is an important limiting factor for population growth of fireflies. Therefore, there was low density of firefly population in dry season, and the population increased gradually due to favorable environment in rainy season. In highland habitat, there is high species diversity. Each species of fireflies occurred in different periods that help to isolate breeding time.

2.2 The habitat utilization of adult fireflies

The habitat utilization of adult fireflies in lowland and highland habitats is not different. The males and females have different proportion of habitat utilization. Both spent most of their lives with flying activity but the males are more than females. Since the flying behavior leads to meet their mates and copulate later. However, the flying females consisted of individuals searching for oviposition site (Yuma and Hori, 1981). In the observation, most fireflies flied in low level and were less active than the males. Buschman (1984) suggested that the gravid females of *Pyractomena lucifera* were found near oviposition site and were too heavy to fly. The females had a proportion of individuals near ground larger than the males because it is an important site for copulation of virgin females and is an oviposition site of old females (Yuma and Hori, 1990). The seasonal changes in behavior and habitat utilization of highland fireflies showed resting near ground, on shrubs, and on trees during rainy season because it is difficult to fly in rain. In winter, the fireflies showed a large proportion of flying activity. However, the general biology of firefly larvae in each habitat is

different. In highland, the larvae are terrestrial and feed on land snails while *L. brahmina* larvae in freshwater area survive in water, as aquatic lives, and feed on aquatic snails (Chunram and Lewvanich, 1996). The *Pteroptyx* larvae are unknown. They probably are terrestrial or semiaquatic.

The Firefly Activities

The difference of sexual communication of firefly species serves as species-isolating mechanism (Carlson and Copeland, 1978). In general, the males fly and flash over the open space for searching the response from recognized females and mating follows as it was found in highland fireflies and *L. brahmina* in freshwater area. While, the *Pteroptyx* species in brackish water area shows different patterns of flashing communication. The males aggregate and flash synchronously in mangrove trees that are known as "firefly trees" along the river and estuaries. That seems to advantage to attract the females (Buck and Buck, 1966; 1976; Lloyd *et al.*, 1989a).

The temporal occurrence of highland fireflies was found in high abundance in the first half of the night. Each species of fireflies had own specific time of flashing activities that is an important factor in isolating species in the same habitat. Buschman (1984) investigated that *Pyractomena lucifera* activities in North America occurred in short periods of flashing, the males began flashing 30 min after sunset, flash activity reached a peak about 5 min later, and then decreased rapidly. Lloyd *et al.* (1989b) explained the temporal activity of Thai *Luciola* fireflies, the males of *L. japonica* began flying and flashing 33-37 min after sunset, then the active numbers gradually increased for the next hour and reduced by 3 hours after sunset. While, *L. cinqulata* was never observed before sunset. In my observation, *L. chinensis* flashes occurred

throughout the night and showed an abundance peak in the first hour after sunset. They began flashing approximately 10-20 min before sunset while *Diaphanes* fireflies began suddenly flashing sunset. This result agrees with Lall *et al.* (1980). They investigated that the time to start flashing activity is highly related to wavelength of firefly bioluminescence in order to adapt sensitivity in their environmental illumination. At twilight, the reflected light from green vegetation is high. Hence, the dusk-active species emit yellow light (long wavelength) while the dark-active species emit green light (short wavelength). The twilight-active firefly, *Photinus scintillans*, has long wavelength receptors in their eyes which dominate under dim illumination condition (closed space), while the short wavelength receptors dominate in bright illumination conditions (open space) (Lall, 1993). The highland habitat has dim illumination condition and closed space, the long wavelength in yellow spectra of *L. chinensis* is an advantage.

Each kind of firefly larvae showed a difference of habitat utilization. In general, the lampyrid larvae spent their lives on ground and pupate in a chamber underground (Buschman, 1984), which were found in *Luciola* and *Lamprigera* larvae. This is different from *Diaphanes* and *Pyrocoelia* larvae. They are arboreal like *Pyractomena* larvae that adapt to live on emergent vegetation over onto flood plain (Buschman, 1984; Lloyd, 1997). That can not be explained in this case. Nevertheless, the difference in larval distribution may be associated with competition in food resource and the risk of predation. In addition the morphology and color pattern of *Diaphanes* and *Pyrocoelia* larvae look like a branch that imitate their environmental background. The different niches are necessary to reduce the competition among larval species.

The effect of moonlight on firefly activities occurred before midnight that indicated by a significant difference between the mean number of fireflies in full moon and new moon. In full moon night, the occurrence of fireflies was higher than in new moon night. Bowden and Church (1973) suggested that the number of lampyrids that were catched by light-trapped in new moon was higher than in full moon because of the influences of background illumination (moonlight) on trap effectiveness. Therefore, the moonlight probably influences on increasing firefly activity. The amount of moonlight depended on the elevation and phase of the moon (Bowden, 1973). The temporal activity of fireflies is probably affected by moonlight. However, the moonlight may cause to decrease the effectiveness of flashing communication of fireflies. The cloud cover and other environmental illumination such as starlight may affect on the variation of moonlight that may cause errors in this experiment.

The Decline of Firefly Population

Although the species diversity of fireflies is highest in tropical region, including Thailand, there are amounts of fireflies in many areas but the firefly population and diversity are declining and may disappear from many areas. That is a warning of human destruction of future. Burger (1997) suggested that the decreasing number of fireflies in Houston might come from many reasons—mosquito spray program, the urban electric light, wrong temperature (too hot or too cold), and lack of food resource for firefly larvae. Besides, the commercial firefly collection for luciferase is also a factor (Tweit, 1999). In my observation, the population of fireflies in Samut Prakarn decreased rapidly when the electric light reached the study site. The effects of outdoor lighting have contributed to the decline of some nocturnal insects because the strong

light can attracted a lot of insects and also disturbs flight, vision, dispersal, mating, and etc (Heliövaara and Väisänen, 1993). The effectiveness of sexual communication was reduced by the high intensity of surrounding light. Successfulness of copulation is probably reduced that leads to low density before total disappearing from the habitat. Some of them might have migrated to other favorable habitats. The destruction of habitat is obviously a major factor in the decline. In Samut Songkram province, many swampy forests along the river were destroyed and became dwelling.

The observation from field population showed that human activities affect directly on decreasing the firefly population. In Japan, many programs for recovering the firefly population were set up. They can improve the surrounding and returned the fireflies in their habitat (The Japan Research Institute, 1997). This shows the attention to nature conservation. Therefore, the fireflies will come back again if we take care the surrounding.

CHAPTER VI

CONCLUSION AND RECOMMENDATION

Conclusion

- 1. In this study, 11 species in 7 genera of highland fireflies and 3 species in 2 genera of lowland fireflies were recorded. There was a high diversity of firefly species in highland habitat that occurred in wet period more than during dry period. There is the same trend of the seasonal abundance of fireflies in each kind of habitats.
- 2. The differences in temporal occurrence of firefly species in highland habitat were investigated. The abundance of the fireflies was high in the first half of the night and showed a peak in 2 hours after sunset. Luciola chinensis, the dominant species in the highland habitat showed difference in specific time with Diaphanes species. Those were related to the environmental illumination. At twilight, the yellow light of L. chinensis is more effective than the green light of Diaphanes fireflies. Therefore, the sunset time probably determines the specific period of flashing activity of fireflies in highland habitat.
- 3. The hourly climatic factor, maximum temperature, affected on the occurrence of fireflies in highland habitat. That can explain of 38.5% the variability in firefly abundance by this equation: √average no. fireflies/site/night = 0.7111*Tmax*-13.465. Other factors—maximum-minimum relative humidity, minimum temperature—relate with the major factor; therefore, they are indirect factors affecting firefly abundance.

- 4. The fluctuation in monthly climatic factor also affected the firefly abundance. The average minimum temperature 20 days before observing ($Tmin_{20}$) is the major factor influencing the total number of highland fireflies (total no. fireflies = 88.688 $Tmin_{20}$ 817.883). Moreover, $Tmin_{20}$ also affected the abundance of firefly larvae (no. larvae = 110.972 $Tmin_{20}$ 1075.505). While, the maximum humidity 10 days before observing ($RHmax_{10}$) is a dominant factor influencing the logarithm number of fireflies in freshwater area (log (no. fireflies) = 11.708–0.110 $RHmax_{10}$). The logarithm numbers of $Pteroptyx\ malaccae$ /number of firefly trees correlates in a strong reverse relation and can be explained with the equation: log (no. fireflies/tree) = 1.919 0.0188 $RHmin_{10}$.
- 5. The moon phase influences the firefly activity in highland habitat in the first half of night. There was high abundance of firefly in full moon night more than during new moon.
- 6. The males and females of adult fireflies have different proportion of habitat utilization. They spent most of their lives with flying activity. The males (83% in highland and 71% in freshwater area) were more than females (57% in highland and 50% in freshwater area). While the females had a proportion of individuals near the ground bigger than the males (18% in highland and 39% in freshwater area) that relate to the role of oviposition.
- 7. The terrestrial larvae in highland habitat showed different niches. The *Luciola* and *Lamprigera* larvae spent their lives on ground while the *Pyrocoelia* and *Diaphanes* larvae are arboreal.

Recommendation

- Because of the habitat specificity of fireflies, the species are extremely different.
 If the data came from many places for each habitat, it might show better results.
- 2. The influence of moonlight on the firefly abundance should be followed during 4 phases of the moon—1st quarter, last quarter, new moon, and full moon—and collected data for long time. The cloudy night caused reducing the illumination of the moon. The study will get better result if the cloud was removed.
- 3. The study of the niche of terrestrial larvae in highland habitat is interesting. It probably relates to their foods. From my observation, there are many species of land snails in this area both on ground and on shrub that use the same niche as the larvae.
- 4. The study of life cycle of fireflies is interesting and important and leads to the conservation of firefly. If possible, the life cycle of each species might be investigated. Because of the long life cycle of fireflies, the rearing might be careful. The controlling of climatic factors is necessary.

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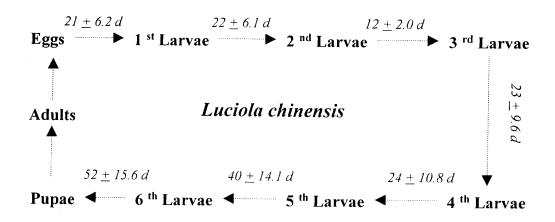
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APPENDICES

Appendix A-1. Life cycle of *Luciola chinensis*, rearing under room temperature (25-30 °C)(Samut Prakarn)



An adult female laid 94-100 eggs on moist soil or moist cotton. Approximately 20% of laid eggs are non-hatched eggs. Egg sizes are about 0.65±0.03 mm. Larvae were feed with earthworms and land snails. The larval instars are long period (~200 days) that compose with 6 stages of molting. Because of high air temperature, a lot of 6th larvae died and had no pupae emerged into adults. That causes uncompleted life cycle.

Appendix A-2. Calculation of species diversity and equitability of highland fireflies through the use of Shannon-Weiner function

In wet period:

Firefly species	No.	pi	log ₁₀ pi	log ₂ pi	(<i>pi</i>)(log ₂ <i>pi</i>)
Luciola chinensis	213	0.807	-0.093	-0.310	-0.250
Luciola circumdata	18	0.068	-1.166	-3.874	-0.264
Diaphanes sp.E	9	0.034	-1.467	-4.874	-0.166
Luciola sp.A	9	0.034	-1.467	-4.874	-0.166
Diaphanes sp.B	7	0.027	-1.577	-5.237	-0.139
Diaphanes sp.A	4	0.015	-1.820	-6.044	-0.092
Luciola sp.B	2	0.008	-2.121	-7.044	-0.053
Diaphanes sp.D	1	0.004	-2.422	-8.044	-0.030
Unknown	1	0.004	-2.422	-8.044	-0.030
Total	264	1			-1.191

$$S$$
 $H' = -\sum pi \log_2 pi = -(-1.191) = 1.191$
 $i = 1$

$$H'_{\text{MAX}} = \log_2 S = \log_2 9 = 3.000$$
 $J' = H'/H'_{\text{MAX}} = 0.397$

In dry period:

Firefly species	No.	pi	log ₁₀ pi	log ₂ pi	$(pi)(\log_2 pi)$
Luciola chinensis	223	0.991	-0.004	-0.013	-0.013
Diaphanes sp.B	1	0.004	-2.352	-7.814	-0.035
Diaphanes sp.C	1	0.004	-2.352	-7.814	-0.035
Total	225	1			-0.082

$$S$$
 $H' = -\sum pi \log_2 pi = -(-0.082) = 0.082$
 $i = 1$

$$H'_{\text{MAX}} = \log_2 S = \log_2 3 = 1.585$$
 $J' = H'/H'_{\text{MAX}} = 0.052$

Appendix A-3. Multiple regression analysis was used to determine the relationship between the number of highland fireflies and hourly climatic factors. It is performed with SPSS 10.0.5 for window program.

Independent variable: *Tmax*

Dependent variable: The number of fireflies in highland habitat

Model Summary:

	D.C.	A 1' 4 . 1 D C	Std. Error of the
K	R Square	Adjusted R Square	Estimate
0.620	0.385	0.371	1.7185

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	84.983	1	84.983	28.776	0.000
Residual	135.849	46	2.953		
Total	220.832	47			

Coefficients:

	=	andardized efficients	Standardized Coefficient	t	Sig.
	В	Std. Error	Beta		
(Constant)	-13.465	3.006		-4.480	0.000
Tmax	0.711	0.133	0.620	5.364	0.000

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Tmin	0.283	1.302	0.200	0.191	0.279
RHmin	0.026	0.126	0.900	0.019	0.311
RHmax	0.186	1.247	0.219	0.183	0.591

Appendix A-4. Linear regression analysis was used to determine the relationship between the total number of highland fireflies and average minimum temperature 20 days before observing. It is performed with SPSS 10.0.5 for window program.

Independent variable: *Tmin*₂₀

Dependent variable: Total number of fireflies in highland habitat

Model Summary:

	D.C.	A 1' 1 D C	Std. Error of the
R	R Square	Adjusted R Square	Estimate
0.539	0.291	0.240	38.7252

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	8600.982	1	8600.982	5.735	0.031
Residual	20995.018	14	1499.644		
Total	29596.000	15			

Coefficients:

		andardized efficients	Standardized Coefficient	t	Sig.
	В	Std. Error	Beta		
(Constant)	-817.88	380.473		-2.15	0.050
Tmin ₂₀	88.688	37.033	0.539	2.395	0.031

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Rain ₂₀	-0.103	-0.442	0.666	-0.122	0.996
RH_{20}	0.198	0.872	0.399	0.235	0.998
$Tmax_{20}$	0.014	0.061	0.953	0.017	0.992

Appendix A-5. Linear regression analysis was used to determine the relationship between the number of highland larvae and average minimum temperature 20 days before observing. It is performed with SPSS 10.0.5 for window program.

Independent variable: *Tmin*₂₀

Dependent variable: The number of larvae in highland habitat

Model Summary:

R	R Square	Adjusted R Square	Std. Error of the
			Estimate
0.669	0.448	0.409	34.4267

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	13466.209	1	13466.209	11.362	0.005
Residual	16592.791	14	1185.199		
Total	30059.000	15			

Coefficients:

	Unstandardized Coefficients		Standardized Coefficient	t	Sig.
-	В	Std. Error	Beta	•	
(Constant)	-1075.505	338.240		-3.180	0.007
Tmin20	110.972	32.922	0.669	3.371	0.005

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
Rain ₂₀	0.011	0.051	0.960	0.014	0.996
$RHmax_{20}$	0.088	0.430	0.675	0.118	0.998
$Tmax_{20}$	-0.142	-0.701	0.495	-0.191	0.992

Appendix A-6. Linear regression analysis was used to determine the relationship between the number of *Luciola brahmina* and average maximum relative humidity 10 days before observing. It is performed with SPSS 10.0.5 for window program.

Independent variable: $RHmax_{10}$

Dependent variable : The log number of fireflies in freshwater area

Model Summary:

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.516	0.266	0.217	0.3591

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	0.702	1	0.702	5.446	0.034
Residual	1.935	15	0.129		
Total	2.637	16			

Coefficients:

	=	andardized efficients	Standardized Coefficient	t	Sig.
	В	Std. Error	Beta		
(Constant)	11.708	4.504		2.600	.020
$RHmax_{10}$	-0.110	0.047	-0.516	-2.334	.034

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
$Tmax_{10}$	0.361	1.701	0.111	0.414	0.962
$Tmin_{10}$	0.351	1.630	0.125	0.399	0.947
$RHmin_{10}$	0.011	0.033	0.974	0.009	0.456

Appendix A-7. Linear regression analysis was used to determine the relationship between the number of *Pteroptyx* fireflies and average minimum relative humidity 10 days before observing. It is performed with SPSS 10.0.5 for window program.

Independent variable: $RHmin_{10}$

Dependent variable: The log number of fireflies / tree

Model Summary:

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.613	0.375	0.306	0.1878

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	0.191	1	0.191	5.407	0.045
Residual	0.317	9	3.526E-02		
Total	0.508	10			

Coefficients:

	Unstandardiz	ed Coefficients	Standardized Coefficient	t	Sig.
	В	Std. Error	Beta	-	
(Constant)	1.919	0.448		4.288	0.002
$RHmax_{10}$	-1.879E-02	0.008	-0.613	-2.325	0.045

Model	Beta In	t	Sig.	Partial Correlation	Collinearity Statistics Tolerance
$Tmax_{10}$	0.038	0.103	0.920	0.036	0.579
$Tmin_{10}$	-0.009	-0.031	0.976	-0.011	0.956
$RHmax_{10}$	0.450	1.724	0.123	0.520	0.834
Rain ₁₀	-0.061	-0.167	0.872	-0.059	0.575

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Appendix A-8. Nonparametric Kruskal-Wallis test was used to compare the mean number of fireflies in full moon and new moon night. It is performed with SPSS 10.0.5 for window program.

Ranks:

Moon Phase	N	Mean Rank
Full	12	16.04
New	12	8.96
Total	24	

Kruskal-Wallis Test:

Dependent Variable: Number of fireflies

Grouping Variable: Moon phase

Chi-Square 6.055 df 1 Asymp. Sig. 0.014 **Appendix A-9.** Linear regression analysis was used to determine the relationship among logarithm number of highland fireflies/hour, luminosity (lux), and time periods in temporal survey. It is performed with SPSS 10.0.5 for window program.

Independent variable: log (lux)

Dependent variable: number of fireflies in highland habitat/hour

Model Summary:

R Square	Adjusted R Square	Std. Error of the
•		Estimate
0.3576	0.3375	8.92060

ANOVA:

	Sum of Square	df	Mean Square	F	Sig.
Regression	2835.01	2	1417.50	17.81	0.000
Residual	5092.93	64	79.5771		
Total	7927.94	66			

Coefficients:

	Unstandardiz	ed Coefficients		
			t	Sig.
-	В	Std. Error		
(Constant)	20.3842	5.11275	3.99	0.0002
Time	-3.30459	0.58570	-5.64	0.0000
lux	-2.06538	2.56057	-0.81	0.4229

Appendix A-10. The habitat utilization of the firefly larvae in highland habitat

T 1	Habitat (%)			
Larval genera	Ground	Shrub		
Luciola	99.79	0.21		
Lamprigera	83.33	16.67		
Pyrocoelia	59.78	40.22		
Diaphanes	3.79	96.21		

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