

RECORDING AND MONITORING FIREFLIES

Methodologies and Guidelines



**International Union for Conservation of Nature
Species Survival Commission
Firefly Specialist Group**

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PREAMBLE

About fireflies, what we know is far less than what we do not know. The purpose of the document is to assist people interested in fireflies to do more than “go seeing fireflies” and help collecting information about fireflies in nature.

Fireflies are directly affected by destructive human activities in habitats, just like other consumers in the ecosystem’s food chain. Furthermore, as light pollution continues to grow, firefly populations are in danger.

In 2017, the IUCN SSC Firefly Specialist Group was established to compile existing knowledge for around 2,000 lampyrid species worldwide concerning their geographic range, population size, and population trends, identify major extinction threats and risk factors, increase public knowledge concerning firefly diversity, ecology and behaviour, and promote long-term conservation efforts.

In principal, methods for surveying insects can be applied to firefly surveys. A distinctive feature of fireflies is their bioluminescence, which sets them apart from all other insect groups concerning the methodologies of finding, recording and counting them.

These guidelines provide general methodologies, examples and considerations for conducting firefly surveys. As fireflies are highly diversified both biologically and ecologically, more efforts need to be put into designing specific methods to address the needs of various species.

INTRODUCTION

WHAT ARE FIREFLIES

Fireflies are one of the most popularly known and charismatic insect groups. Some authors use "glow-worms" in lieu of "fireflies" (Okada, 1928; Harvey, 1957; McDermott, 1953; Ineichen & Rüttimann, 2012). However, "glow-worms" sometimes also refer to the Keroplatidae (Diptera: Mycetophilidae) in USA, Australia and New-Zealand (De Cock, 2009). De Cock (2009) suggested to specify "lampyrid glow-worms" or "firefly glow-worms" to prevent misunderstanding. Fireflies is also called Lightning bugs (Leconte, 1880; Babu & Kannan, 2002; Faust, 2017; Candace *et al.*, 2022).

Fireflies are soft-bodied beetles (Order Coleoptera), members of family **Lampyridae**, which are mostly luminous. Members of the closely-related family **Phengodidae** and family **Rhagophthalmidae** are sometimes regarded as fireflies, because they share very similar luminescent behaviour with the members of **Lampyridae**. Some members of the click beetles – about 100 species in the family **Elateridae** (Costa, 1975) and one species in family **Sinopyrophoridae** (Bi *et al.*, 2019; Kusy *et al.*, 2021) are also luminous. There are 2,419 species of Lampyridae, 258 species of Phengodidae and 53 species of **Rhagophthalmidae** listed on Integrated Taxonomical Information System (retrieval in February, 2022). These five families of luminous beetles are collectively called **Bioluminescent Elateroid Beetles** (Kusy *et al.*, 2021). It is estimated that there are about 2800 species of luminous beetles in the world. We have spent relatively little effort on nocturnal surveys, finding and describing new luminous beetle species, which may mean there are more unknown species than those we know.

GENERAL MORPHOLOGY

Adults

Body is generally yellow, orange, red, light brown, dark brown to black or combinations of dark colours with one or some bright colours. It is believed that fireflies are aposematic. They use their colouration or markings to deter or warn predators. Apparently, aposematic colouration is more profound in diurnal firefly species, but it is also very common in nocturnal species. Some species have dull colouration or markings that could be considered cryptic.

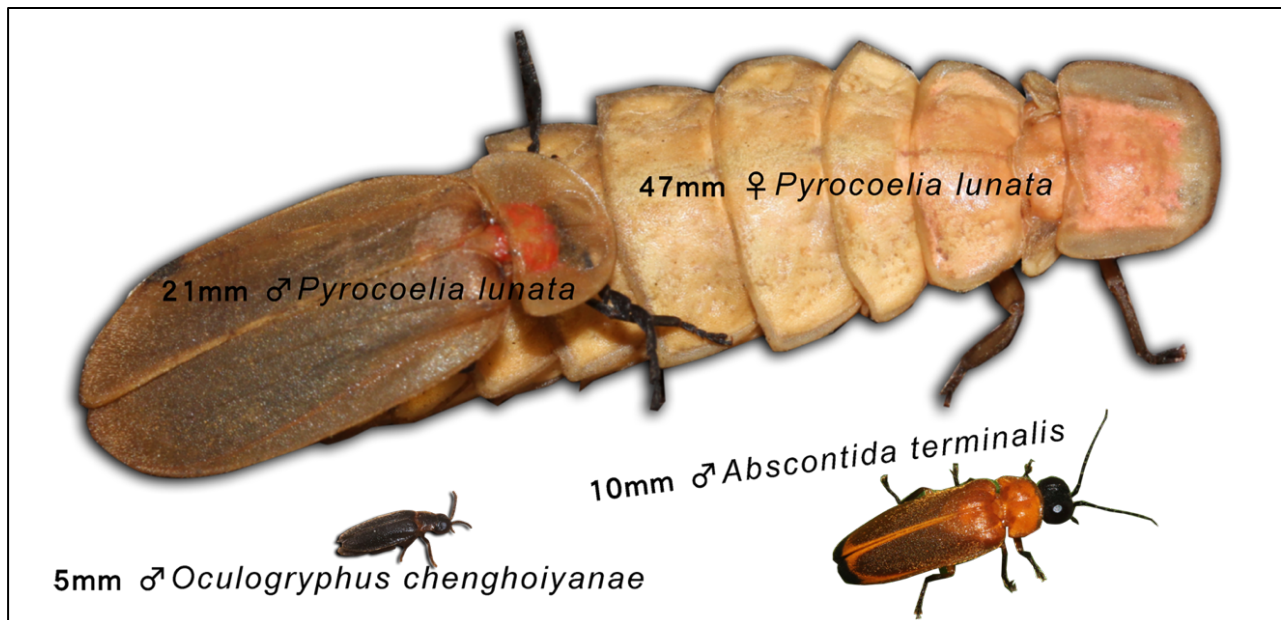


Diurnal firefly – *Pyrocoelia sanguiniventer*



Nocturnal firefly – *Luciola kagiana*

Body is generally soft, sub-parallel to narrowly elliptical, and dorsoventrally compressed. Size varies greatly. Body length measuring from the pronotum anterior end to the elytral posterior end ranges typically from about 4mm to 20mm. It is possible for some species like the *Lamprigera* to have a gigantic female with no wings, measuring over 50 mm in length.



Size comparison of 3 species of fireflies – actual ratio

Head could be exposed, partially exposed or completely hidden under the pronotum. The degree of exposure to male compound eyes of a species is generally associated with the flying ability of its female. In a species where the female can fly, the compound eyes of the male are more exposed. In species where the female is flightless, the compound eyes of the male tends are hidden under the pronotum for better protection.

Antennae of fireflies vary greatly in size and form. Four different forms can be identified: 1. Filiform; 2. Serrate; 3. Unipectinate; 4. Bipectinate. The antennal size and form of a firefly species, particularly adult male, are associated with its compound eyes size. The compound eyes are smaller when the antennae are better developed or more extensive, and vice versa. Nocturnal species generally have larger compound eyes than diurnal species. The compound eyes of the male are usually larger than those of the female of the same

species. Females incapable of flying generally have smaller compound eyes than females capable of flying.

Adult fireflies seldom feed, except for a few predatory species. They may not feed at all or eat only sap and water. Many species still possess a well-developed mouthparts, and a large pair of piercing mandibles are clearly visible.

Pronotum is generally bell-shaped. Sometimes it is more trapezoidal; sometimes, the posterior angles are more pronounced. There are one or more transparent or semi-transparent "windows" on the pronotum, presumably, for better visions of light from above.

It is assumed that adult males of all the known species have fully developed elytra and fully functional hindwings such that they are capable to fly. Elytra are comparatively soft. Like other beetles, the opened elytra cause substantial air resistance during flight. Fireflies are generally not fast flyer. The adult female of many firefly species have shortened or reduced wings such that flying ability is lost. The appearance resembles their larvae. Therefore, they are sometimes called larviform females.

The legs are generally simple and not significantly well developed for walking and clinging to objects.

The abdomen may or may not be fully covered by the elytra. For Lampyridae, the luminous organs, also called light organs, photic organs, lanterns, are usually located on the ventral side, closer to the posterior end of the abdomen. Shapes and configurations of the light organs vary – spot-like, stripe-like, semicircular, rectangular, obround, C-shaped. Apterous female of some species may show a uniform and constant glow of the whole body. Members of Phengodidae and Rhagophthalmidae also have light organs located at the thorax and display up to 33 luminous spotlights. Sexual dimorphism is common. For some species, adult males have more and better developed light organs than adult female of the same species; for others, adult females have more and better developed light organs. Light emitted from the light organ of some species is so weak that it may not be visible to naked eyes, including diurnal species and some nocturnal species



Pygoluciola qingyu Male adult



Pyrocoelia lunata Larva



Rhagophthalmus sp. Female adult



Stenocladus sp. Larva



Stenocladus sp. Female adult



Rhagophthalmus sp. female adult

Larvae

Colour of the larvae is usually cryptic, such as dark, brown and yellow. Some species have a warning colour - combination of dark and bright colours such as red or yellow.

Larvae are generally elongated, slender and almost tapering in both ends. The body is composed of three thoracic and nine abdominal segments. Terga are usually more sclerotized than the ventral side of the body. Intersegmental membranes and flexibility of the ventral part allow a certain degree of elongation, shortening and curling of the body. Larvae of many species can perform leech-like looping movement when they search for preys on the ground or twigs. Degree of sclerotization, size and shape of the tergal plates vary across species. Fully aquatic larva are less sclerotized; sclerotized dorsal plates do not fully cover the soft tissue beneath. Larvae living in wet, soft and muddy habitat, such as the mangrove species, also bear restricted sclerotized tergal plates. Larvae foraging in semi-exposed habitats bear strongly sclerotized dorsal plates which are slightly explanate. Highly mobile larvae, active on dry and hard surfaces, bear strongly sclerotized plates which are extensively explanate.

Head is retractable beneath the pronotum and extensible when searching for preys and attacking preys. Highly extensible head is for those species feeding on the tissue in the coiled shell of snails. Larvae feeding on preys without a protective shell, such as earthworm and slug have less extensible heads. Antennae short, 3-segmented; ocellus on each side. Mouthparts well developed; mandible falcate, strongly sclerotized; maxillae and labium fused forming compound plate covering most of ventral head area; maxillary palpi 4-segmented; labial palpi 2-segmented.

Species with high mobility have longer and better developed legs for chasing prey. Subterranean and fully aquatic larvae have less developed legs.

All larvae bear a pair of spiracles on the laterotergites of abdominal segment 1-8. The spiracles are replaced by gills in aquatic larvae.

Many larvae also bear eversible glands that secrete repellent substances. These eversible glands are only occasionally extruded for a short period of time from the lateral sides of each segment when the larva is under stimuli. The eversible glands are observed to be projected from all segments except the last.

Light organs in firefly larvae exist as a pair of spots in abdominal segment 8 or, in some cases, in both segment 8 and segment 7.

There are a series of eversible filaments at the terminal abdominal segment called pygopods. Pygopods are used as a holdfast for anchorage and assisting locomotion, especially useful in the looping movement. They are also frequently used to hold the shell of their prey as well as for cleaning its pronotum.

FINDING AND COLLECTING

DIRECT ENCOUNTER

Nocturnal fireflies

Majority of fireflies are first noticed by their displaying light in the dark. The light could be displaying in the air or on the ground or foliage or objects closed to the ground. It should be emphasized that the peak light display period of many species only lasts for a short period of time, ranging from approximately 30 to 90 minutes after sunset. Appropriate surveying time is crucial for the effectiveness of the survey.

When ambient light intensity is low, light displays in the air are usually visible from 20m to 40m away, sometimes even further for larger and brighter species. When looking for fireflies in the sky of an open area, or a large area need to be surveyed, the walking pace could be faster in order to increase survey efficiency. A walking pace of 4km/h could results in 2000m x 80m (two sides of the survey route) = 16 hectares of surveyed area done in the 30 minutes.

For species flying in well vegetated woodlands and forests, firefly light display in the air is occasionally blocked by vegetation, walking pace needs to be slowed down to approximately 2km/h. Usually, hand net or even bare hands are able to catch the flying fireflies for identification or sampling. Pointing strong torch light to the firefly could sometimes make it disorientates and quickly lands on nearby vegetation or on the ground.

For fireflies displaying light on the ground or other objects close to the ground, visibility is often blocked by vegetation. Slower walking pace is necessary to ensure survey effectiveness.

Pupil of our eyes constrict when there is bright light emitted from a normal torch, which makes our eyes less sensitive to dim light in the dark. The bright light also dilutes the light emitted from fireflies. Fireflies may also stop emitting light or slow down the light displaying activity when shone by the bright light from the torch. It is important to adjust the intensity of the torch light to a level which is just enough for the surveyor to see the road surface and keep walking safely. It is also helpful to constrict the illuminated area by shorten the distance between the torch and the ground, or attaching a opaque cover with smaller aperture in front of the torch. Another option is using a red light torch. For surveying sites with good visibility. It is also possible to stand still at suitable points with torch off and observe a large area around the observer. Using (dim) red lantern light helps to keep ones own night vision and might be less disturbing the fireflies.

There will be cases where the species cannot be identified by light patterns and there could be more than one species occur at a place hence it requires an observer to catch the firefly using a sweep net for quick identification (with the presence of an expert if possible) and release it back.

Also the use of light or glow lures (see section traps below) during survey walks can be helpful as they may lure both males of glowing as dark flying species within several minutes. So a tactic of stop, put lure(s) on the ground (at several 10's of meters if using more than one), wait (5-10 min) and watch, then continue walk, can be a quite successful technique during search campaigns when one has no opportunity to revisit spots and recollect traps (see below).

Diurnal fireflies

Compare with light in the dark, diurnal fireflies are much more difficult to be found. Using sweep net is an option for collecting fireflies staying on grasses and foliage of shorter plants. Careful active search by sighting could be effective, especially for brightly coloured species staying on foliage or feeding on flowers. Some larger species are often noticed during their slow flight in the air. With some practise and by developing a "search image", smaller and

even dull coloured diurnal species, or (diurnal) larvae that sit on vegetation or that walk on the ground or on bare surfaces can also be spotted successfully.

PASSIVE COLLECTING BY TRAPS

Flight interception trap and Malaise trap

This technique is useful for collecting non-luminous or diurnal fireflies with good flying ability. When placed at appropriate position, large quantity of flying insects including fireflies can be collected. All collected insects will be killed and preserved by the preservative.



Malaise trap

Bright light trap

Some fireflies are attracted to bright white light, black light or UV light. For this reason, fireflies are occasionally found trapped in buildings situating in less disturbed countryside with overnight light on. A mercury vapour lamp is typically used for producing bright light, light coloured material such as clothes and egg cartons can be placed near the lamp for the insects to land on. *Pyrocoelia analis* and *Stenocladius* spp. are examples of attracted fireflies.



Bright light trap

Glow lure traps

This is exclusive for “glow-worm fireflies”. Betalight, LED, glow-in-the-dark paint female-lantern-imitating patterns, and luminescent stickers may be

used as the light source “bait”, mimicking the female displaying light signal and attract male to fly into the trap. It is effective for some species especially Lampyrinae, the female of which usually emit a continuous glow to attract a male. It is still not clear how the efficiency varies across different target species. Usually, yellowish green glow lures are used.

The major advantage of glow lure traps over other traditional insect traps is their non-destructive nature. All or most of the trapped firefly specimens can be released after identification and count. This is particularly important for large scale surveys or surveying a threatened species.



Glow lure trap

IDENTIFYING FIREFLIES

IDENTIFICATION WITHOUT COLLECTING

To minimize impacts on the firefly populations and to increase recording efficiency. Many specimens can be identified and recorded by good photos without collecting for laboratory inspection. For the size range of fireflies, the most useful and high quality photography equipment is a 100mm, 1:1 Macro lens connected to a 35mm Single Lens Reflex camera or equivalent mirrorless cameras. For a camera with an image sensor size smaller than 35mm, the focal length of the 1:1 macro lens would decrease to 70mm, 60mm or 50mm accordingly. A shorter focal length leads to a shorter distance between the lens and the object for the same magnification value. It would limit the flexibility of photography and also causes difficulty in illumination by flashlight, which is also required during macro photography.

To increase the range of photography in the daytime, especially for the moments when the firefly object is not quite approachable. A lens with a longer focal length - 200 mm to 400mm can be used. An extension tube can be installed between the lens and the camera body to increase the maximum magnification value and to reduce the minimum focusing distance.

IDENTIFICATION BY THE SPECIFIC LIGHT DISPLAY SIGNAL

Pattern of light displaying signals of fireflies is highly diversified. Flash patterns can be classified into three main types:

- a. Continuous glow. Light is emitted continuously with only occasional interruptions or light off.

- b. Simple pulsation. Light is on and off repeatedly. Pulsation frequency, duration of pulses, duration of inter-pulse varies across different species.
- c. Composite flash/Flash train. Each repeated flash is composed of 2 or more pulses. A variation in the number of pulses per flash, pulsation frequency, pulsation duration, inter-pulse duration, flash duration and inter-flash duration, could form many different combinations and specific flash patterns.

Identification could be made immediately by direct observation for species with a distinctive flash pattern or by reviewing the photo or video records. However, currently, only a minority of all known firefly species have a clear and accurate record of flash patterns for comparison, and many firefly species display the same continuous glow. Other information is also needed to assist in the identification, including habitat type, the comparative size of light spots, flying speed and height above ground, and month and time of displaying light.

Also the colour of bioluminescence can be very indicative. Most species glow or flash with lime green colours (spectral wavelength peak = 550-555 nm), but many species emit greener (<550 nm) or lime yellow (ca 565 nm) or amber (ca 590-600 nm) to orange light (> ca. 600 nm).

RECORDING FLASH PATTERNS BY LONG EXPOSURE PHOTOGRAPHY

Correct exposure is crucial to how good is the flash pattern is recorded. There are generally four factors affecting exposure:

- a. ISO value – sensitivity of image sensor. Higher value results in a brighter image – both the background and firefly light spots would be brighter. Higher ISO value also results in worse image quality. Depending on the image processing quality, image quality varies greatly across the different cameras. For the purpose of recording firefly flashes, ISO values between 400 to 12800 are normally used in high grade cameras.

- b. Lens focal length. A shorter focal length means a wider field of view and results in a brighter image. For recording firefly flash patterns, 28mm to 70mm is most suitable.
- c. Lens aperture. A larger aperture (smaller numeric value) allows for light entering into the camera and results in brighter image. At the same time, a larger aperture also reduces the depth of view – only objects at a certain distance from the camera are clear, and all other objects are blurred. The phenomenon is more profound when using a lens with a longer focal length. An aperture value of f/2.8 to f/8 is often used for recording firefly flashes.
- d. Exposure time. Minimum exposure time is the duration of the flash plus inter-flash duration. A longer exposure time captures more flashes and shows individual variations. Longer exposure time has no effect on the brightness of the light spots recorded on the image, but longer exposure time results in a brighter background and makes the light spots less visible on the image. Depending on the ambient light intensity, exposure time longer than 30s is usually not acceptable.

Image stacking is commonly used to increase the number of flashes recorded on the same image without increasing the brightness of the background caused by excessive long exposure time. This involves overlaying multiple images with a shorter exposure time without increasing the brightness of the background by software.



A composite flash of *Abscondita terminalis*
 Lens 50mm; ISO 800; Aperture f/7.1; Shutter 9s



Abscondita terminalis Lens 50mm; ISO 800; Aperture f/7.1; Stacking of 168 images.
 Total exposure time = $168 \times 9\text{s} = 1512\text{s}$



Simple pulsation flash of *Medeopteryx hongkongensis* Lens 50mm; ISO 1600; Aperture f/5.6; Stacking of 120 images. Total exposure time = $120 \times 8\text{s} = 960\text{s}$



Continuous glow of *Diaphanes lampyroides* Lens 50mm; ISO 1800; Aperture f/4; Stacking of 28 images. Total exposure time = $28 \times 8\text{s} = 224\text{s}$

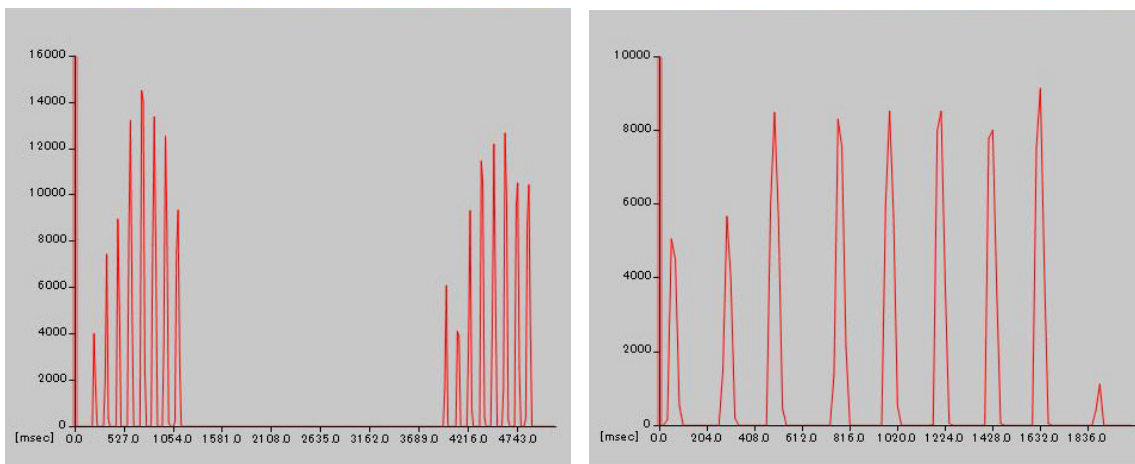
Recording flash patterns by videography.

Requirements for the night imaging capacity of the camera are much higher for firefly flash videography than for firefly flash photography. In order to clearly record the firefly flash pattern, maximal lens aperture should be f/2.8 or larger (smaller value). Maximum capable ISO value of the camera should generally be 25600 or higher. Normally, for recording pulsation flashes or composite flashes, recording frame rate should not be set at a value slower than 50fps or slower than double the pulsation frequency. Example is a mangrove firefly *Pteroptyx maipo*, its pulsation frequency is about 25Hz, recording frame rate should be set as 50 fps or faster. Otherwise, the flash pattern will be incorrectly recorded.

The recorded videos can be used for analyzing flash pattern in two different ways:

- a. Playing back the video.
- b. Feed into software for graphical analysis. Example is the TiLIA, a free open-source software package for signal and flight pattern analyses of fireflies. Download link for the software and user manual:

<https://drive.google.com/open?id=0B2o7FRVs2VohMmx2QzBVX3ZDeDA>



QUALITATIVE SURVEYS OF TEMPORAL DISTRIBUTION

All fireflies undergo four stages in their life history. The adult stage is usually much shorter than the sum of other three immature stages, and larval stage is usually the longest. Many species are known to be univoltine and adults appear once a year for a period of time ranging from 2-3 weeks to months. Adults of some species can be found in most of the time of a year. For example *Pyrocoelia analis*, adults of which can be found from March to December. Some species are known to be multivoltine, more than one generation of adults appear in different ranges of time of the year. The two or more flight periods may or may not overlap. The flight period may last for about 6 months. Some species have a very large distribution range. Sub populations of the same species in different latitude or altitude may have significant different on their flight period.

Number and frequency of surveys required to determine the temporal distribution could vary greatly across different species. It should also be noted that the peak period of adult activities of a species may not be exactly the same in every year. It could be affected by other factors especially weather conditions during the flight period as well as the weather conditions during its immature stages.

It is advisable to allocate regular and repeated surveys to cover a larger range for a particular target species.

Many species only display light actively during a very short period of time in a day – approximately 30 minutes. The peak light displaying period may vary across different species. It is not uncommon that different firefly species sharing overlapping flight period and overlapping habitat show segregation of peak light display period in the same night. For example the smaller *Diaphanes* spp. tend to actively displaying light from 30 to 60 minutes after sunset, but the *Pyrocoelia* spp. in the same place display light from one to four hours after sunset.

Knowing the temporal distribution of different species are very important for effective and valid qualitative surveys on spatial distribution as well as quantitative surveys.

QUALITATIVE SURVEYS OF SPATIAL DISTRIBUTION

Firefly species have various habitat preferences and various degrees of habitat dependency. Some species can be found in a wider range of habitat types. Some species can only be found in very specific habitat types. Examples are the mangrove firefly species and the aquatic firefly species.

If surveying all available and suitable habitat type for a particular species is not possible because of limited surveying manpower, to increase cost effectiveness, there are several strategies:

- a. Surveying larger and more possible sites of the habitat type first, prioritize an area that is known to have fireflies and habitat less disturbed such as a nature reserve;
- b. Surveying sites evenly distributed over a very large area;
- c. Surveying areas close to the known occurrence sites first;

For species with longer flight period, more surveys can be done at different time to cover more sites and a larger area.

For densely populated and easily visible species (flying and luminous), less survey efforts and time can be allocated to each site and more sites and

larger area can be covered. For less common, sparsely populated, or less visible species (flightless or non-luminous), more surveying efforts need to be spent on each site.

Survey efforts could also be greatly affected by the walkability and visibility in different habitat type.

In general, species occurring in heterogenous habits require more sampling efforts than those in homogenous habitats.

QUANTITATIVE SURVEY

It is important to have adequate knowledge on the temporal and spatial distribution of a particular species before designating appropriate sites and methods to conduct quantitative surveys. Methods applicable to individual species varies according to its habitat features, population density, flying ability, mobility (stationary vs. roving) and light display habit.

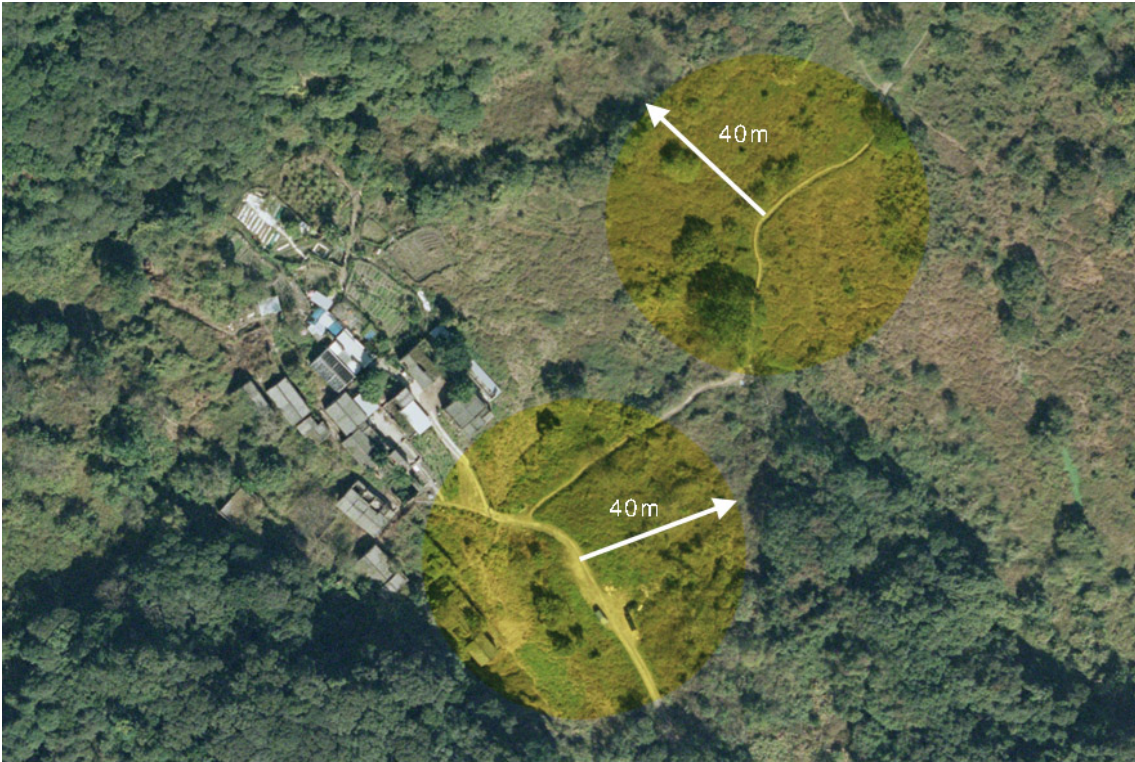
Adults of some species are comparatively difficult to encounter because of very low population density, short flight period, inconspicuous light display, or non-luminous flying male. At the same time the larvae of which may be much more readily found. In such case, larvae could be a better target for evaluating population density. An example is the *Lamprigera* spp. in Asia.

To be sure that a population is present, the encounter of several females and/or larvae may be more informative than recording the presence of (few) males; as males of many species may wander away from spots where females are present. This last is especially relevant in species with less mobile (flightless) females.

POINT COUNT

This is useful for densely populated, roving species displaying light during flight in fragmented sites with limited area. For example, *Abscondita terminalis* (Luciolinae), a flashing firefly occurring in small pieces of abandoned farmlands irregularly surrounded by shrubland and woodlands, in Hong Kong.

The observer stands in the middle or other suitable point of the small survey area. Directly count the number of visible light display in a given period of



Point count of densely populated *Abscondita terminalis* in an abandoned farmland irregularly surrounded by shrubland and woodlands

time. To prevent repeated counting of the same individual, for flashing fireflies, the time duration for counting should be just shorter than one cycle of its flash - the sum of the flash duration and flash interval. For example the flash duration of *Abscondita terminalis* is 0.9s, and flash interval is 1.3s, the counting duration should be 2.1s. For flying species showing continuous glow, the relative position of different species should be noticed in order to prevent repeated counting.

When the density of light display is high, a portion of the visible area, for example 1/4 can be selected to represent the whole area, on the condition that they are more or less evenly distributed.

An option is to take a long exposure photo of the survey area. For flying species showing continuous glow, longer exposure time can be adopted. One continuous light trail represents one individual. For flashing and flying fireflies, exposure time is just shorter than one cycle of its flash. Divide the exposure time by duration of one flash cycle, times the number of flashes recorded in the photo, can be



Light trail of 5 male adult of *Diaphanes lampyroides* shown on a long exposure photo – Shutter 8s, Aperture f/1.6, ISO 1600, lens 50mm



35 flashes of *Abscondita terminalis* shown on a long exposure photo – Shutter 9s, Aperture f/5.6, ISO 6400, lens 85mm. $N = 3.4/9 \times 35 = 13$

regarded as the actual number of flying individuals in the recorded area during the period of recording: $N = \text{Duration of 1 flash cycle} / \text{photo exposure time} \times \text{flash units detected on photo}$.

Another option is to take video records, and do counting in playing back the video clips. High grade videography equipment with strong capability in low light conditions is required. ISO value of 25600 or above and lens aperture f/2.8 or larger (smaller value) is generally needed.

Same principle applies to light displaying, stationary species. Some species have very high density, such as the congregating *Pteroptyx* spp. found on the mangrove trees in tropical Asia, Jusoh & Ibrahim, 2011 proposed to compare the appearance of light spots of the fireflies with a series of percentage charts, ranging from 1% to 50%. Kirton *et al.*, 2012 and Khoo *et al.*, 2012 used digital night photography and image analysis to obtain an index of abundance.

QUADRAT COUNT

This is useful when a species occurs in a large area of land and surveying the whole area is not possible. The assumption is the population density of in the selected portions represents the whole. It is important to have adequate knowledge on the luminescence behaviour, temporal and spatial distribution of a particular species before conducting quadrat count.

The quadrat count should be done and completed within the peak light displaying period of the target species. Manpower availability is not the only factor to consider when determining the quadrat size. Other factors to consider are:

a. Population density. Higher population density may require more time to count and the quadrat cannot be too large.

b. Co-existing species. Additional time is needed for distinguishing the target.

- c. Duration of peak light displaying period. The longer the duration, the higher the flexibility.
- d. Visibility in the habitat. Sparser or lower vegetation enable faster counting of a larger area.
- e. Visibility of the firefly flash signals. Flightless light displaying targets may require more time to find.
- f. Suitability to be recorded by photography or videography and do the counting afterward?
- g. Suitability and necessity to use traps?
- h. Walkability in the survey area.

TRANSECT COUNT

Transect count is similar to quadrat count that a portion of area is selected to represent the whole large area. The difference is the linear feature of a transect could show the change of population density along an environmental gradient.

Transect count is most applicable to:

- a. The habitat of the firefly is in linear form, such as shores, watercourses and margins of particular vegetation types.
- b. The investigation area has low walkability. It can only be easily accessed via roads and paths. Area around the roads or paths become the transect.
- c. An environmental gradient runs across the survey area, which may affect the population density of the firefly. For example, decreasing altitude, gradual change of vegetation or habitat type.

Apart from manpower availability, width and length of the transect depends on a number of factors:

- a. Population density.

- b. Co-existing species. Additional time is needed for distinguishing the target.
- c. Duration of peak light displaying period. The longer the duration, longer transect can be surveyed.
- d. Visibility in the habitat. Sparser or lower vegetation enable faster counting.
- e. Visibility of the firefly flash signals. Flightless light displaying targets may require more time to find.
- f. Suitability to carry photography or videography equipment along the transect do recording and counting is done afterward?
- g. Suitability and necessity to use traps?

The pace of walking along the transect during survey should allow reliable data recording.



A 2km long transect for counting a flightless, light displaying female firefly along a paved road in a well vegetated area.

ENVIRONMENTAL FACTORS POTENTIALLY AFFECTING FIREFLY ACTIVITIES

Some environmental factors may have significant influence on the mobility and light display activity of certain species. These factors need to be noticed or recorded in the survey.

Lunar illumination

It is determined by the moon phase and moon position. Strong lunar illumination may reduce the light displaying activity of some firefly species. It may also reduce visibility of an observer to identify firefly light.

Water vapour in the air – cloud, fog, mist

The water vapour blocks or reduce the moonlight. On the other hand, it reflects and refracts the artificial illumination from the ground far away from the survey area and may substantially increase the ambient light intensity.

Temperature

In general, lower temperature reduce the activities of firefly, but the influence varies greatly across different species and geographic regions. Some species stop flying below 20°C, some species keep flying at 12°C.

Rainfall

It is not clear how much does rainfall influence firefly activities. Presumably, light rainfall has no significant influence. In some tropical areas, two hours after rain has stopped is a good time to observe fireflies.

Wind

In view of comparatively low flying ability of fireflies. Strong wind could significantly slow down or even stop the firefly flight and light display activity.

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