MOTH SURVEYS OF WOODLAND AND SCRUB SHOULD INCLUDE TRAPPING AT HEIGHT

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ABSTRACT

Results of a light trap survey conducted at ground and at 4.5 m canopy level using low-light intensity traps indicated that moths fly at different heights. Fewer individuals and fewer species of moth were recorded in the higher trap. Possible reasons for differences in flight heights include temperature inversions, places to settle after flight and the availability of larval food resources. Forewing length appeared to have no influence on flight height. *Eudonia mercurella* (L.), *Eugnorisma glareosa* (Esper) and *Euthrix potatoria* (L.) appear good candidates for low flight behaviour. July Highflyer *Hydriomena furcata* (Thunberg), despite its vernacular name, does not generally appear to be a high flier. Results show that moth surveys of woodland and scrub habitats with vegetation at different heights should include trapping at higher levels for a more comprehensive survey.

INTRODUCTION

It is well known that butterflies fly at different heights in the course of their normal flight e.g. Small Heath *Coenonympha pamphilus* (L.) flies low amongst the grasses, whereas Purple Emperor *Apatura iris* (L.) flies at the tops of oak and willow trees. The Purple Hairstreak *Favonius quercus* (L.) may be one of our commonest butterflies, unseen on many oak trees as it flies at the tree tops in the late afternoon sunshine. There is no reason to suppose that moths behave differently to butterflies. Indeed, some moths are known to be associated with tree canopies e.g. *Pammene ochsenheimeriana* (Lienig & Zeller) around the tips of the branches (Hancock & Bland, 2015), *Elegia similella* (Zincken) (personal observation) and Red-necked Footman *Atolmis rubricollis* (L.) (Manley, 2021); some of these canopy dwelling moths may be more common and widespread than realised.

Some previous studies have shown that moths fly at different heights. It is well known that migrating moths may fly hundreds of metres above ground. Wood *et al.* (2009), using four years' aggregated radar data for the summer months in southern Britain, found that well-defined layers of large nocturnal migrants form in the early evenings, usually 200–500 m above ground, composed mainly of noctuid moths, especially Large Yellow Underwing *Noctua pronuba* (L.), Heart and Dart *Agrotis exclamationis* (L.), Silver Y *Autographa gamma* (L.), Turnip Moth *Agrotis segetum* (D. & S.), Setaceous Hebrew Character *Xestia c-nigrum* (L.) and Angle Shades *Phlogophora meticulosa* (L.). Taylor & Carter (1961) suggested that nocturnal flying insects are likely to choose their own height of flight. They found the following: Beaded Chestnut *Agrochola lychnidis* (D. & S.) flies mainly 6 m high before midnight, the highest density of Mouse Moth *Amphipyra tragopoginis* (Clerck) was below 2.7 m; Garden Dart *Euxoa nigricans* (L.) and Dark Arches *Apamea monoglypha* (Hufnagel) have a prominent flight maximum at 6 m; Setaceous Hebrew Character *Xestia c-nigrum* (L.) and *Noctua pronuba* (L.) have a flight maximum between 3 m and 6 m. Spalding (2019) found by comparing moth trap catches in the canopy at 9 m and on the ground over six days in 2018 that there was a difference in moth flight height in dense woodland - a ground trap attracted 312 individuals comprising 91 species compared with the canopy total of just 56 individuals of 25 species.

It is well known that nocturnal moths come to light (e.g. Spalding *et al*., 2019). Baker and Sadovy (1978) estimated that the effective range of a 125 W mercury vapour lamp is about 3 m. Attraction range is probably less for lamps with a lower UV output of the appropriate wavelength; Truxa and Fielder (2012) found that predicted percentage recapture rates for moths released at a distance of just 3 m from a weak light trap (15 W UV-light tubes) were between 19% to 39%, so even at this short distance not all moths are attracted to light. van Grunsven *et al*. (2014) found that overall 75% of moths released within 2 m of a 6 W trap were not caught. Qureshi *et al*. (2005) found no difference in the numbers of male *Ostrinia nubilalis* (Hübner) caught by 15 W black light traps and pheromone traps placed only 2 m apart from each other, suggesting that there was no interference between these traps even at this small spatial scale. Brehm *et al*. (2021) found that, when running four moth traps each 10 m from the adjacent trap and 7.1 m from the moth release box at the centre of a darkened rectangular lecture hall, only 10.7% of the moths (12.2% males and 9.2% females) were attracted to a lamp. Weak artificial light sources are therefore an excellent way to accurately characterize and monitor moth communities in selected habitats, since the low attraction radius means that few species from adjacent habitats are likely to be caught by such traps.

Methods

The survey site

The survey site was at Trelusback (SW712383) near Stithians in Cornwall, owned by the Trelusback Foundation. The habitat immediately surrounding the survey points consists of low-lying marshy grassland edged by oak and willow trees, sheltered from the prevailing westerly winds.

Moth communities at ground and canopy level

The aim of the survey was to investigate the moth communities flying and attracted to a light source at ground level compared to those attracted to an identical light source positioned 4.5 m above in the surrounding canopy. Canopy level was chosen rather than just an arbitrary height as moths will probably fly at different heights according to the surrounding vegetation rather than at a fixed height regardless of habitat; for example, Purple Hairstreak butterflies fly at canopy height whether this is 5 m or 10 m above the ground (e.g. Eeles, 2019). The canopy was defined in this case as the upper parts of the highest leaf / branch layer.

The null hypothesis is that there would be no difference between moth catches at 4.5 m above ground and at ground level providing that light sources and moth trap construction are the same.

One moth trap was placed on the ground near a small oak tree, the other at 4.5 m up on a small tower close to the canopy of the oak tree. The canopy trap was about 1–2 m horizontally distant from the ground trap following the methodology of Beck *et al*. (2002), who placed tree crown traps immediately above, or very close to, the corresponding ground trap. At first the trap was placed on a platform at this height but subsequently the trap was raised up by pulley so that the light was about 30 cm lower but free swinging and not obscured by the surrounding safety railings of the canopy tower. The light tube was 0.5 m below the tree canopy. Two 6-watt actinic

Heath traps (Heath, 1965) were used as these have a small attraction area; the light tubes were switched between canopy and ground regularly to ensure that light attraction was equal at both sites. Traps were run overnight; each had a solar switch to ensure that the light went on and off at the same time in the evening and morning. There were long gaps between each night-time survey so that it is unlikely that any individual moths were sampled more than once.

There were 36 overnight surveys between 5 June 2019 and 1 August 2022 (Table 1); the survey period was interrupted by the covid pandemic and therefore extended over three years. There were visits during every month of the year except February. Minimum temperatures were taken at both sites except on five occasions when temperatures were only taken at canopy level. Atmospheric pressure was recorded for 33 of the 36 survey nights. A note was taken on general weather conditions including wind direction; wind speed was not recorded but nights with no wind (both at ground and canopy height) were noted.

Table 1. Record of monthly surveys

Month	Number of trap nights
January	2
February	0
March	4
April	4
May	2
June	4
July	5
August	4
September	3
October	2
November	4
December	2
Total surveys	**36**

Species were identified according to the available identification handbooks. The number of individuals at each site was recorded. At first the canopy trap was opened on the tower platform with moths settled close by on the tower also recorded; later on, the trap was carefully lowered via the pulley to the ground and opened there – moths on the trap exterior were recorded. On the ground some moths settled nearby rather than entering the trap itself; these were recorded if immediately adjacent to the trap on the basis that moths by the canopy trap had nowhere to settle apart from inside the trap and were more likely to have flown into the trap itself; these were relatively few in number and are unlikely to have skewed the results.

Moths in the *Oligia* minor group were not identified to species apart from Rosy Minor *Litoligia literosa* (Haworth) and Middle-barred Minor *Oligia fasciuncula* (Haworth); moths in the *Epirrita* group were not identified to species. Lesser Common Rustic *Mesapamea didyma* (Esper) and Common Rustic *Mesapamea secalis* (L.) were identified by genitalia dissection.

Statistical analysis was by *t-test* and correlation *r*.

Wing size and flight height

The forewing length for each species was taken from Manley (2021). This is a commonly used method for sizing moths and avoids killing or otherwise handling the specimens – see for example van Grunsven *at al.* (2014). These figures are average lengths and of course the moths actually recorded may have been slightly larger or smaller. Where the species was sexually dimorphic, the length of the male forewing was taken. The null hypothesis was that moths with larger wings are likely to fly higher than moths with smaller wings. Matched pairs (i.e. excluding the moths only found at one of the two sites) were tested using the *z-test* for comparing the means of two large samples.

Results

Moth communities at ground and canopy level

During the survey a total of 1685 individual moths were recorded, comprising 516 individuals (30.6% of the total) recorded in the canopy and 1169 individuals (69.4% of the total) at ground level (Table 2). A total of 185 species were recorded. One hundred and one species (54.6% of the total) were recorded in the canopy compared with 166 species (89.7% of the total) on the ground. Eighty-two species (44.3%) were recorded in both trap sites (see Table 3 for a selection of these). Eighteen species were only recorded in the canopy (Table 4) and 84 species were only recorded at ground level.

Table 2. Numbers of moths recorded in the canopy and on the ground month by month

Month	No. of trap nights	No. of moths	canopy	ground
January	2	2	1	1
February	–	–	–	–
March	4	46	17	29
April	4	108	36	72
May	2	54	9	45
June	4	268	73	195
July	5	533	195	338
August	4	447	130	317
September	3	160	49	111
October	2	43	6	37
November	4	22	0	22
December	2	2	0	2
Totals	**36**	**1685**	**516**	**1169**

There were 82 paired species – species recorded both in the canopy and on the ground. There was a significant difference in these paired species ($t = 9.56$, $p = 0.01$) and they were heavily weighted towards the ground trap moths (Fig. 1a & 1b). (Some points in these figures cover several paired species with the same results).

Of particular interest were the following moths which appeared in reasonably large numbers. Rosy Footman *Miltochrista miniata* (Forster), whose larvae feed on arboreal lichens, was slightly more common in the canopy, whereas Dingy Footman *Eilema griseola* (Hübner) was much more common at ground level. Autumnal Rustic *Eugnorisma glareosa* (Esper), Drinker *Euthrix potatoria* (L.) and *Eudonia mercurella* (L.) were only found at ground level and have larvae which feed respectively on low plants, grasses and mosses. *Scoparia ambigualis* (Treitschke), like *Eudonia mercurella* (L.), feeds as larvae on mosses but was found equally at height and on the ground. Although True Lover's Knot *Lycophotia porphyria* (D. & S.) is a heather feeder, a large proportion were found flying at height. July Highflyer *Hydriomena furcata* (Thunberg) did not appear to be a highflyer with only 14 recorded at height compared with 57 on the ground.

Twenty-eight Common Rustic *Mesapamea secalis* (L.) were recorded, of which 17 were in the canopy, with 11 on the ground, compared to five Lesser Common Rustic *Mesapamea didyma* (Esper), of which four were in the canopy and one on the ground. These are grass feeders but were marginally more common at canopy height.

Eighteen species were only recorded in the canopy, all as single individuals except for Dot Moth *Melanchra persicariae* (L.). Many of these moths were flying well above their herbaceous foodplants. Those species associated with trees may naturally fly higher.

Table 3. Some of the moths recorded both at the canopy and on the ground

Name	Common name	Nos in the canopy	Nos on the ground	Foodplants
Agrotis exclamationis (L.)	Heart and Dart	24	25	Herbaceous plants
Cerastis rubricosa (D.& S.)	Red Chestnut	4	16	Herbaceous and woody plants
Diarsia rubi (Vieweg.)	Small Square-spot	14	18	Herbaceous plants
Eilema griseola (Hübner)	Dingy Footman	3	39	Lichens, algae
Hydriomena furcata (Thunberg)	July Highflyer	14	57	Hazel, willows etc
Idaea aversata (L.)	Riband Wave	1	10	Herbaceous plants
Lycophotia porphyria (D. & S.)	True Lover's Knot	8	21	Heathers
Miltochrista miniata (Forster)	Rosy Footman	18	14	Lichens
Mythimna impura (Hübner)	Smoky Wainscot	21	45	Grasses
Noctua pronuba (L.)	Large Yellow Underwing	70	96	Herbaceous plants and grasses
Ochropleura plecta (L.)	Flame Shoulder	67	60	Herbaceous plants
Orthosia cerasi (F.)	Common Quaker	22	32	Trees
Orthosia gothica (L.)	Hebrew Character	10	22	Herbaceous plants and trees
Scoparia ambigualis (Treitschke)		14	14	Mosses
Xestia xanthographa (D. & S.)	Square-spot Rustic	19	27	Herbaceous plants and grasses

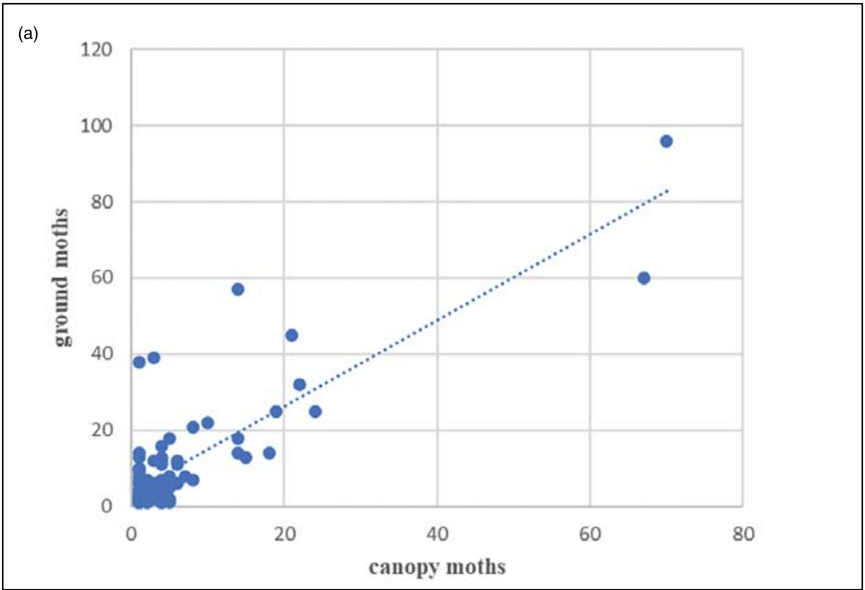

Fig. 1a. Paired results from the canopy and ground traps showing weighting to the ground trap (i.e. where species were found in both traps there were usually more at ground than canopy level). Both axes show the number of moths recorded.

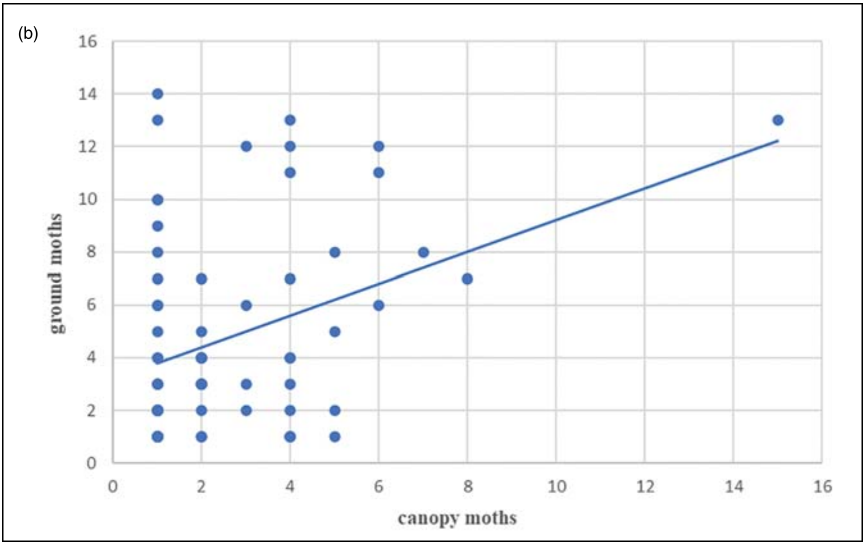

Fig. 1b. Paired results from the canopy and ground level traps showing weighting to the ground trap; the highest figures above 15 are omitted. (see Table 3 for these). Where species were found in both traps there were usually more at ground than canopy level. Both axes show the number of moths recorded.

Table 4. Species recorded only in the canopy trap

Name	Common name	Number recorded in the canopy	Larval foodplants
Abrostola triplasia (L.)	Dark Spectacle	1	Common nettle
Agonopterix heracliana (L.)		1	Umbellifers
Alsophila aescularia (D. & S.)	March Moth	1	Broad-leaved trees
Apamea crenata (Hufnagel)	Clouded-bordered Brindle	1	Grasses
Colocasia coryli (L.)	Nut-tree Tussock	1	Broad-leaved trees
Ditula angustiorana (Haworth)	Red-barred Tortrix	1	Trees and shrubs
Earias clorana (L.)	Cream-bordered Green Pea	1	Willows
Erannis defoliaria (Clerck)	Mottled Umber	1	Broad-leaved trees
Eupithecia vulgata (Haworth)	Common Pug	1	Hawthorn, sallow etc
Herminia grisealis (D. & S.)	Small Fan-foot	1	Healthy, withered and fallen leaves on broad-leaved trees
Hydrelia flammeolaria (Hufnagel)	Small Yellow Wave	1	Alder
Melanchra persicariae (L.)	Dot Moth	3	Polyphagous
Noctua fimbriata (Schreber)	Broad-bordered Yellow Underwing	1	Herbaceous plants
Pandemis cerasana (Hübner)	Barred Fruit-tree Tortrix	1	Polyphagous
Polia nebulosa (Hufnagel)	Grey Arches	1	Polyphagous
Pterapherapteryx sexalata (Retzius)	Small Seraphim	1	Sallows
Timandra comae Schmidt	Blood-vein	1	Herbaceous plants
Yponomeuta rorrella (Hübner)	Willow Ermine	1	Willows

Moth numbers and temperature

Minimum temperatures varied between the two trap sites. Generally the temperature at ground level was equal to (on eight occasions) or lower than (on 17 occasions) at the canopy trap, and the only temperatures below zero were recorded on the ground; on four occasions (2.v.19; 3.v.20; 20.xi.21 and 1.viii.22) minimum temperatures were higher on the ground, in all cases by just 2°C. There was a modest correlation between ambient temperature and moth numbers at ground level ($r = 0.584$; $p = 0.01$ and a non-significant weak correlation at canopy level ($r = 0.313$). On five occasions canopy counts were higher than ground counts – on each occasion the temperature at canopy height was the same or higher than ground level and there was either no wind or the wind was very light.

There were 12 nights with almost no wind. On only one of these nights (27.viii.21) was the moth count higher in the canopy than on the ground (59 to 37 moths) showing that wind speed was not the main factor affecting canopy moth counts; on this occasion the minimum temperature at 10°C on the canopy was much higher than

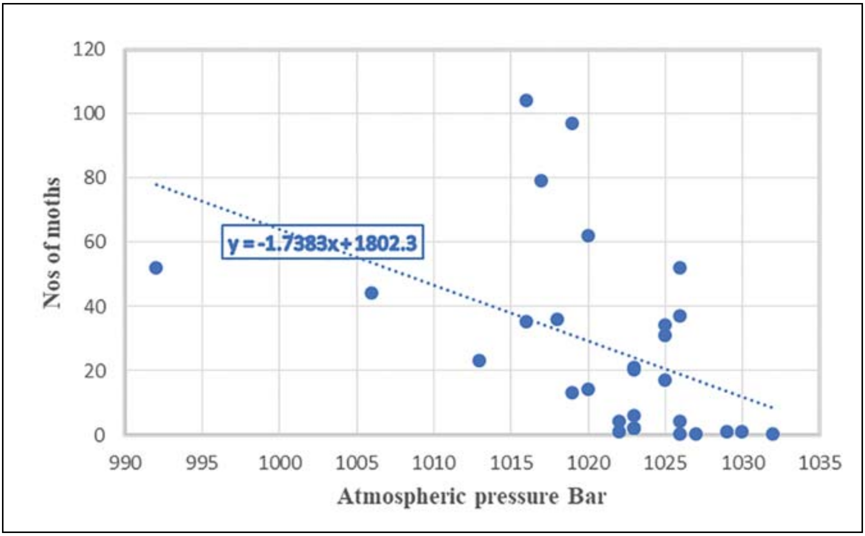

Fig. 2. Numbers of moths in the ground trap at different atmospheric pressures.

on the ground at 6°C, indicating that temperature was the most important factor influencing moth numbers on this night.

Moth numbers and atmospheric pressure

There was a significant correlation between the numbers of moths and atmospheric pressure ($r = 0.495$; $p = 0.01$) (Fig. 2). More moths fly when the atmospheric pressure is low. This may in part be a secondary effect, when the wind is slight and temperatures are high.

Wing size and flight height

Wing size ranged from 8 mm to 30 mm in the canopy moths (mean 16.3 mm; $n = 101$). The largest moth was the Elephant Hawk-moth *Deilephila elpenor* (L.) with a 30 mm forewing, the smallest moth at this trap was *Ditula angustiorana* (Haworth) with an 8 mm forewing. Wing size ranged from 7 mm to 50 mm in the ground-level flying moths (mean 16 mm; $n = 166$); the largest moth was Poplar Hawk-moth *Laothoe populi* (L.) with a 50 mm forewing; the smallest moths were Diamond-back Moth *Plutella xylostella* (L.), Water Veneer *Acentria ephemerella* (D. & S.) and *Cochylis atricapitana* (Stephens), each with a 7 mm forewing.

There was no significant difference in mean wingspan between the two samples ($z = 0.999$); therefore we can say that larger winged moths do not necessarily fly higher than smaller winged moths.

Discussion

Different species fly at different heights

The results show that moths can fly at different heights. Flight height does not seem to be influenced by forewing size but may be influenced to some extent by air temperature. Taylor & Carter (1961) suggested that flight height behaviour was not associated with temperature inversions but flight might be highest when a species is at its commonest and higher when the weather is most suitable. Craik (2020) found that a trap placed at ground level caught significantly more individuals and species per night than a trap placed at 90 cm above ground level; he suggests that more moths fly within a few cm of the ground than at a height of 90 cm but suggests that other explanations are possible.

It is of course possible that moths are more likely to come to a ground-level trap than a high trap because they can turn dorsally to the higher light and continue to fly as normal at a constant height in their chosen direction, but become disorientated by the lower light, turning their backs to the light and plummeting downwards (Fabian *et al*. 2024). This would enhance the difference between trap catches and increase the likelihood that a moth flying between the two lights would be attracted to the lower light.

The effect of vegetation on flight behaviour

It may be that moths prefer to fly and settle near vegetation rather than out in the open. This study found that there were usually moths settled near the ground trap amongst the vegetation whereas in the canopy trap there were no places for moths to settle immediately adjacent to the trap. It may be that moths fly higher where there is tall vegetation than in more open areas with low vegetation and prefer to fly where there are more places to settle after flight comes to an end (e.g. by the advent of daylight). It may be that moths fly low but fly higher when they reach a tree; there might be a difference between male and female activity. Beck *et al*. (2002) found that, in a survey in Borneo rainforest, for Geometridae, species diversity was significantly higher in the understorey where plant species diversity was higher than in the tree canopy.

It may be that flight preference is higher for some moths where there are more potential larval resources higher up (e.g. lichens, mosses and leaves in tree canopies) but it was noticeable that some moth species with larvae feeding on low-growing herbs flew high (e.g. *Melanchra persicariae*) and some tree-feeding species flew low (e.g. *Hydriomena furcata*); it has been said that the common name of this species could refer to a habit of flying at dusk high round bushes (Marren, 2019) but I am not aware of any evidence of this. Table 4 lists 18 species only found in the canopy of which ten feed as larvae on trees, but we do not necessarily know how high up these species feed on the trees and where they pupate.

Many of the moths recorded at ground level feed as larvae mainly on low-growing plants. Of the 15 species listed in Table 3 only two (*Miltochrista miniata* and *Ochropleura plecta*) were slightly more common at canopy level; *O. plecta* feeds as a larva on low-growing plants, whereas *M. miniata* feeds as a larva on lichens, perhaps high up on trees. In contrast, *Eilema griseola* (which also feeds on lichens) was much more common on the ground layer and perhaps favours different parts of the tree. *Scoparia ambigualis* feeds as a larva on mosses and appears equally common at ground level and at height; Parsons & Clancy (2023) indicate that larvae have been found at ground level but it is possible that higher feeding larvae are simply not so easily found. Of the other 12 species listed as more common flying at ground level, eight feed as larvae on low-growing plants, one moth feeds on lichens and mosses, one moth feeds on both low plants and trees and two feed on trees. It therefore seems likely that larval feeding preferences may generally indicate height of flight for many but not all species. It is worth noting that, for example, butterflies with ground-feeding larvae – such as Painted Lady *Vanessa cardui* L. which feed on thistles – may often fly high.

Should moth trapping always include high level traps?

Stork, Adis & Didham (1997) indicated that for some arthropod taxa the major abundance or diversity (or both) in tropical rain forests may be found in the canopy. The present study indicates that the highest moth diversity is at ground level, but 18 species were found exclusively at the higher trap. It may be that, as for butterflies, some moths always fly low, others always fly high, with perhaps the majority flying regularly at different heights influenced by local vegetational structure and weather conditions. *Eudonia mercurella*, *Eugnorisma glareosa* and *Euthrix potatoria* seem good candidates for low flight behaviour. Eighteen species representing 9.7% of the total number of species were only found at canopy level, therefore it is suggested here that two or more traps are needed for full moth habitat surveys, at least one higher up than the others.

Moths and bats

One factor that has not been considered during the present survey is whether bats had been actively predating moths around the traps. A Brown Long-eared Bat *Plecotus auritus* (L.) was found inside the ground-placed trap and occasionally some moth wings were found on the tower around the canopy trap, indicating that bat predation occurred at both trap sites. Bats will forage both near the ground and at canopy level. Staton & Poulton (2012) found significantly more bat activity at canopy height than ground level especially for Common Pipistrelle *Pipistrellus pipistrellus* (Schreber) and Noctule *Nyctalus noctula* (Schreber), whereas *Myotis* bats preferred the understorey in spring but the canopy in summer. Soprano Pipistrelle *Pipistrellus pygmaeus* (Leach) preferred the canopy in summer only. *Plecotus auritus* often glean insects (especially Lepidoptera) from foliage or the ground (Shiel, McAney & Fairley, 1991), detecting prey by sight. Unfortunately it was not possible to determine the effect of bat predation on either trap location as the traps were left untended at night, and in particular whether predation was higher or lower at the canopy trap.

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