models outlined here are feasible and viable. Previous studies used nest length and breadth as criteria to develop models for population estimation of weaver ants[20]. However, the present study has proved that a simple model using the number of leaves involved in nest construction provides better estimates of ant population compared to any other model. Further, as *O. smaragdina* is a vigilant and territorial predator of many insect pests in a number of horticultural crops, population estimation through simple models as indicated in the present study will help in designing colony relocation studies to use them more efficiently in arboreal domains.


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# Moth pests collected in light traps of tea plantations in North East India: species composition, seasonality and effect of habitat type

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**Light trap has often been used in the ecological studies of lepidopteran insect pests in agroecosystems. However, the light trap in Indian agricultural systems is rarely adopted either to monitor the population size or to study the migration of moth pests. In the present study, we have installed light traps in shaded and unshaded tea plantations of North East (NE) India to study (1) the species composition, (2) effect of shade on moth pests, (3) seasonality of major pests and (4) to learn the sex proportion of major pests captured in light traps. The two-year catches in light traps suggested that *Hyposidra talaca* (Geometridae) is a major pest of tea in NE India. It peaks in number during winter months, with relatively few moths caught in the later parts of the year. *Eterutia magnifera* (Zygaeni-**

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**dae) is the second major pest of tea that peaks in number during summer months. *Hyposidra infixaria*, *Buzura suppressaria*, *Ectropis obliqua*, *Ascotis* sp. (all Geometridae) and *Arctornis submarginata* (Lymantridae) were caught in the light traps, but in low numbers. The catches also suggested that shade status has an important role on moth pest population in tea agroecosystems; shaded plantations received significantly higher number of moths of all major pests. The difference in the catches of *H. talaca* moths was significant among years. Pair-wise analysis suggests that the difference in the catches of *H. talaca* in corresponding standard meteorological weeks (SMWs) of two years was not significant for most of the SMWs, which confirms the inter-annual consistency in the life cycle and generations. Male moths constitute more than 77% of the overall catches of *H. talaca*. Overall, our results highlight that light trap is an effective, bias-free monitoring tool of moth pests of tea, which also captures the variability due to habitat type.**

**Keywords:** Habitat type, *Hyposidra talaca*, light trap, tea plantations.

LIGHT trap has been commonly used to study the ecology of moth pests in agroecosystems. The data collected from the light traps have been used to study the species composition of communities, population size, long-term changes in the abundance, seasonality and to certain extent, the local movement and migration of insect pests[1–4]. The data have been used to forecast and alert farmers about crop infestations in relation to weather[5]. Light traps are also frequently used to study the spatial effect on abundance of moth pests[1].

Tea is a major cash crop of India. North East (NE) India contributes more than 60% of the gross national tea production. Tea in NE India is being cultivated in the cleared forest lands of sub-Himalayan plains. The massive deforestation led many forest-inhabiting moths to find refuge in tea plantations for their survival[6]. Among them, geometrids have a greater diversity and abundance in tea plantations of NE India. *Buzura suppressaria* is historically important pest of tea in the region, which was first reported as a major pest in 1903 (ref. 7). Since then, it remained a major pest of tea until the recent past. It is believed that presently *B. suppressaria* is a major pest, but only after *Hyposidra talaca* and *Hyposidra infixaria*, the two recent pests of tea. The larvae of these two sister species and that of *Ectropis obliqua* and *Ascotis* sp. resembled to a great extent in early instar stages. So, it was difficult to determine the species composition based on larval population. The dramatic population outbreak of the latter two species in the Dooars area of North Bengal happened in early 2009 (ref. 6). Since the outbreak, we brainstormed to manage the pest through adopting cultural operations along with the discovery of potential biological pesticide for use[8–10]. Towards the cultural operations, planters were asked to deploy light traps in their plantations to identify and monitor locations receiving frequent severe pest attack. Alongside we used light traps in our experimental plot, specifically to ask the following questions: (1) What is the species composition of moth pests of tea? (2) Can the light-trap catches be used to warn the seasonality of moth pests? (3) Can the light traps capture the variability due to habitat type on the population size of major pests? (4) What is the sex proportion of the captured moths?

The data used in the present study were collected in 2010 and 2011. The two-year monitoring was carried out in the 100 ha experimental plot of Tea Research Association-Nagrakata and adjoining commercial tea plantation.

We have used UV lights (220 V, 18 W, 5.2 nm; make – Actinic blue, Philips) in the light traps. UV lamps (actinic blue) were preferred over mercury-vapour lamps for the following reasons: (1) according to the tea planters, UV lamps are cheap, safe and unlikely to be stolen and have a prolonged life in rainy periods; (2) we also found from previous reports that the UV (actinic blue) lights attract a considerable amount of moths that belongs to both males and females[11,12]. The light frame was horizontally mounted on a bamboo pole and placed 1.15 m above the ground and 15 cm above the sticky collection trap (Figure 1). The smear of used engine oil was efficient to trap the delicate-bodied flies, scaly moths and hard-bodied beetles. In order to prevent water from entering the traps, they were kept under a permanent thatched shade. The light trap stood 50 cm above the tea bush frame.

In order to study the effect of shade status on the geometrid pest activity, light traps (one trap within each of the shaded and unshaded sections of the plantation) were maintained within 2 km radius. The two light traps in the pair were placed approximately 600 m apart. The shaded tea plantation had 120 mature shade trees of 11 species

**Figure 1.** The light trap used in the present study.

**Table 1.** Species composition and summary of their catches in light traps of shaded and unshaded tea plantations of Nagrakata, Dooars, North Bengal, North East India

| | 2010 | | 2011 | | | |
|---|---|---|---|---|---|---|
| | Unshaded | Shaded | Unshaded | Shaded | Sum | Percentage |
| *Hyposidra talaca* (male + female) | 515 | 1575 | 2515 | 6470 | 11075 | 66.88 |
| Male | 434 | 1198 | 2080 | 4903 | 8615 | 77.79 |
| Female | 81 | 377 | 435 | 1567 | 2460 | 22.21 |
| *Hyposidra infixaria* (male + female) | 5 | 13 | 15 | 28 | 61 | 0.37 |
| Male | 2 | 10 | 15 | 24 | 51 | 83.6 |
| Female | 3 | 3 | 0 | 4 | 10 | 16.4 |
| *Eterutia magnifera* (male + female) | 598 | 1207 | 1234 | 1481 | 4520 | 27.3 |
| Male | 596 | 1186 | 1058 | 1184 | 4024 | 89.03 |
| Female | 2 | 21 | 176 | 297 | 496 | 10.97 |
| *Arctornis submarginata* (male + female) | 31 | 54 | 132 | 69 | 286 | 1.73 |
| Male | 27 | 54 | 105 | 49 | 235 | 82.17 |
| Female | 4 | 0 | 27 | 20 | 51 | 17.83 |
| *Buzura suppressaria* (male + female) | 6 | 6 | 0 | 8 | 20 | 0.12 |
| Male | 5 | 2 | – | 5 | 12 | 60 |
| Female | 1 | 4 | – | 3 | 8 | 40 |
| Other moth pests* (male + female) | 213 | 141 | 104 | 139 | 597 | 3.6 |

*Includes *Ectropis obliqua* and *Ascotis* sp.

(mostly legumes) per hectare. There were no shade trees in unshaded tea plantations. Beginning with the first standard meteorological week (SMW) of 2010 the traps were run continuously every alternate day, weather permitting. However, due to severe power failure the traps could be run only for 344 days. The sticky collection trays were emptied daily, and the moths were identified to species and sex. The weather data that are recorded by the Meteorological Department of the Tea Research Association at North Bengal Regional R&D Centre (NBRRD&C) were collected for the study period. The difference in wind speed (mile/h) and rainfall (cm) between the study years was studied using Mann–Whiteny *U*-test. However, our analysis shows that both the monthly average rainfall (11.27 cm (2011) versus 13.92 cm (2010)) and wind speed (0.60 miles/h (2011) versus 0.73 miles/h (2010)) did not vary significantly between years (Mann–Whitney *U*-test: $P = 0.77$ (rainfall); $P = 0.44$ (windspeed)).

Student *t*-test was used to compare the difference in the mean number of moths captured in the light traps of the two plantation types and years. The data used in the analysis was arcsin-transformed in order to attain normality. Pair-wise analysis based on the catches of corresponding SMW of two years was performed (Student's *t*-test) to find out whether the catches were consistent among weeks across years. All the data analyses were performed in R[13].

Overall, 16,559 moths of 8 species were captured from the 2 light traps that were installed in an unshaded and shaded tea plantation, and operated during alternate days for two consecutive years (Table 1); 26.35% of the moths were captured in 2010 and 73.64% were captured in 2011. Overall, *H. talaca* was the most abundant species (66.88%) captured in the light traps (Table 1); however, the abundance of the species was slightly different between two years (Table 1). *Eterutia magnifera* was the second most abundant species captured in the light traps of the two plantation types (Table 1). Other two minor geometrid pests (*E. obliqua* and *Ascotis* sp.) together constituted 3.6% of the overall catches. *Arctornis submarginata* (Lymantridae) was the fourth major species captured by light traps. *H. infixaria* (Geometridae) and *B. suppressaria* (Geometridae) were the least captured species in the light traps (Table 1).

The daily catch of *H. talaca* moths in the light traps was significantly higher in the shaded tea plantation than in the unshaded plantation ($t_{658.74} = –3.28$; $P = 0.001$; Table 2). Overall, 72.64% of all *H. talaca* moths captured in the study were from shaded tea plantation (Table 2). This was between 72% and 75% among two years of the study (Table 2). The two-year sampling showed that the average daily catch of *H. talaca* was high between 1 and 13 SMWs as well as 47 and 52 SMWs of a year (Figure 2 *a*). The year-wise categorical data also showed a similar picture for two plantation types (Figure 2 *b*). The two-year catches, however, showed that *E. magnifera* peaks in number during summer months (7–23 SMWs) in the two plantation types (Figure 3).

The weekly average number of *H. talaca* moths of unshaded ($t_{101.96} = –3.54$; $P = 0.0006$) and shaded ($t_{101.99} = –3.32$; $P = 0.001$) tea plantations was significantly higher in 2011 than that in 2010 (Table 2). Pair-wise analysis showed that the difference in the weekly average number of *H. talaca* moths in the corresponding SMWs ($N = 52$) was significant only for wk 10 ($t_{2.48} = –4.35$; $P = 0.03$), wk 11 ($t_{3.04} = –3.01$; $P = 0.05$) and wk 40 ($t_2 = –5.0$; $P = 0.03$) in unshaded tea plantation, and wk 4 ($t_{4.28} = –3.87$; $P = 0.01$), wk 10 ($t_{2.64} = –5.52$; $P = 0.01$), wk 11

**Table 2.** Abundance and sex proportion of *Hyposidra talaca* in shaded and unshaded tea plantations of NE (percentage is given in parenthesis)

| Year/days | Habitat type | No. of moths | Male | Female | Weekly catches (mean ± SE) | Daily catches/trap (mean ± SE) |
|---|---|---|---|---|---|---|
| 2010 + 2011 | | | | | | |
| 344 | Shaded + unshaded | 11,075 | 8,615 (77.79) | 2,460 (22.21) | | |
| 344 | Unshaded | 3,030 (27.36) | 2,514 (82.97) | 516 (17.03) | | 8.81 ± 1.54 |
| 344 | Shaded | 8,045 (72.64) | 6,101 (75.84) | 1,944 (24.16) | | 23.39 ± 3.82 |
| 2010 | | 2,090 | 1,632 (78.09) | 458 (21.91) | | |
| 164 | Unshaded | 515 (24.64) | 434 (84.27) | 81 (15.73) | 11.65 ± 2.69 | |
| 164 | Shaded | 1,575 (75.36) | 1,198 (76.06) | 377 (23.94) | 32.98 ± 10.63 | |
| 2011 | | 8,985 | 6,983 (77.71) | 2,002 (22.28) | | |
| 180 | Unshaded | 2,515 (28.00) | 2,080 (82.70) | 435 (17.30) | 46.67 ± 15.34 | |
| 180 | Shaded | 6,470 (72.00) | 4,903 (75.78) | 1,567 (24.22) | 123.27 ± 39.42 | |

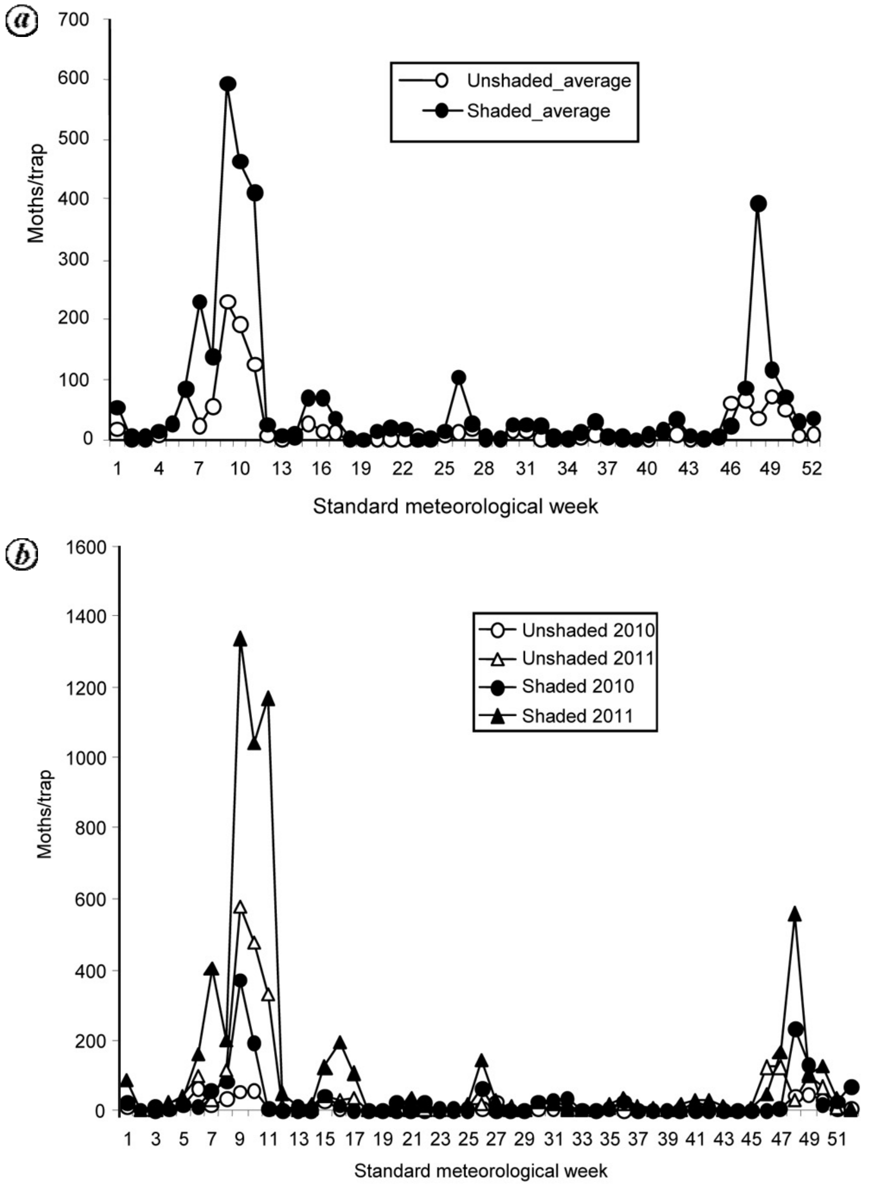


**Figure 2.** (***a***) Two-year average and (***b***) year-wise catches of *Hyposidra talaca* in shaded and unshaded tea plantations of Nagrakata, Dooars, North Bengal, North East India. Weeks are numbered from 1 January.

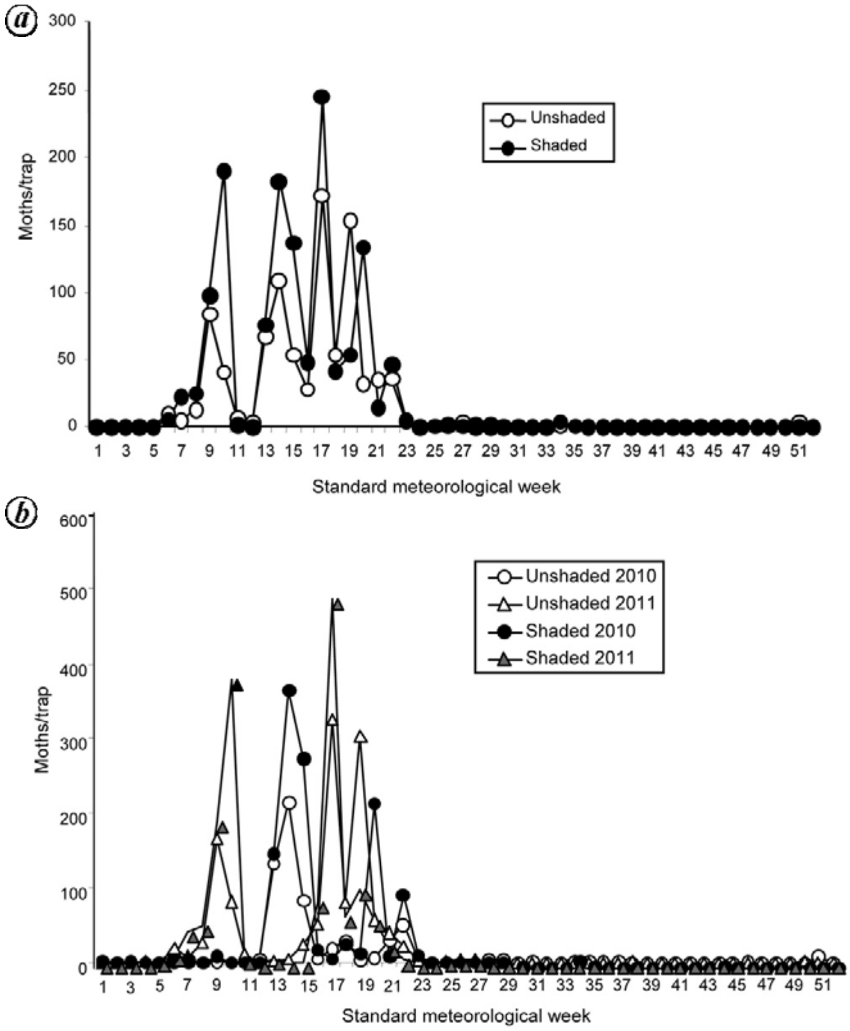


**Figure 3.** (***a***) Two-year average and (***b***) year-wise catches of *Eterutia magnifera* in shaded and unshaded tea plantations of Nagrakata. Weeks are numbered from 1 January.

($t_{3.04}$ = –9.34; $P$ = 0.002), wk 32 ($t_{2.36}$ = 4.67; $P$ = 0.03), wk 40 ($t_{3.2}$ = –8.5; $P$ = 0.002), wk 41 ($t_3$ = –7.83; $P$ = 0.004), wk 43 ($t_3$ = –3.15; $P$ = 0.05) and wk 50 ($t_{3.89}$ = –7.31; $P$ = 0.002) in shaded plantation.

Overall, male moths of *H. talaca* dominated the catches of light traps (77.79%). In 2010 and 2011, the male moths were 78.09% and 77.71% of the entire catches respectively (Table 2). Compared to shaded tea plantation, catches of the unshaded tea plantation had more number of male moths (82.97% versus 75.84%); but the difference was not significant in any of the years. Males of other moth pests also dominated the light traps (60–89%) (see Table 1 for detailed statistics).

This two-year study has confirmed that lepidopteran pest attack is more in the shaded tea plantations than the unshaded tea plantations. It has been established that light-trap catches can discern the effect of habitat type on the diversity, community structure and population dynamics of insects in the tropics[14]. The role of shade status on *H. talaca* in tea plantations was apparent. This is expected as scales of the shade tree timbers were the exclusive oviposition sites of adult females and the foliage of the shade trees was the alternate preferred host of the larvae of *H. talaca* in tea plantations of NE India[15]. Interestingly, the male moth population was higher in unshaded tea plantation (84.27% (2010) and 82.70% (2011)) than in the shaded tea plantation (76.06% (2010) and 75.78% (2011)), although the difference was insignificant. This suggests that the unshaded tea plantation has relatively less female moth activity. Like *H. talaca*, all other moth pests of tea have an affinity towards the shaded tea plantation for their activity.

Results also indicate that the moth pest abundance is not consistent among years, which may be attributed to the environmental features, phenology and dynamics of pest species[6]. In 2010, the total number of *H. talaca* was significantly less than that collected in 2011. Interestingly, the average catch of *H. talaca* moths of most

SMWs in a year was consistent across years. The difference in the catches of only three SMWs and eight SMWs respectively, of unshaded and shaded tea plantations was significant across years. This indicates that the life-cycle pattern and number of generations of *H. talaca* were more or less consistent in a year. The two-year average catch of *H. talaca* moths, further, confirms the finding that the emergence of *H. talaca* in tea plantations is climate-oriented. Thus the present study confirms that *H. talaca* is a winter pest of tea[6] (Figure 2). In the remaining part of the year, particularly during monsoon (April–October), further generations of *H. talaca* had relatively few moths. This period is the peak leaf-flushing period of tea. Hence, pesticide spraying is quite frequent during this period to manage other pests, including sucking and chewing pests. Additionally, natural HytaNPV infection is also quite common during summer-monsoon period[9].

Males dominated overall catches of *H. talaca* and other major lepidopteran pests of tea, which is also observed for other lepidopteran insects in other crops[11]. This causes confusion among planters on the efficiency of light traps to control the pest. Although controlling the pest requires an integrated approach, the data obtained from the light trap are highly useful to alert regarding pest activity among planters that may be effectively utilized to schedule different pest-management operations. This is because the emergence of male and female moths of *H. talaca* is synchronized. If detected early, cultural operations such as debarking and fumigating the shade tree barks can drastically reduce the population of *H. talaca* in tea. This can potentially reduce the pesticides and their residue load in tea leaves.

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