ARTIFICIAL LIGHT AND MOTH BIODIVERSITY: A COMPARISON OF MOTH DIVERSITY ACROSS DIFFERENT HABITATS ON LUNDY TO INVESTIGATE THE EFFECT OF ARTIFICIAL LIGHT

by

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ABSTRACT

Moths perform important roles within ecosystems. Behavioural responses to artificial light disrupt adaptive behaviours, causing population declines. Island populations can assess moth population attracted to artificial light, distinct from urbanisation. Here we present results from day counts of moth larvae and nocturnal Skinner light-traps from Lundy. Findings reveal a significant difference between moth population dynamics and species at differing locations. Overall, numbers of individuals and species caught with the UV-light trap were significantly greater than LED sources. These findings can be applied to potential artificial light changes on Lundy, as well as further changes throughout the United Kingdom.

Keywords: *Lundy, light-pollution, artificial light, moths*

INTRODUCTION

The Earth is currently experiencing substantial biodiversity decline with extinction rates greatly exceeding the long-term average (May, 2010). Insects represent a vital component of terrestrial ecosystems and form a substantial proportion of terrestrial biodiversity (Conrad *et al.*, 2006). They are under-represented in current assessments of biodiversity loss and our knowledge of insects lags behind that of vertebrates and plants (Fox *et al.*, 2011). Common and widespread species undergo dramatic population changes that go largely undocumented, despite playing an important role in supporting the ecosystem (Conrad *et al.*, 2006). Within insect research, there is a bias toward 'charismatic' diurnal pollinating insects (Fox *et al.*, 2011) with butterflies firmly established as model organisms for research (Boggs *et al.*, 2003). Nocturnal insects have been relatively ignored.

Nocturnal moths form an ecologically diverse and species-rich group more representative of terrestrial insects than butterflies and bees (Wolfling *et al.*, 2016). Moths are crucial pollen vectors for a diverse range of plant taxa across the globe, are strong indicators of ecosystem quality and environmental change, and are a critical food source for bats and birds (Truxa & Fiedler, 2012; Fox, 2013). Population declines of moths in the UK are equivalent to the IUCN threshold levels for Red List threat categories (Conrad *et al.*, 2006; Fox, 2013).

Many factors have been implicated in this decline, including habitat loss and urbanisation (Bates *et al.*, 2014). Within urbanisation, light-pollution has been speculated as a causal factor of moth declines (Fox, 2013). Light-pollution affects almost 20% of the earth's land surface across the globe, with a predicted rise of 6% annually (Holker *et al.*, 2010). Light levels are critical for many species, acting as a cue for behaviour patterns. Organisms have evolved circadian rhythms, which are now disrupted by artificial lighting (henceforth AL; Gaston *et al.*, 2015).

A wide variety of taxa are likely affected by light-pollution (Davies *et al.*, 2012). Moths are thought to be most at risk due to their 'flight-to-light' behaviour (Truxa & Fiedler, 2012). AL acts as an ecological trap that attracts large aggregations of moths to sub-optimal environments (Bates *et al.*, 2014). It inhibits normal behaviour, detrimental to the pollination, foraging and life cycle of nocturnal moths (see Shimoda & Honda, 2013). This includes direct mortality, disruption of crypsis and biological development, and increased exposure to predators (Bruce-White & Shardlow, 2011). For instance, AL reduces reproductive behaviour in the winter moth (*Operophtera brumata*) due to reductions in female activity and male responsiveness to female pheromones (van Geffen *et al.*, 2015). This can alter ecosystem services through cascading effects from higher to lower trophic levels (Davies *et al.*, 2012).

However, light-pollution typically occurs alongside other anthropogenic stressors such as urbanisation and habitat loss (Bates *et al.*, 2014). AL must be independently quantified from effects of urbanisation and habitat loss to fully comprehend its influence (Fox, 2013). Lundy represents a model environment, with evidenced moth population and self-maintaining ecosystems (Vitousek *et al.*, 1995). The anthropogenic effects of urbanisation have remained minimal with the majority of its landscape comprising undisturbed rural habitats. Small areas with differential levels of AL emitted from man-made constructions permit the study of artificial night lighting in isolation from urbanisation.

Previous research on Lundy has assessed moth biodiversity, but to our knowledge, no research has considered which species on the island are most at risk of behavioural disruption through flight-to-light behaviour (see Beavan & Heckford, 2014). Specifying the biodiversity on the island in varying locations with pre-existing light pressures will indicate if moths are more prevalent in anthropogenic environments and thus at risk of negative effects of AL. Conventional methods of moth-light-trapping will be used to assess the impact of artificial night lighting on the population dynamics and biodiversity of moth species on the model habitat of Lundy. Cloud cover will also be considered as this may influence the efficacy of light sources (Kyba *et al.*, 2011).

Our findings have the potential to disseminate the direct impact of AL on moth populations and species variation. Our hypotheses are presented in Table 1.

Table 1: Hypotheses to be tested

Number	Hypothesis
H_0	There will be no difference in population dynamics of moths at different sites across Lundy
H_1	There will be a difference in the number of individual moths found at different sites across Lundy. We predict that more moths will be captured in locations where there are higher levels of surrounding artificial lighting
H_0	There will be no difference in species diversity of moths at different sites across Lundy
H_2	There will be a difference in the amount of species of moths found at different sites across Lundy

METHODOLOGY

Study Site

Lundy is situated 12 miles from the coast of North Devon, the UK, where the Atlantic Ocean meets the Bristol Channel (51.1781° N, 4.6673° W). Using Skinner moth traps, five different study sites were sampled for moths (see Table 2 for descriptions). The locations were specifically chosen to understand the effect of varying AL levels across the island's different habitats on moth population densities and species diversity. Quadrats were used to systematically identify species of flora in the surrounding area of each site (see Table 4).

Materials and Procedure

Night-time moth traps

Each location was sampled for five nights (28/04/19-02/05/19) from c.20:00 to c.04:00/05:00. Windspeed, temperature, cloud-cover, precipitation levels and lunar phase were recorded for each night of sampling. The trap locations were randomised (see Table 3) as the traps varied in design and spectral composition. It was not possible to standardise trap designs due to availability of equipment. Traps were collected before dawn to maximise trap efficacy and retention. Moths near but not inside the traps were also sampled. Moths collected were placed into plastic containers to be photographed, identified, and recorded onto data collection sheets before being released after dusk.

Daytime surveys

Each location, and an additional location (see Table 2), were sampled for five days (29/04/19-03/05/19) from c.11:00 to c.16:00. Coupled with moth trap sampling at night, day surveys of moths and larvae day provided a comprehensive picture of moth distributions and potential breeding preferences in terms of habitat. The moths and larvae were surveyed by four researchers at each of the five locations for 30 minutes. Sampling methods involved one researcher sweep-netting, whilst others conducted visual observations for moths and larvae. The order of locations surveyed was randomised to avoid sampling bias. Moths found were photographed and placed into plastic containers for identification and released after dusk at the location where they had been obtained.

Table 2: Description of each location sampled on Lundy (see also Figure 1).

Location	Description	Keywords
Farm*	Situated inland along the main path through the island, near a lambing shed and pigsty, with plant lift around the stone wall along the path (- 51.1678° N, -4.6664° W)	Stone wall, path, farm animals
Garden	Situated on the south coast of the island sheltered behind a small house. Lit with artificial light from 6.30pm to 12.30am. Trap placed in the garden of the holiday home surrounded by plants (51.1640° N, -4.6605° W)	Coastal, artificial light, vegetated, building
Hospital	Situated on the east coast of the island where there was an old ruined hospital chosen for its sheltered rural location within the old walls, overgrown with plants. Chosen due to the lack of artificial light and plant life outside the building. Trap was placed in the centre of the ruined building (51.1700° N, -4.6628° W)	Coastal, dark, building
Tavern	An anthropogenic location with higher density of buildings, light, and people. Trap was placed in an open field behind a barn in the village to capture moths coming from across the field towards the artificial night lighting (51.1649° N, -4.6657° W)	Exposed, artificial light, visitors, buildings
Woodland	A rural location with shelter from trees and bushes and considered a traditional location as a moth habitat. Trap was placed on a small open path in the centre of the woodland (51.1651° N, -4.6613° W)	Sheltered, dark

Note: Locations marked with * represent sites sampled for moth larvae only and were not sampled using light traps. This should be acknowledged when making cross-site comparisons.

Table 3: Moth trap schedule for each location on each night of sampling

Date	Moth Trap ID			
	P1	P2	L1	W1
28/04/2019	Woodland	Hospital	Garden	-
29/04/2019	Garden	Hospital	Woodland	Tavern
30/04/2019	Garden	Woodland	Hospital	Tavern
01/05/2019	Hospital	Garden	Tavern	Woodland
02/05/2019	Tavern	Hospital	Woodland	Garden

Note: P1 and *P2* comprised moth traps using low or medium powered LED light sources in a basic form of a Robinson moth trap. *L1* used a high powered LED source within a Skinner moth trap design whereas *W1* used a UV light source within a Skinner trap.

Ethical Considerations

Several ethical issues were considered. Identification was predominantly accomplished through photographs to reduce handling time. When handling was necessary, surgical gloves were worn to reduce disturbance to individuals and prevent the spread of potentially harmful chemicals or disease. Individuals were housed in separate clear plastic containers with surrounding vegetation from where they were sampled. Individuals were released at dusk from where they were sampled to reduce predation risk.

Figure 1: Map indicating locations of moth traps

Key: H=Old Hospital, F=Farm, T=Tavern, W=Woodland, G=Garden

Table 4: Species of vegetation identified at each location sampled

Species of vegetation	Location				
	F	G	H	T	W
Bluebell *(Hyacinthoides non-scripta)*	-	-	-	-	Yes
Broad-leaved dock *(Rumex obtusifolius)*	-	Yes	Yes	-	Yes
Cat's ear *(Hypochaeris radicata)*	-	-	Yes	-	-
Clover *(Trifolium)*	-	-	Yes	-	-
Common daisy *(Bellis perennis)*	-	-	Yes	-	-
Common dandelion *(Taraxacum officinale)*	Yes	Yes	-	Yes	-
Common gorse *(Ulex europaeus)*	Yes	-	-	-	-
Creeping buttercup *(Ranunculus repens)*	-	-	Yes	-	-
Goosegrass *(Galium aparine)*	-	-	-	-	Yes
Ground ivy *(Glechoma hederacea)*	-	-	Yes	-	-
Meadow-grass *(Poa pratensis)*	-	Yes	-	-	-
Wall pennywort *(Umbilicus rupestris)*	-	Yes	-	-	Yes
Red campion *(Silene dioica)*	-	-	-	-	Yes
Brambles *(Rubus)*	Yes	-	Yes	-	-
Ryegrass (*Lolium perenne*)	Yes	Yes	Yes	Yes	-
Moss *(Sphagnum)*	Yes	Yes	Yes	Yes	-
Stinging nettle *(Urtica dioica)*	Yes	-	Yes	Yes	Yes
Daffodil *(Narcissus)*	-	Yes	-	-	-

Note: Location *F*=Farm, *G*=Garden, *H*=Hospital, *T*=Tavern, *W*=Woodland

RESULTS

Statistical Analysis

All data were analysed using SPSS. Residuals were examined for assumptions of normality and homogeneity of variance, revealing that both were violated for night-time moth trap and daytime count analyses. Accordingly, Generalised Linear Models (GLMs) were computed to investigate differences in moth trap population densities and species across different locations (N=4; woodland, garden, tavern, and hospital) and across different light sources (N=4; UV and LED [lumens: low, medium, high]). Cloud-coverage was entered as a covariate within the models to account for the effects of cloud-coverage on light dispersal. The 1-Simpson's Index was used to obtain species diversity indices (SDIs) at each location for both adult moth and moth larvae data. The formula for the 1-Simpson's Index is given as: $1\text{-SI} = 1-\sum ni(ni-1)/N(N-1)$. Where N is the cumulative number of individuals recorded overall, and ni is the cumulative number of species recorded that helps make up N in total. Scores nearing 1 indicate high diversity and scores nearing 0 indicate low diversity. Differences in daytime population densities and species diversity across location (N=5; additional location of the farm) were investigated using Friedman's tests.

Night-time Moth Trap Survey

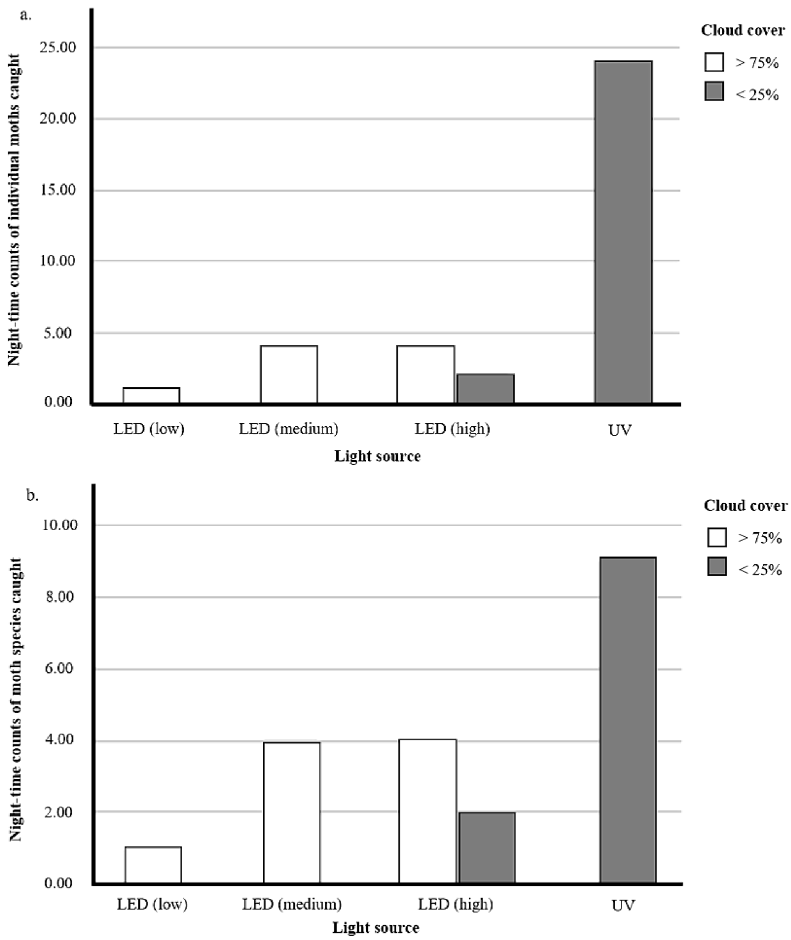
Location and moth population density

Cloud-cover did not influence moth numbers caught across locations when included as an interaction term (Wald $X^2_3=7.20$, $p=0.066$). Main effect of location on the number of moths caught was significant (Wald $X^2_3=17.78$, $p<0.001$; Figure 2a). Parameter estimates revealed that significantly more individuals were caught in the woodland location than all other locations (Wald $X^2_1=12.08$, $p=0.001$, $B=14.96$, $SE\pm=4.30$). All other effects were not significant (Wald X^2's<0.02, p's>0.886, B's<0.62, SE's$\pm=4.30$).

Location and moth species diversity

Cloud-cover did not influence moth species caught across locations when included as an interaction term (Wald $X^2_3=2.43$, $p=0.49$). Main effect of location on species diversity of moths caught was significant (Wald $X^2_3=16.92$, $p=0.001$; Figure 2b). Again, parameter estimates revealed that significantly more species were caught in the woodland location than all other locations (Wald $X^2_1=11.93$, $p=0.001$, $B=5.69$, $SE\pm=1.65$). All other effects were not significant (Wald X^2's<0.14, p's>0.707, B's<0.62, SE's$\pm=1.65$).

Figure 2: The number of individual moths caught (a) and the number of species caught (b) by different light sources as a function of cloud-cover



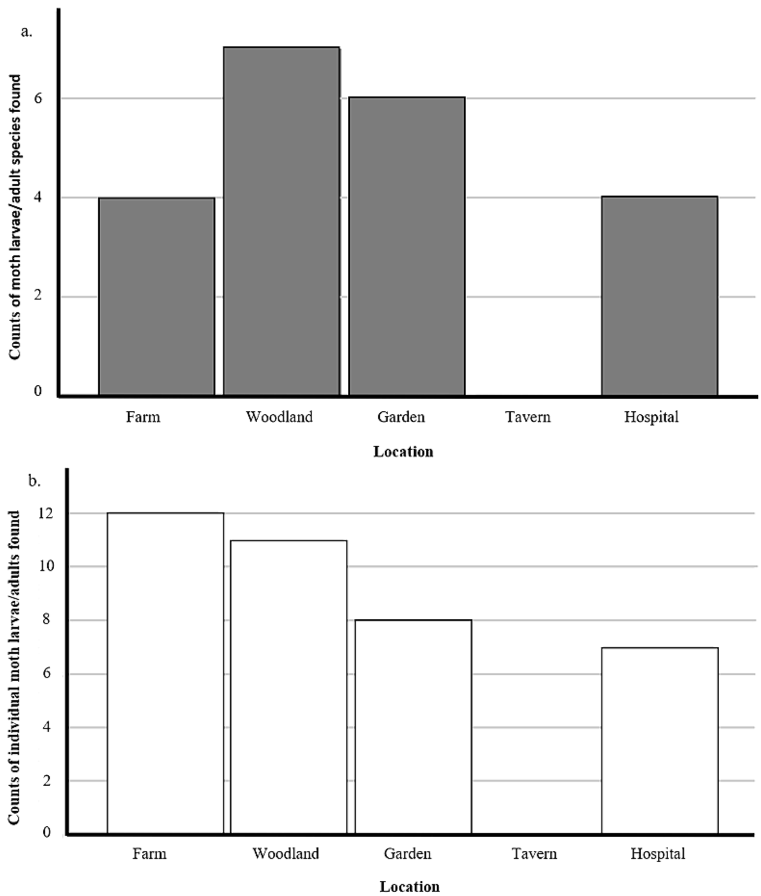
Light source and moth population density

Cloud-cover influenced the number of moth individuals caught across light sources when included as an interaction term (Wald X^2_3=11.28, *p*=0.010). Parameter estimates revealed that the number of individuals caught by the UV-light source significantly differed from the number caught by all other LED light sources, and that this relationship is dependent on cloud-coverage (Wald X^2_1=8.53, *p*=0.004, *B*=-0.21, *SE*±=0.07; Figure 2a). All other effects were not significant (Wald X^2's<0.39, *p*'s>0.530, *B*'s<-0.04, *SE*'s±< 0.08).

Light source and moth species diversity

Similarly, cloud-cover influenced the number of moth species caught across light sources when included as an interaction term (Wald X^2_3=3.46, *p*=0.004). Parameter estimates also revealed that the number of species caught by the UV-light source significantly differed from the number caught by all other LED-light sources, but this relationship was dependent on cloud-coverage (Wald X^2_1=12.49, *p*=<0.001, *B*=-0.11, *SE*±=0.03; Figure 2b). All other interactive effects were not significant (Wald X^2's<2.196, *p*'s>0.139, *B*'s<-0.04, *SE*'s±<0.03).

Figure 3: Bar graph showing the difference in the number of moths (a) and the number of species of moths (b) found at each location during daytime surveys



Daytime Surveys

Daytime survey density between locations

There was no difference in the number of moth larvae/adults found between locations (X^2_4=6.49, Asymp. p=0.165; see Figure 3a; see Table 5 for means and standard deviations).

Daytime survey species diversity between locations

However, there was a significant difference in the diversity of moth larvae/adult species found between locations (X^2_4=9.81, Asymp. p=0.044; see Figure 3b; see Table 5 for means and standard deviations).

Table 5: Means and standard deviations of the number of individuals and number of species of moth and moth larvae found

Location	No. Individuals Found		No. Species Found	
	M	***SD***	***M***	***SD***
Farm	2.40	2.88	0.80	0.84
Woodland	2.20	1.79	2.20	1.79
Garden	1.60	1.52	1.20	1.30
Tavern	0.00	0.00	0.00	0.00
Hospital	1.40	1.52	0.80	0.84

Simpsons Diversity Index

SDIs of adult moths and moth larvae caught in both night-time trapping and day-time surveys varied from 0 to 0.921 between locations; where low scores represent low diversity and high scores high diversity (see Table 6).

DISCUSSION

AL has been implicated as a causal factor of global moth declines due to its negative effects on moth life cycles and behaviours (Bruce-White & Shardlow, 2011). In addition, moths are under-represented in assessments of biodiversity loss (Fox *et al.*, 2011). Where research has been conducted, it is difficult to discern the effects of AL from the influence of urbanisation since the two typically co-occur (Bates *et al.*, 2014). Our study aimed to shed light on the population dynamics and species diversity of nocturnal moths within the model environment of Lundy to isolate the effect of AL from that of urbanisation.

The effect of location and pre-existing AL levels

Consistent with our hypothesis, analyses revealed that the number of moth individuals and species caught in light traps significantly differed across the 4 locations, independent of cloud-coverage. Contrary to our prediction that more moths would be captured in areas of higher surrounding AL, counts of moths caught in the lowly lit woodland location were significantly higher than all other locations. This unexpected finding contrasts with previous literature proposing that high densities of AL act as ecological traps that result in large aggregations of moths to that area (Bates *et al.*, 2014). Our results instead suggest that moths are aggregating in areas abundant in vegetation, shelter and darkness, away from these artificially lit areas.

Table 6: Adult moth and moth larvae species found at each location with Simpsons Diversity Index (SDI)

Species	**Location**				
	F*	**G**	**H**	**T**	**W**
Bright-line brown-eye (*Lacanobia oleracea*)	-	-	-	-	3
Brimstone (*Opisthograptis luteolata*)	-	-	-	-	1
Brown silver-line (*Petrophora chlorosata*)	-	-	-	-	1
Common quaker (*Orthosia cerasi*)	-	-	-	-	4
Dark sword grass (*Agrotis ipsilon*)	-	-	-	-	1
Dogs tooth (*Lacanobia suasa*)	-	-	-	-	1
Dotted border (*Agriopis marginaria*)	-	1	-	-	2
Emperor (*Saturnia pavonia*)	-	1	-	-	-
Garden tiger (*Arctia caja)*	9	1	-	-	1
Hebrew character (*Orthosia gothica*)	-	-	-	-	1
Marbled coronet (*Hadena confusa*)	-	-	-	-	10
Muslin (*Diaphora mendica*)	-	3	-	-	3
Oak eggar (*Lasiocampa dodneata*)	-	-	6	-	2
Oak tree pug (*Eupithecia quercus*)	-	-	-	-	1
Pale tussock (*Calliteara pudibunda*)	-	-	-	-	1
Powdered quaker (*Orthosia gracilis*)	-	-	-	-	2
Red chestnut (*Cerastis rubricosa*)	-	-	-	-	1
Red twin-spot carpet (*Xanthorhoe ferrugata*)	-	-	-	-	1
Twin spotted quaker (*Perigrapha munda*)	-	1	-	-	-
Unknown Species 1	-	-	-	-	1
Unknown Species 2	-	1	-	-	-
Unknown Species 3	-	1	-	-	-
Unknown Species 4	-	-	-	-	1
Vapourer (*Orgyia anitqua*)	-	-	1	-	2
Total	9	9	7	0	40
Simpsons Diversity Index (SDI)	0.00	0.92	0.29	NA	0.92

Note: Location *F*=Farm, *G*=Garden, *H*=Hospital, *T*=Tavern, *W*=Woodland. Locations marked with * represent sites sampled for moth larvae only and were not sampled using light traps. This should be acknowledged when making cross-site comparisons.

However, the number of moths caught by light-traps has been shown to decrease in the presence of other light sources, including AL (Eisenbeis, 2006). It is plausible that the floor effect in the artificially lit setting of the tavern/village does not represent a true picture of how AL influences moth populations. Rather, it represents how AL influences light-trap efficacy. The observed effects of AL on total abundance and species richness may merely be artefacts of the method used to sample these assemblages.

Although this may be the case for night-time trap data, it does not explain why no adult moths or moth larvae were found during day-time surveys at the tavern when competition between light sources did not occur. If our light-traps were simply being outcompeted by stronger surrounding AL, we would still expect to find large abundances of larvae during the day at these sites, if light is to act as an ecological trap as proposed by Bates *et al*. (2014). It may be that although AL draws moths towards it, it also disrupts and inhibits reproductive behaviour. Van Geffen *et al*. (2015) experimentally demonstrated that artificial night-lighting negatively affects natural moth reproductive behaviour. Such impacts likely lead to detrimental cascading effects on biodiversity, trophic interactions, and ecosystem function (Longcore & Rich, 2004). Thus, a lack of adult moth of moth larvae samples in areas with high AL may represent the inhibitory effect of AL on reproduction.

It was also noted that Common starling (*Sturnus vulgaris*) were observed frequently during the daytime survey at the tavern location. Being known to predate on moth larvae, reduced larvae in this area could therefore be related to increased predation risk from these starlings (Cook *et al*., 2012). Records have shown that birds can predate moths, removing from 20% and in extreme cases 100% of the population (Barbaro & Battisti, 2011). This a known problem as stated by the Warden of Lundy; during previous studies on the island birds learned to predate near the traps, requiring a change in location (D. Woodfin Jones, personal communication, 30 April 2019). In future, surveying the species and frequency of birds and bats present in the area surrounding traps is advised to indicate potential predation rates. Both may influence species counts by learning to predate on the aggregations of moths to these light traps (Fox *et al*., 2013).

In support of the argument that AL inhibits reproduction, an emperor moth was identified in the garden light-trap (high AL) and had laid multiple eggs inside the trap. Although this can initially be interpreted as functional reproductive behaviour, it instead indicates the disruptive effect of AL on moth life-cycle since emperor moths traditionally lay their eggs in sheltered locations on plants (Butterfly Conservation, 2019). The increased AL appeared to have disrupted the moth's natural behaviour of laying in a suitable location due to an overriding flight-to-light response. Although anecdotal, we believe this to be an interesting avenue for future research to assess the frequency of egg-laying in light traps.

Species diversity

The number of individual insects found from day-time insect surveys did not differ across location, but the number of species was found to significantly differ. The most species-diverse location for both night and day surveys was the woodland, probably due to the increased natural vegetation and shelter at this location. This included the discovery of a novel species to the island, the Red chestnut moth (*Cerastis rubricosa*).

Although these woodland moths may be less at risk of behavioural disruption from the AL at the tavern, they may still be attracted to smaller, local buildings that use AL until midnight. Merckx & Slade (2014) found that the distance that moths were attracted to artificial light depended on the macro-moth family. Erebidae were attracted up to 27m, geometridae from 23m and noctuidae 10m. 2 erebidae, 5 geometridae, 6 noctuidae and 1 nepticulidae were caught in the woodland. Millcombe House accommodation was <30 metres from the woodland; some moths caught at this location may be at risk of attraction to this AL. Indeed, the laying female emperor moth was trapped at the garden location which had pre-existing artificial light levels and no suitable food plants, suggesting accommodation light may attract species from other nearby areas such as woodland and grassland.

It is worth noting that seasonality impacts different species in different ways (Sinu *et al.*, 2013). This study only takes a sample of the species diversity in April-May. For a more accurate representation, trapping during various seasons throughout the year would be advised for future study.

The effect of cloud cover and UV light sources

UV and LED light sources differed in their trapping efficacy and this relationship was influenced by cloud-cover. At high levels of cloud-cover (>75%) the UV light-trap caught significantly more individuals and species than all of the LED-light sources. Our work also demonstrates the importance of incorporating cloud-cover as an influencing factor when using light-traps since cloud coverage amplifies luminance (Kyba *et al.*, 2011). The results from our study contradict the results from a study by Castrovillo & Carde (1979), who showed that when the cloud-cover increased, the number of moths captured decreased. However, our study the first to our knowledge to investigate the influence of cloud-cover when using different sources of light in moth trapping. As such, to allow for unbiased comparisons between traps, lamp-type should be identical if their locations cannot be randomised. When planning future work portable UV traps are advised as the large size of the trap restricted the locations it could be placed at, however, the ethical considerations previously mentioned should be taken into account when considering the use of the UV-light (see Table 7).

Our work corroborates with work by Cowan & Gries (2009) who demonstrated how the Indian meal moth (*Plodia interpunctella*) were preferentially attracted to UV light over the LED. Worryingly, the attraction of moths to UV light has been shown to cause damage to retinas, alter behaviour, and disrupt circadian rhythms (van Ooik *et al.*, 2008). For instance, exposing *Orgyia antiqua* moths to UV-light for one hour caused permanent eye damage (Mishra & Meyer-Rochow, 2008). Interestingly, van Ooik *et al.* (2008) also demonstrated how plants irradiated with UV-B-light were the preferred food of *Epirrita autumnata* moth larvae, demonstrating the attractiveness of this light source to this species. Happily, the use of LEDs is continually increasing in urban areas due to their energy-saving properties (Yoon *et al.*, 2012). The lack of attraction to this light source during our research suggests that a continuation of this trend could result in a more positive outcome for moth populations.

Table 7: Strengths and limitations of the study

Strengths	**Limitations**
Light trapping method: This allowed data gathering at community and population level. Different sources of lighting can be used (e.g. LED, UV, and coloured) with a large capacity for high numbers of moths. **Sweep netting & visual survey method**: Cost-effective methods applicable across a range of habitats and environmental conditions. Ease of use enables multiple researchers to utilise these methods, helping to reduce researcher fatigue and enable inter-researcher reliability. A strategic approach using these methods also helps minimise risk of pseudoreplication.	**Light trapping method**: Despite displaying signs to warn the public, UV lighting is harmful to human eyes and so it may not be ethical to place in areas with high human populations and densities. Light trapping may also increase predation risk of moths as well as disrupting their behaviour. A cost-benefit analysis should be run before implementing light trapping. **Sweep netting & visual survey method**: Sampling bias against species of burrowing moth larvae (e.g. leaf miners) may have been encountered. Abundance and diversity of food-plants differed across locations which would likely influence distribution and frequency of moth larvae species. As such, varying temporal patterns in food-plant availability will also be related to the distributions of moth larvae over time. Longitudinal research is required to understand these fluctuations.
Future studies: The findings and implications from this current study present interesting further explorations for moth studies on Lundy. The affordability and clarity of methods allow replications of this study procedure to be conducted easily on Lundy which would help inform the reliability of the present findings.	**Future studies**: effects of time of day, lunar phase, weather, and season could not be adequately assessed due to the short nature of the study and so these factors should be investigated more in-depth. A consistent trapping method using identical design and light sources may be preferred in the future, as it may prove more reliable in yielding population and species distribution data.
Applicability: this study is the first to our knowledge to compare the effectiveness of different light sources used in moth trapping on Lundy, offering insights into the influence of the widespread and increasing use of LED lighting.	**Ethical issues**: use of various light sources overnight has the potential to disrupt the natural behavioural patterns of other local fauna and flora.

Conclusions

Our research of the effects of urbanisation and AL on moth species diversity by light trapping and daytime surveys show that the locations without artificial light contained most species diversity and the greatest number of moths. This result contradicts our hypothesis that high populations and species diversity would be found at locations with higher pre-existing AL levels. However, the pre-existing AL may have detracted from the effectiveness of our light-traps; therefore, future work should incorporate pre-existing lights into trapping methods. Additionally, the time of year and weather conditions may have influenced our results as most species of moth are not yet in the flying stage of their life cycle. UV-light shows a greater capability for moth attraction when compared against the results for the LED light sources. The current trend for the use of LED lights in urban environments could, therefore, be of great benefit to the moth populations as it lowers the risk of urban areas becoming ecological traps. Considering the importance of moths and their larvae to the ecosystem, this could help to prevent the global decline in species populations.

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Plate 1: Red chestnut moth (*Cerastis rubricosa*), novel sighting to Lundy, captured during this study © Peter Kidd

Plate 2: From left to right: Peter Kidd (Researcher), Kay Nash (Researcher), Dean Woodfin Jones (Lundy Island Warden), Steph Ford (Researcher), Angeline Rietveld (Researcher)

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