

December 2016

Edge effect on moth richness, abundance, and potential pollination activity in a Costa Rican cloud forest

Christopher Cosma

Follow this and additional works at: https://digitalcommons.usf.edu/tropical_ecology

Recommended Citation

Cosma, Christopher, "Edge effect on moth richness, abundance, and potential pollination activity in a Costa Rican cloud forest" (2016). *Tropical Ecology and Conservation [Monteverde Institute]*. 184.
https://digitalcommons.usf.edu/tropical_ecology/184

This Book is brought to you for free and open access by the Monteverde Institute at Digital Commons @ University of South Florida. It has been accepted for inclusion in Tropical Ecology and Conservation [Monteverde Institute] by an authorized administrator of Digital Commons @ University of South Florida. For more information, please contact digitalcommons@usf.edu.

Edge effect on moth richness, abundance, and potential pollination activity in a Costa Rican cloud forest

Christopher Cosma

Department of Ecology, Evolution, and Marine Biology

University of California, Santa Barbara

EAP Tropical Biology and Conservation Program, Fall 2016

17 December 2016

ABSTRACT

Habitat loss and fragmentation are major threats to biodiversity, especially in tropical forests which house most of the world's species. Edge effects are important considerations when investigating the impact of forest fragmentation on biodiversity, as they can lead to large, and often detrimental shifts in population, community, and ecosystem stability. The taxa-specific effects of forest edges are complex, highly variable, and poorly understood. In this study, I investigated the edge effect on moth richness, abundance, and potential pollination activity in a fragmented tropical cloud forest in Monteverde, Costa Rica by sampling moths with light traps at two different locations: in the forest interior, and at the forest edge. My results suggest that there is a negative edge effect on moth richness, abundance, and potential pollination activity probably caused by wind. By shedding light on the possible edge effects on this extremely diverse and ecologically important taxon, this study provides valuable preliminary insights to ecologists and conservationists working to slow the loss of biodiversity in tropical forests.

Efecto de borde en la riqueza de polillas, su abundancia y la potencial actividad de polinización en un bosque nuboso de Monteverde

RESUMEN

La pérdida de hábitat y la fragmentación son las principales amenazas para la biodiversidad, especialmente en los bosques tropicales que albergan a la mayoría de las especies del mundo. El efecto de borde debe ser tomado como una importante consideración al investigar el impacto de la fragmentación de los bosques en la biodiversidad, ya que pueden dar lugar a grandes cambios a menudo perjudiciales en las poblaciones, las comunidades y la estabilidad de los ecosistemas. Los efectos específicos de los bordes de los bosques son complejos, altamente variables y poco comprendidos. En este estudio, investigué el efecto de borde en la riqueza de polillas, su abundancia y potenciales actividades de polinización en un bosque tropical fragmentado en Monteverde, Costa Rica, muestreando las polillas con trampas de luz en dos lugares diferentes: en el interior del bosque y en el borde del bosque. Mis resultados sugieren que hay un efecto negativo de borde en la riqueza de polillas, la abundancia, y la actividad potencial de polinización probablemente causada por el viento. Al hacer hincapié en los posibles efectos de borde en este taxón extremadamente diverso y ecológicamente importante, este estudio proporciona valiosas conclusiones preliminares a los ecólogos y conservacionistas que trabajan para frenar la pérdida de biodiversidad en los bosques tropicales.

Among the many current anthropogenic threats to global biodiversity, habitat loss and fragmentation rank as some of the largest. Despite widespread awareness and conservation efforts, deforestation and forest fragmentation in most tropical countries still continues at an alarmingly high rate, and is leading to significant species losses (Didham et al 1998). Since the tropics house most of the world's species, this represents one of most pressing problems in the conservation of global biodiversity (Fiedler et al. 2007).

“Habitat fragmentation”, in the sense the term is used today, involves both pure habitat loss and the breaking apart of habitat into fragments. Pure habitat loss has consistent negative effects on biodiversity. In contrast, habitat fragmentation per se, which involves factors such as patch size and patch isolation, varies more in its effects on biodiversity, with some of the documented effects being negative, and some positive (Fahrig 2003). Habitat fragments have historically been described using island biogeography theory. However, habitat fragments are fundamentally different from true islands in that they are not surrounded by completely inhospitable habitat, but instead a matrix of habitat and land-use types that may support potential predators and competitors for the species living within the fragment (Andren and Angelstam 1988). Along with abiotic factors, this may lead to complex edge effects.

A key consequence of habitat fragmentation is the increased abundance of edges (Siu et al. 2016). Edges, as defined by Tschardt et al. (2002) “are the places where two habitat types come together”. Forest edges are well documented for abiotic factors (such as varying levels of light, humidity, and wind velocity), as well as effects on vegetation. However, relatively little is known about how animals respond to tropical forest margins (Fiedler et al. 2007). Edge effects are highly variable, and include many interacting biotic and abiotic factors. This leads to complex and often species-specific effects. Studies suggest that some animals respond positively to forest edges, while many others respond negatively (Laurance et al. 2002).

Forest fragmentation may also disrupt biological processes that are important in maintaining biodiversity and ecosystem functioning (Didham et al. 1996). Of particular significance are those processes involved with reproduction, such as plant-pollinator interactions (Murcia 1996). Negative effects of habitat fragmentation on pollination have been well documented in agricultural plots (Chacoff and Aizen 2005). However, little is known about the effects of forest fragmentation on plant pollination in tropical forests, where most pollination involves interactions with animal pollinators. Only two studies, by Aizen and Feinsinger (1994a,b), have been conducted on the topic. These suggest a negative edge effect on pollination in an Argentina dry forest. By influencing the movement and dispersal of insect pollinators, forest fragmentation may have far-reaching impacts for gene flow in plants, as well as in plant-animal community dynamics (Didham et al. 1996). Cleared spaces in forests may act as physical barriers to insect pollinators through exposure to abiotic elements such as increased wind velocity and rain, as well as biotic elements such as increased predation. Powell and Powell (1987) have shown that even small cleared areas (less than 100 meters) inhibit pollinators from crossing to nearby forested areas. The effects of habitat loss, fragmentation, and edge effect on insect pollinators represents an important and understudied area of research.

While there are studies on the responses of insects to tropical forest fragmentation, the patterns are not well understood, and there is no clear consensus as to why different species react

differently (Didham et al. 1998). However, evidence suggests that edge effects may be one of the main factors affecting insect populations in fragmented forest landscapes (Didham et al. 1996). For example, Jokimaki et al. (1998) showed that arthropods are higher at forest edges than forest interiors in the pine-dominated forests of Northern Finland.

Lepidoptera are one of the most diverse insect orders, and play important roles as pollinators, herbivores, and prey. Over 90% of known Lepidoptera are nocturnal Lepidoptera, or moths (Ricketts et al. 2001). According to Bawa (1990), moth pollination ranks perhaps only second in importance behind bee pollination in terms of number and diversity of plant species pollinated. Moths have been shown to be essential in mitigating the potential devastating effects of habitat fragmentation on plants by promoting gene flow through pollination (Finger et al. 2014). Studies have also suggested that moth taxa may be useful indicators of biodiversity and habitat disturbance (Kitching et al. 2000 and Summerville et al. 2004). Furthermore, they can be readily sampled in large numbers with light traps (Ricketts et al. 2001). For these reasons, moths are particularly useful for studying the effects of habitat fragmentation.

Habitat fragmentation appears to affect different moth taxa differently (Schmidt and Roland 2006), with some families showing strong negative effects, and others showing strong positive effects (Kitching et al. 2000). Slade et al. (2013) showed that general responses to forest fragmentation differs significantly between moth species, and largely depends on life history traits and landscape characteristics. Similarly, edge effect responses appear to differ between moth families (Fiedler et al. 2007). Despite variability in responses, several general trends in moth responses to habitat fragmentation have been identified. For example, a study by Ricketts et al. (2001) found that moths in a disturbed habitat matrix had significantly higher richness and abundance when they were closer to forest fragments. There are several plausible explanations for such observations, including use of forest fragments and habitat edges for resources, shelter from abiotic factors such as wind and rain, and shelter from predators. Considering their importance as pollinators, and their potential as indicators of biodiversity and habitat disturbance, assessing the different responses of moths to habitat loss, fragmentation, and edge effect is crucial, especially in the tropics where they represent a large percentage of the diversity.

In this study, I investigate the edge effect on moths in a fragmented tropical cloud forest in Monteverde, Costa Rica. Specifically, I test if there is an edge effect on their richness, abundance, and potential pollination activity by attracting them with light traps and collecting pollen samples at two different locations: one at the edge of a forest bordering an open space, and the other in the forest interior. I also test specifically for the edge effect of wind by sampling the two locations in windy conditions, and again in calm conditions.

I hypothesize that moths at forest edges bordering open spaces have decreased access to forest resources, such as the flowers that they feed on for nectar. I also hypothesize that the absence of tree cover at forest edges increases the exposure of moths to wind, inhibiting normal activity such as flight and foraging. I therefore predict that I will see both less richness and less abundance of moths at the forest edge than in the forest interior, especially in windy conditions. I also predict that I will see a lower percentage of moths carrying pollen, and less variety of pollen, at the forest edge compared to the forest interior, especially in windy conditions.

MATERIALS AND METHODS

Study Site

The study site is located in Monteverde, Puntarenas, Costa Rica. It is approximately 100 meters down the road from the Monteverde Biological Station. The site consists of an open space on the side of a gravel road, bordered by protected tropical cloud forest, a type of forest ecosystem characterized by frequent low-lying clouds. The open space is approximately 1,000 m², relatively flat, and clear—containing only gravel, dirt, and short grass. The site is approximately 1,500 meters above sea level. I selected two moth-attracting locations: one directly on the edge of the forest on the Northwest side of the open space, and the other 30 meters into the forest on the Northwest side of the open space (Fig 1).



Figure 1: GPS image of study site (Google Earth). Open space outlined. Moth-attracting locations marked with dots. Monteverde Biological Station visible in top right corner.

Data Collection

I used a suspended 2 x 2.5-meter white sheet illuminated with one 20 Watt florescent white lamp and one 20 Watt black lamp to attract moths. Due to possible rain and mist, I suspended a tarp directly above the sheet and light set-up on each night. I turned the lights on at 5:30 pm (approximate time of sunset) on each night of data-collection and left them on until 7:30 pm. During this two-hour time period, I photographed each moth that had a body length greater than one centimeter (tip of head to tip of abdomen), and that landed on either side of the sheet and stayed long enough for me to photograph it on the sheet. I then picked up each moth, and pressed a piece of clear tape against the head, proboscis, antennae, legs, and underside of thorax—areas likely to receive pollen during foraging for flower nectar. I then transferred each piece of tape to a microscope slide. After collecting samples from each moth, I transferred them to a plastic bag to avoid recapture, where they remained until being released at the end of the data collection for that night.

I collected data for a total of four nights beginning on 26 November 2016, and ending on 2 December 2016. At each site, I collected data on one windless night, and one night of strong wind. I alternated between the sites each consecutive night of data collection. All data collection

nights took place between the third and first quarters of the lunar cycle. Some data collection nights had brief periods of light rain.

In the laboratory, I searched for pollen grains on each of the slides using a compound microscope. I photographed each distinguishable type of pollen on each slide through the microscope lens. Afterwards, I identified both moths and pollen by morphospecies using the pictures. All photographs throughout the experiment were taken with an iPhone 6s.

Statistics

I used chi-square tests of independence to test for significant differences between the four nights of data collection in each of three factors: moth abundance, moth morphospecies richness, and percentage of moths carrying pollen. Since I sampled two different locations (forest interior and forest edge), and each in two different wind conditions (calm and windy), calculated differences could be due to the effect of the location or the effect of the wind. Therefore, I also used chi-square one-sample tests for goodness of fit to test for the effects of wind and location independently on each of the three factors.

RESULTS

Throughout the study, I identified a total of 88 moth morphospecies. 56 morphospecies were found in the forest interior, and 49 on the forest edge. Strikingly, the forest interior and forest edge shared only nine out of the total 88 morphospecies. I also identified 17 morphospecies of pollen: 16 found in the forest interior, and seven found at the forest edge. Out of these, six were shared between both locations (Fig 2).

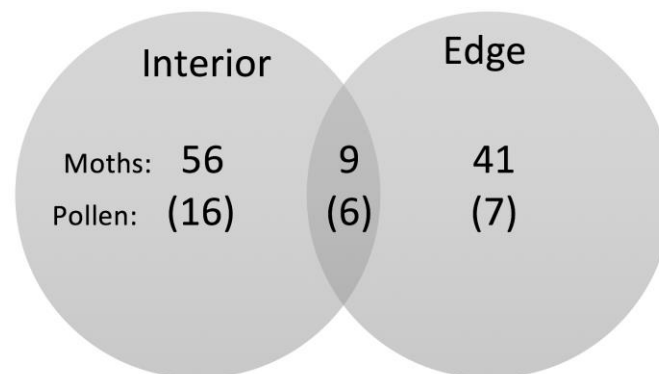


Figure 2: Moth and pollen morphospecies comparison between each location, forest interior (“Interior”), and forest edge (“Edge”). Total moth morphospecies between the two locations was 88. Total pollen morphospecies between the two locations was 17.

Moth abundance, measured by the total number of individuals photographed, differed significantly between days and locations ($X^2 = 10.179$, $df = 1$, $p = 0.001$). There were significantly fewer moths at the forest edge in windy conditions compared to calm conditions ($X^2 = 5.453$, $df = 1$, $p = 0.020$). In contrast, the forest interior did not differ significantly in moth

abundance between calm and windy days ($X^2 = 0.012$, $df = 1$, $p = 0.912$). On windy days, there were significantly fewer moths at the forest edge compared to the forest interior ($X^2 = 8.966$, $df = 1$, $p = 0.003$). In contrast, the forest interior and forest edge did not differ significantly in moth abundance on calm days ($X^2 = 0.333$, $df = 1$, $p = 0.564$; Fig 3).

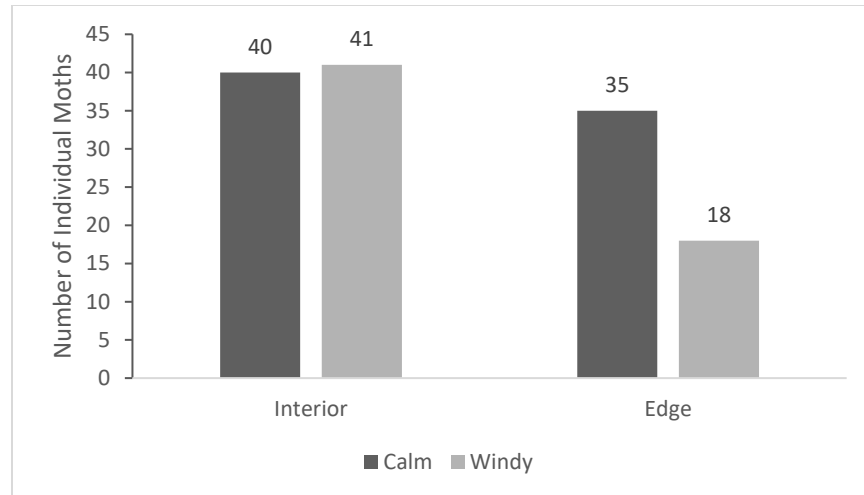


Figure 3: Abundance of moths at each location, forest interior (“Interior”) and forest edge (“Edge”), during calm and windy conditions. Each bar represents one two-hour period of moth collection on an individual night.

The moth morphospecies richness also differed significantly between days and locations ($X^2 = 8.615$, $df = 1$, $p = 0.003$), and followed the same trends as abundance. There were significantly fewer morphospecies on the forest edge in windy conditions compared to calm conditions ($X^2 = 5.0$, $df = 1$, $p = 0.025$). In contrast, the forest interior did not differ significantly in number of morphospecies between windy and calm conditions ($X^2 = 1.0$, $df = 1$, $p = 0.317$). There were also significantly fewer morphospecies on the forest edge versus the forest interior in windy conditions ($X^2 = 3.930$, $df = 1$, $p = 0.047$), whereas there was no significant difference between the locations in calm conditions ($X^2 = 0.545$, $df = 1$, $p = 0.460$; Fig 4).

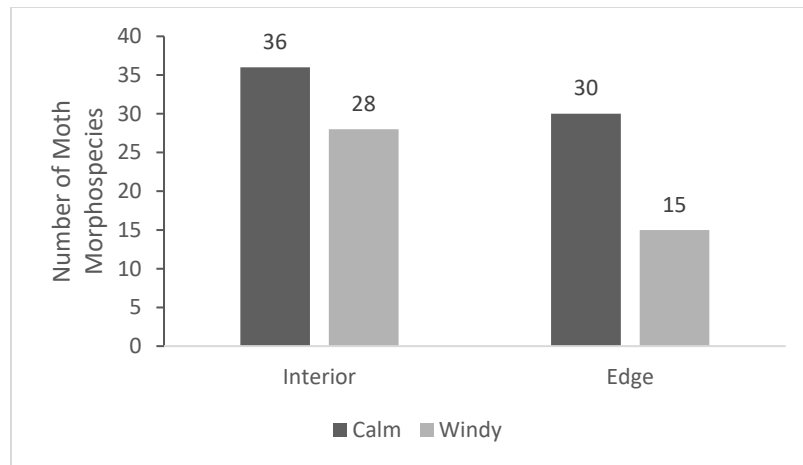


Figure 4: Moth morphospecies richness at each location, forest interior (“Interior”) and forest edge (“Edge”), during calm and windy conditions. Each bar represents one two-hour period of moth collection on an individual night.

The percentage of moths carrying pollen also differed significantly between days and locations ($X^2 = 23.120$, $df = 1$, $p < 0.00001$), again following the same trends as richness and abundance. At the forest edge, a significantly lower percentage of moths carried pollen in windy conditions compared to calm conditions ($X^2 = 9.696$, $df = 1$, $p = 0.002$). In contrast, within the forest interior, the percentage of moths carrying pollen did not differ between wind conditions ($X^2 = 3.268$, $df = 1$, $p = 0.071$). Whereas the percentage of moths carrying pollen did not differ significantly between locations in calm conditions ($X^2 = 0.098$, $df = 1$, $p = 0.891$), a significantly lower percentage of moths carried pollen on the forest edge compared to the forest interior in windy conditions ($X^2 = 23.728$, $df = 1$, $p < 0.00001$; Fig 5)

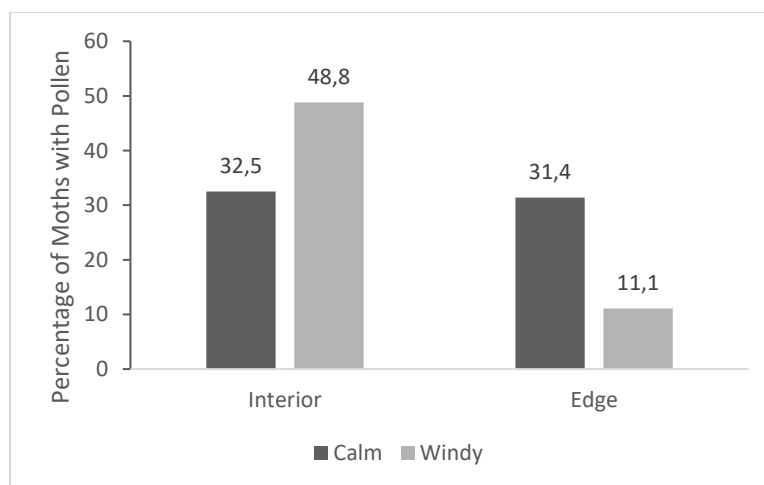


Figure 5: Percentage of moths carrying at least one pollen morphospecies at each location, forest interior (“Interior”) and forest edge (“Edge”), during calm and windy conditions. Each bar represents one two-hour period of moth collection on an individual night.

In the forest interior, I found pollen on a total of 33 moths. There were nine total instances where more than one morphospecies of pollen was found on an individual moth. In eight of the cases, it was two different pollen morphospecies, and in one rare example, four pollen morphospecies occurred on a single moth. In contrast, at the forest edge I found pollen on only 13 moths, and none of these carried more than one morphospecies of pollen (Fig 6).

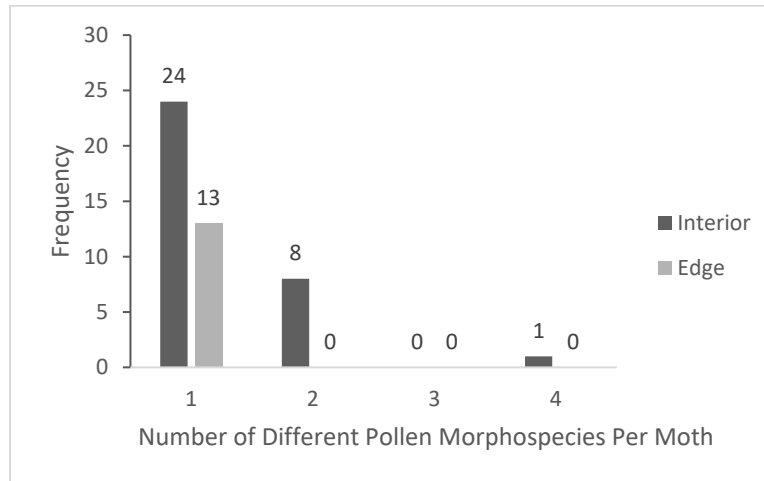


Figure 6: Frequency of one or more pollen morphospecies per moth at each location, forest interior (“Interior”), and forest edge (“Edge”). The two different days at each location are grouped.

DISCUSSION

The results of this study suggest that moth richness, abundance, and pollen-carrying are all significantly lower at the forest edge than the forest interior in windy conditions but not in calm conditions, in part supporting my initial hypotheses. This provides preliminary evidence for a negative effect on moth richness, abundance, and potential pollination activity at forest edges caused specifically by wind and its associated abiotic changes (e.g. temperature shifts). These results are intuitive, as forest edges are inherently more exposed to the wind and its effects due to the decreased tree cover, which in intact forests acts as a wind break and can provide important benefits to both plants and animals.

Wind is perhaps especially problematic for aerial insects, particularly those that are light and have delicate wings, e.g. moths. Cleared spaces in forests may act as physical barriers to moths through exposure to higher wind velocities. Moths may be physically pushed into the forest, or choose to shelter there in windy conditions, which may explain why I found significantly fewer moths at the forest edge during windy conditions, but no significant difference in the forest interior. These findings are especially relevant in many tropical countries which are affected by strong seasonal winds, such as the trade-winds that affect Costa Rica (including during the data-collection period for this study). In a heavily fragmented forest landscape, many cleared areas may become inaccessible to certain moths for large portions of the year, which may impact patterns of movement and dispersal. Large-scale studies are necessary to assess the population-wide impact of cleared spaces and wind on moths.

Forests, even small fragments, may provide moths with necessary shelter from wind. Previous studies have shown that moth species use forest corridors and agricultural windbreaks for movement, avoiding the surrounding exposed habitat matrix (Varkonyi et al. 2003 and Coulthard et al. 2016). In this study, not only did the forest interior show no significant difference in moth richness or abundance between the windy day and the calm day (Figs 3 and 4), but also had a higher (though nonsignificant) percentage of moths carrying pollen (48.8% in windy conditions versus 32.5% in calm conditions; Fig 5). This may suggest that moths, even ones that may frequent forest edges in calm conditions, harbor and forage inside the protection of intact forest fragments in windy conditions. In addition, it provides evidence that even only 30 meters into an intact forest (the distance used in this study) may be enough to provide adequate shelter from wind and access to resources to support moth populations.

There have been no previous studies on the edge effect on moth pollination in tropical forests. My results provide the first preliminary evidence for a possible negative edge effect due to wind on potential pollination activity in moths. It is important to note that finding pollen on a moth does not necessarily indicate pollination activity, as pollination only occurs when pollen is transferred between conspecific plants and deposited in precise locations. In this respect, my measure of “pollination activity” is more directly a measure of foraging activity, as incidence of pollen does indicate that the moths are feeding on flower nectar. However, since moths often unknowingly pollinate while foraging on flowers for nectar, I use the incidence of pollen on moths as an approximation of their *potential* pollination activity.

Acknowledging the significant decrease in moth abundance at the forest edge during windy conditions, a significantly lower percentage of the moths that *were* collected here carried pollen compared to the forest edge during calm conditions, or the forest interior even during windy conditions (Fig 5). In addition, there were no instances of multiple pollen morphospecies on moths at the forest edge, whereas in the forest interior there were nine instances (Fig 6). Although reduced moth abundance and richness around forest edges themselves may negatively impact moth pollination, these results point to an independent negative effect of wind at forest edges on moth potential pollination activity, which could be explained by several possibilities. Wind may force moths to spend more of their time fighting the gusts, thus decreasing foraging activity. Alternatively, it may force the moths into inactivity/shelter to avoid possible negative consequences of being caught flying in the wind. Regardless, by negatively affecting moth foraging at forest edges, wind in fragmented forests may impose significant consequences both to the moths and the plants that they pollinate, such as reductions in moth fitness, and impeded pollen flow in plants. Given the importance of pollination to ecosystem stability, these effects may lead to other ecosystem-wide consequences. Future studies must identify the magnitude and specific mechanisms of the forest edge effect on moth pollination.

Since weak artificial lights have small attraction radii (less than 30 meters) (Fiedler et al 2007), it is likely that the samples collected from 30 meters into the forest interior consisted of moths that were mostly in the forest, while the sample collected at the forest edge may have consisted of moths that were attracted from the forest immediately bordering the open space, the open space itself, and the forest edge. With this in mind, it is important to note that out of the 88 total morphospecies identified, only 9 were shared between the two sampling locations (Fig 2).

There are several plausible explanations for this finding. First, since the windy night spent at the forest edge resulted in significantly fewer morphospecies, it is possible that the full diversity of moths that could be found at the forest edge in calmer conditions are not accurately depicted. Second, it is possible that some of the morphospecies unique to the forest are specifically adapted to living there, and rarely venture to forest edges or open spaces because of unfavorable abiotic or biotic conditions (and perhaps even partly due to the negative effects of wind). Third, the opposite scenario is possible, where some of the morphospecies of moths that were unique to the forest edge may be better adapted to living there. This could be explained by the concept of landscape complementation, where certain moths may require different habitat types throughout their life cycle. These species may benefit from the facilitated mobility between habitat types that forest edges provide (Fahrig 2003).

The results of this study, corroborating those of Powell and Powell (1987), suggest that even small cleared areas in tropical forests—in this case only 1,000 m²—may lead to negative effects on insect populations. The cleared patches may act as ecological “no-man’s land”—barriers to movement through the landscape due to abiotic and biotic interferences. In particular, my results suggest that the abiotic factor, wind, may negatively affect moth populations at forest edges surrounding open spaces, possibly even impacting their interspecific pollination interactions. Future studies with increased sample sizes are necessary to provide further support to these preliminary findings. With possible effects on patterns of diversity, abundance, dispersal, and gene flow in both moth and plant populations in fragmented forests, the results of this study may be relevant to ecosystem stability and should be investigated further and considered in conservation efforts.

ACKNOWLEDGEMENTS

I would like to sincerely thank all of the instructors in the Tropical Biology and Conservation UCEAP program, not only for helping me immensely on this project, but for all that they have done for me and the rest of the group to make study abroad an unbelievably fulfilling and enriching experience. This includes my secondary advisor Andres Camacho, Frank Joyce, Federico Chinchilla, Sofia Arce Flores, Justin Welch, and of course my primary advisor, Emilia Triana. Emilia as an advisor, source of knowledge, instructor, and friend, was ever helpful to me with anything that I needed for this project, and made the research process exceedingly more enjoyable. I would also like to thank Johel Chaves for letting me use his house’s power for my lights. ¡Muchas Gracias!

LITERATURE CITED

- Aizen, Marcelo A., and Peter Feinsinger. "Forest Fragmentation, Pollination, and Plant Reproduction in a Chaco Dry Forest, Argentina." *Ecology* 75.2 (1994a): 330-51. Web.
- Aizen, Marcelo A., and Peter Feinsinger. "Habitat Fragmentation, Native Insect Pollinators, and Feral Honey Bees in Argentine 'Chaco Serrano'" *Ecological Applications* 4.2 (1994b): 378-92. Web.

- Andren, Henrik, and Per Angelstam. "Elevated Predation Rates as an Edge Effect in Habitat Islands: Experimental Evidence." *Ecology* 69.2 (1988): 544. Web.
- Bawa, K. "Plant-Pollinator Interactions In Tropical Rain Forests." *Annual Review of Ecology and Systematics* 21.1 (1990): 399-422. Web.
- Chacoff, Natacha P., and Marcelo A. Aizen. "Edge Effects on Flower-visiting Insects in Grapefruit Plantations Bordering Premontane Subtropical Forest." *Journal of Applied Ecology* 43.1 (2005): 18-27. Web.
- Coulthard, Emma, Duncan Mccollin, and James Littlemore. "The Use of Hedgerows as Flight Paths by Moths in Intensive Farmland Landscapes." *Journal of Insect Conservation* 20.2 (2016): 345-50. Web.
- Didham, Raphael K., Jaboury Ghazoul, Nigel E. Stork, and Andrew J. Davis. "Insects in Fragmented Forests: A Functional Approach." *Trends in Ecology & Evolution* 11.6 (1996): 255-60. Web.
- Didham, Raphael K., Peter M. Hammond, John H. Lawton, Paul Eggleton, and Nigel E. Stork. "Beetle Species Responses to Tropical Forest Fragmentation." *Ecological Monographs* 68.3 (1998): 295. Web.
- Fahrig, Lenore. "Effects of Habitat Fragmentation on Biodiversity." *Annual Review of Ecology, Evolution, and Systematics* 34.1 (2003): 487-515. Web.
- Fiedler, Konrad, Nadine Hilt, Gunnar Brehm, and Christian H. Schulze. "Moths at Tropical Forest Margins: How Mega-diverse Insect Assemblages Respond to Forest Disturbance and Recovery." *Stability of Tropical Rainforest Margins Environmental Science and Engineering* (2007): 37-60. Web.
- Finger, Aline, Christopher N. Kaiser-Bunbury, Chris J. Kettle, Terence Valentin, and Jaboury Ghazoul. "Genetic Connectivity of the Moth Pollinated Tree *Glionnetia Sericea* in a Highly Fragmented Habitat." *PLoS ONE* 9.10 (2014): n. pag. Web.
- Jokimaki, Jukka, Esa Huhta, Juhani Itamies, and Pekka Rahko. "Distribution of Arthropods in Relation to Forest Patch Size, Edge, and Stand Characteristics." *Canadian Journal of Forest Research* 28.7 (1998): 1068-072. Web.
- Kitching, R.l., A.g. Orr, L. Thalib, H. Mitchell, M.s. Hopkins, and A.w. Graham. "Moth Assemblages as Indicators of Environmental Quality in Remnants of Upland Australian Rain Forest." *Journal of Applied Ecology* 37.2 (2000): 284-97. Web.
- Laurance, William F., Thomas E. Lovejoy, Heraldo L. Vasconcelos, Emilio M. Bruna, Raphael K. Didham, Philip C. Stouffer, Claude Gascon, Richard O. Bierregaard, Susan G. Laurance, and Erica Sampaio. "Ecosystem Decay of Amazonian Forest Fragments: A 22-Year Investigation." *Conservation Biology* 16.3 (2002): 605-18. Web.
- Murcia, Carolina. "Chapter 2: Forest Fragmentation and the Pollination of Neotropical Plants." *Forest Patches in Tropical Landscapes*. By John Schelhas and Russell Greenberg. Washington, D.C.: Island, 1996. N. pag. Print.
- Powell, A. Harriett, and George V. N. Powell. "Population Dynamics of Male Euglossine Bees in Amazonian Forest Fragments." *Biotropica* 19.2 (1987): 176. Web.
- Ricketts, Taylor H., Gretchen C. Daily, Paul R. Ehrlich, and John P. Fay. "Countryside Biogeography of Moths in a Fragmented Landscape: Biodiversity in Native and Agricultural Habitats." *Conservation Biology* 15.2 (2001): 378-88. Web.
- Schmidt, B. C., and J. Roland. "Moth Diversity in a Fragmented Habitat: Importance of Functional Groups and Landscape Scale in the Boreal Forest." *Annals of the Entomological Society of America* 99.6 (2006): 1110-120. Web.

- Siu, Jenna C., Daria Kosciński, and Nusha Keyghobadi. "Swallowtail Butterflies Show Positive Edge Responses Predicted by Resource Use." *Landscape Ecology* 31.9 (2016): 2115-131. Web.
- Slade, Eleanor M., Thomas Merckx, Terhi Riutta, Daniel P. Bebber, David Redhead, Philip Riordan, and David W. Macdonald. "Life-history Traits and Landscape Characteristics Predict Macro-moth Responses to Forest Fragmentation." *Ecology* 94.7 (2013): 1519-530. Web.
- Summerville, Keith S., Lisa M. Ritter, and Thomas O. Crist. "Forest Moth Taxa as Indicators of Lepidopteran Richness and Habitat Disturbance: A Preliminary Assessment." *Biological Conservation* 116.1 (2004): 9-18. Web.
- Tscharntke, Teja, Ingolf Steffan-Dewenter, Andreas Kruess, and Carsten Thies. "Characteristics of Insect Populations on Habitat Fragments: A Mini Review." *Ecological Research* 17.2 (2002): 229-39. Web.
- Varkonyi, Gergely, Mikko Kuussaari, and Harri Lappalainen. "Use of Forest Corridors by Boreal Xestia Moths." *Oecologia* 137.3 (2003): 466-74. Web.