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Trabajo de grado para optar por el título de BIÓLOGO

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Abstract

Predation works as a strong selective force on the evolution of morphological and behavioral features of birds. Among the effects of predation, non-lethal are reflected in behavioral changes to avoid predators. Many nocturnal birds responded to variation in habitat environmental conditions (e.g. illumination) according to natural cycles, like the moon cycle. Nocturnal avian communication is mainly acoustical, and the use of vocalizations for reproductive or territorial purposes is necessary. But, during nights with high levels of moonlight illumination, singing may be risky for the transmitter of the signal as it gets exposed to the predator or can be alert possible preys. Owls are important nocturnal predators, but some can also be preys. In fact, bigger owls (i.e *Pulsatrix*) predate smaller owls (i.e *Megascops*). I want to evaluate if the changes in moon light illumination through the lunar cycle impacts the vocal behavior of owls using the records contained in eBird for 24 species of American owls. We used linear regression models for each species to evaluate vocal activity with lunar fraction. We obtained a clear relationship in 5 out of 24 species, weak relationships in 9 species and no relationship in 10 species. Some were positive, few negative but the majority were non-significant, these models were the ones with less records in eBird, suggesting that in the areas when birders are more active, the signal you can get in the database is more accurate.

Key words: predation, moon cycle, moon light, owls, eBird, vocal activity.

Introduction

Predation is pervasive in nature, being an important selective force, which shapes morphological and behavioral features in many animals (Caro, 2005). For this reason, animals have evolved a wide variety of defenses, like camouflage, flocking and aposematism to avoid ending up as someone else dinner (Breviglieri, et al, 2013). Predation is important for both, predator and prey, because predator's fitness depends on hunting success and predation is a strong mortality cause (Penteriani, 2013). Many predators may use chemical, acoustic and visual signals to search for preys, where each signal modality is related to the physical properties or the habitat where preys of interest inhabit (Penteriani, et al, 2009; 2011). Penteriani (2013) explains that interactions between preys and predators are determined by the combined effect of individual characteristics (behavior, physiological conditions, Lima, 2002; Caro 2005), external factors (habitat use, seasonality and weather conditions), and some characteristics of predator and prey populations, such as the spatial and temporal distribution of individuals (Abrams 2000). Nocturnal animals, for example, might use a combination of different searching strategies, depending on the signaling environment, impacting not only the evolution of different type of signals but also foraging and breeding behaviors (Lima, 1999). Nocturnal predators (i.e. owls, small owls) and their preys (e.g. crickets, small owls, lizards) must be strongly influenced by the moon cycles due to changes in light availability which can impact the visibility to predators and in consequence the risk of been predated (Penteriani, et al, 2011; Palmer, et al, 2017; Pratas, et al., 2017).

Lunar cycles influence several behaviors in the life rhythms on a considerable number of organisms (Hecker & Brigham, 1999,York, et al,.2014). Bright moonlight is believed to increase predation risk for nocturnal animals by increasing the ability of predators to detect possible preys (Palmer, et al, 2017). Many preys are not active when the moon is full, but in contrast they are very active when is new or when the sky is cover by clouds (Pratas, 2017). Nocturnal species react to ambient light levels which affect reproduction, foraging and predator-prey interactions (Penteriani, 2013), several studies have focused on the importance of moon cycles and their impact on breeding behavior, communication strategies, circadian cycles, foraging and predation (Kronfeld-Schor, et al, 2013), but few studies have tested the effect of moon brightness on vocal activity of nocturnal birds (Jetz, 2003; Reino, 2015).

Moon cycles are an ecological pressure to nocturnal animal's life due to drastic changes in luminosity, which affect preys and predators, considering that animals change their activity through a cascade of behavioral responses between trophic levels (Lang, et al, 2006, Yamamoto & Trathan, 2015). Moon phases modify the amount of illumination, which may or may not be beneficial according to the characteristics of the organisms (e.g. predator's vs preys) and their patterns of activity (Elangovan & Marimuthu, 2001; Thies, et al, 2006). Singing during the night requires a considerable amount of energy, then animals should assess the predation risk of singing in relation to the energy they are investing while signaling (Mougeot & Bretagnolle, 2000; Schmidt & Belinsky, 2013). Prey-predator interaction has a strong influence particularly on the ecology of prey species, both in terms of survival and behaviour. Preys are therefore likely to adopt different strategies to reduce predation risk by implementing proper behavioral responses (Endler 1991). One of the most frequent anti-predator strategies is avoiding, either in space or time, encounters with predators (Lima & Dill, 1990).

Moonlight variation affects activity patterns of nocturnal predators and preys (Kotler et al. 2010; Penteriani et al. 2011) and markedly influences predator prey interactions among invertebrates (Skutelsky 1996; Tigar & Osborne 1999) and vertebrates (Brown & Kotler 2004, Kotler et al. 2010). During bright nights visual-oriented predators are more effective hunting their preys, therefore, some preys are not very active when the moon is bright, because signaling or just looking for food can be very risky. This type of behavior has been called lunar phobia (Vasquez 1994; Brown & Kotler 2004; Griffin et al. 2005). Other animals showed an opposite pattern of behavior in response to lunar brightness, lunarphilic, these organisms are more active during bright nights (Bockholdt, et al., 2006; Michalski & Norris, 2011).

Bats, mice, pacas (*Cuniculus paca*) and armadillos (*Dasypus* sp., Morrison, 1978) are lunar phobic. These animals are not very active during bright nights, but in some cases, they modified their behavior by moving to darker microhabitats to mitigate the effect of brightness of the moon, avoiding the ideal places that visually oriented predators commonly use for hunting. Crickets, which are preyed upon by small owls (genus *Tettigoniidae*) restrict their reproduction and most of their activities to new moon nights, when illumination is low (Negraeff & Brigham, 1995; Penteriani, 2007; 2011, Pratas, 2017). In other taxa, which are considered lunar philic like goatsuckers (Caprimulgidae Family) the conditions more suitable for singing and foraging occur during bright moonlight (Mills 1986). Top predators that do not experience the risk of predation like the eagle owl (*Bubo bubo*), pumas (*Puma concolor*) or wolves (*Canis lupus*) are considered lunarphilic. These hunters concentrate their activity during full moon nights as they rely on visual clues to hunt or to potentiate some signals (visual or acoustic) associated to several needs or constraints for each individual (Creel, et al, 2008; Penteriani, et al, 2011; Pratas, 2017).

Owls represent a diverse order (Strigiformes) of widely distributed nocturnal birds of prey. Owls have many adaptations to be excellent nocturnal predators: good vision, very sensitive audition and inaudible flight (Mikkola, 2014). First, owls have developed one of the most complex visual systems of birds, an adaptation for hunting effectively in poor light conditions. They also have an extended visual range, bigger cornea, pupil and lens to improve the amount of light that enter the eye; additionally, owls can perceive UV radiation (Penteriani, 2010, Mikkola, 2014). Second, hearing in owls is as sensitive as vision, bigger ear openings and ear position over the facial disc facilitate the perception of sounds. Owls rely in both visual and acoustic clues for hunting, and the combination of both hearing and vision allow owls to locate a potential prey with extreme accuracy (Bettega, 2013; Mikkola, 2014).

Vocalizations in owls are used to defend a territory or a hunting ground, and can be a response to competitors or used to attract possible mates (Penteriani, 2010; Mikkola, 2014). Like other nocturnal birds the main communication channel is acoustic, thus the risk of been detected or preyed upon may be a considerable driver of changes in vocal activity (Garamszegi & Avilés, 2005; Lourenço, et al, 2013). Owls fill different positions in trophic nets, owls can be top predators (i.e. bigger owls) or can be both predators and preys (i.e. small owls), suffering predation pressure from bigger owls or their behavior can be regulated by the prey's availability or activity (Penteriani, 2011). Illumination promotes changes over vocal and activity patterns of predators and preys in different ways, creating a behavioral mediated trophic net, where each level of activity affects both, top or bottom levels (Cadena & Ortíz, 2013; Lourenço, et al, 2013).

However, also visual signals are important, or the combination of both acoustic and visual (multimodal communication). Some owls inflate their throat when they vocalize, sending information by two communication channels. The throat is often white (e.g: Eurasian Eagle

Owl, White throated Screech Owl) contrasting against the cryptic color on the back and the breast. Several studies have shown that white plumage coloration is in some owls, one of the most common ways to convey information (including an individual's quality and social status) to conspecifics, particularly through achromatic patches (pigment free white feathers). These visual signals used in the dark work well in low light conditions, and the achromatic plumage patches that contrast against dark backgrounds make these patches ideal signals to send information (Penteriani et al. 2010, Beggeta, et al., 2013).

Ebird is an online database of bird observations leading by the Cornell Lab of Ornithology. Scientist, citizens and amateur naturalist which observe birds can document the presence or absence of species in their cities and towns. All the observations are submitted to a big database (Sullivan et al. 2014) It is free, and people can access results via interactive queries in the database. Observations can be visual, acoustic or both. The basic dataset includes all the records of one or several species of all validated observations of the checklists entered into eBird. Number of individuals, location, sampling effort, date and hour, geographic coordinates and comments from observers, are the information associated to each checklist (Sullivan et al. 2014, Walker & Taylor, 2017). Some studies have used eBird data focused on migration and spatial use by birds, habitat occupancy models and population surveys but never was used to test the effect of the moon cycles on the vocal activity of nocturnal birds. We assume that most of the records of owls come from aural records, then we used each record as a vocalization event.

I asked whether the number of records of owls is related or influenced by the lunar fraction. In addition. I asked if the effect of moon cycle affect differently owls of different size, due to possible changes in the pressure of predation. We hypothesized that the lunar cycle would influence the vocal activity mostly of small owls (like *Megascops*) due to an increase in the risk of predation by bigger owls. Bright moon periods open a window that facilitates territorial defense, mating and increased amount of resources, but it also increases the predation risk on small owls. Bigger owls act are top-predators, then they in theory are not expose to direct predation pressure. Thus, we predicted that vocal activity would be higher on bright nights or they would not modify their vocal activity in response to moon illumination.

Methods

Species selection

I gathered all the records uploaded in eBird for 24 species distributed throughout America (see table 1). Species were categorized in two body size groups (small and big). Body weights were obtained from the "CRC Handbook of Avian Masses" (Dunning, 2008) and some from the "Handbook of the Birds of the World" (Krabbe & Schulenberg, 2003). For small birds (between 50-250 grams) 19 species of the genus *Megascops*, for big-sized birds (within 250-1500 grams) 3 species of the genus *Ciccaba*, one of the genus *Strix* and only one species of the genus *Pulsatrix* were selected. Habitat type were categorized in 4 types: Dense forest (DF), forest (F), forest edge (FE) and open areas (OA). For each record obtained from eBird we selected the information of the hour and the date of the record.

Lunar fraction and moon phase assignment

Lunar fraction is defined as the fraction of the moon illuminated by sunlight. Lunar fraction can be expressed as a fraction between 0 and 1 or as a percentage (also known as the percent illumination) and is equal to the fraction illuminated 100 times. A fraction of 0% means the moon is completely dark. A fraction of 100 % means it is completely illuminated. The fraction depends on the positions of both the sun and the relative geographic position on the surface of the earth, so it has no single value at a particular time (Urban & Seidelmann, 2014). This measurement ranges from 0 (New Moon) to 100 (Full moon) as a continuous variable.

Lunar illumination data were obtained from the United States Naval Observatory API (Application Programming Interface) (http://aa.usno.navy.mil/data/docs/MoonFraction.php) which provides information about moon position and lunar fraction for any location worldwide, at any time. The API requires geographic coordinates, time of record and UTC offset (hours before or behind UTC) and returns the moonset, moonrise, sunset and sunrise times and lunar fraction. The format of time variables relating to eBird observations were changed to UTC time format, and a time zone offset was calculated using a time zone shapefile (https://github.com/evansiroky/timezone-boundary-builder/releases). I used the packages “httr”, “jsonlite”, “sp”, for RStudio v.3.1.1 to automate requests to the API and calculate time zones (R Core Team, 2017).

Data treatment

Two assumptions were made for using all the records contained in eBird. The first assumption I made was that the majority of the records obtained for owls on this database are aural records. The second assumption was that owl were vocalizing at the time when the list was made by the observer. However, data were filtered using the following conditions before analysis.

Due to the time span of some lists uploaded to eBird being very long, only the records whose duration was less than 240 minutes were selected. Finally, eBird data without time of record were also excluded (generally, historical records uploaded to eBird). In an attempt to improve the quality of the data, we made sure that time and duration of records corresponded to a time when the moon was above the horizon, and after sunset. Using the duration, start time and stop time of each record (the latter calculated from the former two fields included in the eBird database), we created two basic filter conditions: stop time of record must be before moonrise and stop time must be after sunset. In applying the filters, we accounted for moonrise and moonset on subsequent/previous days to the actual eBird record. After data treatment and filtering, from a total of 370,679 observations we finished with 84,947 records.

Data analysis

First, I checked the distribution of the number of days for each category of the lunar fraction during a calendar year or 12 lunar cycles as the baseline or expected frequency. The fraction of lunar illumination has a bimodal distribution, with more time spent around full moon and new moon than intermediate phases, due to its cyclical nature. Then, I calculated the total number of records on each lunar fraction category by species. To extract the proportion for every species we compared the baseline with the number of records. I calculated the number of observations corrected by the base line: the observed fraction frequency less than the expected frequency for each species. If the result is zero there is no difference, if the result is negative, observed is less than expected and if the result is positive, observed is higher than expected.

Linear models were performed to explore the effects of the lunar fraction on the recording frequencies for all species, analyzing the data per species, categories of body size, and habitat type. I evaluated this relationship to determine if the variation in illumination may explain the effects on the frequency of observation throughout the cycle. This study attempted to recognize the effects of habitat type and body size on the response to the lunar cycle; consequently, these variables were included to an ANOVA test in order to explore the variation of vocal activity in front of habitat type and body size. These models were built through the RStudio v.3.1.1 program (R Core Team, 2017).

Results

Database and filtering results

I obtained in total 370.679 records for 24 species of American owls (figure 1A). After all data processing and filtering I evaluated 84.974 recordings for all species (figure 1B). The total number of records obtained were asymmetrically distributed among different species (see Table 1) and the largest number of records were obtained for two species present in Central and North America: *Megascops kennicottii* (n=10.456) and *Strix varia* (n= 61.444). On the contrary, tropical species were the less represented species in the database: *M. petersoni* (n= 47)*, M. marshalli* (n=11) or M. *hoyi* (n=44).

Effects of moonlight on owl vocal activity

I found three patterns: i) some owls showed a positive relationship between the number of records with the proportion of moon illuminated (lunarphilic owls), ii) other showed a negative relationship with lunar fraction (lunar phobic owls) and iii) other do not show any pattern related to changes in the illumination of the moon (see Table 1 and Figure 2).

Lunarphilic owls

We registered the strongest (considering a strong relationship with $p<0,0001$ and adjusted r2 higher than 15% (0,15)) correlation index between lunar fraction and the activity (Table 1) of 5 Megascops species: *Megascops kennicottii* (Figure 2C), *M. trichopsis* (Figure 2B) *M. nudipes, M. clarkii* and *S. varia* (Figure 2A). which show a positive tendency towards the most illuminated parts of the cycle. We obtained significant p values ($p<0.05$) but with adjusted r <0,15 for: *M. petersoni, M. cooperi ,M. barbarus Ciccaba virgata* and *C. nigrolineata*

Lunarphobic owls
We obtained a negative relationship (towards the darkest part of the cycle) for: Megascops ingens M. guatemalae (Figure 2D), Ciccaba huhula (Figure 2F) and *Pulsatrix perspicillata* (Figure 2C).

No relationship were registered for 10 species of *Megascops* genus: *M. choliba (Figure 2G), M. albogularis (Figure 2H), M.koepckeae (Figure 2I)*, *M. marshalli*, *M.hoyi*, *M.colombianus*, *M. santaecatarinae*, *M. roboratus*, *M. seductus* and *M. atricapilla.*

Remarkably, species with a considerable number of records in eBird showed a clear pattern positively related to lunar fraction *S. varia* (n=61,444); *M. kennicottii*, (n=10,456); *M. trichopsis*, (n=2002) and *P. perspicillata* (n=1468). Almost none of the species with very few records n (<200) showed any relationship with the moon cycle due to the low number of records in eBird. However, for *Megascops choliba* (n = 3076) I found many records, but this species did not show any relationship. Finally, two species with few records (*M. ingens* and *M. guatemalae*) showed a significant negative relationship (see Table 1).

Habitat and body size also had an influence in the vocal activity of owls (Figure 3), regardless of lunar phase. Bigger owls show higher vocal activity patterns, than those of small owls regardless of the type of habitat (F=453.07, p>0.0001). I also found that depending on the type of habitat, the variation of vocal activity varies (F=68.19 p<0.0001). It seems that open areas owls sing more that edge and forest owls. I also found and interaction effect between habitat and weight (F=6.70 p=0.001).

Discussion

Vocal activity, measured as the number of records deposited in eBird, was positively related to lunar fraction in five species of owls (see Table 1). This positive relationship was found in four species of Screech-Owls (*Megascops*) and in the Barred owl, a medium size owl species (*Strix varia*). These results were contrary to my expectations; I expected a negative relationship between vocal activity and lunar fraction due to a possible increase in predation risk, in smaller owls. However, Screech owls are preys and predators, and the behavior of predators is also shaped by the behavior of preys (Palmer, et al., 2017). For example, crickets which are one of the favorite preys of Screech owls, are lunar phobic, their activity decreases considerably during bright nights (Negraeff & Brigham, 1995). Therefore, this lunar phobic behavior found in these owls, can be driven by differential food availability throughout a moon cycle. Screech owls are preyed upon by bigger owls (Penteriani, et al.,2011; Lourenco, 2013), but it seems that vocal activity in some small owls is not influenced by the risk of been predated by a bigger owl. Although, microhabitat selection for signaling can be important in reducing the risk of been predated. In a recent, fieldtrip during a full moon night, I heard a Screech owl singing, but the owl was within the forest, probably it was hiding, because I saw a big owl around.

Acoustic and chemical signals work better in the dark of the night, but recently several studies have conveyed the idea that the nocturnal world is full of visual information (Penteriani & Delgado, 2017). Moonlight represents a powerful source of illumination that cannot be neglected from the perspective of visual communication in nocturnal species (Digby, et al., 2014). Probably these lunarphilic owls may use visual signals when singing, but when looking at possible visual clues for signaling (Penteriani, 2010). I could not find any clear pattern which may suggest the use of visual signals in these lunarphilic owls.

Vocal activity in other four owls was negatively related to the lunar fraction, but the degree of the relations was not as strong as in the lunarphilic owls (see Table 1). These lunarphobic owls have different sizes (100 to 250 grams for small owls or more than 500g for bigger owls) and inhabit in different habitats. Bigger owls are top predators in the trophic chain, which means that there must not be apparently any reason for decreasing the vocal activity, because there is no risk of being predated (Brown, 1999). Curiously, sample sizes in these group of lunarphobic owls were very small, suggesting that the amount of records may influence the signal one can get of any temporal pattern. Finally, for ten owls I did not find any relationship between the number of records and lunar fraction. In most of these owls there were very few number of records in eBird. But, in the Tropical Screech owl, the number of recordings (n=3076) was outstanding and there was not any relationship between lunar fraction and number of records. This may suggest that vocal activity is not influenced by the moon in the same way each owl, other parameters like habitat owls use when signaling may influence the response to changes in nocturnal illumination. Owls can move and select microhabitats which are not as expose to increases the risk of predation.

The abundance of prey may affect the activity of owls, because they are mainly visually oriented predators, which in conditions of high illumination get a significant advantage in searching, chasing and catching preys. Is has been shown that a large amount of owls preys like bats or other owls reduce their activity in full moon nights in order to avoid predation (Clarke, 1983; Negraeff, 1995; Elangovan & Marimuthu, 2001; Thies, et al, 2006). But even with this reduction in food availability, it can be more useful hunting on bright nights, as it's easier to find food and the amount of energy investment catching preys may decrease (Lima & Drill, 1990; Delgado & Penteriani, 2010; Prugh & Golden, 2014).

Foraging is linked to individual fitness and efficient energy consumption, it contributes to individual survival and offspring fitness (Lemon 1991, English, 2018). The costs and benefits of foraging are affected by conditions that vary over temporal scales like moon cycle (Erikson, 2000; English, et al., 2018). Full moon implies a dramatic light change over the environment, as conditions changes generate what Schmitz, 1997 call a behaviourally mediated trophic cascade, thus any behavioral change at any level in this trophic cascade affect animals at all levels. Variation in the activity of small owls (which act as both preys and predators) may rely mainly on the behaviour of its preys (e.g: crickets of Tettigoniidae genus). In visually orienting nocturnal animals, the trade-off between singing and foraging, (assuming that calling reduces foraging efficiency) are modulated by the availability of light which, by itself determine activity patterns of both predators and prey (Woods, 2008; Penteriani, 2013). Consequently, as Woods (2008) explains it is not surprising that lunar phases influence behavior of nocturnal animals, especially those that rely on vision, although the direction of this influence may not be clear yet. The spatio-temporal bias in the number of records may determine the strength of the temporal signal captured by the records collected on eBird. For example, two of the North American Owls (*M. kennicottii* and *Strix varia*) have the largest number of records in the entire database, and on these two species the clearest response to the effect of lunar fraction were recovered. In North American countries many birders are uploading information to eBird (Woods, et al; 2011; Sullivan, et al., 2014), and probably this effort is capturing the temporal variation in the activity of birds.

References

1. Treggiari, M. Gagliardone, I. Pellegrino & M. Cucco (2013) Habitat selection in a changing environment: the relationship between habitat alteration and Scops Owl

(Aves: Strigidae) territory occupancy, Italian Journal of Zoology, 80:4, 574-585, DOI: 10.1080/11250003.2013.853843

2. Appel, G., López-Baucells, A., Magnusson, W. E., & Bobrowiec, P. E. D. (2017). Aerial insectivorous bat activity in relation to moonlight intensity. Mammalian Biology-Zeitschrift für Säugetierkunde, 85, 37-46.
3. Barros, O. G., & R. Cintra (2009). The effects of forest structure on ocurrence and abundance of three owl species (aves: Strigidae) in the central amazon forest. Zoologia (Curitiba), 26(1), 85-96.
4. Bettega, C., Campioni, L., del Mar Delgado, M., Lourenço, R., & Penteriani, V. (2013). Brightness features of visual signaling traits in young and adult Eurasian eagle-owls. Journal of Raptor Research, 47(2), 197-207.
5. Bortolotti, G. R., Stoffel, M. J., & Galvan, I. (2011). Wintering Snowy Owls Bubo scandiacus integrate plumage colour, behaviour and their environment to maximize efficacy of visual displays. Ibis, 153(1), 134-142.
6. Breviglieri, C. P. B., Piccoli, G. C. O., Uieda, W., & Romero, G. Q. (2013). Predation-risk effects of predator identity on the foraging behaviors of frugivorous bats. Oecologia, 173, 905-912.
7. Cadena-Ortiz, H., Freile, J. F., & Bahamonde-Vinueza, D. (2013). Información sobre la dieta de algunos búhos (Strigidae) del Ecuador. Ornitologia Neotropical, 24, 469-474.
8. Capers, R. (2010). Foraging decisions of nocturnal mice under direct and indirect cues of predation risk. Graduate Theses and Dissertations. Retrieved from http://scholarcommons.usf.edu/etd/1589
9. Chaparro-Herrera, S., Córdoba-Córdoba, S., López-Ordóñez, J. P., Restrepo-Cardona, J. S., & Cortés-Herrera, O. (2015). Los búhos de Colombia. Los Búhos Neotropicales: Diversidad y Conservación. ECOSUR. México, 277-329.
10. Cherry, M. J., & Barton, B. T. (2017). Effects of wind on predator-prey interactions. Food Webs,
11. Creel, S., & Christianson, D. (2008). Relationships between direct predation and risk effects. Trends in Ecology & Evolution, 23(4), 194-201.
12. Del Hoyo, J., Elliot, A., & Sargatal, J. (1992). Handbook of the Birds of the World. Barcelona: Lynx Editions.
13. Dunning Jr, J. B. (2007). *CRC handbook of avian body masses*. CRC press.

14. E.,Arlettaz, R. (2014). Bright moonlight triggers natal dispersal departures. Behavioral Ecology and Sociobiology, 68(5), 743-747.
15. Eberhart-Phillips, L. J. (2017). Dancing in the moonlight: evidence that Killdeer foraging behaviour varies with the lunar cycle. Journal of Ornithology, 158(1), 253-262.
16. Elangovan, V., & Marimuthu, G. (2001). Effect of moonlight on the foraging behaviour of a megachiropteran bat Cynopterus sphinx. Journal of Zoology, 253(3), 347–350.
17. Emiliano Mori, Mattia Menchetti & Francesco Ferretti (2014) Seasonal and environmental influences on the calling behaviour of Eurasian Scops Owls, Bird Study, 61:2, 277-281, DOI: 10.1080/00063657.2014.897303
18. English, P. A., Nocera, J. J., & Green, D. J. (2018). Nightjars may adjust breeding phenology to compensate for mismatches between moths and moonlight. Ecology and Evolution.
19. Erickson, J. L., & West, S. D. (2002). The influence of regional climate and nightly weather conditions on activity patterns of insectivorous bats. Acta Chiropterologica, 4(1), 17-24.
20. Fisher, D. O. (2000). Effects of vegetation structure, food and shelter on the home range and habitat use of an endangered wallaby. Journal of Applied Ecology, 37(4), 660-671.
21. Hampton, S. E., Strasser, C. A., Tewksbury, J. J., Gram, W. K., Budden, A. E., Batcheller, A. L., ... & Porter, J. H. (2013). Big data and the future of ecology. Frontiers in Ecology and the Environment, 11(3), 156-162.
22. Hecker, K. R., & Brigham, R. M. (1999). Does Moonlight Change Vertical Stratification of Activity by Forest-Dwelling Insectivorous Bats? Journal of Mammalogy, 80(4), 1196–1201. https://doi.org /10.2307/1383170
23. Holt, D.W., Berkley, R., Deppe, C., Enríquez Rocha, P., Petersen, J.L., Rangel Salazar, J.L., Segars, K.P., Wood, K.L. & Marks, J.S. (2018). Whiskered Screech-owl (Megascops trichopsis). In: del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A. & de Juana, E. (eds.). Handbook of the Birds of the World Alive. Lynx Edicions, Barcelona. (retrieved from https://www.hbw.com/node/54982on 16 May 2018).
24. Holt, D.W., Berkley, R., Deppe, C., Enríquez Rocha, P., Petersen, J.L., Rangel Salazar, J.L., Segars, K.P., Wood, K.L. & Marks, J.S. (2018). Western Screech-owl (Megascops kennicottii). In: del Hoyo, J., Elliott, A., Sargatal, J., Christie, D.A. & de

Juana, E. (eds.). Handbook of the Birds of the World Alive. Lynx Edicions, Barcelona. (retrieved from https://www.hbw.com/node/54978on 16 May 2018).

25. Jeroen Ooms (2014). The jsonlite Package: A Practical and Consistent Mapping Between JSON Data and R Objects. arXiv:1403.2805 [stat.CO] URL https://arxiv.org/abs/1403.2805
26. Kajtoch, Ł., Żmihorski, M., & Wieczorek, P. (2015). Habitat displacement effect between two competing owl species in fragmented forests. Population Ecology, 57(3), 517–527. https://doi.org/10.1007 /s10144-015-0497-y
27. Kissling, M. L., Lewis, S. B., & Pendleton, G. (2010). Factors Influencing the Detectability of Forest Owls in Southeastern Alaska. The Condor, 112(3), 539–548. https://doi.org/10.1525 /cond.2010.090217
28. Kotler, B. P., Brown, J., Mukherjee, S., Berger-Tal, O., & Bouskila, A. (2010). Moonlight avoidance in gerbils reveals a sophisticated interplay among time allocation, vigilance and state-dependent foraging. Proceedings of the Royal Society of London B: Biological Sciences, 277(1687), 1469-1474.
29. Kronfeld-Schor N, Dominoni D, de la Iglesia H, Levy O, Herzog ED, Dayan T, Helfrich-Forster C. 2013 Chronobiology by moonlight. Proc. R. Soc. B 280, 20123088. (doi:10.1098/rspb.2012.3088)
30. Kurvers, R. H., & Hoelker, F. (2014). Bright nights and social interactions: a neglected issue. Behavioral Ecology, 26(2), 334-339.
31. Lang, A. B., Kalko, E. K. V, Römer, H., Bockholdt, C., & Dechmann, D. K. N. (2006). Activity levels of bats and katydids in relation to the lunar cycle. Oecologia, 146(4), 659–666. http://doi.org/10.1007/s00442-005-0131-3
32. La Sorte, F. A., Fink, D., Hochachka, W. M., Farnsworth, A., Rodewald, A. D., Rosenberg, K. V., ... & Kelling, S. (2014). The role of atmospheric conditions in the seasonal dynamics of North American migration flyways. Journal of Biogeography, 41(9), 1685-1696.
33. Lima, S. L., & Dill, L. M. (1990). Behavioral decisions made under the risk of predation: A review and prospectus. Canadian Journal of Zoology, 68(4), 619-640.
34. Lima, S. L., & O'Keefe, J. M. (2013). Do predators influence the behaviour of bats? Biological Reviews, 88(3), 626–644. https://doi.org/10.1111/brv.12021
35. Lourenço, R., Goytre, F., del Mar Delgado, M., Thornton, M., Rabaça, J. E., & Penteriani, V. (2013). Tawny owl vocal activity is constrained by predation risk. Journal of Avian Biology, no-no. https://doi.org/10.1111/j.1600-048X.2013.00157.x

36. Lovari, S., Renzoni, A., & Fondi, R. (1976). The Predatory Habits of the Barn Owl (Tyto Alba Scopoli) in Relation to the Vegetation Cover. Bolletino Di Zoologia, 43(1–2), 173–191. https://doi.org/10.1080 /11250007609434894
37. McRae, T. R., & Green, S. M. (2017). Vocalizations associated with predator-type do not elicit predator-specific escape responses in grey squirrels. Behaviour, 154, 997-1012
38. Michalski, F., & Norris, D. (2011). Activity pattern of Cuniculus paca (Rodentia: Cuniculidae) in relation to lunar illumination and other abiotic variables in the southern Brazilian Amazon. Zoología, 28(6), 701–708. http://doi.org/10.1590/S1984-46702011000600002
39. Mikkola, H. (2014). Owls of the World-A Photographic Guide. A&C Black.
40. Møller, A., Nielsen, J., & Garamszegi, L. Z. (2006). Song post exposure, song features, and predation risk. Behavioral Ecology, 17(2), 155-163.
41. Mori, E., Menchetti, M., & Ferretti, F. (2014). Seasonal and environmental influences on the calling behaviour of Eurasian Scops Owls. Bird Study, 61(2), 277-281
42. Morris, D. W., & Vijayan, S. (2018). Trade-offs between sight lines and escape habitat determine spatial strategies of risk management by a keystone herbivore. FACETS. https://doi.org/10.1139/facets- 2016-0062
43. Mougeot, F., & Bretagnolle, V. (2000). Predation as a cost of sexual communication in nocturnal seabirds: an experimental approach using acoustic signals. Animal Behaviour, 60, 647-656.
44. Muñoz-Pedreros, A., Gil, C., Yáñez, J., Rau, J. R., & Möller, P. (2016). Trophic ecology of two raptors, Barn Owl (Tyto alba) and White-tailed Kite (Elanus leucurus), and possible implications for biological control of Hantavirus reservoir in Chile. The Wilson Journal of Ornithology, 128(2), 391-403.
45. Negraeff, O. E., & Brigham, R. M. (1995). The influence of moonlight on the activity of little brown bats (Myotis lucifugus). Zeitschrift Fur Saugetierkunde, 60(6), 330–336.
46. Penteriani, V., & del Mar Delgado, M. (2017). Living in the dark does not mean a blind life: bird and mammal visual communication in dim light. Phil. Trans. R. Soc. B, 372(1717), 20160064.
47. Penteriani, V., del Mar Delgado, M., Campioni, L., & Lourenço, R. (2010). Moonlight makes owls more chatty. PLoS One, 5(1), e8696.

48. Penteriani, V., Kuparinen, A., del Mar Delgado, M., Lourenço, R., & Campioni, L. (2011). Individual status, foraging effort and need for conspicuousness shape behavioural responses of a predator to moon phases. Animal Behaviour, 82, 413-420
49. Penteriani, V., Kuparinen, A., Delgado, M. del M., Palomares, F., López-Bao, J. V., Fedriani, J. M., ... Lourenço, R. (2013). Responses of a top and a meso predator and their prey to moon phases. Oecologia, 173(3), 753–766. https://doi.org/10.1007/s00442-013-2651-6
50. Polis, G. A., Myers, C. A., & Holt, R. D. (1989). The ecology and evolution of intraguild predation: potential competitors that eat each other. Annual review of ecology and systematics, 20, 297-330.
51. Pratas-Santiago, L. P., Gonçalves, A. L., Nogueira, A. J., & Spironello, W. R. (2017). Dodging the moon: The moon effect on activity allocation of prey in the presence of predators. *Ethology*, *123*(6-7), 467-474.
52. Prugh, L. R., & Golden, C. D. (2014). Does moonlight increase predation risk? Meta-analysis reveals divergent responses of nocturnal mammals to lunar cycles. Journal of Animal Ecology, 83, 504-514.
53. Regular, P. M., Hedd, A., & Montevecchi, W. A. (2011). Fishing in the Dark: A Pursuit-Diving Seabird Modifies Foraging Behaviour in Response to Nocturnal Light Levels. PLOS ONE, 6(10), e26763. https://doi.org/10.1371/journal.pone.0026763
54. Ritchison, G., Gehlbach, F., Pyle, P., & Patten, M. (2017). Eastern Screech-Owl (Megascops asio). EKU Faculty and Staff Scholarship. Retrieved from https://encompass.eku.edu/fs_research/160
55. Robert J. Hijmans & Jacob van Etten (2012). raster: Geographic analysis and modeling with raster data. R package version 2.0-12. http://CRAN.R-project.org/package=raster
56.
57. Schmidt, K. A., & Belinsky, K. L. (2013). Voices in the dark: predation risk by owls influences dusk singing in a diurnal passerine. Behavioral Ecology and Sociobiology, 67, 1837-1843.
58. Snäll, T., Kindvall, O., Nilsson, J., & Pärt, T. (2011). Evaluating citizen-based presence data for bird monitoring. Biological conservation, 144(2), 804-810.
59. Sullivan, B. L., J. L. Aycrigg, J. H. Barry, R. E. Bonney, N. Bruns, C. B. Cooper, T. Damoulas, A. A. Dhondt, T. Dietterich, A. Farnsworth, D. Fink, J. W. Fitzpatrick, T. Fredericks, J. Gerbracht, C. Gomes, W. M. Hochachka, M. J. Iliff, C. Lagoze, F. A.

La Sorte, M. Merrifield, W. Morris, T. B. Phillips, M. Reynolds, A. D. Rodewald, K. V. Rosenberg, N. M. Trautmann, A. Wiggins, D. W. Winkler, W.-K. Wong, C. L. Wood, J. Yu, and S. Kelling. 2014. The eBird enterprise: an integrated approach to development and application of citizen science. Biological Conservation 169:31-40. http://dx.doi.org/10.1016/j.biocon.2013.11.003

60. Thies, W., Kalko, E. K., & Schnitzler, H.-U. (2006). Influence of environment and resource availability on activity patterns of Carollia castanea (Phyllostomidae) in Panama. Journal of Mammalogy, 87, 331–338.
61. Todd, M. K., Kavanagh, R. P., Bell, P., & Munks, S. A. (2017). Calling behaviour of the Tasmanian Masked Owl Tyto novaehollandiae castanops. Australian Zoologist. https://doi.org/10.7882 /AZ.2017.030
62. Tuttle, M. D., & Ryan, M. J. (1981). Bat predation and the evolution of frog vocalizations in the Neotropics. Science(Washington), 214, 677-678.
63. Urban, S. E., & Seidelmann, P. K. (2014, January). Explanatory Supplement to the Astronomical Almanac. In *American Astronomical Society Meeting Abstracts# 223* (Vol. 223).
64. Wood, C., Sullivan, B., Iliff, M., Fink, D., & Kelling, S. (2011). eBird: engaging birders in science and conservation. PLoS biology, 9(12), e1001220.
65. Yahya, M. S., Puan, C. L., Azhar, B., Atikah, S. N., & Ghazali, A. (2016). Nocturnal bird composition in relation to habitat heterogeneity in small scale oil palm agriculture in Malaysia. Agriculture, Ecosystems & Environment, 233, 140-14
66. Yamamoto, T., & Trathan, P. N. (2015). Evidences of moon-related effects on animal behaviour. Clinical Obesity, 5, 49-51.
67. York, J. E., Young, A. J., & Radford, A. N. (2014). Singing in the moonlight: dawn song performance of a diurnal bird varies with lunar phase. Biology Letters, 10(1), 20130970. https://doi.org/10.1098 /rsbl.2013.0970

Annexes

Table 1. Results of the linear model for the frequency of observation between moon illuminated fraction.

	Moonlight effect					
Species	**+**	**-**	**NA**	**p**	**R^2**	**n**
Megascops choliba			-	0,728	-0,009	3076
M. koepckeae			-	0.334	-0,005	59
M. albogularis			-	0.275	0,002	227
M. clarkii	***			**1.93e-7**	**0,234**	**218**
M. trichopsis	***			**2.2e-16**	**0,55**	**2002**
M. petersoni	*			0.0699	0,024	47
M. marshalli			-	0.471	-0,004	11
M. hoyi			-	0.330	-0,0004	40
M. ingens		**		0.00952	0,057	150
M. colombianus			-	0.92	-0,01	113
M. kennicottii	***			**2.2e-16**	**0,59**	**10456**
M. cooperi	**			0.00612	0,064	561
M. barbarus	*			0.0136	0,05	35
M. sanctaecatarinae			-	0.6728	-0,008	66
M. roboratus			-	0.5187	-0,005	100
M. guatemalae		*		0.0458	0,03	66
M. nudipes	***			**5.89e-6**	**0,181**	**286**
M. seductus			-	0.7922	-0,009	60
M. atricapilla			-	0.523	0,005	109
Ciccaba huhula		*		0.0107	0,055	243
C. virgata	*			0.07978	0,021	3131
C. nigrolineata	**			0.00347	0,074	949
Pulsatrix perspicillata		***		**0.00044**	**0,11**	**1468**
Strix varia	***			**2e-16**	**0,51**	**61444**

Results of the linear model for all species. (*** = p <0.0001, **p < 0,001, *p<0.05)

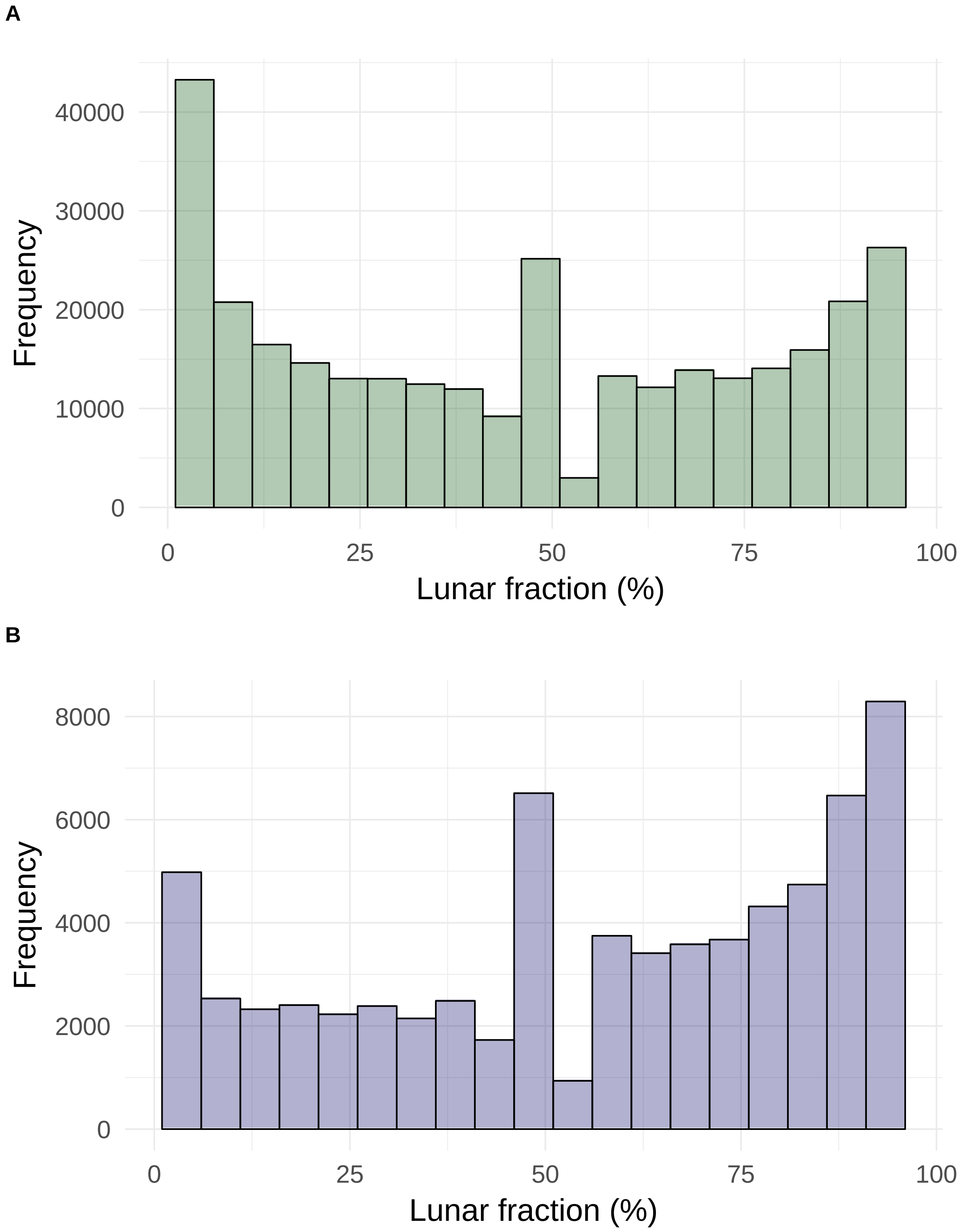

Figure 1. Frequency of registers per lunar fraction. **A.** Data without filtering (n= 370,069) and **B.** Data after filtering (n=84747).

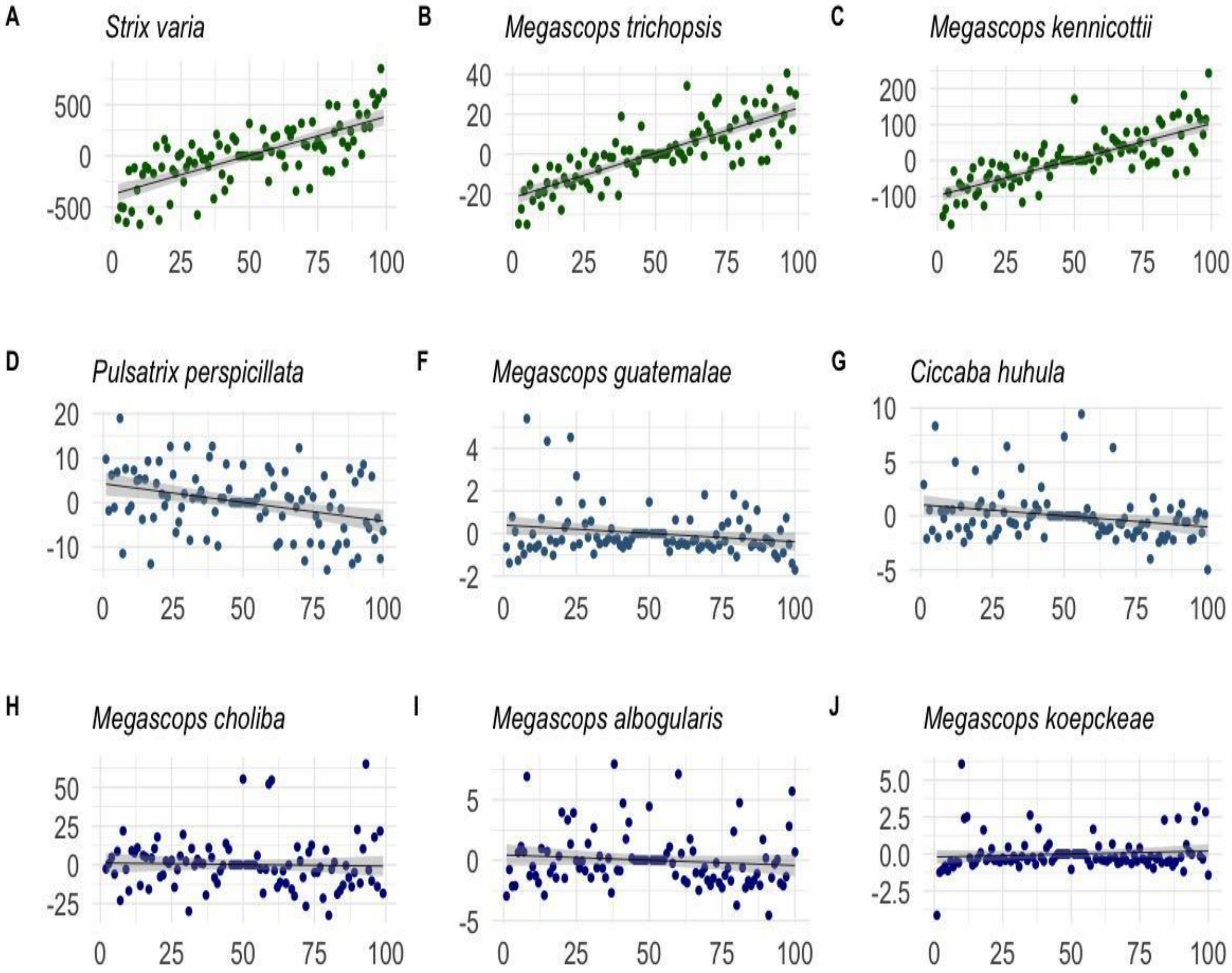

Figure 2. Linear regression models result for 9 of the 24 species evaluated. In the x axis is lunar fraction (from 1 to 100%), in the y axis is the frequency of observations corrected by the lunar fraction.

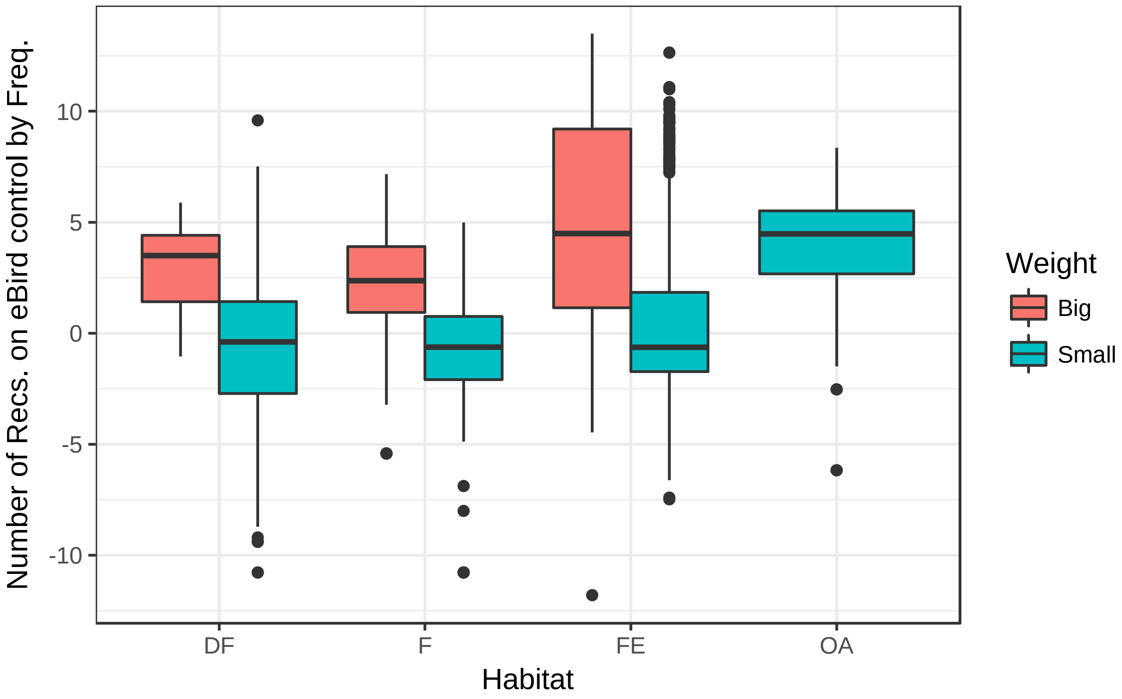

Figure 3. Number of records on eBird in function of habitat (Dense Forest (DF), Forest (F), Forest edge (FE) and Open Areas (OA) and body weight.