The effect of artificial light at night(ALAN) on the nesting behaviour of European Herring Gull parents (*Larus argentatus*)

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Abstract:

This study aimed to explore the effect of artificial light at night (ALAN) on the nesting behaviours of European herring gull (*Larus argentatus)* parents, over a 2 week study period between May-June. A sample of 6 nests were selected, half of which were located on various buildings in the penryn campus and represented the 'high light level' group, the other half were located in various locations away from artificial light around the Falmouth/Penryn area and represented the low light control group. Camera traps and light level meters (measuring lux levels) were placed next to nests and videos recorded between the hours of 10PM-3AM, and light levels recorded (lx) and behaviours observed were compared. A significant difference was found between light levels in the on campus nests compared those in the off-campus locations, however no statistical difference was observed in the behaviours the seagull parents engaged in. The study provides an interesting talking point to the discussion of the behavioural effects of ALAN in free-ranging animals, which has become a major environmental concern in recent years. In addition the study may also aid to inform decisions for experimental design for future studies.

Introduction

The Illumination of environments in which humans preside at night-time is to most, a given, with satellite data showing that approximately 2 thirds of the world population live in areas where the night sky is above the threshold set for polluted status. Currently, 10% of the world population(primarily located in the US and Europe) no longer view the night sky with eyes adapted to night vision, due to this sky-brightness (Cinzano et al, 2001). However, the multifaced term which is light pollution is often solely interpreted -to most- as astronomical light pollution, when in reality another form exists: ecological light pollution, referring to artificial light that alters the natural patterns of light and dark in ecosystems (Longcore and Rich, 2004). Ecologists have been able to attribute the effects of this form of visual pollution to patterns observed in organisms across a very large range of taxa (Dominoni,et al., 2016) (Cinzano et al., 2001).

Perhaps one of the most well-known effects of ALAN (artificial light at night) is its ability to disrupt circadian rhythms due to its effect on melatonin production: by reducing it (Yamada et al., 1988) (Dominoni et al., 2013) (Moaraf et al., 2020). A cause for concern as while it primarily regulates the function of day length, it also affects physiological processes like: regulation of body mass, hormone synthesis, metabolic rate, and immunity, as well as reproductive fitness with experimental examples demonstrating this (Xu et al., 2011) (McFadden et al., 2014) (Fonken et al., 2010) (Vinogradova et al., 2009). However, ALAN has been observed to have had not only a physiological effect on organisms but also a direct effect on organismal behaviours.

Perhaps the best-known examples of the direct effect of Light on organisms are on sea turtle hatchlings, which use the light of the moon reflecting on the water surface on the horizon during their hatching period, in an attempt to navigate the ocean to safety, an effect which ALAN replicates, causing the hatchlings to follow this misdirection. (Lohmann and Lohmann, 1996). This behaviour was observed in a sample of 40 green turtle hatchlings 86% percent of the time (Thums et al., 2016).

As it is very difficult to observe the effect of ALAN on free-living animals, there aren't many significant examples of its effects on mammals(Beier.p., 2006), however, a 5-year study conducted on 2 populations of tammar wallabies paints an equally grim picture, being that exposure to ALAN decreased nocturnal serotonin secretion as well as delaying reproductive activation in the animals, which are seasonally reproducing (Robert et al., 2015). Kangaroo rats have been observed to forage more in the presence of ALAN which could lead to resource depletion, affecting ecological aspects such as predator-prey relationships (Shier et al., 2020). In fact, it has been observed in full moons that many nocturnal mammals will adjust by displaying behaviours such as increased hiding and decrease in travel time, as such it is not outside of the realm of the assumption that these behaviours would be observed in the presence of artificial light(Beier.P.2006).

Invertebrates have also been observed to have been affected by the presence of artificial lights, as is the case with tympanate moths, which were unable to respond to ultrasound in the presence of mercury vapor street lamps, compared to a woodland control group (Svennson and Rydell, 1998), potentially affecting the predator-prey relationship of local bats, in fact, many other studies have observed the effect of ALAN on invertebrates finding similar patterns of disorientation in their presence (Lockett et al., 2021) (Perkin et al., 2011), with 60% of invertebrates being nocturnal(Owens and Lewis, 2018), these responses pose a significant threat on an ecosystemic level considering the already observed downtrend in invertebrate population.

Aves, are a group of organisms on which the effects of artificial light have been recorded in a variety of contexts, with various responses being observed. Like in invertebrates, disorientation has been reported, in the case of shearwater fledgling chicks, which, in a similar case to sea turtles, displayed attraction to streetlight instead of the moonlit ocean upon first flight, leading to mortality rates of up to 39% of fledglings, with a significant decrease of this figure being seen in controls where light was turned off (Rodríguez et al., 2014) a later study reaffirming this observation (Rodríguez et al., 2015). Disorientation by ALAN in birds is observed frequently around large lighting installations (Van Doren et al., 2017) and can pose a large problem when considering migration patterns of avians, which are essential for sustaining populations around breeding seasons, ALAN, therefore, can affect fecundity of entire species in ways which would be near impossible to gauge(Cabrera-Cruz et al., 2018).

However, ALAN not only affects the orientation of birds but a slew of other behaviours as well, circadian rhythms have been reliably altered through the experimental exposure of light in nests of various species of birds with success. Activity patterns have experimentally successfully been altered in great tits with light exposure promoting an earlier onset of activity in the morning (Spoelstra et al., 2018). Birds have also been observed to vocalise more frequently, which is assumed to have been due to their reproductive timings having been shifted due to the nearby streetlighting (Kempenaers et al., 2010). And in peahens, significant increases in vigilance at night time has been observed in the presence of ALAN(Yorzinski et al., 2015). Other behaviours have been observed still, such as an increase in foraging times in other bird species (Kempenaers et al., 2010). In the case of these observed behaviours, it is possible these effects could like other examples previously mentioned affect both predator-prey relationships, as well as have potentially unknown long term influences on fitness.

This study was conducted on the European herring gull (*Larus argentatus*), and involved placing footage recording camera traps as well as light level metres next to nest scrapes, in an attempt to observe parental behaviour during the most important stages of the chick's lives, recording an array of behaviours. These nests were chosen depending on location, with an aim for a comparison between nests that are in the presence of higher light values at night to be made than to those that are not (which will be quantified by lx), by selecting nests that are located on the Penryn campus, which is well lit at night for students and as such are likely to have higher lux values in the study, comparing them to nests which are off-campus, in remote cliffside locations in the Falmouth area. Comparison of the night-time activity of these birds could further elucidate this prominent field, which should be perceived as large a threat to global ecosystem functionality as any other, and be at the forefront of everyone's minds when considering conservation. Additionally, the recording of both parents may provide the opportunity to observe intrasexual differences, with a potential link to lux values.

The herring gull was selected for a few reasons: as a marine bird, it depends on its ability to orientate itself by light more than birds that occupy more terrestrial niches, due to the necessity for them to be able to traverse featureless oceans illuminated only by moonlight. Thus it has been theorised that these birds orientate themselves by a combination of visual and geomagnetic cues (Spiecker et al., 2021). The visual aspect of which has been exploited successfully in the past as a means of hunting (Montevecchi, W. A., 2006). As such there could be a possibility that seagulls are quantifiably affected by the presence of even street lighting, with the potential to affect nesting behaviour, with this being supplemented by the findings of past studies indicating quantifiable melatonin suppression, increased alertness and affected circadian rhythms in different bird species, this study could be an interesting means to provide supply evidence for similar patterns in behaviour in the species. This is a growing concern considering that the European herring gull is an example of an animal that is establishing itself increasingly in urban environments (Goumas et al., 2019), while the overall population is on a downtrend (Eaton et.al., 2015) implying that proportionally more individuals will be exposed to increasing levels of ALAN.

Therefore, I believe that when observing the gulls, the overall trend will be that gulls will be more active in the nests that are more subjected to ALAN, meaning the seagulls on the campus will be more likely to move around more frequently in proportion to other behaviours, and as such may display behaviours like leaving the nests more often, due to the disruptive effect light that the light could have on the gulls. It is also possible, that a pattern similar to (Yorzinski et al., 2015) will emerge, where the parents may become more vigilant due to their restless state, and as such could perform more vocalizations with the potential to even engage in aggressive behaviour toward nearby birds or even their partners. If there is a significant difference between nest scrape light values on and off-campus, with these behaviours being observed in said nests, It would provide proof as to why further research into this field would be encouraged and as such should be conducted.

Methods

The study aimed to identify differences in behaviours exhibited by mother and father herring gulls when compared to areas with higher light values(measured in Lx) with lower ones. 27 nest scrapes containing eggs or already hatched chicks were identified across Falmouth and Penryn and footage recording camera traps and lux meters were placed with a direct view of these nests and their immediate area. The camera traps were triggered by motion, upon which they would record 20.5 or 60.5 seconds of footage and record the temperature, date, and time with the footage over 2 weeks, between the 25th of May and the 9th of June 2021. The light level meters on the other hand recorded light data in 15-minute intervals, not being triggered by motion and therefore the lux values for the recordings were selected by choosing the nearest interval in which lux was recorded to the time when the nest footage was captured.

Of these 27 nest scrapes, 6 were selected for this study, based on factors such as identifiability of the mother and father gull, visibility of nests, and general clarity of the footage. 3 of these 6 nests, were labelled as the ‘low’ light level nests, as these were located in areas distanced from artificial light, such as cliffsides, and as such acted as a control group. The other 3 nests were all located on the Penryn campus, which is lit at night, exposing the nests to this artificial light, therefore these acted as the ‘light’ group.

Footage between 10 PM and 3 AM each night during the nesting period over which the cameras recorded was utilized for each nest, as this time period was well after sunset and before sunrise in the dates within which the footage and light values were captured. Resulting in a total number of 242 motion-triggered videos, that recorded the dates, time, as well as other parameters such as temperature as well as whether it was or was not raining in the footage. For each video the behaviours of the mother and father were recorded, with the duration (in seconds) of what behaviour the subject was displaying via the use of the following ethogram:

Behaviour	**Description of behaviour**
Alert	The subject is displaying agitated upright posture while glancing around rapidly, also including alarm vocalisations.
Provision	The subject is regurgitating food for the chicks
Attack	The subject is actively in the process of attacking another animal
Camera	The subject is interacting with the camera directly
Loafing	The subject is sat down, with extremely minimal or no head movement to be observed, also includes subject sleeping
Nest care	The subject is actively positively interacting with the chicks
Moving	The subject is walking/flying
Out of sight	The subject is not in sight of the camera

Figure 1: Ethogram used to record parent behaviour in footage

These behaviours were selected for their ease of distinguishability and broadness, displaying the overall state of mind of the gulls well. Identifiers for these behaviours were inspired by Tinbergen's: The herring gulls world, a compendium of information that provides extremely thorough accounts of nesting behaviours as well as general gull behaviours of the over a 20 year time period in which many different *L. Argentus* breeding colonies had been studied. Providing a perfect observational reference(Tinbergen, 1953).

The sex of the parent was able to be differentiated without the use of visual markers, as while they are relatively subtle, with plumage being near identical to the human eye between males and females throughout all stages of development, sexual dimorphisms remain between the two. Males are often significantly larger, with larger wingspans, body sizes, and beak lengths, resulting in larger head-shapes that are rounder, with a more 'aggressive' look than their female counterparts(Arizaga et al., 2008) (Ingolfsson, 1969). Males also exhibit the sex-exclusive display of 'courtship feeding' where the female is fed as a form of bonding, providing a great identifier between the two(Tinbergen, 1953).

Results

Firstly, to find out if there was a significant difference between light values in on and off-campus nests the average lux values over the 2 week study period were compiled for each of the observed nests in each location and the means compared. A welches t-test was used, which found that there was a statistically significant difference between lux values between nests on and off Campus (Welch's two-sample t-test, $t_{2087.7}$=7.7222, p-value=$1.761e^{-14}$) with the mean lux value around on campus nests being 3.44×10^{-2}, higher than the off-campus lux value of 4.62×10^{-3}.

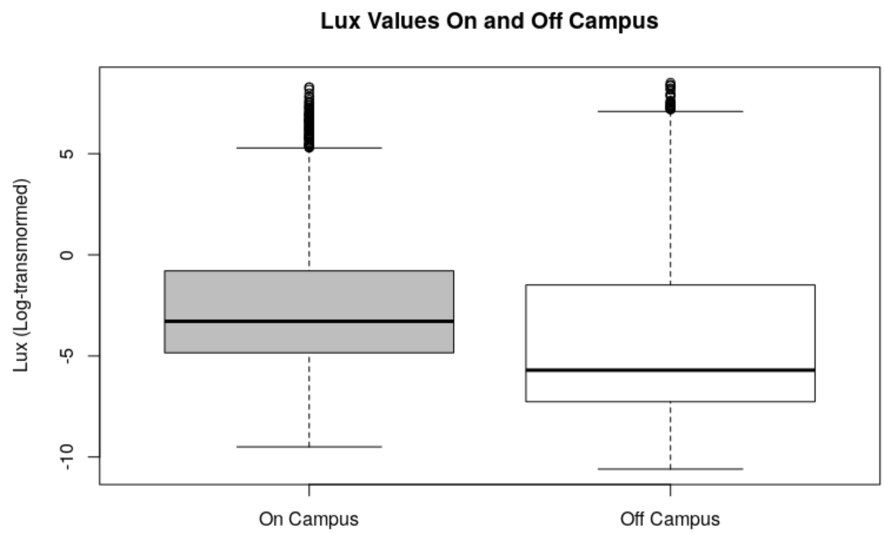

Figure 2: Boxplot displaying the difference between lux values in on and off-campus nests

When analysing the behaviours observed in the parent gulls, the total time in seconds spent engaging in each state was compared also, to see if there was a significant difference in behaviours for each on and off-campus: as behavioural times were not normally distributed neither in mother or father, Kruskal Wallis tests were performed for the mother and father comparing on and off-campus behavioural data each: In the mothers, it was found that there was no significant difference in time spent engaging in each behaviour when comparing on and off-campus nests (H= 5.6084, df=4, p-value= 0.2304)

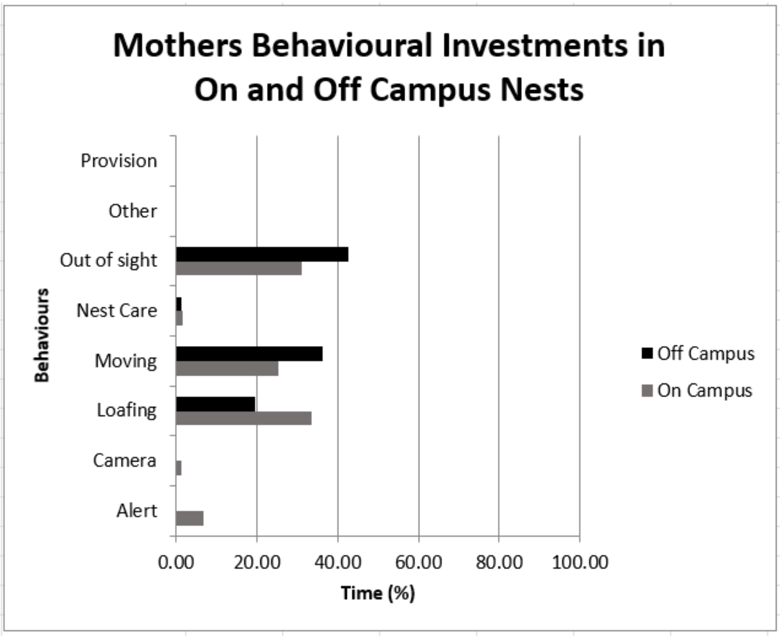

Figure 3: Percentage time mother spent engaging in each behaviour (%)

with the same pattern having been observed with the father gulls (H= 5.3333, df=3, p-value=0.149).

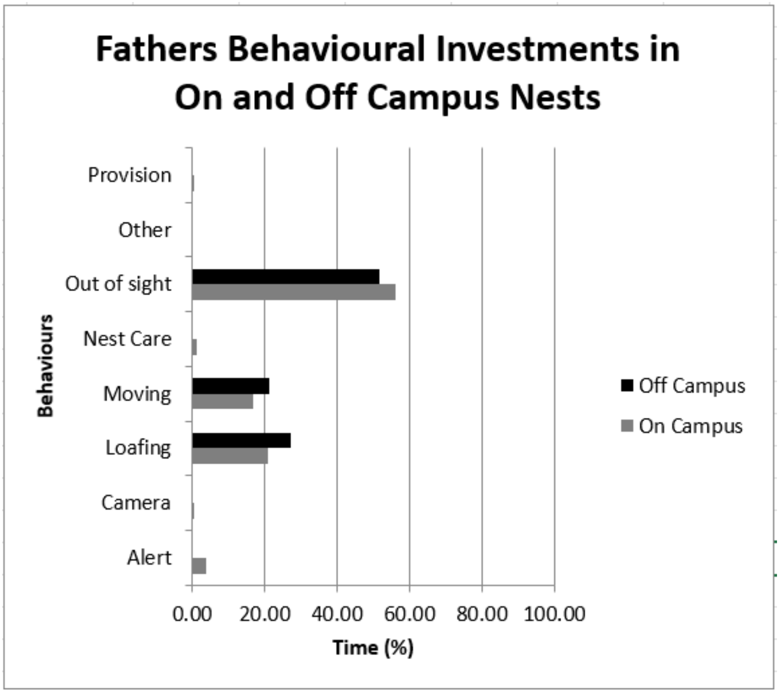

Figure 4: Percentage time (%) Father spend engaging in each behaviour

Although overall differences in behaviour were not found to be statistically significant, there were some differences to be found in what behaviours fathers and mothers engaged in compared to the locations with the higher light values to the ones with the lower ones.

	Mother State Behaviours – Duration(%)							
	Alert	Camera	Loafing	Moving	Nest Care	Out of sight	Other	Provision
On-Campus	6.73	1.47	33.45	25.42	1.70	31.24	0.00	0.00
Off-Campus	0.00	0.00	19.68	36.28	1.28	42.76	0.00	0.00
Difference	-6.73	-1.47	-13.77	10.86	-0.42	11.53	0.00	0.00
	Father State Behaviours – Duration(%)							
	Alert	Camera	Loafing	Moving	Nest Care	Out of sight	Other	Provision
On-Campus	3.98	0.18	20.80	16.93	1.22	56.27	0.00	0.61
Off-Campus	0.00	0.00	27.11	21.16	0.00	51.72	0.00	0.00
Difference	-3.98	-0.18	6.31	4.23	-1.22	-4.55	0.00	-0.61

Figure 5: Percentage breakdown of behaviours observed on and off-campus

Alert: Strikingly both Seagull parents were found to have shown alert postures and displayed behaviours associated with this emotional state only on campus, with this behaviour having been observed almost 7% of the time on average in the mother seagulls on campus when recordings were triggered.

Camera: Another instance in which no behaviour was recorded on-campus compared to off-campus, however difference in time budget spent actively engaging with the camera is slim with the highest value being the mother having engaged with the camera 1.47% of the time.

Loafing and moving: This was one of the most identified behavioural states observed in the footage, however behavioural differences on and off-campus aren't what was predicted, with mothers having been observed loafing 33.45% of the time on campus to the lower 19.68 seen in off-campus nests, with the mothers moving 36.28% of the time, 10% higher than the mothers off-campus, this trend was also observed in father with 4% more movement overall but the time spent loafing was similar both on and off-campus.

Nest care and provision: Nest care was observed both in on and off-campus nests a very low amount, with no parent in on or off-campus nests spending more than 2% of their time in the footage actively interacting with their chicks. And in the case of provision, it wasn't recorded at all over the study period by both parents on and off-campus.

Out of sight: In many of the videos, either one or both parents were out of sight, which means that often it was likely the chicks that triggered the camera traps, parents moving then leaving the shot or another unknown form of movement.

The time spent engaging in different states wasn't very different among each gull sex in nests on and off-campus, and as such the effect of light couldn't reliably be observed to have correlated with different behavioural patterns observed in the gulls. Differences in behaviour between parents were observed, however. With fathers seemingly attending the nests for a lower percentage time than mothers.

Discussion

Lux values were found to have been statistically different from on-campus nests compared to off-campus ones, with them being markedly higher, proving that the form of ALAN on campus is able to reach the nests and make contact with the gulls and the developing chicks. However, when comparing the percentage of time that the seagulls spent engaging in behaviours defined by the ethogram, the study found no real significant difference in the activities that both the mother and father were found to have engaged in when rearing the chicks.

When observing the footage there were certain aspects that could have impacted the results found were there a relationship between the explanatory variable and behaviours observed. One thing, in particular, was the particularly high value when it came to the behaviour "alert" on on-campus nests. A reason for why this behaviour may have been so high – though lux values were higher on campus- was potentially less to do with the light values and more to do with the proximity of the nests observed to other gull nests in general. I saw that the "alert" posture was assumed often and vocalisations were very common in 2 of the on-campus nests observed, attacks themselves did not occur but gulls did appear very wary of the animals in their surroundings and the surroundings of their chicks, therefore this congregation of individuals could be an explanation for observed behaviour. This wariness could have also explained the fact that the camera was interacted with only in on-campus nests and not on-campus ones, as new additions near the nest scrape may have been treated with more caution, a strange-looking object like the motion camera fulfil these conditions.

Another common observation that could have also led to a potential skew in the data was the "out of sight" observation. This observation typically came hand in hand with the 'moving' observation, where parents would often be walking around the nest scrape, but then walk out of sight of the camera for either the rest of the footage or spend most of the time when the camera was recording out of view of the lens before re-entering the shot, this caused many of the seconds in the recordings to be listed as 'out of sight when it was obvious that the gull was just out of shot, though, as there was no way of confirming the behaviour in which the gull would be engaging in just out of view, the data implies it wasn't near the nest. This could help explain why the father was "out of sight" so much more than the mother in both tests groups. This leads me onto the unusually high "out of sight" values that were recorded for the father seagull, in both on and off-campus nests, being by the percentage of time spent much higher than that of the mother gull, providing a hypothesis in the interest of intersexual differences between mother and father that could be explored when exploring the idea of another study while using this explanatory variable.

As the findings of this study were found to be insignificant, were the study to be taken further, there are various parameters that should be addressed should it be reproduced. Perhaps the most obvious one is the sample size of the nests for which data was to be observed. Only 6 nests were observed despite footage for 27 being available due to a variety of factors: Firstly, around 10 nests were not useable due to multiple factors. Condensation on/ fogging of the camera lens was common, and external elements such as obstruction by the growth or movement of flora also blocked vision in a few cases. Therefore it would be advisable to set up nest cameras accounting for this, as revisiting nests to move them manually would be a poor idea considering human activity has been observed to affect nesting behaviour negatively in birds(Strasser and Heath, 2013). The knocking over of the camera trap itself was also observed in 2 cases, once by passing sheep and another by a curious seagull parent, with these cameras no longer being able to record useable footage. Therefore bolting the camera traps down or otherwise fixing them in place could provide a simple solution to this problem. Though the Penryn campus has a significantly higher level of ALAN than the off-campus nests, it is likely far lower than city areas, which can have light levels over 20x higher by measurement(Kyba et al., 2017) than most rural areas in first world countries such as the UK. Therefore including such nests within the sample size could give an even better indication as to how the birds respond to this factor.

Though chick behaviour data was also gathered in preparation for this study, it was not reliable and therefore discarded, due to the fact that the nests observed contained two chicks each. This was an issue as differentiation between the chicks was often not at all possible, due to there being no visible dimorphism between sex at their age, as well as the poor visibility at night, preventing identification through features such as the speckling of the plumage. Therefore perhaps a means of identification between birds would be advisable, such as a leg band over the observation period, which has been employed with success on herring gulls before (Marion and Shamis, 1977). However, precaution should be taken when considering this step due to the aforementioned factor of human disturbance and the potential for markings to affect social behaviour in the birds(Calvo and Furness, 1992) (Burley et al., 1982) (Johnsen et al., 1997) with rings also being lost (Spear, 1988) (Poulding, 1954), despite this, this measure is still recommended, as it would also further help differentiation between mother and father also(which were not always indistinguishable), to help further increase the accuracy of results.

The results also open themselves up to the prospect of studying the effects of the types of ALAN that humans typically surround themselves with. Most modern street lights use high-pressure sodium bulbs(Rea et al., 2009), however, other common forms of bulbs that are used for outdoor lighting include: metal halide, mercury vapour and Led lights. Experimentation of these different forms of light on the birds could be informative when considering ecologically conscious urban planning. In recent years, LEDs have started replacing light sources, due to their energy efficiency, with 2700-3000k lamps utilising as much energy as common-place 5000k ones. However, research has shown that a simple change such as this can have strong effects on behaviour, especially in invertebrates, which have been observed to have been affected by differing types of streetlighting differently, with LEDs having disoriented them significantly less than the other popular forms (Eisenbeis, G., Eick, K., 2011). As there have been studies on an array of other species across different taxa (Longcore et al., 2018) but with none discussing the effect of these different forms of streetlighting on herring gulls, this question would be worth exploring. Along with different forms of street lighting, the effect of distance of artificial lights from nests should also be explored, which has also been shown to affect animal behaviour (Degen et al., 2016). Therefore tests should potentially take place in nest scrapes with known distances from ALAN for which the exact light specifications of bulbs is known and could be useful for informing decisions when considering new building projects with ecologically conscious lighting fixtures for all species that engage in behaviours affected by ALAN.

While light levels can be quantified with lux, the variable is only one form of measurement of light itself. Simply being a measure for illuminance. Other aspects of light can also be measured are other variables such as colour temperature (K) and B/G:G/R ratio(a measurement that compares the ratio of blue to green to the red light of which colour in light is composed). These other light measurements have been utilised as explanatory variables in the past, expanding the field regarding understanding the exact effects of light on species. Studies have associated the effects of melatonin suppression with blue light in the ranges of 425-560nm (Brainard et al., 2001) with a recent mathematical index that gives a measurement of how the colour spectrum of light can affect the other: the melatonin suppression index (MSI) (Aubé et al., 2013) (Sánchez de Miguel et al., 2019). Melatonin suppression through blue light has been observed through visual pathways, of which examples have been recorded in monkeys (Dacey et al., 2005) , horses (Walsh, 2013) as well as humans (West et al., 2011). The effects of blue light within this range have been observed in birds with similar effects like the aforementioned behaviours of disorientation (Zhao et al ., 2020) (though different wavelengths of light have been observed to have had similar effects (Wiltschko and Wiltschko, 2001) (Evans, 2010) (Wiltschko et al., 1993)) .Behavioural effects of light across the colour spectrum have been observed also in broiler chickens, which spent more time sitting and standing under blue light while spending more time feeding under green light (Sultana et al., 2013), chick activity was also observed to have increased in another experiment under red-light treatment (Prayitno, et al., 1997). These examples in the difference of bird behaviour according to the colour spectrum of light are a good indication that were this experiment to be taken further, interesting results may be observed in general behaviour in response to these differences in the colouration of ALAN, performing this type of study on free-living marine birds like herring gulls in which behaviour was observed, would serve as a good reference when addressing the problem of wildlife disturbance, especially around coastal towns and cities as well the effect of nesting behaviour of across the class in general.

Finally, future work on the topic could involve the physical measurement of melatonin levels in the herring gulls themselves on a regular basis, as it has been utilised as a direct indicator for the effect that ALAN quantifiably has (Moaraf et al., 2020) (De Jong et al., 2016). Measurement of this factor can: 1 strengthen the significance of the potential results of the experiment itself if they were found to be significant and 2: allow for the potential of an ANOVA to be performed with these melatonin levels against other hormones that could be indicative of behaviours observed, such as corticosterone which has been found to indicate stress in animals (Silverin,

1998) (Harvey., 1980). A direct link can therefore be provided between the behaviours observed, such as nest care ability, which has been noted to have been impacted previously by elevated corticosterone levels resulting in the decreased nest-care in mourning doves (Miller et al., 2009) and affecting successful fledgling numbers in great tits (Ouyang et al., 2015) specifically in response to ALAN also. Observing the relationship between melatonin levels mediated by ALAN and corticosterone would provide further evidence for significant differences in behaviour between parents in nests with different levels of lighting, and may even serve to help understand other issues, such as human-animal conflict, which is especially prevalent between humans and seagulls.

This study provided the outline of a scientific method that could find a relationship between light values (lx) and the behaviour of a free-living avian species that has adapted better than many other organisms to an increasingly anthropogenically manipulated global environment, and shows that the few that seemingly adapt well are still not unaffected. While the results, however, were not found to be statistically significant, this study still provides a talking point when considering the omnipresent ecological issue of increasing levels of ALAN that many species must live within our increasingly urbanised world.

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