Artificial light at night causes advanced initiation of dawn song in songbirds in Linköping, Sweden

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It is known that artificial light at night has a role in disrupting many birds’ routines when it comes to timing of dawn song. However, studies show various results on which species that are affected, how much and on what latitude. Birds at northern latitudes is experiencing longer and brighter natural nights during the breeding season as the spring is progressing, compared to birds living in areas more south. The bright nights might affect how the birds respond to the artificial light at night. This study’s aim was to investigate how different species of songbirds in Linköping (58°N), Sweden, time their dawn song during breeding season, depending on presence or absence of artificial light at night coming from street lamps. The results show that early singing species are more affected than late singing species. The common blackbird for example, advanced its song because of artificial light, up to over an hour on average. Late singing birds was also affected by the urban lights, though not as strongly as the early singing species. Also shown was that the temperature and the amount of cloudiness, did not affect the difference in timing of dawn song between the locations. Future studies should focus on collecting data from more northern latitudes. The effect the advanced timing of dawn song, both regarding the birds on an individual scale and also regarding the ecosystems in total, should also be investigated further.

Urbanization, artificial light at night, dawn song, common blackbird, European robin, great tit, blue tit, chaffinch, wren
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1. Abstract

It is known that artificial light at night has a role in disrupting many birds’ routines when it comes to timing of dawn song. However, studies show various results on which species that are affected, how much and on what latitude. Birds at northern latitudes is experiencing longer and brighter natural nights during the breeding season as the spring is progressing, compared to birds living in areas more south. The bright nights might affect how the birds respond to the artificial light at night. This study's aim was to investigate how different species of songbirds in Linköping (58°N), Sweden, time their dawn song during breeding season, depending on presence or absence of artificial light at night coming from street lamps. The results show that early singing species are more affected than late singing species. The common blackbird for example, advanced its song because of artificial light, up to over an hour on average. Late singing birds was also affected by the urban lights, though not as strongly as the early singing species. Also shown was that the temperature and the amount of cloudiness, did not affect the difference in timing of dawn song between the locations. Future studies should focus on collecting data from more northern latitudes. The effect the advanced timing of dawn song, both regarding the birds on an individual scale and also regarding the ecosystems in total, should also be investigated further.
2. Introduction

Urbanization and the expansion of the network of roads results in habitat loss, fragmentation and isolation (Ceballos et al., 2015). The loss of habitat leads to reduced population sizes among the resident species, and therefore also the species’ persistence against changes in their environment. Less habitat also leads to reduction of the diversity among populations in the affected areas and the balance between trophic levels in the ecosystems is disrupted. Reduction of nutrient retention and movements in metapopulations is other effects of habitat loss (Haddad et al., 2015). The fragmentation isolates populations and the environmental characteristics in the fragments left untouched is permanently changed, partly because of the larger proportion of habitat edges that arises (Lindenmayer and Fischer, 2006). Therefore, urbanization threatens several taxa, such as amphibians (Hamer and McDonnell 2008), insects, plants, mammals and birds (Haddad et al., 2015). Contributing factors that affects urban habitats, and reduces population sizes and biodiversity, apart from fragmentation is the presence of artificial light, noise and chemicals (Gaston et al., 2012).

Artificial light at night is often referred to as light pollution and is a well-known factor to cause behavioral changes in birds. When studying the effects of habitat variations on biodiversity, birds are considered being a good indicator since they are sensitive to environmental changes (Xi et al., 2017), changes such as artificial light at night. The daily routine is important for the birds’ survival and reproduction, and the timing of behavior plays a big role in many physiological and behavioral processes (Aschoff, 1984). The increase in daylength is for instance an initiation factor for growth of reproductive organs in birds (Dawson et al., 2001). Birds living in light polluted habitats in urban areas can experience changes in their behavior, due to having their daily and seasonal routines altered by the variation of light levels during a 24-hour day (Davidson and Menaker, 2003). Artificial light at night does not only affect birds living in urban habitats. It can disorientate nocturnally migrating birds (Wiltshko, 1993) and cause problems such as collisions with illuminated windows and buildings (Evans-Ogden, 2002; Parkins et al., 2015). The selection of resting places during migration might also be influenced by bright light sources which could affect foraging and food resource availability (McLaren, 2018).

It is suggested that songbirds might pick up small changes in light intensity during the 24-hour of the day to be able to maintain the daily routines of their behavior (Steiger et al., 2013). It also appears to differ between diurnal birds living in habitats at different latitudes. Birds living
close to the Arctic Circle shows a more variable timing of activity than the same species of birds living in temperate regions (Daan and Aschoff, 1975; Pohl and West, 1976). Some birds, such as migratory sandpipers that breed in arctic habitats, show flexibility in their daily routines and behavior because of changes in natural lighting during spring and summer (Lesku et al., 2012; Steiger et al., 2013). Other species of birds seem to show less plasticity in their behavior and keep their 24-hour routines, for instance species of songbirds, such as Lapland longspurs (Calcarius lapponicus L.; Ashley et al., 2013; Steiger et al., 2013), willow warblers (Phylloscopus trochilus L.; Brown, 1963; Silverin et al., 2009) and breeding songbirds in subarctic areas (Daan and Aschoff, 1975; Holmes and Dirks, 1978; King, 1986; Pohl and West, 1976). These species might be more sensitive to changes in the daily routine and therefore, they will be more affected by the cost of being active for long days, for instance being more sensitive to lack of sleep (Kavanau, 1998; Tononi and Cirelli, 2014). Birds living at northern latitudes experience a different change in natural light over the year than birds living at latitudes closer to the equator. The winter is characterized by short, bright days and long, dark nights and the summer with almost continuous daylight. The contrast between night and day in spring and summer at the northern latitudes is vague. Thus, birds and other animals living in these areas have different ways to pick up the light cues to time behavior compared to animals living in more temperate regions (Stokkan et al., 1986; van Oort, 2005).

It is important to investigate and compare the different routines in birds living at different latitudes to understand how they cope with different exposures of artificial light as a consequence of human activity and urbanization. It is particularly important since the use of artificial light has been increasing world-wide the last decades (Falchi et al., 2016). The growing area affected by artificial light makes the contrast between day and night in these areas even more vague than in areas with only natural night lighting. The artificial light in some areas is even brighter than nights during full moon (Gaston, 2014).

Songbirds singing at dawn is an example of a group of birds being affected by light conditions and therefore artificial light at night. Male birds use singing to mark their territory, for social interaction with nearby birds, to attract or defend females or to encourage reproductive development (Staicer et al., 1996). It has been shown that the time of initiation of dawn singing is earlier during cloud free nights (Bruni et al., 2014; York et al., 2014) and that it is delayed on cloudy nights (Bruni et al., 2014; Da Silva et al., 2014). Several species of songbirds living in light-polluted areas has shown to have their onset of dawn singing earlier
relative to sunrise than birds living in naturally lighted areas (Da Silva et al., 2014; Kempenaers et al., 2010; Miller, 2006; Nordt and Klenke, 2013). The timing of onset of dawn singing can have consequences for the reproductive success for the individuals (Kempenaers et al., 2010). Different species of birds have different niches in the timing of dawn song and is singing earlier or later at dawn (Thomas et al., 2002). The onset of dawn singing is coupled with higher light intensities during the break of the day (Allard, 1930; Hutchinson, 2002; Leopold and Eynon, 1961). The thresholds of light intensity for birds initiating song earlier in the mornings relative to sunrise seem to be lower than for birds singing later in the morning (Thomas et al., 2002). Singing earlier in the mornings may also be beneficial since the amount of birds singing that time of the day is smaller, and the competition in finding a partner might be lower. However, the cost of singing earlier might be loss of sleep and resting time and less time searching for food.

In this study, the timing of onset of dawn singing during breeding season was compared between two different kind of locations, locations affected by artificial light at night and locations only affected by natural night lighting. Audio recordings of a selection of six common species of songbirds in the chosen area were collected during a four-week period during breeding season. The six study areas were chosen close to the city of Linköping, three urban forests illuminated by street lamps and three forests with only natural light. The aim was to investigate how different species of songbirds in Linköping (58°N), Sweden, time their dawn song during breeding season, depending on presence or absence of artificial light at night coming from street lamps. The results can be used to compare with results from studies made at different latitudes, and help to get a more complete picture of how birds timing of dawn song at northern latitudes is affected by artificial light at night.
3. Materials & methods

Recordings of bird song was collected during a four-week period during breeding season in spring time with two equivalent recorders (Olympus VN-741PC and Olympus WS-852). Recordings was initiated 4 hours before local sunrise and ended 1.5 hours post local sunrise. The onset of dawn song for each species was noted when its strophes were repeated at least three times in five minutes. Temperature (°C), the presence of rain (Yes/No) and cloudiness (%) at the time of sunrise were also noted. These factors and the timing for local sunrise were taken from open data of observed weather conditions from Sweden Meteorological and Hydrological Institute (SMHI, 2018).

3.1. Locations

Six different locations were chosen as study areas during the project, three with natural night lighting conditions (later referred to as naturally lighted forests, NLF) and three urban forests under influence of artificial light from street lamps (later referred to as artificially lighted forests, ALF). The study areas were chosen because of their similar environmental characteristics with only the presence or absence of artificial light making them different. They were under little influence, and at similar levels, of noise pollution and other anthropogenic factors that could affect the routines of the birds and thereby timing of dawn song. Each study area was divided in several sub-sites, located 200-300 m from each other. Every new day of recording the position of recording equipment was rotated between the subsites inside each study area. Dividing the locations in several subsites instead of using only six study areas preventing the risk of recording the same individuals singing. The division results in a wider range of individuals in the populations and a more general perspective of urban habitats in the city of Linköping.

3.2. Studied species

The studied species was the European robin (Erithacus rubecula), the common blackbird (Turdus merula), the great tit (Parus major), the blue tit (Cyanistes caeruleus), the common chaffinch (Fringilla coelebs) and the wren (Troglodytes troglodytes). Generally, among the studied species the robin and the blackbird are usually singing earlier at dawn relative to sunrise, whilst wrens, blue tits, great tits and the chaffinches are species that usually sing later at dawn (RSPB, 2018).
3.3. Statistical analysis

The prime comparison between the species in the study areas was made comparing the timing of dawn song, relative to sunrise, for the participating species. Independent sample t-tests were used since the majority of the data set were normally distributed. The data that was not normally distributed was used as if they were, since bigger samples in the data sets probably would have shown normally distributed data. The t-test is also stable to small changes if the data is not normally distributed. A linear regression was used to examine if the temperature and/or cloudiness was factors affecting the timing of dawn singing. Rain was only present during one sunrise, therefore, no statistical tests were performed to investigate if presence of rain had an influence of the timing of dawn song.

4. Results

Among the studied species, the timing of dawn song was significantly earlier in the ALF compared to the NLF for the blackbird ($t_{17.79}=4.13, P=0.00$), the robin ($t_{18.51}=2.52, P=0.02$) and the blue tit ($t_{26.98}=2.59, P=0.02$). The results also indicate that the great tit initiate dawn song earlier in the ALF compared to the NLF ($t_{31}=1.88, P=0.07$). No significant difference was found for the chaffinch ($t_{32}=-0.19, P=0.85$) and the wren ($t_{26}=-0.14, P=0.89$) (Fig. 1).
Figure 1. The onset of dawn song relative to sunrise for each species. First row: The common blackbird and the European robin. Second row: The blue tit and the great tit. Third row: The chaffinch and the wren. The regression lines (solid for NLF and broken lines for ALF) shows how their song routines progressed throughout the studied period.

All species but the wren were singing earlier in the ALF compared to the NLF, though the difference for all species was not significant. The average time difference between the NLF and ALF was highest for the common blackbird which started 62 minutes earlier in the ALF compared to the NLF. The second and third highest difference were shown for the
European robin and the blue tit, which sang 47 and 26 minutes earlier, respectively. The great tit and the chaffinch sang 22 and 2 minutes earlier respectively. As for the wren, dawn song was initiated 2 minutes later relative to sunrise in the ALF compared to the NLF.

Neither the temperature or cloudiness had an influence on the difference in timing of dawn song, for any of the studies species, between the two different locations (Table 1). As spring progressed, and the temperature rised, almost all species sang earlier. Further, when there was a cloudy day, the birds tended to sing later in the morning. However, this applies to both ALF and NLF, and did not affect the difference in timing between them.

Table 1. Statistics from linear regression for each species testing the cloudiness and temperatures influence on the difference in timing of dawn song between the NLF and ALF. Df=17.

<table>
<thead>
<tr>
<th>Species</th>
<th>Variable</th>
<th>Coefficient</th>
<th>SE</th>
<th>t</th>
<th>p-value</th>
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<td>Common blackbird</td>
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<td>0.60</td>
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<td>-0.43</td>
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</tr>
<tr>
<td>European robin</td>
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<td>0.56</td>
<td>1.31</td>
<td>0.21</td>
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<tr>
<td></td>
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<td>4.27</td>
<td>-0.07</td>
<td>0.94</td>
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<tr>
<td>Blue tit</td>
<td>Cloudiness</td>
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<td>1.78</td>
<td>1.42</td>
<td>0.17</td>
</tr>
<tr>
<td>Great tit</td>
<td>Cloudiness</td>
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<td>0.29</td>
<td>0.79</td>
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</tr>
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<td>Temperature</td>
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<td>2.11</td>
<td>1.02</td>
<td>0.32</td>
</tr>
<tr>
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<td>0.20</td>
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<tr>
<td>Wren</td>
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<tr>
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<td>Temperature</td>
<td>2.41</td>
<td>2.19</td>
<td>1.10</td>
<td>0.29</td>
</tr>
</tbody>
</table>
5. Discussion

The results show that three of the studied species (the common blackbird, the European robin and the blue tit) living in ALF initiated dawn song significantly earlier relative to sunrise, compared to NLF. The common blackbird and the European robin also showed the largest average difference in minutes between the ALF and NLF compared to the other four species. Thus, the results indicate that early singing species are more affected by artificial light than late singing birds. The same conclusion is also suggested by Thomas et al. (2002) that studied early singing birds on a northern temperate latitude (around 51°N).

However, Da Silva and Kempenaers (2017) suggests the opposite in their study made at a higher latitude (65°N). Their study shows a significant difference between ALF and NLF as an effect of artificial light at night for the late singing birds, the blue tit, the great tit and the chaffinch. For early singers, the common blackbird and the European robin, however, there were no significant difference on the northern latitude. In the present study, the late singing species (the chaffinch and the wren) were not affected in the same way as in Da Silva and Kempenaers (2017). Even though the difference between 65th and 58th (where the present study is performed) latitude is small, it seems to be of significance in this matter. Mechanisms affecting this difference in result between the different northern latitudes, might be for instance the amount of natural light presence or physiological variations between the late and the early singers. The species singing at different times, for example the common blackbird and the great tit, might react differently to the amount of light.

The results from the present study strongly point towards artificial light as responsible for the birds’ change of behavior. But other factors, such as noise and road-related pollution, should not be forgotten when looking at the reasons for the change in birds’ song routines. Birds in Bogota, Colombia, showed no response to artificial light, but to the anthropogenic noise that comes with living in urban areas (Adriana et al., 2016). In contrary, Da Silva et al. (2014) concluded that the artificial light, and not traffic noise, is the main factor affecting European birds’ timing of dawn song. Furthermore, European birds’ reaction to experimental, artificial light in rural areas previously not affected by artificial light was tested. The birds did not show a difference in timing of dawn song, regardless of wavelength on the light that was used (Da Silva et al., 2017). However, the scientists suggest that the amount of experimental light was too small to give the same effect as lights from urban areas does. Since the disturbance of noise from roads in the present study was small, the influence of light pollution from street lamps are probably the reason for
the birds’ change in song routine in this study. Regardless of for what reason the birds start singing earlier in the mornings in urban areas, it is interesting to look into what effect the behavioral changes have on the birds, both physiologically and ecologically.

The great tit has shown to be able to adapt quite well to different light levels at night. They can change their daily routines, and then be able to adjust their behavior again if the light levels change back (Spoelstra et al., 2018). The plasticity in changes in behavior suggests that there are no long-term effects in behavior caused by artificial light at night, at least not for the great tit. However, looking at a physiological perspective, great tits living in lighted areas are more active at night and it affects the balance in their immune system (Ouyang et al., 2017). Common blackbirds living in light-polluted regions has been shown to have more unstable routines and are active more hours per day than common blackbirds living in habitats with natural lighting (Turdus merula L.; Dominoni et al., 2013a; Dominoni. and Partecke, 2015). Physiological studies made on the common blackbird has shown that birds living in urban forests not only sing earlier at dawn, but also extends their foraging to later in the evening. Even though they spent more time searching for food, they did not gain extra benefits from it, such as more body fat (Russ et al., 2015). Common blackbirds living in urban forests has a lower amount of melatonin in winter. The same applies to blackbirds living in naturally lighted forests in springtime (Dominoni et al., 2013b). The low amount of the hormone outside of breeding season, might start physiological processes that is not supposed to start until later in the season. Melatonin helps regulate seasonal processes like timing of hatching and migration, and is also important for functions in the immune system (Bentley, 2001). The hormonal change might for instance affect reproductive behavior. Other studies confirm this phenomenon, the gonadal growth and reproductive hormone levels in common blackbirds peaked earlier when living under influence of artificial light (Deviche and Davies, 2013). This could cause the breeding to be initiated when the temperature and the amount of food is low, which in turn might affect hatching and survival of offsprings. Further, a lab study shows that artificial light caused lower testosterone levels, failure in developing gonads and interrupted molt in male common blackbirds (Dominoni et al., 2013c).

5.1. Future research

This study suggests that early singing birds at the 58th latitude are more affected by artificial light coming from street lamps, than bird species singing later at dawn. Other studies at a higher latitude suggests the
opposite. It would be interesting to see where the break point for this result is geographically and perform similar studies and collect data on different northern latitudes. There are many questions left unanswered that future studies should focus on answering. Why is there a difference in between the northern latitudes and what is the effect of the advanced timing of dawn song? Furthermore, studies should continue focusing on what the effects are on birds advancing their dawn song: is the increased number of active hours per day a cost in terms of for instance body condition, success in finding a partner, finding food and does it affect the numbers of surviving hatchlings etc.? Do early singing species react differently to the artificial light than the late singing birds? If the artificial light is disrupting the birds’ reproductive behavior, it might affect the fitness of the involved species. Lower reproductive success for the species might lead to a decline in the populations, and in turn have an effect on a bigger scale between the trophic levels in the ecosystems.

5.2. Social & ethical aspects

According to the Swedish law of Animal Welfare, 19a § (1988:534), approval from the regional board for ethical animal testing is needed if animal tests is made on the taxonomic classes mammalia, aves, reptiles, amphibians, fishes, cyclostomes and squids and octopuses. However, there is an exception for studies made on free living animals. In this study, no birds were caught or in any other way handled by humans. The recordings of bird song were made in absence of humans, therefore this study was in no need of ethical trials (Djurförsök, 2018).

The result from this study might strengthen the evidence that city expansion planning and other activities, that increase the amount of artificial light at night is done, needs to be well planned. Well planned urbanization might help to decrease the risk of declining survival of the resident species.

6. Acknowledgements

I thank my tutor Karl-Olof Bergman for supporting me when structuring this study from scratch and giving me input on my work throughout the period. I also thank Lars Westerberg for assistance with statistical analysis, Kjell Carlsson for help with analyzing the recordings and my two opponents Madeleine Mickelsson and Tove Brolin for giving me constructive criticism on my work.
7. References


