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The Influence of Environmental Cues and Anthropogenic Activity on Roost Departure Times in the Northwestern Crow (*Corvus caurinus*)

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ABSTRACT.—While communal roosting is fairly common in animals, the costs, benefits, and proximal factors influencing this behavior are poorly understood. Moreover, many species with communal roosting that have been studied to date have a strong association with humans; however, there have been few formal tests of how human activity might influence roosting behaviors. We studied roosting activity in the Northwestern Crow (*Corvus caurinus*) within a highly urbanized setting. Specifically, we were interested in whether variation in anthropogenic noise influenced departure times of crows from their roosts. We tested this by comparing roosting activity between days that differed in the extent and timing of automobile noise. We also tested whether other environmental factors (i.e., sunrise time and precipitation) might also influence roost departure times. We found that morning departure was later on rainy mornings and was largely correlated with sunrise time, consistent with previous studies of other species. We also found departure times accelerated over the season, to the point where the first groups of crows were waking well before any perceptible light (i.e., prior to astronomical dawn). We found no evidence that variation in anthropogenic activity, particularly from automobile noise, had any effect on crows' roost departure time. These results suggest that, although many corvids are closely associated with urbanized landscapes, these crows appear to maintain natural circadian rhythms at least for roosting departures, likely by means of detecting cues from natural light and other environmental factors. *Received 21 November 2014. Accepted 25 April 2015.*

Key words: anthropogenic noise, Northwestern Crow, roosting behavior, seasonality, weather.

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INTRODUCTION

Although communal roosting is fairly common in animals, particularly among birds, mammals and insects, the costs and benefits of this behavior are poorly understood (Kunz 1982, Eiserer 1984, Finkbeiner et al. 2012). At least in birds, there are a number of ultimate explanations for why roosting may be beneficial, including (but not limited to): thermoregulatory benefits, by locally increasing the density of individuals which can reduce major heat losses (Walsberg 1990, du Plessis et al. 1994, McKechnie et al. 2006); a decreased predation risk, where very large flocks of birds may deter predators that avoid confronting high numbers of individuals (Eiserer 1984); and communication opportunities, where communal roosts may act as information centres where individuals can share information about the location of valuable resources (Caccamise and Morrison 1986, Bijleveld et al. 2010). Communal roosting behavior also has several disadvantages, including the cost of daily movement to and from the roosting site, the increase in intraspecific competition, and disease/parasite transmission because of a locally high density of individuals (Eiserer 1984).

It is also unclear the proximate cues that birds use to determine when to congregate and depart from the roost. A number of studies have demonstrated that light intensity, cloud cover, precipitation, and sunrise/sunset times are important environmental cues for roosting times (e.g., Counsilman 1974, Swingland 1976, Gill and Dow 1985, Mahabal and Vaidya 1989, Perlmutter 1992). However, while many species studied to date have a close association with humans, to our knowledge there have not been many formal tests of how human behavior might influence roosting behaviors. For example, the starling roosts studied by Davis (1955) were found in two towers of a hospital in Baltimore, Maryland. Davis (1955) found strong seasonal variation in the timing of roosting behavior; however, it was not clear how anthropogenic factors, such as hospital activity, might be influencing roosting on a finer scale. For instance, at least in cities, there is a large amount of noise produced by automobile traffic, which can be relatively loud (e.g., 65–75 dBA along highways; Wakefield Acoustics 2004) and can vary strongly within a day, depending on the time of rush-hour, and also weekly, with weekends having less overall traffic (Fig. 1). We were interested in knowing whether such large differences in anthropogenic noise might influence the waking time of roosting birds, possibly disrupting other rhythms generated by natural factors. For instance, in other avian systems, anthropogenic traffic noise has been shown to strongly influence singing patterns (Nordt and Klenke 2013), habitat use (McClure et al. 2013), and the effects of noise on animals is generally of interest to conservation biologists (McGregor et al. 2013).

We addressed this by studying the roosting behavior of the Northwestern Crow (*Corvus caurinus*) in a large roost within a highly urbanized setting. The Northwestern Crow is a medium-sized corvid that resides along the coast of the Pacific Northwest, with a range that extends from Northwest Washington to Alaska, including coastal islands such as Vancouver Island and the Queen Charlotte Islands (Campbell et al. 1997, Verbeek and Butler 1999). Northwestern Crows are omnivorous generalists, although two types of populations can be distinguished in British Columbia: the insular populations, which are tightly linked to intertidal beaches and mostly prey on marine invertebrates, and the urban populations that have adapted to human settlements. This latter group feeds primarily on terrestrial invertebrates and human refuse from city parks, residential areas, roadsides, farmlands, and garbage landfills (Butler 1974, Campbell et al. 1997). This urban population's close association with humans is particularly important during winter, when natural food sources become scarce (Campbell et al. 1997).

The size and composition of these roosts are not constant. Butler (1980) studied a roost of Northwestern Crows on Mitlenatch Island, B.C., and concluded that the sociality of different age classes varies over the seasons, leading to a variation in the roost's numbers: breeding adults tend to become territorial and leave the roost during the breeding season (from Mar–Apr to Jul), whereas non-breeding adults and yearlings stay grouped. This trend was also observed in a massive urban roost in Burnaby, where numbers vary from about 500 Crows in June to over 30,000 in winter (Verbeek and Butler 1999). In other studies of corvids, evidence suggests that urban roosting and roost sizes have increased in association with humans (Marzluff et al. 1994).

While Northwestern Crows have no reported seasonal migratory behavior, they fly every evening from their foraging grounds to communal roosting sites where they congregate in large flocks of hundreds to tens of thousands of individuals (Butler 1980, Verbeek and Butler 1999). This type of roosting behavior is fairly common amongst corvids (Haase 1963, Swingland 1976, Butler 1980, Møller 1985, Marzluff et al. 1996, Wiles 1998, Verbeek and Butler 1999, Everding and Jones 2006). During the gathering process, local crows flock into small, noisy groups in pre-roosts, from where they fly to the next pre-roost, joined by other small groups, and so on until they reach the final communal roosting site (Verbeek and Butler 1999). The process is reversed every morning, where the roost gradually splits into smaller groups at post-roosts en route to foraging grounds (Verbeek and Butler 1999).

It is not currently known the role that vocal communication plays in directing communal behaviors of Northwestern Crows and how that might be influenced by anthropogenic noise. However, in other corvids vocal communication is assumed to be important in transferring important information amongst members of a roost (Marzluff et al. 1996, Richner and Heeb 1996, Wright et al.

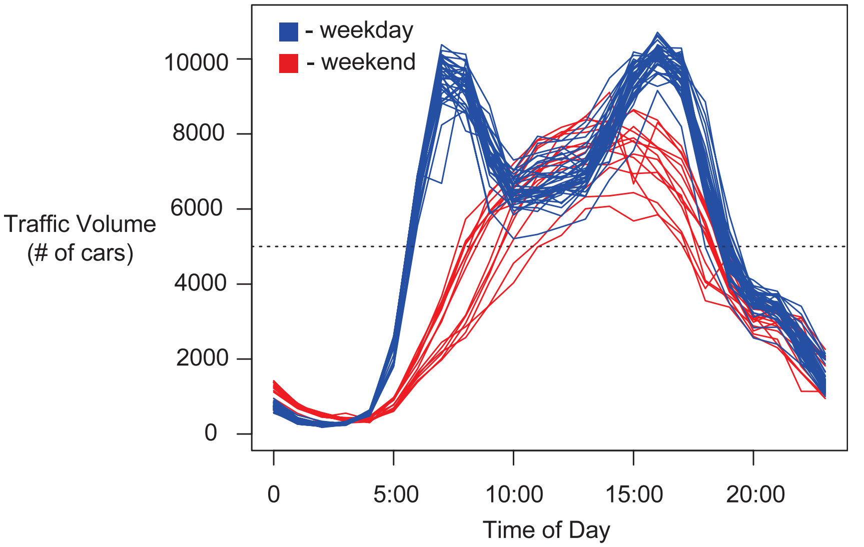

FIG. 1. Traffic data near the crow roost under study between January and April in 2014 (www.th.gov.bc.ca/trafficData/index.html). The lines show hourly roadway volume for north and southbound traffic along Highway 1 in Vancouver, B.C. The colors distinguish weekdays (blue) and weekends (red). Weekends have lower peak traffic, volume increases later in the morning, show more variance between weeks, and display a unimodal pattern of volume compared to weekdays. Note that times are adjusted for daylight savings.

2003). For instance, ravens express conspicuous vocalizations that builds 'to a crescendo' prior to synchronous roost departure in the morning, which are thought to provide cues to birds about food resources (Marzluff et al. 1996).

The aim of this study was to describe the variation in the timing of early morning post-roosting activity by crows over the weeks of the non-breeding season in one of the largest known roosts of Northwestern Crows, near Still Creek in Burnaby, B.C. We were first interested in asking what environmental cues might influence the time of departure of birds from this roost. Specifically, we tested for possible effects of precipitation as well as variation in daylight times. Based on previous research in other systems (e.g., Counsilman 1974), we hypothesized that roost departure would change gradually over the season and that birds would wake later on mornings with precipitation. Next, we were interested in whether birds adjusted their roosting based on two large-scale changes in human behavior: first, we tested for differences between weekdays and weekends, which differ in both the timing and intensity of traffic (Fig. 1) and second, we looked for an effect of roost departure time before and after daylight savings, which results in 1-hr shift in human behavior, most notably during the weekdays. We hypothesized that if crow behavior was strongly influenced by human-produced noise, crows would exhibit later roost departures on weekends versus weekdays.

METHODS

The Northwestern Crow is currently identified as a distinct species but is closely related to the American Crow (Verbeek and Butler 1999). The two species hybridize extensively where they come into contact, an observation that has led some to question the status of the Northwestern Crow as a distinct species (Johnston 1961). In keeping with current taxonomic conventions, we refer to it here as the Northwestern Crow, recognizing that it may be lumped with the American Crow in the future. We monitored morning activity of crows along Still Creek in Burnaby, B.C. between 28 January and 5 April 2014. We attached a sound recorder (Wildlife Acoustics Song Meter SM2, Wildlife Acoustics Inc., Maynard, MA, USA) to a tree nearby the Burnaby Lake Sports Complex West (49° 15′ 10″ N, 122° 58′ 6″′ W) and set it to record every morning for 240–330 min. The start times of the recorder were adjusted periodically to begin recording earlier to encompass the entirety of the morning activity (e.g., recording began at 0500 at the start of the study and at

0300 by the end). The few mornings that do not have recordings (see results) were a function of battery failure and not an absence of crow activity. We used the vocal activity on the recordings as a metric of crow movement throughout the morning. The recording area is a short distance from the main roost and, upon leaving the roost, crows fly into and past this forested park en route to their foraging areas. While it is difficult to follow individual birds, groups of birds would move into the park and then depart. This allowed us to use the vocal activity of birds in the area as coarse scale quantification of the number of individuals moving by the recorder and, subsequently, estimate the timing of the roost departure.

We analyzed the recordings with the Raven sound analysis software (Bioacoustics Research Program 2014) and quantified the timing of the morning activity of crows by using two different variables:

1. The time at which the first group of two or more individuals was heard in the morning, referred to as "first group," and used as a proxy for the beginning of the morning activity.
2. The time at which 50% of the vocalizations of the morning activity were heard, referred to as "peak crow activity," used as a proxy for the average timing of crow activity. To determine peak crow activity, recordings were systematically sub-sampled with minute long sampling units every 5 min on the spectrograms. Within these sampling units, the number of vocalizations was estimated using bins that started with 10 vocalizations, and then from 25 onwards with an addition of 25 vocalizations at each category until the final category of 300+ Crows (i.e., 13 bins). This coarse scale estimate of vocalizations was used to measure the intensity of crow activity. We then calculated the cumulative number of vocalizations over the morning period. For each recording, we then fit a locally weighted regression (LOESS) in R to this cumulative vocalization curve to predict the mid-point of Crow activity, which we defined as the peak Crow activity (i.e., the time at which 50% of the total estimated number of birds had passed the recorder; see Fig. S1 in the Supplementary Material for an example of how this parameter was estimated). It is important to note that while this variable is correlated with relative abundance of crows in the auditory arena, it is not a direct measure of the absolute number of birds. For example, at the extremes, few crows may vocalize many times during a short period of time, whereas many crows may remain silent and may not be detected. Overall, however, we found this metric to be a robust and consistent measure of the number of birds moving through the area.

Sunrise and astronomical dawn (i.e., when the sun is 18° below the horizon) times were drawn from the website www.timeanddate.com (Time and Date AS 2014). We obtained traffic data from the British Columbia Traffic Data Program (Ministry of Transportation and Infrastructure 2014) from along Highway 1 along on the southern side of the Second Narrows Bridge (ID: P-15-2EW-N). This is the closest permanent traffic monitoring station and is <5 km away from the roost, along the highway where the roost is located. We obtained the hourly roadway volume (in numbers of cars) for combined north and southbound traffic for January, February, March, and April 2014. The number of vehicles is strongly correlated with increasing noise, where 10,000 vehicles are perceived as twice as loud as 1,000 vehicles (Wakefield Acoustics 2004). 10 February, a 3-day weekend holiday, showed traffic patterns more consistent to weekends and was treated as such in our analysis.

We could note the presence or absence of rain from listening to the recordings. To test for an effect of 1) rain and 2) weekend versus weekdays on roost departure time, we first used a LOESS smoothing function to describe the gradual daily changes in our behavioral characteristics (first group and peak crow; see results). We then calculated the residuals for each day between these times and the resulting LOESS function. An important caveat is that while the LOESS smoothing controls for seasonal/temporal effects within the series, there may be other factors influencing the patterns we did not test for. We used a Welch two sample *t*-test to compare residuals on days with and without rain as these samples had unequal variances. We used the same residuals to compare weekends and weekdays, although in this case we used a Kruskal-Wallis rank sum test as these samples differed significantly from a normal distribution.

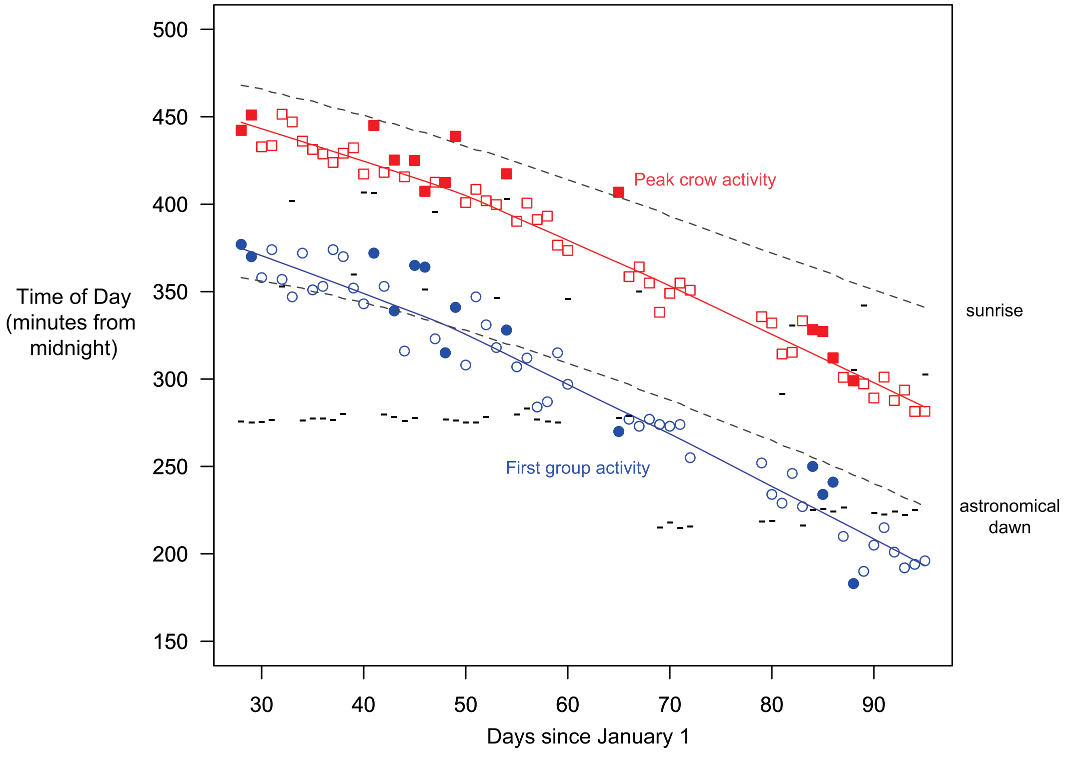

FIG. 2. Variation in roost departure times by Northwestern Crows from January to April. Circles in blue are the times of the first group of crow vocalizations for that day; squares in red show the time of the majority of crow vocalizations (i.e., "peak crow activity"; see methods). The solid lines show the LOESS smoothing function for each group. Sunrise and astronomical dawn times are shown with the dotted lines. Open and filled points distinguish between days with rain versus clear days, respectively. The horizontal black ticks show the start of morning traffic, defined here when traffic exceeds 2,000 cars per hour (see Fig. 1). The 1-hr shift in traffic volume on day 68 corresponds to the start of daylight savings time (i.e., these times are not adjusted, in contrast to Fig. 1).

RESULTS AND DISCUSSION

The departure time of Northwestern Crows in the large, urban roost in southwest British Columbia changed gradually over the study period. This was largely correlated with sunrise time (first group, $r^2 = 0.97$, df = 56, $P < 0.001$; peak crow $r^2 = 0.98$, df = 56, $P < 0.001$), however the departure time occurred increasingly earlier over the season (Fig. 2). By the end of the study, the first group of crows during the mornings were becoming active ~2 hrs prior to sunrise (Fig. 2). For the final 30 days of the study, the first groups of crows were waking well before any perceptible light (i.e., 30 min prior to astronomical dawn; Fig. 2). This early awakening and departure has been observed among various bird taxa, which are inclined to start their vocalizations very early in the darkness and earlier towards the summer solstice, keeping pace with the sunrise (Allard 1930). For instance, Allard (1930) studied the morning vocalizations of multiple species, including Song Sparrows (*Melospiza melodia*) and American Robins (*Turdus migratorius*), and noted that the time of first morning songs deviated from sunrise toward the astronomical dawn as the summer solstice approached. A possible explanation for this phenomenon is the anticipation hypothesis (Leopold and Eynon 1961), which states that birds awaken in the dark without benefit of environmental clues, get ready to leave, and wait for the optimal moment to fly away from their roosting site. This anticipatory behavior is likely triggered by an internal clock, maintained by interacting light accumulated during previous days and endogenous rhythms (Leopold and Eynon 1961, Counsilman 1974), and the earlier waking towards the breeding season likely allows individuals to exploit additional resources throughout the longer days.

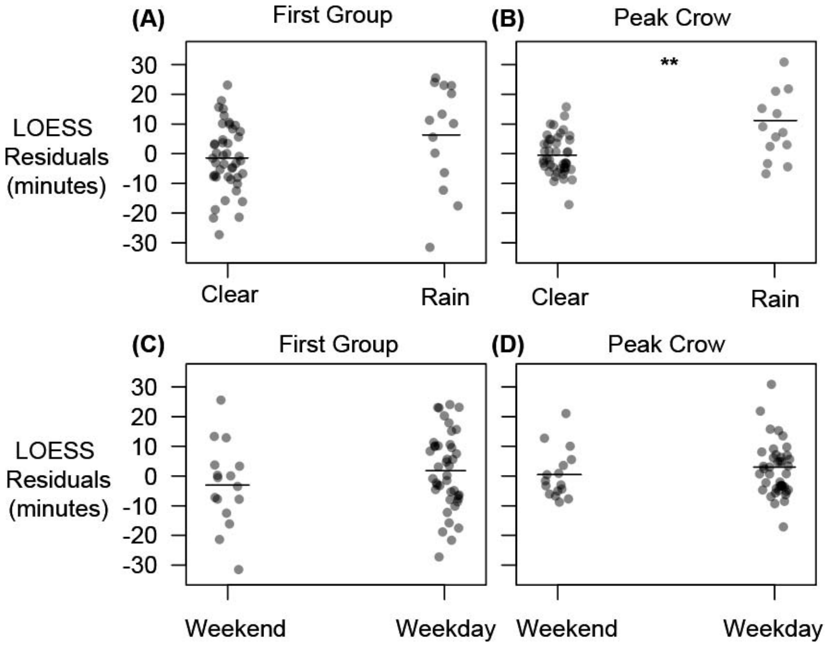

FIG. 3. Comparison of roost departure times on days with and without rain (A–B) and on weekdays versus weekends (C–D). Times are residuals (in mins) compared to the LOESS smoothing functions (shown in Fig. 2).

We found that the majority of birds departed later on rainy mornings (peak crow activity occurred 11.6 min later on rainy versus clear days: $t = -3.1$, df = 15, $P = 0.008$), and there was a similar trend for the first group of birds, although it was not significant ($t = -1.5$, df = 16, $P = 0.14$). These results are generally consistent with a study of Indian Mynas (*Acridotheres tristis*) by Counsilman (1974), who found that mynas departed on average later on rainy and overcast mornings and that their departure was more protracted on these days. It is unclear whether this was because of a direct effect of rain or was an indirect effect of general weather patterns, such as drops in ambient light intensity and temperature that are associated with overcast days (Counsilman 1974, Mahabal and Vaidya 1989). It would be ideal to study additional crow roosts to determine the generality of these observations.

We found no evidence that variation in anthropogenic activity, particularly from automobile noise, has an effect on crows' departure time from roosts. On weekday mornings, traffic activity near the roost begins prior to 0500 and peaks around 0700 (Fig. 1). At the beginning of the study, roost departure time of the first crows occurred after the initial onset of traffic but before the peak of the morning rush hour (i.e., average first group departure for the end of Jan = 0610). However, towards the end of the study, birds were waking earlier than traffic (i.e., the first group departure for the beginning of Apr was 0420, adjusted for daylight savings). Moreover, in contrast to traffic patterns, the crows timing changed gradually throughout the study and showed little correlation with differences in traffic timing (Fig. 3). We also found no difference between weekdays versus weekends for the departure time of the first crows (K.W. $\chi^2 = 1.32$, df = 1, $P = 0.25$) or the majority of individuals (peak crow: K.W. $\chi^2 = 0.88$, df = 1, $P = 0.35$). There was also no observable difference before and after daylight savings, where human behavior shifts notably by 1 hr (day 68 in Fig. 2). To our knowledge, this is the first study to test for an effect of this type of anthropogenic noise on roosting behavior. However, numerous studies have studied the effect of urban landscapes on bird behavior. Most notably, the effect of urban noise and light pollution on bird song has been particularly well studied, suggesting that many species adjust their singing times and spectral characteristics in urbanized environments (Slabbekoorn 2013; Da Silva et al. 2014, 2015).

In conclusion, this observational study of the Northwestern Crows suggests that factors that shape the patterns and timing of communal roosting behaviors are mostly independent of humans, at least in terms of anthropogenic noise. Thus, although many corvids are closely linked to urbanized landscapes, they appear to maintain natural circadian rhythms, likely by means of detecting cues from natural light and other environmental factors. However, human influence and impacts can be measured in various ways and should be considered in more detail in future investigations. In addition, it will be useful to study additional roosts in other locations to confirm the generality of these results. We suggest the analytical method presented here is an excellent system to apply to additional roosts and for studies of behavior across the entire annual cycle.

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