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Effect of environmental factors on the communal roosting behavior of House crow (*Corvus splendens*)

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Abstract

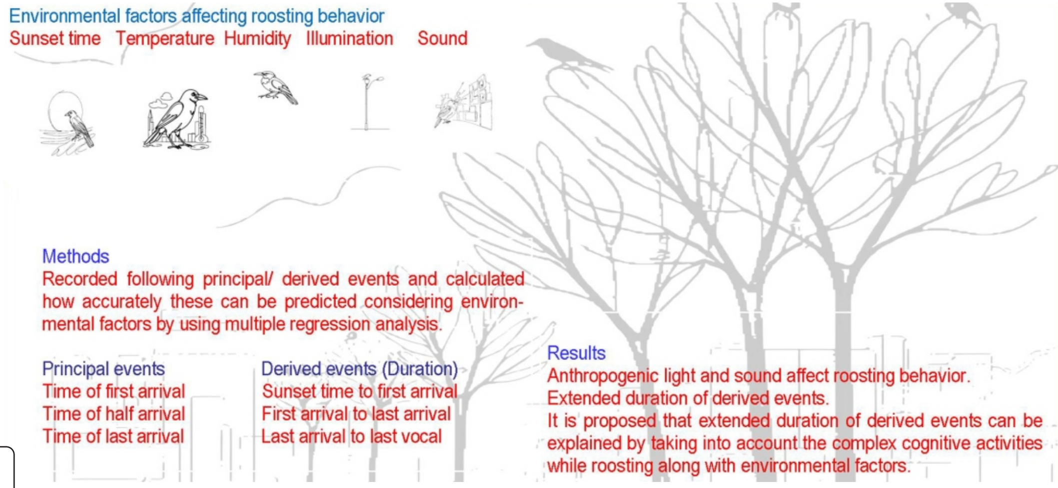
Aim: To observe the effect of environmental factors influenced by the anthropogenic activities on various events of roosting behavior of House crow (*Corvus splendens*) .

Methodology: All Roost sites were located in the vicinity of highly urbanized settlements with ample anthropogenic light and sound. Correlation analysis was carried out to work out how environmental factors affect various roosting events. Multiple regression analysis suggested best fitted model to explain the variability observed in roosting events. Sunset time, temperature, humidity, illumination and sound intensitywere recorded. Four principal events viz., time of first arrival, time of half arrival, time of last arrival and mean time of last vocal were observed. In addition, three derived events viz. duration between sunset time to first arrival, first arrival to last arrival and last vocal were also studied.

Results: It was found that sunset time, temperature, humidity, illumination and sound intensity in part were correlated and predictors for different principle and derived roosting events. Anthropogenic light and sound affected roosting events via altering intensity and duration of light and sound. An extended duration of derived events were observed on comparing our findings with previously available record. It was proposed that in addition to altered abiotic conditions, interplay of various other complex cognitive processes while roosting may be a contributor to these times lapsed.

Interpretation: Environmental factors along with anthropogenic light and sound affect roosting events. Therefore, anthropogenic activities should be managed to avoid adverse consequences on roosting behavior and thus, the survival of birds.

Key words: Anthropogenic light and sound, Environmental factors, House crow, Roosting behavior



Methods
Recorded following principal/ derived events and calculated how accurately these can be predicted considering environmental factors by using multiple regression analysis.

Principal events
Time of first arrival
Time of half arrival
Time of last arrival

Derived events (Duration)
Sunset time to first arrival
First arrival to last arrival
Last arrival to last vocal

Results
Anthropogenic light and sound affect roosting behavior.
Extended duration of derived events.
It is proposed that extended duration of derived events can be explained by taking into account the complex cognitive activities while roosting along with environmental factors.

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Introduction

Communal roosting is characterized by a congregation of individuals of a species for considerable period, especially at night. It is a common phenomenon in birds but also observed in bats, primates and insects. It is sparked by environmental signals and animals return to the same site with the reappearance of these signals (Richner *et al.,* 1996; Finkbeiner *et al.,* 2012). Although communal roosting is fairly common in animals, the costs and benefits of this behavior are poorly understood (Kunz, 1982; Finkbeiner *et al.,* 2012). Previous studies have reported that thermoregulation, decreased predation risk and communal opportunities all facilitated through increased roost density are some proposed benefits for roosting behaviour (McKechnie *et al.,* 2006; Bijleveld *et al.,* 2010). There are some limitations that include the cost of daily movement, increased intraspecific competition and disease/parasite transmission (Eiserer, 1984). House crow is known to form large communal roosts in highly urbanized settings (Saiyad *et al.,* 2017).

Interspecific interactions between Indian house crow and Indian large-billed crow have been observed elsewhere during roosting (Mahesh and Suseela, 2021). Roosting in anthropogenic structures is well characterized in bats also (Betke *et al.,* 2024). Various studies have demonstrated that light intensity, cloud cover, precipitation, wind speed, haziness, sound intensity and sunrise/sunset times are important environmental cues for roosting behavior (Zammuto and Franks, 1981; Mahabal and Vaidya, 1989; Peh, 2002; Kim *et al.,* 2013). However, proximate cues that bird employ to determine when to congregate or depart from the roost are opaque. The impact of anthropogenic activity, especially automobile noise had any effect on crows' roost departure time is not reported in literature (Peh, 2002; Khadraoui and Toews, 2015). It has been reported that ecologically relevant artificial light at night (ALAN) intensities affect crickets' behavioural patterns, lead to decoupling of locomotion and stridulation behaviours at the individual level, and loss of synchronization at the population level (Levy *et al.,* 2021). Roosting behavior of cattle egret was found to be affected by weather condition. Bad weather reduced the number of individuals in the roost, extended the duration and advanced the timing of gathering, and reduced the rate of gathering in the roost (Youcef *et al.,* 2019).

Brandt's myotis (*Myotis brandtii*) favored roost sites in landscape not affected by human disturbance within 5 km radius. It was suggested that roost sites should be protected and considered in land-use planning (Suominen *et al.,* 2023). Various roosting activities of mynas seemed to be governed by endogenous rhythms, influenced by endocrine secretions (Mahabal and Vaidya, 1989). Many bats occupy roosts exclusively at night and are spatially separated from maternity roosts. The roosting time vary both daily and seasonally in relation to the reproductive condition of the bats, prey density, and ambient temperature. During lactation, females return to maternity roosts between foraging bouts, and night roosts are used only briefly and sporadically. Long night roosting periods and short foraging periods are associated with cool nights and low prey density (Anthony *et al.,* 1981). House crows may be regarded as flying apes due to high cognitive abilities (Hunt, 1996). It is an intelligent bird, pilfering food items for future use. It makes tool to fulfil some purposes (Goodwin, 1976; Hunt, 1996; Srivastava *et al.,* 2014). It is thus clear that roosting behavior is largely controlled by environmental factors that may be influenced by the anthropogenic activities. Furthermore, roosting period may scaffold various cognitive functions. In the view of the above, the present study was conducted with the aim to investigate the effect of environmental factors on roosting behavior of House crow influenced by anthropogenic activities.

Materials and Methods

The present study was conducted in Prayagraj (Allahabad) (25°45' N to 81° 85' E, 90 m above msl) Uttar Pradesh, India. This city is located at the confluence of the river Ganga and Yamuna with a population of about 1.53 million (2011 census). Average density of the city is 4200 Km^{-2}. Study area experience humid subtropical climate characterized by periodical monsoon. Adequate feeding opportunities and roosting sites were available for house crows (*Corvus splendens*) in this highly urbanized area. The roosting behavior of House crow was studied following the methodology of Peh (2002). In total 12 roost sites (i.e. number of sampling units) of house crow were visited during January, 2022 to December, 2022 encompassing part of winter season, and summer and monsoon seasons once each (Fig. 1A). Total 48 observations were made during study period. All Roost sites were located in the vicinity of highly urbanized settlements with ample anthropogenic light and sound and similar vegetation and food availability. It was assumed that light and sound near roost sites was product of anthropogenic activity at least after sunset.

Roosting sites were tracked from suitable places via binocular to ensure accurate and precise observation. Only active participant of the flock were considered. Observation began 15 min before crows started to return to their roost sites and ended until crows shouting stopped being heard. The mean sunset time (MST) was noted as per meteorological record in the newspaper. The mean temperature (MT), mean humidity (MH), mean illumination (MI) and mean sound intensity (MSI) were recorded hourly with the help of maximum minimum thermometer (brand SATMED), hygrometer (brand HAAR), lux meter (brand real instruments), and sound level meter (brand LABART), respectively. Four principle events characterizing the roosting behaviour were observed. Mean time of first arrival (MFA) marks the time after which the first crow started to roost continuously or was in close vicinity of roosting tree.

Mean time of half arrival (MHA) was the time at which 50% population arrived at the roost site. Mean time of last arrival (MLA) was characterized by time after which none member of the flock was sighted hovering over the roost site or was too dark to observe. Mean time of last vocal (MLV) marks the time after which no shouting was heard. In addition, three derived time spans viz. duration between sunset time to first arrival (STFA), first arrival to last arrival (FALA) and last arrival to last vocal (LALV) were also worked out. These time spans explained, if environmental factors were the main cause or some other cognitive activities were involved in roosting behavior. Average population of house crow at each roost site was estimated by Roost Count method (Davis, 1982; Radaria, 2013). We counted the crows returning to the roost sites. The numbers of roosting crows were considered as the total count for the arrivals minus the number of departure. Data collected was analyzed for multivariate regression using SPSS version 23. Environmental variables were represented as mean ± SE. Correlation graphs were drawn for dependent variable against each environmental variable with the help of MS excel (version 2010). Significance level for statistical tests were set at 95% confidence (p=0.05).

Results and Discussion

During the observation period, the mean values of environmental variables such as sunset time, temperature, humidity, illumination and sound intensity were monitored.The sunset time (HH:MM) was 18.04±0.07 along with 30.89±0.89 mean temperature (ºC). Other environmental variables such as humidity, illumination and sound intensity were 42.52±3.34 %, 4185.01±214.21 lux and 75.81±1.45 dB, respectively. The mean time of each principal event was recorded and time lapsed during each derived event was calculated accordingly. The mean time (HH:MM) of principal events, *viz.* first arrival (MFA), half arrival (MHA), last arrival (MLA) and last vocal (MLV) were 16.03±0.04, 17.09±0.07, 18.17±0.08, 19.24±0.06. The mean time lapsed (HH:MM) during derived events *i.e.,* sunset time to first arrival (STFA), mean time lapsed first arrival to last arrival (FALA) and mean time lapsed last arrival to last local (LALV) were 01.32±0.03, 02.27±0.03 and 00.33±0.02, respectively. The communal roosting of the House crows at the study site and the mean population of House crows at various roost sites are presented in Fig. 1 (A, B).

The mean time of first arrival was 121±0.20 min before sunset time. MST (r=0.861), MT (r=0.820), MI (r=0.384) and MSI (r=0.866) were significantly correlated (p<0.05) and collectively able to explain maximum 92.0% of variance observed in MFA ($F_{1, 43}$= 15.779; p<0.0001). Therefore, these variables collectively are best predictor for crows to arrive at roost sites (Fig. 2, 3; Table 1). Various workers have reported different time intervals between sunsets to first arrival. The mean time of first arrival on roost trees was 98 ±3 min before sunset. Time of first arrival was significantly correlated to sunset time and humidity, while non-correlated with light intensity and temperature (Peh, 2002). This time lag was 60 min and 50-40 min before sunset in case of Large-billed crows and House crow, respectively (Mahesh and Suseela, 2021). Arrival flights began on average 77.4 ± 31.1 min before sunset. On average, the median time was 8.7 ± 21.7 min before sunset.

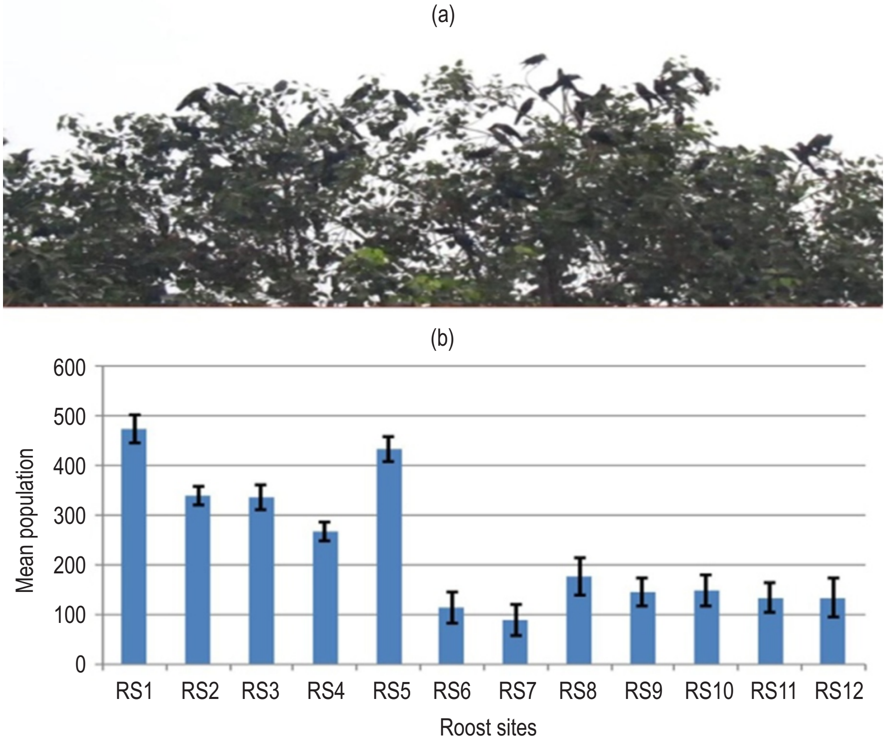

Fig. 1: (A) Communal roosting of the House crows at the study site and (B) mean population of House crows at various roost sites.

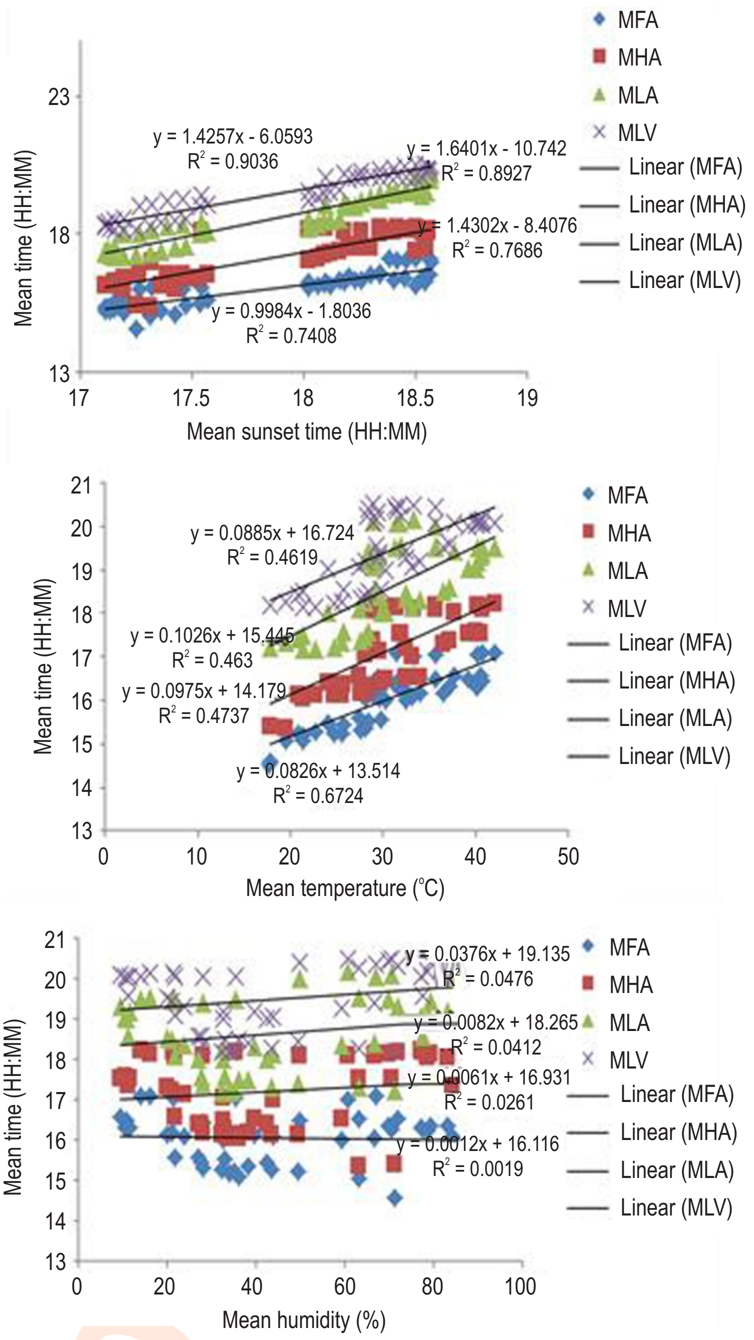

Fig. 2: Correlation of each principal events with environmental factors viz. mean sunset time, mean temperature and mean humidity.

Only day length (23.9%) and cloud cover (22.2%) had positive significant effect on arrival times. All other environmental factors were excluded from the model (Janicke and Chakarov, 2007). The time of roosting was closely correlated with light (Jumber, 1956; Davis and Lussenhop, 1970). Adverse weather conditions, such as high wind velocity, low temperatures, rain, snow and higher light intensities caused early assembly (Jumber, 1956). Further, entrance in the roosting place began at the same time in the evening regardless of the distance from the roosting site at which starlings (Sturnus vulgaris) were foraging (Stewart, 1977).

Some workers considered the departure time from the feeding ground instead of arrival time at roost site in characterizing roosting behavior. In one such case, the departure time of starlings from the feeding areas was better correlated with light intensity than with first arrival (Davis and Lussenhop, 1970).

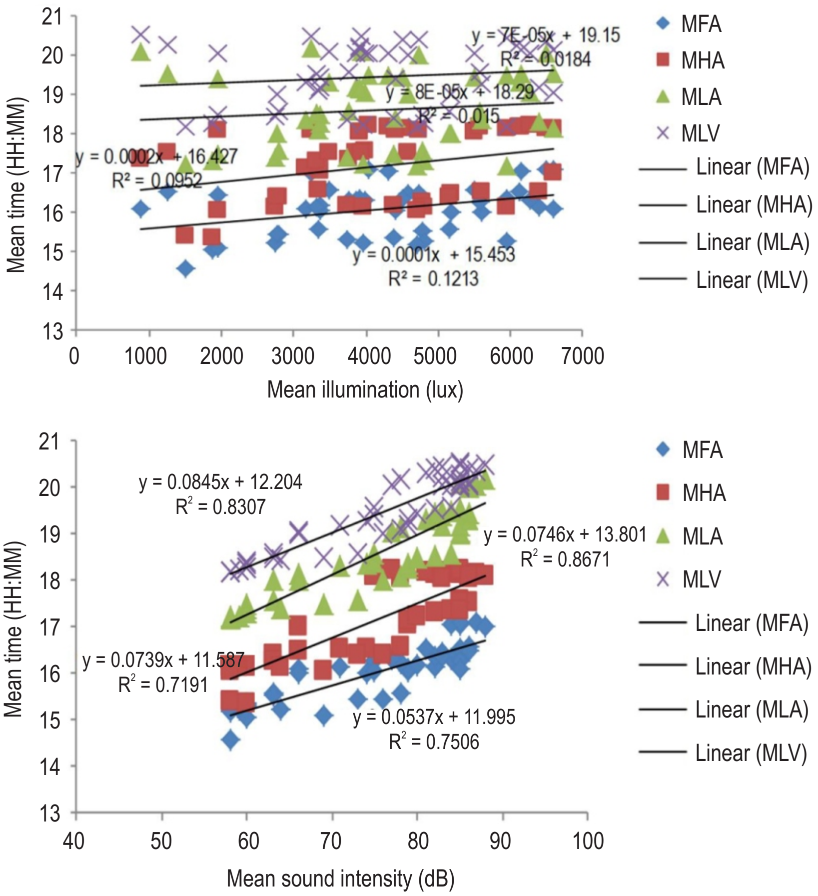

Fig. 3: Correlation of each principal event with environmental factors viz. mean illumination and mean sound intensity.

It was identified that Starlings arrival at the roost was not a function of the light-time stimulus, because it also depends on the light intensity at the time starlings began flying from the feeding grounds (Davis and Lussenhop, 1970). The time of sunrise and sunset were more closely associated with the mean time of peak exit or entrance of Chimney swifts (Chaetura pelagica) at the roost than temperature, wind speed, cloudiness, rainfall, and haziness (Zammuto and Franks, 1981).

In case of Brown-headed Cowbird (*Molothrus ater*), the movement towards the roosting area was closely associated with the daily amount of solar radiation (Krantz and Gauthreaux Jr., 1975). Thus, on an average basis, an early arrival was observed at roost sites, which may be due to differences in topography of study area and genetic makeup of species. Present finding that the mean sunset time, mean temperature, mean illumination and mean sound intensity are correlated and best predictor for the crows that will start to roost is in agreement with previous reported studies, excluding sound intensity and humidity (Zammuto and Franks, 1981; Khadraoui and Toews, 2015). Thus, the findings of present study demonstrate that sound intensity may play pivotal role in roosting behaviour. Half population arrived at roost sites 57±0.20 min before sunset. It took 66±0.21 min from first arrival. MHA was significantly correlated ($p<0.05$) with MST (0.877), MT (0.688), MI (0.309) and MSI (r= 0.848). However, best fitted model included only MST and MI to predict maximum 87.2% of variance in MHA ($F_{1,45}$= 36.313; $p<0.0001$) (Fig. 2, 3; Table 1). The mean time of half arrival was 26 ±3 min before sunset. Time of half arrival showed correlation with all the environmental variables viz. sunset time, light intensity, relative humidity and temperature (Peh, 2002). Time consumed for arrival of 50% population from first arrival was 50-60 min and 15-20 min in case of Large billed crows and House crow, respectively (Mahesh and Suseela, 2021). Therefore, in this study longer duration for half population to arrive at roost sites was detected. Similarly, significant correlation of half arrival to mean sunset time, mean temperature, mean illumination and mean sound intensity instead of humidity was noted. Furthermore, the best fitted model included only MST and MI to predict maximum variance in MHA. Therefore, anthropogenic sound was correlated with arrival process.

Time lapsed was 13±0.03 min from sunset to last arrival. MLA was significantly correlated ($p<0.05$) with MST (r=0.945), MT (r=0.680) and MSI (r=0.911). However, the best fitted model also

Table 1: Multiple regression analysis of principal/ derived events against each environmental factor

Dependent variable	Predictors	Multiple r	r 2	β	t	Significance
MFA	MSI	0.866	0.751	0.165	1.117	0.270
	MI	0.932	0.868	0.279	5.931	<0.0001
	MST	0.944	0.891	0.528	3.984	<0.0001
	MT	0.959	0.920	0.276	3.972	<0.0001
MHA	MST	0.877	0.769	0.881	16.522	<0.0001
	MI	0.934	0.872	0.321	6.026	<0.0001
MLA	MST	0.945	0.893	0.676	10.187	<0.0001
	MI	0.955	0.911	0.040	0.966	0.340
	MH	0.960	0.921	0.291	5.336	<0.0001
	MT	0.973	0.947	0.359	4.618	<0.0001
MLV	MST	0.951	0.904	0.346	4.379	<0.0001
	MH	-	-	-	9.048	<0.0001
	MT	0.981	0.963	0.292	5.581	<0.0001
	MSI	0.987	0.975	0.398	5.059	<0.0001
	MI	0.989	0.978	0.065	2.421	0.020
STFA	MI	0.662	0.439	0.653	6.759	<0.0001
	MH	0.761	0.580	0.376	3.886	<0.0001
FALA	MST	0.686	0.470	0.644	6.818	<0.0001
	MH	0.777	0.604	0.369	3.907	<0.0001
LALV	MT	0.479	0.230	0.479	3.702	0.001

Mean time of first arrival (MFA); Mean time of half arrival (MHA); Mean time of last arrival (MLA); Mean time of last vocal (MLV); Sunset time to first arrival (STFA); First arrival to last arrival (FALA); Last arrival to last vocal (LALV); Mean sound intensity (MSI); Mean illumination (MI); Mean humidity (MH); Mean temperature (MT) and Mean sunset time (MST).

included MI (r=0.122) and MH (r=0.203) as variables collectively able to explain 94.7% variance in MLA ($F_{1, 43}$ = 21.330; p<0.0001) and thus, best predictor for time of last arrival (Fig. 2, 3; Table 1). Various workers measured last arrival in different birds with reference to sunset time. The mean time of last arrival of House crow was 17 ±2 min after sunset (Peh, 2002). The end time for arrival *i.e.,* last arrival of all Large-billed crows and House crow was 20-30 min and 40 min after sunset, respectively (Mahesh and Suseela, 2021). In common raven (*Corvus corax*), arrival ended 25.6 ± 17.1 min after sunset and arrival flights lasted 102.0 ± 37.0 min, ranging from 25 to 161 min (Janicke and Chakarov, 2007).

Chimney swift entered in roost sites about 21 min after sunset (Zammuto and Franks, 1981). There was no correlation between the time of last arrival and light intensity but sunset time, temperature and humidity (Peh, 2002). As the roost approached there was weaker correlation between light intensity and time of departure from rendezvous areas. It was insisted that time of departure from the feeding areas was better correlation with light intensity than would the time for final assemblies (Davis and Lussenhop, 1970). In this case we observed shorter duration after sunset time and longer time span from first arrival needed to settle all crows at roost sites. In the present study, MLA was significantly correlated with mean sunset time, mean temperature and mean sound intensity. Best fitted model also included mean illumination and mean humidity as variables to predict MLA. Thus, anthropogenic sound and illumination cannot be ignored. Illumination influence rate of arrival, the varying distances starlings must fly to the final roost, and behavioural interactions en route (Davis and Lussenhop, 1970). Termination of roosting was more closely correlated to light intensity following sunset. Furthermore, the timing of roosting behaviour in relation to the quantity and quality of light was in accordance with the circadian rule (Krantz and Gauthreaux Jr., 1975). These statements strengthen our claim.

Vocalization lasted up to 80±0.11 min after sunset. The duration between last arrival to last vocalization was 0.33±15 min. MST (r=0.951), MT (r=0.680) and MSI (r=0.931) were significantly correlated (p<0.05) with MLV. These variables together with MH (r=0.218) and MI (r=0.136) were collectively able to explain a maximum 97.8% variance observed in MLV (F 1, 42= 5.862; p< 0.020) and thus up to what time crows will scream (Fig. 2, 3; Table 1). The mean time of last vocalization was 25 ± 2 min after sunset. The cessation of the crows' vocalization was correlated to sunset time and relative humidity (Peh, 2002). A considerable longer duration between sunset time to last vocalization was noticed. In addition to mean sunset time, the mean temperature and mean sound intensity correlated to MLV. Further, the mean humidity and mean illumination were also involved in prediction of MLV. Noise could disrupt information on danger in natural eavesdropping webs and so compromise survival of birds (Zhou *et al.*, 2023).Some workers noted no correlation between roosting behaviour to anthropogenic noise (Khadraoui and Toews, 2015). It will be good to mention that they considered only departure from roost site during early morning,

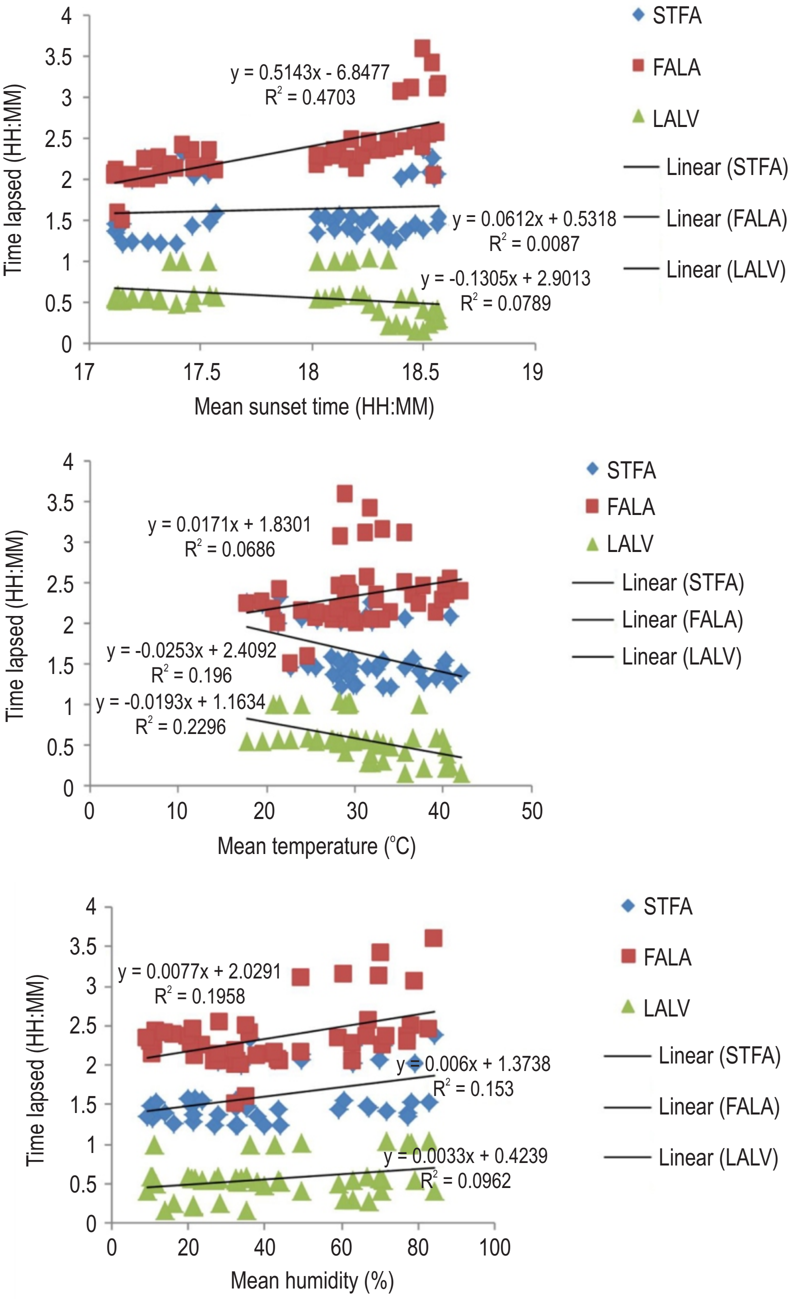

Fig. 4: Correlation of each derived event with environmental factors viz. mean sunset time, mean temperature and mean humidity.

where contribution of anthropogenic sound may be less. Therefore, sound and illumination generated by anthropogenic activities is important for predicting the extent of vocalization. STFA was significantly correlated ($p<0.05$) with MT(r=0.443), MH (r=0.391) and MI (r=0.662). However, the best fitted model suggested that only MI and MH collectively were able to explain maximum 58.0 % variance in STFA (F1, 45= 15.102; $p< 0.0001$) and thus, time elapsed from sunset to first arrival. MST (r=0.686), MT (r=0.262), MH (r=0.443) and MSI (r=0.621) were significantly correlated ($p<0.05$) with FALA. However, the best fitted model included only MST and MH collectively able to explain 60.4% variance in FALA (F 1, 46= 15.261; $p<0.0001$) and thus, times elapsed between first arrival to last arrival. MST (r=0.281), MT (r=0.479), MH (r=0.310) and MSI (r=0.249) were significantly correlated ($p<0.05$) with LALV. However, the best fitted model included only MT which was able to explain 23.0% variance in LALV ($F_{1,\ 46}$=13.708; p=0.001) (Fig. 4, 5; Table 1). Thus the environmental factors were quite inadequate to reveal how long

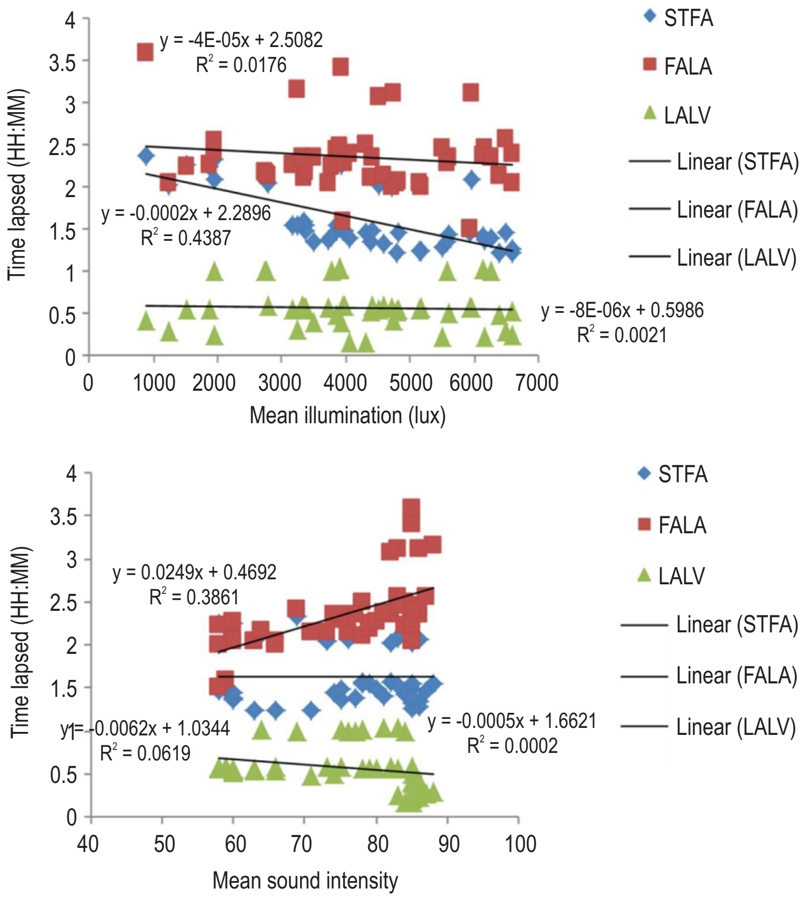

Fig. 5: Correlation of each derived event with environmental factors viz. mean illumination and mean sound intensity.

crows would caw after last arrival. It is clear from the results that principle events (MFA, MHA, MLA and MLV) can be predicted quite confidently considering the environmental factors but derived events (STFA, FALA and LALV). It appears that principle events are quite stereotyped in response to environmental factors but derived events are some more. Therefore, some other factors are involved during such interplay. The Brandt's myotis (*Myotis brandtii*) prefer roost sites in landscape that remain unaffected by human disturbance within 5 km radius. Thus surrounding habitat around a roost plays a vital role for bat species (Suominen *et al.,* 2023). Human activities may affect animal habitat and resource use. Effect of human activity on bird's behaviour is differential, i.e., some birds are benefitted while other not (Warrington *et al.*, 2022). Although house crow is well suited for human habitation but specific characters for a roost site cannot be ignored. Leaving foraging ground is not simply a response to handful environmental factors. It is a complex cognitive process and animals have to decide where and when go next (Farine, 2022).

Vocalisation may drive both the timing of departures and the cohesion of roost members (Dibnah *et al.,* 2022). Farine (2022) suggested that increasing intensity of vocalisations (or more individuals calling simultaneously) is a precursor to departure, and vocalisation can act as a voting process. Thus vocalization simultaneously by many birds is a decision making process analogous to voting process in human society. Many vertebrates eavesdrop on alarm calls of other species, as well as responding to their own species' calls. Perception or recognition of calls may be difficult with increasing anthropogenic noise (Zhou *et al.,* 2023). Avian time–activity budgets are known to be affected by environmental factors (Janicke and Chakarov, 2007). House crows are found to share roosting sites with Large-billed crow (*Corvus macrorhyncus culminatus*), Cattle egrets (*Bubulcus Ibis*) and Indian Myna (*Acridotheres tristis*) and thus, inter specific interactions cannot be eliminated (Sirsat and Patil, 2013; Madhu Sharma *et al.,* 2018).

Canopy cover, vegetation structure and its composition affected by human developmental processes may alter the occurrence and range distribution of avifaunal communities in urban landscape (Rajashekara and Venkatesha, 2017; 2018). Crows prefer sites for roosting with large cannopy height (Saiyad *et al.,* 2017).The diversity and abundance of birds changes with seasons (Rajashekara and Venkatesha, 2017). These factors inturn may affect interspecific interactions and thus, the roosting behaviour scenario. Pilfering and hoarding food items for future use, tool making are now well established in House crow (Goodwin, 1976; Srivastava *et al.,* 2014; Hunt, 1996). Besides thermoregulation, decreased predation and cost of mates' assessment, it is proposed that roosting acts as information centre about where food may be found (Marzluff *et al.,* 1996; Zahavi, 1996; Dall, 2002). Radio-tagging study supported this hypothesis (Sonerud *et al.*, 2001). Crows are capable of matching stimuli on the basis of analogical relations (size, colour and shape), thus, animals capable of spontaneous analogical reasoning other than primates (Vonk, 2014). Interplay of complex cognitive processes together with environmental factors, especially anthropogenic light and noise play an important role in roosting behaviour. These may be the reason for extended time periods observed while roosting. Derived events are manifestations of these processes.

Therefore, environmental factors altered by anthropogenic light and sound affect roosting events. It can be inferred that structure of roosting sites and interplay of complex cognitive processes taking place during roosting may also be considered while predicting various events. It is suggested that anthropogenic activities should be managed to avoid adverse consequences on roosting behaviour and thus survival of birds.

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