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ACKNOWLEDGEMENTS. We thank Dr V. V. Ramamurthy, Principal Scientist (Retd.), Division of Entomology, IARI, New Delhi, India for constant guidance and support during the studies. We also thank the Director, Joint Director (Res.), IARI, Head, Division of Entomology, IARI, New Delhi for facilitating the study. We acknowledge the help extended by the Jaipur, Palampur and Almora centres of AINP on Soil Arthropod Pests, FARMER (NGO), Ghaziabad, UP, State Agricultural Universities, Department officials and local farmers of the four states in facilitating the sampling of white grubs.

Received 28 December 2014; revised accepted 6 March 2017

doi: 10.18520/cs/v113/i02/322-329

Influence of astronomical (lunar)/meteorological factors on the onset of dawn song chorus in the Pied Bush Chat (*Saxicola caprata*)

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Climatic factors which prevail during the breeding season of avian species in spring and early summer may trigger the onset of singing behaviour in songbirds. To understand the effect of climatic variables on the onset of dawn song chorus, we conducted a study in the natural habitats of a tropical songbird, the Pied Bush Chat *Saxicola caprata* in Haridwar, Himalayan foothills, India during early spring. The results indicated that the onset time of dawn chorus depends on a number of environmental factors. The song bout length depended on daily temperature, rainfall rate, wind direction, photoperiod, lunar phase, indices of apparent temperature, dew point, sunrise timing and day length, whereas the song rate depended on daily temperature, photoperiod, indices of apparent temperatures, dew point, sunrise timing and day length. Further, stepwise multiple regression revealed that onset time of dawn chorus was dependent on photoperiod and lunar phase, while song bout length and song rate were influenced by day length and sunrise timing respectively.

Keywords: Onset of dawn song, Pied Bush Chat, tropical songbird.

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THE mutual relationship between the sun and seasons may affect animal behaviour as a change in climatic variables may activate specific behavioural patterns among animals[1,2]. The onset of dawn chorus in songbirds is one such visible change that has been the focus of many studies[3–6].

The dawn chorus of passerines is a classic example of the peaks in sexual signalling and territorial displays that occur across a range of taxa where environmental factors have been marked to be important in this context[7]. It has been accepted that the effect of sunrise timing and other microclimatic conditions may influence onset of chorus[8,9]. It has long been projected that each species has its own particular awakening time and the regularity with which birds first sing in the morning is under the influence of sunrise timing[3]. It is also believed that birds have a highly developed sense of time as their biological clock can perceive the changes in the quality of light and day length which may trigger the course of breeding in them[10,11].

Other than annual fluctuations in day length and sunrise timing, it has also been proposed that moonlight may influence the start of a bird's singing[12–14]. The weak light intensities preceding the beginning of civil twilight are also sufficient to stimulate daybreak singing in many temperate-zone avian species such as the field sparrow (*Spizella pusilla*), catbird (genus *Ailuroedus*) and cardinal (genus *Paroaria*). It has been reported that the low-light dawn singing is a reliable indicator of male quality, perhaps more so than singing at other times of the day[15].

Recently, it has been projected that lunar cycles may affect the behaviour of diurnal species, especially those which carry out their breeding protocols in the twilight period which has received little direct empirical testing[16,17]. Additionally, the climatic variables such as rise in temperature and decrease in relative humidity could also pose similar effects on the onset of singing behaviour[18]. It is believed that the songbirds have their singing pattern tuned to the change in climatic variables and seasonal attenuation in daily high temperature, low temperature and gradual rise in temperature[19,20]. It has been suggested that low temperature and high humidity at dawn may restrict the activity of birds[21]. In contrast, low wind speed in this period is more favourable for sound to travel with consistency[7]. A positive relationship between singing and ambient temperature has been documented[19,20,22,23]. However, climatic factors during seasons may be difficult to segregate as sometime a given variable may not act independently on biological behaviours. For instance, it has been argued that temperature or humidity alone may not be precisely successful in terms of their impact on the singing behaviour[18,24]. The interaction of two or more parameters can significantly alter the impact of each other when acting jointly. It may be mentioned that the study of dial pattern in song delivery has received little attention than the song repertoire size and song learning while the quantitative documentation of patterns of song output remains unusual[25–27].

In light of the above, we conducted a field study to demonstrate the extent to which astronomical (lunar) and meteorological factors influence the onset of dawn song chorus during the beginning of the breeding season in a tropical songbird, the Pied Bush Chat (*Saxicola caprata*).

The Pied Bush Chat (order Passeriformes, family Muscicapidae) is a tropical songbird that is found discontinuously from Trans-Caspia and the Indian subcontinent to Southeast Asia, the Philippines, Indonesia, New Guinea and New Britain. The breeding season is mainly February–August, with a peak in March–June. The natural habitat of Pied Bush Chat is majorly an open cultivated landscape or a grassland, especially paddy and sugar canefields.

The study was carried out during 1 January to 28 February 2015 (59 days) in Haridwar (Himalayan foothills; 29°55′N and 78°08′E), India. The male Pied Bush Chat usually start their singing activities from the last week of January and their singing behaviour becomes quantifiable from the first week of February. The biological variables (singing parameters) considered for this study were onset time of dawn chorus (°hours) – it is the time when males initiated their dawn song chorus (uttered first phrase), song bout length, i.e. the total duration of dawn song delivery (min), and song rate (song type/min). The biological variables were the average (mean ± SD) of six individuals per day. The onset timing of whichever individual male sang earliest was considered in the study.

We selected 12 male birds in their respective territories and observed 6 males each morning during the study period. For identification purposes, the males were ringed with plastic colour bands at the beginning of the breeding season. The males generally delivered their song bouts from regular song posts (perches) throughout the breeding season. In a given day all six males were attended/recorded by six different observers simultaneously. The males were observed from the initiation of their dawn song chorus till they terminated their daily song delivery. The onset time was noted with the help of synchronized stop-watches. We recorded the timing of onset of dawn song delivery of each male during alternate days.

The singing behaviour of birds was then recorded (Sennheiser ME 67 directional microphone attached to a Marantz PMD 660 and 670 digital sound recorders). We collected about 180 (30 days × 6 males) recordings by the end of February. These were saved as WAV format with input sampling frequency of 24,000 Hz and amplitude format of 16 bit. Spectrograms were prepared for the calculation of song rate using Avisoft SAS Lab Pro 4.1 software[8].

For climatic factors, we used data that were received from a weather station at the Department of Zoology and Environmental Science, Gurukula Kangri University, Haridwar, India, which was connected to a display devise

((Davis) Vantage Pro2™). The climatic data were recorded at each hour via a data logger attached to a stationary computer system for 24 h during the study period. All study sites were open-cultivated landscapes, open scrub or grasslands, sparse bushes (as mentioned above) and within 3 km radius from the location of the weather station. The climatic factors include a range of variables such as photoperiod, i.e. the period of time each day during which the studied species received illumination (h), lunar phase, i.e. the shape of the illuminated (sunlit) portion of the moon as seen by an observer on earth (% visibility), solar radiations, i.e. energy radiated from the sun in the form of electromagnetic waves, including visible and ultraviolet light and infrared radiation (W/m^2), daily solar energy, i.e. radiant light and heat from the sun (langley: 1 langley = 11.622 $W\text{-}h/m^2$ and 41.84 kJ/m^2), bright sunshine hours measuring the duration of sunshine in a given period (usually a day) for a given location on earth (h), sunrise timing, i.e. the instant at which the upper edge of the sun appears over the horizon in the morning (°hours), mean temperature (°C), high temperature (°C), low temperature (°C), rainfall rate (inches), wind speed (km/h), wind direction (°), humidity (%), dew point (°C) and day length (h). The interactions of parameters were also considered. For instance, the combined effect of daily temperature, humidity and wind speed was calculated using apparent temperature such as THWI (this index uses temperature, humidity and wind to calculate an apparent temperature that incorporates the cooling effects of wind on the perception of temperature) and the combined effect of temperature, humidity, solar radiation and wind was tested via THSWI (this index uses temperature, humidity, heating effect of direct solar radiation and cooling effect of the wind to calculate an apparent temperature). The definitions of all climatic factors and indexes (combined parameters) studied were adopted from the manual of the weather link 5.7.1 (available at http://www.davisnet.com/product_documents/weather/manuals/07395-234_IM_06312.pdf). The recordings of all windy and rainy days were included in the observation chart.

Data analysis was done using NCSS Statistical Graphics and Sample Size Software. We used circular interval scale for time of day, where a day was divided into 24 equal intervals called hours. One hour of a day corresponds to 150 (i.e. 3600/24) of a circle, and 10 of a circle corresponds to 4 min of a day. In general, we converted *X* time units to an angular direction (*A*, °hours), where *X* was measured on a circular scale having *k* time units in the full cycle: $A = (3600)(X)/k$. For example, to convert a time of day (*X*, (h)) to an angular direction, $k = 24$ h. A Spearman's rho correlation (two-tailed) was performed to find the correlation between song parameters and climatic factors. We applied the stepwise multiple regression to determine the effect of independent variables, i.e. climatic factors on dependent variables such as onset time of dawn chorus, song bout length and song rate.

Correlation analysis showed that the onset time of dawn chorus depends on daily temperature, rainfall rate, bright sunshine hours, photoperiod, lunar phase, indices of apparent temperature (THWI and THSWI), dew point, sunrise timing and day length. Similarly, song bout length was found to be correlated with daily temperature rainfall rate, wind direction, photoperiod, lunar phase, indices of apparent temperature, dew point, sunrise timing and day length, and song rate was influenced by daily temperature, photoperiod, indices of apparent temperature, dew point, sunrise timing and day length. Table 1 and Figures 1–3 show the correlations (±) among climatic factors and onset time of dawn chorus, song bout length and song rate.

The onset time of dawn chorus was found to be influenced by photoperiod (standard coefficient = –1.1, *T*-value = –8.34, probability level = 0) and lunar phase (standard coefficient = –0.29, *T*-value = –2.24, probability level = 0.03), while song bout length was influenced by day length (standard coefficient = 0.86, *T*-value = 8.35, probability level = 0), and song rate by sunrise timing (standard coefficient = –0.7, *T*-value = –4.86, probability level = 0.000059).

In the wild, the success of survival of a species depends upon its ability to breed at the most propitious time of the year, and prediction of the favourable season is based on the interaction of annual changes in day length with the biological clock mechanism of the species[10,29]. It appears that male Pied Bush Chat can efficiently read the photoperiodic cues as all the parameters related to singing behaviour, such as onset time of dawn song chorus, song bout length and song rate were found significantly correlated with photoperiod and multiple regression has also indicated the impact of photoperiod on the onset time of dawn song chorus. It has been predicted that the start of dawn chorus should be mostly affected by variations in the light intensity[6]. The song output of Pied Bush Chat was coherent with sunrise timing and bright sunshine hours also influenced the onset time of dawn song chorus. The multiple regression models have indicated the impact of day length and sunrise timing on song bout length and song rate respectively. Since the weak light intensity preceding the beginning of morning civil twilight is sufficient to stimulate day break song in Pied Bush Chat, the early singers may harvest benefits in terms of territory defence, mate attraction and mate guarding[30].

It has been reported that the full moon has an effect on the morning awakening time of some bird species[14]. It is interesting to note that during the initial singing performance, the moon phase is of utmost importance for the Pied Bush Chat in order to trigger the commencement of their daily singing activity. A similar behaviour has been reported earlier[12,25,26]. Data from the present study showed that the lunar phase was positively correlated with the onset time of dawn chorus of Pied Bush Chat. A similar behaviour has been reported in White-browed sparrows (*Plocepasser mahali*), and it was argued that the birds

Table 1. Correlation between climatic factors and various song parameters (onset time of dawn chorus, song bout length and song rate)

Climatic factors	Correlation	Climatic factors	Correlation
Onset time of dawn chorus versus climatic factors			
Mean temperature	$n = 30, r_s = -0.61, t = -4.1, df = 28, P = 0.0003$	THWI	$n = 30, r_s = -0.61, t = -4.16, df = 28, P = 0.0002$
High temperature	$n = 30, r_s = -0.58, t = -3.79, df = 28, P = 0.0007$	THSWI	$n = 30, r_s = -0.63, t = -4.35, df = 28, P = 0.0001$
Low temperature	$n = 30, r_s = -0.56, t = -3.63, df = 28, P = 0.001$	Humidity	$n = 30, r_s = 0.21, t = 1.18, df = 28, P = 0.247$
Rainfall rate	$n = 30, r_s = 0.55, t = 3.52, df = 28, P = 0.001$	Solar radiation	$n = 30, r_s = 0.09, t = 0.52, df = 28, P = 0.6$
Wind speed	$n = 30, r_s = 0.18, t = 1.01, df = 28, P = 0.32$	Solar energy	$n = 30, r_s = 0.09, t = 0.52, df = 28, P = 0.6$
Wind direction	$n = 30, r_s = -0.17, t = -0.93, df = 28, P = 0.36$	Dew point	$n = 30, r_s = -0.55, t = -3.53, df = 28, P = 0.001$
Bright sunshine hours	$n = 30, r_s = 0.45, t = 2.67, df = 28, P = 0.01$	Sunrise timing	$n = 30, r_s = 0.73, t = 5.81, df = 28, P = 0.000003$
Photoperiod	$n = 30, r_s = -0.76, t = -6.22, df = 28, P = 0.000001$	Day length	$n = 30, r_s = -0.76, t = 6.22, df = 28, P = 0.000001$
Lunar phase	$n = 30, r_s = 0.59, t = 3.87, df = 28, P = 0.0005$		
Song bout length versus climatic factors			
Mean temperature	$n = 30, r_s = 0.67, t = 4.89, df = 28, P = 0.000037$	Lunar phase	$n = 30, r_s = -0.42, t = -2.5, df = 28, P = 0.01$
High temperature	$n = 30, r_s = 0.74, t = 5.87, df = 28, P = 0.000003$	THWI	$n = 30, r_s = 0.69, t = 5.08, df = 28, P = 0.000022$
Low temperature	$n = 30, r_s = 0.53, t = 3.34, df = 28, P = 0.002$	THSWI	$n = 30, r_s = 0.7, t = 5.28, df = 28, P = 0.00001$
Rainfall rate	$n = 30, r_s = -0.53, t = -3.38, df = 28, P = 0.002$	Humidity	$n = 30, r_s = -0.34, t = -1.96, df = 28, P = 0.06$
Wind speed	$n = 30, r_s = -0.15, t = -0.82, df = 28, P = 0.419$	Solar radiation	$n = 30, r_s = 0.19, t = 1.07, df = 28, P = 0.2937$
Wind direction	$n = 30, r_s = 0.41, t = 2.4, df = 28, P = 0.02$	Solar energy	$n = 30, r_s = 0.2, t = 1.13, df = 28, P = 0.268$
Bright sunshine hours	$n = 30, r_s = -0.05, t = -0.31, df = 28, P = 0.758$	Dew point	$n = 30, r_s = 0.58, t = 3.78, df = 28, P = 0.00075$
Photoperiod	$n = 30, r_s = 0.77, t = 6.4, df = 28, P = 0.000001$	Sun rise timing	$n = 30, r_s = -0.73, t = -5.8, df = 28, P = 0.000003$
		Day length	$n = 30, r_s = 0.77, t = 6.4, df = 28, P = 0.000001$
Song rate versus climatic factors			
Mean temperature	$n = 30, r_s = 0.46, t = 2.75, df = 28, P = 0.01$	Lunar phase	$n = 30, r_s = -0.32, t = -1.82, df = 28, P = 0.079$
High temperature	$n = 30, r_s = 0.36, t = 2.1, df = 28, P = 0.044$	THWI	$n = 30, r_s = 0.48, t = 2.96, df = 28, P = 0.0062$
Low temperature	$n = 30, r_s = 0.46, t = 2.81, df = 28, P = 0.008$	THSWI	$n = 30, r_s = 0.46, t = 2.8, df = 28, P = 0.009$
Rain rate	$n = 30, r_s = -0.28, t = -1.6, df = 28, P = 0.12$	Humidity	$n = 30, r_s = -0.11, t = -0.59, df = 28, P = 0.559$
Wind speed	$n = 30, r_s = -0.05, t = -0.3, df = 28, P = 0.76$	Solar radiation	$n = 30, r_s = 0.007, t = 0.04, df = 28, P = 0.96$
Wind direction	$n = 30, r_s = 0.17, t = 0.93, df = 28, P = 0.36$	Solar energy	$n = 30, r_s = 0.02, t = 0.11, df = 28, P = 0.913$
Bright sunshine hours	$n = 30, r_s = -0.14, t = -0.75, df = 28, P = 0.45$	Dew point	$n = 30, r_s = 0.51, t = 3.19, df = 28, P = 0.0034$
Photoperiod	$n = 30, r_s = 0.57, t = 3.69, df = 28, P = 0.009$	Sun rise timing	$n = 30, r_s = -0.61, t = -4.15, df = 28, P = 0.00028$
		Day length	$n = 30, r_s = 0.57, t = 3.69, df = 28, P = 0.0009$

might sing earlier during fullmoon[31]. On the other hand, the male Pied Bush Chat composed smaller song bouts during full moon and vice versa, as the lunar phase was found negatively correlated with song bout length. It is believed that predators' eavesdropping may increase the vulnerability of a continuously vocalizing bird from a constant song post, particularly during twilight. Theoretically, if the light is low, then chances are that the prey is at some advantage and may deliver a longer song bout. Thus, if moonlight is bright, then the song bout length should be less and vice versa[32]. Hence, it can be mentioned that male birds may have tailored their initial daily dawn singing time according to phases of the moon.

It is generally presumed that the environmental conditions under which signals are generated can affect a receiver's response. Such variations in sexual signals can convey information about the quality of signallers[33]. For example, an individual singing in the cold may infer his quality to tolerate cold as singing in cold weather is thermally challenging[4]. The daily song cycle of the male Pied Bush Chat shows the gradual influence of increased abiotic factors as the onset time of dawn chorus, song bout length and song rate were found to be accelerated by daily temperature. Also, male birds tend to sing at low temperature while the coherence in the progression of singing behaviour under regular increase in seasonal heat was well displayed by them. It was suggested that song rates in Great Tit (*Parus major*) may be influenced by air temperature[19]. The increase in song rate is supposed to have a connection with mate choice[30,34] and song rate may advance with the gradual rise in temperature[23]. Similar results have been reported in Pied Flycatcher (*Ficedula hypoleuca*), where song rate was found highly correlated with air temperature and timing/date of the season[5,35]. Interestingly, in another study, it has been reported that the Female Linkon Sparrows (*Melospiza lincolnii*) show behavioural bias toward songs produced in the cold, as song production in low temperature is thermally challenging[4].

Upon considering the combined effect of individual parameters in terms of THWI and THSWI in Pied Bush Chat, it is apparent that onset time of dawn chorus, song bout length and song rate are impacted by the combined climatic factors; the independent effects of parameters such as humidity or wind are less influential, but upon combining with other parameters such as temperature, the indexes show greater effects on the singing parameters. It has been shown that both strong wind and rainfall may affect the daily timing of the dawn song chorus[5]. Rainfall

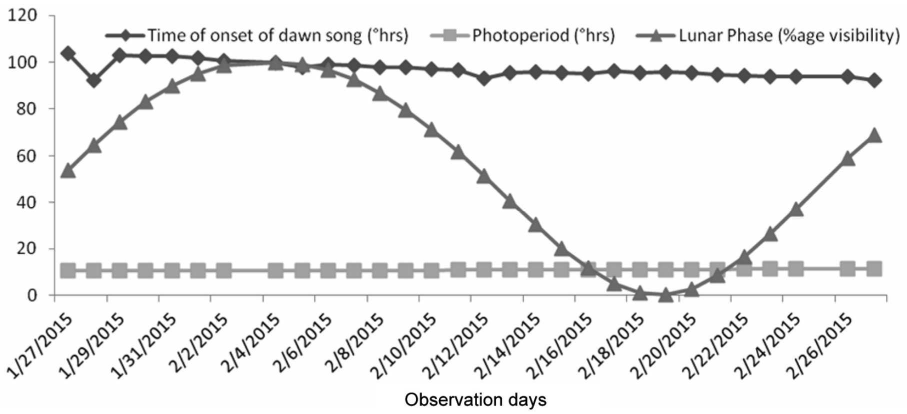

Figure 1. Progression of time of onset of dawn song versus photoperiod and lunar phase.

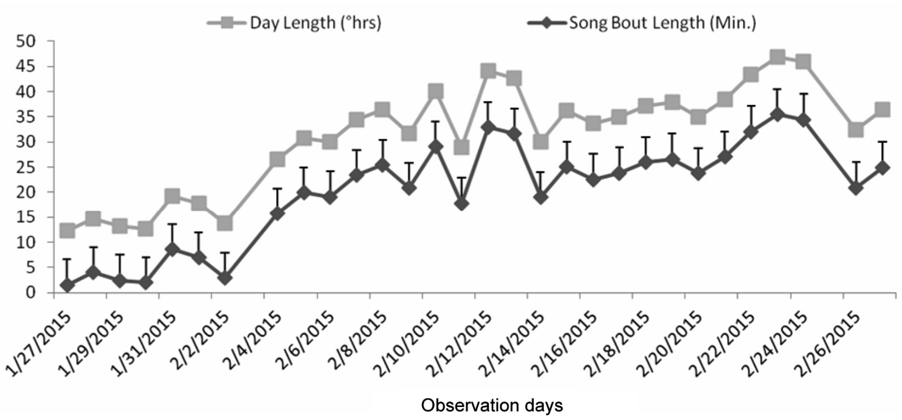

Figure 2. Progression of song bout length and day length.

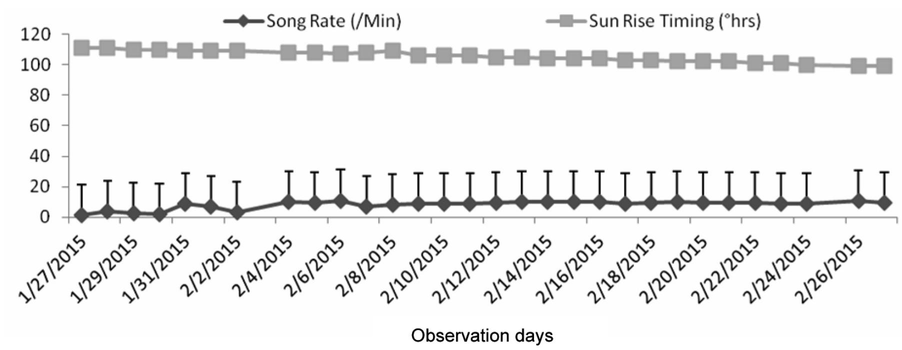

Figure 3. Progression of song rate and sunrise timing.

and wind can act directly through increased noise, reducing the ability to communicate efficiently or through increased cost of singing such as thermoregulation[38]. The present study indicates that the Pied Bush Chat sings at regular perches, and if the occupied perch is constantly confronted by a directional wind, the males may stop their dawn song chorus as such communication may not be efficient. Hence, such directional winds may leave the males with smaller song bouts[5,37–41].

In conclusion, this study on avian species of the Indian subcontinent indicates that climatic factors can significantly influence the onset of dawn singing. We found that in natural habitats of Pied Bush Chat, the timing and sequence in which the birds start and stop singing were consistent and predictable. The results further revealed that the onset time of dawn chorus, song bout length and song rate might be regulated by daily temperature, photoperiod and sunrise timing. It is interesting to note that despite experiencing lesser changes in annual day length and season compared to temperate-zone birds, the onset of dawn chorus of the tropical Pied Bush Chat can be influenced by climatic factors.

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ACKNOWLEDGEMENTS. We thank the Department of Science and Technology, Government of India (GoI) and the University Grants Commission-Special Assistance Programme for funds; Head, Department of Zoology and Environmental Science, Gurukula Kangri University, Haridwar for providing infrastructural facility to carry out this work and Prof. Mewa Singh (Department of Psychology and Institute of Excellence, University of Mysore, Mysuru) for his guidance in the statistical analysis of the data.

Received 13 September 2016; revised accepted 29 January 2017

doi: 10.18520/cs/v113/i02/329-334