SHORT COMMUNICATIONS

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DAILY SONG PATTERNS IN GOLDEN-CROWNED SPARROWS AT 62°N LATITUDE

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Juliet:

> Wilt thou be gone? It is not yet near day;
> It was the nightingale, and not the lark,
> That pierced the fearful hollow of thine ear;
> Nightly she sings on yon pomegranate tree;
> Believe me, love, it was the nightingale.

Romeo:

> It was the lark, the herald of the morn,
> No nightingale: look love what envious streaks
> Do lace the severing clouds in yonder east:

Had Shakespeare's *Romeo and Juliet* been staged at a more northern latitude, these amorous adolescents could have used the daily onset of bird song to warn them that their time was growing short, but they would have parted long before Juliet's household would arise. Despite continuous daylight at high latitudes during the summer, birds exhibit regular behavioral periodicities (e.g., Cullen 1954, Brown 1963).

Fluctuations in photoperiod, temperature, and humidity have been suggested as possible environmental cues influencing circadian patterns (Armstrong 1954). Laboratory studies have paid particular attention to photoperiod and have demonstrated its influence on avian activity (e.g., Farner and Lewis 1971, Daan and Aschoff 1975). Here we present data on the daily and seasonal patterns of singing in free-living Golden-crowned Sparrows (*Zonotrichia atricapilla*) at approximately 62° N latitude during the breeding season.

Our study took place between early May and late July 1976 in the Independence Mine valley of south central Alaska, about 80 km N of Anchorage. The altitude of the valley is 915 m (300 m above timberline) and the habitat is a typical low arctic-alpine tundra characterized by several species of *Salix*, herbaceous plants, grasses and sedges. Vegetation ranges from 3 to 100 cm in height, excluding willows which reach 10 m in moist areas. Along with Golden-crowned Sparrows, the most common passerines were the Water Pipit (*Anthus spinoletta*), Savannah Sparrow (*Passerculus sandwichensis*) and Wilson's Warbler (*Wilsonia pusilla*).

The song of the Golden-crowned Sparrow is distinct and easily recognized, consisting of three high descending notes of plaintive minor quality. During several two-minute periods of each hour we recorded the number of Golden-crowned Sparrow songs heard from a fixed location. All hours of the day were sampled at least four times per week except for the hours of maximum song rates (01:00–04:00) which were each sampled about seven times per week. Daytime sampling was spread evenly throughout each week. However, data from 24:00–05:00 were collected on two nights per week, separated by at least two days. We did not sample during days of extremely heavy rain or snow. Several times each week we both sampled the same two-minute period to assess our reliability in sampling. Based on 13 randomly chosen periods, we found no significant difference between the song counts made by each of us ($t = .93$, d.f. $= 12$, $P > .10$ two-tailed).

In this report, song rates for any given hour are rates measured from data collected during the designated hour, e.g., a song rate reported for 01:00 is based on data collected from 01:00–01:59. Weeks are denoted by their starting date.

The first Golden-crowned Sparrow on the study site was observed on 13 May and the first song heard on 14 May. (We had been at the study site since late April.) During the week after this initial song, we heard several abbreviated, two-note songs lacking the typical final note. Thus, birds assumed to be males (see below) arrived on the breeding ground in mid-May. Within a week, they were singing typical songs, but with some variation. By the week of 13 July, singing had almost ceased although we heard it occasionally as late as 10 August.

Figure 1 presents, for each week, the mean number of songs heard per minute, i.e., the song rate for each hour of the day. These data are for all birds combined and are not rates per individual. Song rates were highest in the early morning (01:00–04:00), fell to a lower, consistent rate lasting throughout the remainder of the day, and declined further at about 21:00. A quiescent period occurred from 22:00–00:30. The highest song rate occurred during the early morning hours of the first week, reaching a mean of 24.0 songs per minute at 03:00.

A grand mean song rate was calculated for each week by summing hourly means during a week and dividing by 24. Then, *t*-tests were used to compare means between consecutive weeks with significance levels chosen to correct for the problem of performing multiple *t*-tests. We found significant differences only between 2 June and 9 June and between 6 July and 13 July ($t = 3.12$, d.f. $= 23$, $P = .005$ and $t = 7.30$, d.f. $= 23$, $P < .0001$, respectively).

Figure 2 presents the relationship between the time of sunrise, time of song onset, and time of maximum song rate on 12 arbitrarily chosen days. (Sunrise is nautical sunrise, local standard time computed from a nautical almanac.) Onset of song is defined as the mean time of the first two samples in the early morning when two or more songs per minute were recorded. The time of maximum song rate is defined as the mean time of the three samples of highest song rate. Although the relationship is undoubtedly complex, Figure 2 generally shows that both song onset and the time of maximum song track the time of sunrise across the breeding season.

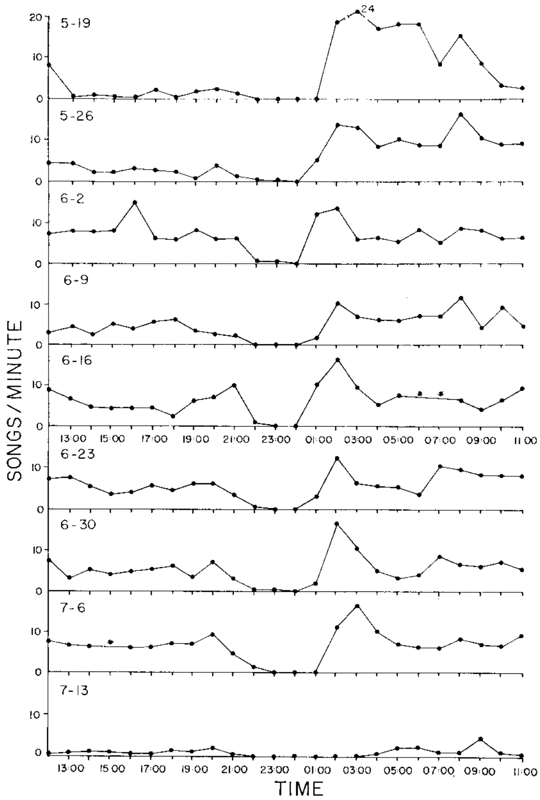

FIGURE 1. Mean song rate (songs/minute) of Golden-crowned Sparrows in relation to time of day for the nine weeks of the breeding season. Rates are for all audible birds, not rates per individual. An asterisk indicates missing data.

The diurnal behavior cycle exhibited by many animals commonly has been shown to be related to photoperiod (Daan and Aschoff 1975, Daan 1976). Cloudsley-Thompson (1960) labelled light the "master-factor" in the entrainment of circadian rhythms. Our results show a relationship between photoperiod and singing in Golden-crowned Sparrows (see Fig. 2) and seem important in providing detailed data on a diel rhythm in free-living birds. Furthermore, the rhythm is demonstrated in a bird population living under unusual light regimes—the nearly continuous light of an arctic summer.

Discussion of proximate explanations for the daily song pattern is hampered by the lack of published information on the breeding behavior of Golden-crowned Sparrows. However, much is known about the annual cycle of the closely related White-crowned Sparrow (*Zonotrichia leucophrys*) and we assume parallels in the breeding behavior of these two species. Consequently, we assume that singing was done by males and served as a territorial advertisement, although other functions also are possible.

The relatively short period of active singing—nine weeks—suggests a compressed breeding cycle as Lewis (1971) suggested for *Z. l. gambelii.* This is implied by the immediate occurrence of maximum song rates during the first week when males arrived on the breeding ground and by the cessation of song within one week in July. (Numerous independently foraging juveniles also were seen at this time, indicating the end of the breeding season.)

From week to week, grand mean song rates differed significantly only once (2 June vs. 9 June), other than the last two weeks of the breeding season. The behavioral meaning of this early season difference is unclear. Records for five nests showed that territories already had been established but eggs had not been laid. The decrease in singing may have coincided with pair formation, assuming a 7–10 day

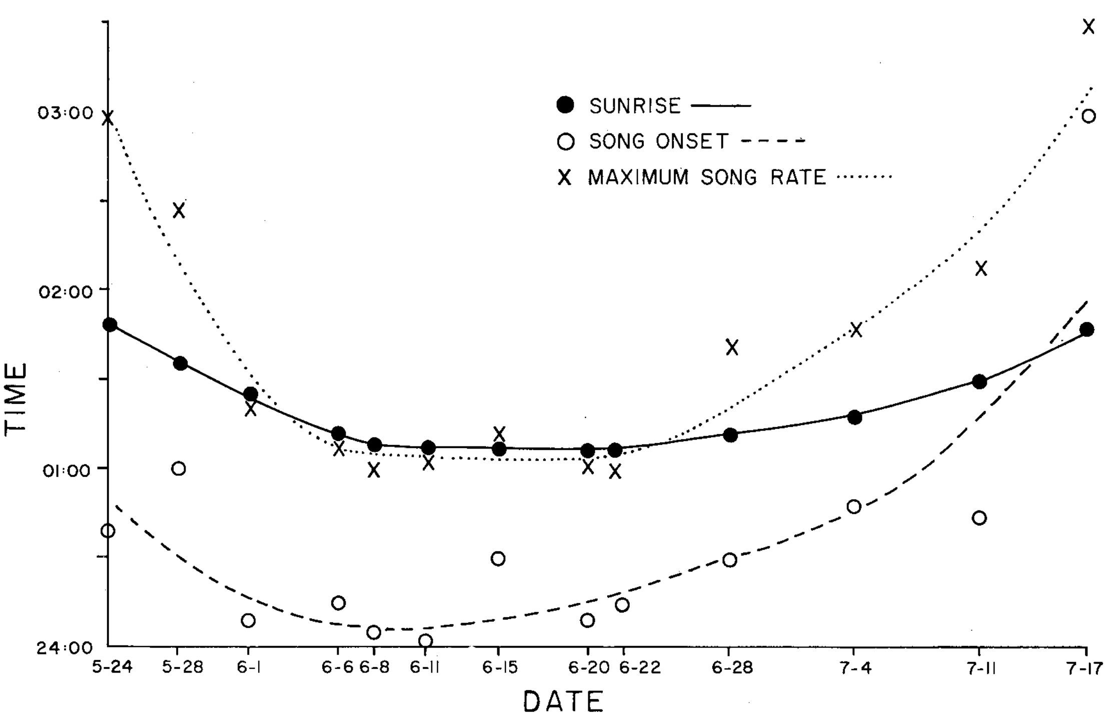

FIGURE 2. The relationship between sunrise (nautical sunrise, local standard time), the time of song onset, and the time of the maximum song rate on 12 arbitrarily chosen days. Curves are fitted by eye.

interval between pair formation and first egg laying as occurs in *Z. l. pugetensis* (Lewis 1971). The significant difference in song rates between the last two weeks, 6 July vs. 13 July, was expected as this coincided with the end of the breeding season. The lack of a significant difference in song rates between the first two weeks is another indication of the rapid onset of breeding activities.

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EFFECTS OF ALTERED PHOTOPERIOD ON MIGRATORY ORIENTATION IN WHITE-THROATED SPARROWS (*ZONOTRICHIA ALBICOLLIS*)

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A variety of orientation cues are available to nocturnal migratory birds. Perhaps best established is the use of the information in the celestial sky. Emlen (1967) and Gauthreaux (1969) have shown that the apparent nightly movement of the stars caused by the earth's rotation aids in providing a bird a north-south axis or compass information. Early planetarium experiments (Sauer and Sauer 1960) suggested that the seasonal reversal of directions was due to recognition of changing star patterns during the year. However, subsequent experiments (Emlen 1967) failed to confirm these results and instead suggested that internal rather than external factors were important in initiating migratory orientation.

Rowan's experiments (1929, 1930, 1932) with Dark-eyed Juncos (*Junco hyemalis*) and Common Crows (*Corvus brachyrhynchos*) suggested a physiological basis to orientation. Emlen (1969a) tested the orientation of Indigo Buntings (*Passerina cyanea*) in opposite migratory conditions simultaneously under a "spring" planetarium sky. His results indicated that birds which were prepared for a fall migration did orient to the south even when allowed to view a sky appropriate for spring migration. He concluded that annual changes in the physiological condition, not environmental cues, contributed to the major reversals in migratory orientation. The present study further tests this conclusion with White-throated Sparrows (*Zonotrichia albicollis*) under a natural celestial sky instead of in a planetarium. In addition, all tests were conducted during the fall migratory season instead of the spring (the latter being when Emlen 1969a carried out his study).

METHODS

Two groups of White-throated Sparrows were brought into spring and autumn migratory condition simultaneously by modifying their photoperiod. The annual cycle in the experimental group was altered so that the physiological condition (spring) of these birds conflicted with the potential seasonal information in the autumn celestial sky. This group was captured with mist nets from migrating flocks in the autumn of 1974. These birds were kept in small individual cages in an outdoor aviary under the natural photoperiod until December 1974. They were then moved to an environmental chamber and maintained on 9 h light and 15 h dark (LD 9:15) until the testing period in September 1975. On 21 September 1975, 15 days before the first test, they were exposed to a spring photoperiod (LD 15:9). Weise (1962) found that White-throated Sparrows could be maintained indefinitely in a winter physiological condition as long as they were kept on short days. Subsequent exposure to long days induced a spring migratory and breeding condition.

A "control" group of birds was captured in May 1975 during spring migration. These birds were kept in individual cages in an outdoor aviary under a natural photoperiod for the entire duration of the experiment. Each bird in both groups was examined approximately every 10 days for weight, fat deposits, and molt status. The results of these measurements are summarized in Figure 1.

Under the extended winter photoperiod, birds in the experimental group did not attain the spring