A SOLAR TIME CLASSIFICATION FOR DATA WITH DIURNAL VARIABILITY

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INTRODUCTION

Many biological and meteorological variables undergo systematic diurnal changes. Common examples from each field are bird weights and temperature lapse rate. The most rapid and significant changes are governed by the times of sunrise and sunset in contrast to many human activities controlled by an arbitrary clock time. Thus, maximum understanding of diurnal variability in natural systems can only be achieved by use of a time system based on those events that trigger the initiation and direction of diurnal changes.

Weights of birds captured in banding operations have been recorded by the writer since 1939. Early unpublished studies of these data showed the need for an improved chronology for classifying weights with reference to time of day and a system was devised for daylight hours only nearly 20 years ago (unpubl. data). This solar time classification was extended to cover both day and night (Singer and Raynor, 1958) and used in a number of meteorological studies (Singer and Raynor, 1957; Singer and Nagle, 1962; Raynor et al., 1974). Because these papers are not generally known to the ornithological community and studies using the classification are being prepared for publication, a brief description of the system is given here with a new graphical display and an example of its use.

SOLAR TIME CLASSIFICATION

The solar time system for 40°N 75°W is illustrated in Figure 1. The day is divided into four periods bounded by sunrise, midday, sunset, and midnight. Each period is assigned a code number that constitutes the first digit of a two-digit number. The second digit indicates the hour within the period counting in both directions from sunrise and sunset. The graph may be entered with the date and time to find the correct solar time.

The system is also presented in tabular form in Table 1. Here, major fractions of an hour are listed as a full hour. Thus, the table is only accurate to within one-half hour but further subdivision did not appear practical. If greater precision is desired, Figure 1 may be used.

Due to the variation in length of daylight and dark throughout the year, 30 solar hours are possible at this latitude although only 24 can occur on any one day. During June, for example, there are 15 daylight hours and 9 nighttime hours, while in December, the numbers are reversed. However, 18 solar hours occur throughout the year and those hours that occur only at certain seasons occur during the middle of the day or night when conditions are changing least. Thus, data from these hours can be grouped or averaged if preservation of 24 "hours" per day seems desirable. The system was designed for maximum usefulness near sunrise and sunset when most important changes take place.

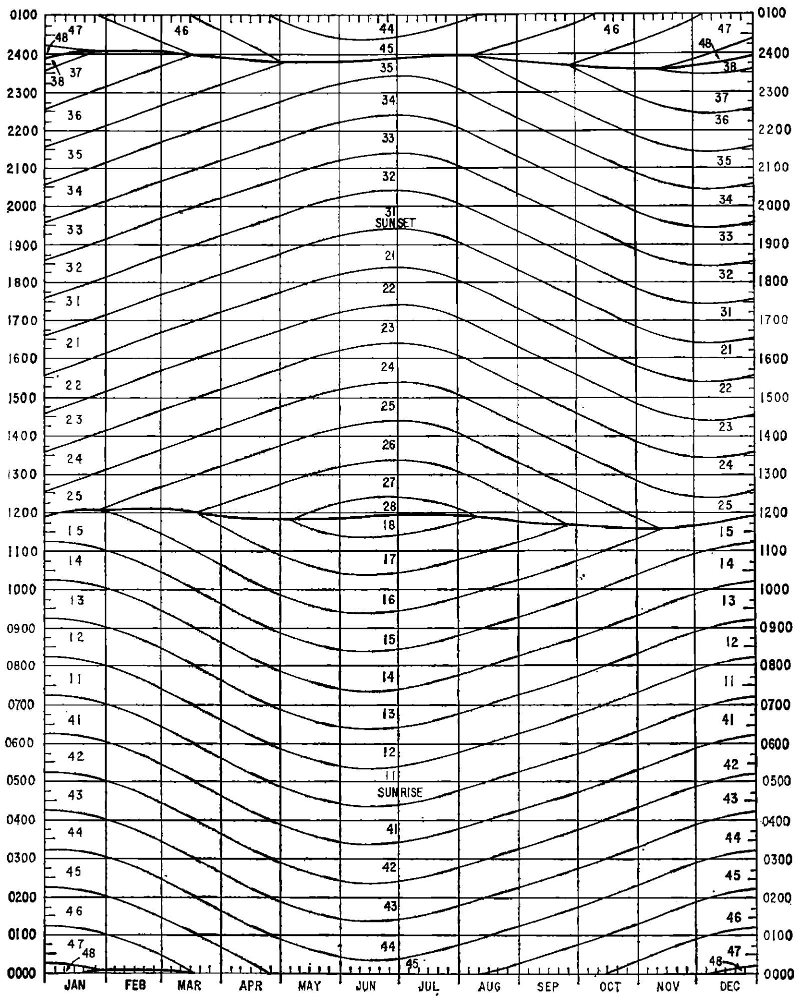

FIGURE 1. Solar time system for 40° N and 75° W. Photo courtesy of Brookhaven National Laboratory.

Obviously, a separate solar time index must be constructed for each significant change in latitude and longitude within each time zone. Inasmuch as time zones vary widely from their nominal 15-degree width to follow political boundaries, local standard time at the same latitude may differ by more than one hour from solar time within a single time zone. At high latitudes, more solar hours will occur during the year, and towards the equator, fewer. At that location, the difference between local time and solar time would not be significant.

Table I. Annual Solar Time Index [a]

Hour Ending (EST)	Jan. 1-15	Jan. 16-31	Feb. 1-15	Feb. 16-28	Mar. 1-15	Mar. 16-31	Apr. 1-15	Apr. 16-30	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	Aug. 1-15	Aug. 16-31	Sept. 1-15	Sept. 16-30	Oct. 1-15	Oct. 16-31	Nov. 1-15	Nov. 16-30	Dec. 1-15	Dec. 16-31
0100	47	47	47	47	46	46	45	45	45	45	44	44	45	45	45	45	45	46	46	46	46	47	47	47
0200	46	46	46	46	45	45	44	44	44	44	43	43	44	44	44	44	44	45	45	45	45	46	46	46
0300	45	45	45	45	44	44	43	43	43	43	42	42	43	43	43	43	43	44	44	44	44	45	45	45
0400	44	44	44	44	43	43	42	42	42	42	41	41	42	42	42	42	42	43	43	43	43	44	44	44
0500	43	43	43	43	42	42	41	41	41	41	11	11	41	41	41	41	41	42	42	42	42	43	43	43
0600	42	42	42	42	41	41	11	11	11	11	12	12	11	11	11	11	11	41	41	41	41	42	42	42
0700	41	41	41	41	11	11	12	12	12	12	13	13	12	12	12	12	12	11	11	11	11	41	41	41
0800	11	11	11	11	12	12	13	13	13	13	14	14	13	13	13	13	13	12	12	12	12	11	11	11
0900	12	12	12	12	13	13	14	14	14	14	15	15	14	14	14	14	14	13	13	13	13	12	12	12
1000	13	13	13	13	14	14	15	15	15	15	16	16	15	15	15	15	15	14	14	14	14	13	13	13
1100	14	14	14	14	15	15	16	16	16	16	17	17	16	16	16	16	16	15	15	15	15	14	14	14
1200	15	15	15	15	16	16	17	17	17	17	18	18	17	17	17	17	17	16	16	16	16	15	15	15
1300	25	25	25	26	26	26	26	27	27	27	27	27	27	27	27	27	26	26	25	25	25	25	24	25
1400	24	24	24	25	25	25	25	26	26	26	26	26	26	26	26	26	25	25	24	24	24	24	23	24
1500	23	23	23	24	24	24	24	25	25	25	25	25	25	25	25	25	24	24	23	23	23	23	22	23
1600	22	22	22	23	23	23	23	24	24	24	24	24	24	24	24	24	23	23	22	22	22	22	21	22
1700	21	21	21	22	22	22	22	23	23	23	23	23	23	23	23	23	22	22	21	21	21	21	31	21
1800	31	31	31	21	21	21	21	22	22	22	22	22	22	22	22	22	21	21	31	31	31	31	32	31
1900	32	32	32	31	31	31	31	21	21	21	21	21	21	21	21	21	31	31	32	32	32	32	33	32
2000	33	33	33	32	32	32	32	31	31	31	31	31	31	31	31	31	32	32	33	33	33	33	34	33
2100	34	34	34	33	33	33	33	32	32	32	32	32	32	32	32	32	33	33	34	34	34	34	35	34
2200	35	35	35	34	34	34	34	33	33	33	33	33	33	33	33	33	34	34	35	35	35	35	36	35
2300	36	36	36	35	35	35	35	34	34	34	34	34	34	34	34	34	35	35	36	36	36	36	37	36
2400	37	37	37	36	36	36	36	35	35	35	35	35	35	35	35	35	36	36	37	37	37	37	38	37

[a] The first figure of the index is an indicator identifying the period as follows:

1. Hours after sunrise
2. Hours before sunset
3. Hours after sunset
4. Hours before sunrise

The second figure gives the hour number within the period.

The index for any location is readily assembled from a table or graph of local times of sunrise and sunset. For valid comparison between users of the system, it is recommended that the index be referenced to local standard time and not to daylight savings time which seems subject to frequent political manipulation.

APPLICATION

Table 2 shows the average weight of a hypothetical bird for each month for all hours from midnight to noon. This bird is typical in having both a diurnal and an annual weight variation. The period of weight gain between the morning minimum and the midday plateau is enclosed by solid lines. The upper line approximates the time of sunrise.

TABLE 2.
Average weight of a hypothetical bird by hour and month for the hours from midnight to noon.

	Month											
Hour	J	F	M	A	M	J	J	A	S	O	N	D
00:00	23	23	22	22	20	20	20	20	21	21	22	23
01:00	22	22	21	21	20	19	19	19	20	21	22	22
02:00	22	22	21	21	20	19	19	19	20	21	22	22
03:00	22	22	21	20	19	18	18	19	20	21	21	22
04:00	22	22	20	20	19	18	18	18	19	20	21	22
05:00	21	21	20	20	19	19	19	18	19	20	21	21
06:00	21	21	20	21	20	20	20	19	19	20	21	21
07:00	21	21	21	22	21	21	21	20	20	21	21	21
08:00	22	22	22	23	22	22	22	21	21	22	22	21
09:00	23	23	23	24	23	22	22	22	22	23	23	22
10:00	24	24	24	24	23	22	22	22	23	24	24	23
11:00	25	25	24	24	23	22	22	22	23	24	25	24
12:00	25	25	24	24	23	22	22	22	23	24	25	25

Suppose we wish to analyze the morning increase in weight using data collected throughout the year. If we average weights for each clock hour (0500, 0600, etc.) we find that weight gain ranges from 0.3 to 0.9 and averages 0.54 g/hr. If we classify the data by solar time, we find that gain ranges from 0.9 to 1.0 g/hr with a mean of 0.98. The same result could, of course, be obtained by finding gain per hour for each month separately, choosing those hours between the morning minimum and the beginning of the midday plateau and then averaging these results. However, in practice, weights are obtained from many different individuals at random times and the analyst may not know *a priori* either the pattern or the magnitude of the diurnal variability. Thus, solar time can relate diurnal changes unequivocally to the solar cycle and proves a useful tool for systematic studies of diurnal variability in any natural phenomenon.

Some previous studies of bird weights have classified the data into broad time groups such as morning and afternoon. The present system allows data to be classified to the nearest hour relative to sunrise or sunset. If greater time precision is desired, the data can be classified with reference to minutes before or after sunrise or sunset expressed as local solar time. However, this method produces so many time categories that few investigators are likely to obtain enough data to give statistically significant numbers of cases in each.

Suggested applications in ornithology in addition to study of bird weights are daily activity patterns such as time of entrance to and leaving roosts, beginning and cessation of song, and feeding. Beginning and ending of migratory flights are at least partially triggered in similar fashion.

LITERATURE CITED

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