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CYCLIC CHANGES IN LIVER AND SPLEEN WEIGHTS IN MIGRATORY WHITE-CROWNED SPARROWS

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This paper reports part of a study of physiologic changes paralleling the reproductive cycle in a migratory race of the White-crowned Sparrow (*Zonotrichia leucophrys*). The cycle in the testis and concomitant changes in body weight, subcutaneous fat, and molt have been worked out for *Zonotrichia leucophrys gambelii* on its wintering grounds at Davis and Santa Barbara, California (Blanchard and Erickson, 1949), and for *Z. l. pugetensis* on both wintering and breeding grounds (Blanchard, 1941). It is proposed now to probe deeper into the question of metabolic changes, to learn something of their direction and magnitude and, if possible, of the endocrine mechanisms involved.

Analysis of seasonal changes in liver weight constituted the first point of attack, since they can be recorded without complicated apparatus and are likely to reflect more deep-seated endocrine changes hard to detect in wild animals in the field. Spleen weights were also recorded to check whether or not changes paralleling those in the liver, such as Riddle (1928) found in Ring Doves, occur in the White-crowned Sparrow.

Although liver and spleen weights have been analyzed for a number of captive species (for example Riddle, 1928 and 1929; Kirkpatrick, 1944), few data are available for wild birds in their native environments. In this connection, the material obtained from Mountain Village, Alaska, while disappointingly meager owing to the need to save most of the sparse breeding population there for behavior studies, is especially valuable.

ACKNOWLEDGEMENTS

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I wish to express my appreciation to Mr. Henry C. Kyllingstad for allowing me to draw upon his banding records and observations of White-crowned Sparrows in Alaska, and to Mr. and Mrs. George Sheppard, of Mountain Village, Alaska, for extending to me the hospitality of their home.

I am indebted to my husband, Nels Oakeson, for drawing the graphs and helping with the calculations for the tables, and to Dr. Mary M. Erickson, for help in collecting material at Santa Barbara and for criticism of the manuscript.

MATERIAL AND METHODS

One hundred and ninety-one specimens of *Z. l. gambelii* were taken at approximately two-week intervals from late September through April at Santa Barbara, California (lat. 34°30′N.). The material for January through April was collected in three successive years (1949-1951), that for September through December, in 1949 alone. Seventeen birds were collected from May through July, 1950, at Mountain Village, Alaska (lat. 62°07′N.). No material is available for August.

All birds from Santa Barbara were trapped at dawn at points where the flocks went to feed immediately upon leaving their roosts. Except for a few seeds of bait, therefore, the birds had eaten nothing since the evening before. Two to fifteen minutes after they were trapped the birds were killed, put on ice, and taken to the laboratory for dissection. Body weight, amount of fat, diameters of testis or of ovarian follicles, and stage of molt were recorded. Between one-half and two hours after death, the liver, without gallbladder, and spleen were weighed fresh, on a Roller-Smith precision balance. The gonads and other endocrine glands were fixed in Bouin's and prepared for histological examination.

At Mountain Village most of the birds were shot, since it was imperative in May to get new arrivals, and trapping would have involved several days' delay for the birds to discover the bait. Specimens were cooled en route back to headquarters by the icy wind, which blew almost continuously. Data identical with those for the Santa Barbara birds were recorded, and the time elapsing between death and weighing averaged about the same. The livers and spleens were weighed on a pan balance accurate to one milligram.

Measurements of structures least subject to seasonal wear, that is, tarsus, middle toe and beak, were made to check whether the Santa Barbara birds differed significantly from those at Mountain Village in mean values for body dimensions.

In the statistical analysis, the formula used for comparison of means of two samples is that given by Simpson and Roe (1939:193):

$$\sigma_d = \sqrt{\frac{\Sigma(d_1^2) + \Sigma(d_2^2)}{N_1 N_2}}$$

In April, birds which had wintered on the spot were distinguished by banding and observation from those already in migration from more southern wintering grounds. About one-fourth of the birds taken at Santa Barbara in April had been banded there in winter by Dr. Mary M. Erickson. The unbanded birds in the same flocks with and trapped at the same time as the banded individuals had undoubtedly also wintered on the spot. In addition, many banded birds were retrapped in April, released and watched, to determine the dates of departure. Individuals taken after all banded birds had disappeared from the trapping grounds were presumed to be migrants from more southern wintering grounds. Three males and two females included in the "fat and very fat" April birds in tables 2 and 3 are in this category. In tables 4 and 5 they are grouped separately.

Observation and banding were also used to identify the Mountain Village specimens as members of the local breeding population. The first birds to reach Mountain Village in May, 1950, began at once to establish territories. Those collected were, up to the moment of death, behaving like others color-banded and subsequently followed throughout the nesting season. One male had been hatched nearby two years before. In July, 1948, it had been banded as a juvenile by Mr. H. C. Kyllingstad about a mile from where I collected it in 1950.

From September through early April immature White-crowned Sparrows can be distinguished by their brown heads, and are shown in the figures by hollow dots. Freshly-molted birds taken in mid-April may include some which had not bred, since the immatures have by then acquired adult plumage. The present material gives no hint of consistent differences between organ weights of adults and those of immatures. The latter are omitted from all but the first table, since their numbers are too small to provide statistically significant data.

RESULTS

Although the ensuing discussion involves comparison of wintering Santa Barbara birds with those breeding at Mountain Village, no identity of population is implied. There is little chance that a White-crowned Sparrow of the race *gambelii* banded in winter will ever be found on its breeding grounds, although this actually happened in the case of two individuals of the related race, *Z. l. pugetensis* (Clabaugh, 1929; Abbott, personal communication). Failing this piece of luck, we shall never know precisely where members of a given winter flock of *gambelii* go to nest. By analogy with *pugetensis*, however (Blanchard, 1942), there is reason to think that Gambel Sparrows flocking within a few hundred miles of the southern extreme of the wintering range come from far northern breeding grounds and therefore that both at Santa Barbara and Mountain Village we are dealing with strongly migratory populations, which may nest in latitudes not far apart. It is at least a cogent possibility that our necessarily composite data approximate the cycle in individual sparrows of far northern breeding populations.

LIVER WEIGHTS

Males.—The results are graphed in figures 1-3 and are summarized in tables 1, 2, 4, 6 and 7. In tables 1 and 2 monthly means are given. In table 4 the data are grouped into periods according with the broad divisions of the annual cycle.

Figure 3 shows a rise in mean values of absolute liver weights in adult males from November, 1949, through April, 1950. With the exception of February, this is also true if material for three seasons is included in the monthly averages for January through April (table 2). Table 4 shows a consistent rise for successive periods (I through IV) of the annual cycle. Table 6 shows that the increase of liver weights of fat April males, on the verge of migration, over November males is 30.0 per cent. A still higher figure is obtained if October is used as the starting point, but migration is still in progress in early October, and some of the birds collected then may not have belonged to the local wintering population.

Between the time just before departure from Santa Barbara and that when males arrived on their breeding grounds at Mountain Village, a period of about six weeks in 1950, the liver weights show a sharp drop (figs. 1 and 3, and tables 2 and 4). If the mean value for all April males with adult plumage is compared with that for males taken in Mountain Village in May, 1950 (table 2), the percentage drop is 29.4. The value for 1950 alone is comparable: from the mean for April (1089.0 mgm.) to that for May (775.4 mgm.), the percentage drop is 28.8. Table 6 shows a still greater decrease from the fat and very fat April birds wintering at Santa Barbara to the birds collected in May at Mountain Village (30.7 per cent). This figure nearly balances the 30.0 per cent increase from November to April.

Table 7 shows that the differences between the means for November and the spring months, and for April and May, are highly significant. (The method used is reliable only if $N_1 + N_2 = 25$ or more, so the pairs of months or periods with joint totals less

Table 1

Monthly Means of Body, Liver and Spleen Weights

MALES

Month	Number All	Number Ad.	Number Im.	Mean total body weight (gm.) All birds	Adults	Immatures	Mean liver weight (mgm.) All birds	Adults	Immatures	Mean spleen weight (mgm.) All birds	Adults	Immatures
Sept.	1	1	....	26.3	26.3	....	769	769	....	50	50	......
Oct.	11	9	2	26.28	26.50	25.30	842.1	842.0	842.5	33.1	33.7	30.5
Nov.	12	10	2	25.80	26.03	24.65	866.3	850.6	945.0	33.7	35.8	24.5
Dec.	5	5	....	26.46	26.46	....	915.2	915.2	....	50.4	50.4	......
Jan.	29	18	11	26.67	27.02	26.11	990.0	984.8	998.6	46.3	41.4	55.2
Feb.	9	7	2	26.29	25.97	27.40	917.4	890.7	1011.0	37.8	35.0	47.5
Mar.	33	21	12	27.29	27.32	27.24	1025.5	1043.1	994.8	46.8	46.8	46.9
Apr.	35	32	3	28.31	28.42	27.17	1084.3	1097.8	940.3	40.1	39.2	50.0
May	8	8	....	25.94	25.94	....	775.4	775.4	....	19.6	19.6	......
June	1	1	....	28.9	28.9	....	951	951	....	17	17	......
July	2	2	....	26.00	26.00	....	847.5	847.5	....	28.5	28.5	......
Total	146	114	32									

FEMALES

Month	Number All	Number Ad.	Number Im.	Mean total body weight (gm.) All birds	Adults	Immatures	Mean liver weight (mgm.) All birds	Adults	Immatures	Mean spleen weight (mgm.) All birds	Adults	Immatures
Sept.	1	1	....	23.6	23.6	....	850	850	....	56	56	......
Oct.	3	3	....	24.27	24.27	....	799.7	799.7	....	30.3	30.3	......
Nov.	5	3	2	24.44	24.47	24.40	853.0	886.0	803.5	32.8	27.7	40.5
Dec.	2	1	1	21.60	21.7	21.5	736.0	666	806	25.0	19	31
Jan.	6	5	1	23.67	23.82	22.9	832.7	862.0	686	31.4	24.5	59
Feb.	3	1	2	23.20	23.8	22.90	800.3	830	785.5	38.7	38	39.0
Mar.	10	9	1	24.80	24.93	23.6	946.0	957.7	841	37.9	32.8	79
Apr.	26	25	1	26.08	26.08	26.0	1041.5	1039.0	1106	34.9	34.6	42
May	3	3	....	25.50	25.50	....	979.7	979.7	....	32.3	32.3	......
June	....	....	....	....	....	....	....	....	....	......	......	......
July	2	2	....	22.90	22.90	....	827.5	827.5	....	24.0	24.0	......
Total	61	53	8									

than 25 are omitted). The variation between the mean values for livers of adult November and March birds, for example, cannot be due to accidents of sampling, since the difference divided by its standard error is greater than 3: $(\frac{d}{\sigma_d} = 4.13)$. The difference between means for November and April is of course even greater and the significance still higher $(\frac{d}{\sigma_d} = 4.63)$. The most significant difference is that between the mean for all April birds and that for the Mountain Village birds collected in May: $(\frac{d}{\sigma_d} = 5.35)$.

What is important from the point of view of possible metabolic reserves for migration is that the ratios of liver to total body weight show seasonal variations parallel

Table 2

Monthly Means of Liver Weights (in mgm.) of Adults for All Years

Month	No.	Extremes	Mean	σ_m	σ	$\sigma\sigma$	Ratio, liver to body weight
MALES							
September	1	....	(769)	......	....	......	2.92
October	9	653–1010	842.0	40.2	120.6	28.4	3.18
November	10	675– 993	850.6	30.8	97.4	21.8	3.27
December	5	744–1112	915.2	63.8	142.3	45.0	3.46
January	18	805–1254	984.8	30.3	128.5	21.4	3.64
February	7	761–1006	890.7	30.3	80.4	21.5	3.42
March	21	739–1238	1043.1	28.7	131.6	20.3	3.82
April							
(a) all birds	32	843–1403	1097.8	28.3	159.9	20.0	3.86
(b) no, little, and moderately fat	20	859–1355	1067.2	31.1	139.2	22.0	3.91
(c) fat, and very fat	12	843–1403	1148.9	51.4	178.0	36.5	3.79
May	8	666–1058	775.4	42.2	118.9	29.7	2.99
June	1	....	(951)	......	....	......	3.29
July	2	820– 875	847.5	19.4	27.5	13.8	3.26
Total	114						
FEMALES							
September	1	....	(850)	......	....	......	3.60
October	3	782– 818	799.7	8.5	14.7	6.0	3.30
November	3	778– 956	886.0	44.7	77.5	31.8	3.62
December	1	....	(666)	......	....	......	3.07
January	5	741–1050	862.0	51.5	114.9	36.4	3.62
February	1	....	(830)	......	....	......	3.49
March	9	630–1309	957.7	70.3	210.8	49.7	3.84
April							
(a) all birds	25	749–1340	1039.0	32.0	159.7	22.6	3.98
(b) no, little, and moderately fat	16	749–1340	996.4	35.8	143.1	25.3	3.95
(c) fat, and very fat	9	819–1320	1114.7	53.1	159.4	37.6	4.04
May	3	867–1177	979.7	80.9	140.0	57.4	3.84
June	....	....	....	......	....	......	......
July	2	767– 888	827.5	43.2	60.5	30.3	3.61
Total	53						

with those already described, that is, the highest and lowest mean values for this ratio coincide with the beginning and end of migration, respectively (figs. 1 and 3 and table 2). The mean value for all April birds with adult plumage (3.86), for example, is higher than that for January adults (3.64) and for November adults (3.27) despite the fact

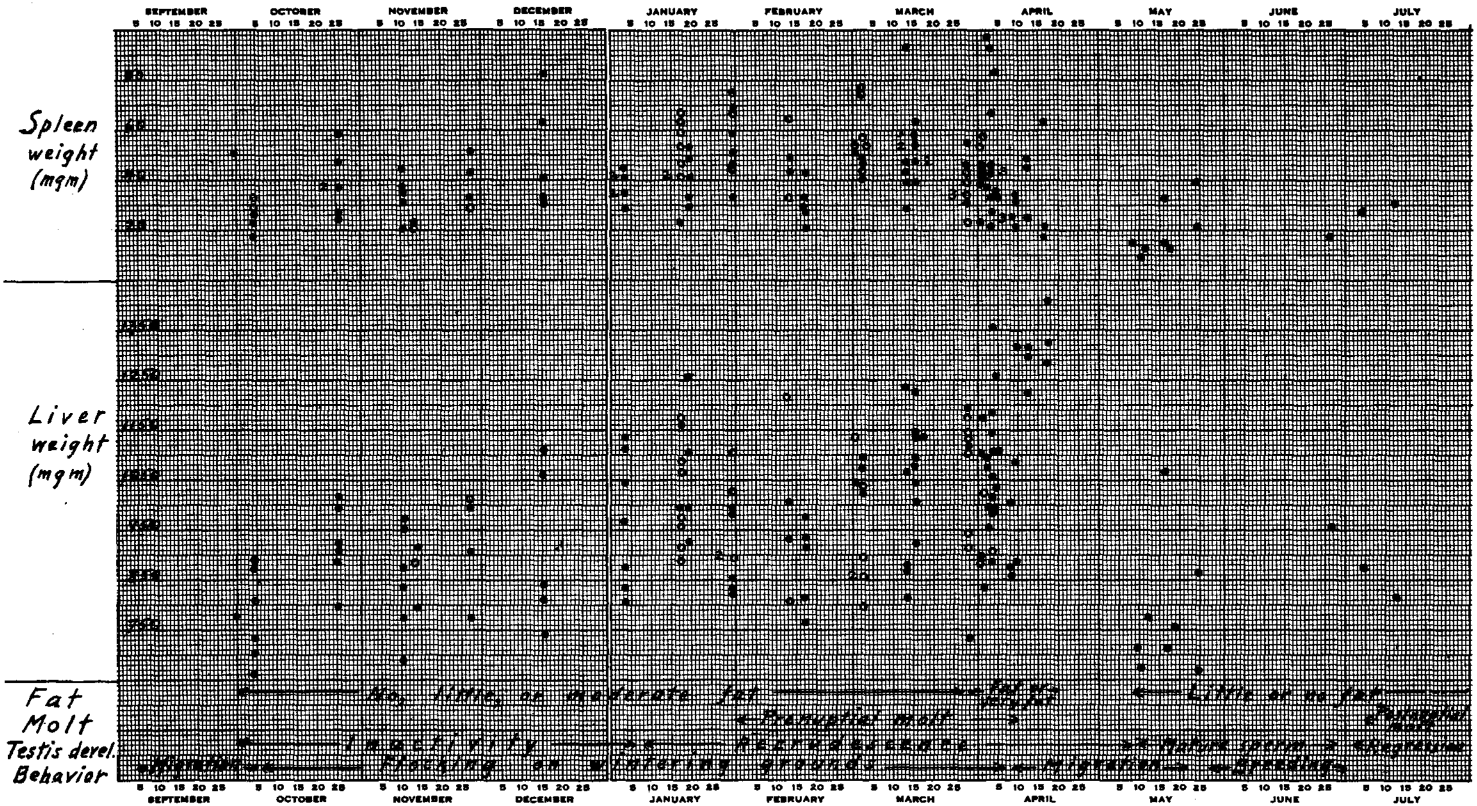

Fig. 1. Liver and spleen weights in relation to other elements of the annual cycle in males of *Zonotrichia leucophrys gambeli.* Solid dots, adults; circles, immatures. September-April, specimens taken at Santa Barbara. May-July, specimens taken at Mountain Villege, Alaska.

that the April value includes 12 fat and vary fat birds whose mean body weight (30.30 gm.) is 10.8 per cent higher than that of the birds taken in January and 14.0 per cent higher than that of the adults collected in November. If the ratio of liver to body weight for only those April birds with no, little, or moderate amounts of fat is used (3.91), the contrasts with November and January are more marked.

Table 3

Monthly Means of Spleen Weights (in mgm.) of Adults for All Years

Month	No.	Extremes	Mean	σ_M	σ	σ_σ	Ratio, spleen to body weight
MALES							
September	1	....	(50)	....	......	....	0.19
October	9	17–58	33.7	4.0	12.1	2.8	0.14
November	9	20–51	35.8	3.2	9.7	2.3	0.14
December	5	31–84	50.4	9.2	20.6	6.5	0.19
January	18	22–69	41.4	2.7	11.4	1.9	0.15
February	7	22–49	35.0	3.3	8.7	2.3	0.13
March	20	28–63	46.8	0.6	2.8	0.4	0.17
April							
(a) All birds	32	17–97	39.2	3.5	19.7	2.5	0.14
(b) no, little, and moderately fat	20	21–97	44.5	5.1	22.7	3.6	0.16
(c) fat, and very fat	12	17–45	30.5	2.3	8.0	1.6	0.10
May	8	9–38	19.6	3.5	9.9	2.5	0.08
June	1	....	(17)	......	......	....	0.06
July	2	27–30	28.5	1.1	1.5	0.8	0.11
Total	112						
FEMALES							
September	1	....	(56)	....	......	....	0.24
October	3	27–34	30.3	1.7	2.9	1.2	0.12
November	3	22–37	27.7	3.9	6.7	2.7	0.11
December	1	....	(19)	....	......	....	0.09
January	4	14–36	24.5	4.4	8.9	3.2	0.10
February	1	....	(38)	....	......	....	0.16
March	8	23–51	32.8	3.0	8.5	2.1	0.13
April							
(a) all birds	24	16–58	34.6	1.9	9.5	1.4	0.13
(b) no, little, and moderately fat	15	25–58	38.3	2.1	8.3	1.5	0.15
(c) fat, and very fat	9	16–40	28.3	2.6	7.9	1.9	0.10
May	3	23–41	32.3	4.3	7.4	3.0	0.13
June	....	....	......	....	......	....	......
July	2	19–29	24.0	3.5	5.0	2.5	0.10
Total	53						

The group with the highest value for this ratio consists of the three fat males collected on April 13, 1951, several days after the last banded wintering birds had been seen. As already explained, these were presumably birds from more southern wintering grounds passing through Santa Barbara on the first lap of the journey north. Their ratios of liver to body weight averaged 4.11. The ratio for the eight Mountain Village males collected in May (2.99) is lower than that of any of the April values, despite their lower mean body weight (25.94 gm. as compared with 28.42 gm. for all April adults, or 30.30 gm. for fat April adults).

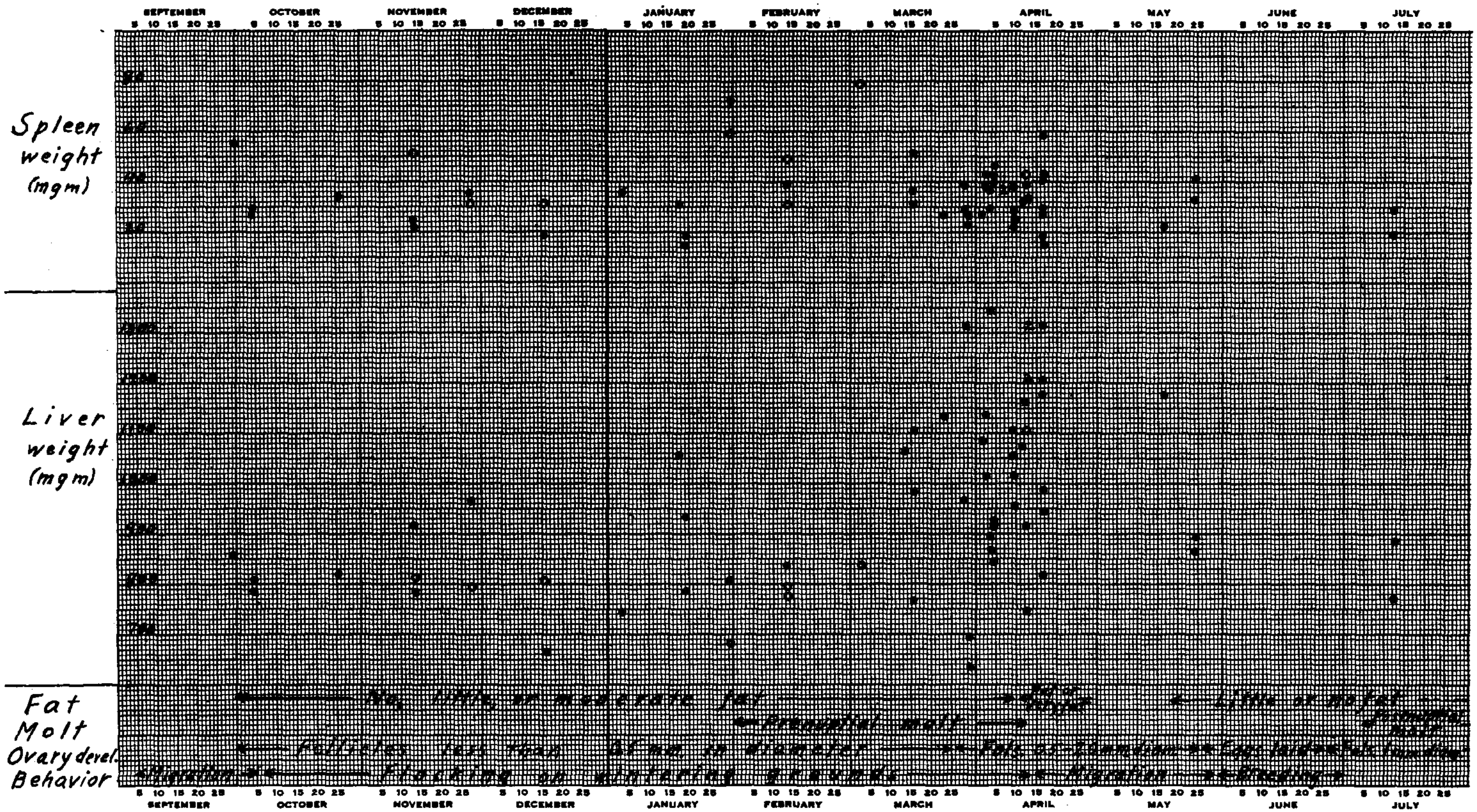

Fig. 2. Liver and spleen weights in relation to other elements of the annual cycle in females. For explanation of symbols, see figure 1.

There is some indication that a decrease in ratio of liver to body weight may also occur between July and September but the numbers involved are too small to be conclusive.

Females.—The results are graphed in figure 2 and summarized in tables 1, 2, 5 and 6. Although the much less abundant material for females justifies no detailed comparisons with the males, a few points are worth brief mention: The means for females for abso-

Table 4

Means of Body, Liver and Spleen Weights and Testis Volumes for Successive Periods of the Annual Cycle in Adult Males

Period	No.	Body weight (gm.)	Liver weight (mgm.)	Spleen weight (mgm.)	Testis volume ($mm.^3$)
I. Arrival on wintering grounds (Sept.-Oct.)	10	26.48±0.54	834.7±36.9	35.3±3.9	0.59±0.09
II. Wintering (Nov.-Dec.)	14	26.30±0.14	878.2±32.2	41.0±4.3	0.46±0.04
III. Preparation for migration: gonad recrudescence, molt and assumption of fat.					
A. Early (Jan.-March)	46	27.00±0.21	997.1±19.8	43.9±1.9	0.76±0.08
B. Middle (April; birds with no, little, or moderate fat)	20	27.30±0.35	1067.2±31.2	44.5±5.1	1.47±0.08
C. Late (April; fat or very fat birds)	9	30.04±0.78	1106.0±57.3	30.1±2.9	1.38±0.02
IV. Start of migration (April; migrants passing through Santa Barbara)	3	31.07±0.45	1277.7±16.5	32.0±3.2	1.88±0.43
V. Arrival on breeding grounds (May)	7	25.77±0.31	735.0±23.6	17.6±3.4	151.97±22.26
VI. Breeding (June)	1	28.9	951	17	266.1
VII. Gonad regression and molt (July)	2	26.00±0.29	847.5±19.4	28.5±1.1	17.93±1.43

Table 5

Means of Body, Liver and Spleen Weights and Follicle Diameters for Successive Periods of the Annual Cycle in Adult Females

Period	No.	Body weight (gm.)	Liver weight (mgm.)	Spleen weight (mgm.)	Diam. largest follicle (mm.)
I. Arrival on wintering grounds (Sept.-Oct.)	4	24.10±0.57	812.3±12.6	36.8±5.7	Less than 1
II. Wintering (Nov.-Dec.)	4	23.77±0.78	828.5±60.0	25.5±3.4	Less than 1
III. Preparation for migration:					
A. Early (Jan.-March)	15	24.48±0.36	917.2±47.3	30.6±8.2	Less than 1
B. Middle (April; birds with no, little or moderate fat)	16	25.23±0.77	996.4±35.8	38.3±2.1	Less than 1
C. Late (April; fat or very fat birds)	7	27.77±0.87	1136.3±61.9	26.3±2.9	Less than 1
IV. Start of migration (April; migrants passing through Santa Barbara)	2	26.95±0.47	1039.0±87.0	35.5±2.5	Less than 1
V. Arrival on breeding grounds (May)	3	25.50±0.61	979.7±80.9	32.3±4.3	1.86 mm.
VI. Breeding (June)	....	....	....	....	......
VII. Gonad regression and molt (July)	2	22.90±0.99	827.5±42.8	24.0±3.5	1.0 mm.

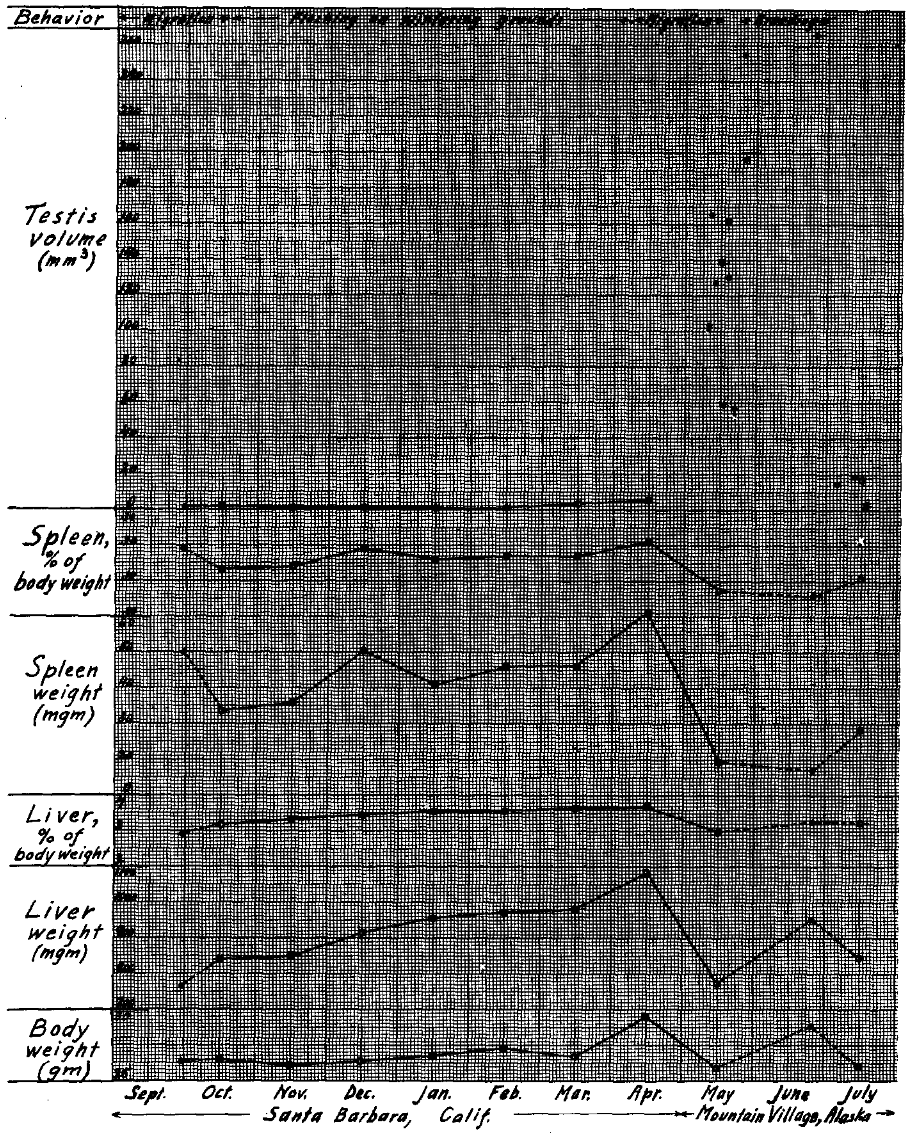

Fig. 3. Testis volume and monthly means of body weight and of absolute and relative organ weights for adult males in 1949–1950. Circles, monthly means; solid dots, individual specimens.

lute liver weights are slightly lower in five of the seven months for which more than one specimen is available (table 2). There is a parallelism between male and female, in the direction of the changes in mean liver weights between November and April, April and May, and period II and the subdivisions of period III (tables 2, 4 and 5). There is close approximation of values for both sexes for the percentage increase in liver weights between November birds and the fat and very fat April wintering birds (table 6). However, the percentage decrease between the fat April birds and those newly arrived at Mountain Village is of much smaller magnitude in females (table 6).

Females show a higher value for the ratio of liver to body weight in most months (table 2). This is especially striking for May. If more abundant material should substantiate this point and the lesser decrease of liver weight in the course of spring migration, a sexual difference in the response to the exigencies of migration may be indicated. It is also possible, however, that the females, which appear to migrate later, on the average, than do the males, may encounter less severe weather en route. Banding, observation and analysis of fat accumulation and progress of molt indicate that the first birds of a given winter flock to be ready to depart are males. Toward the end of the departure period, the birds taken from flocks not previously depleted by collecting are preponderantly females. Furthermore, in 1950 the males arrived at Mountain Village from five to fourteen days ahead of the females. Since the period of migration coincided with the steepest part of the curve of increase in daily mean temperature at Mountain Village, a difference of a week or two in arrival time meant the females were subjected to less severe weather conditions on the breeding grounds and, presumably, on at least the last lap of the journey north.

Table 6

Percentage Change in Mean Liver Weights

	Males		Females	
Month or category	Mean liver weight (mgm.)	Per cent change over preceding value	Mean liver weight (mgm.)	Per cent change over preceding value
November	850.6		886.0	
January	984.8	+15.8	862.0	− 2.7
March	1043.1	+ 5.9	957.7	+11.1
April (thin birds)	1067.2	+ 2.3	996.4	+ 4.0
April (fat wintering birds)	1106.0	+ 3.6	1136.3	+14.0
November	850.6		886.0	
April (fat wintering birds)	1106.0	+30.0	1136.3	+28.3
May (breeding birds)	775.4	−30.7	979.7	−13.8

The smaller numbers of females do not permit the statistical treatment shown for males. The difference between mean liver weights for November and for all April females is nearly significant ($\frac{d}{\sigma_d} = 2.71$). The difference between April and May is not statistically significant on the basis of the material available.

SPLEEN WEIGHTS

Spleen weights of individuals taken in the same month vary even more widely than do liver weights (table 3). Therefore, collection of further material is necessary before the following points can be considered as other than tentative.

Figure 3 shows a general rise in mean values for male spleen weights from October, 1949, through April, 1950. Table 4 shows an increase in mean spleen weights of males from period I through period IIIB, but this is not statistically significant on the basis of material now available. The females show increases in mean values from period II through period IIIB (table 5).

A statistically significant drop in mean spleen weights of males, between thin April birds and those newly arrived on the breeding grounds, parallels that of the liver (table 4). The difference between the two means is 26.9 mgm. and $\frac{d}{\sigma_d} = 3.06$. A decrease in the ratio of spleen to body weight occurs in the same segment of the cycle (table 3). In females, the decreases from thin April birds to May birds, both in absolute weights and in ratio of spleen to body weight, are too small to be significant.

In all months for which material is available except May, the females show lower values for mean absolute spleen weights than do the males. The same is true for relative spleen weights.

COMPARISON WITH RING DOVES

Our findings are similar to those reported by Riddle (1928) for Ring Doves in that in most months the females show higher means for relative liver weights than do the males. Our results differ from those obtained by Riddle in the following respects.

Table 7

Statistical Analysis of Differences in Liver Weight in Adult Males

Category	N_1	N_2	M_1	M_2	d	σ_d	$\frac{d}{\sigma_d}$
I. Pairs of consecutive months							
1. January and February	18	7	984.8	890.7	94.1	52.1	1.81
2. February and March	7	21	890.7	1043.1	152.4	52.7	2.89
3. March and April	21	32	1043.1	1097.8	54.7	41.9	1.31
4. April and May	32	8	1097.8	775.4	322.4	60.3	5.35
II. Pairs of non-consecutive months							
1. November and January	10	18	850.6	984.8	134.2	46.6	2.87
2. November and March	10	21	850.6	1043.1	192.5	46.6	4.13
3. November and April	10	32	850.6	1097.8	247.2	53.4	4.63
4. January and April (fat and very fat birds)	18	12	984.8	1148.9	164.1	56.0	2.93
III. Pairs of periods from table 4							
1. Nov.-Dec. and Jan.-March	14	46	878.2	997.1	118.9	40.1	2.96
2. Jan.-Mar. and fat April winter residents	46	9	997.1	1106.0	109.9	52.6	2.09
3. Jan.-Mar. and fat April migrants	46	3	997.1	1277.7	280.6	77.7	3.61

In the White-crowned Sparrow the mean absolute liver weights of females are in most months lower than those of males, whereas in Ring Doves, Riddle found they were usually higher. In the White-crowned Sparrow both absolute and relative spleen weights average lower in females than in males, except in May. In Ring Doves Riddle found that spleens of females were not only relatively, but also absolutely, larger than those of males at all seasons. In male White-crowned Sparrows the livers and spleens are heaviest in April and lightest in May, whereas in the nonmigratory Ring Doves, Riddle found these organs largest in spring and summer and smallest in autumn and winter.

DISCUSSION

While we have no direct evidence for migratory White-crowned Sparrows as to the nature of the changes in the liver responsible for its gain or loss of weight, it seems reasonable to assume from what is known of the physiology of other birds and mammals that seasonal variations in liver weight reflect changes in the food reserves available in times of emergency or heightened activity. The point to be emphasized is that the highest and lowest values for liver weight come at precisely the times when we should expect them, if the bird draws heavily upon reserves in the liver during the flight north.

This does not imply, however, that reserves in the liver gradually diminish from a maximum as the bird flies north and are not at least partially replenished en route. The studies of Irving and Paneak on arctic migrants (report presented at the Third Alaskan Science Conference, September, 1952) do not support such a concept. The seasonal changes in liver weight herein reported are rather to be viewed as one conveniently measurable sign of endocrine changes which precede, and accompany or immediately follow, migration.

The lighter liver and spleen weights of the new arrivals at Mountain Village as compared with those of the Santa Barbara birds could, however, be due, in part at least, to several factors not directly related to migration. Besides the difference in dates of collection, at least three other possible variables must be considered: differences in (1) collection methods; (2) genetic constitution of the Mountain Village and Santa Barbara populations; and (3) stage of reproductive cycle.

The first variable is probably relatively unimportant, at least with respect to the liver, since if variations in collection methods influenced the results to any appreciable degree, they probably minimized the difference between trapped and shot birds. The trapped birds struggled to escape during the few seconds they could see me coming, whereas the shot birds had to be nearly motionless and presumably unsuspicious, at least just before death, or I could not have shot them. The effects of different collection methods on spleen weights is more doubtful; the momentary fright of the trapped birds may perhaps have been matched by the bleeding of the shot birds, although the small size and number of shot entering the specimens caused very slight bleeding.

The second consideration, that of difference in genetic constitution, cannot be dismissed, although it seems highly improbable that such a difference could be responsible for so large a variation in liver weights as was found between April and May. It is worth noting that no external structural differences between the two groups have been detected. The color and pattern of plumage are identical, and the means of those body dimensions least subject to seasonal wear are so close as to suggest near identity. (Means for length of tarsus, middle toe and beak for 83 adult males from Santa Barbara are 22.18 ± 0.06, 15.73 ± 0.04, and 7.94 ± 0.02 mm., respectively. For 13 males from Mountain Village the means for these dimensions are 22.51 ± 0.12, 15.75 ± 0.08, and 7.95 ± 0.04 mm.). Nonetheless there is always the possibility that different breeding populations of the same race, however similar in external appearance, may differ in less obvious characters. Riddle (1947) has found significant differences in relative liver weights in races of Ring Doves developed in his laboratory, but these races also differ in a variety of readily observable characters.

The effect of the third variable, that of stage of reproductive cycle, cannot be assessed at present, although it is of interest that Riddle found in the nonmigratory Ring Doves that liver and spleen weights were highest in spring and summer, when ovary and testis are largest. Fortunately we have in California an almost perfect natural control, a permanently resident race of White-crowned Sparrow, *Z. l. nuttalli,* the testis cycle of which is identical as to histologic stages, although not as to timing, with that of *Z. l. gambelii.* Analysis of organ weights in relation to testis stage in *Z. l. nuttalli,* now in progress, may throw light on this aspect of the problem.

SUMMARY

Seasonal changes in liver and spleen weight have been analyzed for strongly migratory wintering and breeding populations of *Zonotrichia leucophrys gambelii.* At Santa Barbara, California (lat. 34°30′N.) 191 specimens were taken from September through April during three consecutive years. At Mountain Village, Alaska (lat. 62°07′N.), 17 were collected from May through July, 1950.

In adult males significant seasonal differences in liver weight, analyzed in several ways, were found. Monthly means increased from November through April and dropped sharply in May; means for fat April males ready to migrate averaged 30.0 per cent

higher than for November males, and 30.7 per cent higher than for males newly arrived on their breeding grounds. Parallel variations in the ratio of liver to body weight occurred, the highest and lowest values coinciding with the beginning and the end of migration, respectively.

Females paralleled males in direction and timing, but not in magnitude, of changes in absolute liver weight. In most months females averaged higher as to relative liver weight. The possibility of a sexual difference in the response to exigencies of migration is suggested.

Although spleen weights are more individually variable than liver weights, both sexes showed increases in mean spleen weights for certain of the successive periods of the annual cycle. A significant difference between mean spleen weights of thin April males and that of May males was found.

The data for the White-crowned Sparrow are briefly compared with those reported by Riddle for Ring Doves.

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