THE EFFECT OF THIOURACIL ON THE DAILY ACTIVITY PATTERNS OF THE GOLDEN-CROWNED SPARROW ZONOTRICHIA ATRICAPILLA (GMELIN)

BY

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THE EFFECT OF THIOURACIL ON THE DAILY ACTIVITY PATTERNS OF THE GOLDEN-CROWNED SPARROW. ZONOTRICHIA ATRICAPILLA (Gmelin).

Introduction

The German word Zugunruhe broadly translated into English means nightly restlessness in caged migratory birds during the migratory season. This nightly restlessness has been known and studied for close to one hundred forty years. Farner (11) citing von Homeyer (22), 1881, mentions Naumann's paper published in 1822, as having a description of the Zugunruhe of caged nightingales. Wachs (47) states that Zugunruhe was described in some detail as early as 1828 by Eckström. It has been assumed by many workers, with good evidence, that the physiology of Zugunruhe is a reasonable representation of the physiology of migration. The investigation of Zugunruhe, consequently, has been used as an instrument in the study of the annual stimulus of migration.

This study of the annual stimulus of migration through the years has involved a number of different experiments and several different hypotheses. The first of these, the gonadal hypothesis, was begun by Rowan in 1925, who was the first to use the experimental approach, with controlled observations. The theory of Rowan (40) was that the secretion of the interstitial cells of the gonads was responsible for arousing migratory behavior, and
that with the disappearance of this tissue the stimulus to migrate lapses. His first work was done with Slate-colored Juncos, \textit{Junco hyemalis}. In later work with the American Crow, \textit{Corvus brachyrhynchos}, Rowan (41) concluded that the southward passage "appears to be independent of the influence of the gonads." Still later Rowan (42) suggested that the pituitary and the "entire physiology of the animal" are involved in the stimulation of migration, although he still placed the emphasis on the role of the gonads.

Kendeigh (24) in 1934, showed that there was a direct endocrinal stimulus important in migration. His belief was that the hormones from the gonads, varying as part of the reproductive cycle were most important as the primary cause of migration. The theory of the gonads as a primary factor in migration was almost negated by Hann (17) in 1939. Hann experimented with three different species of birds, the Slate-colored Junco, \textit{Junco hyemalis}, the Red-eyed Towhee, \textit{Pipilo erythrophthalmus}, and the White-throated Sparrow, \textit{Zonotrichia albicollis}. He castrated these birds prior to the migratory season and then freed them during the regular migratory period, finding that the castrated birds migrated right along with the normal birds used as controls. This according to Hann, would point to eliminating the possibility of the gonads having a primary function in migration. Wolfson (51) also was against the gonads as having a primary role
in migration, having worked with both migrant and resident juncos in Berkeley, California. He kept the birds in outdoor aviaries until well after the usual spring migration time and then released them, but found that the birds migrated anyway. Since he kept the birds until well past the normal period of migration and also past the nesting or breeding time, he believed that if the gonadal secretions had direct control over the migratory behavior and the breeding behavior is only a function of gonadal condition as Rowan believes, then the migrant birds he released should have remained sedentary. This upholds Hann's work and would again tend to eliminate the gonad entirely as being the primary factor of migration. However, Bullough (5) states that the gonads are actively growing and secreting their hormones when the spring migration takes place. He also believes there is evidence that an unseasonable migration may occur by experimentally inducing unseasonable gonad growth. One of the latest opinions on the gonadal hypothesis comes from Farner, Hewaldt, and King (15). They say that primary or secondary gonadal regulation cannot or should not be denied at the present time. It was their opinion that the close correlation between gonadal recrudescence and the development of Zugunruhe or natural migration more probably indicates that both are the effects of more fundamental changes involving the anterior pituitary, at least in part. According to them it would be desirable to seek
explanations in terms of the nongonadotropic effects of the photoperiodically activated anterior pituitary. It is their belief that in order to understand these relationships there remains much interesting research.

Another major hypothesis to undergo experimentation is the thyroid hypothesis, an idea originating in Germany in the early 1930's. Although this hypothesis has had little work done on it compared to research on the gonadal hypothesis, it is this idea that initiated the research of this thesis. Wagner (48) using thyroid extracts obtained a simulated Zugunruhe in his experimental White-throats. He believed definitely that the thyroid hormone may have a role in the natural stimulation of Zugunruhe. One suggestion for the thyroid function, made by Riddle, Smith and Benedict (39), was that the thyroids of migratory birds fail to respond to the onset of cold weather by increasing activity while those of non-migratory ones do. Thus, the migratory bird migrates while the non-migratory bird does not. Merkel (30, 31, 32) using White-throats and European Robins produced a simulated Zugunruhe with relatively small doses of thyroxine or thyrotrophic hormone preparations. He obtained an interrupted or inhibited Zugunruhe with larger doses. He suggested that an integral role could be played by the thyroid gland in the annual stimulation of migration. Particularly, he thought that if the birds were in metabolic condition to migrate,
a very small increase in thyroid activity could be responsible for the initiation of the fall, as well as the spring, migratory behavior. Putzig (36) in his work with European Robins, *Erithacus rubecula*, injected thyrotrophic hormone in small doses and found it to be ineffective, whereas with rather large doses he obtained an enhanced or simulated Zugunruhe. However, Farner (11) has stated that these results should be interpreted with caution as this simulated Zugunruhe might simply be increased metabolic activity due to the injection of the thyrotrophic hormone. Höhn (21) in his paper in 1950 reported there is probably a relationship between the thyroid and migratory behavior, but it still needs further investigation.

Nevertheless the present author thought that since these workers got a simulated or enhanced Zugunruhe with injections of thyroxine or thyrotrophic hormone, it would be very interesting to see what the deprivation of thyroxine would do to the activity patterns of a migratory bird. According to Sadhu (43) and Blaxter, Reineke, Crampton and Peterson (4) there are a number of substances which inhibit thyroxine formation and produce enlargement of the thyroid gland. These substances are called antithyroid agents or goitrogens. According to Sturkie (45 p. 367), there are two goitrogens which are commonly used on birds, these being thiouracil and thiourea. They are equally effective in producing hypertrophy of the thyroid gland. Thiouracil is nontoxic over a wide
range of dosages, whereas thiourea is toxic for the chicken when fed at levels of 0.15 percent in water. In the work of Astwood, Bissell, and Hughes (2), it was found that 0.1 percent thiouracil would totally prevent any thyroxine formation in chicks and if fed for periods of ten weeks would enlarge the thyroid gland to 45 times its original size. It was assumed in the present work that if 0.1 percent would prevent thyroxine formation in the chick it would work equally well in the small migratory bird chosen for experimentation. The bird chosen was the Golden-crowned Sparrow, *Zonotrichia atricapilla*, a bird which could be obtained readily and upon which no published information could be found regarding the problem which had been selected. The experimental birds were given a 0.1 percent thiouracil-water mixture for drinking water and from these birds twenty-four hour activity patterns were recorded. The patterns were then checked for any deviation from the control patterns of birds which were drinking tap water.
Methods and Materials

The Golden-crowned Sparrows used as experimental and control birds were collected early in the winter of 1959-60, on Kiger Island just south of Corvallis, Oregon, with the use of Japanese mist nets. In an attempt to reduce the mortality rate, which was previously thirty to fifty percent, a small carrying cage was made from a fish net of light cotton cord, which was stretched out to fit loosely the interior of a box-shaped frame. As soon as the birds were removed from the mist net they were placed in this carrying cage and covered with a light blanket, which appeared to keep them quiet. In three successive collections utilizing this cage the mortality rate was kept between ten and seventeen percent.

The birds, when brought into the laboratory, were placed in one of the six individual activity cages or in one of three larger cages, measuring three feet by three feet by two feet in which were kept all of the reserve birds. All birds were fed, ad libitum, dry dog meal which was pulverized in a Waring Blender until a fine powdery meal remained. In birds previously kept in captivity on a diet of commercial bird seed there were many cases of malnutrition evident after one to two months in the laboratory, but after switching the diet to dog meal there was no trouble with malnutrition and the birds seemed to waste less food. All birds were kept in a secluded room with two large windows allowing the
room a near normal light intensity. All light from the adjacent laboratory was eliminated by heavy tape over all cracks and a heavy canvas curtain over the one entrance door.

The method of recording and the recording apparatus, with few modifications, were similar to that of Farner and Mewaldt (13), and were located in the laboratory adjacent to the room in which the birds were kept. The recorder (1) as shown in Figure 1 was a Phipps and Bird continuous ink-recording kymograph with horizontal ink-writing signal markers (2). Each of six of the attached signal markers was connected electrically to an individual activity cage (3) with the seventh signal marker attached to the synchronous clock (4) and its individual power supply (5). Since the recorder would hold not quite a twenty-four hour supply of recording paper, an external supply of paper (6) was arranged to allow continuous recording for a longer period of time without interruption. By cutting the paper between the drive roller and the take-up roller, a twenty-four hour recording could be removed without stopping the recorder. With a large water supply and two feeders on each of the activity cages it was not necessary to enter the room in which the birds were located more often than every third day to feed and water them. If it was necessary to enter the room on the day of a recording, the hour following entry was deleted from the experimental data. The perch (7) of each cage when depressed, mechanically operated a 2-way microswitch (8)
which was electrically connected to a signal marker through the capacitor-discharging circuit. When the bird was off the perch the capacitor (9) in each of the six circuits was charged; as the perch was depressed by the bird, the capacitor-charging circuit was broken and the capacitor-discharging circuit was completed, dissipating the charge of electricity through the signal marker, resulting in a mark or "blip" on the recording paper. The capacitor-charging circuit was completed again as the bird left the perch with the capacitor-discharging circuit being broken. The capacitor of each circuit would then become immediately charged and be potentially ready to again activate the signal marker when the perch was depressed.

A rectified power supply (10), changing the incoming current from AC to DC and diminishing the voltage to about forty five volts at two hundred fifty milliamperes, was built to operate these circuits in an effort to eliminate the expense of buying and replacing DC batteries. The double circuit setup was used to alleviate the chance of burning out a signal marker, a common event in a single circuit setup when a bird chose to sit on the perch for an extended length of time.

The temperature of the room containing the cages was recorded continuously during the period of the experiment with the use of a recording thermometer. Once a week the birds were removed from the cages and weighed to the nearest half gram, and
Figure 1. A double circuit continuous recording mechanism.
at the same time the birds were checked for condition of molt, control birds and experimental birds being compared.

Recordings were made over a period of ten weeks in the spring of 1960. An attempt was made to get at least a forty-eight hour recorded period every week with the first recording being made on the twelfth of March and the last recording being made on the ninth of May. Counting the "blips" on the daily recordings was simply a matter of tediously going over the recorded paper, counting every one of the marks made by the signal markers. As they were counted they were placed in one hour groups for the twenty four hour period.

Since the size of the kymograph limited the number of the activity cages, the number of control birds and the number of experimental birds were limited to three each. The control birds were given straight tap water for drinking whereas the experimental birds were given a 0.1 percent thiouracil in water mixture.

At the termination of the experiment, two of the control birds and two of the experimental birds were autopsied, their thyroids removed, and the sex of each bird was noted. After the extraneous tissue was removed from each thyroid they were immediately weighed on a torsion balance to the nearest tenth of a milligram and were then placed in Bouin's solution until the time of embedding in paraffin. They were then sectioned at seven micra,
placed on slides, and stained with hematoxylin and eosin stain.
Results

The temperature during any day of recording never rose above 83° F. nor fell below 43° F. in the room in which the activity cages were kept. The majority of the high temperature periods came between the hours of five and six in the afternoon while five high temperature periods appeared between ten and eleven thirty in the morning. The low temperature periods came usually between six and seven in the morning with the low periods on three days coming between eleven and twelve at night, and on one day at three in the morning. Table I gives the high and low temperature periods and their respective times each day.

Table I

Temperatures recorded in the room in which the birds were located grouped to show high and low periods and time of day.

<table>
<thead>
<tr>
<th>Date</th>
<th>High</th>
<th>Hour</th>
<th>Low</th>
<th>Hour</th>
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<tr>
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<td>62</td>
<td>1730</td>
<td>48</td>
<td>0600</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>66</td>
<td>1700</td>
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<td>68</td>
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<td>43</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>72</td>
<td>1800</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>77</td>
<td>1800</td>
<td>53</td>
</tr>
<tr>
<td></td>
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<td>50</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>56</td>
<td>1030</td>
<td>56</td>
</tr>
<tr>
<td>April 10</td>
<td>75</td>
<td>1115</td>
<td>43</td>
<td>0700</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>69</td>
<td>1100</td>
<td>52</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>May 8</td>
<td>74</td>
<td>1800</td>
<td>61</td>
<td>0600</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>83</td>
<td>1600</td>
<td>59</td>
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The individual weights, which were taken once a week, are expressed as an average of all the birds in each group, i.e., experimental or control birds. The average weight of the control birds at the first weighing on March 12 was 34.3 grams, and with the exception of a decrease on March 17, March 22, and April 27, steadily increased until the termination of the experiment on May 9, when the average weight was 45.6 grams. The average weight of the experimental birds also increased from an average of 32.8 grams on March 12, to an average of 43.3 grams on May 9, when the experiment was terminated. With the experimental birds as with the controls, there was a decrease in weight at one time when the birds were weighed on March 27. The average weight of the birds at the time "Zugunruhe" was first shown to be present was 33.4 grams. After the onset of nightly restlessness the weight apparently did not influence "Zugunruhe" as some birds would not show it on certain nights even at a heavy forty nine grams, and much lighter birds, at 32.6 grams, showed a great amount of nocturnal activity. The average gain in weight for the control birds was 11.3 grams and that for the experimental birds was 10.5 grams. Figure 4 shows the increase in body weight at the onset of "Zugunruhe" and the continuing increase in weight until termination of the experiment.

Moltin first appeared in both experimental birds and controls on April 10. No difference could be seen in rate and amount of
molting between the birds on thioauracil and those on tap water. At the time of examination on April 27, all birds were completely through the molt as far as could be determined. Following the termination of the experiment, the experimental birds were taken off the thioauracil-treated drinking water diet and given tap water for drinking. The birds very soon began to molt and did not molt in stages as normally done, but showed excessive dropping of the feathers, especially the tail feathers and the primaries of the wings. Most birds could not fly and some birds could not lift themselves off the ground more than six inches because of the loss of feathers.

Table II

<table>
<thead>
<tr>
<th>Date</th>
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<th>Control</th>
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<tr>
<td>March 12</td>
<td>32.8 grams</td>
<td>34.3 grams</td>
</tr>
<tr>
<td>&quot; 17, 18</td>
<td>34.3 &quot;</td>
<td>32.8 &quot;</td>
</tr>
<tr>
<td>&quot; 22, 23</td>
<td>35.6 &quot;</td>
<td>32.6 &quot;</td>
</tr>
<tr>
<td>&quot; 27, 28</td>
<td>34.0 &quot;</td>
<td>33.8 &quot;</td>
</tr>
<tr>
<td>April 10, 11</td>
<td>37.5 &quot;</td>
<td>40.0 &quot;</td>
</tr>
<tr>
<td>&quot; 21, 22</td>
<td>40.0 &quot;</td>
<td>43.6 &quot;</td>
</tr>
<tr>
<td>&quot; 27</td>
<td>42.6 &quot;</td>
<td>42.6 &quot;</td>
</tr>
<tr>
<td>May 8, 9</td>
<td>43.3 &quot;</td>
<td>45.6 &quot;</td>
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The thyroids of the experimental birds responded to the thioauracil administration as noted in the literature for other
Figure 1. Thyroid gland of a thiouracil-treated bird showing increase in number and size of cells and absence of colloid.

Figure 2. Thyroid gland of a normal bird showing colloid filled follicles.
and showed a great increase in size over the birds on tap water. The experimental birds had thyroid weights of 54.1 milligrams per 100 grams body weight and 43.0 milligrams per 100 grams body weight, whereas, the control birds had thyroid weights of 3.1 milligrams per 100 grams body weight and 8.3 milligrams per 100 grams body weight. The average thyroid weight for the experimental birds was 48.5 milligrams per 100 grams body weight and for the control birds it was 5.7 milligrams per 100 grams body weight.

As Figure 2 shows, the thyroid gland treated with thiouracil shows definite hypertrophy and hyperplasia, but lacks the colloid-filled follicles of the normal thyroid gland, shown in Figure 3. No difference in size of the thyroid glands could be detected between the male and female birds.

For the first twenty-four hour recording, on March 12, there was no nocturnal activity apparent in any of the birds. For the recorded period on the seventeenth and eighteenth of March, one group of birds showed extensive nocturnal activity, while the other group showed very little activity during the night hours. Since the first group of birds showed thirty percent nocturnal activity, this was considered the first appearance of "Zugunruhe," but some birds did not show signs of nightly restlessness until the twenty-second of March. It was on this day that for the first time all birds showed signs of "Zugunruhe." Thiouracil
Figure 4. Percent body weight increase for the ten week period. Symbols as below.

Figure 5. Recorded daily activity patterns for the ten week period. Solid line = control birds, broken line = experimental birds.
treatment had been started on March 21, but since it takes five days for the effect of thiofouracil to become apparent (45, p. 352), any difference in the behavior of the birds due to the inhibition of thyroxine secretion would not show until the recordings of the next week on the twenty-seventh and twenty-eighth of March. The birds did show a difference in activity on these days as Figure 5 shows, but in the following recorded period on the tenth of April, the experimental birds and control birds were very similar in amount of nocturnal activity. On the eleventh of April, the nocturnal activity of the control birds dropped to about sixteen percent of the total daily activity, while that of the experimental birds remained just above thirty one percent. On the twenty first of April and each following recorded period, the nocturnal activity of the control birds remained down around five percent of the total activity for that particular day with the exception of the last recorded period on the ninth of May when it rose to eleven percent. The percent nocturnal activity of the experimental birds remained much higher than that of the control birds, showing twenty-three percent on the twenty first of April, nineteen percent on the twenty seventh of April, twenty seven percent on the eighth of May, and twenty three percent of the ninth of May, which was the final day of recording.
Discussion

It has been noted by several authors in the literature that nocturnal activity in the spring under outdoor conditions begins about the middle of April. Farner (12) working with the Golden-crowned Sparrow, *Zonotrichia atricapilla*, found it began very close to the second week in April, and other workers (15) found that the inception of spring nocturnal activity began in the White-crowned Sparrow, *Zonotrichia leucophrys gambelii*, at the time when the spring molt was becoming less intense and reached its maximum development about the first week in May. Odum (34) found the White-throated Sparrow, *Zonotrichia albicollis*, to undergo pre-nuptial molt in late March and early April, followed by the nightly restlessness, which began during the second or third week in April. The present study, using Golden-crowned Sparrows, *Zonotrichia atricapilla*, showed that nocturnal activity began on the seventeenth of March, at least two to three weeks before the onset of nocturnal unrest shown by other studies. It is believed that in this case the cause of the unrest appearing so early can be directly attributed to the environmental temperature. Farner and Mewaldt (14) have found it possible to induce extensive nocturnal activity in mid-winter in the White-crowned Sparrow, *Zonotrichia leucophrys gambelii*, solely by increasing the environmental temperature. They seem to believe this nightly unrest
becomes possible as a result of an improved metabolic condition because of a diminished expenditure of energy in thermoregulation, and can be considered analogous to the condition of Zugdisposition, as conceived by Merkel and others. Spring migration in the White-throated Sparrow, Zonotrichia albicollis, may be influenced, it is thought by Siebert (44), by a delicate water balance that is easily upset by relatively high temperatures. He believes also that southward migration may be induced because decreasing photoperiods and colder temperatures combine to prevent the birds from absorbing sufficient food to maintain an energy balance over the twenty-four hour day. Weise (50) in his work with the White-throated Sparrow, Zonotrichia albicollis, and the Tree Sparrow, Spizella arborea, found early fall and spring nightly restlessness to be enhanced by warm fronts and high environmental temperatures and inhibited by cold fronts and low temperatures. This "high environmental temperature" has a maximum in influencing an increase in nightly activity, however, as Eyster (10) found a temperature of 33°C suppressed both diurnal and nocturnal activity. In the present study the temperature apparently was buffered enough inside the room to prevent any correlation between temperature and activity being noticed, as the experimental data showed no close connection between higher temperatures and increased nightly activity. Since the birds were located inside the building, temperatures low enough to inhibit nightly activity
probably did not occur. It could be determined, however, that as the temperature rose and fell over a twenty-four hour period, the temperature inside the room with the birds always maintained a level five to ten degrees Fahrenheit above that of the natural outdoor temperature. This higher level which was always maintained within the room is the probable reason, it is thought, for the onset of Zugunruhe at such an early date, which was two or three weeks earlier than noted by any of the other authors.

Weight, or more specifically fat deposition, plays an important role in the spring migration as shown by a large number of authors, and it has been found that this fat deposition is rather rapid, keeps increasing through the migratory period, and begins to decrease just before the summer molt. Farner et al. (16) showed even in mid-winter that with extended photoperiods the White-crowned Sparrow, Zonotrichia leucophrys gambelii, would deposit large amounts of visceral and subcutaneous fat and develop migratory behavior comparable to natural vernal migratory behavior. They also found the Oregon Junco, Junco oregonus montanus, to respond alike, although less extensively, and suggested this less extensive nightly activity may be correlated with the birds' more restricted migratory movements. King (25) believes the vernal fat deposition in the White-crowned Sparrow, Zonotrichia leucophrys gambelii, prior to migration to be principally a result of a light-induced hyperphagia. Wolfson (52) maintains there is a significant correlation between an increase in body
weight toward a maximum and the beginning of spring migration in the Oregon Junco, *Junco oregonus*, and also found (53) a heavy deposition of intraperitoneal and subcutaneous fat in migrant Oregon Juncos at the time of migration, whereas the resident juncos showed no deposition of fat. Wolfson (54) found the White-throated Sparrow, *Zonotrichia albicollis*, also to demonstrate a premigratory weight increase in the spring, with the peak being reached in late May and early June. The Golden-crowned Sparrow, *Zonotrichia atricapilla*, as reported by Linsdale and Sumner (28) shows a progressive increase in weight throughout the spring preceding migration. They also indicated (29) that this high weight from the fat deposition was maintained until arrival on the breeding grounds. The birds in the present study also showed a progressive increase in weight during the experimental period and still showed indications of increase on May ninth, the day the experiment was terminated. There was a slight decrease in weight at different periods in both control and treated birds which cannot be explained, but as Figure 4 shows there was a great increase in body weight which amounted to an increase of 32 percent and 33 percent in the treated birds and control birds respectively on May ninth. Weise (49) treated the White-throated Sparrow, *Zonotrichia albicollis*, the Tree Sparrow, *Spizella arborea*, and the Slate-colored Junco, *Junco hyemalis*, with thiouracil in an attempt to induce artificial fat
deposition to determine if this alone would initiate nightly unrest, but found that thiouracil would not cause a deposit of fat. Andrews and Schnetzler (1) found that thiouracil fed at levels of 0.1 percent tended to reduce the rate of gain in the chick if fed for a period of eight weeks. The experimental birds in the present study were not hindered in weight increase by the thiouracil at the 0.1 percent level as can be seen by Figure 4 where the weight increases of both the control birds and experimental birds are plotted, showing a close similarity between periodic increase and the final percent increase of 32 percent and 33 percent, respectively, for treated birds and control birds. Linsdale and Summer obtained average weights in March, April, and May, and found them to be 29.5 grams, 30.9 grams, and 35.5 grams respectively in the Golden-crowned Sparrow, Zonotrichia atricapilla, with the females consistently lighter in weight but still showing the deposition of fat as in the male. The average weights were 33.4 grams, 42.6 grams, and 45.6 grams for the birds in the present study for March, April, and on May ninth. Since none of the birds were autopsied to determine sex it was not determined whether the sexes varied in weight. Differences in weights were noticed among the birds, but according to Baldwin and Kendeigh (3), the differences which occur between the weights of different birds are scarcely greater than those which may occur in the weight of a single individual at different times. Eyster (10)
found in his research with White-throated Sparrows, Zonotrichia albicollis, that although the birds were under identical environmental conditions, only the birds in the migratory state or Zugdisposition would show marked nocturnal unrest. Odum (34) believes that many female White-throated Sparrows migrate without evident fat deposition or weight increase. In the present study all birds gained weight, but there was no noticeable correlation in amount of nightly restlessness and weight. It would appear possible that after a threshold weight is reached or Zugdisposition is attained, there are intrinsic and/or extrinsic conditions which influence nightly unrest rather than purely a weight or fat deposition influence.

In the present study the examining of the birds for molt was primarily a check between the experimental birds and control birds to determine if there was any difference as to beginning date, extent, and length of molt. Although no bird showed any signs of molting until well after the appearance of Zugunruhe, the molting in both groups, experimental and control, was no different in appearance. It is evident that the molt appeared at the normal time as other workers have shown, but the onset of Zugunruhe was premature, placing the molt after the beginning of nocturnal activity rather than before; no explanation can be given for this reversal in sequence of events with apparently no altering effect to either molt or the onset and continuance of Zugunruhe. Riddle
and Fisher (38) indicated in 1925 a correlation between the thyroid gland and the molt in the domestic pigeon because of an increase in thyroid size prior to molting. Hohn (20), (21) believes without a doubt there is a relationship between the molt and increased thyroid activity because of the widespread occurrence of a phase of high thyroid function preceding the molt. Oakeson and Lilley (33) found the migratory White-crowned Sparrow, Zonotrichia leucophrys gambelii, to have the highest thyroid activity just prior to the premolt in the spring. Davis and Davis (7) noticed also in the English Sparrow, Passer domesticus, an increase in thyroid activity prior to molting and considered this "premolt activity." It would seem then, according to these authors, that if the thyroxine secretion were inhibited, there would be an inhibition of the molt. This is the case Hohn (21) has found in some species of birds where there is a complete suppression of the molt if the bird is thyroidectomized sufficiently far ahead of the next molt due. This suppression of the molt did not occur, however, in the present study and the only explanation that can be rendered at this time is that the thiouracil treatment was not begun early enough to inhibit or even slow the molt. Van der Meulen (46) found that by feeding dried, extracted, ground pig thyroid gland to White Leghorn chickens the birds would undergo a molt varying from slight to complete, seven or eight days after thyroid administration. The progress of the molt followed the natural procedure and a large dose usually
caused a more definite molt than a smaller dose. According to Hisaw (18) it is highly probable that when a bird is given a treatment of thiouracil over an extended length of time and the treatment is then suddenly stopped, the thyroid gland will for a short while show a hyperfunctioning by secreting an overabundance of thyroxine. Since it is not known if this actually occurs in the bird it is only suggested by the present author that this may be the cause of the extensive molt which occurred in the experimental birds when the treatment of thiouracil was stopped.

As has been stated in the introduction, the birds on thiouracil treatment showed a great increase in the size of the thyroid glands as Astwood, Bissell, and Hughes (2) indicated in their paper. This enlargement is a result of hypertrophy and hyperplasia of the thyroid gland caused by the goitrogenic thiouracil with an inhibition of thyroxine secretion. Keating et. al., (23) and Rawson and Salter (37) have found that thyroid glands stimulated by the thyrotrophic hormone show hypertrophy and hyperplasia, giving the same histological picture as with thiouracil, but with the thyrotrophic hormone there is an increase in thyroxine formation and secretion. Hoffman and Shaffuer (19) found that low temperature affected the chick thyroid gland in the same manner. Larson, et. al., (27) in attempting to determine the method of goitrogenic action of thiouracil, fractionated the radioactive
iodine of thiouracil-fed chick thyroid glands into inorganic and organic iodine, and found that thiouracil does not decrease the uptake of inorganic iodine, but prevents the thyroid gland from binding it to protein, or in effect, decreases the organic iodine. Chaikoff and Taurog (6) demonstrated the same results in mammals.

The goitrogenic action can be inhibited in thiouracil-fed chicks according to Dvoskin (9) by subcutaneous injection of elemental iodine in solution. Thiouracil then acts upon the thyroid gland by interfering with the synthesis of thyroxine, probably by inhibiting necessary enzymatic reactions, according to Sturkie (45, p. 355). Dempsey (8), using histological techniques, has shown that the enzymes alkaline phosphatase, and peroxidase, which are normally present in the thyroid gland, disappear after thiouracil administration. The appearance of the normal thyroid gland and the thiouracil treated thyroid gland from the Golden-crowned Sparrow, Zonotrichia atricapilla, shown in Figures 2 and 3 as found in the present study compare very closely to the appearance of the chick thyroid gland on the same treatment as shown by Larson et. al., (26).

Most of the discussion of activity patterns is considered under the section concerned with temperature, but some interesting information may be given here which pertains to the results of the present study. Eyster (10) found that nightly rest pauses usually
occurred before and after the onset of nocturnal activity in the White-throated Sparrow, Zonotrichia albicollis, during spring migration. Palmgren (35) found that, as a rule, a short period of sleep preceded nightly activity, with the activity culminating before midnight and gradually fading out. This was not found to be the case in the present study in either experimental birds or control birds; the birds often began nightly activity early in the evening and kept it up most of the night without pausing, but nightly restlessness varied so much between individual birds that a greater sample size would have to be employed to really determine anything definite. The amount of nocturnal activity varied between the experimental birds and the control birds enough to make it impossible to conclude anything in this respect, but it can be said that the thiouracil definitely did not inhibit the treated birds from showing as much Zugunruhe as the control birds, especially in the latter part of the study when the experimental birds showed much more nocturnal activity than did the control birds. Farmer (12) found that in the White-crowned Sparrow, Zonotrichia leucophrys nuttalli, a non-migratory bird, five to ten percent of the total activity in a twenty-four hour period would be nocturnal in March, April, and May. The control birds in the present study showed no more than this for the last five recorded periods, whereas the experimental birds remained at a level between nineteen and thirty seven percent in nocturnal
activity during these same periods. The control birds actually then did not show any more nightly unrest than the non-migratory White-crowned Sparrow, but at the same time the experimental birds showed much more extensive Zugunruhe, indicating that the thiouracil did not inhibit the vernal nocturnal activity. Based upon the results of the present study, as discussed above, it is thought that thyroxine has no direct influence on the migratory behavior of the Golden-crowned Sparrow, Zonotrichia atricapilla.
1. Zugunruhe or nightly restlessness was known and described as early as 1822 and it is now considered that the physiology of Zugunruhe is a reasonable representation of the physiology of migration. Migratory studies have been concerned with a number of different hypotheses, one of which is the thyroid hypothesis. Even though the results of each worker varied, the basic result was a simulated or enhanced Zugunruhe. The results of injected thyroxine instigated the present study with thiouracil, which was an attempt to determine the effect on the activity patterns of birds deprived of thyroxine.

2. The birds, Golden-crowned Sparrows, Zonotrichia atricapilla, were placed in six small activity cages with a perch in each cage connected electrically to a continuous recording kymograph. Three birds were given a 0.1 percent thiouracil water mixture for drinking, three were given tap water for drinking, and daily activity patterns were recorded from both groups. Recordings were made for ten weeks in the spring of 1960 from March twelfth to and including May ninth.

3. No correlation could be determined between temperature and
the amount of nocturnal activity. It is thought that the birds being located inside a building minimized temperature influence because of a more constant temperature level, i.e., the room prevented the temperature fluctuations from being as severe as they were outdoors.

4. The birds were weighed once a week and showed an increase in weight, with the exception of two slight decreases, from the beginning of the study period until the day of termination. Total increase percent on May ninth was thirty two percent for the experimental birds and thirty three percent for the controls. Weight appeared to have no influence on amount of nightly unrest.

5. Molting occurred at the regular time as found by other workers and no differences could be seen between experimental birds and control birds. When the thiouracil treatment was suddenly stopped at the termination of the study, the experimental birds molted excessively and were completely incapable of flying. It is thought that a hyperfunctioning of the thyroid gland caused this irregular molting.

6. At the termination of the study two thyroid glands each of the experimental and control birds were dissected out, weighed, fixed, sectioned at seven micra, and stained with hematoxylin and eosin. The thyroid glands subjected to thiouracil showed a great increase in weight and also showed hypertrophy and hyperplasia with inhibition of thyroxine secretion as shown in
photomicrographs. The average thyroid weight for the control birds was 5.69 milligrams per 100 grams body weight and that for the experimentals was 48.53 milligrams per 100 grams body weight.

Nocturnal activity began two or three weeks before the time found by other workers and early occurrence is attributed to elevated temperatures in the room in which the birds were located, which were always five to ten degrees Fahrenheit above those of the outdoors. The inhibition of thyroxine secretion did not suppress or inhibit nocturnal activity, and therefore it is thought that the thyroid gland has no direct influence on the spring migration of the Golden-crowned Sparrow.


