AN ASTRONOMICAL DETERMINATION OF THE HEIGHTS OF BIRDS DURING NOCTURNAL MIGRATION.

BY FREDERIC W. CARPENTER.

TWENTY-FIVE years ago W. E. D. Scott, in the 'Bulletin of the Nuttall Ornithological Club,'[1] called attention to the telescope as a means for actually observing against the moon as a background the nocturnal migratory flight of birds. Realizing the possibilities of this method in throwing light on the unsettled question of elevation, Mr. Scott, with the aid of Professor Young of the Astronomical Department of Princeton University, made the following observations and calculations. A nine and one-half inch telescope was pointed toward the moon in the month of October, 1880. Numbers of birds were seen flying in a general southeasterly direction. Since these birds were clearly outlined they must have been at least one mile from the observers, for if nearer the telescope they would have been out of focus. A distance of one mile was, therefore, taken as the inferior limit of the field of observation; and on the assumption that birds would not fly at a greater height than ten thousand feet the superior limit of the field was fixed at a distance of four miles. These distances and the angle at which the telescope was inclined gave the data for the conclusion that the birds observed were flying from one-half[2] to two miles above the earth.

F. M. Chapman followed a few years later with a report in this journal[3] of observations made with a six and one-half inch telescope during a night in September, 1887. With the assistance of an astronomical friend, John Tatlock, Jr., the writer prepared a table

[1] Scott, W. E. D.,'81. Some Observations on the Migration of Birds. Bull. Nuttall Ornith. Club, Vol. VI, No. 2, pp. 97–100, 1 fig. Migration of Birds at Night. *Ibid.*, No. 3, p. 188. Note by J. A. Allen appended to each article.

[2] This lower limit is given by J. A. Allen and Newton and Gadow as one mile. In the original paper Mr. Scott makes no actual statement of the dimension, but in his figure (p. 100) the distance is represented by the perpendicular of a right triangle, having an angle of 30° opposite, and an hypotenuse one mile in length, This would make the perpendicular one-half mile long.

[3] Chapman, F. M., '88. Observations on the Nocturnal Migration of Birds. Auk, Vol. V, No. 1, pp. 37–39.

showing the probable limits of height between which the birds were flying. In so doing it was necessary to assume that the least distance from the observer at which birds could be seen was one mile, and the greatest distance five miles. The computation of the heights showed that the birds were flying between six hundred and fifteen thousand feet; and since it was evident that "the major portion passed at what may be termed the middle distance" the average height was apparently far above the inferior limit. To both observers a nearer approach to an accurate measurement of the altitude did not appear possible. Mr. Chapman wrote: "The problem of determining this height exactly is not, so far as we can now judge, capable of a definitive solution, for the reason that we have no means of ascertaining the distance of the bird from the observer."

The foregoing observations have been accepted by J. A. Allen,[1] Newton and Gadow[2] and other ornithologists as fair evidence that migrating birds fly at night at very considerable altitudes, and comment has often been made on the favorable position in which birds are thus placed for observing the prominent features of the landscape which may serve to guide them on their way. As an example of an extreme view in this connection it should be recalled that Gätke in his book entitled 'Die Vogelwarte Helgoland' gives his reasons for supposing that an altitude of thirty thousand feet or even more may be attained.

More recent attempts to measure the altitude of the migratory flight have indicated that this has been over-estimated. The methods used have, however, like former ones, involved apparently unavoidable assumptions, which, though probable, do not admit of strict verification.

The heights of migrating birds seen against the moon in September, 1896, at the Ladd Observatory, Providence, Rhode Island, were calculated by F. W. Very,[3] who compared the apparent size

[1] Notes appended to the articles by W. E. D. Scott cited above. Also review of Gätke's 'Heligoland.' Auk, 1896, Vol. XIII, No. 2, pp. 137–153.

[2] Newton, A., and Gadow, H., '93–96. A Dictionary of Birds. London, xii + 1088 pp.

[3] Very, F. W., '97. Observations of the Passage of Migrating Birds across the Lunar Disk on the Nights of September 23 and 24, 1896. Science, N. S., Vol. VI, No. 141, pp. 409–411.

of the birds with the size of prominent lunar features. Assuming the average actual length of these birds (presumably small ones) to be six inches, he was able to compute their distance from the observer and their height above the sea-level, the latter proving to be about two thousand feet. A larger bird, whose distance was determined by focal adjustment, had an altitude of only 687 feet.

In an extensive paper[1] on bird migration published in 1902, H. A. Winkenwerder gives the result of work done by himself and several collaborators in different parts of the country. At Beloit the telescope directed toward the moon's disk showed birds which were apparently following the course of a river not far from the observatory. It being taken for granted that these birds were over the river it was an easy matter to determine their approximate heights. The majority were not over fifteen hundred feet from the earth. The same conditions at Detroit gave evidence that the flight was "somewhat more than one-half mile above the surface.'

Two papers concerned with the height of birds in diurnal migration have come to my notice. In England R. A. Bray,[2] while looking at the sun through an eight-inch telescope at three P. M. on September 30, 1894, saw birds pass slowly across the field in a southerly direction. The birds came one every few seconds for a space of ten minutes. They were invisible to the unaided eye. As both the birds and the sun were in focus the former must have been, in the opinion of the writer, two or three miles away.

The height as well as the velocity of a daytime flight of ducks were accurately determined in December, 1896, by H. H. Clayton[3] at the Blue Hill Observatory, Massachusetts. This observer, assisted by S. P. Fergusson, was engaged in measuring the heights and velocities of clouds, making use of theodolites especially adapted to these purposes. The appearance of a flock of ducks flying southwest gave opportunity for applying the instruments to or-

[1] Winkenwerder, H. A., :02. The Migration of Birds with Special Reference to Nocturnal Flight. Bull. Wis. Nat. Hist. Soc., N. S., Vol. II, No. 4, pp. 177–263, pls. i–viii, 1 photo.

[2] Bray, R. A., '95. A Remarkable Flight of Birds. Nature, Vol. LII, No. 1348, p. 415.

[3] Clayton, H. H., '97. The Velocity of a Flight of Ducks Obtained by Triangulation. Science, N. S., Vol. V, No. 105, p. 26. The Height and the Velocity of the Flight of a Flock of Geese Migrating Northward. *Ibid.*, No. 119, pp. 585–586.

nithological ends. Their readings indicated that the birds were 958 feet above the ground, and were flying at the rate of 47.8 miles an hour. Under similar conditions in March of the following year the same observer ascertained that a flock of geese migrating northward was 905 feet high, and had a velocity of 44.3 miles an hour.

During the spring and autumn of 1905 Professor Joel Stebbins of the Astronomical Department of the University of Illinois and the writer made a series of observations on the nocturnal flight of migrating birds. The work was done at the Astronomical Observatory in Urbana, Illinois. Professor Stebbins became interested in the matter of determining the heights of the birds, and devised a method which we believe furnishes the solution of this problem. The entire credit for accomplishing this belongs to Professor Stebbins, who has published in the February number of 'Popular Astronomy'[1] a full account of his procedure with the mathematical data and calculations. The object of the present paper is to bring to the attention of ornithologists the results of this successful application of astronomical methods to a hitherto unsolved biological problem.

In order to obtain the necessary data for the computations two telescopes were used in making the observations. These were three-inch and four-inch equatorial instruments, placed from ten to twenty-one feet apart on a line running east and west. The magnifications were about twenty-five and thirty diameters respectively, and the powers being low objects as near as one thousand feet could be seen without difficulty. Both telescopes were directed toward the moon, and an observer stationed himself at each. Birds passing through a certain area between the telescopes and the moon could be simultaneously seen by the two observers. In the accompanying diagram this area is included by the triangle *E C D*, through which the majority of the birds flew approximately at right angles to the plane of the figure. There are also shown the two areas, *A C E* and *B D E*, in which passing birds were visible to one of the observers only. The figure has necessarily

[1] Stebbins, J., : 06. A Method of Determining the Heights of Migrating Birds. Popular Astronomy, Vol. XIV, No. 2, pp. 65–70, 2 fig. Also separate, pp. 1–6 (repaged).

been drawn out of its true proportions, the horizontal dimension being greatly exaggerated as compared with the vertical.

The eye-piece of each telescope was provided with cross-hairs which divided the field into octants, and each observer had at hand an outline drawing of the phase of the moon for the night. On this chart were drawn radiating lines corresponding to the cross hairs of the eye-pieces. The telescopes were centered on the moon's disk, the whole of which appeared in the fields of view, and each eye-piece was rotated until one of the cross-hairs was parallel with the diurnal motion of the moon. Birds which passed through the areas limited to one telescope (*A C E* or *B D E*) were merely counted by the observer who saw them, but when a bird appeared in the area covered by both telescopes (*E C D*) its course across the face of the moon was immediately marked on the charts by straight lines, and the hour was noted. The cross-hairs made it possible to locate with considerable accuracy the line described by the bird in passing before the moon's disk. These lines of flight were recorded by the observers independently, and appeared at different places on the two charts, as can readily be seen by considering the projection from *A* and *B* of any point (representing the bird) in the area *E C D* upon the line *C D*, which indicates the moon's disk. The distance between these two projections of the point will vary in accordance with variations in the vertical position of the

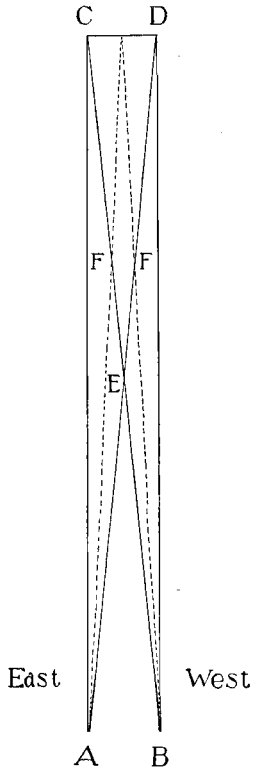

Diagram showing areas of observation. A and B, telescopes; C D, moon's disk; A C D, area of observation for telescope A; B C D, area of observation for telescope B; E C D, area in which birds were simultaneously visible through both telescopes; A C E, area in which birds were visible through telescope A only; B D E, area in which birds were visible through telescope B only.

point in question, *i. e.*, with the distance of the bird from the telescopes.

With these chart records and the necessary astronomical data Professor Stebbins was able to ascertain the "parallax" of each bird, that is, the angle at the bird subtended by the two observers, which is equal to the angular distance between the two lines of flight appearing on the chart. Using this as a basis the distance of the bird from the observers and its height above the ground were computed. The probable direction of flight was also determined, although in so doing it was necessary to assume that the flight was horizontal, as it doubtless was in the majority of cases. This assumption was not needed in calculating the heights.

The accuracy of the measurements depended on the skill of the observers in making their records and on the amount of "parallax." In Professor Stebbins's opinion the computation of the greatest height (5400 feet) involved a possible error of twenty-five per cent., while the lesser heights were probably correct within ten per cent.

Observations were made on several nights in both spring and autumn, the best success being met with on May 19–20, and October 10. On the first date 78 birds were seen during two and one-half hours, 11 by both observers, 33 by Professor Stebbins only, and 34 by the writer only. On October 10, in two hours, 57 birds were counted, 11 being visible through both telescopes: of the remainder Professor Stebbins saw 17 and the writer 29.

From nine satisfactory chart records of each night Professor Stebbins has prepared the material for the following tabular views.

TABLE I.

Birds migrating on the night of May 19–20, 1905, one day after full moon. Weather clear. Wind northwest, 4 miles an hour. Temperature at 9 P. M. 55° F.

Number of bird	1	2	3	4	5	6	7	8	9
Time of observation	10.06	10.18	10.38	11.24	11.40	12	12.09	12.24	12.33
Distance from observers in ft.	7100	4100	5600	4300	3400	4900	3100	2400	2600
Height above ground in feet	2300	1500	2200	2000	1600	2400	1500	1200	1300
Direction of flight	W N-W	W N-W	N-W	N-W	N-W	N N-E	N N-W	N-E	N-W

TABLE II.

Birds migrating on the night of October 10, 1905, three days before full moon. Weather clear. Wind west, 12 miles an hour. Temperature at 9 P. M. 48° F.

Number of bird	1	2	3	4	5	6	7	8	9
Time of observation	9.15	9.25	9.32	9.45	9.49	10.06	10.25	10.38	10.55
Distance from observers in ft.	5800	3600	2800	6700	2100	7700	5800	2100	3300
Height above ground in feet	4000	2500	1900	4700	1400	5400	4100	1400	2300
Direction of flight	S-E	S by E	S S-E	S by E	S	S S-E	S-E	S S-E	S

Table I shows that on May 19–20 no birds were one-half mile above the ground, and one was as low as 1200 feet. On October 10, however, as can be seen from Table II, a single bird was slightly over a mile high. Three others ranged between one-half and one mile, while the remaining five were below one-half mile, two being at an elevation of 1400 feet only. It should be noted that the position of the telescopes did not permit the measurement of birds which may have been lower than the point marked *E* in the diagram, which point on May 19–20 varied between 550 and 1100 feet from the ground, and on October 10 between 750 and 800 feet. As the diagram shows, the area of simultaneous observation (*E C D*) becomes narrower as the point *E* is approached, and as a consequence the chances of birds appearing therein are correspondingly decreased.

The conditions, then, were most favorable for the detection of the uppermost birds, and it seems probable that the majority were considerably below the highest records obtained. On both nights the calls of birds apparently not far overhead were frequently heard. Furthermore, Professor Stebbins has determined the upper limit of over half of those birds seen by one of the observers only on October 10, and shows that these must have been below 1600 feet. In the diagram it will be seen that the area of observation of each telescope has been divided into halves by dotted lines. If the observer at *A* saw a bird, not seen from *B*, against the right half of the moon that bird must have been in the area *A F E*.

Similarly, a bird seen from B only, against the left half of the moon must have been in the area $B\ F'\ E$. On October 10 the points F and F' ranged between 1500 and 1600 feet from the ground, never being higher than the latter distance. Of the 46 birds seen by the observers separately, 24 were in the areas $A\ F\ E$ and $B\ F'\ E$, and, therefore, certainly less than 1600 feet high. The remaining 22 birds were in the areas $A\ C\ F$ and $B\ D\ F'$, and the upper limit of their height could not be determined.

If observations and measurements such as those recorded above could be made at various places over the country, especially along well traveled routes of migration, the result would be an accumulation of statistics in regard to the height and direction of the migratory flight, the value of which is apparent to every ornithologist.

GENERAL NOTES.

Audubon's Shearwater and Peale's Petrel Breeding in Bermuda. — On March 4, 1906, Mr. Louis L. Mowbrey of St. George, Bermuda, took an Audubon's Shearwater (*Puffinus auduboni*) and egg on a small islet off the southeastern end of Bermuda. Another bird and egg were taken on March 11. In each instance the bird was taken on the nest, which was in a hole of the rock without moss or lining of any kind. As far as I can learn this is the most northern record for the breeding of this bird. One of these birds and an egg is now in my collection.

On Feb. 22, 1906, Mr. Louis L. Mowbrey took a Peale's Petrel (*Œstrelata gularis*) in a hole of the rock overlooking the sea and washed by the spray. The bird was taken after a southwest gale. Peale's Petrel is not included in the A. O. U. Check-List, but I am sure of the identification of the bird, and am glad to be able to put on record the first instance of Peale's Petrel being taken in the Northern Hemisphere. The bird is now in the collection of the Bermuda Natural History Society.— Thomas S. Bradlee, *Nahant, Mass.*

The Water Turkey and Tree Ducks near Tucson, Arizona.—September 12, 1893, a Water Turkey (*Anhinga anhinga*) was killed on Silver Lake, a small body of water on the Santa Cruz, about two miles south of Tucson. At that time it was the only bird of the kind I ever saw, and, so far as I know, the only one taken in the Territory. It was a female