A METHOD FOR THE INTENSIVE STUDY OF BIRD SONG.[1]

BY ALBERT R. BRAND.

Plates V–VI.

By photographing bird sound on motion picture film it is possible to bring bird song into the laboratory and study it intensively under the microscope. In sound photography several types of sound tracks are produced depending on which of several methods of photography is employed. In our work we use the Fox-Movietone method or one of the so-called variable density methods. A sound track one tenth of an inch wide running parallel to the length of the film is produced. The photographed sound appears as straight light and dark lines at right angles to the length of the track. Eighteen inches of film pass in front of the light gate of the sound camera each second. The distance between the light and dark lines determines the frequency of the sound. The closer together these vertical lines on the track are to each other the higher pitched is the sound. Hence the vertical lines on the sound track determine the character of the sound (Plate V, upper figure).

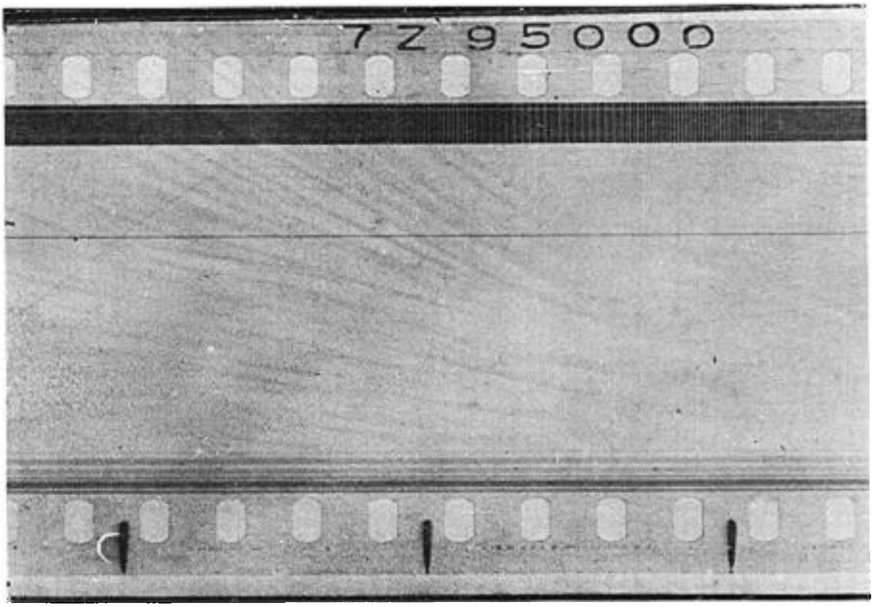
The sound track of the developed negative is carefully examined under a low power, usually $\times$ 25. The microscope is fitted with an eye-piece micrometer; then by multiplying the number of lines on the track per eye-piece micrometer unit by the number of such units per eighteen inches of film, the number of lines (double vibrations or cycles) per second is arrived at.

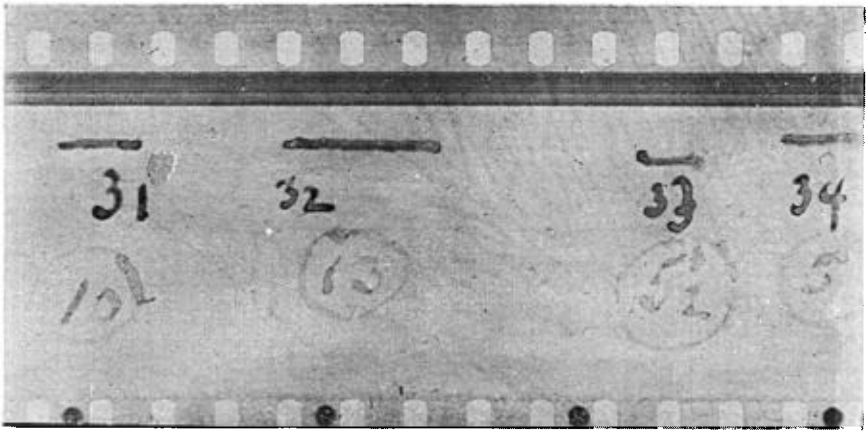
The length of a song and the length of an individual note in a song can be accurately measured to the 1/500 of a second. The frequency of a note can be counted and calculated with far greater accuracy than can be done by even the most highly trained ear. Extremely short notes and those of very high pitch, often inaudible to the human ear, can be clearly seen and studied.

The margin of possible error in making recordings is negligible. The speed of the camera is regularly and carefully checked, while a variation in speed of more than 5% in either direction is detectable to the ear when the developed film is reproduced. Under the microscope the possible inaccuracy in counting is small, as in practically every song examined numerous counts are made of many similar notes, and a difference of even 100 or 200 cycles per second in five or ten thousand, in the count of a very high sound, such as bird song, does not materially change the results.

Plate V, lower figure, is a reproduction of a piece of worked over film three inches long. It is from the recording of a Song Sparrow's song, and is of

[1] Read at the Fifty-second Stated Meeting of the A. O. U., Chicago, Oct. 24, 1934.

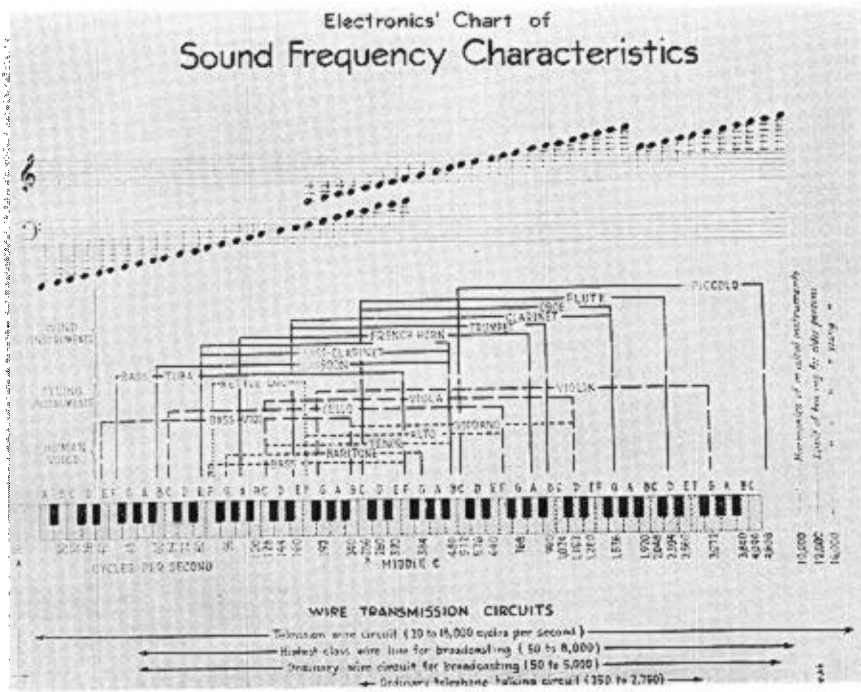




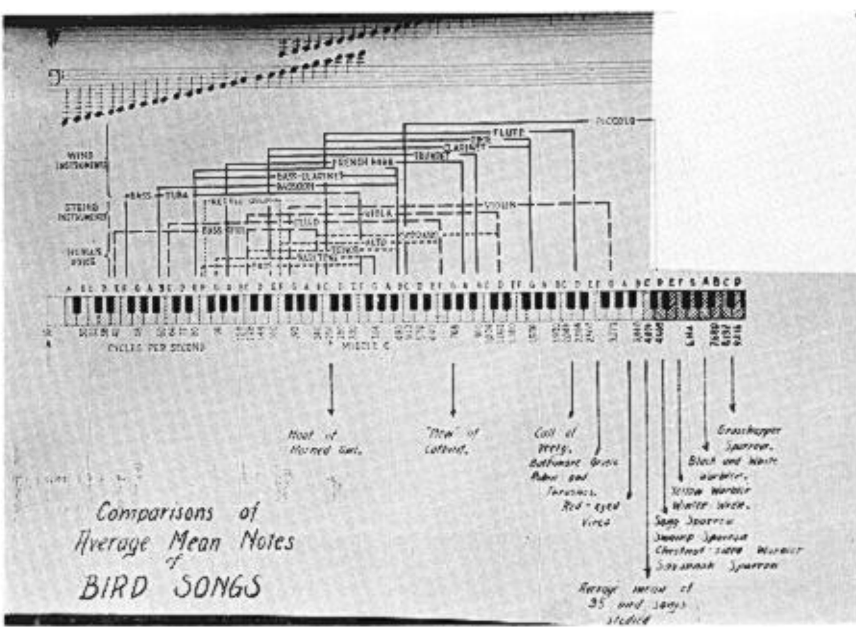
SOUND FILMS.

UPPER: NOTE VERTICAL LINES ON BLACK STRIPE SHOWING FREQUENCY OF SOUND AND INTERVALS.

LOWER: A STUDIED SONG SPARROW FILM.



Electronics' Chart of
Sound Frequency Characteristics
WIND INSTRUMENTS
STRING INSTRUMENTS
HUMAN VOICE
PICCOLO
FLUTE
OBOE
CLARINET
TRUMPET
FRENCH HORN
BASS-CLARINET
BASSOON
BASS
TUBA
VIOLIN
VIOLA
CELLO
BASS VIOL
SOPRANO
ALTO
TENOR
BARITONE
BASS
CYCLES PER SECOND
MIDDLE C
WIRE TRANSMISSION CIRCUITS



WIND INSTRUMENTS
STRING INSTRUMENTS
HUMAN VOICE
PICCOLO
FLUTE
OBOE
CLARINET
TRUMPET
FRENCH HORN
BASS-CLARINET
BASSOON
BASS
TUBA
VIOLIN
VIOLA
CELLO
BASS VIOL
SOPRANO
ALTO
TENOR
BARITONE
CYCLES PER SECOND
MIDDLE C
Hoot of Horned Owl.
"Mew" of Catbird.
Call of Wren.
Red-eyed Vireo
Grasshopper Sparrow.
Black and White Warbler.
Yellow Warbler
Song Sparrow
Swamp Sparrow
Chestnut-sided Warbler
Savannah Sparrow
Average ... of 35 bird songs studied
Comparisons of Average Mean Notes of BIRD SONGS

about one sixth of a second duration. Four notes, numbers 31, 32, 33, and 34 of a song are shown. The film takes ink readily. The length of each note is indicated by the horizontal ink lines under the track. Below each line the note number is written; and the lighter numbers in the circles are the count of the number of lines (frequencies) per eye-piece unit. Thus note 31 was quite high, there being ten lines per eye-piece unit; note 32 was somewhat—about two notes—higher, while note 33 was about an octave lower than note 31; and note 34 was about a half note lower than the one that preceded it.

This small piece of film shows that in the very short space of one sixth of a second four distinct notes were produced with a range of considerably over an octave. It should be understood, however, that while these notes show on the film as three distinct notes, and they are such, it is impossible to hear them as such. They are delivered so quickly that to the human ear they appear as one note or even as a part of one note.

No attempt has been made as yet to study the overtones or harmonics of bird song. What are commonly called fundamentals, or what could be better described as the most accentuated tones or pitch determining frequencies, alone have been considered.

Musical tones are a composite of a highly accentuated tone and numerous overtones and so-called undertones. To be strictly accurate, tones consist of a fundamental—always the lowest tone produced—and numerous overtones or harmonics. However, quite frequently the fundamental and some of the lower harmonics are partially or almost fully suppressed, and a certain higher harmonic is heavily accentuated. Only comparatively recently has it been realized that this heavily accentuated tone is in actuality a harmonic and not a fundamental. This has led to certain confusion in terms. The heavily accentuated harmonic is often referred to as the fundamental, the lower suppressed tones, be they harmonics or actual fundamentals, have been called undertones. However, practically every tone has one factor, either fundamental or harmonic, which is much more greatly accentuated than all other components of the tone. It is this factor which determines the tone's pitch. In these studies I have considered primarily this highly accentuated factor. The less accentuated components are extremely interesting, and they determine what is known as the quality of a tone. They are extremely varied and numerous. I leave their study to the future.

While harmonics are present in many bird songs, there are many others in which I have been unable to detect even a trace of them. In fact bird song as a whole, when compared with human speech, instrumental music, etc., is remarkably free from harmonics. The reason can only be guessed at, but it is probably correlated with the excessively high pitch of these sounds. Possibly these high pitched sounds are normally lacking in overtones; what seems more probable is that there are overtones but they are so high as to be both inaudible to the human ear and unrecordable with our present equipment.

Our studies show that the individual notes in many bird songs are far more numerous than had been supposed.

TABLE I.

NUMBER OF NOTES IN SONGS.

	Length in seconds	Number of notes in song	Number of notes sung per second
Winter Wren, Song I	7.17	113	16
Winter Wren, Song II	6.72	106	16
Goldfinch	2.43	22	9
Song Sparrow, Song I	2.33	35	15
Song Sparrow, Song II	2.08	36	17
Song Sparrow, Song III	2.48	36	15

Two songs of the Winter Wren studied under the microscope show that an average of sixteen distinct notes with a corresponding number of distinct stops were produced each second.

Compare this with Aretas A. Saunders' report in 'Bird Song' (New York State Museum Handbook 7; 1929, page 175). He graphs the song of a Winter Wren heard on the Mt. Marcy trail, July 25, 1925. His song is 7.20″ long, practically the same length as my Song I; but he counts only five distinct notes compared with the 113 shown on my film. This should not lead to the conclusion that Mr. Saunders is an inaccurate observer. On the contrary my studies show him to be very remarkably accurate. It merely shows how far more accurate sound photography is than the human ear at its best.

In three film reproductions of the Song Sparrow's song studied, I found an average of about sixteen notes and corresponding stops per second. Mr. Saunders graphing a song of the same species, 2.80″ long (The Auk, Vol. 33, 1915, page 175) found only nine notes or an average of a little more than three notes per second.

Many of the notes in the Song Sparrow's song and in the songs of many other species are of incredibly short duration; so short that they could not possibly be heard by the human ear except in combination with the preceding or following notes. About three quarters of them in my Song Sparrow song II being less than 1/50″ long, and in my other Song Sparrow songs there are many notes that are short.

The silent intervals between notes are even shorter and in many instances are less than 1/200″. Visualize a note 1/50″ long succeeded in 1/200″ by another note equally short, and you will realize what a very rapid thing bird song is. Very short notes and very short intervals are present in many bird songs and I have found examples of this in the songs of the Winter Wren, House Wren, Field Sparrow, Goldfinch and many other birds.

Naturally a silent space of as short a duration as 1/50″ is not perceptible to the human ear as such. Hence what often sounds like a continuous note is really a group of rapidly delivered notes. Sometimes this appears orally as a trill, as is probably the case in the song of the Winter Wren; in other cases, however, it is heard as one note. Trills, incidentally, can be caused in several ways, I believe.

After the film has been studied under the microscope, and the number of notes, the length of the notes and the stops, and the various frequencies have been tabulated, it is possible to graph the curve of a song.

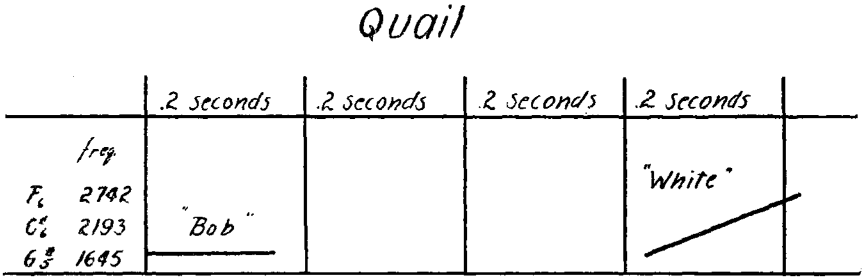
Two methods of plotting have been used. For short songs, or songs with comparatively few notes, the pitches of the notes are plotted along the ordinate or vertical direction. Thus the higher the note the nearer the top of the paper is the plotting. The abscissa or horizontal direction shows the length of the notes and the stops.

When plotting songs with many notes I ordinarily plot only the pitch of the notes, the horizontal direction then represents only the sequence of notes. This is done for practical reasons; the size of the graph would otherwise become unwieldy and inconvenient to work with.

An interesting phenomenon noted in these studies is the way in which pitch changes within the note itself. Many songs show this characteristic, as is well illustrated by the graphs of the common Bob-white call and that of the Eastern Meadowlark's song. It is also shown in exaggerated form in the graph of a few notes of the song of the Goldfinch (Figs. 1–3).

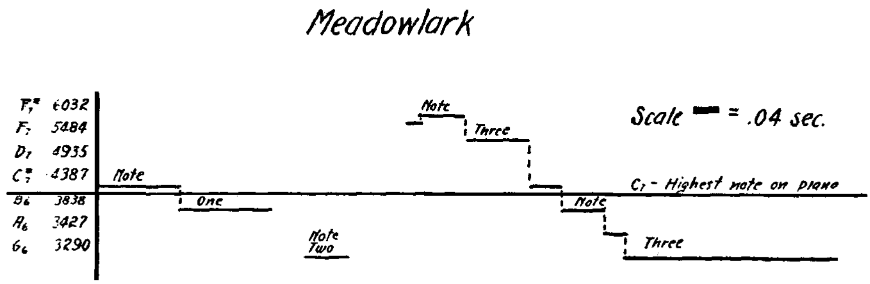
In the Bob-white call the '*white*' note ends almost an octave higher than it begins. This call is among the lowest pitched of any sounds found in these studies. Thus the first note of 1919 cycles is only about two notes higher than the highest note that a very high soprano reaches. The second note is interesting in that it is not on any definite pitch, but is an upward slur: in about one fifth of a second the pitch varies from a low of A to the F ♯ above it, or about six full notes.

In the example of one of the many variations of the song of the Eastern Meadowlark, notes I and III start at a higher pitch than they end. In the language of the musician this bird has a tendency to flat. In Note III the pitch is almost constantly changing. This note took about .6″ to be delivered. In that short space of time at least seven different frequencies were observed, and the note had a range of almost a complete octave. It starts at almost the high of the song, reaches the absolute high very quickly, drops about a full note, then over two, then about a note at a time, ending on the lowest pitch of the song. In other words in Note III both the highest and



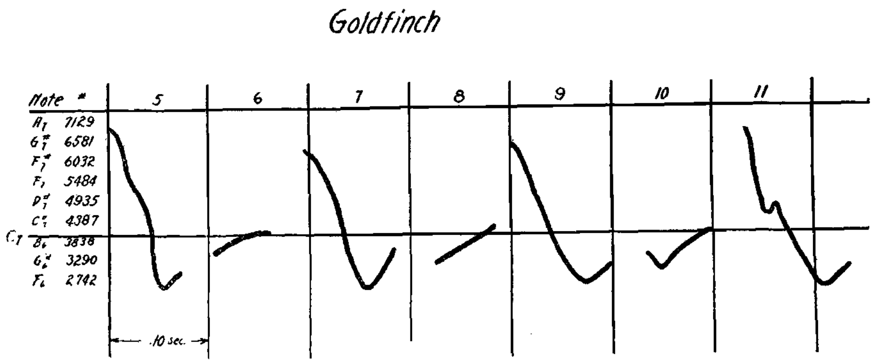
Graph of "Bob White" call of Quail

Fig. 1.



Graph of Eastern Meadowlark's song drawn to scale
Variables: pitch and length of notes and intervals

Fig. 2.



Notes from Goldfinch song

Fig. 3.

the lowest pitches in the song occur. Notes with this constantly changing quality are quite common in bird song, and probably are the reason why it is so difficult to say accurately what pitch a note has from field observations.

The graphs of the Bob-white and the Meadowlark, though produced mechanically, give a very good indication of what we should imagine the picture of the songs of these birds should look like. This is often the case with these mechanically constructed graphs but there are notable exceptions.

The graph of some of the notes from the song of a Goldfinch illustrates the excessive variations in the individual notes. (These notes are of the mating song and not the commoner call so often heard in winter.) The song has a very definite pattern according to the graph, every second note being similar to the second previous one. The odd series, numbers 5, 7, 9, etc. starts high, drops over an octave, and ends a little higher than the absolute low. The even series starts about a note under the highest note on the piano, and ends slightly higher than the last note on the keyboard. None of the silent spaces on the graph is over 1/25″ long. The notes are between .06″ and .1″ in length.

There are often great differences in volume in the various components of a song, but I have not shown this on the graphs as this factor is a matter of degree, and it is very difficult to measure accurately. However, it is quite apparent on the film, and shows up as varying density of the photographed vibrations. Quite frequently one note will be very heavily modulated,—we should probably say "over-exposed" in a picture,—the next will be much under-exposed; so light, in fact, that the lines are all but uncountable. These undermodulated areas are quite as common among low frequency notes as among high ones. This phenomenon, the rapidity of change in modulation of bird song, is one of the most distressing troubles of the sound recorder. Songs that have it very markedly are extremely difficult to record accurately, for if the exposure is correct for one part of the song it is not so for another. As notes with widely different modulation follow each other in very quick succession, often in less than 1/100″, it is obviously impossible to change exposures during the song.

Plate VI*a* shows the range of the piano and the relative pitches of the various muscial instruments and human singing voices. I include this chart in order to make it clearer where bird song is pitched and what the range of frequencies is. We must bear in mind that the range of one octave doubles the number of cycles per second of the sound. Thus if middle C on the piano is 256 cycles, the C an octave higher is just double, or 512 cycles. The highest note on the piano is, according to this chart, 4,096 cycles or C_7. We have found bird notes as high as 8,000 or 9,000 cycles, or more than an octave above the highest note on the piano.

Plate VI*b* shows the piano scale and the various instruments and voices in direct comparison with the range of bird song. The highest soprano note of the human voice, variously estimated as between 1,200 and 1,500 cycles, is over two and a half octaves below the highest note of a bird, as found in these studies, and an octave and a half, at least, below the average of the thirty-five species studied. Few bird songs, even the alto sounding ones such as the Thrushes, go as low as the highest note of a high soprano. Bird song is much higher than the violin, flute or piccolo. In order to include the range of bird song in this chart, notes beyond the range of the piano had to be added. The eight, heavily shaded, notes on the extreme right are above the keyboard. It is in this octave that most of the higher pitched bird songs occur. Only two of the bird sounds studied are within the range of the human singing voice. Thus the Horned Owl is about the center of the baritone range, and the Catbird's *mew* falls just above the contralto's high and about the middle of the soprano's range. The call of the Veery, and the bell-like songs of the Thrushes are all above the human register; in fact they are pitched about the high of the violin.

As these studies were made with the purpose of finding out how high birds sing, it might be interesting to look at a few figures of the thirty-five songs studied. The songs were taken at random, and are not a specially picked group. The studies were made from sound films of the following birds: Bob-white, Killdeer, Northern Flicker, Phoebe, Alder Flycatcher, Black-capped Chickadee, House, Winter and Long-billed Marsh Wrens, Catbird, Robin, Wood and Hermit Thrushes, Veery, Starling, White-eyed, Yellow-throated and Red-eyed Vireos, Black and White, Yellow and Chestnut-sided Warblers, Ovenbird, Louisiana Water-Thrush, Yellow-breasted Chat, Hooded Warbler, Eastern Meadowlark, Red-winged Blackbird, Baltimore Oriole, Cardinal, Goldfinch, Savannah, Grasshopper, Field, Swamp and Song Sparrows.

TABLE II.

RÉSUMÉ OF HIGH FREQUENCIES IN 35 BIRD SONGS.

Highest note: Grasshopper Sparrow; 9,141 cycles or D_8, over an octave higher than the highest note on the piano.

Six other songs with notes between 8,000 and 9,000 cycles.
Four " " " " " 7,000 and 8,000 cycles.
Twenty-seven songs with notes higher than C_7, 4,138 cycles, which is the highest note on the piano.
Five songs were within a note of C_7.

All but three of the songs contained notes as high as the next to highest note on the piano.

These statistics merely show the highest notes or pitches found in the studies. Quite frequently one or two very high notes will be found in a song, the remaining notes being more moderately pitched. The figures show, however, that a great majority of the bird songs studied are higher in range than the piano, and practically all but a very few go to within a note of that level.

However, while a song may contain an excessively high frequency or two, its average pitch is the one I would now like to consider. The highest pitches are very interesting, but quite frequently these notes are of such short duration that they could not possibly be distinguished as separate notes by the human ear. The average note, however, is the one, very probably, that determines the audible pitch of a song. I have tried, from my tables of the charts and graphs of the songs, to approximate this average note of each song.

In several songs, notably the Starling, Chat and Catbird, it has been impractical to do this because of their excessive variations. These birds sing all over the map, so to speak. In most bird song, however, an approximation can be arrived at. These figures are not exact; but they are correct to within possibly three or four hundred cycles. At the range of bird song, in these very high frequencies, that difference is not important.

TABLE III.

HIGH FREQUENCIES FOUND IN BIRD SONGS STUDIED.

(C_7 = HIGHEST NOTE ON PIANO 4,138 CYCLES.)

	Highest note in song	Lowest note in song	Approx. ave. pitch of song
Grasshopper Sparrow	9,141 (D_8)	7,678 (B_7)	8,400 (C_8)
Winter Wren	8,775	3,290	6,000
Yellow Warbler	8,775	3,469	5,900
Chestnut-sided Warbler	8,775	3,108	5,000
Black and White Warbler	8,043	5,302	6,900
Savannah Sparrow	8,775	3,290	5,000
Starling	8,226	1,096	——
Song Sparrow	7,678	2,742	5,000
Swamp Sparrow	7,495	3,437	5,000

The song of the Grasshopper Sparrow has a component as high as 9,141 cycles, (the highest bird sound I have found thus far) but the whole song is pitched a shade lower or around 8,400 cycles. This is the highest average pitch I have found in these studies, being a note or a note and a half higher than other high ones, such as the Black and White Warbler averaging around 6,900, the Yellow Warbler and Winter Wren averaging around 6,000, and the songs of the Swamp and Savannah Sparrows around 5,000. The average pitch of all the songs studied was slightly higher than 4,000 cycles. In other words, bird song averages around the highest note of the piano. There is only one musical instrument with a higher range than the piano; that is the piccolo, and that is only one half note higher. Thus it can be said that bird song goes higher than any man made music.

In the graphs of the songs of the Winter Wren and the Song Sparrow (Figs. 4–5) the only variables to be considered were the frequencies and the number of the notes. The dots on the curve represent individual notes.

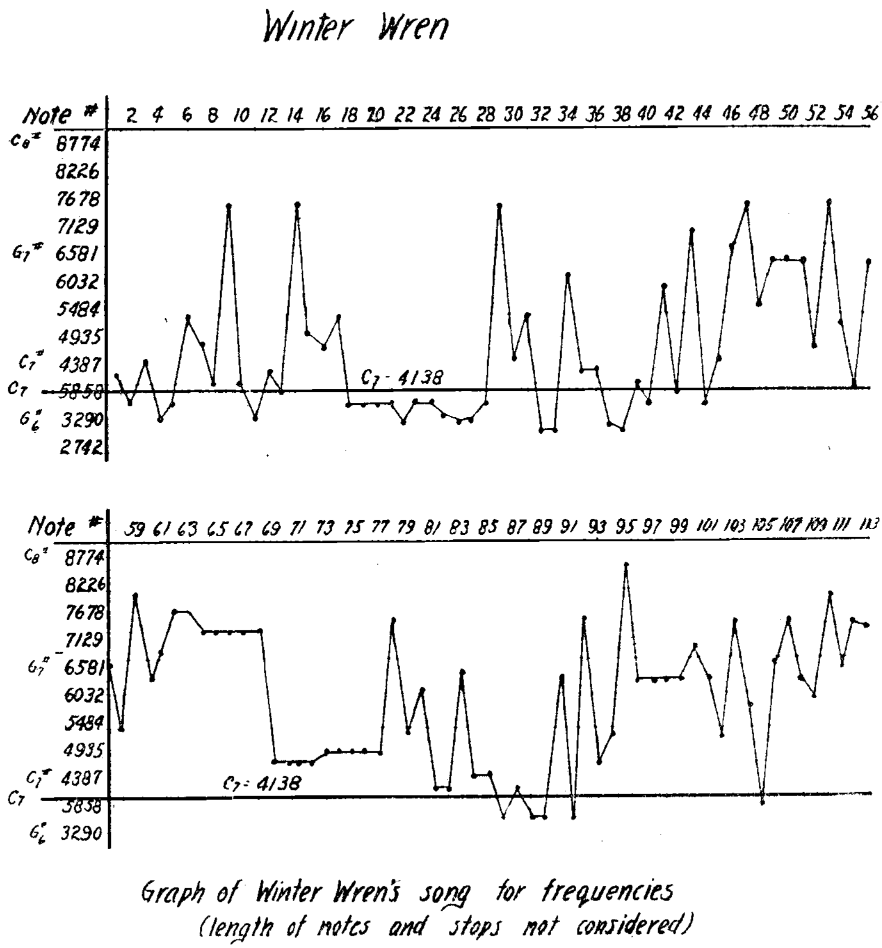
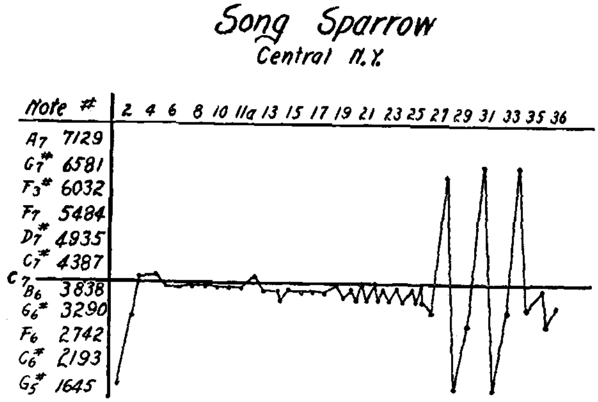


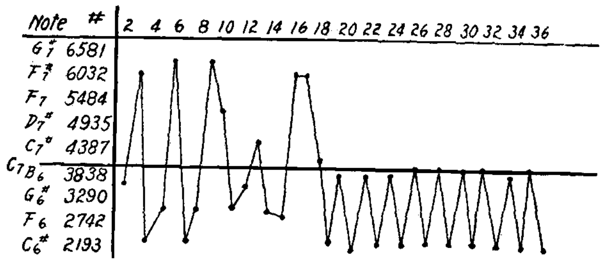
Fig. 4.

Because of the great number of notes in the Winter Wren's song (113 in all), it has been necessary to divide the graph in half. The upper half represents the first half of the song, the lower represents the second half. Here an interesting phenomenon will be noticed at once. The second half of the song is almost an exact repetition of the first half, except that it is a couple of notes higher. This is exactly what is heard, although some observers have guessed that the second half was a full octave higher than the first.

The graphs of the Winter Wren and Song Sparrow songs illustrate with what rapidity a singing bird goes through the whole scale and back again. These abrupt and lightning quick changes in pitch are most astonishing.



Song No 1 of Song Sparrow for frequencies
(stops not considered)

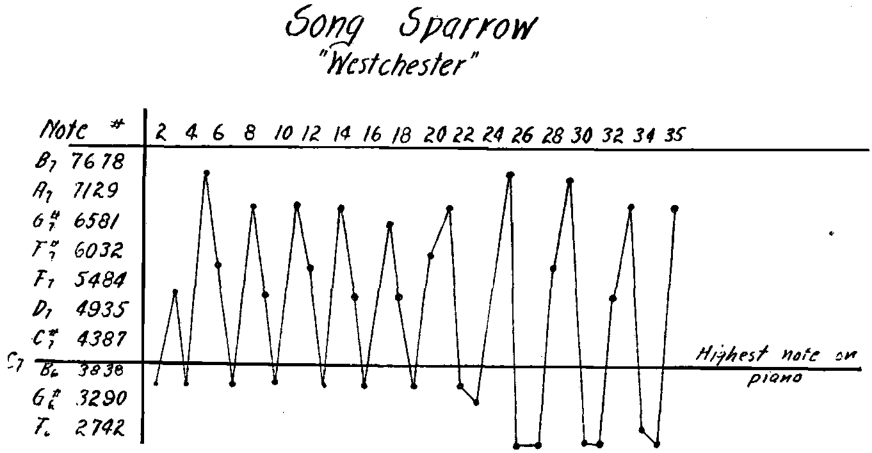


Song No 2 of Song Sparrow for frequencies
(stops not considered)

Fig. 5.

Numerous birds have almost infinite variations in their songs. In many species two members of the species rarely sing exactly the same cadence, and an individual bird may have eight or ten or more variations of his ancestral song. Mrs. Nice has noted this in her Song Sparrows, and A. A. Saunders has counted over 600 variations in the songs of that species.

He reports over 1,000 variations in the Eastern Meadowlark's song. These differences are easily detectable on the film, and by making graphs such differences can be carefully studied. Also the interesting way in which a bird often repeats one variation a number of times, and then starts another variation can be studied. In Fig. 5, two variations of a Song Sparrow's song are shown. These songs were taken at the same recording within a few minutes of each other. The bird repeated the first song several times, then started singing the second variation. I examined several samples of the first song; they were practically identical, and if graphed would have made the same curve. Note how different the second song is, however, and



Song No 1 of Song Sparrow for frequencies
(stops not considered)

Fig. 6.

yet there are certain marked similarities of the curves, among them the changes in pitch.

Fig. 6 also represents the song of a Song Sparrow, but it was produced by an entirely different bird than the author of the songs in Fig. 5. Yet there is a marked similarity between it and one of those in Fig. 5. The songs in Fig. 5, were recorded at Cortland, in central New York, while the other song was recorded in Westchester County, New York.

I make no attempt to go into a detailed analysis of these graphs, but merely offer them to illustrate the possibilities of this type of study. One thing that is apparent from even a casual look at the graphs, is that song is not haphazard. Repetition is one of its most striking characteristics, and this is true in what appear to the ear as rather unrepetitious songs. Certain phrases within the individual song appear over and over again.

I quote from a Song Sparrow study in my note book: "There is a definite pattern to this song which goes from beginning to end as is clearly shown by the graph. The rhythm was visually quite noticeably a 'three note and repeat' pattern in the early part of the song. It was as follows:—a low, long note followed by a short, very high one, and another short one but not quite so high. In the second half of the song the long, low first note is broken up into two short low ones, and the order of the following high notes is reversed. When studying the film I could know, after a little while, exactly what form of note to expect in the microscope eye-piece, the arrangement was so orderly."

These studies indicate that bird song on the whole is higher than we had been led to assume. Musical instruments do not go that high, and that is probably one of the many reasons why it is impossible to imitate bird sound successfully with such instruments.

Experience has shown that phonograph recordings are far from satisfactory with bird songs in which the high frequencies are prominent and long sustained, while lower pitched songs are easily recordable. Commercial phonographs are not refined enough to play back the excessively high vibrations of certain bird sounds. We further conclude that many songs which sound continuous are not so, but are broken up into more numerous notes and stops than the ear can detect.

From the study of the film it seems highly probable that some few birds sing beyond the range of human hearing. In the song of the Winter Wren we struck a rather startling indication of this. This song was recorded by my co-worker, Mr. Paul Kellogg, assisted by my son. Mr. Kellogg developed the film, and edited it very carefully by ear by playing it back through a sound projector. He marked the end of each song in ink on the film. Later when I studied this film under the microscope I found that in all of the fourteen songs so marked, each had the end marked several notes before the actual end as seen in the microscope. It varied, but Mr. Kellogg had missed from three to eight or nine notes in each song. In one song of 113 notes the end was marked at the 106th. It was obvious that the sound was so high that Mr. Kellogg, who is a most meticulous worker with an ear well-trained for such sounds, and who was particularly anxious not to mutilate his recordings, had not heard the ending notes.

In studying some songs on the film, the character of certain notes and the way in which they stop abruptly on the film, seem to indicate that further sound was produced by the bird, probably so high as to be inaudible, and also too high to be photographed by our present apparatus. However, this is merely surmise; further work will have to be done before these guesses can be established as facts; but with the constant refining of the machinery used in sound photography, we should be able to decide these points in the near future.

American Museum of Natural History,
New York City.