SONG SHARING AND ASSESSMENT OF INDIVIDUAL IDENTITY IN HOUSE FINCHES:

A WHITE PAPER TO ACCOMPANY THE HOUSE FINCH (*HAEMORHOUS MEXICANUS*) RECORDINGS OF PAUL C. MUNDINGER DEPOSITED AT THE MACAULAY LIBRARY OF NATURAL SOUNDS

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15 May 2015

The late Professor Paul C. Mundinger recorded hundreds of house finches (*Haemorhous mexicanus*), among many other species, between 1964-1982. All of his house finch recordings have been or will be deposited in the Macaulay Library of Natural Sounds at the Cornell Laboratory of Ornithology. CLO staff have carefully digitized each analog recording, and sent the streams to the laboratory of D. C. Lahti at Queens College CUNY, where a small army of undergraduates has been parsing them by individual and song, transcribing Prof. Mundinger's vocal track, and linking these to scans of field notes and cassette and reel box covers (a process overseen by one of us thoughout (KK)). Thus, every song by every individual house finch will be separately available to Macaulay Library users as a sound file, in addition to the original streams with all songs in context, together with any available audio transcripts, field notes, and liner notes.

In several cases in this body of recordings, multiple males are recorded at the same location. Prof. Mundinger identified these males as different (e.g., Male 1, 2, and 3), but usually did not band them. Whereas the detection of a second bird can be assumed to be relatively straightforward, a third bird in the same location during the same recording event could possibly have been the same individual as the first bird, and so on. Prof. Mundinger explains his precaution regarding this situation in his classic 1975 *Condor* article, "Song dialects and colonization in the house finch, *Carpodacus mexicanus*, on the East Coast", as follows:

> "To prevent or reduce such duplication each bird was recorded only when it was visible to me; when it flew out of sight the recording session ended and no other recordings were made within 100 meters (0.1 mile on an auto odometer) of that site. The only exceptions involved situations when two or three males were seen together. If I was able to keep them in view as I recorded them in sequence, they were treated as different individuals sampled at the same site." (p.407).

As a quality control measure, we have sought, on the basis of song data alone, to recover Prof. Mundinger's assessment of individual identity in cases where he identified three or more individuals at the same location.

We (specifically FCG) also recorded birds in western Long Island (including Queens and Brooklyn) in more recent years (2010-2014) using Prof. Mundinger's effective itinerant strategy, to assess the extents of individual repertoires and sharing; and we banded a smaller group of individuals in order to accumulate extended individual repertoires, among other reasons. Here we consider sharing on the basis of phoneme sequence, where a phoneme (sometimes considered a "syllable" or "element"), is a continuous or nearly continuous pattern of sound separated by other such patterns within a song by at least 20 ms.

Our analysis of recordings from the Mundinger sample together with contemporary recordings has yielded a number of interesting results that will be published elsewhere on their own. Here we draw from these results just enough examples to demonstrate that ***the extent of song sharing in house finches at the phoneme sequence level is diverse at any one time and also has changed dramatically in New York over time, such that no overall rule can be applied to the species as a whole, nor even to a single population over a long period of time, in order to corroborate or recover individual identities as reported by a recordist.*** Aside from the scientific implications or explanations that are beyond our present scope, the main implication for the use of this audio collection is that in general, unless some remarkable bioacoustic tools arise to prove us wrong, Prof. Mundinger's attribution of individual identity is as final a word on the matter as we will have. This could be unproblematic because Prof. Mundinger had a general and explicit policy of moving on after recording a single individual, or else keeping multiple individuals in sight, as described above. However, in light of the findings we present below, if a researcher is concerned about the lack of *post hoc* corroboration of individual identity, individuals numbered 3 and and higher at the same location can simply be excluded from analysis.

Examples of diversity in song sharing within a single location at a single point in time

To illustrate the variation in house finch song sharing in a qualitative but intuitive manner, we provide examples of phoneme sequence alignments (analogous to alignments of base pairs in DNA) within an individual and between neighboring individuals. All alignments were performed by the same person (CM). We use colored shading to draw attention to shared or inserted/deleted phonemes. We make no claims here as to the stereotypy or overall characterization of any individual's song repertoire, as many songs would have to be recorded to establish a full repertoire at the phoneme level (see Fig. 1). Our goal is simply to show that, given a finite random sample of songs from an individual's repertoire, the variation within an individual together with the variation in extent of song sharing with neighboring individuals can be so great as to preclude reliably distinguishing individuals on the basis of gross phoneme sequence alone.

1) Sharing of one or more whole songs

In the following case, taken from file 1981-16, Dubbed Side B, Prof. Mundinger (hereafter, PCM) recorded three males within the same location (Mannetto Hill Road, Plainview, NY.) They were parsed as PCM-1981-16 Dubbed Side B-1: M9, 10, and 11. Comparison of spectrographs typical of each male's song types reveals that Males 10 and 11 share two complete song types, while Male 9 does not share any phoneme sequences with the other two males (Fig. 2a-c).

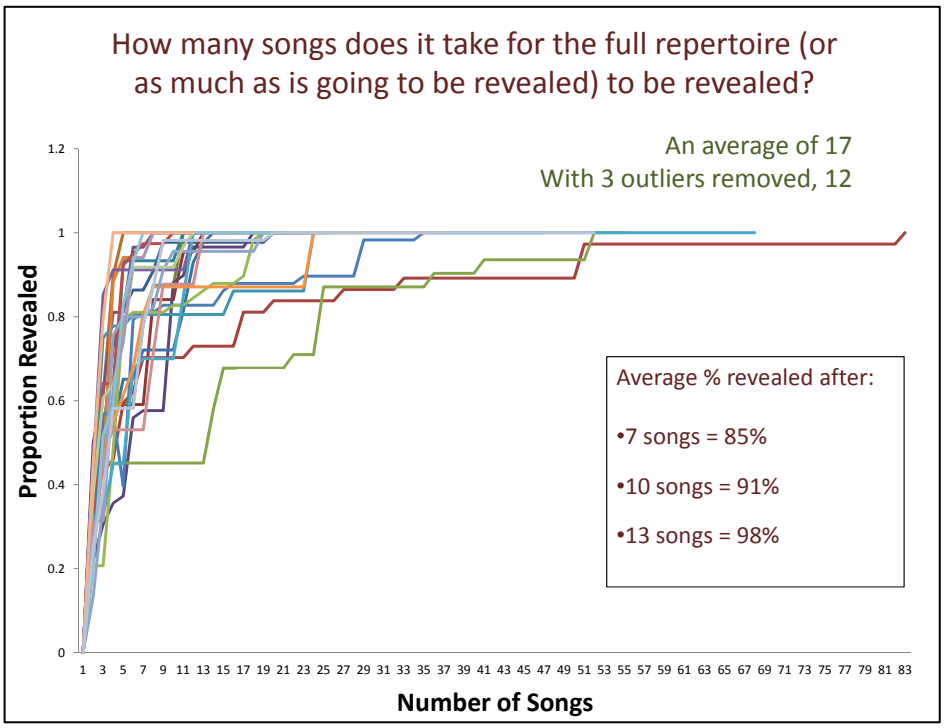

Figure 1. Proportion of individual house finch phoneme repertoires (without regard to song type, and based on qualitative assessment of phoneme identity by FCG) that are revealed according to the number of songs recorded. Data are from western Long Island, recorded 2012 by FCG. Each line is an individual.

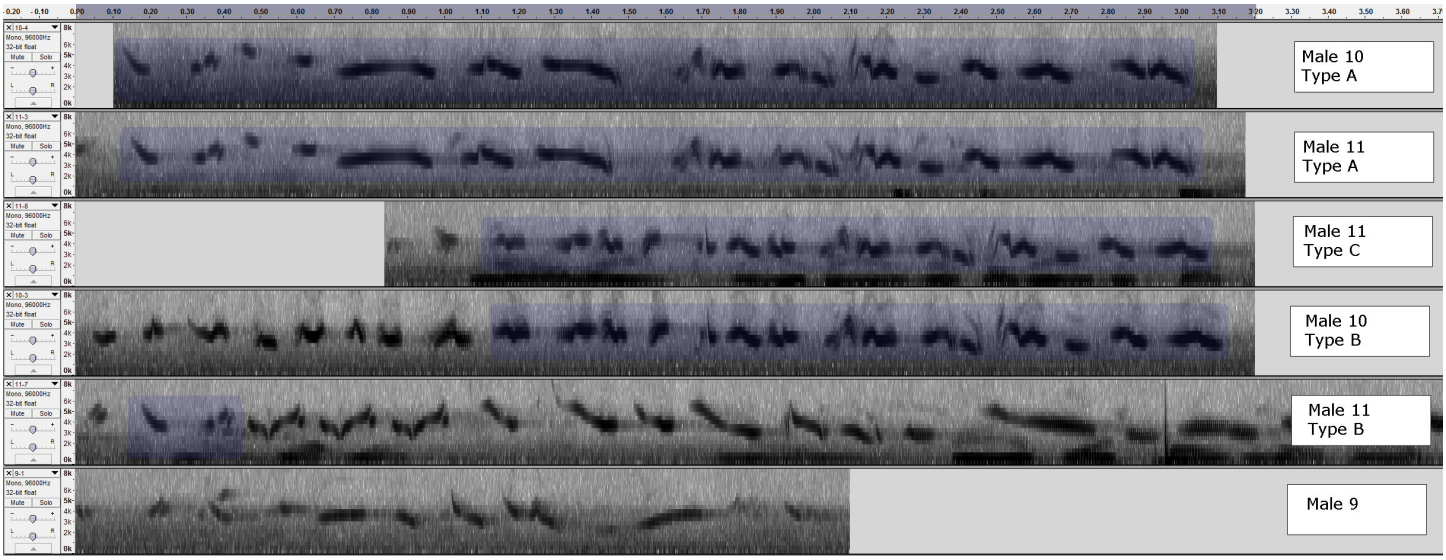

Figure 2a. Songs from Males 9, 10, and 11 from 1981-16 Dubbed Side B. The first four songs (rows 1-4) show a high level of sharing between two different song types of Males 10 and 11 (blue shading). The fifth song is a third song type of Male 11, sharing only a small opening phoneme sequence with another song type. The last song is of Male 9, and exhibits no major similarities to the songs of the other two males.

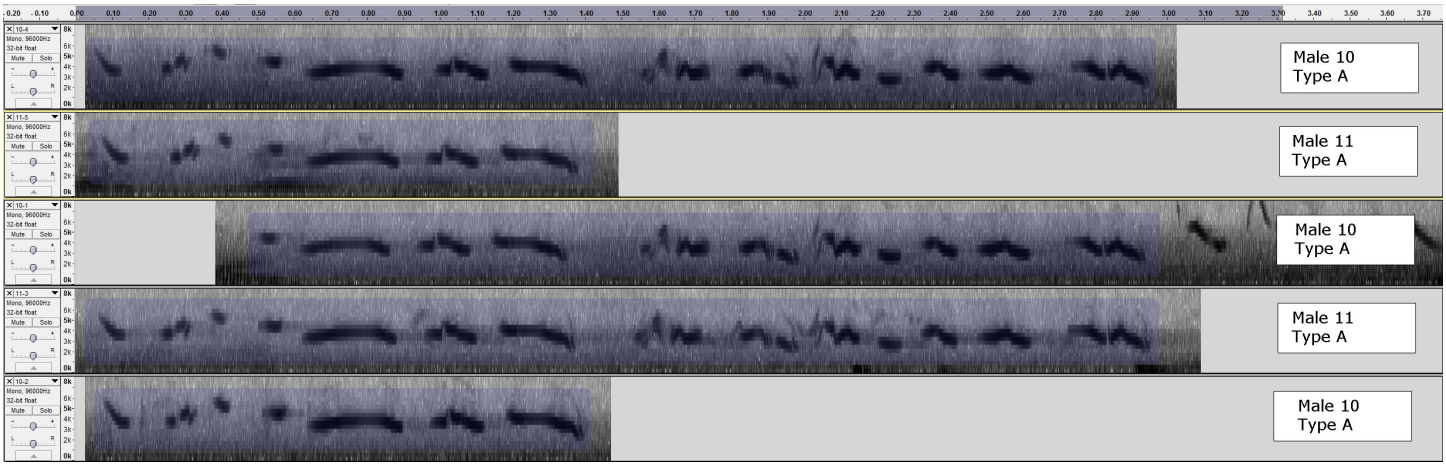

Figure 2b. Examples of song type A of Male 10 and of Male 11. Consistency in phoneme sharing is high, with little to no difference between renditions of the two individuals.

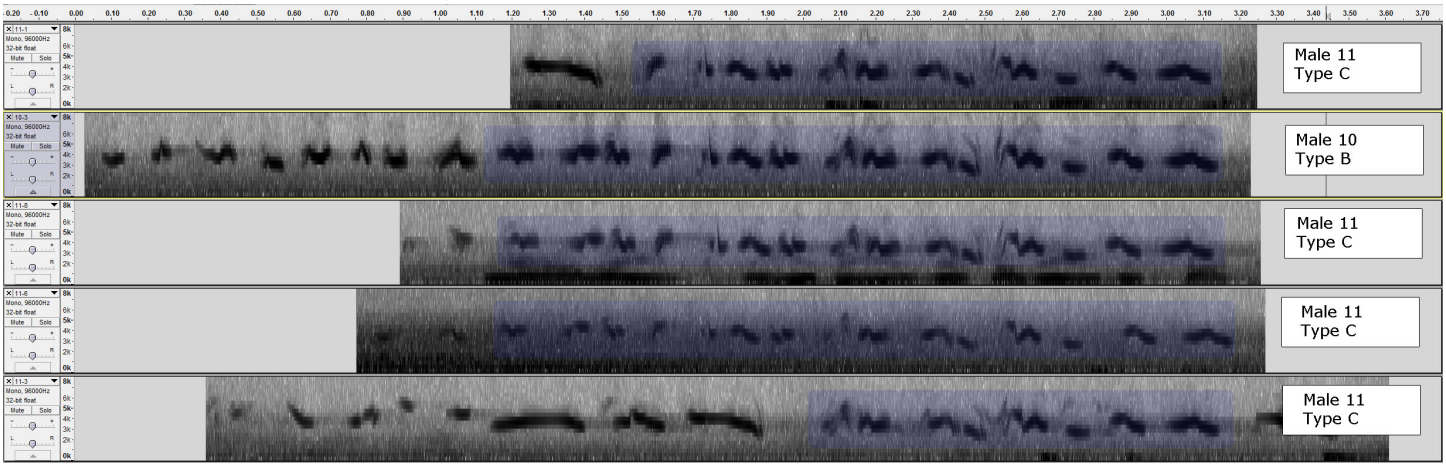

Figure 2c. Close sharing between song type B of Male 10 and song type C of Male 11.

A second example of complete song sharing between adjacent individuals is shown in Fig. 2d, parsed as Males 1, 2, and 3 from file 1981-8 Dubbed Side B. They were recorded by PCM in Parkville, Maryland on 21 May 1981. Shared song sequences between Males 1, 2, and 3 are labeled as SS1 and SS2. Males 1 and 2 share two whole songs, with only one slight modification in the type A song of Male 2. In addition, Male 3 also can be characterized as sharing the same “SS1” song, as seen by their compared spectographs (Fig. 2d).

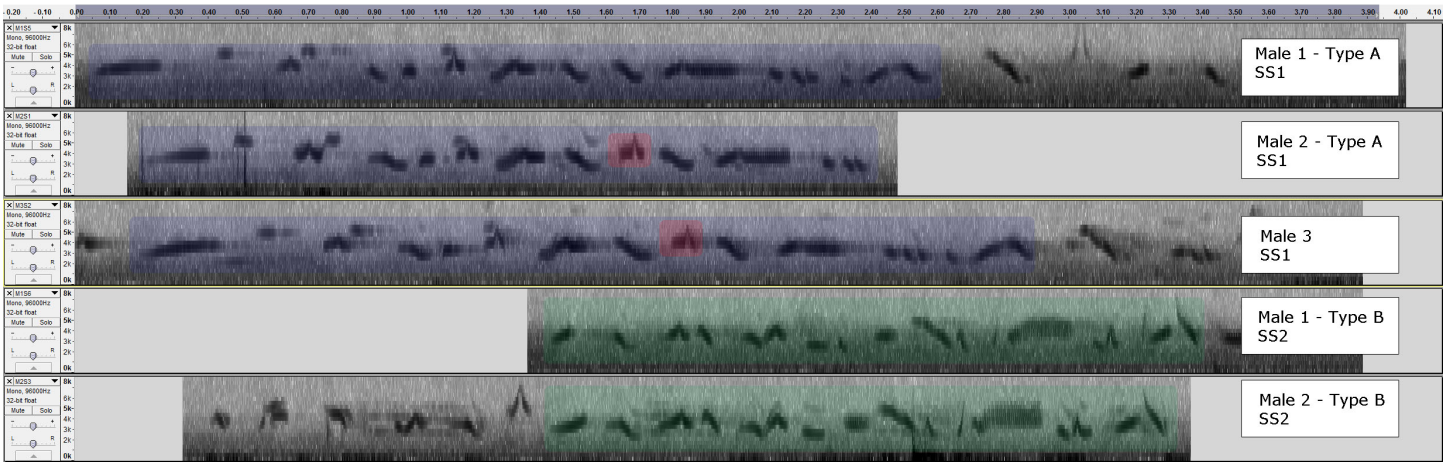

Figure 2d. Songs from Males 1, 2, and 3 from 1981-8 Dubbed Side B. This shows two sets of songs that are completely shared between Males 1 and 2. The first set of similar songs, labeled SS1, shows a high level of sharing consistency between the type A songs of Males 1 and 2, as well as the song of Male 3. The only unshared phoneme is an inserted phoneme in the the songs of Male 2 and Male 3 (or deleted in male 1). The second set of similar songs, labeled SS2, again shows complete phoneme sharing, between the Type B songs of Males 1 and 2.

A third example of whole song sharing is shown in Fig. 2e, taken from file 1981-19 Dubbed Side A, with 3 males recorded by PCM at the intersection of Hudson and Bartow Avenue in Greene, New York. The three males were parsed as Males 7, 8, and 9. Males 7 and 8 share a whole song, while Male 9 has no similarities when comparing spectrographs (Fig. 2e). It is possible that the complete repertoires were not sampled from these birds; the point here is that a random sample of songs from two or more individuals might be similar enough to be considered whole-song matching.

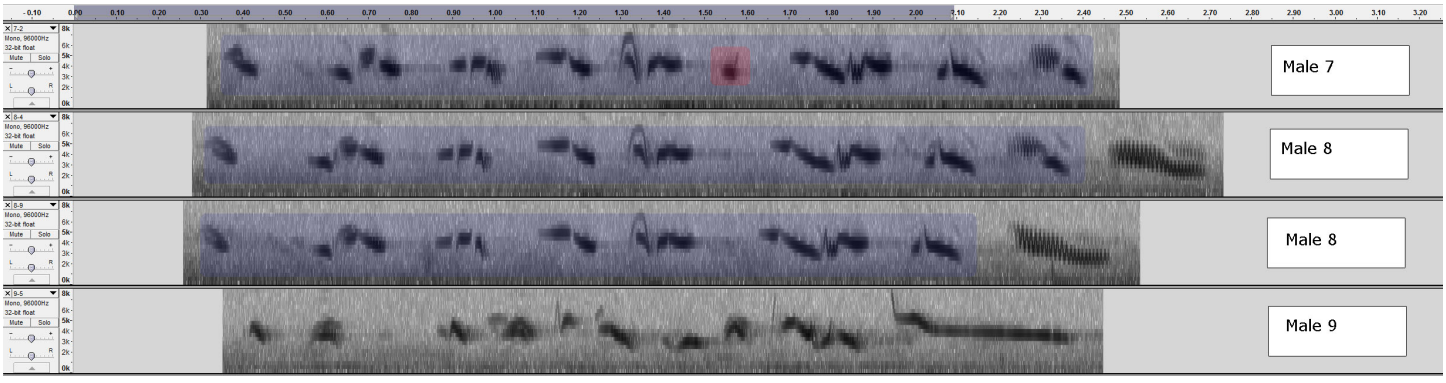

Figure 2e. Songs from Males 7, 8, and 9 from 1981-19 Dubbed Side B. Males 7 and 8 show a complete sharing of phoneme sequences, other than one small inserted region in male 7's song. Male 9 shows no phoneme similarities to the neighboring two males.

2) No song or sequence sharing

In the following example (Fig. 3a), taken from file 1981-3 Dubbed Side A, PCM recorded 3 males in Dogwood Lane, Odessa, Delaware. They were parsed as PCM-1981-3 Dubbed Side A: Males 5, 6, and 7. No phoneme sequence is shared among the three males. Of course, these songs might be shared with other males in the same neighborhood; the point here is that a randomly selected group of males in the same area can at times share no songs, in contrast to the previous examples of whole-song sharing.

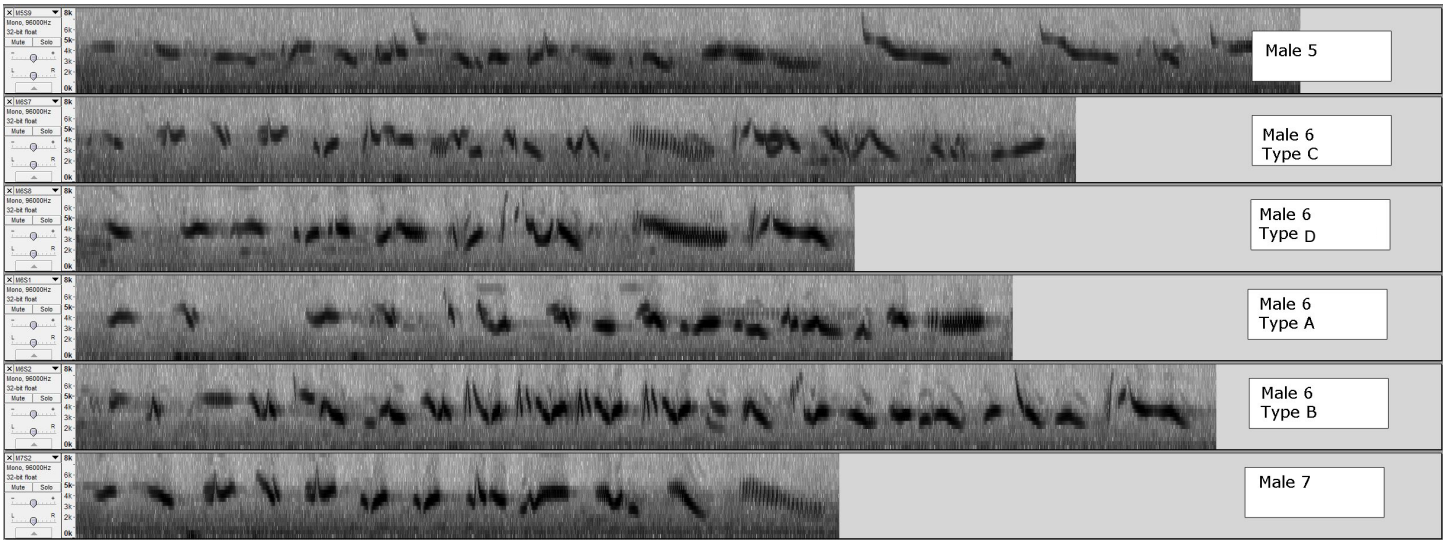

Figure 3a. Songs from Males 5, 6, and 7 from 1981-3 Dubbed Side A. No phoneme sequence is shared among these three males, for any song type. One or two phonemes might be shared (for example, a beginning phoneme before the main song), but sequence similarities are not evident.

In addition, Male 6 from Figure 3a varies between renditions of a given song type, which would compound the difficulty in differentiating among individual males by song (Fig. 3b). Such variation across renditions of a song type appears to be less common in PCM's recordings from 1975-1981 than it is today in our (FCG's) recordings in the same geographical area, although we have not thoroughly tested this observation. In addition, as is the case in many songbirds, individuals recorded before crystallization have a less stereotyped song (FCG, personal observation); a recordist might not be able to determine from a single recording whether a bird has achieved its full adult repertoire with crystallized stereotypy.

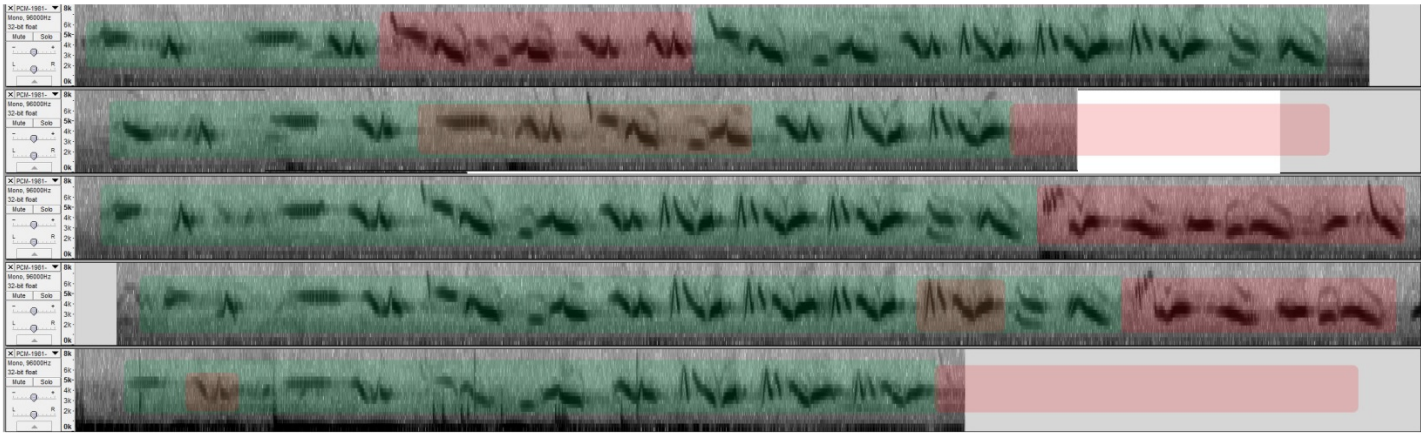

Figure 3b. Type B song of Male 6 from 1981-3 Dubbed Side A. These five renditions show modified regions within the song, modifications at the end of a song, as well as abbreviations, or early endings.

3) Partial song sharing

Birds recorded in the same area might also share some sequences but not others. An example in Figure 4 is taken from file 1981-20 Dubbed Side B, with individuals parsed as Males 7, 8, and 9. PCM recorded these males on 25 June 1981 in Highland Falls, New York. In the vocal track, PCM noted multiple males within the same area, with some singing at the same time. The three birds share some sequences of phonemes among each other, but have regions without sharing as well (Fig. 4).

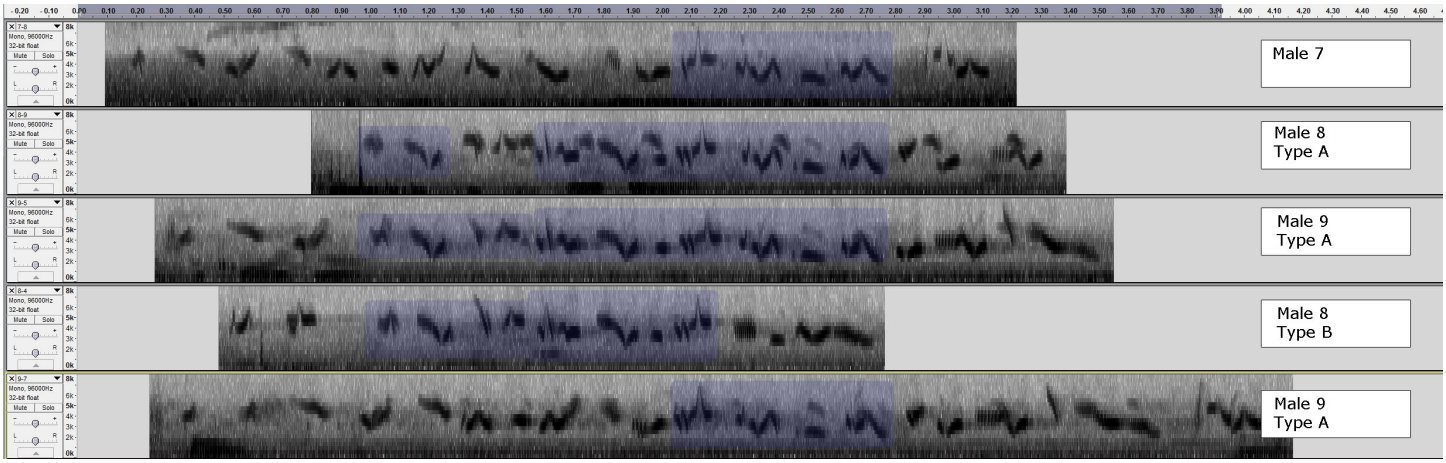

Figure 4. Males 7, 8, and 9 all show some degree of sharing among their songs. In particular, Type A of Male 8 and Type A of Male 9 (rows 2-3) are shared, with only a few modifications. Moreover, a sequence in Male 7's song (row 1) and the middle sequence of Type B of Male 8 (row 4) are shared with Type A songs of Males 8 and 9 respectively. Also note the major differences between renditions of the Type A song of Male 9 itself (rows 3 and 5), if indeed these two renditions can be considered a single "type". We shall take up this issue elsewhere.

As these examples illustrate, a male house finch can exhibit different levels of phonological variation between renditions of his own songs, and in comparison with those of near neighbors. This result suggests that examining one or even a few songs will not, or at least not easily, permit one to determine "by eye" (i.e. by a gross assessment of phoneme sequence similarity) whether two sets of recordings are playing songs from the

same or different males. The ubiquity of such examples in PCM's recordings, and the continuous scale of sharing variation across the dataset, tell against the possibility that cases of whole-song sharing resulted from PCM's mistaken identification of one male as two, especially given PCM's restrictive rules quoted above for recording in single locations. In addition, recordings of banded males in the 2010s corroborate this issue of variable sharing between neighboring individuals (FCG, unpublished data). Next we expand on this discovery of temporal change in the extent of song sharing.

Change in song sharing over time in a population

Even if some rule could be devised that effectively distinguished among individuals in a given time and place based on song features, facilitated for instance by extensive sampling of individuals' repertoires, this rule would not be generalizable to other times and places, nor even to other times in the same place. We compared PCM's recordings of 1062 songs from 94 individuals in western Long Island, NY in 1975, to recordings by one of us (FCG) of 981 songs of 96 individuals in the same area (and using PCM's rules to reduce or eliminate misidentification as quoted above) in 2012. In each case an individual was only included if high-quality recordings of more than five songs were available.

We used *FinchCatcher* (original software written by CJ) to automatically classify all of the phonemes in both datasets based on several shape-related features of the spectrogram (for more details see Ju et al. "Characterizing bird song diversity between individuals and populations: a computational approach" (in review), or email us). Then we calculated a pairwise similarity score between each pair of songs of two different individuals, as the proportion of phonemes shared between the two songs and appearing in the same order (but not necessarily consecutively), using the shorter of the two sequences as the basis for comparison. For example, given two song sequences with phonemes 1,2,4,5,6,7,8 and 2,3,8,6,7,4, the three underlined numbers common to both sequences, and in the correct order, comprise the shared sequence. Using the shorter sequence as the basis for comparison, the proportion of sharing is 3/6 phonemes, or 0.5. Figure 5 shows the distribution of such similarity scores for all pairwise comparisons of songs (between individuals only), for each (1975 and 2012) sample. Clearly, house finches in Western Long Island shared more phonemes with each other in 1975 than they did in 2012. However, we have discovered that song sharing at the phoneme level decays with geographic distance (Ju et al., unpublished data). Thus the result in Figure 5 could result from the sampled individuals being more distant from each other in the 2012 sample than in the 1975 sample. Thus we established that the two samples are similar in the range of distances between individuals (Fig. 6).

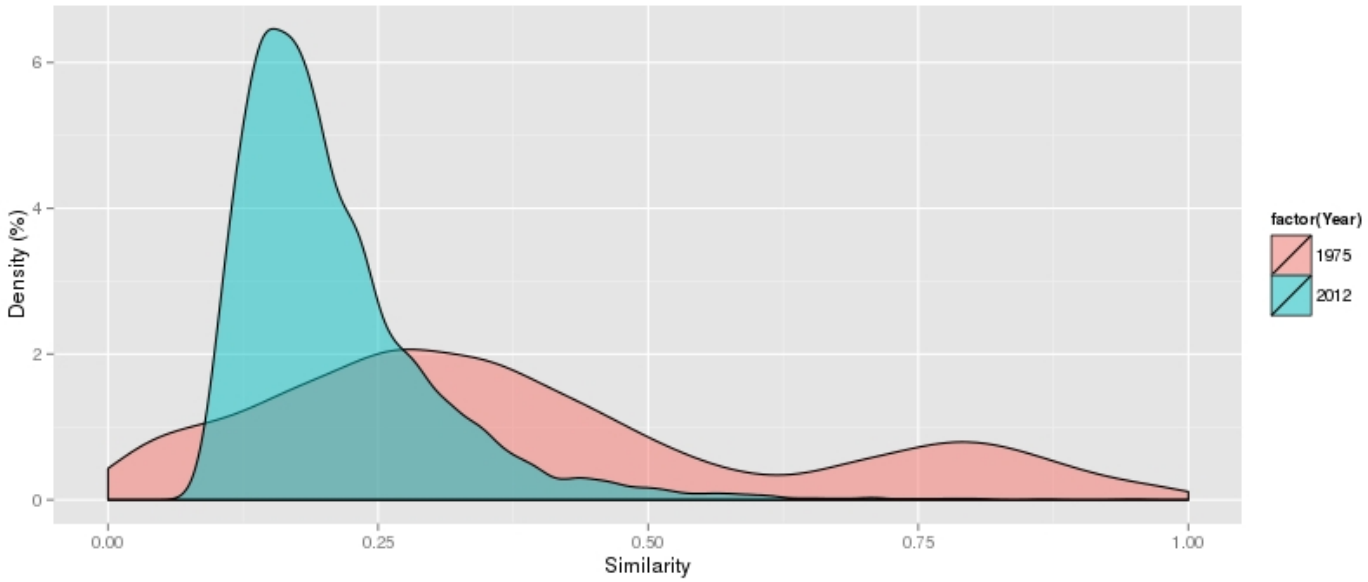

Figure 5. Distribution of similarity scores, in terms of proportions of shared phonemes, in all pairwise comparisons of songs between house finch individuals in 1975 (1062 songs from 94 individuals) and in 2012 (981 songs from 96 individuals), in western Long Island, NY. Bin width on the x axis is 1/30 of the range of the data. The y axis is the percent of all pair-wise song comparisons between individuals.

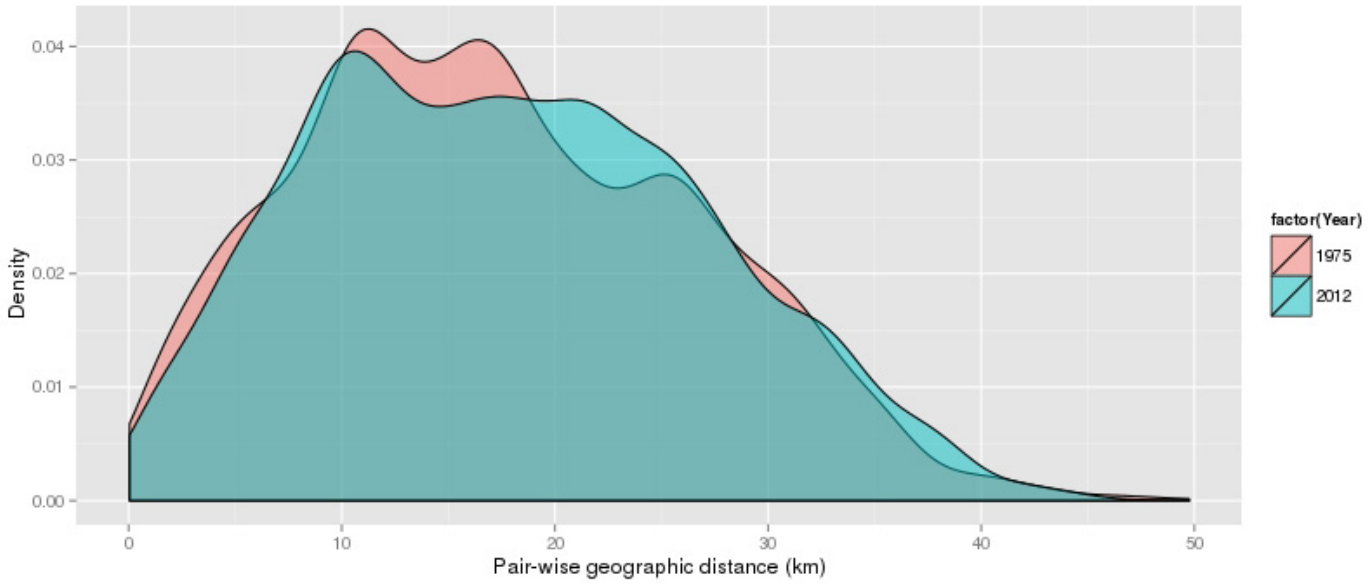

Figure 6. Geographic pair-wise distances among males in two samples of house finches, one from 1975 (94 individuals) and one from 2012 (96 individuals), in western Long Island, NY. Bin width on the x axis is 1/30 the range of the data. The y axis is the proportion of all pair-wise song comparisons between individuals.

Stereotypy and possibly the number of song types recorded per individual might likewise be different between the two time periods, and a more careful analysis would have to account for this. Nevertheless, whatever the relative contribution of within-individual and between-individual variation to the difference shown in Figure 5, clearly one cannot assume that patterns of song similarity and prospective rules for distinguishing between individuals on the basis of song phonology are generalizable across time periods in the house finch.

Conclusions

Just as individual identification of speech patterns has proved mightily difficult in human forensics, the song learning and production programs of at least some birds, like the house finch, can yield sounds that are surprisingly complex, variable, and defiant of simple categorization. Here we demonstrate that one cannot take a casual set of recordings of the songs of multiple house finches, and reliably distinguish between individuals *post hoc* by either a subjective qualitative analysis or (at least one) quanitative shape-related analysis. The reasons for this are that (1) individual males vary in their renditions of a single song type; (2) individuals also have multiple song types that apparently do not bear any greater resemblance to each other than to the song types of different males; (3) the extent of song sharing between individuals at the phoneme sequence level is too diverse even among neighboring males (ranging from whole-song sharing to virtually no shared sequences) to admit of a general rule; and (4) any rule that might pertain to the songs of a particular geographical area could change over time, as the songs did in Western Long Island, New York between 1975 and 2012. Therefore, at least by the assessment tools we used here, individual identities reported by a recordist are the last word on the matter. As mentioned above, this issue might be moot in some cases, if for instance the recordist employs a reliable means of avoiding the inadvertent recording of multiple individuals in the same location. In the Mundinger dataset, a conservative researcher can avoid this issue altogether merely by excluding individuals numbered 3 and higher at any given location from analysis.

Acknowledgments

We thank the National Science Foundation (grant #1137888 to DCL); and especially Dr. Mary O'Neil Mundinger, Edward M. Kennedy Professor of Health Policy and Dean Emeritus of the Columbia University School of Nursing, for supporting this project on the cultural evolution of house finch song. We are also grateful to Simon Lee and several other undergraduate research assistants, and to the Cornell Laboratory of Ornithology and the Macaulay Library of Natural Sounds.

Paul & Mary Mundinger, 2007