



# Chirping across continents: variation in urban house sparrow (*Passer domesticus*) vocalizations across North America and Europe

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**Abstract** The house sparrow (*Passer domesticus*) is one of the most widespread invasive bird species, with numerous and dense populations established across urban-agricultural landscapes of North America. Although this species has been widely studied to identify the traits that explain its global ubiquity, descriptions of house sparrow acoustic features across

its native and introduced range are limited in the literature. We recorded male house sparrow vocalizations from 13 cities across Europe and North America to quantify the structural features of its common “chirrup” vocalization. Although the basic structure and duration were consistent across the two geographic regions, the vocalizations differed in their minimum frequencies and bandwidth. In a post hoc analysis of 140 museum specimens, we found that European house sparrows had larger bills and bodies than those in North America. Thus, we propose that these frequency shifts could be a result of synergistic interactions between morphological differences, potential

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differences in ambient noise, acoustic overlap with other species within the soundscape, or other acoustic features of European and North American cities. House sparrows seem to be a good model for future bioacoustics studies, given their worldwide distribution and acoustic plasticity, to test hypotheses related to urbanization traits and invasion potential.

**Keywords** Bandwidth · Chirrup · Frequency · Invasive · Urban bioacoustics · Urban ecology

## Introduction

The house sparrow (*Passer domesticus*) is considered one of the most widespread invasive birds (Anderson 2006; García-Arroyo et al. In Press). Native to the Near East region as a non-commensal species (Ravinet et al. 2018), the house sparrow range-expanded into Europe and eventually was introduced to North America, among other regions, via multiple introductions, quickly expanding its geographic distribution over the past century (Baughman 2003; Wagner 1959). Due to the species' impressive plasticity and invasive range-expanding capacity (Anderson 2006), the house sparrow has been widely studied regarding their morphological, physiological, genetic, and behavioral characteristics (Anderson 2006; Liebl et al. 2015).

Birds have the potential to shift their vocalizations in response to a variety of environmental variables to maximize transmission, as noted in the acoustic adaptation hypothesis (Morton 1975; Grimes et al. 2024).

This is particularly important in urban environments, where birds have shown the capacity to increase their song frequencies to avoid being masked by urban noise, among other adjustments (Brumm and Slabekoor 2005; Derryberry et al. 2020; Dowling et al. 2011; Francis et al. 2011; Gil and Brumm 2013). In particular, house sparrows can increase their minimum song frequencies in response to the presence of low-frequency ambient noise (Sheldon et al. 2020). In addition to responding to local habitat features, songbirds may also pass along alterations in their vocalizations via imitative learning (Kroodsma 1996) and cultural transmission (Luther and Derryberry 2012), potentially resulting in differing song dialects (Podos and Warren 2007; Dahlin et al. 2024), especially in instances following colonization (Potvin and Clegg 2015). In anthropogenically modified landscapes, this may result in constrained sound propagation and modified song structure and diversity (Laiolo and Tella 2005; Grimes et al. 2024).

Song evolution is not only shaped by environmental conditions in which birds attempt to communicate, but also by their body morphology (Podos 2001; Ryan and Brenowitz 1985). Particularly, body and beak size tend to constrain song characteristics and performance across species (Demery et al. 2021; Friis et al. 2022). Evidence suggests that larger birds or birds with larger beaks can produce songs with lower minimum frequencies (Demery et al. 2021; Huber and Podos 2006; Palacios and Tubaro 2000) and narrower frequency bandwidths (Derryberry et al. 2018; Huber and Podos 2006; Podos 2001). Changes in avian body or beak size in a population (e.g., due to

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founder effect with an introduced population) could therefore result in modifications in song structure (Podos 2001).

Given the widespread distribution of house sparrows across continents and knowing their propensity to alter songs due to environmental constraints, we hypothesized that urban house sparrow vocalizations would differ between Europe and North America. For this, we recorded urban house sparrow vocalizations from both regions and tested if their acoustic features varied. Based on our field observations, we expected European sparrow vocalizations to be softer and higher pitched when contrasted with North American sparrows. Additionally, recognizing that their morphology, mainly beak and body size, may constrain vocal structure and performance, we post hoc measured museum specimens to determine if any geographic variation in morphology was associated with acoustic structure in Europe and North America. Additionally, we foresaw differences in house sparrow body morphology and beak size among regions, with larger sparrows in Europe, based on previous literature (Hamilton and Johnston 1978; Johnston and Selander 1973).

## Methods

We recorded urban house sparrow vocalizations from January to May 2020 in six European cities (Trondheim, Norway; Uppsala, Sweden; Trakai, Lithuania; Choisy-le-Roi, France; Burgas, Bulgaria; Coimbra, Portugal) and seven North American cities (Pittsburg, USA; Lubbock, USA; Monterrey, Mexico; Guadalajara, Mexico; Xalapa, Mexico; Puebla, Mexico; San Cristóbal de las Casas, Mexico) (Fig. S1). We recorded songs using the built-in microphones of smartphones, utilizing the RecForge II application (sampling rate of 44.10 kHz and 16 bits) for Android or the built-in application for iPhone (sampling rate of 22.05 kHz and 16 bits). Recordings were high-pass filtered at 2 kHz and low-pass filtered at 7 kHz to eliminate background noise and normalized to -1 dB using Audacity 2.3.3 (Audacity Team 2018).

We analyzed the structural characteristics of the most frequently recorded house sparrow song type among surveyed cities: a two-peak “chirrup” (referred to as chirrup hereafter) (Anderson 2006; Lowther, Cink 2020). For this, we selected an average of 5.3

( $\pm$  SE 0.47; range 3–8) vocalizations from different individuals at each location with no overlapping background sounds and a high signal-to-noise ratio. We then generated digital spectrograms for each of the 69 selected chirrup vocalizations with Raven Pro software (version 1.6.1 Beta) (Center for Conservation Bioacoustics 2019) using Hann sampling and a discrete Fourier transform (DFT) of 256 samples and 90% overlap.

To contrast the songs of European and North American sparrows, we quantified 13 fine structural characteristics of the 69 chirrups (Table S1), describing their length (i.e., chirrup duration; seconds), frequency (i.e., minimum, maximum frequency, and four percentages including the energy within the selection: 25%, 50%, and 75%, 95%; kHz), bandwidth (i.e., total, 50%, and 90% of the frequency range; kHz), energy (i.e., dB), and entropy (i.e., minimum, maximum; bits). We quantified frequency using the threshold method (-15 dB) to standardize measurements by establishing a threshold that corresponds to a percent value of the amplitude relative to the maximum value of amplitude detected in each signal (Fernández Gómez et al. 2020; Podos 1997; Ríos-Chelén et al. 2016). We also used the waveform to determine each song’s beginning and ending time to determine song duration.

To assess the potential relationships between the measured acoustic features (independent variables) and the origin of the assessed house sparrows (Europe, North America; dependent variable), we performed a binomial generalized linear model (GLM). Given that many of the quantified acoustic measures were correlated (Table S2), we performed a variance inflation factor (VIF) assessment to address potential collinearity. For this, we dropped all variables showing VIF values  $> 10$  (Chatterjee and Hadi 2013). Thus, the final model only included the set of independent variables whose VIF was  $< 10$ .

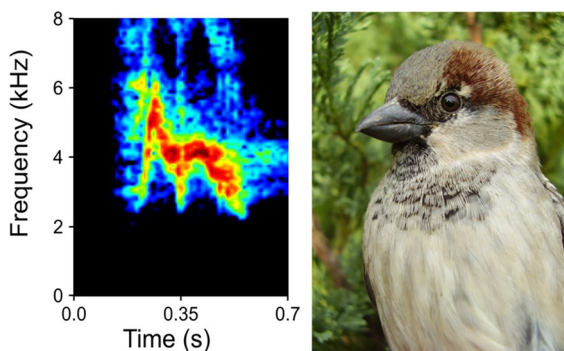
After determining that there was a structural difference between North American and European house sparrow vocalizations, we tested whether these performance differences were due to beak morphology. To obtain a representative sample of beak morphology across North America and Europe, we measured 140 adult house sparrow specimens (70 per region) all housed at the University of Kansas Biodiversity Institute and Natural History Museum (Lawrence, KS, USA). We measured the following morphological

traits for specimens collected near our song recording locations using calipers (mm): beak culmen, width, and height, and tarsus length (proxy of overall body size). We calculated beak conical volume to represent beak size. We also recorded weight (g) upon capture, as indicated on the collection tag. Of the 70 house sparrow specimens per region, weight was provided for 48 European and 68 North American specimens. We ran a binomial GLM to test differences in house sparrow body size (tag weight; g) and beak volume ( $\text{mm}^3$ ) by their collection location (Europe, North America).

## Results

The recorded house sparrow chirrup vocalizations were short and had a mean duration of  $0.12 \pm 0.03$  s (standard deviation;  $N=69$ ) consisting of a double utterance. Structurally, the chirrup song analyzed consisted of two notes, similar to an “M” shape, with the frequency at the beginning rising rapidly and then falling at the end in both notes (Fig. 1).

After dropping five variables (i.e., total bandwidth, bandwidth 50%, frequency 50%, 75%, and 95) due to multicollinearity, the final GLM ( $r^2=0.26$ , for which we considered the quasi-likelihood method due to model overdispersion; residual deviance=76.45, degrees of freedom=60) showed two variables to be significantly related with the origin of the assessed house sparrow (Europe, North America): minimum frequency and bandwidth 50% (Table 1). These results indicate European house sparrow chirrup



**Fig. 1** A spectrogram representation of the house sparrow disyllabic “chirrup” vocalizations with two peaks (left) and a house sparrow (*Passer domesticus*) (right)

**Table 1** Final GLM results for testing acoustic ( $N=69$ ;  $r^2=0.26$ ) and morphological ( $r^2=0.43$ ) features of the House Sparrow by their origin (Europe, North America). We measured beak volumes for 140 sparrow specimens, of which specimen weight upon capture was provided for 48 European and 68 North American sparrow specimens.  $P$  values  $<0.05$  are bolded

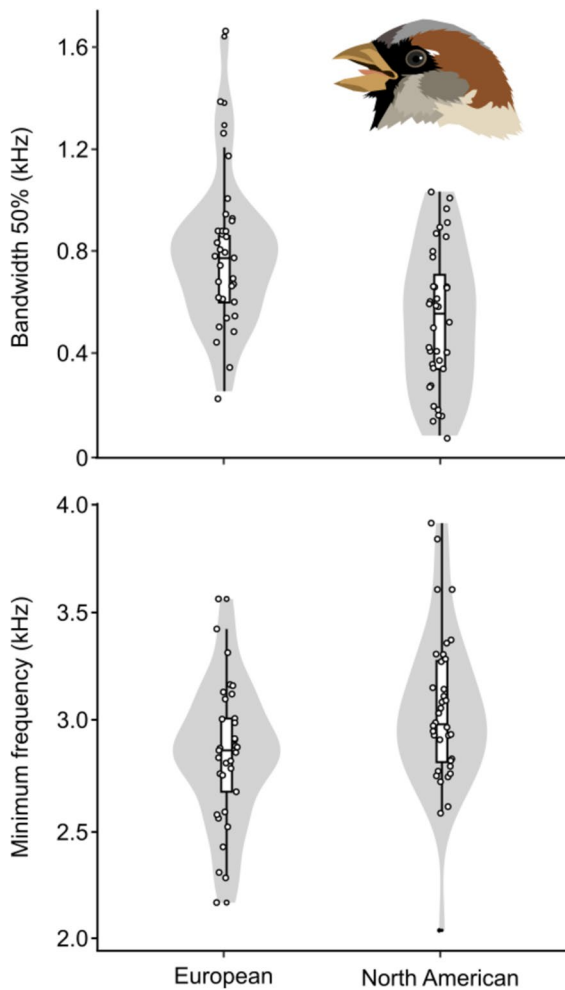
Model	Feature	df	$\chi^2$	$P$
<i>Acoustic</i>	Duration (s)	67	93.585	0.163
	Minimum frequency (kHz)	66	87.783	<b>0.016</b>
	Maximum frequency (kHz)	65	85.858	0.165
	Frequency 25% (kHz)	64	83.147	0.099
	Bandwidth 50% (kHz)	63	77.361	<b>0.016</b>
	Energy (dB)	62	77.084	0.598
	Maximum entropy (bits)	61	76.680	0.524
	Minimum entropy (bits)	60	76.457	0.637
<i>Morphology</i>	Beak volume ( $\text{mm}^3$ )	114	149.69	<b>0.006</b>
	Body weight (g)	113	120.71	<b>&lt;0.001</b>

vocalizations had a significantly wider frequency bandwidth (at 50% of the frequency range) and lower minimum frequency when contrasted to the North American vocalizations (Fig. 2).

The GLM ( $r^2=0.43$ , for which we also used the quasi-likelihood method due to model overdispersion; residual deviance = 120.71, degrees of freedom = 113) that focused on the morphological features of house sparrow museum specimens showed that both beak volume and body weight were significantly different between the sparrow’s region (Table 1). European house sparrows were larger in weight (9.5%) and had slightly larger beaks (3.5%) than North American specimens (Fig. 3).

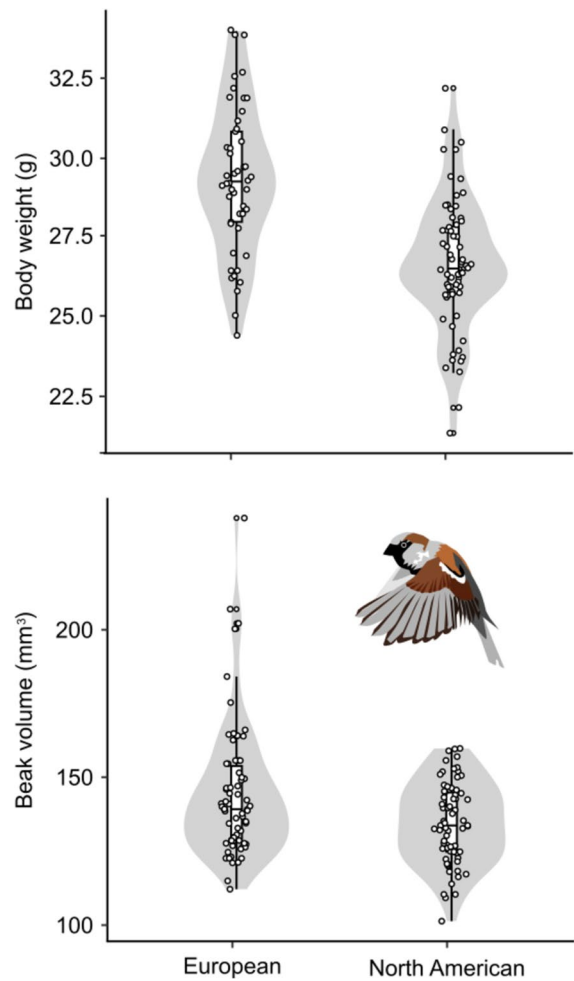
## Discussion

The most frequent chirrup vocalizations we recorded were one of the two-peak variations, as reported by Anderson (2006). Here we analyzed one of the most common disyllabic chirrup produced by house sparrows in cities across North America and Europe. Although most acoustic features were similar across both studied regions, the house sparrow chirrup had a higher minimum frequency and narrower bandwidth



**Fig. 2** European House Sparrows produce chirrup vocalizations with wider frequency bandwidths and lower minimum frequencies as compared to North American sparrows. Each dot is an individual bird. Shading represents a kernel density estimation of the data distribution

in its introduced North American range compared to Europe. Thus, we were able to confirm our initial predictions after opportunistically observing softer, higher-pitched acoustic features of European house sparrows, compared to those in North America. These differences indicate that while the temporal and structural features of the chirrup were generally retained throughout the house sparrow geographical range in the studied regions, there was a clear shift and narrowing of song frequencies perpetuated in house sparrows in cities throughout North America, potentially due to differing body morphology.



**Fig. 3** European House Sparrow museum specimens had larger body weights upon capture and larger beaks (conical volume) compared to North American specimens. Each dot is an individual bird. Shading represents a kernel density estimation of the data distribution

The key acoustic spectral parameters of the house sparrow chirrups that changed across its geographic range were related to the song's frequency. Frequency and bandwidth alterations of house sparrow's vocalizations may have occurred due to the effects of anthropogenic noise in the different sampled cities. European cities, on average, have lower noise limits as compared to North American cities (Perna et al. 2022). Thus, if the sampled North American cities were generally louder than their European counterparts, our results align with the literature regarding shifts into higher minimum frequency as a communication strategy to avoid signal masking in North



American house sparrows. Adapting to noisy environments, some species have experienced shifts in amplitude, spectral and temporal characteristics, redundancy, and timing in their vocal behavior (Brumm and Zollinger 2011; Gómez-Catasús et al. 2022). Actually, previous studies have shown that house sparrows can increase their minimum song frequencies in loud environments to avoid signal masking (Sheldon et al. 2020). Although we did not directly measure if European and North American cities differ in their ambient noise and acoustic features, urban noise may provide one explanation as to the differences in house sparrow chirrup frequencies across their range.

Another strategy for increasing acoustic signal detectability in noisy environments is to increase the amplitude and signal redundancy. The high repetition rate or redundancy within vocalization bouts in house sparrow could favor the likelihood of signal detection under high anthropogenic noise levels (Gil and Brumm 2013; Gómez-Catasús et al. 2022). Future studies measuring the amplitude and signal redundancy would facilitate quantitative measurement of whether house sparrow can modify that parameter of their vocalizations in different urban environments throughout their native and introduced ranges.

Lastly, structural features of bird vocalizations are not only in response to acoustic environments, but they are constrained by and may be less variable due to the bill morphology of individuals (Giraudeau et al. 2014; Podos 2001; Ryan and Brenowitz 1985). This is particularly relevant in the house sparrow, as bill morphology is a highly heritable, polygenetic trait in the species (Lundregan et al. 2018) and differs between North American and European populations (Hamilton and Johnston 1978). Through the use of museum specimens, we found that European house sparrows generally had larger body and beak sizes, which could correspond to their vocal output. Larger-beaked birds typically produce songs with lower minimum frequencies (Huber and Podos 2006; Palacios and Tubaro 2000), which matched our findings. However, we also found that European sparrows produced chirrups with wider frequency bandwidths, which goes against the literature that suggests larger-bodied birds with larger beaks tend to produce songs with narrower bandwidths (Derryberry et al. 2018; Huber and Podos 2006; Podos 2001). Although

we did find significant differences in beak sizes between North American and European sparrows, this difference was small and its biological meaning for song production is not completely clear. This connection between body and beak size should be further explored, as we were unable to directly measure the body sizes and beaks of the birds that we recorded. Even so, our trends between North American and European house sparrow vocalizations can be explained by such morphological differences.

The shifts in acoustic features of the house sparrow may be a synergistic interaction of natural (i.e., acoustic adaptation hypothesis) and artificial selection pressures stemming from its introduction to North America. To yield contemporary small North American house sparrows, small-bodied individuals from Europe may have, by chance, been the ones selected for introduction, which may be a consequence of the founder effect (Barton and Charlesworth 1984), resulting in acoustic frequency shifts over time as populations grew. Additionally, upon introduction, house sparrows may have required vocalizations at new frequencies to best fit within the acoustic soundscape of the North American bird community. As house sparrows expanded in their range and cities became more urbanized, house sparrows may have also responded accordingly. Urbanization has the potential to influence shifts in body (Pena et al. 2023) and beak sizes (Giraudeau et al. 2014), resulting in new vocalization patterns. Thus, the combined result of the introduction of the house sparrow, local environmental features, and other soundscape characteristics, both historic and contemporary, have the potential to result in the higher and narrower frequency chirrups of North American sparrows today. Future studies on this topic could include individuals from non-urban areas (primarily agricultural regions) in both regions to better distinguish between geographic and environmental factors influencing changes in sparrow vocalizations. Additionally, a broader sample that better captures the variation within differing Eurasian populations of the sparrow, along with the consideration of seasonal changes in how they process sound across their range, would provide valuable insights and help clarify the findings of this study (Henry and Lucas 2009; Ravinet et al. 2018).

## Conclusions

We provide evidence regarding the wide variation in house sparrow behavioral and morphological traits across their European and North American introduced range. When contrasting these two populations, house sparrows are known to differ regarding their behavior (MacGregor-Fors et al. 2019; Quesada et al. 2022), color (Johnston and Selander 1964; Summers-Smith and Gillmor 1988), and size (Hamilton and Johnston 1978; Johnston and Selander 1971). Thus, the house sparrow provides an excellent model system on which to test key research questions centering on evolutionary and behavioral adaptations to invasions and urbanization (Hanson et al. 2020). We question if these behavioral and morphological traits differ across their native and introduced range due to the initial isolation of the few North American individuals with limited trait variation, or if environmental changes caused by urbanization promote such shifts (or a synergistic interaction between both non-exclusive forces). Additionally, this species seems to be a good model for bioacoustics studies, yet acoustic communication studies on the house sparrow remain relatively scarce. Given its worldwide distribution, abundance, and trait plasticity, we encourage future research on the mechanisms behind these behavioral and morphological adaptations.

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**Data availability** Research data will be made available upon publication. Supplementary material is available online.

## Declarations

**Competing interests** The authors have no relevant financial or non-financial interests to disclose.

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## References

- Anderson T (2006) Biology of the ubiquitous house sparrow: from genes to populations. Oxford University Press, Oxford
- Audacity Team (2018) Audacity(R): free audio editor and recorder. 2.3.3 edn
- Barton NH, Charlesworth B (1984) Genetic revolutions, founder effects, and speciation. *Annu Rev Ecol Evol Syst* 15:133–164. <https://doi.org/10.1146/annurev.es.15.110184.001025>
- Baughman MM (2003) Reference atlas to the birds of North America. National Geographic Society
- Brumm H, Slabbekoorn H (2005) Acoustic communication in noise. In: Slater PJB, Snowdon CT, Roper TJ, Brockmann HJ, Naguib M (eds) *Advances in the study of behavior*. Gulf Professional Publishing, pp 151–209
- Brumm H, Zollinger SA (2011) The evolution of the Lombard effect: 100 years of psychoacoustic research. *Behaviour* 148:1173–1198. <https://doi.org/10.1163/000579511x605759>
- Center for Conservation Bioacoustics (2019) Raven Pro: interactive sound analysis software, 1.6.1. The Cornell Lab of Ornithology, Ithaca
- Chatterjee S, Hadi AS (2013) *Regression analysis by example*. Wiley, New Jersey
- Crawley MJ (2012) *The R book*. Wiley, Chichester
- Dahlin CR, Smith-Vidaurre G, Genes MK, Wright TF. 2024 Widespread cultural change in declining populations of Amazon parrots. *Proc. R. Soc. B* 291: 20240659. <https://doi.org/10.1098/rspb.2024.0659>
- Demery A-JC, Burns KJ, Mason NA (2021) Bill size, bill shape, and body size constrain bird song evolution on

- a macroevolutionary scale. *Ornithology* 138:ukab011. <https://doi.org/10.1093/ornithology/ukab011>
- Derryberry EP, Seddon N, Derryberry GE et al (2018) Ecological drivers of song evolution in birds: disentangling the effects of habitat and morphology. *Ecol Evol* 8:1890–1905. <https://doi.org/10.1002/ece3.3760>
- Derryberry EP, Phillips JN, Derryberry GE et al (2020) Singing in a silent spring: birds respond to a half-century soundscape reversion during the COVID-19 shutdown. *Science* 370:575–579. <https://doi.org/10.1126/science.abd5777>
- Dowling JL, Luther DA, Marra PP (2011) Comparative effects of urban development and anthropogenic noise on bird songs. *Behav Ecol* 23:201–209. <https://doi.org/10.1093/beheco/arr176>
- Fernández Gómez RA, Morales-Mávil JE, Sosa-López JR (2020) Geographic variation and divergence of songs in the olive sparrow species complex. *J Field Ornithol* 91:77–91. <https://doi.org/10.1111/jofo.12320>
- Francis CD, Ortega CP, Cruz A (2011) Different behavioural responses to anthropogenic noise by two closely related passerine birds. *Biol Lett* 7:850–852. <https://doi.org/10.1098/rsbl.2011.0359>
- Friis JI, Sabino J, Santos P et al (2022) Ecological adaptation and birdsong: how body and bill sizes affect passerine sound frequencies. *Behav Ecol* 33:798–806. <https://doi.org/10.1093/beheco/ara042>
- García-Arroyo M, Rega-Brodsky CC, MacGregor-Fors I (in press) Bird invasions in a humanizing world. In: Edwards SV, Reed MJ (eds) *New Perspectives in Ornithology*, Oxford University Press.
- Gil D, Brumm H (2013) Acoustic communication in the urban environment: patterns, mechanisms, and potential consequences of avian song adjustments. In: Gil D, Brumm H (eds) *Avian urban ecology*. Oxford University Press, pp 69–83
- Giraudeau M, Nolan PM, Black CE et al (2014) Song characteristics track bill morphology along a gradient of urbanization in house finches (*Haemorhous mexicanus*). *Front Zool* 11:83. <https://doi.org/10.1186/s12983-014-0083-8>
- Gómez-Catasús J, Barrero A, Llusia D et al (2022) Wind farm noise shifts vocalizations of a threatened shrub-steppe passerine. *Environ Pollut* 303:119144. <https://doi.org/10.1016/j.envpol.2022.119144>
- Grimes SE, Lewis EJ, Nduwimana LA, Yurk B, Ronald KL (2024) Urbanization alters the song propagation of two human-commensal songbird species. *J Acoust Soc Am* 155:2803–2816
- Hamilton S, Johnston RF (1978) Evolution in the House Sparrow—;VI. Variability and Niche width. *Auk* 95:313–323. <https://doi.org/10.1093/auk/95.2.313>
- Hanson HE, Mathews NS, Hauber ME et al (2020) The house sparrow in the service of basic and applied biology. *Elife* 9:e52803. <https://doi.org/10.7554/eLife.52803>
- Henry KS, Lucas JR (2009) Vocally correlated seasonal auditory variation in the house sparrow (*Passer domesticus*). *J Exp Biol* 212:3817–3822
- Huber SK, Podos J (2006) Beak morphology and song features covary in a population of Darwin's finches (*Geospiza fortis*). *Biol J Lin Soc* 88:489–498. <https://doi.org/10.1111/j.1095-8312.2006.00638.x>
- Johnston RF, Selander RK (1964) House sparrows: rapid evolution of races in North America. *Science* 144:548–550
- Johnston RF, Selander RK (1971) Evolution in the house sparrow. II. Adaptive differentiation in North American populations. *Evolution* 25:1–28. <https://doi.org/10.2307/2406496>
- Johnston RF, Selander RK (1973) Evolution in the house sparrow. III. Variation in size and sexual dimorphism in Europe and North and South America. *Am Nat* 107:373–390
- Kroodsma DE (1996) Ecology of passerine song development. In: Kroodsma DE (ed) *Ecology and evolution of acoustic communication in birds*. Cornell University Press, Ithaca
- Laiolo P, Tella JL (2005) Habitat fragmentation affects culture transmission: patterns of song matching in Dupont's lark. *J Appl Ecol* 42:1183–1193. <https://doi.org/10.1111/j.1365-2664.2005.01093.x>
- Liebl AL, Schrey AW, Andrew SC et al (2015) Invasion genetics: lessons from a ubiquitous bird, the house sparrow *Passer domesticus*. *Curr Zool* 61:465–476. <https://doi.org/10.1093/czoolo/61.3.465>
- Lowther PE, Cink CL (2020) House sparrow (*Passer domesticus*), version 1.0. In: Billerman SM (ed) *Birds of the world*. Cornell Lab of Ornithology, Ithaca
- Lundregan SL, Hagen IJ, Gohli J et al (2018) Inferences of genetic architecture of bill morphology in house sparrow using a high-density SNP array point to a polygenic basis. *Mol Ecol* 27:3498–3514. <https://doi.org/10.1111/mec.14811>
- Luther DA, Derryberry EP (2012) Birdsongs keep pace with city life: changes in song over time in an urban songbird affects communication. *Anim Behav* 83:1059–1066. <https://doi.org/10.1016/j.anbehav.2012.01.034>
- MacGregor-Fors I, Quesada J, Lee JGH et al (2019) On the lookout for danger: house sparrow alert distance in three cities. *Urban Ecosyst* 22:955–960. <https://doi.org/10.1007/s11252-019-00874-6>
- Morton ES (1975) Ecological sources of selection on avian sounds. *Am Nat* 109:17–34
- Palacios MG, Tubaro PL (2000) Does beak size affect acoustic frequencies in woodcreepers? *The Condor* 102:553–560. <https://doi.org/10.1093/condor/102.3.553>
- Pena JC, Ovaskainen O, MacGregor-Fors I et al (2023) The relationships between urbanization and bird functional traits across the streetscape. *Landsc Urban Plan* 232:104685. <https://doi.org/10.1016/j.landurbplan.2023.104685>
- Perna M, Padois T, Trudeau C et al (2022) Comparison of road noise policies across Australia, Europe, and North America. *Int J Environ Res Public Health* 19:173. <https://doi.org/10.3390/ijerph19010173>
- Podos J (1997) A performance constraint on the evolution of trilled vocalizations in a songbird family (Passeriformes: Emberizidae). *Evolution* 51:537–551. <https://doi.org/10.2307/2411126>
- Podos J (2001) Correlated evolution of morphology and vocal signal structure in Darwin's finches. *Nature* 409:185–188. <https://doi.org/10.1038/35051570>
- Podos J, Warren PS (2007) The evolution of geographic variation in birdsong. In: *Advances in the study of behavior*. Academic Press, pp 403–458



- Potvin DA, Clegg SM (2015) The relative roles of cultural drift and acoustic adaptation in shaping syllable repertoires of island bird populations change with time since colonization. *Evolution* 69:368–380. <https://doi.org/10.1111/evo.12573>
- Quesada J, Chávez-Zichinelli CA, García-Arroyo M et al (2022) Bold or shy? Examining the risk-taking behavior and neophobia of native and exotic house sparrows. *Anim Biodivers Conserv* 45:97–106. <https://doi.org/10.32800/abc.2022.45.0097>
- Ravinet M, Elgvin TO, Trier C et al (2018) Signatures of human-commensalism in the house sparrow genome. *Proc R Soc B Biol Sci* 285:20181246. <https://doi.org/10.1098/rspb.2018.1246>
- Ríos-Chelén AA, McDonald AN, Berger A et al (2016) Do birds vocalize at higher pitch in noise, or is it a matter of measurement? *Behav Ecol Sociobiol* 71:29. <https://doi.org/10.1007/s00265-016-2243-7>
- Ryan MJ, Brenowitz EA (1985) The role of body size, phylogeny, and ambient noise in the evolution of bird song. *Am Nat* 126:87–100. <https://doi.org/10.1086/284398>
- Sheldon EL, Ironside JE, de Vere N et al (2020) Singing under glass: rapid effects of anthropogenic habitat modification on song and response behaviours in an isolated house sparrow *Passer domesticus* population. *J Avian Biol* 51:1–8. <https://doi.org/10.1111/jav.02248>
- Summers-Smith JD, Gillmor R (1988) *The sparrows: a study of the genus Passer*. T & AD Poyser, Calton
- Wagner VHO (1959) Die Einwanderung des Haussperlings in Mexiko. *Ethology* 16:584–592. <https://doi.org/10.1111/j.1439-0310.1959.tb02075.x>

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