

Acoustic differences persist in urban *Parus major* (Great Tit) over two decades of declining anthropogenic noise in Paris, France

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ABSTRACT

Anthropogenic noise pollution induces changes in the behavior of wild animals. Birds exhibit a well-characterized response to noise pollution: by vocalizing at higher frequencies, birds can escape the masking effects of low-frequency anthropogenic sounds. Although Paris ranks among the world's largest and most densely populated cities, in recent years Parisians have piloted a multi-faceted effort to reduce anthropogenic noise. Are the city's noise reduction efforts sufficient to affect the frequency characteristics of city-dwelling birds? We used directional microphones to collect field recordings of *Parus major* (Great Tit) in noisy urban sites within Paris and quiet forest sites outside of Paris in Fontainebleau. We recorded birds at both sites during two time periods, separated by two decades, in 2003 and 2023. We collected field measurements of ambient noise using a calibrated sound level meter and we evaluated long-term noise monitoring data collected by the French government. We predicted that birds would sing higher frequency songs in noisy urban Paris compared to quiet natural areas, and we predicted that the magnitude of these differences would diminish in 2023 compared to 2003 given the city's recent noise reduction efforts. We show that urban birds sing at higher frequencies when noise levels increase, matching previous findings from across Europe. Long term data reveal a decline in anthropogenic noise in Paris over the past decades, with average noise levels in 2023 reaching half of their previous intensity. Despite noise reduction efforts, urban birds continue to sing with higher frequencies compared to non-urban birds, and those frequencies have not declined over two decades. We conclude that the noise reduction efforts in Paris have decreased anthropogenic noise levels, but that birds maintain songs with higher minimum frequencies in spite of this change.

Keywords: anthropogenic effects, anthropogenic noise, birdsong, noise pollution, Paris, urban ecology

How to Cite

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LAY SUMMARY

- Noise pollution changes the songs of birds: to be heard over the sounds of traffic, birds often sing at higher pitches (higher frequencies).
- We recorded *Parus major* (Great Tit) in Paris in 2003 and 2023, over a 20-yr interval when the people of Paris have worked to reduce noise pollution.
- We ask whether the noise reduction efforts in Paris are enough to change the pitch of the songs of city-dwelling birds?
- We show that *P. major* sing at a higher pitch when noise levels are high.
- We show that Paris has become quieter in recent decades, but even with lower noise levels, the pitch of *P. major* songs has not changed.
- Therefore, noise reduction efforts in Paris have decreased noise pollution, but city birds continue to sing at higher pitches than forest birds, even though the city has become quieter.

Les différences acoustiques persistent chez les *Parus major* urbaines malgré deux décennies de diminution du bruit anthropique à Paris, en France

RÉSUMÉ

Le bruit anthropique provoque des modifications du comportement des animaux sauvages. Les oiseaux présentent une réponse bien caractérisée à cette pollution acoustique: en vocalisant à des fréquences plus élevées, ils peuvent échapper aux effets masquants des sons anthropiques de basse fréquence. Bien que Paris figure parmi les villes les plus grandes et les plus densément peuplées du monde, les Parisiens ont mis en œuvre ces dernières années une stratégie globale de réduction du bruit d'origine humaine. Ces efforts sont-ils suffisants pour influencer les caractéristiques fréquentielles des oiseaux urbains? Nous avons utilisé des microphones directionnels pour enregistrer les chants de *Parus major* (mésanges).

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charbonnières) dans des zones urbaines bruyantes de Paris et dans des zones forestières calmes de Fontainebleau. Les enregistrements ont été effectués sur les deux sites à deux périodes, séparées par vingt ans, en 2003 et 2023. Nous avons mesuré le bruit ambiant à l'aide d'un sonomètre calibré et utilisé des données de surveillance du bruit à long terme collectées par l'État français. Nous avons prédit que les oiseaux chanteraient à des fréquences plus élevées dans le Paris urbain bruyant que dans les zones naturelles calmes, et que l'ampleur de ces différences diminuerait en 2023 par rapport à 2003, compte tenu des efforts de réduction du bruit déployés par la ville ces dernières années. Nos résultats montrent que les oiseaux urbains chantent à des fréquences plus élevées lorsque les niveaux de bruit augmentent, ce qui concorde avec des observations antérieures réalisées dans toute l'Europe. Les données à long terme révèlent une diminution du bruit anthropique à Paris au cours des dernières décennies, les niveaux de bruit moyens en 2023 ayant atteint la moitié de leur intensité précédente. Malgré les efforts de réduction du bruit, les oiseaux urbains continuent de chanter à des fréquences plus élevées que les oiseaux non urbains, et ces fréquences n'ont pas diminué en vingt ans. Nous concluons que les efforts de réduction du bruit à Paris ont diminué les niveaux de bruit anthropique, mais que les oiseaux conservent des chants avec des fréquences minimales plus élevées malgré ce changement.

Mots-clés: effets anthropiques, bruit anthropique, chant des oiseaux, pollution sonore, Paris, écologie urbaine

INTRODUCTION

Noise pollution diminishes the natural world, altering the behavior of animals, changing natural soundscapes, and affecting the health of human and non-human animals (Slabbekoorn et al. 2018). Non-human animals show diverse effects of anthropogenic noise, including behavioral changes and fitness consequences (Francis et al. 2009, Barber et al. 2010, Kunc and Schmidt 2019, Erbe et al. 2022). Humans also show detrimental effects due to anthropogenic noise, with connections between anthropogenic noise and cardiovascular health and lifespan (World Health Organization 2011, Vienneau et al. 2015, Ribeiro et al. 2020). Although we often overlook noise pollution as a threat to conservation, it has severe consequences that may be on par with the most calamitous pollutants affecting wildlife in the Anthropocene (Jerem and Mathews 2021).

At the start of this century, studies of urban birds revealed that anthropogenic noise drives songbirds to sing at higher frequencies, providing some escape from the masking effects of low-frequency noise pollution. Within the city of Leiden, the Netherlands, *Parus major* (Great Tit) dwelling in areas with higher noise levels sang songs with higher minimum frequencies than nearby birds in quieter areas, thereby minimizing masking by low-frequency noise (Slabbekoorn and Peet 2003). At a broader scale, across 10 cities in Europe, birds in urban areas again showed higher minimum frequencies compared to nearby non-urban sites (Slabbekoorn and den Boer-Visser 2006). For example, *P. major* singing in the noisy park beneath the Eiffel Tower had a minimum frequency 400 Hz higher than *P. major* singing in the quiet forest of Fontainebleau outside of Paris (Slabbekoorn and den Boer-Visser 2006). An experimental study revealed the underlying mechanism for this phenomenon, demonstrating that birds sing fewer repetitions of low-frequency songs under noisy urban conditions (Halfwerk and Slabbekoorn 2009). Many follow-up investigations replicated this study and revealed the same effect for *P. major* in other cities (Mockford and Marshall 2009, De Canto et al. 2010, Husby and Slagsvold 2023) and in other bird species in many cities (Hu and Cardoso 2010, Brumm and Zollinger 2013, Hao et al. 2024). Anthropogenic noise induces diverse effects on songbird behavior, yet higher song frequencies are the most commonly reported change in singing behavior in noise-polluted areas (Husby and Slagsvold 2023).

Paris is a model city for studying changing noise levels and their impact on urban animals. In recent decades, Parisians have fought to reduce noise levels: *la guerre contre le bruit* or “the war on noise pollution” (Van Eeckhout 2015). Although Paris ranks among the largest and most densely populated cities

in Europe, many recent practical and political changes stand to reduce the city's high levels of anthropogenic noise. Paris has developed an agency called Bruitparif to monitor and oversee anthropogenic noise reduction (Mietlicki et al. 2015, Bruitparif 2019). Parisians have converted many car traffic lanes to bicycle lanes; bicycle lanes have increased from 250 km in 2003 to more than 800 km in 2023 (Gelb and Apparicio 2020). Parisians have installed anti-noise coatings to the walls of the city's major ring-road, they have experimented with noise-reducing asphalt, and they have reduced speed limits for cars on existing roads (Van Eeckhout 2015). Since 2022, Parisians have installed traffic noise detectors with microphone arrays that triangulate vehicles producing excessive sounds and issue tickets for noise level violations (Bubola 2022, Yeung 2022). Furthermore, given the proliferation of quiet electric vehicles (Maffei and Masullo 2014), including an electric bus fleet, the existing traffic is quieter than traffic of the past in the City of Light. With these proactive efforts in place, we can anticipate that birds in Paris might exhibit a release from the acoustic pressures of anthropogenic noise, especially when we recognize that short periods of noise reduction during the Covid-19 lockdowns gave rise to lower sound frequencies in other species of wild birds in other cities (Derryberry et al. 2020). Are the noise reduction efforts in Paris sufficient for urban birds to return to songs with lower minimum frequencies that match non-urban birds?

In this investigation, our goal was to study the songs of *P. major* singing in urban noise, and to quantify whether vocal frequency variation has changed after two decades of activities intended to reduce urban noise in Paris. By recording songs from birds in both downtown Paris and a nearby non-urban reference site with low noise levels in both 2003 and 2023, we sought to evaluate long-term changes in bird vocal frequency based on changing anthropogenic noise levels. The acoustic adaptation hypothesis posits that animal sounds have evolved to propagate optimally through the local environment (Morton 1975), and the urban noise hypothesis posits that animals in areas with high anthropogenic sound levels vocalize at higher frequencies in order to escape the masking effects of low-frequency noise (Slabbekoorn and Peet 2003). Based on previous findings across 12 studies of *P. major* and urban noise (Husby and Slagsvold 2023), we predicted that birds would exhibit different vocal behaviors in noisy urban Paris compared to quieter natural areas, singing at higher frequencies in areas with higher levels of noise. Based on the idea that policy changes and practical changes should have reduced sound levels over the last two decades in Paris, we predicted that the

magnitude of these differences would be diminished in 2023 compared to 2003. We were motivated by a desire to understand whether one of the world's most active noise reduction programs could engender a release from the well-characterized anthropogenic effect of noise pollution on the vocal behavior of urban animals.

METHODS

General Field Methods

We collected recordings of *P. major* during two expeditions 20 yr apart, both in busy areas of downtown Paris (hereafter “urban areas”) and forested sites outside of Paris (hereafter “non-urban areas”). The landscape of the urban areas was highly developed regions of Paris dominated by buildings, sidewalks, and roads with scant vegetation except for planted trees on boulevards, squares, small parks, and cemeteries (Figure 1). The landscape of the non-urban areas was forested regions of Fontainebleau with no buildings, no nearby roads, and total vegetation cover.

In spring of 2003, H.S. recorded birds in urban areas of Paris (48°51'11"N, 2°20'56"E) on April 13 and 14, collecting recordings of 27 song types from 27 individuals (i.e., one song type per individual). On April 14 and 15, 2003, H.S. recorded birds in non-urban areas of Forêt de Fontainebleau (48°25'10"N, 2°42'53"E), collecting recordings of 49 song types from 48 individuals (i.e., two song types from one individual; one song type from the remaining 47 individuals). Results from these 2003 recording sessions were reported in Slabbekoorn and den Boer-Visser (2006). Twenty years later, in spring of 2023, D.J.M. recorded birds in urban areas of Paris between March 23 and May 5, 2023, collecting recordings of 69 song types from 57 individuals. Recordings were collected in the same areas where H.S. had recorded in 2003, as well as nearby areas in the same locations within downtown Paris (Figure 1). On April 19, 2023, D.J.M. recorded birds in non-urban areas of Forêt de Fontainebleau, collecting recordings of 32 song types from 30 individuals, recording in the same region where H.S.

had recorded birds in 2003. *Parus major* are short-lived songbirds, with an average lifespan of 1.9 yr, and many generations of birds would have elapsed between 2003 and 2023 (Kirwan et al. 2024, Recalde et al. 2024, 2025).

We located birds that were singing spontaneously and did not use playback or other lures to incite singing. We ensured that we did not repeatedly sample the same individual by always recording in different locations within the urban and non-urban sites. Sometimes, while recording one individual, we detected another individual singing nearby, and we moved to record the second bird after collecting a recording of the first bird. We did not include in our analyses any neighboring birds that were singing shared song types, as in Slabbekoorn and den Boer-Visser (2006), recognizing that the dynamics of counter-singing exchanges in *P. major* would give rise to non-independent data. We followed these same approaches in both 2003 and 2023.

Recording Devices

In both 2003 and 2023, we collected recordings using the same model of shotgun microphone: Sennheiser ME67/K6. In 2003, H.S. recorded songs using a Sony TCM-5000EV tape recorder onto TDK-SA90 tapes, which were digitized with SIGNAL bioacoustics software at a sampling rate of 25.0 kHz at 16-bit depth. In 2023, D.J.M. recorded songs from 76 of 87 urban birds using a Zoom F3 digital recorder at a sampling rate of 48.0 kHz at 32-bit depth. Also in 2023, D.J.M. recorded 11 of 87 individual birds in urban areas with a Wildlife Acoustics Song Meter Mini recorder, recording in stereo at 48 kHz at 16-bit depth (these birds were encountered during a different project; Mennill et al. 2025), and we selected the recording channel with the highest signal: noise ratio for analysis. We confirmed that the use of the two different recording devices in 2023 did not influence the patterns we describe below by excluding the 11 Song Meter data points from our analysis; we found the same patterns held true (see Supplementary Material) and therefore we retained the full dataset in our analyses. Although we used different recording devices in 2003 and

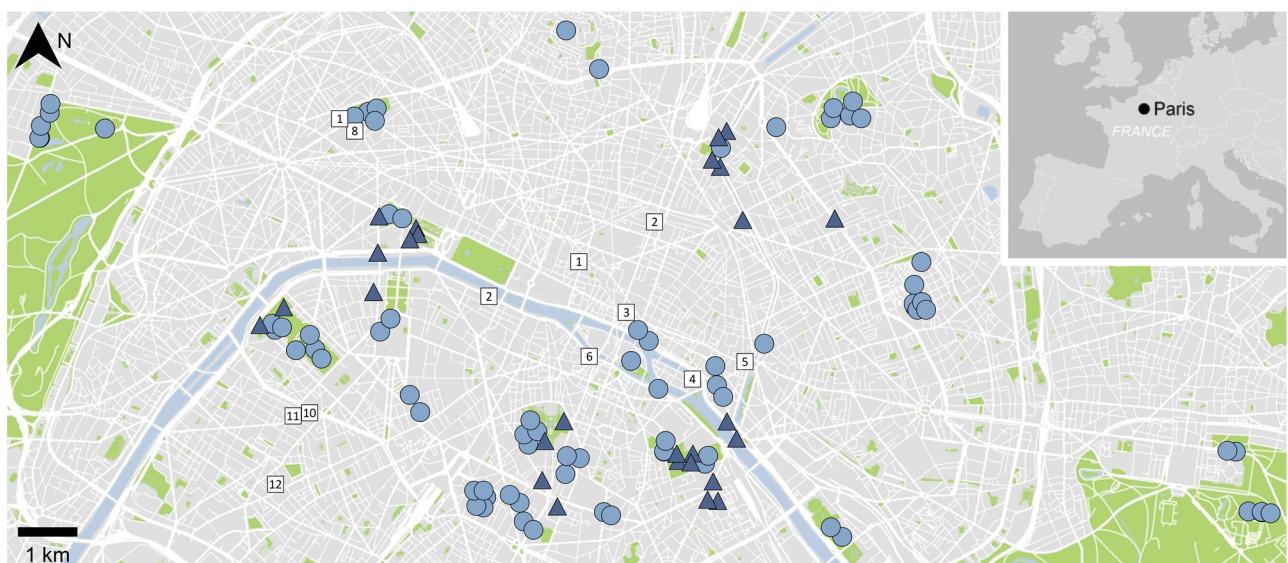


FIGURE 1. Map of downtown Paris, France, showing the recording location of *Parus major* (Great Tit) recorded in 2003 (dark blue triangles) and 2023 (light blue circles) as well as the location of 12 noise monitoring stations (white squares; numbers refer to site details in Supplementary Material Table S1). Inset map shows the location of Paris, France in Western Europe.

2023, we found no indication of systematic differences in our recordings that we could attribute to the different devices. In particular, we found no difference between the minimum frequency of songs in the quiet reference site of Fontainebleau in 2003 vs 2023 (see Results) supporting the idea that the use of tape recordings in 2003 and digital recordings in 2023 did not influence the patterns in our results.

Sound Level Measurements

In 2023, to measure noise levels over short time periods in the urban and forest locations, we collected field-based measurements of ambient noise levels concurrent with our recording of 100 individuals, 68 in urban areas and 32 in non-urban areas. We measured amplitude using a calibrated sound level meter (REED R8080 sound level meter with a REED R8090 calibrator). As soon as the recordist detected a singing individual, he activated the sound level meter, which was mounted on a small tripod and placed on the ground nearby the recordist, with the sound level meter oriented upwards. The sound level meter collected instantaneous noise level measurements every 10 s for an average duration of 2 min (109 ± 6 s). We report an average noise level across all measurements at each of the 106 sites.

To measure noise levels over long time periods in Paris, beyond just the time periods when we were collecting recordings, we used the historic archive of ambient noise levels recorded by Bruitparif (Mietlicki et al. 2015). We downloaded data from Bruitparif's RUMEUR database at 12 of the longest-running noise monitoring sites (Supplementary Material Table 1), focused on measurement sites within the core of downtown Paris inside of the area bound by the Boulevard Périphérique. We downloaded hourly average noise level measurements. We focused our analyses on hourly data collected throughout the months of March, April, and May (see Supplementary Material); these are the months when we collected recordings. This sampling period corresponds with springtime in Paris, a time of year when most birds are highly vocal and a time of year when we would expect the strongest impact of anthropogenic noise on avian communication (Halfwerk et al. 2011). We used data from the Bruitparif archive beginning in 2008, and most of the recordings span the period of 2012 to 2023 or 2018 to 2023 (Supplementary Material Table 1). No ambient noise recordings are available prior to 2008 and therefore we are left to infer ambient noise levels prior to 2008 when Bruitparif began systematically collecting noise data in Paris. We make the assumption that noise levels in Paris in 2003, when the first *P. major* were recorded, were similar to 2008, when the first ambient noise levels were recorded. We are not aware of any policy changes or technological changes between 2003 and 2008 that would have given rise to noise level changes during the 2003–2008-time period. Inspection of the long-term trends (see Supplementary Material) reveal that noise levels were consistent between 2008 and 2017, further supporting the idea that noise levels measured during this period can provide a good proxy for 2003 noise levels. No historic noise archive was available for our non-urban reference site at Fontainebleau, and we make the assumption that this site experienced the same low noise levels in 2003 and 2023.

Acoustic Analyses

We conducted acoustic analyses in AviSoft bioacoustics software (R. Specht). We used the automated parameter

measurements feature of AviSoft to minimize subjectivity in analyses (Ríos-Chelén et al. 2017). We converted all recordings to 22,050 Hz at 16-bit accuracy, and visualized sound spectrograms with a Hann window at 1,025 Hz, 75% frame size, and 93.75% overlap; these settings provided an effective frequency resolution of 22 Hz and a temporal resolution of 3 ms. We employed a spectrogram cut-off frequency of 2.5 kHz to prevent low-frequency background sounds from influencing automated parameter measurements. We measured the minimum frequency of each note automatically at a threshold of -20 dB relative to the note's peak frequency. For each individual, we measured the song that had the least amount of overlapping noise from heterospecific animals, since those sounds might influence the automated parameter measurements. *Parus major* songs consist of a phrase that is uttered repeatedly; we measured only one phrase per song, selecting the second phrase in each song, unless that phrase was of inferior quality and other phrases within the same song were not affected (e.g., as a result of interference by other sound sources).

Statistical Analyses

We compared minimum frequency to ambient noise levels with Pearson correlations. We used Student's *t*-tests to contrast the ambient noise levels in urban versus non-urban areas, the minimum frequency of songs in urban versus non-urban areas, and the minimum frequency of songs in 2003 versus 2023. All statistical tests were conducted in JMP 17.2 (SAS Institute, Cary, NC). Frequency data and sound level data met the assumptions of normality and homoscedasticity. Values are presented as means $\pm$ standard error.

RESULTS

Parus major sang with considerable variation in minimum frequency (Figure 2). Birds in urban Paris and the forests of Fontainebleau sang at higher minimum frequencies when ambient noise levels were high (Figure 3). By comparing minimum song frequency to instantaneous ambient noise levels during recordings in 2023, we found that urban birds sang at higher minimum frequencies when ambient noise levels were higher ($r = 0.27$, $p = 0.03$, $n = 68$; Figure 3). This pattern also held true for non-urban birds in the forests of Fontainebleau, outside of Paris, where ambient noise levels spanned a much smaller range across much lower amplitudes ($r = 0.24$, $p = 0.04$, $n = 32$; Figure 3). As expected, ambient noise at urban recording sites (57 ± 1 dB(A), $n = 68$ sites sampled in 2023) were higher than those at non-urban recording sites (42 ± 1 dB(A); $n = 32$ sites sampled in 2023; *t*-test: $t = 13.8$, $p < 0.0001$, $n = 100$).

Ambient anthropogenic noise levels across downtown Paris show a decline over time. Recordings of anthropogenic noise from 2008 to 2023, collected at 12 sites across downtown Paris by the French government agency Bruitparif, reveal a decline from an average of 69.3 dB(A) in 2008 to an average of 66.2 dB(A) in 2023, with the steepest decline occurring between 2018 and 2023 (Figure 4). Recognizing that the decibel scale is logarithmic, this decrease of 3.1 dB between 2008 and 2023 means that Paris experienced lower anthropogenic noise in 2023, at approximately half of the sound intensity. Noise levels were unusually low during the first two years of the COVID-19 pandemic in 2020 and 2021, and yet the declining pattern of noise levels between 2008 and 2023 is evident whether these two especially quiet years are included or not (Supplementary Material).

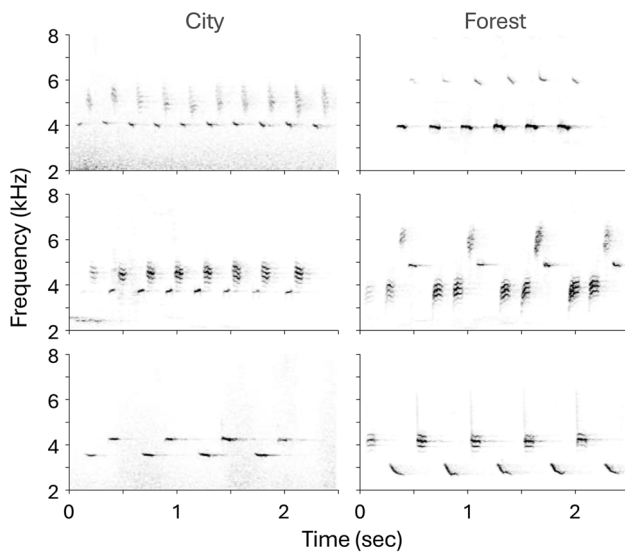


FIGURE 2. Sound spectrograms of songs of 6 *P. major* recorded in urban areas of Paris (left) and non-urban areas in the forests of Fontainebleau (right). The particular songs chosen for representation here are the songs representing the 90th percentile (top row), 50th percentile (middle row), and 10th percentile (bottom row) of the minimum song frequency values from the 2023 dataset.

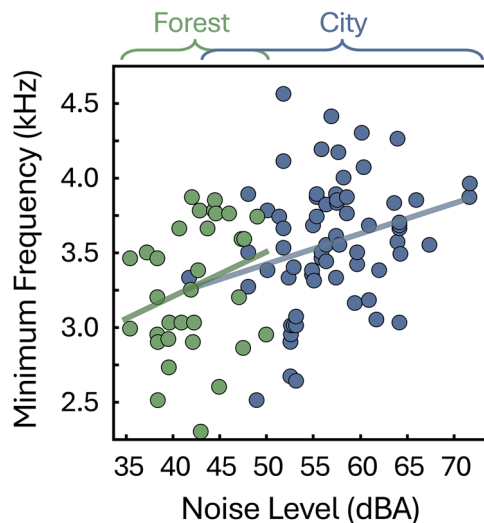


FIGURE 3. Plots of the relationship between ambient noise levels and the minimum frequency of the songs of *P. major* recorded in 2023 in urban areas of Paris (blue dots) and non-urban areas of the forests of Fontainebleau (green dots), revealing higher minimum frequency of songs in urban areas, and higher minimum frequencies of songs in areas with higher levels of ambient noise. A line of fit is shown for both the forest points (green line) and the city points (blue line).

In spite of declining anthropogenic noise levels, the minimum frequencies of *P. major* songs did not decline between 2003 and 2023 (Figure 5). The minimum frequency of songs in urban areas of Paris has not shown a significant change between 2003 (3428 ± 87 Hz; $n=27$) versus 2023 (3535 ± 50 Hz; $n=82$; Figure 5; $t=1.1$, $p=0.29$). Similarly, the minimum frequency of songs in quiet non-urban areas outside of Paris has not shown a significant change between 2003 (3460 ± 71 Hz; $n=49$) versus 2023 (3255 ± 88 Hz; $n=32$; Figure 5; $t=1.8$, $p=0.08$). Birds recorded in 2023 in urban Paris show higher minimum song frequencies (3535 ± 47 Hz; $n=82$) than birds living in quiet

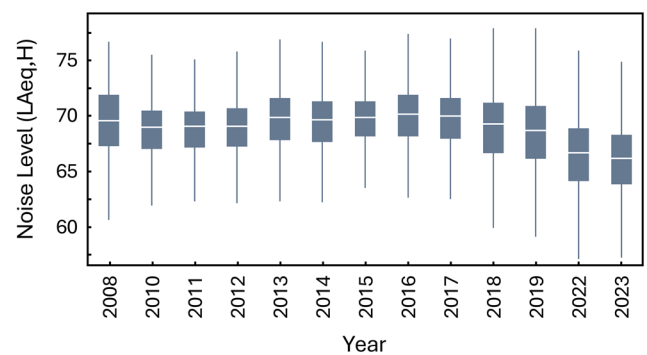


FIGURE 4. Box plots of average ambient noise levels at 12 sites in urban areas of Paris sampled in springtime in 2008 through 2023 demonstrating declines in anthropogenic noise over time, especially since 2017. Box plots show the mean (white line), the 25th to the 75th percentile (box), and the 10th to the 90th percentile of data (whiskers).

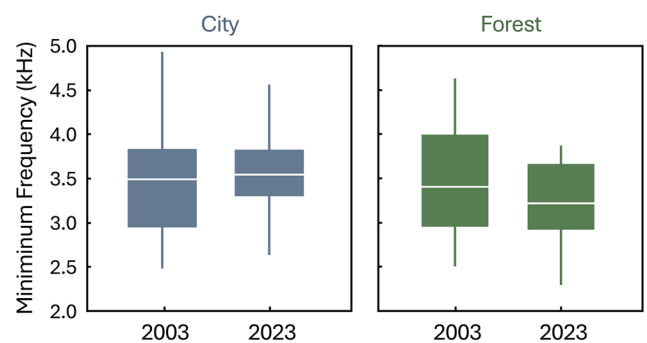


FIGURE 5. Box plots of the minimum frequency of songs of *P. major* recorded in urban areas of Paris (left) and non-urban areas in the forests of Fontainebleau (right), sampled in 2003 and 2023, revealing no change in minimum frequency over this 20-yr interval. Box plots show the mean (white line), the 25th to the 75th percentile (box), and the 10th to the 90th percentile of data (whiskers).

non-urban sites outside of Paris (3256 ± 75 Hz; $n=32$; t -test: $t=3.2$, $p=0.002$, $n=114$), matching the pattern found in 2003 (Slabbekoorn and den Boer-Visser 2006).

DISCUSSION

In urban areas of Paris with high levels of anthropogenic noise, *P. major* sing with higher minimum frequencies, matching our first prediction and mirroring patterns observed in the songs of urban birds in other cities (Slabbekoorn and Peet 2003, Slabbekoorn and den Boer-Visser 2006, Husby and Slagsvold 2023). Recent noise reduction efforts in Paris have successfully diminished noise levels, with noise levels decreasing by 3 decibels over the last 15 yr, as measured by on-the-street sound level meters maintained by French government agency Bruitparif. Yet in contrast to our second prediction, birds have not lowered their minimum song frequency following this gradual decrescendo in noise pollution; the minimum frequency of urban songs remains significantly higher than non-urban songs, matching the minimum song frequencies observed when Paris was even noisier, two decades ago. We conclude that the efforts to reduce anthropogenic noise in urban Paris are successful, but that the quieter noise levels remain associated with higher song frequencies for urban birds compared to non-urban birds.

Following the initial description of vocal differences in urban versus non-urban *P. major* (Slabbekoorn and Peet 2003), at

least 10 additional studies have explored the acoustic features of this species in response to anthropogenic noise in different urban locations (reviewed in [Husby and Slagsvold 2023](#)). The most common response to anthropogenic noise is an increase in minimum song frequency: this effect has been documented in 5 investigations ([Husby and Slagsvold 2023](#)). Our work adds a further instance of a documented increase in minimum vocal frequency associated with anthropogenic noise. Less common responses to increasing noise include a decrease in song bandwidth and a decrease in song duration (found in two studies each; [Husby and Slagsvold 2023](#)). We observed the former effect in our 2023 dataset, where songs had narrower bandwidth in higher noise environments, but we did not observe a change in song duration ([Supplementary Material](#)). For species other than *P. major*, changes to minimum frequency, bandwidth, and song length appear to be common responses of wild birds to anthropogenic noise ([Brumm and Zollinger 2013](#)). This growing evidence makes it clear that noise pollution induces changes in the songs of many urban birds.

Urban environments became much quieter during the lockdowns of the Covid-19 global pandemic, both in Paris ([Supplementary Material](#)) and around the globe ([Lecocq et al. 2020](#); [Challéat et al. 2024](#)). This “anthropause” provided a natural experiment to investigate how animals respond to decreased levels of background noise ([Rutz et al. 2020](#)). During the anthropause in San Francisco, anthropogenic noise returned to low levels that had not been observed in seventy years; the local *Zonotrichia leucophrys* (White-crowned Sparrow) sang at significantly lower minimum frequencies, as well as lower amplitudes, when released from the pressure of anthropogenic noise ([Derryberry et al. 2020](#)). The noise reduction during the pandemic lockdowns in San Francisco (~7 dB) was larger than the noise reduction we have documented over the last two decades in Paris (~3 dB). Several ideas follow from this comparison between *P. major* in a quieter Paris (i.e., the current study) and *Z. leucophrys* in a quieter San Francisco (i.e., [Derryberry et al. 2020](#)). First, perhaps birds in Paris would sing at lower frequencies if noise reduction efforts can further reduce anthropogenic sounds, more akin to the reduced noise levels reached during the Covid lockdowns in San Francisco. Second, perhaps different species exhibit different reactions to anthropogenic noise reductions. Further noise reduction efforts, and more extensive studies of urban birds, will help us to explore these ideas.

Bird song is a culturally transmitted trait for wild birds, where young animals learn their song based on exposure to adult tutors early in life ([Catchpole and Slater 2008](#), [Mennill et al. 2018](#)). The high levels of anthropogenic noise of Paris in recent decades may have acted as a selective force driving *P. major* to sing songs at higher frequencies, and higher-frequency songs may have been preferentially learned by young birds either because they were less masked, or because they were uttered more frequently by nearby tutors. Although today’s lower anthropogenic noise levels might facilitate effective communication using songs with lower frequency components, there may be few tutors with low-frequency songs for today’s birds to learn from ([Hansen 1979](#), [Slabbekoorn 2013](#)). It is possible that lower frequency songs might transmit effectively through the quieter soundscape of today’s Paris, but such songs cannot be learned without available tutors. Dispersal of lower-frequency tutors from quieter regions outside of Paris into the city core might change this cultural pattern over time. Studies of

captive-reared *Z. leucophrys* reveal that nestlings preferentially learn higher-frequency sounds that are less masked by anthropogenic noise ([Moseley et al. 2018](#)), whereas captive-reared *P. major* exposed to noise still learn songs across a broad frequency range even when exposed to playback of anthropogenic noise ([Zollinger et al. 2017](#)). The broad spectral distribution we found for urban birds in 2023 ([Figure 2](#)) suggests that birds in the city still sing some low-frequency song types at quiet moments, but emphasize high-frequency song types in noisy conditions. Similarly, in Utrecht, the Netherlands, *P. major* are still capable of singing across a broad range of minimum frequencies, but they sing fewer repetitions of low-frequency songs under noisy traffic conditions ([Halfwerk and Slabbekoorn 2009](#)). In areas with high anthropogenic noise, we may expect cultural changes over time in response to selection for more songs in the upper end of the frequency spectrum.

Several retrospective analyses have quantified changes in bird songs over extended time periods, providing longitudinal evidence of the effects of noise pollution on a singing behavior of wild birds. Over three-and-a-half decades, *Z. leucophrys* showed an increase in minimum song frequency, in concert with rising intensities of anthropogenic noise, and a playback experiment revealed that contemporary high-frequency songs were stronger territorial signals ([Luther and Baptista 2009](#), [Luther and Derryberry 2012](#)). In a multispecies investigation, five European songbird species, including *P. major*, advanced the onset of their dawn chorus to avoid overlapping noise from a nearby airport ([Dominoni et al. 2016](#)); years later, when the airport closed and noise levels declined, several species, including *P. major*, returned to typical dawn chorus start times that matched quiet reference sites away from the airport ([De Framond and Brumm 2022](#)). As we expand our understanding of the effects of anthropogenic noise on wild birds, long-term comparisons stand to help us appreciate the effects of noise pollution on vocal frequency, vocal timing, and perhaps other vocal features as well.

Although anthropogenic noise levels continue to increase across the globe ([Jerem and Mathews 2021](#)), active efforts within the city of Paris have led to a decrease in anthropogenic noise between 2008 and 2023 ([Figure 4](#)). Through diverse efforts that include minimizing vehicle traffic, enhancing bicycle traffic, promoting electric vehicles, deploying quieter road surfaces, and installing noise monitoring devices ([Bruitparif 2019](#)), Paris has effectively reduced anthropogenic noise, providing a model for other urban areas interested in improving the acoustic environment. Given the widespread effects of anthropogenic noise on animals ([Slabbekoorn et al. 2018](#)) these efforts are expected to benefit wildlife. Nevertheless, Paris remains quite loud in spite of noise reduction efforts; urban sites in 2023 in Paris were approximately 15 dB louder than quiet reference sites outside of Paris. Our comparison of the minimum frequency of songs of *P. major* in the anthropogenic noise of 2003 versus 2023 Paris reveals no response in the minimum frequency of bird songs in a quieter urban jungle. Further noise reduction efforts in urban areas will be required if city birds are to return to the lower frequencies seen in their counterparts in non-urban, wilderness areas.

Supplementary material

[Supplementary material](#) is available at *Ornithological Applications* online.

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Ethics statement

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Conflict of interest statement

The authors declare no conflicts of interest.

Declaration of AI use

We have not used AI in creating this paper.

Author contributions

DJM collected the 2023 field recordings, measured all sounds, and wrote the manuscript. HS collected the 2003 field recordings and shared in writing, revising, and editing the manuscript. Both authors gave approval for submission.

Data availability

The data are openly available through the Borealis data archive: <https://doi.org/10.5683/SP3/VIHDVR>

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