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Urban pigeons loosing toes due to human activities

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1 ABSTRACT

2 Measuring the impacts of urban pollution on biodiversity is important to identify potential
3 adaptations and mitigations needed for preserving wildlife even in city centers. Foot
4 deformities are ubiquitous in urban pigeons. The reasons for these mutilations have been
5 debated, as caused by frequenting a highly zoonotic environment, by chemical or
6 mechanistic pigeon deterrents, or by necrosis following stringfeet. The latter would mean
7 that pigeons frequenting pavements with more strings and hairs would be more exposed so
8 subject to mutilations. We tested these hypotheses in Paris city (France), by recording the
9 occurrence and extent of toe mutilations on samples of urban pigeons at 46 sites. We
10 hypothesized that mutilations would be predicted by local overall environmental conditions,
11 potentially related to local organic, noise or air pollutions, so gathered such environmental
12 predictors of urban pollutions. We showed that mutilations do not concern recently fledged
13 pigeons, and that their occurrence and frequency are not related to plumage darkness, a
14 proxy of a pigeon's sensitivity to infectious diseases. Toe mutilation was more frequent in
15 city blocks with a higher degree of air and noise pollution, while it tended to increase with
16 the density of hairdressers. In addition, the number of mutilation on injured pigeons was
17 higher in more populated blocks, and tended to decrease with increasing greenspace
18 density, and to increase with air pollution. Pollution and land cover changes thus seem to
19 impact pigeon health through toe deformities, and increasing green spaces might benefit
20 bird health in cities.

21

22 *One sentence summary*

23 Toe mutilation in urban pigeons are linked to human-induced pollution

24

25 *Keywords*

26 *Columba livia*, feral pigeon, toe mutilation, stringfeet, urban pollution

27 **1. Introduction**

28

29 Cities represent the most domesticated landscapes on the planet, hosting wildlife that tend
30 to follow humans, most being generalist species that are tolerant of a wide range of
31 environmental conditions (Kareiva et al., 2007). Urban environments are among the most
32 polluted habitats used by terrestrial fauna (McKinney, 2002), with either organic waste along
33 the streets, organic pollution in water, noise pollution (Warren et al., 2006) and permanent
34 gas emissions from transport and heat systems (Lucas, 1958; Kennedy et al., 2009).
35 Measuring the impacts of such pollution on biodiversity is important to identify potential
36 adaptations and mitigations needed for preserving biodiversity even down city centers
37 (Pollack et al., 2017). While urban wildlife is recognized as promoting human health and
38 wellbeing in cities (Barton and Pretty, 2010), the One-Health philosophy clearly link the
39 health and wellbeing of humans, animals and their various environments (Zinsstag et al.,
40 2005; Atlanta Report, 2011). Within such a framework, studying the health of urban wildlife
41 should provide valuable information of the potential health of humans inhabiting the same
42 cities. The potential interactions between urbanization and wildlife diseases have mostly
43 been considered under the prism of hosts, pathogens and vectors (Bradley and Altizer,
44 2007).

45 Feral pigeons (*Columba livia*) living in cities are highly sedentary birds that remain in
46 local habitats with only short distance dispersal (Frantz et al., 2012). Urban pigeons are
47 tightly linked to human activities for feeding and nesting, making the species a good
48 candidate to mirror local urban environmental conditions (Cai and Calisi, 2016). Pigeons live
49 in almost all cities across continents (Jerolmak, 2008), are abundant and easily approached
50 and observed. The reported accumulation of heavy metals in their feathers attests that feral
51 pigeons are useful models to monitor pollution in urban environments (Frantz et al., 2012).
52 As a consequence, the local health of these birds might well depend on local environmental
53 conditions, potentially related to local organic, noise or air pollutions. These environmental
54 components vary spatially within a city according to the locations and density of inhabitants,
55 workers, tourists, trades, buildings, transport infrastructures, parks and green corridors, etc,
56 hence in a broader sense they might mirror human density, activities and development.

57 The bad condition of urban pigeons is often illustrated by their ubiquitous foot
58 deformities (Fisher, 1957). Anyone who watches pigeons in cities has probably noticed birds

59 with injured legs or missing toes. Such mutilations have certainly consequences on the
60 fitness and survival of injured individuals, impacting their foraging ability, their capacity to
61 copulate, to access breeding sites, while ongoing necrosis might induce a higher temporal
62 vulnerability to diseases. A general belief is that pigeons get foot infections from standing in
63 their own excrement. Various hypotheses have been proposed to explain this particularity of
64 urban pigeons: deformities could arise from infection by *Staphylococcus* bacteria, provoking
65 an inflammatory reaction called ‘bumblefoot’ (Halliwell, 1975). Another hypothesis relates
66 to potential corrosion or injury ensuing from chemical or physical (porcupine wires)
67 deterrents used on buildings to discourage pigeons from perching there (Haag-Wackernagel
68 and Geigenfeind, 2008). In captive pigeons, hereditary deformities have also been reported
69 (Flach and Cooper, 1991). However, a close observation of foot and toe injuries
70 systematically reveals the presence or former presence of a string or more generally human
71 hair caught on digits (Skandrani et al., 2018), a problem called ‘stringfeet’. The string or hair
72 tightens more and more and eventually cut off the blood supply, further necrosis causing the
73 toe to fall off. Furthermore, pigeons with toe in remission display a basal healed wound
74 witnessing a former garrote.

75 The present study arose from such observation that numerous feral pigeons display
76 mutilation on their toes, presumably due to necrosis following stringfeet. We hypothesized
77 that pigeons’ toe mutilations arise from the use of sidewalks or pavements with a high
78 density of strings or hairs, coming from human wastes and releases. These releases can have
79 different origins, and could be related to various proxies of human population density and
80 activities, and potential associated pollutions. We first used proxies related to street litter
81 dirtiness, such as the presence of infrastructures that potentially release strings or hairs
82 (outdoor food markets, hairdressers), or more directly to human population density, such as
83 inhabitant density, or the flow of humans frequenting the streets. We also gathered
84 information on noise and air pollution, as potential proxies related to human density too.
85 We tested our hypothesis in Paris, the capital city of France, by assessing the state of toes on
86 both legs in urban pigeons recorded at numerous local blocks across this metropolis,
87 through the two following variables: mutilation occurrence, i.e. the proportion of pigeons
88 with at least one mutilation within a sampled group; and mutilation extent, i.e. the number
89 of mutilated toes for injured pigeons. We expected these two approaches to be
90 complementary to detect potential correlations with environmental predictors. As melanin-

91 based coloration is related to parasite intensity and cellular immune response in urban
92 pigeons (Jacquin et al., 2011), their sensitivity to environmental conditions could depend on
93 their phenotype (Gasparini et al., 2011). Indeed, if foot deformities were to arise from
94 bacterial or viral infections, we would potentially expect less frequent mutilations in
95 melanistic individuals, so we also recorded the plumage darkness of the surveyed birds. We
96 conducted a first preliminary analysis to verify that recently fledged juveniles are safe of
97 mutilation, because of their short exposition to potential damage causes, and controlled that
98 darker pigeons are not less injured than paler ones.

99 For each surveyed block, we gathered information on local environmental conditions
100 with various available variables. We developed a first set of predictors to inform the local
101 frequentation by humans, as the inhabitant density and the number of people frequenting
102 underground stations, but also the air and noise pollution, avoiding considering correlated
103 predictors in a model. A second set of variables intended to capture variations in potential
104 organic pollution, reporting the activity of open-street food markets and the density of
105 hairdressers. We predicted a sensitivity of toes' condition to some of these predictors
106 mirroring the potential extent of local human-induced urban pollution. If mutilations were to
107 occur from bacterial, viral or fungal diseases, we expect a correlation between the
108 occurrence and number of mutilations on one foot and the other in a pigeon, and dark
109 pigeons to be less mutilated. So first, we predicted an absence of foot deformities in recently
110 fledged juveniles, and no variation of toes' condition according to plumage darkness. Then,
111 we expected that trends in some predictors related to human population density,
112 development and activities should predict trends in the occurrence and/or extent of foot
113 deformities.

114

115 **2. Material and methods**

116 *2.1. Study sites*

117 We conducted our study in Paris, France. We organized our sampling design in order to
118 monitor blocks of homogeneous habitat type, called TRIRIS, a within-district classification
119 developed by the French National Institute for Statistics and Economical Studies (INSEE) and
120 based on geographical, demographic and statistical criteria. There are 20 districts subdivided
121 into 285 TRIRIS within Paris city, in which we organized a random stratified selection of 46
122 TRIRIS where we surveyed feral pigeons (Fig. S1 in Supplementary Material). The

123 stratification was based on districts (Paris being partitioned in 20 administrative districts,
124 called ‘arrondissements’), and consisted in a sample per district proportional in size to the
125 number of TRIRIS within the district. A TRIRIS is thereafter referred to as a ‘block’, nested
126 within a district.

127

128 *2.2. Counting toes and recording phenotypes*

129 In each surveyed block, we recorded the eventual mutilation on pigeons’ toes for 30
130 different individuals, found by walking within the block during a maximum of one hour,
131 between 9am and 16pm, avoiding rainy days, in April and May 2013. For each pigeon, we
132 noted the state of each toe of both legs, obtaining a score potentially ranging from 0 (no
133 mutilation) to 8 (all toes damaged – deformed, shortened or absent). We did not consider
134 the extent of the mutilation, e.g. a toe was considered as mutilated if it was partially or
135 totally damaged. We also recorded the age of the pigeon (juvenile vs. adult) based on
136 morphological criteria (uniform fresh plumage, greyish legs, brown iris and restricted pale –
137 not white - skin at bill base in juveniles). For each pigeon, we also recorded the color morph
138 (grey, brown, grizzled) and the degree of plumage melanism, based on the extent of dark
139 color on upperwing (wing bars and coverts), with a code ranging from 0 (no wing bar), 1
140 (uniform pale coverts but two black bars) to 4 (all dark wings) (Skandrani et al., 2018).

141

142 *2.3. Repeatability of mutilations, age and morph effects*

143 To first confirm that the information collected locally at once on 30 different pigeons
144 does not vary with time and is representative of the local pigeon population which is often
145 more abundant, we sampled more intensively three populations located in three blocks with
146 5th district), a place with a daily open food market (site 2, Place Aligre, 11th district), a place
147 with no market but two hairdressers (site 3, Place du Colonel Bourgoïn, 12th district). We
148 sampled pigeons five times at each of these sites during the period 18-24 April 2013, by
149 recording the phenotype, age and eventual mutilations on 30 individuals at each date. We
150 further run a general linear model to test whether the mutilation occurrence (binomial
151 distribution) varied between sites but not between dates at a given site, after considering
152 potential effects of age and phenotype (color morph and plumage melanism).

153

154 *2.4. Land cover*

155 To obtain variables on land cover, we used the MOS (Modes d'Occupation des Sols; see
156 e.g. Jeliaskov et al., 2014) provided by the IAU (Institut d'Aménagement et d'Urbanisme) for
157 the year 2012 (downloaded from [https://data.iledefrance.fr/explore/dataset/mode-
159 doccupation-du-sol-mos-en-11-postes-en-2012/export/](https://data.iledefrance.fr/explore/dataset/mode-
158 doccupation-du-sol-mos-en-11-postes-en-2012/export/)). We extracted the total area of
160 each block, and within each block the area covered by parks and gardens (including
161 cemeteries), further calculating a density of green spaces within each studied block by
162 dividing the area of green spaces by the area of the block.

162

163 2.5. Humans

164 For each block, we gathered information on the number of inhabitants per block (as
165 recorded during a census conducted in 2015; data downloaded from
166 <https://www.insee.fr/fr/statistiques/fichier/3627376/base-ic-evol-struct-pop-2015.zip>) and
167 deduced an inhabitant density, dividing the number of inhabitants by the area of the block.
168 We also gathered information on human numbers frequenting a block though not
169 necessarily inhabiting it (e.g. workers, tourists, transients...). We estimated the human flow
170 in a block from the data reporting the numbers of humans entering railway/suburb stations
171 during the year 2014 (data downloaded from
172 [https://datarap2.opendatasoft.com/explore/dataset/trafic-annuel-entrant-par-station-du-
174 reseau-ferre/export/?refine.ville=Paris&sort=trafic](https://datarap2.opendatasoft.com/explore/dataset/trafic-annuel-entrant-par-station-du-
173 reseau-ferre/export/?refine.ville=Paris&sort=trafic)). We summed the total numbers across
175 stations of a same block, and divided this sum by the area of the block to obtain a variable
176 referred to as 'human flow'.

176

177 2.6. Organic pollution

178 Globally, all kinds of pollution could affect the health of urban wildlife, while Gasparini
179 et al. (2011) already reported an impact of urban pollutants on the immune system of urban
180 pigeons. We therefore considered different types of pollution as predictors.

181 The organic pollution might be a proxy of human population density, and might provide
182 food for the pigeons, attracting them on ground. We estimated variables susceptible to
183 mirror the organic pollution ensuing from food markets, household waste and hairdressers.
184 We considered within each block (1) the total weekly opening duration (in hours) of open
185 street market(s) (data for 2013; downloaded from
186 <https://opendata.paris.fr/explore/dataset/liste-des-marches-de-quartier-a-paris/table/>);

187 (2) the density of household waste, using data on the annual amount of waste in tonnes for
188 each district in Paris (data for 2011; source:
189 https://opendata.paris.fr/explore/dataset/tonnages_des_dechets_bacs_verts and
190 https://opendata.paris.fr/explore/dataset/tonnages_des_dechets_bacs_jaunes; (3) the
191 density of hairdresser shops (data for 2014; downloaded from
192 <https://opendata.paris.fr/explore/dataset/commercesparis/export/>). These latter two
193 variables were divided by the area of the block to obtain the referred densities.

194

195 *2.7. Noise pollution*

196 Noise pollution could also correlate in some way with human density and activities, so
197 was considered as a potential predictor. Bruitparif (www.bruitparif.fr) provides information
198 on the exposure of inhabitants to the traffic noise measurements in front of buildings
199 between 6am and 10pm, for each district (<https://carto.bruitparif.fr/>). We retained the
200 proportion of the inhabitant population exposed to a high noise intensity (>70 decibels) per
201 district, with the same value for each block of a district.

202

203 *2.8. Air pollution*

204 Air pollution could also correlate in some way with human density and development, so
205 was considered as a potential predictor. We obtained values of an index of air quality per
206 district for the year 2015 (European index Citeair; data downloaded from
207 [https://www.data.gouv.fr/fr/datasets/indices-qualite-de-lair-citeair-journaliers-par-polluant-
208 sur-lile-de-france-les-departements-les-communes-franciliennes-et-les-arrondissements-
209 parisiens/#](https://www.data.gouv.fr/fr/datasets/indices-qualite-de-lair-citeair-journaliers-par-polluant-sur-lile-de-france-les-departements-les-communes-franciliennes-et-les-arrondissements-parisiens/#)). This index is given for three pollutants of the air: nitrogen (NO₂), ozone (O₃)
210 and fine particles of a diameter < 10 µm (PM10). We ran a PCA with the three index values
211 (function PCA() of the *FactoMineR* package in R). The variables resumed in a single principal
212 component caught 80% of the variance in atmospheric pollutant indices (Supplementary
213 Material S1), so we retained this principal component as representative of the atmospheric
214 pollution in a district (applied to all blocks of the considered district).

215

216 *2.9. Statistical analyses*

217 We first ran univariate models to test if each predictor explained part of the variance in
218 the occurrence of toe mutilation. In such univariate models, we tested for potential

219 quadratic effects by considering the predictor and its squared value. We further retained the
220 quadratic term in multivariate models only if it was significant or close to significance ($P < 0.1$)
221 in the predictor-dedicated univariate model, and verified that the AIC of the multivariate
222 model including the quadratic term was lower ($\Delta AIC < 2$) than when excluding the quadratic
223 term.

224 Before running our statistical analyses, we first used pairwise scatter plots comparing
225 covariates to detect obvious correlations (see Fig. S3 in Supplementary Material). Human
226 population density and waste quantity appeared as strongly correlated ($r = 0.79$), so we
227 included only the first predictor in further multivariate models. Other predictors were also
228 relatively correlated (human population, human flow, hairdresser with r values between
229 0.35 and 0.5), though we decided to base their inclusion or exclusion in multivariate models
230 using a stepwise procedure relying on variance inflation factors (Zuur et al., 2010).

231 We ran linear mixed models to investigate the potential effects linking the
232 occurrence (binomial distribution, $n = 1214$) and extent (Poisson distribution, mutilation-free
233 individuals excluded, $n = 274$) of toe mutilation and environmental variables. To account for
234 the non-independence of our data we included block as a random effect nested in district.
235 We investigated the linear effects of the following variables: human population density,
236 human flow, green space density, open street market, hairdresser density, waste quantity,
237 noise pollution, air pollution. We further calculated variance inflation factors (VIF) on each
238 model (multiple regressions; see Table S2 in Supplementary Material) to identify excessive
239 correlation among explanatory variables and excluded highly correlated variables through a
240 stepwise procedure using a threshold value of two (Zuur et al., 2010).

241 Concerning the presence/absence of mutilation, the multivariate models with
242 uncorrelated predictors included human population density, human flow, green space
243 density, open markets, hairdresser density and associated quadratic term, noise pollution,
244 air pollution. Concerning the number of mutilations for injured pigeons, the multivariate
245 models with uncorrelated predictors included human population density and associated
246 quadratic term, human flow, green space density, open street markets, noise pollution and
247 air pollution. Results for these multivariate models are presented in Tables S3 and S4 of the
248 Supplementary Material. Tables 1 and 2 report the final outputs of multivariate models
249 when including only predictors with P values < 0.1 in the final stepwise models.

250

251 **3. Results**

252 *3.1. Repeatability, age and color morph*

253 To first confirm that the information collected locally at once on pigeons does not vary
254 with time and is representative of the local pigeon population, we sampled 30 pigeons
255 sampled at five occasions in three blocks with different neighboring environments. In this
256 sample, a generalized linear model revealed a difference of mutilation occurrence between
257 juveniles and adults (estimate \pm s.d. = -0.31 ± 0.10 ; $F_{1,314} = 8.82$, $P = 0.003$), confirming the
258 field evidence that juveniles (i.e. freshly fledged young pigeons) have still all their toes.
259 Beyond this age effect, we failed to find any effect of color morph, plumage darkness or
260 date, but we found a significant effect of site on mutilation occurrence ($F_{2,314} = 6.50$, $P =$
261 0.002). With the intercept group being the first site (a green park), pigeons from both other
262 sites were more frequently injured than the reference group: second site (daily open food
263 market; estimated difference = $+0.22 \pm 0.08$, $t = 2.75$, $P = 0.006$) and third site (urban place;
264 estimated difference = $+0.17 \pm 0.05$, $t = 3.37$, $P < 0.001$). We found no difference in the
265 frequency of mutilations affecting the right and the left feet (out of 276 pigeons with at least
266 one mutilated toe, 188 had a mutilated right foot, 182 a damaged left foot). For pigeons with
267 at least one mutilated toe, being mutilated on one foot (either left or right) does not provide
268 an increased probability of being mutilated on the other foot ($n = 276$, $z = -0.18$, $P > 0.98$);
269 the number of mutilated toes on one foot (left or right) was not related to the number of
270 mutilated toes on the other foot ($n = 276$, $t = 0.06$, $P > 0.95$). Given these results, we
271 conducted further analyses by considering non-juvenile pigeons only of any color morph,
272 and mutilations of both feet for each pigeon, to investigate environmental variables that
273 could predict the occurrence and the extent of toe mutilation.

274

275 *3.2. Predictors of mutilation occurrence and extent*

276 We then analyzed a larger dataset to predict the occurrence and number of mutilation
277 in non-juvenile pigeons. We studied a sample of 30 pigeons at each of 46 sites across Paris
278 city. We further gathered environmental predictors for each site, mirroring human activities
279 and organic pollutions. After excluding correlated predictors, we ran generalized linear
280 models and applied a stepwise selection procedure of variables based on variance inflation
281 factors (see Materials and Methods for details). We identified noise pollution and air
282 pollution as the main predictors of mutilation occurrence (Table 1, Fig. 1a and 1b). No other

283 predictors were significant, though the quadratic term of hairdresser density was close to
284 significance ($P=0.075$; Fig. 1c). In the complete model, P-values for all other predictors were
285 above 0.4 (see Table S3 in Supplementary Material). For pigeons with at least one damaged
286 toe, the number of mutilations was predicted by the quadratic term of human population
287 density, with close to significance effects of green space density and air pollution (Table 1).
288 In the complete model, P-values for all other predictors were above 0.8 (see Table S4 in
289 Supplementary Material).

290

291 **4. Discussion**

292 As expected, we did not find differences in mutilation occurrence according to the
293 darkness of the plumage. As dark pigeons are be more resistant to pathogens (Gasparini et
294 al., 2011), and as darkness provides no advantage facing toe mutilations, this result is not in
295 favor of health-based origin of mutilations. The absence of relationship between mutilation
296 on one feet and the alternate in individual pigeons further supports an alternative
297 explanation to mutilations beyond potential bacterial, viral or fungal diseases.

298 We first highlighted that toe mutilation in urban pigeons occurs in areas where
299 pollution is high, identified here as air and noise pollution, and that mutilation are more
300 numerous where human inhabitants are more numerous. Air and noise pollution, though
301 not correlated, probably account here mainly for overall pollution arising human activities,
302 such as transports and car traffic (Azimi et al., 2005). We further used proxies of potential
303 higher density of strings and hairs on the ground, as the density of hairdressers and the
304 activity of open-street food markets in the sampled blocks. Open street food markets are
305 visited by thousands of people gathering in high concentrations, and provide a large amount
306 of wasted food for pigeons in the afternoon when sellers and clients are gone. Hair cut at
307 the hairdressers are removed by garbage collection services with household wastes, and
308 during this process, we could expect residual cut hair to end on the sideways and
309 pavements. Indeed, we found that pigeons tended to be more frequently mutilated where
310 hairdressers are more numerous. However, there are also more hairdressers where human
311 population density is higher ($r=0.57$; see Fig. S2 in Supplementary Material), leading to a
312 potential indirect effect of human population density.

313 Restricting the investigations to the only mutilated pigeons, by trying to predict the
314 number of mutilations, we found quite similar results, and confirmed an effect of human

315 population density, though with a quadratic effect as previously for hairdressers. We also
316 found a tendency for pigeons to have more toes where green spaces are denser, and less
317 toes where air pollution is higher. Green spaces appear as more natural environments sites
318 with a lower human frequentation within the city, providing a lower risk for a pigeon to
319 encounter a hair or string while ground walking, so a lower probability to get its feet
320 strangled. On the contrary, an increasing human density certainly increases the density of
321 fallen hair and other waste on the ground, hence the probability of getting a potential
322 garrote on toes.

323 We acknowledge that urban feral pigeons are naturally infected with a number of
324 viruses (Phan et al., 2013), bacteria, fungi (Kaleta and Hönicke, 2004) and protozoa (Bart et
325 al., 2008) that can be pathogenic to humans (Haag-Wackernagel and Moch, 2004; Haag-
326 Wackernagel, 2006). A common belief is that this potential zoonotic environment is
327 responsible for their foot damages. With this study, we provide evidence that this is not the
328 case: as long as their toes are concerned, pigeons are victims of urban human-based
329 pollution, though might benefit from the protection of gardens and parks. Biomonitoring of
330 urban pollution in big cities can therefore rely on pigeon's feathers for e.g. metal traces
331 (McKinney, 2002; Frantz et al., 2012; Cai and Calisi, 2016), but can also count on their
332 fingers.

333 Large numbers of pigeons are often considered to cause problems in cities, like
334 damage to buildings and transmission of disease and parasites (Jerolmack, 2008). The
335 species is often considered as a pest or an invasive species, leading to attempts to control its
336 populations. Managing pigeon numbers is efficient if reducing the carrying capacity of its
337 habitat, in terms of food and nesting sites, while pigeon culling is inefficient as breeding
338 populations have a high demographic compensatory potential (Jacob et al., 2015). Pigeons
339 are to live in cities in the future, and for ethical reasons, we should pay attention to better
340 manage our street wastes to protect wildlife health. There is no ethical reason for accepting
341 that pigeons should suffer from mutilation due to human development without trying to
342 reduce their pain (Paquet and Darimont, 2010).

343 Urbanization is intensifying worldwide, and little is known about how changes in
344 urban landscapes influence wildlife health in cities. Continued rapid urbanization, together
345 with risks posed by multi-host pathogens for humans and vulnerable wildlife populations,
346 emphasize the need for future research on wildlife diseases in urban landscapes (Bradley

347 and Altizer, 2007), while rapid urbanization can promote disease emergence in sympatric
348 urban wildlife, livestock and humans (Hassell et al., 2017). Here we highlight that urban
349 interfaces raise concerns not only about disease emergence, but also about mechanical
350 injuries to urban wildlife, arising from human activities and development. Accounting for
351 such impacts of urbanization is certainly crucial to embrace the one-health philosophy, as a
352 worldwide strategy for expanding interdisciplinary collaborations and communications in all
353 aspects of health care for humans, animals and the environment (Christopher, 2015). The
354 growing recognition of the value of urban wildlife for human well-being requires the
355 protection of wildlife health as well as human health (Stephen 2018).

356

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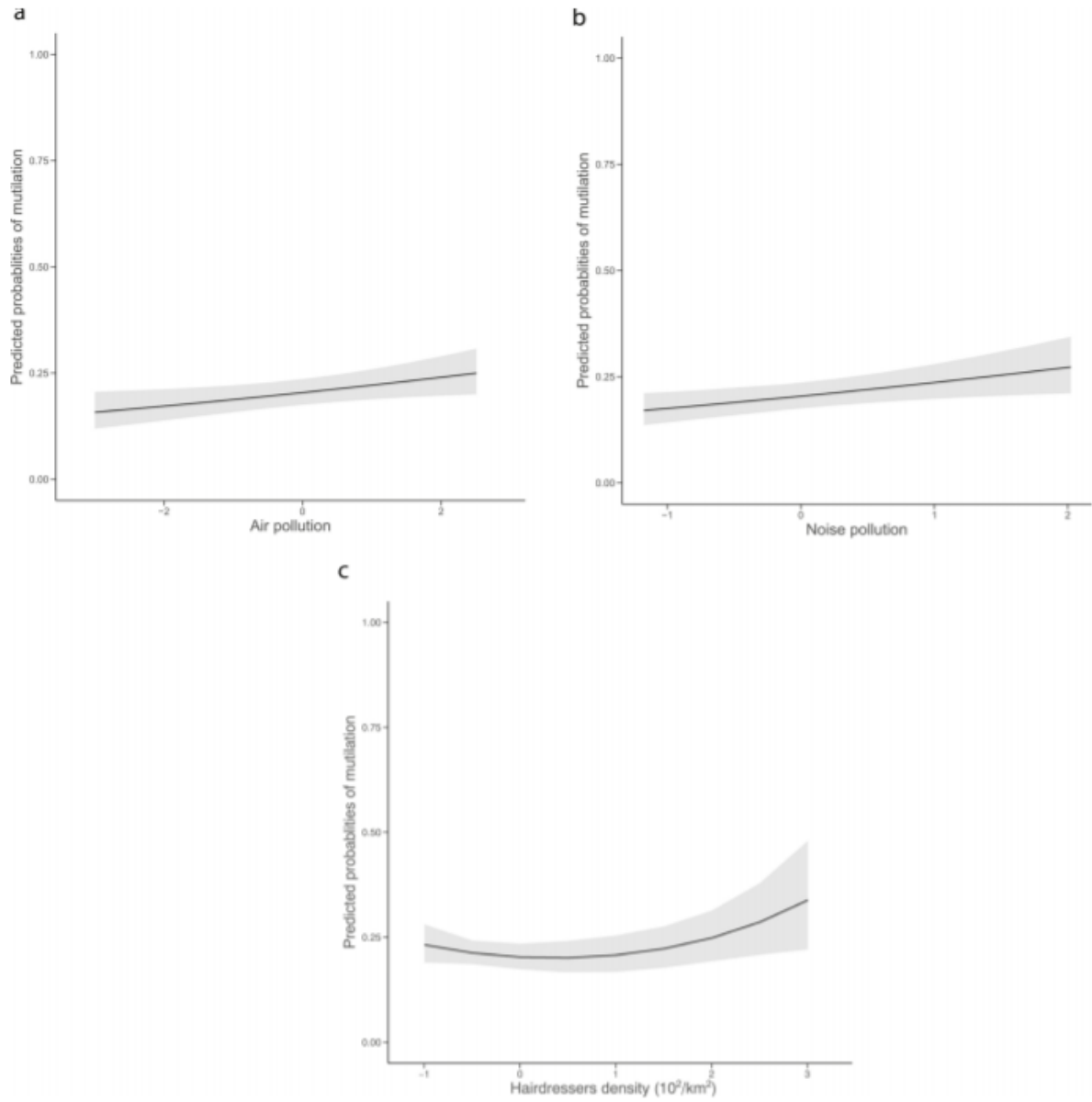
441 **Table 1**

442 Results of the reduced general linear models predicting (a) the occurrence and (b) the
 443 number of toe mutilation in urban pigeons with environmental factors related to human
 444 populations and their activities. Outputs of models with predictors reduced to those with P-
 445 values <0.1 in complete models (see Tables S3 and S4 for output of the complete models).
 446 ^2 is for quadratic terms. (**) for P-values < 0.01, (*) for P-values < 0.05, (.) for P-values < 0.1
 447

| | Variable | Estimate | SE | z-value | P-value | |
|----------------------------------|-----------------------------|-----------------|-----------|----------------|----------------|----|
| (a) mutilation occurrence | hairdresser density | -0.071 | 0.107 | -0.66 | 0.506 | |
| | hairdresser density ^2 | 0.101 | 0.054 | 1.89 | 0.059 | . |
| | noise pollution | 0.188 | 0.075 | 2.52 | 0.012 | * |
| | air pollution | 0.105 | 0.045 | 2.34 | 0.019 | * |
| (b) mutilation number | human population density | -0.014 | 0.04 | -0.347 | 0.729 | |
| | human population density ^2 | 0.08 | 0.028 | 2.805 | 0.005 | ** |
| | green space density | -0.09 | 0.046 | -1.935 | 0.053 | . |
| | air pollution | 0.05 | 0.027 | 1.872 | 0.061 | . |

448
 449

450 Figure 1. Predicted probabilities of deformities occurrence in pigeons' foot according to (a)
451 air pollution and (b) noise pollution (linear effects) and (c) the density of hairdressers
452 (quadratic effect).



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455 Figure 2. Feet of two urban pigeons from Paris, left with undamaged toes, right with
456 damaged toes following necrosis.

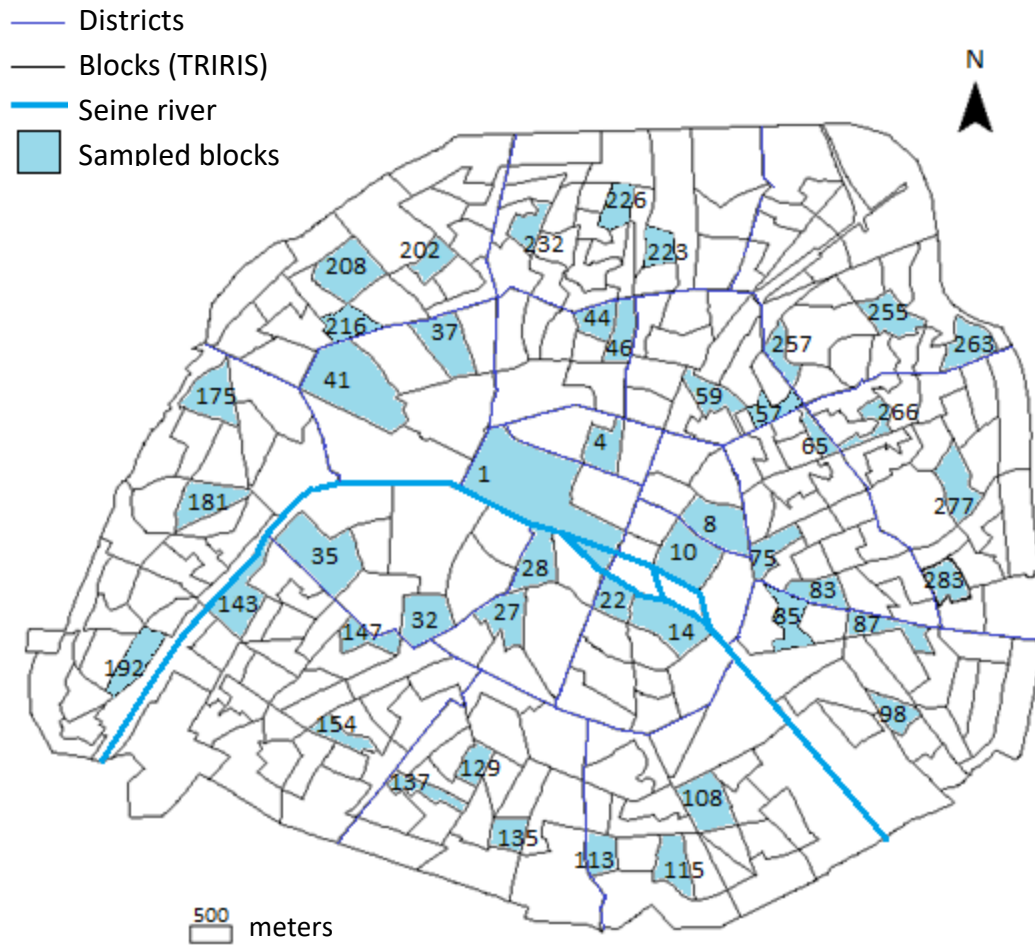


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SUPPLEMENTARY MATERIAL

Fig. S1. Location of the blocks where pigeons have been surveyed in Paris, France. Numbers are the administrative reference of the TRIRIS (e.g. blocks).



463
464

465 **Table S1**

466 Eigenvalues and proportion of variances retained by the principal components (PCs)

467 performed on air pollution indices Citeair.

| | eigenvalue | percentage of variance | cumulative percentage of variance |
|------|------------|------------------------|-----------------------------------|
| PC 1 | 2.401 | 80.03 | 80.03 |
| PC 2 | 0.558 | 18.58 | 98.61 |
| PC 3 | 0.042 | 1.39 | 100.00 |

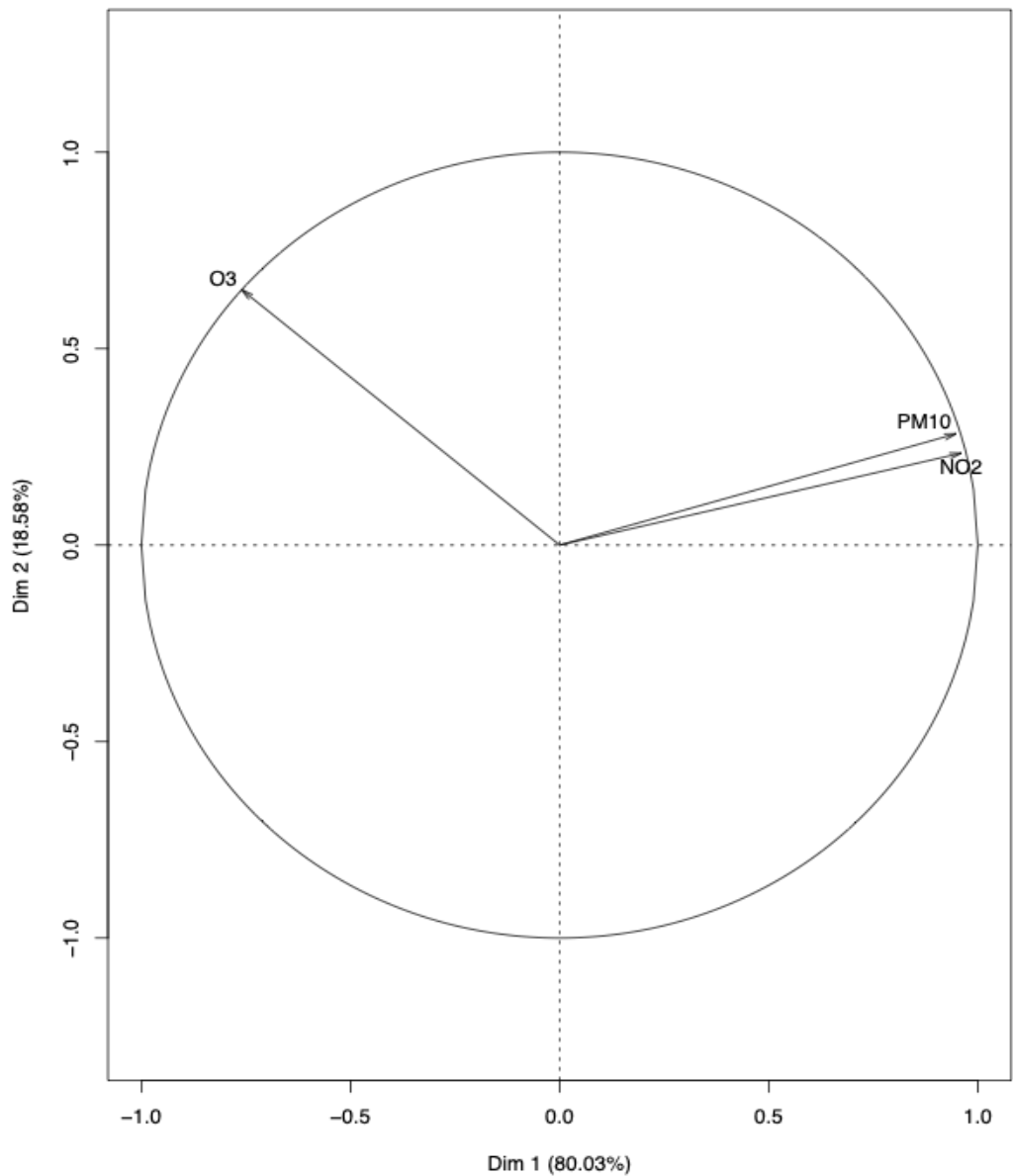
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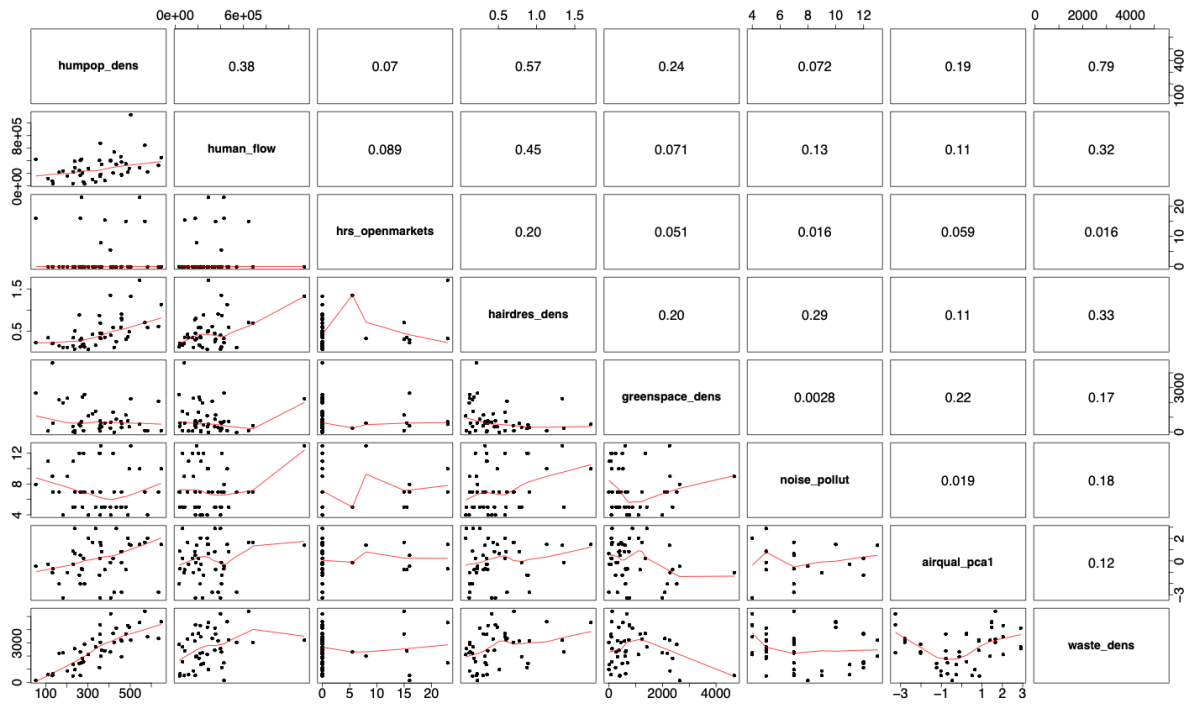
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472 **Fig. S2.** Plot of the circle of correlations from Principal Component Analysis run on the three
473 air pollution indices (NO₂, O₃, and PM₁₀).



488 **Fig. S3.** Multicollinearity between explanatory variables. *humanpop_dens* = 'Human
 489 population density'; *human_flow* = 'Human flow'; *hrs_openmarkets* = 'Total number of
 490 opening hours of the open street markets'; *hairdres_dens* = 'Density of hairdressers';
 491 *greenspace_dens* = 'Density of green spaces'; *noise_pollut* = 'Noise pollution'; *airqual_pca1* =
 492 'Air pollution' (PCA first component); *waste_dens* = 'Density of waste'.
 493



494 **Table S2**

495 Variance inflation factor (VIF) values for the full generalized linear models predicting
 496 mutilation occurrence and mutilation extent.

| | VIF (full model – mutilation occurrence) | VIF (full model – mutilation extent) |
|-----------------------------|--|--------------------------------------|
| human population density | 4.291 | 4.968 |
| human population density ^2 | | 1.183 |
| human flow | 1.311 | 1.424 |
| open market | 1.149 | 1.113 |
| hairdresser density | 4.001 | 1.150 |
| hairdresser density ^2 | 2.627 | |
| noise pollution | 1.215 | 2.445 |
| green space density | 1.186 | 1.310 |
| waste density | 3.038 | 3.631 |
| air pollution | 1.120 | 1.064 |

497

498

499

500 **Table S3**

501 Results of the complete multivariate model predicting the occurrence of toe mutilation in
 502 urban pigeons, when considering only uncorrelated predictors. Significance: ‘***’ for $P \leq 0.01$;
 503 ‘*’ for $P \leq 0.05$; ‘.’ for $P \leq 0.1$.

504

| Variable | Estimate | SE | z-value | P-value |
|--------------------------|----------|-------|---------|----------|
| human population density | 0.048 | 0.100 | 0.48 | 0.632 |
| human flow | -0.011 | 0.081 | -0.14 | 0.891 |
| green space density | -0.022 | 0.079 | -0.27 | 0.785 |
| open market | 0.019 | 0.077 | 0.24 | 0.808 |
| hairdresser density | -0.113 | 0.142 | -0.80 | 0.427 |
| hairdresser density ^2 | 0.107 | 0.060 | 1.78 | 0.075 . |
| noise pollution | 0.201 | 0.078 | 2.59 | 0.010 ** |
| air pollution | 0.098 | 0.047 | 2.10 | 0.036 * |

505

506

507

508 **Table S4**

509 Results of the complete multivariate model predicting the number of toe mutilation in urban
 510 pigeons, when considering only uncorrelated predictors. Significance: ‘***’ for $P \leq 0.01$; ‘.’ for
 511 $P \leq 0.1$.

512

| Variable | Estimate | SE | z-value | P-value |
|-----------------------------|----------|-------|---------|----------|
| human population density | -0.010 | 0.045 | -0.22 | 0.828 |
| human population density ^2 | 0.080 | 0.030 | 2.70 | 0.007 ** |
| human flow | -0.010 | 0.043 | -0.22 | 0.826 |
| green space density | -0.088 | 0.047 | -1.87 | 0.062 . |
| open market | -0.002 | 0.038 | -0.04 | 0.968 |
| noise pollution | 0.001 | 0.042 | 0.01 | 0.990 . |
| air pollution | 0.050 | 0.027 | 1.88 | 0.061 |

513