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# Use of Large-Scale Acoustic Monitoring to Assess Anthropogenic Pressures on Orthoptera Communities

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**Abstract:** *Biodiversity monitoring at large spatial and temporal scales is greatly needed in the context of global changes. Although insects are a species-rich group and are important for ecosystem functioning, they have been largely neglected in conservation studies and policies, mainly due to technical and methodological constraints. Sound detection, a nondestructive method, is easily applied within a citizen-science framework and could be an interesting solution for insect monitoring. However, it has not yet been tested at a large scale. We assessed the value of a citizen-science program in which Orthoptera species (Tettigoniidae) were monitored acoustically along roads. We used Bayesian model-averaging analyses to test whether we could detect widely known patterns of anthropogenic effects on insects, such as the negative effects of urbanization or intensive agriculture on Orthoptera populations and communities. We also examined site-abundance correlations between years and estimated the biases in species detection to evaluate and improve the protocol. Urbanization and intensive agricultural landscapes negatively affected Orthoptera species richness, diversity, and abundance. This finding is consistent with results of previous studies of Orthoptera, vertebrates, carabids, and butterflies. The average mass of communities decreased as urbanization increased. The dispersal ability of communities increased as the percentage of agricultural land and, to a lesser extent, urban area increased. Despite changes in abundances over time, we found significant correlations between yearly abundances. We identified biases linked to the protocol (e.g., car speed or temperature) that can be accounted for ease in analyses. We argue that acoustic monitoring of Orthoptera along roads offers several advantages for assessing Orthoptera biodiversity at large spatial and temporal extents, particularly in a citizen science framework.*

**Keywords:** agricultural, citizen science, functional traits, insect, road, Tettigoniidae, urbanization

El Uso de Monitoreos Acústicos a Gran Escala para Estudiar las Presiones Antropogénicas sobre Comunidades de Orthoptera

**Resumen:** *El monitoreo de la biodiversidad a grandes escalas espaciales y temporales es una necesidad en el contexto de cambios globales. Aunque los insectos son un grupo rico en especies y son importantes para el funcionamiento de los ecosistemas, han sido ignorados en estudios y políticas de conservación, principalmente debido a restricciones técnicas y metodológicas. La detección sonora, un método no destructivo, se aplica fácilmente dentro de un marco de ciencia ciudadana y podría ser una resolución interesante para el monitoreo de insectos, sin embargo no se ha probado a gran escala. Estudiamos el valor de un programa de ciencia ciudadana en el que especies de Orthoptera (Tettigoniidae) fueron monitoreadas acústicamente a lo largo de las carreteras. Usamos análisis bayesianos de promedio de modelos para probar si podíamos detectar patrones ampliamente conocidos de efectos antropogénicos sobre insectos, como los efectos negativos de la urbanización o de la agricultura intensiva sobre poblaciones y comunidades de Orthoptera. También examinamos correlaciones sitio- abundancia entre años y estimamos los sesgos en la detección de especies para evaluar y mejorar el protocolo. La urbanización y los paisajes de agricultura intensiva afectaron negativamente a la riqueza de especies de Orthoptera así como a la diversidad y la abundancia. Este hallazgo va de acuerdo con los resultados de estudios previos sobre Orthoptera, vertebrados, carábidos y mariposas.*

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*La masa promedio de comunidades disminuyó conforme incrementó la urbanización. La habilidad de dispersión de las comunidades incrementó conforme incrementaba el porcentaje de tierra agrícola, y en una menor cantidad, el área urbana. A pesar de los cambios en abundancias a lo largo del tiempo encontramos correlaciones significativas entre abundancias anuales. Identificamos los sesgos vinculados con el protocolo (p.ej.: velocidad del auto o temperatura) que pueden señalarse fácilmente en los análisis. Proponemos que el monitoreo acústico de Orthoptera a lo largo de las carreteras ofrece varias ventajas para estudiar la biodiversidad en extensiones grandes tanto espaciales como temporales, particularmente en un marco de ciencia ciudadana.*

**Palabras Clave:** agricultura, carretera, ciencia ciudadana, insecto, rasgos funcionales, Tettigoniidae, urbanización

## Introduction

In the context of global changes and the general decline of biodiversity, the need for biodiversity monitoring at large spatial and temporal scales is widely recognized (Balmford et al. 2005; Green et al. 2005; Pereira & Cooper 2006). It is crucial to assess biodiversity and changes in species distributions and abundances at a large spatial extent and to predict long-term biological responses to anthropogenic pressures and global changes (Balmford et al. 2003; Pereira & Cooper 2006; Jones et al. 2010). Policy makers are becoming more involved in monitoring biodiversity. Their involvement has prompted the United Nations to declare a decade of biodiversity (2011–2020) through which they will encourage the scientific community to create new programs to improve knowledge of biodiversity and to develop biodiversity indicators (http://www.cbd.int/2011–2020/). This desire on the part of environmental managers and policy makers is echoed at the local scale (Danielsen et al. 2005).

The total effort that can be allocated to biodiversity monitoring partly determines the probability of detection and the precision of estimating trends in biodiversity (Yoccoz et al. 2001; Nielsen et al. 2009; Lindenmayer et al. 2011). The collection of large amounts of data with highly standardized and well-designed protocols is one of the keys to project success because it increases the statistical power for detecting biological patterns and trends (Schmeller et al. 2009; Dickinson et al. 2010). Unfortunately, it is also expensive and time consuming. Data collection by highly skilled specialists is limited because of high costs or because these personnel are often already working on other projects (Levrel et al. 2010). To reduce the cost of monitoring and increase sample size, programs that train and coordinate volunteer observers have been proposed within the framework of citizen science (Couvet et al. 2008; Dickinson et al. 2010). With appropriate survey designs that optimize detection probabilities and reduce identification errors, bias in habitat sampling, and spatial and temporal autocorrelation, volunteer-based monitoring programs maximize sampling effort and can provide reliable data that can be used to detect significant spatial and temporal changes in biodiversity (Schmeller et al. 2009). In addition, these programs have the advantage of educating participants and increasing public awareness (Stafford et al. 2010), which have also been highlighted as a priority by the United Nations (http://www.cbd.int/2011–2020/).

Insects are the most species-rich group of multicellular organisms. They represent over 50% of the world's biodiversity and significant biomass and play an important role in ecosystem functioning (Weisser & Siemann 2004). However, their conservation status and monitoring plans have been poorly considered (Dunn 2005). Therefore, for the purpose of conservation, there is a critical need to improve knowledge about insects, particularly their spatial and temporal changes in abundance (Cardoso et al. 2011). The decline of insects, such as butterflies, has been assessed by examining the change in their distribution range (Telfer et al. 2002). However, this approach underestimates the rate of population decline because important changes in population size can occur long before any conspicuous changes in species distributions (Thomas & Abery 1995). In addition, most of the available distributional data suffer from differences in sampling effort over time. It is possible to correct for variations in sampling effort (Telfer et al. 2002), but the results should be treated with caution (van Swaay et al. 2008). Hence, data that are based on population abundance are expected to result in the best estimates of trends (Yoccoz et al. 2001). However, this monitoring approach is the most time-consuming approach due to the nature of the data. In this context, new technologies can be useful tools for increasing the amount of data collected and reducing error and bias due to variation in the observers (Dickinson et al. 2010) because they require less human interpretation than traditional methods. Some of these technologies are based on the storage and analysis of photographs, videos, or sound recordings (e.g., Sueur et al. 2008). These remote and noninvasive techniques allow post hoc validation of the data by experts. These monitoring techniques could be of great interest because they can be coupled with automated signal recognition (Blumstein et al. 2011) to reduce even further bias due to differences in observers.

Acoustic recording may be a particularly useful method for monitoring insects (Mankin et al. 2011), which are currently poorly monitored. However, not all species produce sound, and sounds are not necessarily species specific. Among insects Orthoptera are good candidates for acoustic monitoring because they produce mating calls (Ragge & Reynolds 1998) that have a role in premating isolation and mate recognition (Paterson 1985), features that ensure the species specificity of the call. Hence, even without taxonomic expertise, Orthoptera songs (or stridulations) are reliable signals for species classification (Riede 1998) and can even yield precise information about the abundances of species (Fischer et al. 1997). Songs can be used to monitor these taxa, for which sampling techniques are difficult to set up and require specific skills (Gardiner et al. 2005) that are not compatible with large-scale monitoring. Furthermore, the automatic identification systems for Orthoptera that have been implemented seem to accurately recognize taxonomic units even at the species level (Riede et al. 2006; Ganchev et al. 2007). Hence, sound detection, which is a nondestructive and thus well-accepted sampling method, could be a monitoring technique for Orthoptera that is well suited to a citizen-science framework.

We assessed the value of a citizen-science monitoring program in which volunteers acoustically sampled Orthoptera along roads. Since 2009, the French Museum of Natural History has conducted such a project (http://vigienature.mnhn.fr). To evaluate the effectiveness of this program and its potential to provide reliable data on changes in species abundances, distributions, and biological trends, we tested whether we could detect widely known effects of anthropogenic disturbances on species richness, diversity, and abundance (e.g., negative effects of urbanization; McKinney 2002 and intensive agriculture; Krebs et al. 1999; Robinson & Sutherland 2002 and negative effects of such factors on Orthoptera; Marini et al. 2008; Nufio et al. 2009; Cherrill 2010). We then assessed the spatial and temporal biases of the program in the detection of species to evaluate and improve the protocol. Because insect dynamics are often chaotic and can lead to large variations in abundance over time (Dennis et al. 2001), we also tested the temporal stability of Orthoptera abundance by studying changes in annual abundances.

## Methods

We conducted our study in the Paris, France, region, which is highly populated (12 million inhabitants, 668 inhabitants per km$^2$), densely urbanized in the north, and characterized by intensive agricultural land use in the south (most of which is cropland).

### Orthoptera Data

The national biodiversity monitoring scheme coordinated by the French Museum of Natural History (http://vigienature.mnhn.fr/) provided the data set. Data were collected along roads, which are often used as survey areas in citizen-science programs because they are readily available and allow for public access to a wide variety of landscapes and gathering of a large amount of data (Dickinson et al. 2010).

The protocol focused on insects that produce stridulations with frequencies above 8 kHz that are not masked by the noise produced by cars. Because species with these characteristics such as Tettigoniidae are most active around dusk, surveys were conducted in the early evening. Observers completed 2 surveys per year along the same circuits in 2009 and 2010 at different times: June–July (surveys 2009-a and 2010-a) and August–September (surveys 2009-b and 2010-b). They continuously recorded sounds on a Zoom H2 digital recorder (Samson Technologies, Hauppauge, NY, USA) at a sampling rate of 96 ks/s from the high-frequency output of an ultrasonic detector (D240X, Pettersson Elektronik, Uppsala, Sweden). This device detects species with weak stridulations for up to 20 m. (Y. Bas, personal observation). The detector was fixed to the passenger-side window at a 45° angle. The distance to road edges was thus similar all along the circuits. See Supporting Information for more details.

Ten 30-km circuits (1 circuit per volunteer) were traveled during dry nights when temperatures were $>12$ °C. Observers were asked to drive at a constant speed of approximately 25 km/h and to begin recordings 30 min after dusk (Fig. 1). Although volunteers defined each circuit for security reasons (volunteers' knowledge of road traffic), randomization was generated with the following process. The museum defined a random starting point, and the circuit was divided into ten 2-km road segments, separated by a 1-km road segment in which no recording was made (Fig. 1). This sampling design resulted in a strong correlation between the proportion of habitat sampled and the proportion of habitat existing at the regional scale ($R^2 = 0.94$), although our sample area contained a greater proportion of urban area. Due to protocol constraints and safety issues (Supporting Information), all roads were of similar type: about 10 m wide, paved, and low traffic.

We analyzed the sonograms with Syrinx, a program designed for research in animal acoustic communication (Burt 2006). Each call sequence was attributed to one individual and geolocated along the road with time and speed parameters (see Supporting Information for more details). We identified each individual to the species level (sonograms and sound samples are given in Supporting Information). We measured the abundance of male activity, which is not a direct measure of the abundance of insects but is nonetheless highly correlated to it, as did Fischer et al. (1997) in direct catch experiments.

We divided each 2-km road segment into 400-m segments with a geographic information system (GIS)

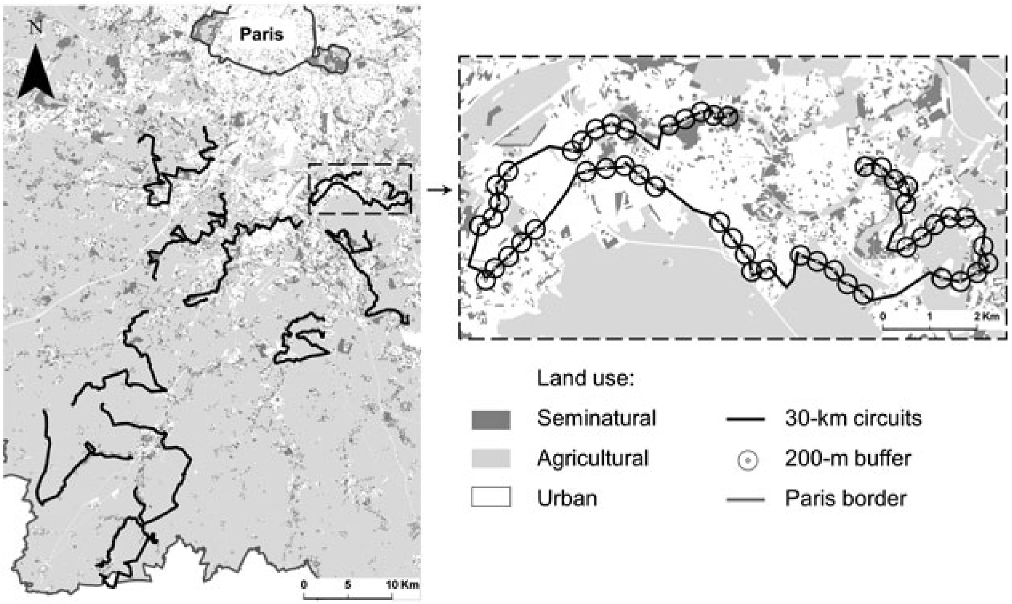

*Figure 1. Locations of routes driven by observers to sample Orthoptera sounds within 3 types of land uses (buffer, circular area around the midpoint of each segment).*

(ARCGIS, version 9.3, ESRI, Redlands, California). We allocated all the Orthoptera detected along a segment to the coordinates of its central point. We delineated 500 segments of which 492 were properly recorded. We, thus, recorded Orthoptera on more than 390 ha (20 m × 400 m × 492 segments). For each segment, we collected the following data: car speed (mean = 23.7 km/h [SD 1.9]), time elapsed after dusk (mean = 49.9 min [SD 23.1]) and temperature (mean = 19.8 °C [SD 3.1]).

### Landscape Data

We delineated a circular area (hereafter buffer) with a 200-m radius around the midpoint of each segment and calculated for each buffer the proportion of urban and agricultural (intensive crops) area with a detailed, regional georeferenced land-use database of landscape features (IAURIF 2003). Penone et al. (2012) report that a 200-m radius is large enough for the detection of landscape effects on species. At this distance our buffers did not overlap, which greatly limited data dependence. We defined urban cover in each buffer as the proportion of built and impervious surfaces, and this parameter varied from 0% to 100% (mean = 31.2 [SD 30.2]). Agricultural cover varied from 0% to 100% (mean = 30.8 [SD 34.9]). At the regional scale, urban and agricultural covers were 16% and 51%, respectively.

### Community Indexes

For each segment, we calculated species richness and diversity with the Shannon index. We characterized the dispersal ability of each species with a 3 classes index (1, low; 2, moderate; 3, highly mobile) according to Reinhardt et al. (2005) and Marini et al. (2010). We characterized body mass following Vahed and Gilbert (1996) (Table 1). We then calculated the community-weighted mean values for these 2 traits (Diaz et al. 2007). A community dispersal-ability index (CDI) was calculated as the average dispersal of the species detected, weighted by local species abundance:

$$\mathrm{CDI}j = \frac{\sum_{i=1}^{n} aij(Di)}{\sum_{i=1}^{n} aij}, \qquad (1)$$

where $n$ is the total number of species recorded and $a_{ij}$ is the abundance of individuals of species $i$ (with a $D_i$ dispersal ability index) in segment $j$. Similarly, we used body masses of species to calculate index values of community mass (CMI). Brown-spotted bush-cricket (*Platycleis tessellata*) was abundant in our data set, but we did not find its mass quantified in the literature. Thus, we calculated it through an exponential regression model with the sizes and masses of the other species and the size of brown-spotted bush-cricket. We then recalculated the CMI including this species. For the analyses of both indexes, we kept only the segments with non-null abundances ($n = 935$) (i.e., 95% of the data set used for the analyses) because a null CDI or CMI signified the lack of a community.

### Statistical Analyses

We used Bayesian model averaging (BMA) for generalized linear models (GLM) to determine the environmental variables that were the most useful predictors of insect

**Table 1. Traits of insect species and the number of singing males detected during each survey period.**

| *Species* | *Dispersal ability* | *Male body mass (mg)* | *Insect abundance*[a] *2009-a* | *2009-b* | *2010-a* | *2010-b* | *Total* |
|---|---|---|---|---|---|---|---|
| *Tettigonia viridissima* | mobile | 1450 | 275 | 608 | 420 | 518 | 1821 |
| *Leptophyes punctatissima* | sedentary | 175 | 18 | 3535 | 62 | 6218 | 9833 |
| *Phaneroptera nana* | mobile | 289 | 1 | 929 | 12 | 421 | 1363 |
| *Ruspolia nitidula* | mobile | 556 | 0 | 597 | 12 | 743 | 1352 |
| *Pholidoptera griseoaptera* | sedentary | 498 | 0 | 2041 | 149 | 2293 | 4483 |
| *Platycleis tessellata* | sedentary | NA[b] | 434 | 2875 | 120 | 325 | 3754 |
| *Phaneroptera falcata* | mobile | 187 | 0 | 351 | 12 | 116 | 479 |
| *Platycleis albopunctata* | intermediate | 479 | 233 | 153 | 59 | 64 | 509 |
| *Conocephalus fuscus* | mobile | 150 | 0 | 122 | 4 | 224 | 350 |
| *Metrioptera roeselii* | intermediate | NA | 82 | 4 | 22 | 4 | 112 |
| Total | | | 1043 | 11215 | 872 | 10,926 | 24,056 |

[a] *Total abundances of insects for all the circuits, which are the same in each survey period.*
[b] *Not available.*

richness and abundances (bic.glm function, BMA package in R). Contrary to classical inferences, BMA accounts for the uncertainty linked to the choice of one model over all other possible models (Ellison 2004; Pellissier et al. 2012). It estimates the importance of each predictor variable by computing its posterior probability and provides an average estimate and standard deviation for each variable. Following Viallefont et al. (2001) and Azeria et al. (2009), we characterized variables with posterior probabilities of $>0.75$, 0.5–0.75, and $<0.5$ as strong, weak, and not useful predictors, respectively. These values corresponded to the classical $p$ values $<0.01$, 0.01–0.05, and $>0.05$, respectively.

In the model, we included the predictor variables car speed, time elapsed after dusk, and temperature (tested to assess the bias on species detection due to our protocol). We also included landscape variables (built and agricultural surfaces within a buffer) to determine whether the information collected with acoustic monitoring followed widely known patterns (e.g., showed the negative effect of urbanization or intensive agrarian landscapes on species richness, diversity, and abundance; Robinson & Sutherland 2002; Devictor et al. 2007).

To account for spatial autocorrelation, we added an autocovariate (i.e., a distance-weighted function of neighboring response values; Dormann et al. 2007) with the autocov_dist function in R (package spdep). We scaled all continuous predictor variables to standardize their effect sizes and to allow for the comparison of the resulting regression parameters. We used the normal distribution for species richness, diversity, and community indexes and the negative binomial distribution for species abundances to account for overdispersion (Crawley 2009). We evaluated multicollinearity in the explanatory variables of our models by calculating variance-inflation factors (VIF) on the full models (Fox & Monette 1992), and all variables had VIF $< 5$. Because the detected abundances during the first survey period (June–July: surveys 2009-a and 2010-a) were weak, we ran the analyses on data collected during the second period (August–September: surveys 2009-b and 2010-b) for both 2009 and 2010. Thus, we added year as a covariate in the models. We performed the abundance analyses on species occurring in $>100$ segments and representing over 5% of total abundances.

Because temporal variation in abundances can mask spatial variation, we examined the temporal stability of Orthoptera abundances. We tested the correlation between the 2009 and 2010 residuals of the modeled relation (species abundance $\sim$ temperature $+$ car speed $+$ time elapsed after sunset), computed separately for the second survey period of each year (i.e., 2009-b and 2010-b). In this analysis, we used a GLM with a negative binomial distribution. We then performed a Spearman's test on residuals of the 2 above models to examine the relation between the 2 years (2009-b and 2010-b). We expected significant correlations in site abundances between years when the variation in Orthoptera abundances were not simply random.

## Results

On recordings made by citizen scientists, we detected 24,056 singing individuals belonging to 11 species of bush-crickets from the Tettigoniidae family (12,258 in 2009 and 11,798 in 2010). Most of them ($n = 22141$) were detected during the second survey periods (August–September). Six species were found in more than 100 segments: great green bush-cricket (*Tettigonia viridissima*), speckled bush-cricket *(Leptophyes punctatissima)*, four-spot bush-cricket (*Phaneroptera nana)*, large conehead (*Ruspolia nitidula)*, dark bush-cricket *(Pholidoptera griseoaptera)*, and brown-spotted bush-cricket. Four species were almost absent during the first survey period (June–July): four-spot bush-cricket, sickle-bearing bush-cricket (*Phaneroptera falcata)*, large conehead, and long-winged conehead (*Conocephalus fuscus)* (Table 1). We found significant correlations between

**Table 2. Relation between residual abundance$^a$ of insect species per road segment in 2009-b and 2010-b (August–September surveys).**

| | *Rho*$^b$ | p |
|---|---|---|
| *T. viridissima* | 0.54 | <0.001 |
| *L. punctatissima* | 0.57 | <0.001 |
| *P. nana* | 0.34 | <0.001 |
| *R. nitidula* | 0.38 | <0.001 |
| *P. griseoaptera* | 0.57 | <0.001 |
| *P. tessellata* | 0.63 | <0.001 |

[a] *Residual abundances are the residuals of the modeled relation (species abundance ∼ temperature + car speed + time elapsed after sunset).*

[b] *Spearman's rank correlation.*

2009 and 2010 residual abundances for the second survey periods (surveys 2009-b and 2010-b) (Table 2). This result confirmed that variation in Orthoptera abundances was not simply random.

### Landscape Effects

The ratio of urban and agricultural cover in the 200-m buffer had negative effects on species richness, diversity (Table 3), and abundance for most of the species, except for four-spot bush-cricket (for urban land cover), large conehead, and brown-spotted bush-cricket (for agricultural land cover) (Supporting Information). Agricultural cover also had a positive effect on the CDI; that is, there were proportionally more good dispersers in communities when the percentage of agricultural land cover was high. Urban cover had a positive effect on CDI too, but it was very weak (PP < 50%). Urban cover had a negative effect on CMI: the lightest Orthoptera were proportionally more abundant in the species assemblage when urbanization was higher (Table 3). These results were similar when brown-spotted bush-cricket mass (460 mg) was included.

### Protocol Biases

Car speed was never selected as a reliable predictor in our models. Time after dusk was selected once, for dark bush-cricket. Temperature was also selected once, for large conehead. All species abundances, richness, diversity, and other indexes were positively associated with the spatial autocovariate (Table 3 & Supporting Information).

## Discussion

The sampling protocol did not provide an exhaustive inventory of Orthoptera or an exact estimation of insect abundances because it only detected actively singing males. However, singing male abundances are linked to abundances of whole populations (Oertli et al. 2005). Therefore, the protocol provided a measure of the relative abundance of each species, and it appeared to detect large temporal and spatial changes in Orthoptera abundances. Thus, the data it provided could be used to answer ecological questions at the landscape scale.

Our results showed it was possible to detect with acoustic monitoring well-known patterns of effects of anthropogenic land uses on biodiversity, such as the negative effects of urbanization and intensive agricultural landscapes on species richness, abundance, and diversity. Indeed, Orthoptera, similar to many other taxa, are negatively affected by both urbanization (Marini et al. 2008; Nufio et al. 2009) and agricultural intensification (Marini et al. 2009; Cherrill 2010). In addition, we found some patterns in Orthoptera that have been highlighted for other insects (e.g., carabid beetles), such as a decrease in the average mass of the Orthoptera community (CMI) as urbanization increased. Species size, which is correlated with species mass (Magura et al. 2006), is linked to the decline of carabid beetles in an urban context (Niemelä & Kotze 2009). Heavier, larger species are more likely to be affected by urbanization because of a lack of resources or alternative habitats in urban areas and because of their greater sensitivity to disturbance (Magura et al. 2006).

The increase in the average dispersal ability in the Orthoptera community (CDI) as the percentage of agricultural area increased or, to a lesser extent, as urban cover increased was also consistent with findings for other

**Table 3. Results of the Bayesian model averaging analyses of insect species richness, diversity, and indexes.**

| *Predictor variables* | *Richness* | | | *Shannon diversity* | | | *Community mass index* | | | *Community dispersal ability* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *mean* | *SD* | *PP* | *mean* | *SD* | *PP* | *mean* | *SD* | *PP* | *mean* | *SD* | *PP* |
| Autocovariate | 0.775 | 0.063 | 100.0 | 0.160 | 0.017 | 100.0 | 69.993 | 8.117 | 100.0 | 0.496 | 0.038 | 100.0 |
| Time after dusk | −0.012 | 0.047 | 9.0 | −0.007 | 0.015 | 21.3 | 0.211 | 1.761 | 3.1 | 0.024 | 0.045 | 25.0 |
| Temperature | 0.000 | 0.000 | 0.0 | 0.002 | 0.009 | 8.6 | 0.000 | 0.000 | 0.0 | 0.000 | 0.000 | 0.0 |
| Car speed | −0.014 | 0.037 | 15.0 | −0.004 | 0.012 | 17.8 | 0.000 | 0.000 | 0.0 | 0.000 | 0.000 | 0.0 |
| Urban | −0.344 | 0.062 | 100.0 | −0.098 | 0.018 | 100.0 | −19.091 | 13.908 | 71.7 | 0.043 | 0.053 | 45.7 |
| Agricultural | −0.294 | 0.058 | 100.0 | −0.071 | 0.017 | 100.0 | 7.351 | 11.708 | 32.8 | 0.140 | 0.043 | 100.0 |

*Mean is average estimate and PP is posterior probability. Variables with the posterior probabilities >75, 50–75, and <50 were strong, weak, and not useful predictors, respectively.*

taxa, such as butterflies, carabids, and spiders (Niemelä & Kotze 2009; Ekroos et al. 2010). Species with good dispersal abilities are more likely to colonize small and isolated habitat patches that are typical of urban and intensive agricultural landscapes (Hanski 1999). The only species for which we did not detect a significant negative effect of urbanization was four-spot bush-cricket, which is common in urban areas (Bellmann & Luquet 2009). This finding suggests that acoustic road sampling, which has the advantage of covering large areas in a relatively short time, could provide results similar to, although less precise than, other protocols.

Our results also indicated that acoustic monitoring enabled the detection of biological patterns and, in particular, those linked to species phenology. For example, we detected 4 species (four-spot bush-cricket, sickle-bearing bush-cricket, large conehead, and long-winged conehead) only during the second survey period (August–September), as expected due to their phenology. In France these 4 species, unlike the other species we detected, reach the imago stage at the end of July or in August (i.e., after our first survey period) (Bellmann & Luquet 2009). The relations between species abundances in surveys conducted in different years at the same time showed that despite interannual variations, the abundances at sites were correlated among years (accounting for temperature, car speed, and time elapsed after sunset). Even when only tested over 2 years, this was an encouraging result because it highlighted the repeatability of the method, which is useful for long-term monitoring. In light of these results, the second survey period seemed to be better suited to an acoustic Tettigoniidae monitoring effort at a large scale because during this period, most species have reached the adult stage and thus it is possible to detect singing males. All these findings suggest that acoustic sampling can be useful for collecting a large amount of data to monitor spatiotemporal changes in biodiversity.

### Protocol Bias

We detected biases linked to the protocol that are imperative to consider for analyses of this type of acoustic data. However, car speed had no effect and time elapsed after dusk and temperature had limited effects on Orthoptera detection, partly because the observers carefully followed the protocol, and, thus, these variables did not vary greatly.

The time elapsed after dusk had a species-level effect. Some species are more active after dusk and others are active all night long (Bellmann & Luquet 2009). This bias is likely to be attenuated by the fact that the circuits were short (1.5 h maximum). Therefore, to limit this bias it would be wise not to lengthen the circuits.

Temperature, which also affected some species, is more difficult to control, and it is difficult to add additional temperature constraints to the protocol (in France 12 °C can be considered a moderate constraint). Citizen-science protocols must be as standardized as possible and as simple as possible (Matteson et al. 2012) so that they do not discourage observers from participating in the programs. Our protocol in its current form seemed to limit most of the sources of bias that can be controlled. We did not detect an effect from car speed on species abundances. This parameter was highly standardized, and, in fact, its limited variation indicated observers followed the protocol carefully.

Sampling from roads can also be biased because housing landscapes are likely to be oversampled (Dickinson et al. 2010), a finding consistent with our results. Thus, it is important to account for land cover in future analyses. Another bias was linked to the difference of song types between species. Species that produce relatively short and isolated bursts of sound could be overestimated compared with those that produce either continuous sound or regularly and rapidly repeated short bursts of sound (see Supporting Information). Although in our comparative study we could assume this bias yielded a constant error and thus was not problematic, it is important to account for it in future studies comparing abundances among species.

We identified the species ourselves; however, in citizen-science programs, identification errors by volunteers can create a bias in the data (Kremen et al. 2011). A large number of sites can counteract this bias (Schmeller et al. 2009; Jiguet et al. 2012). Some researchers are working on automatic identification systems capable of identifying Orthoptera, even to the species level. This technology would reduce the amount of time spent by volunteers and decrease the bias linked to observers. Therefore, once improved, automatic detection could be a cost-effective solution that enhances the sustainability of the program. The cost of a monitoring program partly determines its success because it acts positively on the monitoring power in space and time (Jones et al. 2010). This improvement, similar to other improvements linked to the use of new technologies, could be introduced into the program later from the perspective of adaptive monitoring (Lindenmayer et al. 2011) and help ensure the long-term success of such a program. Furthermore, the creation of online worldwide sound archives, as suggested by Riede et al. (2006), would also be helpful in setting up acoustic monitoring programs in other countries. Finally, it could also be useful to couple Orthoptera monitoring with bat monitoring because their monitoring protocols are similar (Roche et al. 2011). The creation of international sound archives and the coupling of Orthoptera with bat monitoring could ensure a rapid and easy set-up of nocturnal Orthoptera monitoring around the world. Such programs would produce data sets that could be compared, studied, and used to understand trends in biodiversity on broader scales.

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## Supporting Information

Details on methods (Appendix S1), sonograms and sound samples of the main species (Appendix S2), and the results of the BMA analysis of the abundance of the main species (Appendix S3) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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