PARMENIDE

Farmland mosaic landscapes and novel indicators of ecoacoustic diversity

BIOSEFAIR Metaprogram

Project summary: 2024 – 2026

February 2026

Temperate rural landscapes have undergone profound changes since the post-war period due to the combined effects of climate and land-use changes. To better quantify the underlying socio-ecological dynamics, there is a need for integrative metrics that capture the complexity of the relationships between agricultural practices, landscape heterogeneity and biodiversity. The acoustic component of biodiversity has seen significant conceptual and methodological advances with the emergence, over the past decades of landscape ecoacoustics and the use of acoustic diversity metrics that allow for the simultaneous quantification of sounds of biological origin (biophony) and anthropogenic origin (anthropophony). In the PARMENIDE project, we tested the hypothesis that the acoustic diversity of rural landscapes would be correlated to the compositional and configurational heterogeneity of landscape mosaics and enhanced by production systems tending towards the extensification of management practices (notably organic farming). To test this hypothesis, we gathered a large-scale sample of long-term study sites in France drawn from the networks of INRAE sites (Sebiopag, UREP, UE St Laurent de la Prée), CNRS (Zones Ateliers Armorique, Arc Jurassien and Pyrénées-Garonne

) and Regional Natural Parks (Baronnies Provençales, Pyrénées Ariégeoises). By combining approaches from ecoacoustics and landscape ecology, we tested the effect of the proportion of different types of land use (organic or conventional, perennial or non-perennial) on indices of acoustic diversity (derived from passive acoustic recorders), as well as the effect of the degree of naturalness of the surrounding landscape at multiple spatial scales extending up to 1 km around the recorders.

At the national scale, our results show that landscape heterogeneity and the shift toward large-scale extensification of farming practices are key factors in acoustic diversity. In particular, the amount of permanent grassland, the extent of organic farming in the landscape, and the degree of naturalness promote biophony, whereas techno-anthropophony dominates in the most fragmented rural landscapes. At the regional scale, we observe that the effects of organic farming extent and landscape heterogeneity vary depending on the local composition of bird communities—as measured by the acoustic complexity of bird choruses. These results open new perspectives for the study of the acoustic diversity of mosaic farmland landscapes, within which the multiplicity of sound sources makes their analysis both complex and integrative of socio-ecological dynamics. The perspectives of the PARMENIDE project are currently being explored within the framework of its follow-up Biosefair project, FARMSOUND, in which we are expanding the response metrics to include those derived from bird acoustic communities identified via deep learning (BirdNET) and the geomatics variables to include those describing historical landscapes before and after post-war agricultural land consolidation. These two approaches also make it possible to significantly expand the interdisciplinary scope of the research undertaken within PARMENIDE by emphasizing the integration of concepts and methods from geomatics and artificial intelligence with those already employed from landscape ecology, ecoacoustics, and agroecology.

Detailed results

The acoustic data were collected from 10 regional clusters of sites spread across 7 French administrative regions (Figure 1). These acoustic data were collected at each site over several consecutive days in the spring (during the main bird vocalization period) using passive recorders between 2020 and 2025.

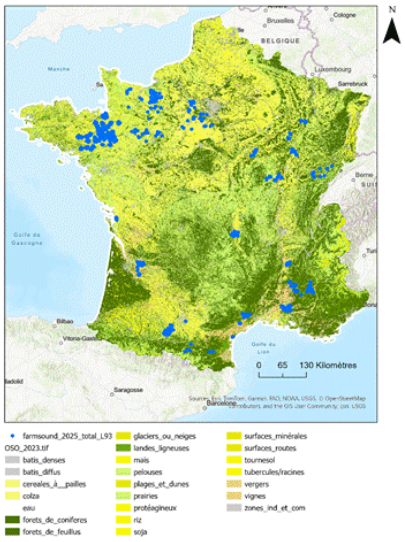


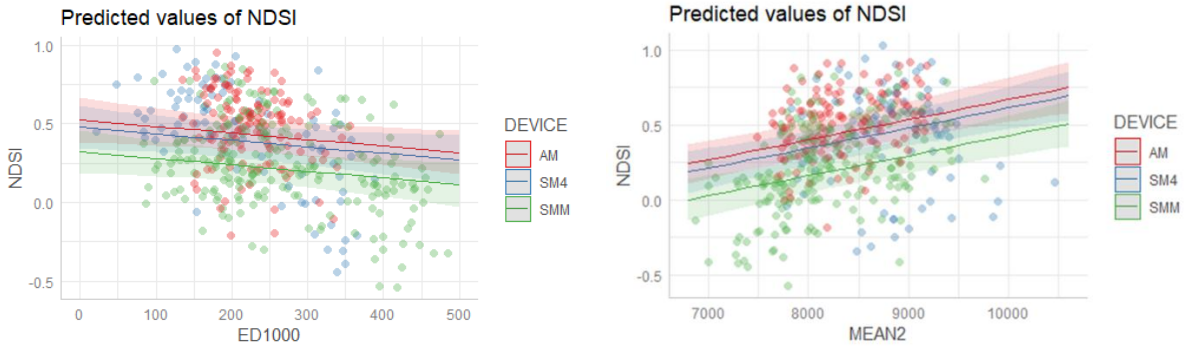
Figure 1. Location of the 780 initial recording sites in France.

In total, four acoustic indices (ACI, BI, NDSI, NP)—averaged over the entire recording period and over a 24-hour period—were calculated for each site after dividing each original audio file

into standard one-minute intervals. We also calculated a set of landscape metrics derived from several complementary geomatics sources (OSO, CartNat, CartoBio) at four increasing buffer distances (100, 250, 500, and 1000 m) around the recorders.

Effect of fragmentation sensu stricto on the biophony/anthropophony ratio

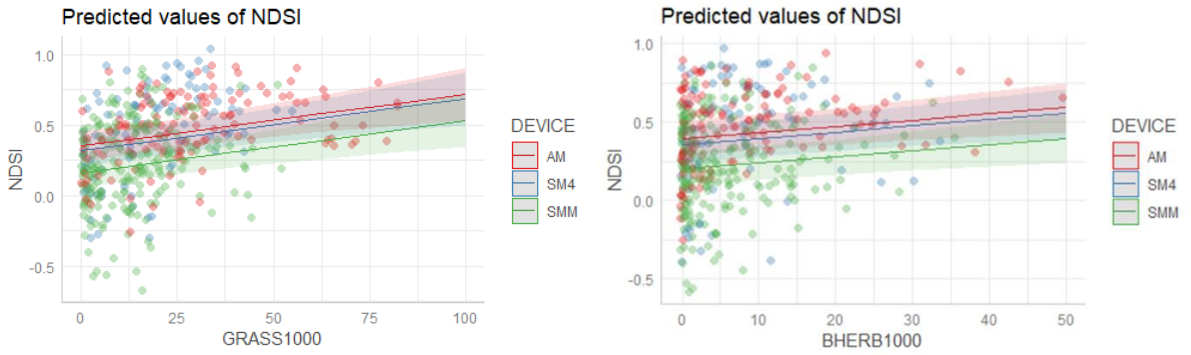
Across the entire dataset analyzed to date (N = 428 soundscapes), we identified a significant effect of fragmentation per se (sensu Fahrig et al. 2026) on the biophony/anthropophony ratio measured by the NDSI, irrespective of the dominant habitat types within the landscape mosaic. This result confirms the hypothesis that the level of biophony is inversely correlated (i) with techno-anthropophony and (ii) with soundscape fragmentation (measured by the density of ecotones within a 1 km radius around the sensors). We also found a significantly positive relationship between the NDSI and the average value of layer 2 of the naturalness map for France published by the IUCN, which measures the spontaneity of natural processes in inverse relation to anthropization as measured by the density of built-up areas and the road network (Guetté et al. 2021).



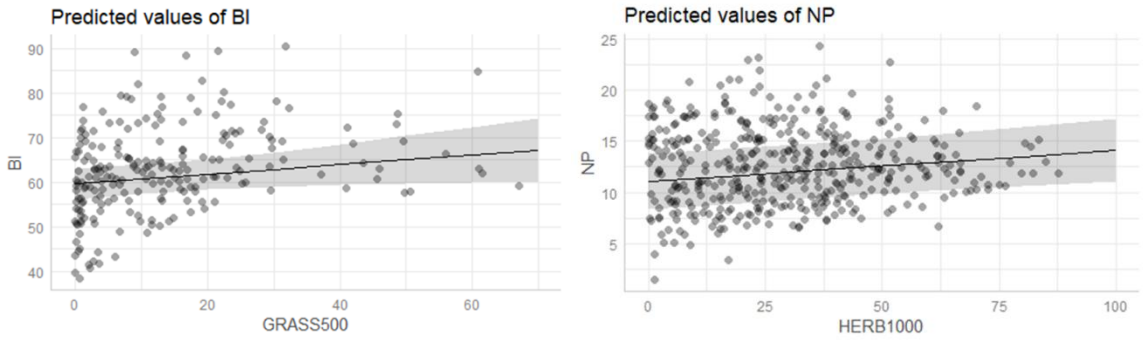
Figures 2a and b. Effects of fragmentation per se (ecotone density) and the naturalness of the surrounding landscape (inverse of building and road density, layer2 CartNat) within a 1-km radius around the sensors on the relative proportion of biophony (positive values) and techno-anthrophony (negative values).

Effect of the amount of permanent grasslands in the landscape on biophony

The relative proportion of biophony to techno-anthrophony (NDSI) in the recordings increases significantly with the amount of semi-natural (permanent and hay)grasslands within a 1 km radius around the recorders (Figure 3a). The proportion of permanent and hay grassland plots managed under organic farming within a 1 km radius also has a significant positive effect on the NDSI (Figure 3b). The positive effect of the amount of permanent semi-natural grasslands on biophony is also detectable through two other acoustic indices measuring biophony levels in the recordings: the number of frequency peaks (NP) and the bioacoustic index (BI). These two indices also show an increase with the amount of permanent grasslands within 500 m (BI) and of total grasslands within 1 km (NP) around the recorders (Figures 4a and b). Note that this effect is detectable for the bioacoustic index only in recordings from Song Meter Minis (N = 215).



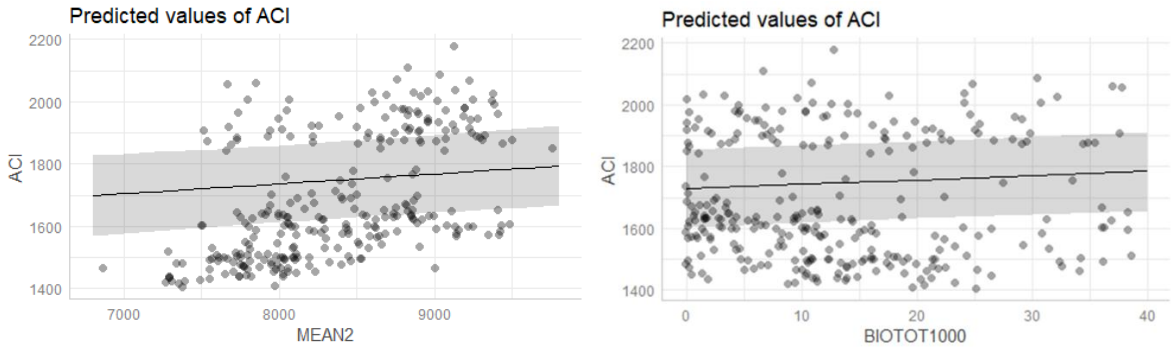
Figures 3a and b. Effects of the area of permanent grassland and total grassland managed under organic farming within a 1-km radius of the recorders on the NDSI.



Figures 4a and b. Effects of the amount of permanent grassland within a 500-meter radius and of total grassland within a 1-kilometer radius around the recorders on biophony levels (BI: bioacoustic index, NP: number of frequency peaks).

The effect of naturalness and organic farming on acoustic complexity

Acoustic complexity, as measured by the ACI index, is also enhanced by the naturalness of the processes and the extent of organic farming in the surrounding landscape within a 1 km radius buffer. However, whilst this effect is significant overall, it varies in magnitude depending on regional clusters and the local composition of songbird choruses, and must therefore be analysed at a regional scale to better reflect the local dynamics of different agricultural practices on biophony (Figures 5a and b).



Figures 5a and b. Effects of landscape naturalness (layer2) and the total amount of organic farming within a 1 km radius of the recorders on acoustic complexity (ACI).

Conclusion

Our results confirm the hypothesis that the level of landscape naturalness promotes acoustic diversity. In particular, less fragmented farmland landscapes with a high proportion of permanent grasslands, as well as landscapes characterised by more extensive management practices (notably organic farming), clearly foster biophony.

Scientific perspectives

Firstly, the landscape-level effects observed on acoustic diversity – and in particular the strong positive effect of permanent semi-natural grasslands – raise questions about the history of the landscape and the impact of its long-term stability: what effect does the historical extent of permanent grassland within the landscape have on current acoustic diversity? Are the landscapes that have undergone the deepest changes (linked to either agro-pastoral decline or urbanisation) those that exhibit the lowest acoustic diversity today? Or do these changes result in a time lag in the response of acoustic biodiversity to these historical landscape changes?

Secondly, and beyond acoustic diversity, we aim at characterising acoustic bird communities using sound recordings, by optimising the use and expert validation of detections via deep learning algorithms for species vocalisations. Also, we ask whether biotic interactions can be measured through sound, such as the coexistence of predatory birdsand their prey (insectivorous birds of high conservation concern and prey orthoptera such as the field cricket *Gryllus campestris*, for example)? Can we thus standardize the characterisation of bird acoustic communities, and how should we define this new concept of community, which differs significantly from that used for decades in community ecology and biodiversity conservation?

Finally, can we infer, from the composition of bird communities identified and validated through the combined use of AI and human ornithological expertise, community metrics that would reflect the cultural significance of songbird choruses and associated soundscapes in farmland soundscapes in terms of human perception and well-being, or even the mental health of a local inhabitants?

These questions have notably led to the submission of the FARMSOUND project, which currently constitutes the natural extension of PARMENIDE, as well as to the participation of part of the consortium in the PEPR Biodicapt 2026–2029 project.