Building future monitoring together — towards improved acoustic monitoring of European birds and bats

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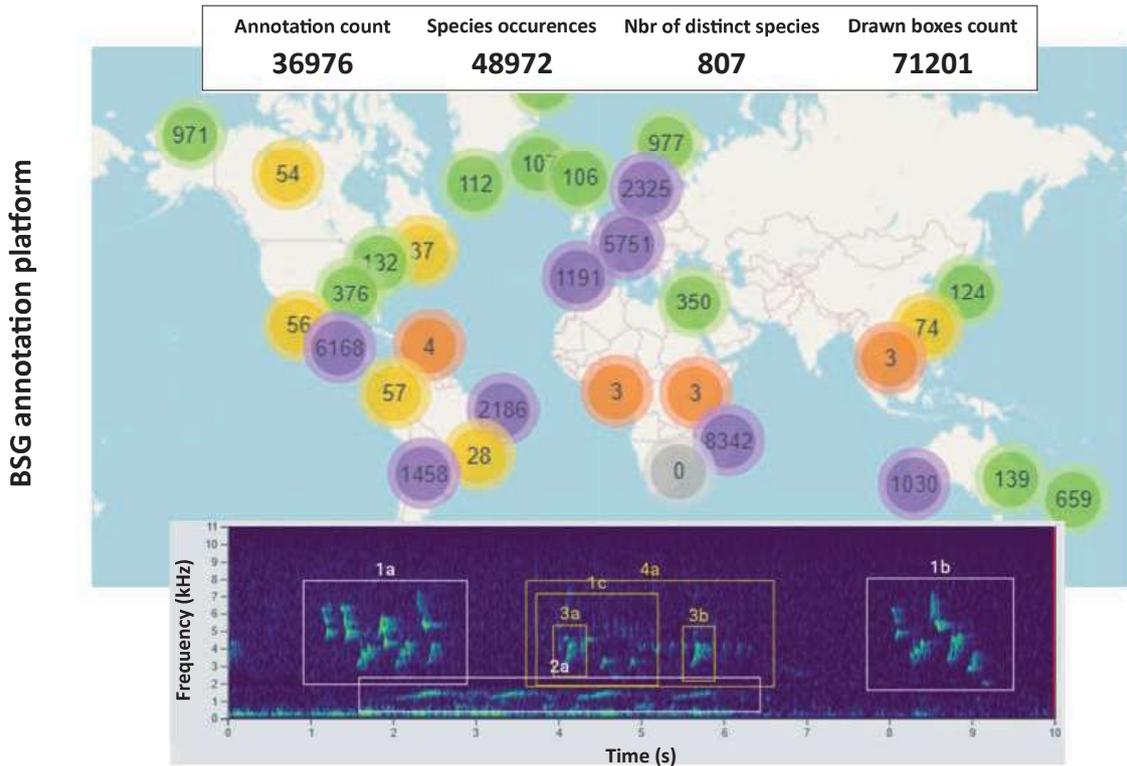Corresponding author Otso Ovaskainen: otso.t.ovaskainen@jyu.fi

Abstract. Acoustic biodiversity monitoring is increasingly popular, but its wide and effective implementation across Europe remains challenging. To clear current obstacles, we propose new forms of collaboration among European bird and bat researchers. First, we suggest building improved bird and bat classifiers through a portal that facilitates joint annotation efforts and end-to-end workflows for model building. Second, we suggest using new technology for streamlining the prevailing "collect first and analyze later" -paradigm to achieve truly real-time audio monitoring. Third, we suggest using new smartphone apps and digital twinning to enable also non-expert citizens to contribute to real-time monitoring.

We present our suggestion for increased collaboration within the European (and worldwide) acoustic community in terms of three challenges and three potential solutions. These address (1) the need for more reliable classifiers for acoustic monitoring; (2) the need for more streamlined workflows for rapidly converting acoustic data to research and monitoring outputs; and (3) untapping the full potential of citizen science in (real-time) biodiversity monitoring. We believe that all these challenges are solvable but reaching them requires coordinated joint efforts. We hope you are interested in joining these efforts in one way or another — if so, we warmly invite you to contact any of the authors (e.g., by emailing to the corresponding author) to express your interest.

Challenge 1: We need more reliable classifiers for acoustic monitoring

Passive acoustic monitoring (PAM) provides unprecedented potential for research and monitoring of birds, bats and other vocal animals. PAM can provide massive data, such as >100 years of audio generated by the global biodiversity sampling campaign LIFEPLAN (Hardwick et al. 2024; Somervuo et al. 2025). The massive size of the data is a blessing and a curse. It is a blessing, because the information content of the data increases with its size. It is a curse, because the logistic challenges related to storing, managing, and analyzing audio also increase with the size of the data. The primary challenge in processing PAM audio is how to reliably classify the species that vocalize in the audio. Manual analysis requires expensive expert time and results in loss of information if (and when) one needs to resort to subsampling. For large-scale studies, the use of automated classifiers is in practice the only feasible option for processing the audio. Generic and openly accessible classifiers such as BirdNet (Kahl et al. 2021) are widely used, but their performance varies greatly from case to case. Specific performance depends on how well the data used to train the classifier corresponds to the audio to be analyzed in terms of the species to be classified, the type of background noise, as well as the recording devices used. To resolve this, finetuned

BSG annotation platform

Annotation count	Species occurences	Nbr of distinct species	Drawn boxes count
36976	**48972**	**807**	**71201**

Example soundscape annotation made by a citizen scientist at Bird Sound Global (BSG): Pied Flycatcher (1), Arctic Loon (2), Chaffinch (3) and Willow Warbler (4).

BSG model builder workflow

1. Define the target species list and study area

2. Select the training data annotations

3. Train, calibrate and validate the classifier

4. Deploy the classifier to desktop

The performance of BSG model builder approach exemplified by the baseline Bird-NET model finetuned for Central Europe birds.
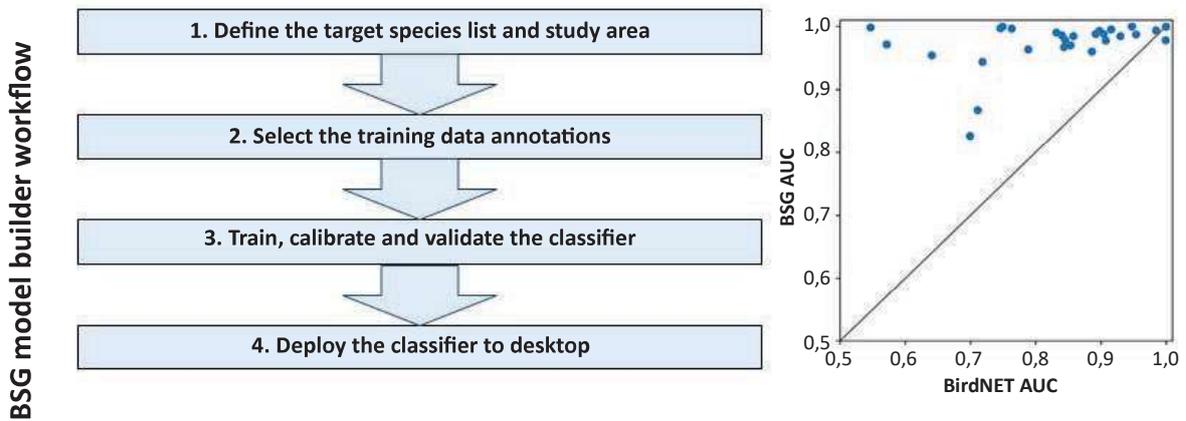
Figure 1. The BSG annotation platform and BSG model builder. The BSG annotation platform enables expert users to annotate 10-second soundscapes by listing the species that vocalize in the soundscape and drawing bounding boxes around the vocalizations. These annotations are fed into the BSG model builder, which finetunes the baseline BirdNET model to the desired species community. As exemplified in the figure with a model finetuned for Central European birds, the approach leads to improved classification performance.

models can be constructed to optimize the performance for each specific case study (Lauha et al. 2022). However, developing finetuned models has remained tedious, as it requires substantial annotation effort to generate the training data, as well as substantial expertise in machine learning to successfully train an optimally performing classifier.

Solution 1: Bird and Bat Sound Global — model builder

We suggest developing improved acoustic classifiers through community efforts. To facilitate such a process, we have developed the Bird and Bat Sound Global (BSG; https://bsg.laji.fi/) annotation platform, where anyone who has the ex-

pertise to identify bird or bat species from their vocalizations can annotate sound clips originating from various audio sources, such as those resulting from the LIFEPLAN sampling campaign. The annotators can generate so-called strong labels by not only specifying the species vocalizing in the audio clips but also drawing bounding boxes around the vocalizations in time-frequency space (Fig. 1). Such strong labels are essentially useful for finetuning classifiers (Hershey et al. 2021). Currently, the bird section of BSG has resulted in annotations of 37,000 ten-second soundscape clips, involving 71,000 bounding boxes that represent 800 bird species. The bat section of BSG has resulted in annotations of 4,000 ultrasound clips, involving 5,600 bounding boxes that represent 30 bat species. The bird annotations have global coverage, representing especially Europe and Madagascar, whereas the bat annotations are currently restricted to Europe only. The BSG platform follows an open science model, with all annotations being published through the Xeno-canto database (Xeno-canto Foundation, 2005). Most importantly, BSG is not only an annotation platform, but contains a systematized model builder workflow for finetuning classifiers (Lauha et al. 2025). We have developed and tested the BSG model builder workflow through six bird classifiers (targeted to Finland, Central Europe, the Iberian Peninsula, Madagascar, Mexico and the Dry Chaco of Argentina; Lauha et al. 2025) and a European bat classifier (Meramo et al. 2025), in each case demonstrating improved performance compared to alternative classifiers. By enabling each user to annotate soundscapes for their own research needs, while simultaneously contributing to a shared global database of reference annotations, BSG fosters a global community effort to advance automated bird sound classification. ***We invite researchers to take full advantage of these new resources, to thereby jointly develop more reliable classifiers for birds and bats within and outside Europe.***

Challenge 2: The workflow from collecting acoustic data to research and monitoring outputs needs streamlining

The lack of sufficiently reliable classifiers is not the only bottleneck with audio monitoring. Another, yet related, bottleneck is the resource intensity of the entire process from field work to the delivery of the actual monitoring outputs. For example,

collecting the >100 years of global audio data in the LIFEPLAN project required (1) hundreds of researchers to visit the sampling sites on a weekly basis to change the memory cards and batteries of the AudioMoth devices (Hill et al. 2018); (2) the upload of the data to a common server through internet connection or shipping hard drives; (3) excessive amount of storage capacity to host ca. 1000 GB of audio; (4) several months of computational time in a high-performance environment to classify the audio in terms of soundscape indices and species contents; (5) manual validation of subsets of classifications to assess their reliability. Taking all these steps took several years before we could eventually statistically analyze the data to address the research questions that motivated collecting the data (e.g., Somervuo et al. 2025). Clearly, the long delay from data collection to research outputs is not rewarding, and the resource intensity of the process, in terms of researcher time and access to storage and computational facilities, limits the broad applicability of large-scale passive audio monitoring.

Solution 2: Real-time audio monitoring with BirdPipe

The above-mentioned challenges can be solved with recent technological developments. For example, the open-source real-time audio monitoring device BirdPipe that we have developed classifies audio through edge computing and transmits both the classifications and the raw audio wirelessly to the researcher (Fig. 2). As a result, the researcher will receive a species detection essentially in real time, e.g. within a minute since the bird or bat vocalization actually took place in the field. In some environments, such as urban environments, recording sound may be problematic from the legislative point of view because of risk of eavesdropping. In such a case, BirdPipe can be used in pure edge computing mode, in which case the audio is recorded and classified directly in RAM-memory without storing audio information into any external memory such as disk or SD card from where it could be recovered. BirdPipe is very easy to use: all one has to do is to set up the device in the desired location and turn it on. BirdPipe will then figure out where and when it is and integrate these central metadata into the classifications. The R-package BirdPipe enables users to monitor the data flow in real time, thus facilitating quality control and

Real-time bird monitoring with BirdPipe

- **Mobile or satellite connection**
- **Customized GNSS (including GPS) for position and time**
- **Raspberry Pi for edge computing**
- **Battery bank and/or solar panel**
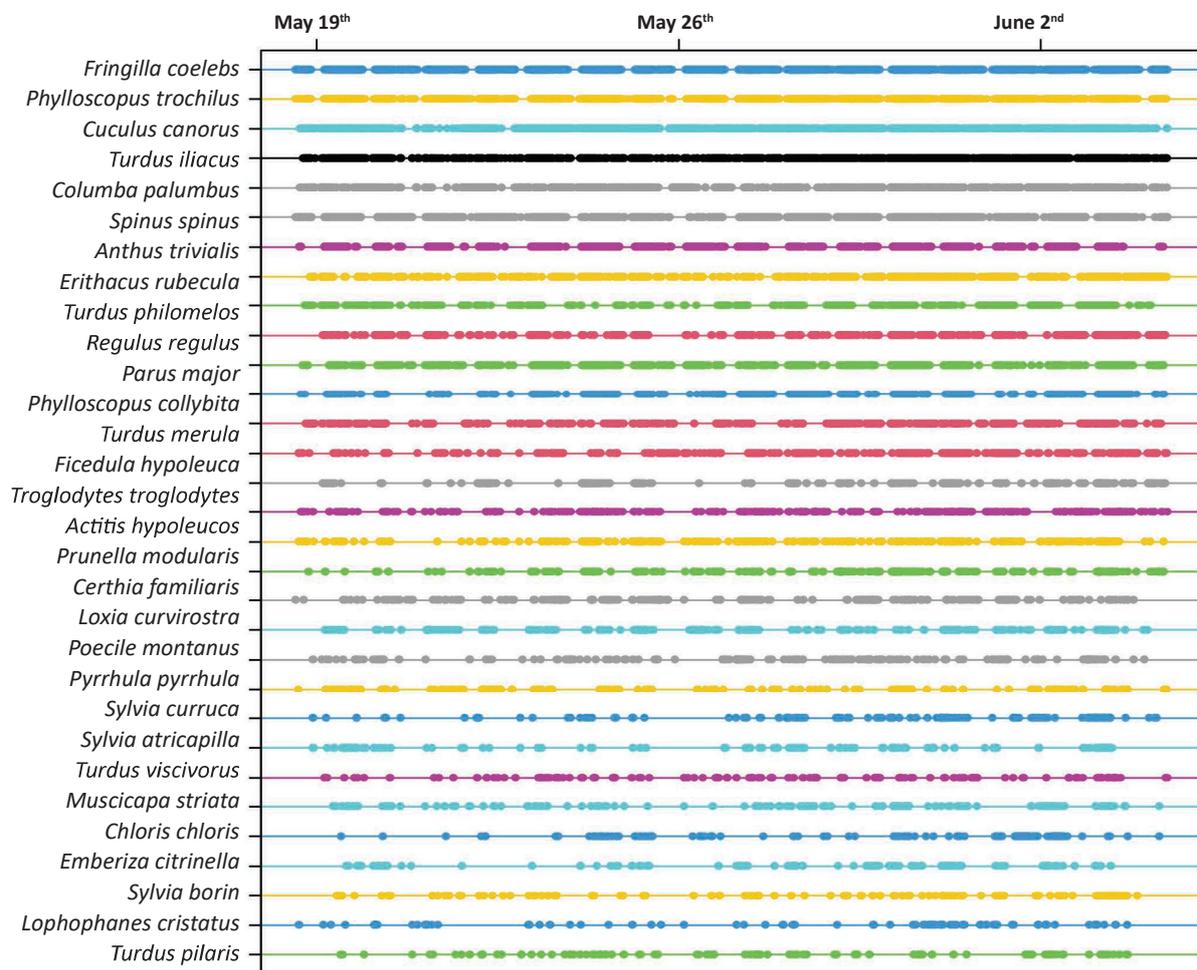- **Constructed from standard waste pipe and 3D printed cover**

Figure 2. The open-source real-time monitoring device BirdPipe. BirdPipe is easy to use, as the user just needs to deploy it to the desired location and turn it on. BirdPipe will then find out where and when it is and start classifying birds from the soundscape using edge computing. The classifications are transmitted wirelessly, enabling the user to monitor the data flow in real time, as illustrated here for detections that accumulated over a 17-day pilot study that we conducted in 2025. The data shown are restricted to the most common 30 species.

fast response to potential problems (Fig. 2). As the BirdPipe device performs classification with

machine learning, it surely makes mistakes — but less so in the future as the classifiers will improve

(see Solution 1). Importantly, also the optional use of manual validation has been streamlined. As default option, the R-package BirdPipe picks only the vocalizations of highest confidence for manual validation, resulting in substantial saving in expert time. We tested BirdPipe by rotating 10 devices across 116 locations that varied in terms of forest management, using a 24-hour recording cycle in each location. Species classification by edge computing revealed a total of 23,478 detections with at least 0.3 classification probability. Utilizing BirdPipe, it took only one working day of expert time to manually validate the detection of each species at each location. Thus, the approach yielded unvalidated classifications in real-time, and a manually validated species times locations data matrix one day after the study was finished. ***We invite researchers to take full advantage of this newly emerging technology, moving from the still prevailing "collect first and analyze later" -paradigm towards audio monitoring in real time.***

Challenge 3: The full potential of citizen science in real-time biodiversity monitoring remains partially untapped

The use of citizen science in biodiversity research and especially in bird research has long traditions. This is because people are generally interested in birds, and many citizens are very skillful identifying birds in the field. A large number of initiatives have focused on converting these citizen science activities into data that are valuable for research and monitoring. Thanks to these efforts, bird data has become very widely available. For one example, the Global Biodiversity Information Facility (GBIF) database is actually dominated by bird observations (Hughes et al. 2021), and these data are widely used for research purposes (Heberling et al. 2021). For another example, the eBird platform has recruited some 1.1 million birdwatchers, who collect data using procedures that involve systematic quality control and quantification of user skills (Sullivan et al. 2009). The eBird data enables many kinds of research and monitoring outputs, such as status and trends -products provided by the Cornell Lab of Ornithology data scientists (Fink et al. 2025). In spite of all this progress, there are two perspectives from which the full potential of citizen science in bird research and monitoring still remains untapped. First, most data are currently contributed by sea-

soned birdwatchers, even if less skilled citizens may also spend much effort in observing birds. While many smartphone apps exist for automatically classifying birds from their audio, these apps have not yet been fully integrated into research and monitoring. For example, Merlin Bird ID leverages eBird data to develop the classification algorithms and create lists of likely birds for given locations, but the information only flows one way from monitoring outputs to citizens using the ID app. Thus, a key question concerns how citizens who themselves are unable to reliably identify birds may best partake in distributed efforts of audio monitoring. Second, there is typically a long delay from citizen science observations to research and monitoring outputs. For example, the status and trends -products based on eBird data are provided periodically by utilizing data that has accumulated over recent years (Fink et al. 2025). We argue that it is possible to streamline the full workflow from citizen science data collection to research and monitoring outputs into real-time, providing great added value not only from the point of view of research and monitoring, but also for the citizen who takes part in data collection.

Solution 3: MK smartphone app and digital twinning enables ordinary citizens to contribute to real-time monitoring

To enable ordinary citizens to take part in real-time bird monitoring, we developed a research-oriented smartphone app (Nokelainen et al. 2024) and integrated it into a digital twinning environment (Ovaskainen et al. 2026) (Fig. 3). We call the app here by the acronym MK, which refers to the app's Finnish name 'Muuttolintujen Kevät', meaning Spring of Migratory Birds. This name of the app was inherited from a nature themed program run by the Finnish national broadcasting company Yle, a key collaborator in this project. In spite of its name, the MK app is targeted not just at migratory birds but at all the 263 bird species regularly occurring in Finland, and not just for spring but for year-around use. The MK app was launched in 2023, and rapidly gained popularity among Finns, with 300,000 citizens (5% of the national population) having submitted >43 million bird detections. A key feature of the MK app is that all detections are based on a machine learning based classifier rather than users identifying the birds themselves. This en-

MK smartphone app

Real-time monitoring by digital twinning
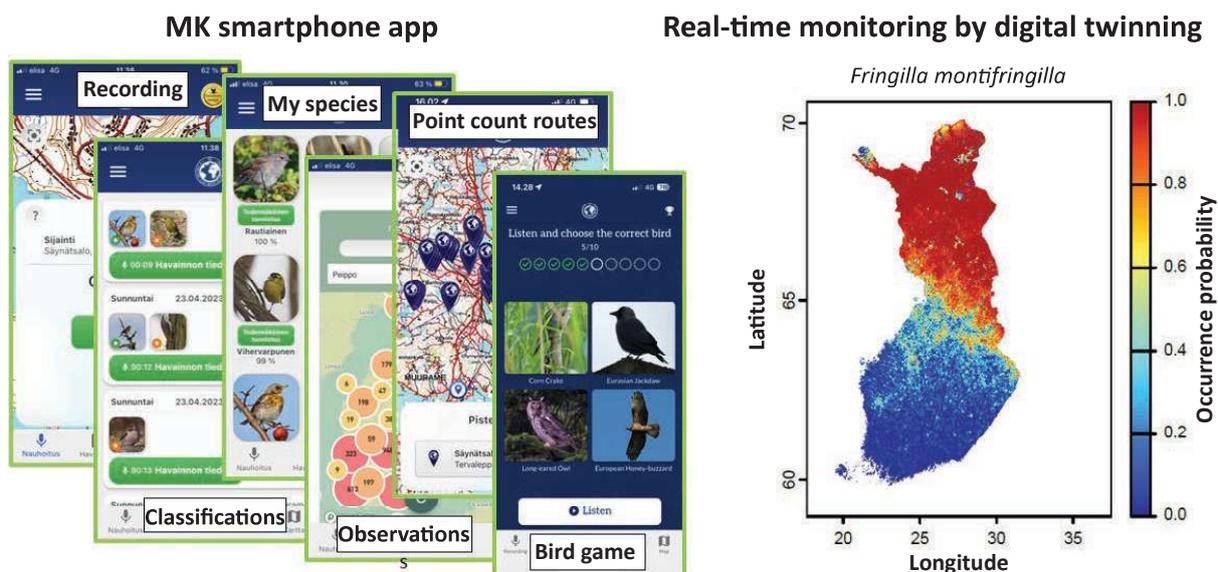

Fringilla montifringilla

Figure 3. Real-time bird monitoring with smartphone-based citizen science and digital twinning. The MK smartphone app implements three recording modes: direct recording, interval recording, and systematic point count recording. In addition to providing engaging feedback to the user, the app submits the audio to a computational backend, which combines the data with long-term bird census data to provide daily updating species distribution maps at 1ha resolution, exemplified here by the Brambling (*Fringilla montifringilla*).

ables any citizen to provide equally valid data, whether they are able to classify the birds themselves or not. To counteract mistakes in machine learning based classifications, the backend of the database stores all the audio, enabling quality control by manual validation, and reclassifying the data with continuously improving classifiers (see Solution 1). While most detections are opportunistic (the citizens make direct recordings triggered by an interesting bird vocalization), the MK app also includes two other recording modes that are targeted to producing higher quality data that avoid some of the detection biases of opportunistic observations. First, the MK app facilitates interval recordings, enabling users to detect birds that, for example, vocalize overnight in their yard. Second, in collaboration with Finnish national parks and municipalities, we have implemented a permanent citizen science point counting network, which currently includes 580 pre-selected locations where citizens can conduct a systematic five-minute recording. To streamline the workflow from citizen scientists making observations to monitoring outputs, we have implemented a digital twinning approach, which integrates the newly accumulating MK app detections with long-term breeding bird survey data on birds (line transects), resulting in daily updating species distribution maps (Ovaskainen et al. 2026). We have successfully validated these predictions with independent data obtained by bird experts conducting manual point counts in the field (Ovaskainen et al. 2026).

If there is sufficient interest from European bird researchers to utilize this technology in citizen science projects, we would be happy to upscale the MK app and the digital twinning approach to the European scale, and to effectively integrate these data with other data sources such as EuroBirdPortal.

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