



## SOFTWARE TOOL ARTICLE

**REVISED** ecoSound-web: an open-source, online platform for ecoacoustics [version 3; peer review: 3 approved]Kevin F.A. Darras <sup>1-4\*</sup>, Noemí Pérez<sup>3\*</sup>, Liu Dilong <sup>5</sup>, Tara Hanf-Dressler<sup>3</sup>, Matthias Markolf <sup>6,7</sup>, Thomas C Wanger<sup>2,8</sup>, Anna F. Cord<sup>9</sup><sup>1</sup>Computational Landscape Ecology, TU Dresden, Dresden, Sachsen, 01737, Germany<sup>2</sup>Sustainable Agricultural Systems & Engineering Laboratory, School of Engineering, Westlake University, Hangzhou, 310030, China<sup>3</sup>Agroecology, University of Göttingen, Göttingen, Niedersachsen, 37077, Germany<sup>4</sup>EFNO, INRAE, Nogent-sur-Vernisson, 46290, France<sup>5</sup>Quality Technology Centre, Nanjing Julong Steel Pipe Co. Ltd, Nanjing, 211800, China<sup>6</sup>IUCN SSC Center for Species Survival Cologne Zoo, Cologne Zoo, Cologne, North Rhine-Westphalia, 50735, Germany<sup>7</sup>Behavioral Ecology & Sociobiology Unit, German Primate Centre, Göttingen, Niedersachsen, 37077, Germany<sup>8</sup>Key Laboratory of Coastal Environment and Resources of Zhejiang Province, Westlake University, Hangzhou, China<sup>9</sup>Agro-Ecological Modeling Group, Institute of Crop Sciences and Resource Conservation, University of Bonn, 53113, Bonn, Germany

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**V3** First published: 12 Oct 2020, 9:1224  
<https://doi.org/10.12688/f1000research.26369.1>

Second version: 01 Mar 2023, 9:1224  
<https://doi.org/10.12688/f1000research.26369.2>

Latest published: 08 Nov 2024, 9:1224  
<https://doi.org/10.12688/f1000research.26369.3>

**Abstract**

Passive acoustic monitoring of soundscapes and biodiversity produces vast amounts of audio recordings, but the management and analyses of these raw data present technical challenges. A multitude of software solutions exist, but none can fulfil all purposes required for the management, processing, navigation, and analysis of acoustic data. The field of ecoacoustics needs a software tool that is free, evolving, and accessible. We take a step in that direction and present ecoSound-web: an open-source, online platform for ecoacoustics designed and built by ecologists and software engineers. ecoSound-web can be used for storing, re-sampling, organising, analysing, and sharing soundscape recording or metadata projects. Specifically, it allows manual annotation of soniferous animals and soundscape components, automatic annotation with deep-learning models for all birds and for UK bat species, peer-reviewing annotations, analysing audio in time and frequency dimensions, computing alpha acoustic indices, and providing reference sound libraries for different taxa. We present ecoSound-web's structure and features, and describe its operation for typical use cases such as sampling bird and bat communities, using a primate call library, and the analysis of

**Open Peer Review****Approval Status**

	1	2	3
<b>version 3</b> (revision) 08 Nov 2024			
<b>version 2</b> (revision) 01 Mar 2023			 view
<b>version 1</b> 12 Oct 2020	 view	 view	

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- Any reports and responses or comments on the

soundscape components and acoustic indices. ecoSound-web is available from: <https://github.com/ecomontec/ecoSound-web>

article can be found at the end of the article.

### Keywords

Soundscape, sound analysis, ecoacoustics, passive acoustic monitoring, automated sound recording, autonomous recording units, spectrogram, audio annotation



This article is included in the **Ecology and Global Change** gateway.

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**Author roles:** **Darras KFA:** Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Pérez N:** Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Dilong L:** Investigation, Methodology, Software; **Hanf-Dressler T:** Investigation, Methodology, Validation, Writing – Review & Editing; **Markolf M:** Investigation, Writing – Original Draft Preparation, Writing – Review & Editing; **Wanger TC:** Funding Acquisition, Supervision, Writing – Original Draft Preparation, Writing – Review & Editing; **Cord AF:** Funding Acquisition, Supervision, Writing – Review & Editing

**Competing interests:** No competing interests were disclosed.

**Grant information:** This work was funded by the Deutsche Forschungsgemeinschaft, grants number SFB990/1 and SFB990/2 and project number 460036893, as well as PostDoc research grants from Westlake University  
*The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.*

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**How to cite this article:** Darras KFA, Pérez N, Dilong L *et al.* **ecoSound-web: an open-source, online platform for ecoacoustics [version 3; peer review: 3 approved]** F1000Research 2024, 9:1224 <https://doi.org/10.12688/f1000research.26369.3>

**First published:** 12 Oct 2020, 9:1224 <https://doi.org/10.12688/f1000research.26369.1>

**REVISED Amendments from Version 2**

ecoSound-web includes recording re-sampling, automated annotation using BirdNET and batdetect2 in recording batches, and metadata management.

The abstract, main text, and figures were updated to reflect the latest developments.

Table 1 is outdated and was removed, one co-author is no longer involved and was removed.

We added a new co-author involved in the software tool development.

**Any further responses from the reviewers can be found at the end of the article**

## Introduction

Passive acoustic monitoring, i.e. PAM is a powerful means for monitoring biodiversity and the environment in the field of ecoacoustics<sup>1</sup>. The resulting soundscape recordings - comprising all sounds recorded in a sea- or landscape<sup>2</sup> - present new opportunities for ecologists. However, they yield huge amounts of data that are challenging to manage<sup>3</sup> and to analyse for extracting their ecological information – such as biodiversity, human activities, or geophysical events. Overall, soundscape ecologists require a dedicated tool that allows for such a comprehensive workflow<sup>4</sup>, and which aligns with FAIR research principles<sup>5</sup>.

Tools for managing ecoacoustic data still undergo rapid development. Annotations identifying sound sources are increasingly generated with artificial intelligence (i.e., AI) methods based on machine learning<sup>6</sup> to forego laborious but still common manual annotation by humans. However, even leading AI networks such as BirdNET<sup>7</sup> require expert validation to yield usable results<sup>8</sup>, underlining the importance of vetted reference recordings found in sound libraries to ascertain the identification of sound sources<sup>9,10</sup>. Alternatively or in addition to taxonomic annotation of recordings, soundscapes can be characterised with automatically-computed acoustic indices that can measure spectral and temporal variation, entropy, or complexity, and be linked to biodiversity metrics<sup>11,12</sup>. General acoustic feature sets can also be used to detect anomalous sound events in an unsupervised manner<sup>13</sup>. In marine ecoacoustics, annotating and quantifying the temporal proportion of soundscape components (i.e., sounds of biological, geophysical, and human origin) is well-established<sup>14</sup>, and the sound pressure levels from calibrated equipment are a common metric for studying noise impacts on biological activity<sup>15</sup>. Finally, in bioacoustic or ethological studies, but also for the identification of bats<sup>16</sup> and soundscape characterisation<sup>17</sup>, the target sounds need to be analysed further by measuring their properties in the frequency-time-amplitude space<sup>18</sup>.

At the time of writing and to our knowledge, few or no open-source, online software exists that integrates all these different data processing stages into a consistent, integrated workflow for ecoacoustic data across realms, taxa and regions. Reference sound or call libraries are still scarce for particular species

groups<sup>3,19</sup>, even though recent advances were made for Orthopterans on Xeno-Canto<sup>9</sup> (additionally to well-studied birds), and bats on ChiroVox<sup>10</sup>. Software that handles audio data needs to be built sustainably to benefit a large user base in the research community and to stimulate research<sup>20</sup>. While the majority of tools are free, few are online-based, many are specialised on specific taxa, realms or regions, only some are open-source, and most cover only parts of the workflow described below. It is essential to have free tools that all researchers and practitioners can use, irrespective of their budget constraints. Also, only open-source projects, in conjunction with long-term vision and funding<sup>20</sup>, guarantee that they can be continuously developed to keep up with the pace of technological progress, that they stay accessible over time, and that the actual functions are transparent and replicable. Accessibility, which is essential for international collaboration and verification of ecoacoustic data<sup>21</sup>, also requires online solutions that are mostly independent of operating systems or commercial software. Finally, solutions that integrate multiple steps of the workflow outlined earlier will be inherently less complex for users, more practical, and more replicable than workflows involving separate, specialised tools. In a nutshell, the field of ecoacoustics requires an open-source, online, comprehensive software tool.

Here, we present ecoSound-web: an open-source online platform for ecoacoustics, designed and built by ecologists and software engineers (for the related GitHub project see: <https://github.com/ecomontec/ecoSound-web>). Currently, ecoSound-web can be used to 1) upload, re-sample, and organize soundscape recordings and metadata within collections and visualize them on maps and timelines; 2) to manage different user types and their access privileges to collections within dedicated projects; 3) to play back, navigate, and filter their sound and spectrograms; 4) to create manual annotations and execute AI models on recording batches for automated annotation of sound sources (i.e., BirdNET for birds<sup>7</sup> and batdetect2<sup>22</sup> for UK bats); 5) to peer-review recording annotations; and 6) to measure sounds and compute acoustic indices. ecoSound-web was forked from BioSounds (c.f. article version 1). We detail the structure and functionality of ecoSound-web in the following and announce our development goals.

## Methods

### Implementation

**Coding languages, libraries, and tools.** ecoSound-web is a web-based application written in PHP 7<sup>23</sup>, Python 2.7 and 3.10<sup>24</sup>, Javascript<sup>25</sup>, JQuery 3.4<sup>26</sup>, Twig 2<sup>27</sup>, CSS<sup>28</sup> and HTML 5<sup>29</sup>. It uses Web Audio API<sup>30</sup>, Sox 14.4<sup>31</sup>, Lame<sup>32</sup>, ImageMagick<sup>33</sup> and Scikit-maad 1.3.12<sup>34</sup> software for sound and image processing, getID3 for audio metadata processing<sup>35</sup>, a MySQL<sup>36</sup> database for organising the data (Figure 1), a RabbitMQ<sup>37</sup> queue for file processing, Plupload 1.5 as a visual file upload tool<sup>38</sup>, GADM as administrative regions for the sites<sup>39</sup>, JQuery UI 1.12<sup>40</sup>, JCrop 0.9<sup>41</sup>, Bootstrap 4.3<sup>42</sup>, Leaflet<sup>43</sup>, Timeline.js<sup>44</sup>, Bootstrap-selected<sup>45</sup>, JQuery.cookie<sup>46</sup>, DataTables<sup>47</sup> and the Symfony 4 process component<sup>48</sup> for managing the scripts execution. Further Python libraries used are: Numpy<sup>49</sup>, Pillow<sup>50</sup>, Audiolab 0.8<sup>51</sup>, Matplotlib<sup>52</sup>, SciPy<sup>53</sup>, Scikit-image<sup>54</sup>, TensorFlow<sup>55</sup>, BirdNET-analyzer<sup>7</sup> and

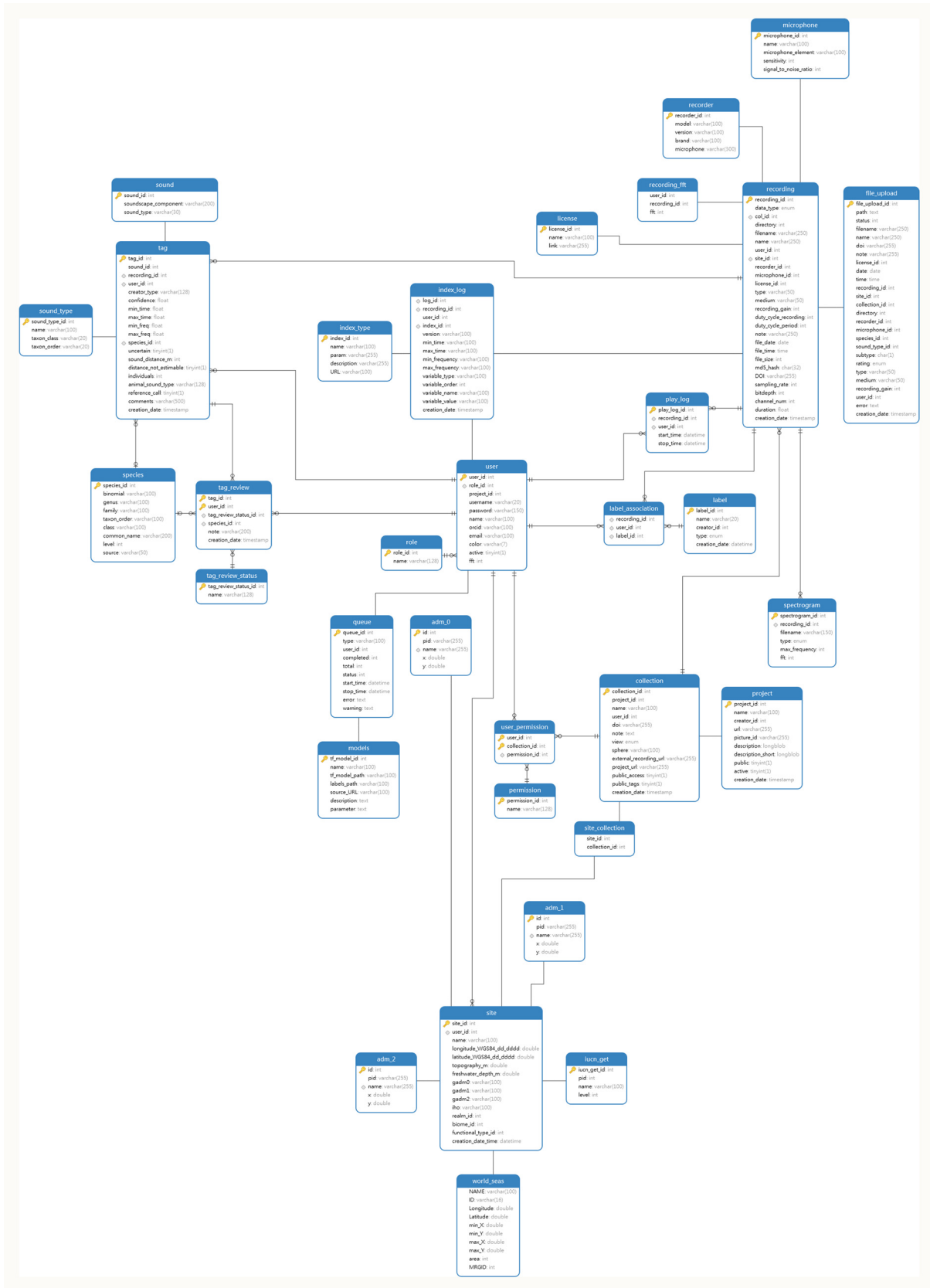


Figure 1. MySQL database structure in ecoSound-web.

batdetect<sup>56</sup>. We containerized the project using Docker<sup>57</sup>, which spares software developers the time for installing libraries, the database, and configuring the server. This setup allows developers to run the project on their machines quickly and free of typical installation issues like library version incompatibilities.

**Audio visualization and playback.** The core sound visualisation and playback tasks are handled by two distinct components. First, spectrogram images are generated by the Python script ‘sound visualization tool’, which was created for the discontinued ‘Pumilio’ project<sup>58</sup>. This script generates spectrograms by computing a Fast Fourier Transform on the waveform of the audio recording, at a user-specified window size (at 128, 256, 512, 1024, 2048, or 4096). Second, sound playback and speed control use Web Audio API, a high-level application programming interface for processing and synthesizing audio in web applications. It is included in modern browsers to take advantage of the browser resources without requiring any extra media player or library in our project.

## Operation

**Ecoacoustic workflow.** In ecoacoustics, a general workflow is currently not comprehensively defined. We therefore combine insights from different literature sources and our own experience to propose a general workflow as follows: 1) Data management: Acoustic data need to be backed up, archived, and organized according to space, time, and other meta-data<sup>58</sup>. 2) Signal processing: Recordings can be amplified, re-sampled, split, filtered, compressed, etc. for facilitating the next workflow steps. 3) Audio navigation: Sound recordings can be visualized with spectrograms (i.e., sonograms) or waveforms, navigated in the temporal and spectral dimensions, and played back. 4) Acoustic analysis: Recordings can be annotated with the sound source identity or comments, spectral, temporal, and amplitude properties of the recordings can be measured or summarised with acoustic indices or other metrics<sup>59</sup>. Note that compared to the second version of the present article, we merged the annotation step into the acoustic analysis step and removed the collaboration step, which is not specific to an ecoacoustic workflow. In the following we introduce ecoSound-web to enable the ecoacoustic community to follow and use most parts of the workflow introduced here.

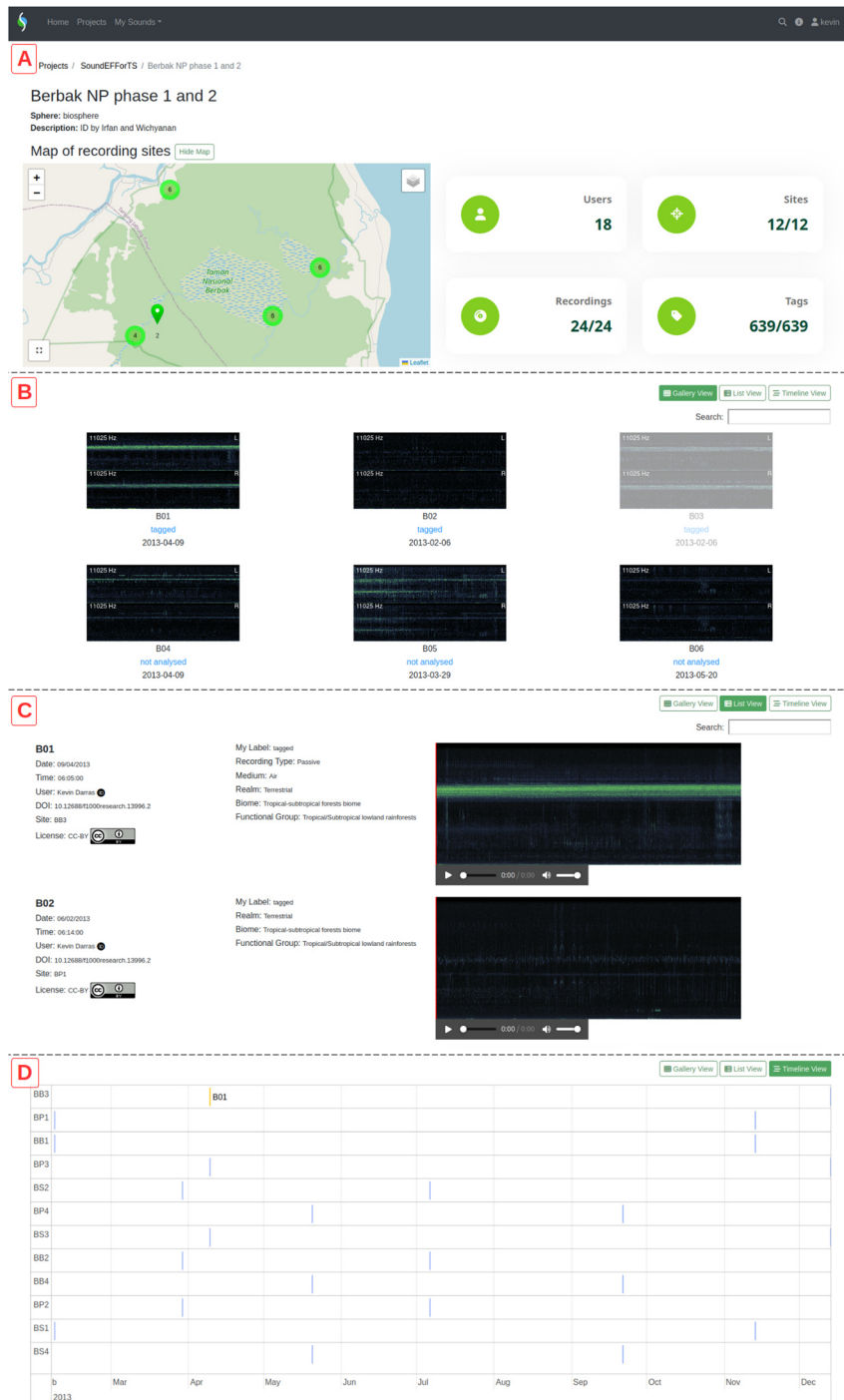
**Installation.** The ecoSound-web code is published in a GitHub repository<sup>60</sup>. It needs to be installed in a web server or locally to run. Instructions and general information regarding the setup for developers and the production server are included in the README file on GitHub. The ecoSound-web installation for local development (in the developer’s machine) is facilitated by a Docker setup. We provide a set of Docker configuration files that can also aid the server installation, but the final setup should be carried out by the server administrator (or devOps engineer) of the institution. For server installations without Docker, a step-by-step installation guide is provided in the repository’s Wiki pages.

**Online access.** We run an online instance of ecoSound-web<sup>61</sup> where the use cases described below can be reproduced. The

website hosts several projects belonging to different research groups. All projects have project managers and most projects hold data from PAM schemes; one project hosts public reference collections (i.e., reference audio libraries) for Chiroptera, Primata, and Anura. Soundscape projects and project managers can be created per request to KD. Users can access ecoSound-web (both the existing instance and future installations) via a desktop browser with an internet connection. ecoSound-web works with Windows, Linux, and MacOS operating systems and the most common internet browsers (Firefox, Chrome, Safari), but recordings above 96 kHz cannot be played back in Firefox due to browser limitations.

**Projects and collections.** ecoSound-web organises audio recordings within collections, which are grouped under projects. All projects can be accessed through the “Projects” menu, which provides a public overview. Projects and collections are managed in the dashboard (previously “administrative interface”). Projects can contain public (i.e., open) and closed collections accessible only to defined users (c.f. “Users” section). Recordings can be uploaded into collections in most common audio formats<sup>31</sup>. Users can choose to downsample audio recordings during the upload stage. PNG image previews of the spectrograms and MP3s (for audible sound) or OGGs (for ultrasound > 44100 Hz) of the audio files are generated after insertion into the database and the progress of batch insertions of files is shown in the queue tab in the dashboard. The original audio files (or resampled files, if applicable) are retained on the server. Audio recordings can have custom names to hide the original information present within file names. Collections’ geographic locations (“sites” hereafter) are shown on Leaflet-based maps with an OpenStreetMap base layer (Figure 2A); the recordings listed in the collection are dynamically filtered and clustered based on the current map extent, and the map can be filtered by ecosystem type (as defined by the IUCN Global Ecosystem Typology<sup>62</sup>). Collections can be displayed as 1) a simple gallery view displaying spectrogram thumbnails (Figure 2B); 2) a list view with larger spectrograms, descriptive data, and a simple audio player, which is particularly suitable for call libraries (Figure 2C); 3) a navigable timeline view where recordings are ordered by sites on the Y axis against a time axis on X that can be zoomed and panned (Figure 2D).

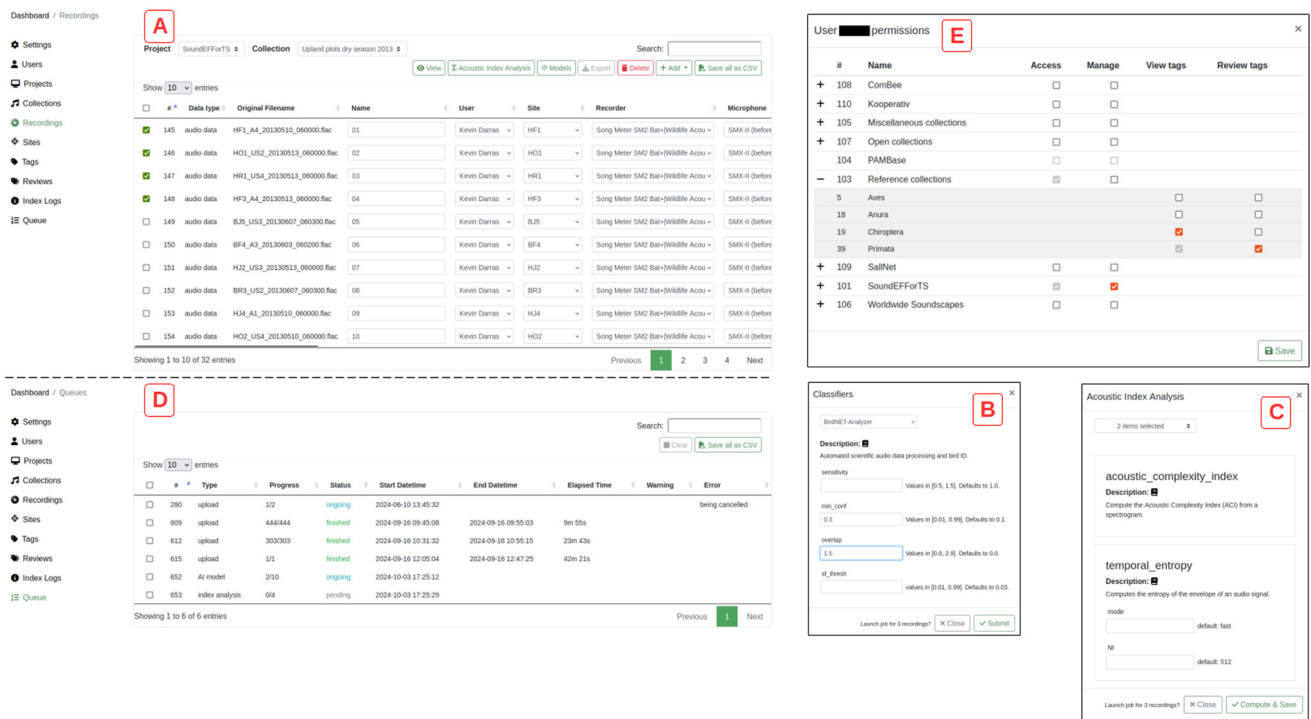
**Recordings.** Recordings can be managed from the dashboard (Figure 3A). The original files can be downloaded individually. Their metadata are visible and editable in a table, and the read-only audio tag information of the corresponding files are displayed there (currently supporting ID3Tag, Vorbis, RIFF formats). Recordings are assigned to sites determined by their latitude, longitude, topography (both above and below sea level), depth below the water surface (for freshwater bodies) and ecosystem type. Acoustic index or AI models can be executed on batches of recordings from the dashboard, and the progress of these “jobs” can be checked in the queue tab of the dashboard, where warnings and errors are logged, and jobs can be cancelled and cleared after execution. Meta-recordings can also be integrated in batches with a CSV upload tool. Meta-recordings consist of metadata describing when and where acoustic sampling has been conducted, and with which audio settings



**Figure 2.** The interactive site maps (A) are shown on top of three available collection views for recordings in ecoSound-web: vignette galleries (B), detailed list with small audio player (C), and navigable timeline (D).

(sample rate, channels number, bit depth, recorder and microphone). In contrast to real audio recordings, duty cycles (e.g., 1 minute on, 9 minutes off) can be specified and displayed on the interactive timelines. Large meta-recording collections have been created to provide a global overview of PAM (i.e., Worldwide Soundscapes<sup>63</sup>).

**Users.** ecoSound-web has two registered user classes with differing privileges: normal users and administrators (Figure 3E). Administrators currently include the project lead and web developers; they have privileges for creating, accessing, editing, and deleting projects, collections, recordings, tags, reviews, and acoustic index logs, and disabling users. They can transform



**Figure 3. The administrative interface for project managers and administrators.** The recordings management tab (A), which allows to run AI models (B) or acoustic index analyses (C) on batches of recordings, whose progress can be checked under the “queue” tab of the dashboard (D). User privileges window visible to administrators and project managers (E).

users into administrators, or give management privileges to normal users for specific projects so they can act as project managers. Project managers have privileges for creating, accessing, editing, and deleting collections, recordings, tags, reviews, and acoustic index logs, and disabling users belonging to their projects. They can give tag view and review privileges to normal users. Normal users without project management privileges have privileges for creating, accessing, editing, and deleting their tags belonging to their collections. If applicable, they can view and review tags of other users as determined by their privileges, and thus act as peer-reviewers (i.e., annotation validators).

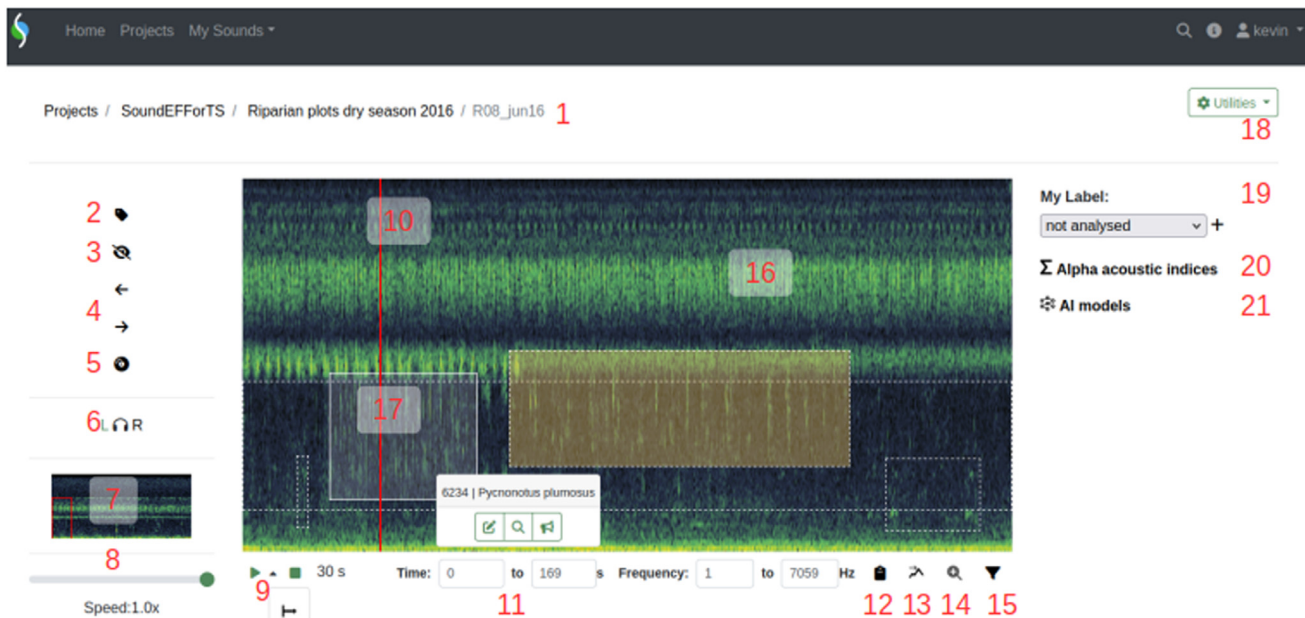
**Spectrogram player.** Recordings can be opened in the spectrogram player (Figure 4). Spectrograms are visualisations of sound where sound amplitude is shown in color, time is shown on the X axis, and frequency is displayed linearly on the Y axis. Audio channels can be displayed separately. The current spectrogram image and the compressed audio recording (MP3 for audible sound, OGG for ultrasound) as well as the original recording can be downloaded. The spectrogram player offers various functionalities for tagging sounds: it is possible to play back sound (at speeds between 0.05 and 1), filter frequencies outside of the current spectrogram view, navigate the spectrogram (zooming per selection, shifting frame sideways, playback at specific display densities), annotate spectrogram regions (creating tags per selection, assigning them to soundscape

components, sound types or soniferous animal species, reviewing and hiding them), label recordings with pre-defined and custom labels and perform sound analysis using alpha acoustic indices and AI models such as BirdNET and batdetect2. batdetect2 was chosen as it performed well in comparison with other bat call detection and classification AI models and it was easily integrated as a python-based algorithm. The execution parameters of the AI models can be set in the user dialogue and their output is saved as new annotations. Spectrograms are generated after every navigation command, and audio is downloaded on-demand for playback.

**Use cases**

**Bird community analysis (Manual and automated annotation, expert peer-review)**

Soundscape recordings can be annotated manually or automatically for bird vocalisations, and their annotations peer-reviewed by expert ornithologists, as exemplified in the collection “Upland plots dry season 2013”. Manual annotation of any other sound-producing organism is also possible. Users can scan recordings visually and aurally using the built-in reading mode, which zooms into the recording to display 15 pixels per second over the entire frequency range (additionally, custom display densities can be set), and enables continuous playback between spectrogram frames until the recording end. For stereo recordings, the left or right channel can be selected for visually checking vocalisations that may be audible on



**Figure 4. ecoSound-web spectrogram player.** Numbers correspond to the following sections: 1: Project/collection/sound name (navigation Breadcrumb). 2: annotate (i.e., tag) sounds. 3: hide/show tags. 4: pan spectrogram left and right 5: playback mode (zoom to pre-defined display density). 6: audio channel selection. 7: overview spectrogram, red rectangle shows current view. 8: playback speed slider. 9: playback/pause (expanded sub-menu allows to activate continuous playback) and stop buttons, time position. 10: playback cursor. 11: time and frequency coordinates of current view or selection. 12: copy time and frequency coordinates to clipboard. 13: export frequency of maximum energy to clipboard. 14: zoom into current selection. 15: frequency filter toggle. 16: tags of different users shown with different colours: reviewed tags with solid border, not yet reviewed tags with dashed border; tags without detection distance with orange shading. 17: tag ID and species/sound type appear on click, with buttons for editing, zooming, and estimating distance. 18: utilities menu, containing: download compressed recording of current view, download original entire recording, download of spectrogram image, file info, recording-level FFT window size settings. 19: assigning pre-set or custom label to recording. 20: computing alpha acoustic indices. 21: executing AI models (BirdNET and batdetect2).

another channel than the one currently visible. All avian species can be tagged/annotated based on rectangular spectrogram selections along the frequency and time axes. Users can choose species from the integrated species list based on the IUCN Red List taxonomy, and links to Xeno-canto and Google image searches to help the user with identification (Figure 5). Unclear identifications can be marked as uncertain and additional comments be given. Tags can be designated as reference recordings to be included into future reference collections.

Automated bird identification with BirdNET can be run on any recording (or recordings batch, from the dashboard). The spatial coordinates of recording site are automatically used for filtering BirdNET results, while other execution parameters remain at their default values unless modified by the user (Figure 3B, custom species list input not yet supported). BirdNET execution will result in the creation of 3-second tags over the entire frequency range, which can subsequently be reviewed by experts. Tags can be zoomed into and sharing links can be generated and copied to the clipboard. Any current audio portion can be downloaded as a spectrogram or audio file for sharing with collaborators. Detection distances can be estimated by using the distance estimation function (Figure 4): this will execute full-spectrum viewing and playback of the 30 first seconds of the tags; additional audio recordings of test tones emitted at known distances

are required to help human listeners calibrate themselves to estimate detection distances in an unbiased way<sup>64</sup>.

Acoustic recordings can be verified and validated at multiple levels to produce accurate datasets<sup>65</sup>. Tags can be peer-reviewed to validate species identifications and auxiliary data (e.g., distance). Users with reviewing privileges can either accept species identifications, revise them by suggesting other species, mark them as uncertain, or reject them (Figure 5). Administrators can also check the listening durations of each user (in the MySQL database) for each recording to verify that all recordings have been listened to in entirety, and to extract a measure of the sampling intensity. Finally, it is possible to train annotators - after granting them tag viewing privileges - with example annotations of other users. Subsequently, their performance in comparison to already annotated recordings, after revoking tag viewing privileges, can be tested. After these validity checks, the tag data can be exported from the dashboard as a CSV file for further statistical analysis.

#### Bat community analysis (Manual and automated ultrasound annotation, Chiroptera reference collection)

Ultrasonic soundscape recordings can be analysed for bat vocalisations, as shown in the collection “Bat point counts and automated recordings 2019”. However, bat call annotation



Tag 6196 for recording R01\_jun16 (ID 575) ✕

**Phony** **Sound Type**

biophony

**Species**

Orthotomus ruficeps  Uncertain?

Images | Xeno-canto (for birds only)

**Time**

375.1 - 452.6 sec

**Frequency**

2674 - 5100 Hz

**Sound Distance**

18  Distance not estimable

**Individuals** **Animal Sound Type**

1 Song  Reference call

Insert your comments

Created by [redacted] on 2017-12-31 23:00:00 (UTC) ↻

Accept
Revise
Delete
Uncertain

**New Review Species**

Insert your comments

Reviewer	Status	Species	Date
Kevin Darras	Accepted		03/02/2023

Save
Delete

**Figure 5. The tag editing window.** The soundscape component (currently “phony”) and sound type selection is remembered for faster tagging. Species, sound distance, individuals, and animal sound type fields are only shown when “biophony” is selected. Sound distance estimation is greyed out because values can only be entered with the dedicated function or declared as not estimable. Green sharing button: copies a URL to the clipboard to open the exact spectrogram region. The entire right pane is only visible to users with reviewing privileges. When applicable, the AI model name is displayed after “Creator type” and the confidence score of the detection shown next to it.

and analysis present specific challenges. First, bat calls are very short and occur in rapid succession (milliseconds). Because of this, ecoSound-web generates new spectrograms after zooming, based on the spectrogram selections. Frequency filtering is enabled by default (but can be disabled), so that users hear only what they see on the spectrogram, but it can also be disabled. The Fast Fourier Transform (FFT) window size can be set for all recordings accessible to the user (in the dashboard) and for each recording (Figure 4) to visualise bat calls better by choosing the ideal trade-off between the frequency and time resolution of the spectrogram. Finally, as ultrasound is not audible, users can adjust playback frequency (continuously between 0.05 and 1) with the playback speed slider to make ultrasound calls artificially audible (analogous to time expansion).

Bat species identification is challenging, as calls from different species can be similar. Additionally to species, custom tag identities can be used for bat sonotypes (i.e., bat call types with similar characteristics across different bat species)<sup>66</sup>.

Exact measurement of bat call features usually determines the assignment of bat calls to specific species. Using the clipboard button (Figure 4), users can copy the frequency and time coordinates of currently-selected bat calls to derive the start and end frequency, as well as call and call interval duration. Additionally, a dedicated button computes the frequency of maximal energy of the current spectrogram, a metric used for species identification (usually abbreviated “FmaxE”, Figure 4). For uncertain identifications, users can refer to reference collections such as the open “Chiroptera” collection (currently covering selected Southeast Asian species) to corroborate their identifications. As manual distance estimation of bat calls is impractical due to their mobility and the fact that humans cannot intuitively estimate distances of usually inaudible sounds, tags’ distances can be marked as “not estimable”. For automated identification of UK bat species, batdetect2 can be run on any recording (or recordings batch, from the dashboard). The detection threshold stays at its default value unless changed by the user. Upon execution, batdetect2 generates precise tags covering

each individually-detected call in the frequency and time dimensions, which can then be reviewed by experts.

### Primate bioacoustics (working with reference sound libraries)

Reference calls, i.e., example recordings of an animal vocalisations, can accelerate the detection of the call (visually or using AI) and facilitate the verification of the species identities found in soundscape recordings. Large reference call libraries already exist for birds (Xeno-Canto) and bats (ChiroVox) but are lacking for many other sound-producing animal groups. Available calls from more general libraries such as tierstimmenarchiv (“tierstimmenarchiv”) contain mostly recordings of captive animals or animals with unknown geographic locations, resulting in unclear taxonomies. For primates, acoustic communication has been studied in detail<sup>67</sup>. However, the potential of PAM has only recently been acknowledged<sup>68</sup> and applied to analyze, e.g., individual caller identity in orangutans<sup>69</sup>, occupancy in chimps and gibbons or howler monkeys<sup>70-72</sup> or density in fork-marked lemurs<sup>73</sup>, and reference calls have yet to be openly published.

Primate call repertoires range from 7–8 call types in ancestral primates<sup>74</sup> to more than 30 individual call types in bonobos<sup>75</sup>. Many primate vocalizations transmit indexical cues - specific call signatures linked to individuality, sex, population, or species - and they are distributed over a wide range of frequencies extending in the ultrasound field for some basal primates<sup>74</sup>. This diversity of behaviour underlines the importance of their vocalizations<sup>76</sup>. Although most primate call types are probably used in social contexts over relatively short distances, there is extensive evidence for loud, long-distance calls (several hundreds of meters), that are usually used for intergroup spacing, territorial defence, alarm situations, or as mate advertisement calls<sup>77,78</sup>. This provides additional arguments for analysing soundscapes, which can record calls of primates over large areas, to improve future primate population monitoring. Therefore, we initiated the first public primate reference call library based on georeferenced field recordings and annotated vocalisations. Each recording is assigned to a selectable Creative Commons license and attributed to its recordist. The collection currently contains 76 reference calls of 32 primate species from Indonesia, Myanmar, Madagascar and Peru. Vocalisations are classified into 13 behavioural contexts, such as affiliative, agonistic, contact, or alarm call (see [online Wiki](#)). The collection is shown in the public “[Reference collection Primata](#)” and is open for contributions. DOIs of the respective publication can be assigned to the reference recordings. Distance estimation and collaborative tagging can be used as described above.

### Soundscape analyses (soundscape components and acoustic indices)

Beyond particular animal species, soundscapes have components that inform us about organismal, human, and geophysical events<sup>4</sup>, and their diversity can be measured with acoustic indices<sup>11</sup>. ecoSound-web hosts the Worldwide Soundscapes project<sup>63</sup>, a global inventory of PAM conducted in all IUCN realms (i.e., terrestrial, marine, freshwater, and subterranean). Recording sites were assigned to specific ecosystem types, and

the interactive sampling site maps can be dynamically filtered to show particular ecosystem selections on three levels (realm, biome, [functional group](#)), thereby allowing to identify sampling gaps. Recordings of the project’s [demonstration collection](#), containing samples from different realms, were annotated with three different soundscape components: biophony (sounds of organismal origin), anthropophony (sounds of human origin), and geophony (sounds of geophysical origin) and validated by their recordists using the tag peer-review functionality. The soundscape occupancy (i.e., the occupied proportion of the spectro-temporal space) was thereby analysed after exporting the validated tags’ data as CSV in order to analyse macroecological biophony trends. Soundscape components are the highest level of the sound typology, and sound types can be specified within, using custom labels. However, no systematic typology of sound types currently exists. Furthermore, any currently generated audio portion and channel, and any batch of recordings selected in the dashboard, can be analysed with alpha acoustic indices — which in some cases correlates with biodiversity<sup>11</sup> — provided by the integrated python package scikit-maad<sup>59</sup>. Parameters can be input for each function or left at their default values and multiple indices can be chosen for batch analysis jobs ([Figure 3C](#)). Results can be saved by each user and downloaded as a CSV file from the dashboard’s “index logs” tab ([Figure 3D](#)) for further analysis of the acoustic diversity.

### Future development

We are continuously expanding the functionality of ecoSound-web. Open-source code is a requirement for future development and maintenance, but it is not a guarantee either, so we welcome new collaborators to support the project development who could become co-authors on subsequent versions of this article. In the future, we plan to implement the following functions:

1. Expanding acoustic analysis functions by enabling sound pressure level calibration, facilitating sound detection space measurement, and providing end-to-end validation of AI models
2. Increasing interoperability by linking ecoSound-web to taxonomic databases, external storage, and other software tools

### Conclusion

ecoSound-web can be used to store, re-sample, organize, visualise, play back, peer-annotate, analyse, and share soundscape recordings, tags, collections, and projects online, publicly or with specific users. The recordings can be analysed collaboratively for quantifying soniferous animal species activities (currently birds and bats). Furthermore, soundscape components can be quantified in time, space, and frequency, alpha acoustic diversity indices can be computed, and AI models can be run on recording batches. ecoSound-web has already been used successfully to analyse bird communities<sup>79</sup>, to measure bat activities<sup>80</sup>, to host reference recordings<sup>73</sup>, and to share global meta-recording collections<sup>63</sup>. Region- and taxon-specific reference collections can be created, like the anuran and primate call collection that we host<sup>73,81</sup>.

We acknowledge the necessity of having a diversity of software tools that fulfill the varied needs of users. However, the fields of ecoacoustics and soundscape ecology require a software tool that standardises and unifies the management and analysis of acoustic data. We propose one such tool, but the field is overrun by a multitude of mushrooming software tools with unique advantages (see Table 1 in version 2), and their sheer number impairs discoverability, standardisation of workflows, and adoption. This is why we decided to integrate existing tools for acoustic index analysis (i.e., scikit-maad) and bird and bat identification (BirdNET and batdetect2), and chose a broad thematic scope to include projects from any region, taxon, or realm. A funding- and interest-related partitioning and specialisation of the available research platforms (e.g., WildTrax for terrestrial Canada, OPUS for marine Germany, etc.) may be counteracted by APIs enabling inter-operability, and in the broader sense, the FAIR research principles<sup>4</sup>. Ultimately, such developments will stimulate reproducible, cross-realm, and synthetic research based on PAM, potentially even across the Earth System Sciences, where not only ecological, but also geophysical phenomena are analysed.

## Data availability

All the recordings referred to here are accessible in open collections without login on our online instance of ecoSound-web: <https://ecosound-web.de>.

## Software availability

Source code available from: <https://github.com/ecomontec/eco-Sound-web>

Archived source code at the time of publication: [10.5281/zenodo.13889948](https://zenodo.org/doi/10.5281/zenodo.13889948).

License: GNU General Public License v3.0 (GPLv3).

## Acknowledgements

We thank the principal investigators of the phase 1 and 2 B09 sub-project of EFForTS Teja Tschardt and Ingo Grass for their continued support of ecoSound-web development through student helper funds, as well as colleagues, users and students who provided feedback. We thank Westlake University for funding earlier development and related staff salaries of this work through a Westlake University startup grant a postdoctoral research fund. We thank the NFDI Consortium Earth System Sciences - NFDI4Earth, coordinated by TU Dresden, funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - project number: 460036893. We thank the ECODIV department of INRAE for funding the continued development of ecoSound-web and acknowledge the Sounds of Life Huma-Num consortium for training support. We thank the Gesellschaft für Wissenschaftliche Datenverarbeitung mbH Göttingen (GWDG) for hosting and managing the ecoSound-web servers.

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# Open Peer Review

Current Peer Review Status:   

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Version 2

Reviewer Report 16 October 2023

<https://doi.org/10.5256/f1000research.144078.r214163>

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**Anthony Truskinger** 

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The authors present ecoSound-web, an ecoacoustics data management system. They explain the workflow they are targeting and the various features they've built into the platform. Several features are novel for web-based ecoacoustics software - such as the use of the Web Audio API. The use of modern software stacks - particularly docker - are explained and validate the claims of maintainable software.

The lineage for the presented software is Pumilio -> BioSounds -> ecoSound-web. No specific reason was given as to why the project was forked from BioSounds - it would be good if that were addressed.

This reviewer is the primary developer of the Acoustic Workbench software, an open-source white label ecoacoustics data management platform. There are two instances of the platform: Ecosounds ([ecosounds.org](https://ecosounds.org)) and the Australian Acoustic Observatory (<https://acousticobservatory.org/>).

Given this context, the use of the name ecoSound-web is perhaps a poor choice given the existing Ecosounds project.

The acoustic workbench supports 5 out of 6 of your workflow steps. It is comparable to (though less feature rich than) ecoSound-web. Given the similarities, one wonders why collaboration or convergence with the Acoustic Workbench is not viable. There are certainly valid reasons, but they don't appear to be explained in your article. As pointed out in your conclusion, our field needs more consensus and less repeated effort to make software sustainable.

Despite that, the article sufficiently explains the software presented, presents an architecture that makes sense and is technically sound, and is easily replicable.

**Is the rationale for developing the new software tool clearly explained?**

Partly

**Is the description of the software tool technically sound?**

Yes

**Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?**

Yes

**Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?**

Yes

**Are the conclusions about the tool and its performance adequately supported by the findings presented in the article?**

Yes

**Competing Interests:** Non-financial competing interest: I develop similar software with a similar name.

**Reviewer Expertise:** Ecoacoustics software development

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 25 Oct 2024

**Kevin Darras**

Thank you for critically reviewing our contribution.

We will choose a new name, hosting server, and non-forked GitHub repository for the upcoming fourth milestone of ecoSound-web, in line with a continued institutional support that we are currently building up.

We are open for collaboration with ecoacoustic software tools that share the same goals, as discussed separately. We are currently mapping all available tools for an overview that will be published in a dedicated living systematic review. This necessary first step will help us to achieve transparency in this domain and potentially pave the way for convergence. We discovered many more software tools, so Table 1 was removed but kept for reference in the second version of the present paper.

**Competing Interests:** No competing interests were disclosed.

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Version 1

Reviewer Report 20 November 2020

<https://doi.org/10.5256/f1000research.29110.r74280>

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**Erin M. Bayne** 

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Biosounds is a very important step forward in the field of bioacoustics. Being able to manage large volumes of digital audio files and the various data that result is a large task that requires "big data" tools. Biosounds is a great step in this direction that continues on from past efforts. I greatly appreciate the efforts the authors have taken to continue developing tools that already existed. Building off of those tools and bringing them together into an easily setup system is a big advance.

A gap in this particular draft of the paper are other similar efforts that do exist. For example, the group I work with has developed Wildtrax ([www.wildtrax.ca](http://www.wildtrax.ca)) that has been operational for several years in Canada. This online system is used by partner agencies in provincial and federal governments, not for profits, industry, and academia. It has similar processes to Biosounds in the area of bioacoustics while also providing a platform for the storage of digital images taken by remote cameras. Including this effort as part of the comparison seems warranted. The key difference is Wildtrax is a centralized database system with the goal of sharing data amongst users Canada-wide rather than have each group setup their own server etc. It too is in development and has many things in common with the list of things Biosounds would like to see developed. The key difference seems to be that we have centralized the process and focused on users bringing their data to one place rather than managing things individually.

While the rationale for WildTrax and Biosounds are different, it does raise what I think is a very important point that would help expand this paper. How do we use tools like WildTrax and Biosounds to create international collaborations and data sharing standards and where might this repository lie? This paper is an excellent description of a wonderful tool but how users that download and setup servers, etc., should consider sharing/using data together is underemphasized. By providing this type of tool Biosounds provides the infrastructure to help us start developing this vision but I feel this paper should also include at least a section for how we should discuss something greater through shared centralized repositories that build off initiatives like Biosounds and WildTrax. Whether a country by country nodal structure is an option that should be discussed rather than having individual labs, researchers, or local government departments create their own systems is the next step in determining how we can better utilize the amazing power that autonomous recording devices give us. A discussion of how such a process might be facilitated internationally (i.e. through ornithological societies, bat societies, etc.) would help develop the vision that I think Darras *et al.* and others envision.

Darras et al must be complemented for developing such a useful tool that will undoubtedly improve the field of bioacoustics immeasurably. It is now up to the bioacoustics and wildlife biology fields to determine the best ways of making this data the most useful for the advancement

of science and conservation.

**Is the rationale for developing the new software tool clearly explained?**

Yes

**Is the description of the software tool technically sound?**

Yes

**Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?**

Yes

**Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?**

Yes

**Are the conclusions about the tool and its performance adequately supported by the findings presented in the article?**

Yes

**Competing Interests:** My primary comment on this paper is simply that it does not include all platforms that I believe relevant and one of those is a tool I am developing that shares similar functionality.

**Reviewer Expertise:** I am working in very similar areas trying to achieve a similar objective. My group uses ARUs for a multitude of objectives and needed a tool that could do what is described here. We took a different path than Biosounds but what they have developed is an excellent resource I can see drawing from.

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 06 Feb 2023

**Kevin Darras**

Thank you for your very interesting, complementary appreciation of our work. In the meantime, we have deployed a new version, adding project management, acoustic indices, phonies, maps, and timelines to ecoSound-web.

We have discussed the important points you raised in the conclusion with a new paragraph, and we adapted the goals to emphasize inter-operability. These points, together with the need for standards, are also themes in the focus of the first authors' current research projects and interests, which will be expanded further in the next article iteration and website version (c.f. GitHub issues). Note that we already implemented DOI referencing and the choice of Creative Commons licenses for the recordings.



**Competing Interests:** No competing interests were disclosed.

Reviewer Report 10 November 2020

<https://doi.org/10.5256/f1000research.29110.r74102>

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In this study Darras *et. al* present Biosounds, an open source web-based platform for archiving, exploring, and tagging eco-acoustic data. The tool fulfills an important role, and provides ecologists with a user friendly, powerful tool for managing data acquired from projects deploying acoustics.

Whilst the paper was generally well written and clear, my line by line recommendations/comments are as follows:

### Introduction

- “19 reported software tools by Priyadarshani” consider rephrasing to “19 software tools reviewed by...” to ensure it is clear that these tools weren’t developed by Priyadarshani *et. al*.
- Table 1 presents a comprehensive comparison between Biosounds and other tools. However, it is difficult to parse efficiently in its current format, with a large number of factors to consider, and sorting all the options just alphabetically. Maybe sorting from most to least features, or grouping tools in some way would allow for faster comparisons to be made between the offerings. Additionally, wherever it is placed, putting Biosounds in bold would improve the table.
- Table 2, whilst again comprehensive, is arguably not too interesting. Picking out the key few differences and presenting them inline in the text may be a clearer way to present this information – readers are perhaps unlikely to read through the entire page long table. The full table could then be left in supplementary materials

### Methods

- “by computing a fast fourier transform” – what are the parameters for this? And why were they chosen? Are they customisable / do they adapt based on recording parameters?
- “Soundscape collections, due to their larger size, can be integrated up to a manageable size” – giving an indicative size in GB/TB is crucial for readers to assess whether this tool is

suitable for their own projects.

- “upload recordings in most common audio formats” – please detail exactly which formats are supported.
- “MP3s of the audio file are generated after insertion into the database” – are the original uploaded audio files retained on the server (e.g., in the case of raw WAV files being uploaded)? Can the users download these back at a later date, or only MP3s? How are the MP3s generated (which codec) and at which compression level?

#### Use-cases

- “distances are estimated in a standardised way” – how? Using spherical sound absorption assumptions, or by other means? Also, how is distance estimated without knowing the typical source SPL value of a species’ call?
- “export the tag data through a MySQL database” – are users (not administrators) also able to access this data? It would also be useful to add CSV export option for those not so comfortable with SQL DBs.
- “bat morphospecies .... named with single letters from A to J” – you should either detail how these morphospecies differ (what are the identifying call characteristics that places a bat in B for example), or if irrelevant leave out this level of detail and just mention that morphospecies are supported too.

I also had a play around with the live demo running at <https://soundefforts.uni-goettingen.de/biosounds/>. My overall impression was very positive – the site was intuitive to interact with and things generally worked as advertised. I do have a few very minor recommendations below but appreciate that fulfilling these may be more difficult than the suggested manuscript changes:

- Opening the player view for a large file can take some time, and it just seems as if the connection has dropped (until finally the page is ready). This is not an issue when going forward and backward within the collection as there is a loading overlay, which makes it clear what is happening.
- When loading a large file into the player view the “play” icon is grayed out until some background loading is done. It isn’t clear that this is happening until this is done though – maybe a loading indicator in place of the gray play icon would be clearer.
- Once I’d zoomed in on a part of the spectrogram I couldn’t return to the original, zoomed-out view without refreshing the page. This should be possible.
- When in the player mode there is no indication of sampling frequency or labels on the spectrogram’s Y axis. This info can be inferred from the frequency selection box values, but it should be more clearly apparent in my opinion as it is such an important piece of information. If an expert is searching for calls from a specific species, frequency labels on the Y axis can make this a lot quicker.
- When searching through a collection, if you click on a species from the dropdown prompt, the expected behaviour is that the search will be performed. However, instead a search isn’t actually triggered until you click the search button manually.

**Is the rationale for developing the new software tool clearly explained?**

Yes

**Is the description of the software tool technically sound?**

Yes

**Are sufficient details of the code, methods and analysis (if applicable) provided to allow replication of the software development and its use by others?**

Yes

**Is sufficient information provided to allow interpretation of the expected output datasets and any results generated using the tool?**

Yes

**Are the conclusions about the tool and its performance adequately supported by the findings presented in the article?**

Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** eco-acoustics, bioacoustics, ecological monitoring, software development

**I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.**

Author Response 06 Feb 2023

**Kevin Darras**

Thank you for the detailed appraisal of our work. In the meantime, we have deployed a new version (adding project management, acoustic indices, phonies, maps, timelines) and addressed your comments.

Introduction: We removed the ambiguous sentence, which was mentioned in the discussion anyway. ecoSound-web is now in bold, and the Table 1 structure follows the classification of purposes announced in the introduction. Table 2 was deleted.

Methods: We newly implemented FFT window size settings for the users (globally and per recording) and mention the available values in the text. We removed the uninformative "manageable size" and mention the user self-registration feature (which depends on long-term funding) in the conclusion's goals. Regarding the SoX audio formats: the list is too long so we prefer to refer to the SoX homepage with a citation, but you can find them at <https://sox.sourceforge.net/soxformat.html>. We now mention that original audio files are retained on the server, but we don't provide download features yet (see issue #99 on GitHub).

Use cases: We already provide a citation (10.1111/2041-210X.13031) for the standardised estimation of the detection distances but added some more information to make clear that the reference recordings help human listeners to estimate distances. We now offer CSV export functions for the various data tables (tags, recordings, collections, acoustic indices) that are accessible to users with variable privileges instead of the impractical MySQL access option. Finally, the mention about using letters to distinguish morphospecies (we use “sonotypes” instead) was removed too.

Regarding general usability comments: Spectrogram computation is still time-consuming as it is computationally demanding, but we implemented on-demand audio loading: the playback button can be clicked, it will become gray while the audio is loaded, and start playback and transform into a pause button. This avoids downloading large files for users who are only tagging visually (e.g., for bat recordings). We have restored the functionality for returning to the previous spectrogram view with an instant back browser button press. However, we decided to keep the time and frequency indications inside the selection boxes only instead of adding scales, as we find that information redundant and haven't found a best practice implementation yet (but see issue #162). Finally, our new collection search function instantly searches across all the files' meta-data and does not require a search button press.

**Competing Interests:** No competing interests were disclosed.

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