Ecology and acoustics at a large scale

There is likely no silent place on Earth. Sounds produced by inanimate sources, as well as by plants, animals and humans, permeate all environments from the deep-sea to the atmosphere, 24 h a day (Stocker, 2013). Eavesdropping on animal vocal communications has been an active field of research for more than 60 years (Busnel, 1963) and has, for example, alerted us to the possible deleterious effects of anthropogenic noise on animal physiology and behavior (Barber et al., 2011; Brumm and Slabbekoorn, 2005). Such research is the domain of bioacoustics, the study of the emission, propagation and reception of sound by animals (Bradbury and Vehrencamp, 1998).

Bioacoustics is necessarily interdisciplinary, with links to ethology, physiology, neurobiology, biomechanics and evolution, but it tends to focus on the acoustic behavior of individuals, groups, or populations almost always with reference to the biological concept of a species. In other words, it is a species-centered discipline. However, species do not live in closed systems — rather they are part of larger hierarchical structures such as guilds, communities, ecosystems and landscapes. Acoustic interactions between species and between species and their environment may impose important constraints on the structure of these higher-level systems and their development through time. The justification for this special edition on ecological acoustics is the need for investigations of the role of acoustics at higher levels of biological organization. Such investigations link bioacoustics to ecology and point to new ways of understanding both animal sounds and ecosystem processes.

First attempts to link acoustics with ecology involved the development of acoustic diversity indices as indicators of biodiversity (Pieretti et al., 2011; Sueur et al., 2008) and with the formalization of soundscape ecology (Pijanowski et al., 2011a). Acoustic diversity indices were inspired by classical indices used in biodiversity assessment with the community level as the unit of sampling and analysis. Soundscape ecology is “the study of sound in landscapes based on an understanding of how sound, from various sources — biological, geophysical and anthropogenic, can be used to understand coupled natural–human dynamics across different spatial and temporal scales” (Pijanowski et al, 2011b) (Fig. 1).

Scaling up to community or landscape level would help to address three important challenges in ecology: (1) monitoring animal diversity, (2) understanding the interactions between animal species and (3) measuring and mitigating human noise pollution. Monitoring global changes in biodiversity due to urbanization, ecosystem fragmentation, climate change etc. will require techniques that can scale massively. Acoustic monitoring techniques offer this possibility and a key objective of this special edition is to report on acoustic monitoring techniques that can scale. For example, what kind of acoustic-sensing networks are required to monitor oceans, landscapes and cities? Can acoustic diversity indices act as proxies for biodiversity? Can acoustic indices be used to identify sites of conservation interest or to detect sudden changes in biodiversity composition? Is there an acoustic correlate to the ecological concept of a niche that will help us understand acoustic competition between species? What are the consequences at ecosystem level of human noise pollution?

Our ability to broach these questions has been made possible by rapid advances in informatics. Indeed it is now possible to acquire far more acoustic data than anyone can ever listen to. Terabytes of acoustic data is becoming the norm. New methods of data management, analysis, visualization and tagging will be required to cope with this deluge of data. The increasing popularity and effectiveness of citizen science will inevitably have a role to play. Changing scale from species to communities and ecosystems also demands a change of perspective. The acoustic target might still be a single species but in the context of an assemblage of interacting species and other acoustic components (geophony, anthrophony) within a soundscape. There is no longer an acoustic foreground embedded in a background of noise. All the acoustic content potentially conveys information. This requires technical changes to hardware and software. Parabolic microphones must be replaced by omnidirectional microphones; batteries may need to be replaced by renewable power sources (e.g., solar); and software will need to extract more general acoustic indices rather than species identifiers. It is worth noting that large scale monitoring has moved beyond purely academic interest. Both New Zealand and Australia have already introduced elements of a large scale acoustic monitoring program (Parsons and Towsey, 2012).

The fourteen articles in this special edition cover a broad range of contemporary problems in ecological acoustics. Six of the papers address the challenge of monitoring the numbers and migration patterns of particular groups of species. Four papers are concerned with the marine acoustic environment and the remaining four papers explore ecological applications for acoustic indices.

The assessment and monitoring of animal diversity is one of the main motivations for deploying acoustic sensors. Frommolt et al. demonstrate that the number of calling males within a population of the endangered Eurasian bittern could be estimated using a set of four four-channel microphones. Over a five year study, the authors documented changes in the number and spatial distribution of calling birds, which could be linked to changes in habitat structure.

Andreasen et al. developed new sensor hardware and associated machine learning techniques to capture and identify echo-locating bats. A test in real conditions generated more than 230 GB of data, revealed the existence of two unrecorded species and identified (unexpectedly) the occurrence of social calls.

Keen et al. tested a suite of automated classification methods to identify four warbler species based on their flight calls. They conclude that automated methods can help but not yet replace human-based
identification. It remains extremely difficult to develop fully autonomous systems for animal call identification. Ross and Allen also address the problem of identification of nocturnal flight calls and likewise arrive at the conclusion that machine learning techniques greatly reduce the human labor input but cannot replace it entirely.

Potamitis reports how appropriate signal parameterization and probabilistic modeling can lead to accurate classification of flying insects based on wing-flap features. The method could lead to more general automated monitoring of economically important pest insects. Balakrishnan and her collaborators also investigated insect species, but whereas most studies depend on field-gathered data, they used a three-dimensional simulation model to better understand how acoustic overlap may constrain the simultaneous nocturnal choruses of five insect species. Their study reveals that, on average, species-even choruses (equal numbers of the five calling species) resulted in higher levels of effective hetero-specific acoustic overlap than choruses with strong dominance structures. Of the articles in this special edition, this is the only one to address the important problem of competition for acoustic bandwidth in natural environments.

The four papers in this special edition dealing with the marine acoustic environment use different sampling strategies and recording systems. Fujioka et al. report significant improvements in the mapping and visualization of data in a biogeographic database that combines datasets from different acoustic platforms. Interactive tools to explore large amounts of passively acquired data that can be used for ecological, conservation and educational purposes. Denes et al. compared the data provided by two different autonomous recording systems in the Bering Sea and concluded that they yield similar biodiversity information, in particular for daily species counts. Parks et al. describe for the first time an acoustic diversity index applied to marine recordings on a world scale, with hydrophones placed in three oceans. Their results indicate that acoustic entropy values did not...

Fig. 1. Four examples of terrestrial and marine recorders to record at large spatial and temporal scale: (A) an autonomous Wildlife Acoustics Recorder SM2 settled in French Guiana tropical forest (picture by Jérôme Sueur, see Rodriguez et al.), (B) an ultrasound recording device developed to monitor bats installed on a roof in Denmark (picture by Thor Andreassen, see Andreassen et al.), (C) a 4-microphone recording station designed to monitor populations of Eurasian bittern in Germany (picture by Karl-Heinz Frommolt, see Frommolt & Tauchert), and (D) marine autonomous recording units (MARU) developed by Cornell’s Bioacoustics Research Program for deployment on the ocean floor at depths up to 6000 m (Oceanic Preservation Society).
correspond to biological patterns and that noise from seismic air-gun activity masked biological signals. However, a simple background noise removal technique on raw recordings led to a compensated index that was more reflective of biological patterns. Rice et al. address the problem of long-term variations in underwater noise at ten locations along the North-West Atlantic Coast. Anthropogenic noise is clearly a critical factor for those animals that communicate with sound as it can change perceptions of the underwater environment and the ability to detect conspecifics.

Four papers in this special edition explore the use of acoustic indices to provide ecological useful insights. Gage and Axel report the analysis of four years of recording (probably the longest acoustic study yet reported) of an island location (a small uninhabited island in Lake Michigan, North American). Calculating a Normalized Difference Soundscape Index, they discern striking seasonal patterns in the soundscape particularly concerning changes in dawn and dusk choruses.

An important challenge in animal diversity assessment is the estimation and monitoring of species richness through acoustic indices. Towsey et al. derived 14 indices at one minute resolution from very long acoustic recordings and tested their ability to obtain indirect estimates of avian species richness. Combining sets of indices can lead to a more efficient estimation of bird species richness than single indices. Farina et al. successfully used the Acoustic Complexity Index to identify compositional changes and acoustic fluctuations in Mediterranean community. Rodriguez and her collaborators deployed a 3D array of microphones in French Guiana looking for the spatio-temporal dynamics of the tropical forest. The recordings reveal a 24 h pattern of acoustic activity, clear differences between the understory and canopy soundscapes, and horizontal acoustic heterogeneities.

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References