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Discussion

Using ecoacoustic methods to survey the impacts of climate change on biodiversity

Bernie Krause[a], Almo Farina[b,c,*]

[a] Wild Sanctuary, POB 536, Glen Ellen, CA 95442, USA
[b] Department of Pure and Applied Sciences, Urbino University, Italy
[c] International Institute of Ecoacoustics, Fivizzano, Italy

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ABSTRACT

Climate change is an important cause of the irreversible transformation of habitats, of the rapid extinction of species, and of the dramatic changes in entire communities, especially for tropical assemblages and for habitat- and range-restricted species, such as mountaintop and polar species.

In particular, climate change effects several aspects of animal sounds (e.g., song amplitude and frequency, song post, and sound phenology). Animal sounds, which are life traits characterized by high plasticity, are able to cope with even modest variations of environmental fundamentals like vegetation cover, land mosaic structure, temperature, humidity, and pH (for aquatic medium). Moreover, the climatic effects on these biophonies can be observed earlier than change in vegetation patterns and visible landscape structures.

Ecoacoustics, the discipline that investigates the role of sound on animal ecology from species to landscapes, offers robust models, such as acoustic adaptation, acoustic niche, acoustic active space, acoustic community, and acoustic phenology to investigate the effect of climate change on species, populations, communities, and landscapes.

From an operational perspective, ecoacoustics procedures can be applied in different contexts, such as locations, weather, species, populations, behavior, physiology, and phenology. In addition, thematic priorities can be selected, such as latitudinal and altitudinal gradients, restricted habitats, stopover areas, extreme environments, weather conditions, short distance migrants, species at high vocal plasticity, sink-source status, active space, social attraction, physiological modifications, dawn and dusk choruses, sound from stressed plants, and time series analysis.

The noninvasiveness of passive acoustic recording, the simultaneous collection of important data, such as community richness and diversity, immigration and extinction events, and singing dynamics as well as the availability of innovative noninvasive technologies operating over a long-term period, establish ecoacoustics as a new and important tool with which it is possible to analyze massive acoustic data sets and quickly predict and/or evaluate the effects of climate change on the environment.

Moreover, passive recording is supported by cheap, user-friendly field sensors and robust data processing and may be part of the citizen science research agenda on climate change.

1. Introduction

The effects of climate change on the environment caused by the accumulation of greenhouse gases of anthropogenic origin in the atmosphere are extensively documented by scientific research (IPCC, 2013). A crude anthropogenic perspective (cost/benefit, energy, trade, and resource control) is blended with a more genuine concern for the state of the Earth in a period during which humanity has reached such a level of ecological intrusion that Nobel prize laureate Paul Crutzen and his colleague Eugene Stoermer applied the term *Anthropocene* to distinguish the current geological epoch (Crutzen and Stoermer, 2000).

The anthropogenic influence on the Earth's climate has complex latitudinal and altitudinal effects on all the scales from individual species that enter into a lottery of winners and losers (e.g., Moss, 1998) to biome shifts (IPCC, 2014), creating great impacts for the speed with which such changes occur, impeding the majority of species to adapt (Parmesan, 2006).

Complex interactions triggered by the extreme events associated with climate change have a strong impact inside trophic chains with cascade effects, like the irreversible transformation of habitats, the rapid extinction of species, and dramatic changes in entire communities where key species are involved (Easterling et al., 2000; Alois and Cheng, 2007).

* Corresponding author at: Department of Pure and Applied Sciences, Urbino University, Italy
E-mail address: almo.farina@uniurb.it (A. Farina).

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A different distribution of meteorological events associated with temperature rise modifies growth rate and reduces the chances of survival of plants and animals, especially for tropical assemblages and for habitat and range-restricted species like mountaintop and polar species.

When possible, animals avoid physiological stress, changing their geographical distribution, but this reduces their chances to have access to necessary resources (sensu Farina, 2012) and populations may easily shift their source status to a sink condition (Pulliam, 1988) with consequences on their survivorship.

Among the most mobile animals, many species of birds are able to adjust their geographical distribution, and a long-term perspective confirms the strict relationship between avifauna and vegetation during the last 180,000 years due to glacial episodes (Holm and Svenning, 2014). Birds with a restricted distribution may have a larger impact compared with ubiquitous species, and the same is expected for long-distance migrants that could face shifts of winter and breeding areas. Changes may also occur along the migratory routes for stopover species (e.g., Huntley et al., 2006; Gordo, 2007) and new studies are necessary to forecast the impacts (e.g., Gregory et al., 2009; La Sorte and Jetz, 2010).

The increase of global temperature is expected to have a major effect in tropical areas for terrestrial ectotherms because they are close to the optimum of temperature and small changes may have a deleterious consequence on a great number of species. For instance, in Ecuador, temperature was found to be a discriminant factor for cricket species in cloud forest ecosystems. In lowland rainforests, a change in temperature could have great consequences regarding the distribution of these groups of species (Nischck and Riede, 2001). Important effects have resulted in species where the gender ratio is driven by environmental temperature. For instance, in the population of marine turtles of the southern United States, a higher number of females is expected because of a warming of only 1 °C (Hawkes et al., 2007). However, species living at higher latitudes have a broader thermal tolerance because they are living in cooler areas than their physiological optimum (Deutsch et al., 2008).

Climate change is continuously monitored due to an extensive application of advanced remote sensing technologies based on the survey of atmospheric physics, aquatic chemistry, and vegetation parameters that are able to cover the entire planet at a common spatial and temporal resolution. The majority of the studies of the effects of climate change on organisms is still based on predictive large-scale models to cope with the abiotic information from satellite sensors, as argued in a recent review by Crick (2004), although some bioclimatic models are quite accurate (Williams et al., 2003).

However, the effects of climate change on the ecological processes, although evident and well documented (Walther et al., 2002), often escape the more thorough enquiries necessary for developing efficient mitigation or remediation policies at medium and small geographic scales. The necessity to develop new approaches and methods is urgent. Among these, sound is an important medium for intra- and interspecific communication among hetero- and homoeothermic groups of animals and produces one of the most interesting candidates.

Unfortunately neglected by ecological investigations for long a time, sounds have an important role in detecting early signs of animal stress connected to climate change from the scale of individual species, populations, communities, and landscapes. The study of sound with an ecological perspective is a focus of ecoacoustics (Sueur and Farina, 2015).

Acoustic communication has proven to be related to animal metabolism, creating an energetic constraint. As a result, this produces a great variety of sounds used to communicate. For this reason, the relationship between climate change that modifies the energetic field in which organisms operate and the results of acoustic emissions are strictly related (Gillooly and Ophir, 2010).

Therefore, the goals of this paper are as follows:

1) To demonstrate through published material and by personal account examples of how the climate affects the attributes of vocalizing organisms and 2) to provide a framework to use ecoacoustics, a recent extension of bioacoustics into the ecological domain (Sueur and Farina, 2015), to investigate the effects of climate change.

In this narrative, climate change has been considered in terms of direct and indirect effects on ecoacoustic processes described according to acoustic adaptation (hypothesis), acoustic niche (hypothesis), acoustic active space, acoustic community, and acoustic phenology postulates.

In this paper we consider ecoacoustic methods and provide an agenda to promote ecoacoustics approaches. The majority of the examples focus on species like frogs and birds, two groups of animals that extensively use sound to communicate, and partitioning of important traits of their ecological niches.

2. The ecoacoustics competence

There is evidence that the majority of acoustic performances and their patterns are the result of complex interactions between the energetic environment, the animal biomass, and the structure of the social interactions (e.g., Brackenbury, 1979; Wallschager, 1980). The energetic basis of acoustic communication confirms that patterns and individual acoustic performances are both potentially sensitive to environmental conditions (e.g., temperature, humidity, noise, and social organization) (Gillooly and Ophir, 2010). For the extreme plasticity of the acoustic characters, every change in the environment is immediately reflected in the acoustic behavior of organisms. However, research priorities are necessary to quantify the variation in acoustic activity of individuals and assemblages over time within the same habitat (Farina and James, submitted for publication).

Ecoacoustics has been extensively used in biodiversity assessments, such as species of interest (Bardeli et al., 2010), number of species (Towsey et al., 2014a), acoustic diversity (Rodriguez et al., 2014; Desjonquères et al., 2015), habitat evaluation (Bormpoudakis et al., 2013), habitat quality changes (Piercy et al., 2014), and habitat selection (Figueira et al., 2015) and in population ecology, such as distribution and dynamics (Risch et al., 2014), population density (Lucas et al., 2015), viability (Laiolo, 2008), structure (Laiolo and Tella, 2006), and species invasion (Both and Grant, 2012). Similarly, the ecoacoustics approach has been adopted to investigate the ecology of the acoustic communities, such as composition and dynamics (Sueur et al., 2008), acoustic diversity (Gasc et al., 2013), and acoustic interactions (Tobias et al., 2014) as well as the relationship with the landscape (Farina et al., 2011; Joo et al., 2011; Tucker et al., 2014). An important contribution has been offered by ecoacoustics in conservation biology and, in particular, in the analysis of the effects of anthropophonic disturbances (e.g., Barber et al., 2011; Pieretti and Farina, 2013; Azzellino et al., 2011).

2.1. Acoustic adaptation (hypothesis)

The acoustic adaptation (hypothesis) (Morton, 1975; Marten and Marler, 1977; Cosens and Falls, 1984; Ey and Fischer, 2009) assumes that the acoustic properties of habitats such as ground morphology, plant structures, and atmospheric content have a direct effect on the characteristics of animal sounds with the result of maximizing sound propagation. Signal-generating organisms try to reduce attenuation and degradation of the broadcasting acoustic signals in a specific habitat through an adaptation that extends over a long period.

Indirect effects that often drive genetic variation inside populations and alter plasticity capacity or resilience can be linked to small differences in vegetation or landscape (Rubenstein, 1992). Often the indirect effects are not surveyed because too few data are available at microcosm scales.

Habitat structures correlate with the highest frequency song in *Phylloscopus* and *Hippolais* warblers (Badyaev and Leaf, 1997). In closed habitats, these species avoid using rapidly modulated signals and use fewer and longer syllables with larger intervals when compared with species living in open habitats.