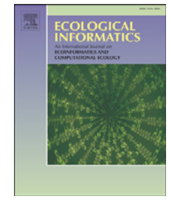
Ecological Informatics 21 (2014) 4–12

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf



Applying bioacoustic methods for long-term monitoring of a nocturnal wetland bird

Karl-Heinz Frommolt [a,*], Klaus-Henry Tauchert [b]

[a] *Museum für Naturkunde, Leibniz-Institut für Evolutions- und Biodiversitätsforschung, Invalidenstraße 43, D-10115 Berlin, Germany*
[b] *BfUL/Sächsische Vogelschutzwarte Neschwitz, Park 2/D-02699 Neschwitz, Germany*

ARTICLE INFO

Article history:
Received 15 May 2013
Received in revised form 15 October 2013
Accepted 10 December 2013
Available online 22 December 2013

Keywords:
Bioacoustic monitoring
Acoustic pattern recognition
Hyperbolic localization
Population size

ABSTRACT

Bioacoustic monitoring is becoming more and more popular as a non-invasive method to study populations and communities of vocalizing animals. Acoustic pattern recognition techniques allow for automated identification of species and an estimation of species composition within ecosystems. Here we describe an approach where on the basis of long term acoustic recordings not only the occurrence of a species was documented, but where the number of vocalizing animals was also estimated. This approach allows us to follow up changes in population density and to define breeding sites in a changing environment. We present the results of five years of continuous acoustic monitoring of Eurasian bittern (*Botaurus stellaris*) in a recent wetland restoration area. Using a setup consisting of four four-channel recorders equipped with cardioid microphones we recorded vocal activity during entire nights. Vocalizations of bitterns were detected on the recordings by spectrogram template matching. On basis of time differences of arrival (TDOA) of the acoustic signals at different recording devices booming bitterns could be mapped using *hyperbolic localization*. During the study period not only changes in the number of calling birds but also changes in their spatial distribution connected with changes in habitat structure could be documented. This semi-automated approach towards monitoring birds described here could be applied to a wide range of monitoring tasks for animals with long distance vocalizations.

1. Introduction

Recently bioacoustic methods have become a powerful tool for monitoring biodiversity. Their specific potential lies in the detection of cryptic vocalizing animals, even in the absence of an observer. Birds are good subjects for bioacoustic census methods since most of the species use vocalizations to attract mates and to advertise territories (Gaunt and McCallum, 2004). Most of the recently used monitoring schemes for birds are based on the detection of territorially behaving animals, mostly through mapping singing males (Gregory et al., 2004). In applying bioacoustic methods for nature conservation we must bear in mind that the results should meet the requirements for long-term monitoring. We should expect an improvement in monitoring schemes either in terms of effectiveness or in terms of accuracy. The aim of monitoring biodiversity is to assess changes in ecological communities through time. Surveys should be designed in such a way that the obtained data are precise enough to identify trends (Magurran et al., 2010). Good indicators on environmental health are based on quantitative surveys allowing estimation of population trends of key species (Gregory and van Strien, 2010). This means for bioacoustic monitoring that we need an appropriate recording technique, an appropriate data acquisition protocol, effective tools to detect species within the recordings and methods for estimating the number of animals.

Recent digital audio recording devices allow unsupervised registration of vocal activity for several hours over a time schedule of even several months. For monitoring the acoustic activity of wild animals both specialized recorders and custom built solutions based on consumer recorders are now used (Fristrup and Mennitt, 2012; Mennill et al., 2012; Steer, 2010; Venier et al., 2012). Based on the sound material, the species composition of bird communities can be estimated. When using high sensitivity or highly directional microphones, by listening to sound recordings only small differences have been found in the number of species detected on the recordings and number of species detected directly at the observation sites (Haselmayer and Quinn, 2000; Hobson et al., 2002). However when microphones with low sensitivity were used, the observer at the study site obtained better results than an observer in the lab listening to the recordings (Hutto and Stutzman, 2009). Making sound recordings in parallel with a common bird census, similar results with respect to species composition were obtained using point count surveys (Venier et al., 2012) or line mapping (Frommolt et al., 2008). Wimmer et al. (2013) have demonstrated that targeted sampling with acoustic sensors could even reveal a significantly higher number of bird species than would be detected in a traditional bird survey.

In the future, species composition could be more effectively estimated by applying acoustic pattern recognition techniques. There are already some specialized recognizers allowing for automatic detection of certain species within long-term recordings (Bardeli et al., 2010; Towsey et al., 2012). Based on a linear predictive coding (LPC) transform, Boucher et al. (2012) could even distinguish all 14 species of a down

* Corresponding author.
E-mail address: karl-heinz.frommolt@mfn-berlin.de (K.-H. Frommolt).

1574-9541/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ecoinf.2013.12.009

chorus in a semi-rural location in Australia with a priori knowledge of species composition.

The biggest challenge seems to be determining the number of individuals on the basis of sound recordings. Stereo or quadraphonic records make it possible to reproduce a two or three-dimensional impression of the soundscape and thus facilitate an estimate of the number of birds by a skilled observer listening to the recordings (Celis-Murillo et al., 2009; Rempel et al., 2005). Another approach is the use of individual voice features in order to distinguish birds. This requires, however, that the acoustic characteristics are stable enough at least for the acquisition period. Gilbert et al. (1994) previously applied sound recordings for population surveys of Eurasian bitterns (*Botaurus stellaris*) and black-throated loons (*Gavia arctica*) to distinguish between individuals. Since 1990 sound recordings were used to monitor the (very small) British bittern population and to recognize individuals by voice (Gilbert et al., 2002).

The number of recorded calls or song bouts has also been used as a measure of the number of animals, especially when studying bird migration. However it was difficult to estimate the absolute number of animals because the call rate differs between species and even within a species, the call rate being strongly dependent on the particular environmental conditions (Farnsworth, 2005; Farnsworth et al., 2004; Hüppop and Hilgerloh, 2012). Buxton and Jones (2012) found that nocturnal call activity can at least provide information on the relative population density of cave breeding birds. Comparing different methods of bird surveys Buckland (2006) found that the census based on song activity delivered results with a rather poor precision.

Microphone arrays open new ways for monitoring birds by allowing an estimate of the location of the vocalizing animal (Blumstein et al., 2011). On basis of the time delay for the arrival of the signals at different microphones, the position of the vocalizing animal can be estimated with an accuracy of a few meters depending on the distance between the sensors (Mennill et al., 2006, 2012). However Wahlberg et al. (2003) could localize booming bitterns only with an accuracy of more than 100 m using a four microphone array with a distance between neighboring microphones of between 65 and 294 m.

Here we present data from a long-term monitoring project where a quantitative assessment of a bird population was achieved on the basis of audio recordings. As a focus species we selected the Eurasian bittern. The characteristic vocalization of this species is a loud boom which is uttered in sequences of a few elements, called boom trains. The main element of the boom, which can be heard over distances of more than 1 km, is a tonal element with a mean frequency of approximately 150 Hz and a mean duration of approximately 500 ms (McGregor and Byle, 1992). In regions with high population density the population size of bitterns is difficult to estimate since the bird is hard to detect in dense reed vegetation, most vocal activity occurs at night and the signal is almost impossible to localize by a human listener. Our approach includes long-term sound recordings, detection of calls of the focus species within the recordings, discrimination of individual animals based on acoustic features and spatial distribution and a plot of a distribution map.

2. Materials and methods

2.1. Study area

Our study was conducted in the newly created wetland restoration area “Polder Große Rosin” in the north-eastern Germany. The restoration area belongs to the Nature Reserve “Peenetal von Salem bis Jarmen”. Formerly the landscape along the river Peene was characterized by extended reed bog complexes. Due to amelioration, the area was transformed during the last century into extended grassland areas. Dramatic changes occurred in the 1970s when the area was surrounded by dams. Pumping stations were built to keep the ground water level low. As a result of drainage and the agricultural use of the area, there was a destruction of the peat soil, which was accompanied by a lowering of the ground level. Beginning in the year 2000, the Federal State of Mecklenburg-Western Pomerania started an extended program for the restoration of destroyed bog complexes (MLUV MV, 2009). The restoration of the “Polder Große Rosin” began in 2006 by shutting down the pump station. In 2008 the desired water level had been reached. A wetland area of 841 ha was thus created. The data presented here are one part of a long term monitoring project to follow up the *succession processes* in this protected area.

2.2. Sound recordings

From April 2008 until June 2012 we made continuous sound recordings from sunset until sunrise during selected nights with almost no or light wind. We used a uniform recording setup consisting of four Edirol R44 four-channel field recorders (Roland Corporation, Hamamatsu, Shizuoka, Japan) and four Beyerdynamic MC930 cardioid condenser microphones (Beyerdynamic GmbH & Co, Heilbronn, Germany) per recording device during the field seasons 2009 until 2012. The four microphones of each recording device were mounted at a height of 1.5 m in a cross-like configuration under a rigid foam plate which served as protection from rain (Fig. 1). The distance between the membranes of neighboring microphones was 30 cm. Using a Meridian Pro precision magnetic compass (Kasper & Richter GmbH & Co. KG, Uttenreuth, Germany), microphones were aligned so that the central axis between the first two microphones was in a north–south direction. In 2008 we made recordings with two Edirol R4 four channel recorders (Roland Corporation, Hamamatsu, Shizuoka, Japan) and four pairwise placed Fostex FR2-LE stereo recorders (Fostex Company, Akishima, Tokyo, Japan) with Sennheiser ME 64 (Sennheiser electronic GmbH & Co. KG, Wedemark, Germany) and Behringer B5 microphones (Music Group IP Ltd, Manila, Philippines). The recording devices were placed on former lanes, preferably in an L-shaped configuration at a mean distance of 200 m (150 to 500 m) between each other. The position of the recording device was estimated by Garmin Geko and Garmin Etrex GPS navigators (Garmin International Inc., Olathe, KS, USA). At each position air temperature and humidity was measured using PCE-HT71 USB data loggers (PCE Deutschland GmbH, Meschede, Germany). For the purpose of synchronization of the audio tracks of the different recorders at the beginning of the recording sessions a synthetic signal was recorded simultaneously at each device. Then the recorders were brought to their final place without stopping the recording. In 2011 and 2012 the synthetic signal was also recorded at the end of the recording sessions in order to allow an estimate of differences in the internal clocks of the recorders. Sound recordings were stored as wav-files with a 48 kHz sampling rate and 16 bit data depth. In total we were able

Fig. 1. Arrangement of the microphones of a recording unit. Four cardioid microphones were mounted orthogonally under a rigid foam plate.