Monitoring Techniques for Temperate Bird Diversity: Uncovering Relationships between Soundscape Analysis and Point Counts

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Abstract

Our goal was to establish a relationship between measures of avian diversity from point counts and soundscape metrics such as normalized difference soundscape index (NDSI), biophony levels, technophony levels, and sound file species richness. Soundscape analysis and the recording devices it uses are far less invasive than point counts, collect more high-quality data, and can be immediately uploaded to the internet for long-term storage and further analysis. Consistent with our hypotheses, we found that observed species richness was positively related to sound file species richness. NDSI values were significantly positively related to Shannon's diversity index, species richness, and sound file species richness while technophony values significantly negatively related with Shannon's diversity index, species richness, and sound file richness. Biophony values showed no relationships with point count data, which ran contrary to our hypotheses. The link we established between point count diversity and soundscape data could allow scientists to use recording devices to non-invasively monitor diversity which would allow for far more efficient diversity monitoring and open new opportunities for further study.

Introduction:

A soundscape is defined as "the collection of biological, geophysical and anthropogenic sounds that emanate from a landscape and which vary over space and time reflecting important ecosystem processes and human activities" (Pijanowski et al. 2011a). Biological, geophysical, and anthropogenic sounds are referred to as biophony, geophony and technophony, respectively (Gage et al. 2001; Napoletano 2004). Early soundscape analysis has focused on the interplay of these three sound types over both temporal and spatial scales (Krause et al. 2011; Gage et al. 2008; Pijanowski 2011). Using soundscape analysis for monitoring species diversity is a relatively new development in the young science of soundscape ecology. Recent studies have used soundscape data to bolster traditional diversity-measuring methods, such as point count sampling, as well as a standalone tool for monitoring diversity (Tegeler et al. 2012; Gage et al. 2008; Depraetere et al. 2012). Soundscape analysis offers some advantages over traditional methods used to monitor diversity because recording units are less invasive than traditional methods of diversity measures, recording units can collect more data over longer periods of time with less labor input, and recorded data can be instantly available for analysis via the internet (Sutherland 1996, Gage et al. 2008). Both soundscape recordings and data can be stored and processed in various ways based upon the goals of the project. Soundscape data can be used and re-used for a wide variety of projects as well as provide a long-term record for future comparisons, which enables biologists to detect changes in ecosystems and make management decisions based on this information (Krause et al. 2011). It is clear that soundscape monitoring methods have a wide variety of potential applications and will become increasingly important for monitoring diversity, especially as ecological monitoring agencies such as the National Ecological Observatory Network (NEON) expand and explore soundscape analysis as a tool for monitoring diversity (NEON 2012).

In order to utilize soundscape analysis to answer questions relating to avian diversity, it is essential to directly compare soundscape metrics with measures of diversity derived from classical methods (e.g. point counts). A point count is commonly used to quantify diversity and richness in temperate zones (Ralph et al. 1995; Sutherland 1996). This classic method gives scientifically-accepted measures of diversity and richness for the sampled area despite being labor intensive and potentially disruptive to the surrounding environment (Ralph et al. 1995; Sutherland 1996). While measures of diversity have been derived from soundscape data in the recent past (Depraetere et al. 2012), to our knowledge this study is the first to attempt to establish a relationship of observed bird diversity and species richness with soundscape metrics such as normalized difference soundscape index (NDSI), biophony levels, and technophony levels.

We will compare the relationship between species richness observed in the field with species richness found on the recordings, or “sound files”. We predict that there will be a significant positive relationship between these two values. The next step will be to test for relationships between observed species richness (from point counts) and diversity with computer-calculated metrics biophony, technophony, and NDSI, which is a metric normalizing biophony by technophony. NDSI and total biophony are expected to have a positive relationship with observed diversity and richness values. Additionally, a negative relationship is expected between observed species richness and total bird diversity with technophony values. Finally, the aforementioned relationships are expected between NDSI, biophony, and technophony with the sound file species richness. Establishing a relationship between soundscape metrics and observed bird diversity will provide wildlife managers and researchers with a method to monitor avian diversity without disturbing the habitat while reducing the associated costs. In the future, soundscape ecology could be used not only to characterize spatial-temporal changes in techno-, geo- and bio-phony, but also to discover patterns in diversity and species richness.

Methods

Point Counts

We conducted point counts at 19 locations on the property of the University of Notre Dame Environmental Research Center (UNDERC) in Northern Wisconsin in conjunction with the Upper Great Lakes Soundscape project (Gage et al. 2008). Point counts were conducted in a variety of habitats including pristine woodlands, riparian, and bog habitats. Each count was conducted for 3 three minute intervals for a total of nine minutes and followed the protocol established by Ralph et al. (1995). Point counts nine minutes in length would allow for comparisons with the more standard 10 minute lengths used in other studies (Ralph et al. 1995; Sutherland 1996); however, for all of the subsequent analyses, only the first 3 minute interval of the point count was used so that direct comparisons could be made to recorded sound files. Point counts took place during the morning (5 am-10 am) and evening choruses (5 pm-9pm) in order to maximize bird observations to provide a more accurate depiction of the diversity of birds in the area. A total of 223 point counts were conducted throughout the breeding season from May 29th to June 27th.

Soundscape recordings

Soundscape recordings used in this project came from the REAL Upper Great Lakes Project, a series of 19 microphone recording stations spread out over UNDERC. Recording locations were the same as the point count locations to allow for direct data comparisons. Recordings were made using the Wildlife Acoustics Song Meter 2 (Wildlife Acoustics 2012). This device records sound in monaural at 22,050 Hz for 1 minute duration every half hour. Recordings were automatically digitized and stored on 16 GB SD cards (Gage et al. 2008). At the end of the study period files were transferred to a computer and uploaded to the REAL database. These files are the sound files from which we derive sound file richness, NDSI, biophony, and technophony data. Once in the database, the REAL lab utilized MATLAB to split each sound file into eleven frequency bins from 0-11 kHz (Gilat 2004). The value in each bin was calculated from the recording using the Power Spectral Density (PSD) via the Welch method (Welch 1967). These values were in turn used to calculate biophony, technophony, and NDSI. Biophony is the sum of the PSD values from 2-11 kHz. Technophony is the PSD value from 1-2 kHz (S. Gage, personal communication 2012). Finally, NDSI is a simple calculation that normalizes the PSD data into a usable ratio. The calculation is as follows: $NDSI = \frac{(Biophony-Technophony)}{(Biophony+Technophony)}$. NDSI values range from -1 (all technophony) to +1 (all biophony) (S. Gage, personal communication 2012). Therefore, each sound file has an associated biophony, technophony, an NDSI value, as well as a PSD value in each individual frequency bin.

I used three recordings, or "sound files", that aligned with the same date and time as the point count. For example, if I did a point count on 7-2-2012 at 7 am, I analyzed the sound files from the same site and date at 6:30 am, 7 am, and 7:30 am. Each 1 minute recording (n=699) was listened to by J. McLaren to determine audio recorded species richness.

Statistical analysis

Shannon's diversity index and species richness was calculated for each of the 223 3-minute point counts using the R statistical programs reshape and vegan (Wickham 2007; Oksanen et al. 2012). The values for sound file richness, NDSI, biophony, and technophony were averaged for each triplet set of sound files corresponding to each point count. Since there were 223 point counts, there were 223 averaged sound file data points. Both the point count and sound file data was further averaged by site and time of day (a categorical variable indicating morning vs. evening) to eliminate pseudo-replication. The final dataset consisted of 18 morning and 18 evening average values of Shannon's diversity index, Species richness, NDSI, biophony, technophony, and sound file species richness value.

We used simple linear regressions to compare sound file richness with observed richness, NDSI, biophony, and technophony values. Multiple regression models used both time of day (AM/PM) and soundscape metrics like biophony, technophony, and NDSI as factors to explain observed diversity and richness values.

Results

A total of 669 minutes were recorded for a total of 11.15 hours of recording time. 59 total species were detected in the recordings while 76 were detected during point counts. Linear regression revealed that observed species richness (during point counts) was significantly and positively related to sound file species richness (β=1.4546, $T_{34} = 14.399$, $p<0.0001$, R^2=0.855, Figure 1).

Multiple regression revealed that NDSI and time of day were significantly related to Shannon's Diversity Index values (R^2=0.5365, F=21.25, $p<0.00001$). NDSI was positively related to Shannon's Diversity Index (β=1.1055, T_{33}=2.351, p=0.0248) and Shannon's Diversity Index was lower during evening chorus (β=-0.4121, T_{33}=-3.516, p=0.0013, Figure 2). The interaction between NDSI and time of day was not significantly related to Shannon's Diversity index (β=0.3502, T_{32}=0.311, p=0.758). As hypothesized, the multiple regression model revealed that NDSI and time of day were significantly related to species richness (R^2=0.5245, F=20.3, $p<0.00001$). NDSI was positively related to species richness (β=4.8384, T_{33}=2.039, p=0.049528) and species richness was significantly lower during evening chorus (β=-2.1676, T_{33}=-3.665, p=0.000861, Figure 3). The interaction between NDSI and time of day was not significantly related to species richness (β=-1.001, T_{32}=-0.176, p=0.861).

Biophony was not significantly related to either Shannon's diversity index (β=-.1385, T_{34}=-0.374, p=0.7104) or species richness (β=-1.279, T_{34}=-0.697, p=0. 4903).

Multiple regression model revealed that technophony and time of day were significantly related to Shannon's Diversity Index (R^2=0.5357, F=21.19, $p<0.00001$). Shannon's diversity index was significantly negatively related to technophony (β=-1.1875, T_{33}=-2.338, p=0.0256) and Shannon's diversity was significantly lower during evening chorus (β=-0.3402, T_{33}=-2.466, p=0.0190, Figure 4). The interaction between technophony and time of day was not significantly related to Shannon's Diversity index (β=-0.08184, T_{32}=0.311, p=0.072). Furthermore, multiple regression revealed that technophony and time of day were significantly related to species richness (R^2=0.5372, F=21.31, p<0.00001). Observed species richness was significantly negatively related to technophony (β=-5.7497, T_{33}=-2.276, p=0.0295) and species richness was significantly lower during evening chorus (β=-1.7439, T_{33}=-2.541, p=0.0159, Figure 5). The interaction between technophony and time of day was not significantly related to species richness (β=2.244, T_{32}=0.395, p=0.695).

Linear regression revealed that NDSI was significantly positively related to sound file species richness (β=13.978, T_{32}=3.764, p=0.000633, R^2=0.2942, Figure 6). Similar to prior regressions with biophony as a factor, linear regression revealed that biophony was not significantly related to sound file species richness (β=-4.180, T_{32}=-1.489, p=0.1489,R^2=0.03358). Finally, linear regression revealed that technophony was significantly negatively related to sound file species richness (β=-15.692, T_{32}=-5.17, p<0.0001, R^2=0.4237, Figure 7).

Discussion

We found that species richness from point counts had a positive relationship with species richness on recorded sound files (Figure 1). This important relationship establishes a connection between traditional estimation of species richness through point counts, and species richness estimated from sound recordings and establishes that soundscape analysis can be a viable tool for calculating species richness. We also found a significant positive relationship between NDSI and Shannon's Diversity Index (Figure 2) and species richness from point counts (Figure 3) thus demonstrating that the relationship between a purely computer-calculated metric and real-world observations. The initial regression of observed and sound file richness required listening to hours of audio files. Our study used a comparatively small data set of around eleven hours of audio compared to some other studies which have hundreds of hours (Depraetere et al. 2012; Krause et al. 2011; Tegeler et al. 2012; Joo et al. 2011). Eliminating the need to listen to these hours of recordings would allow for almost complete automation of monitoring diversity and richness.

Interestingly, biophony provided no significant relationships with diversity or richness (P=), an unexpected result since biophony values are used to calculate NDSI values. It is possible that geophony, particularly wind and rain, invaded the biophony spectrums thereby skewing the results by creating high biophony values when bird diversity and richness were actually low. Alternatively, the frequency range used to calculate biophony could have been too large, creating large values for biophony values again when diversity richness were actually low. Most birds sing between 3 and 8 kHz (Gage personal communication 2012, Krause et al. 2011), so our inclusion of 2-11 kHz may have been inappropriate. In the future, usage of geophony-eliminating mathematical programs (Depraetere et al. 2012) or narrowing the range of frequencies encompassing biophony could reduce or eliminate this problem.

We also found that technophony had a negative relationship with both Shannon's diversity index (Figure 4) and species richness (Figure 5), as predicted in our hypotheses. The discovery of these relationships adds more evidence to the notion that soundscape-based metrics could be used to predict richness and diversity without the need to conduct point counts. Of the linear models that were found to be significant, these were among the strongest (Shannon's R^2=0.5372, richness R^2=0.5372). We therefore believe that technophony might be a very important factor for determining bird diversity. Previous studies have found connections between urban/rural gradients and biodiversity with technophony as a possible explanation for why biodiversity decreases toward urban areas (Joo et al. 2011). Other studies have found that technophony can interfere with avian communication and can reduce biodiversity (Laiolo 2010; Barber et al. 2010). The fact that we found a significant relationship between biodiversity and technophony even in our relatively pristine sample area highlights the importance of monitoring technophony and its effects on biodiversity.

Lastly, we compared sound file richness to metrics calculated from those same sound files to provide further evidence that NDSI, biophony, and technophony were valid metrics to use to predict richness and diversity. In Depraetere et al. (2012), the Acoustic Diversity (AD) metric came solely from soundscape recording data. We wanted to use a similar method in developing relationships between soundscape metrics and species richness. The fact that NDSI and technophony retained their significance with sound file species richness further supports what was found when comparing those same soundscape metrics to observed diversity and richness. Biophony was once again not significantly related to species richness and is not recommended for predicting richness or diversity. Furthermore, the comparison between soundscape metrics and soundscape species richness allows researchers to double-check metric-richness comparisons without needing to conduct field sampling like point counts.

Future research should sample over larger spatial and temporal scales to see if these relationships hold during the non-breeding season, in different habitats, and across a variety of spatial scales. Another possible avenue for future study is to explore the relationship between the diversity of sound and species diversity. This could be accomplished by computing a new metric "diversity of sound" using PSD values and Shannon's or Simpson's diversity indices to quantify how the sound spectrum is used by birds. Furthermore, diversity of sound might better predict avian diversity and richness as well as allow researchers to explore acoustic partitioning and strategies by comparing places such as the tropics, to places like the northern temperate zones. Using a “diversity of sound index” one could also explore how birds use the sound spectrum to communicate with conspecifics without interfering with other birds or technophony. There seems to be promise in this line of study since interfering factors like technophony seem to have significant impacts on bird diversity and behavior, so clearly how birds partition themselves in the sound spectrum is of great importance (Laiolo 2010; Slabbekoorn and Ripmeester 2008).With these avenues for further study along with the relationships discovered above, the science of soundscape analysis is poised to allow for quick determinations of biodiversity and species richness, as well as analyzing the effects of technophony, without the labor or invasiveness of traditional field methodologies (e.g. point counts).

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Appendix

Figure 1: Relationship between species richness observed during point counts and richness from sound files

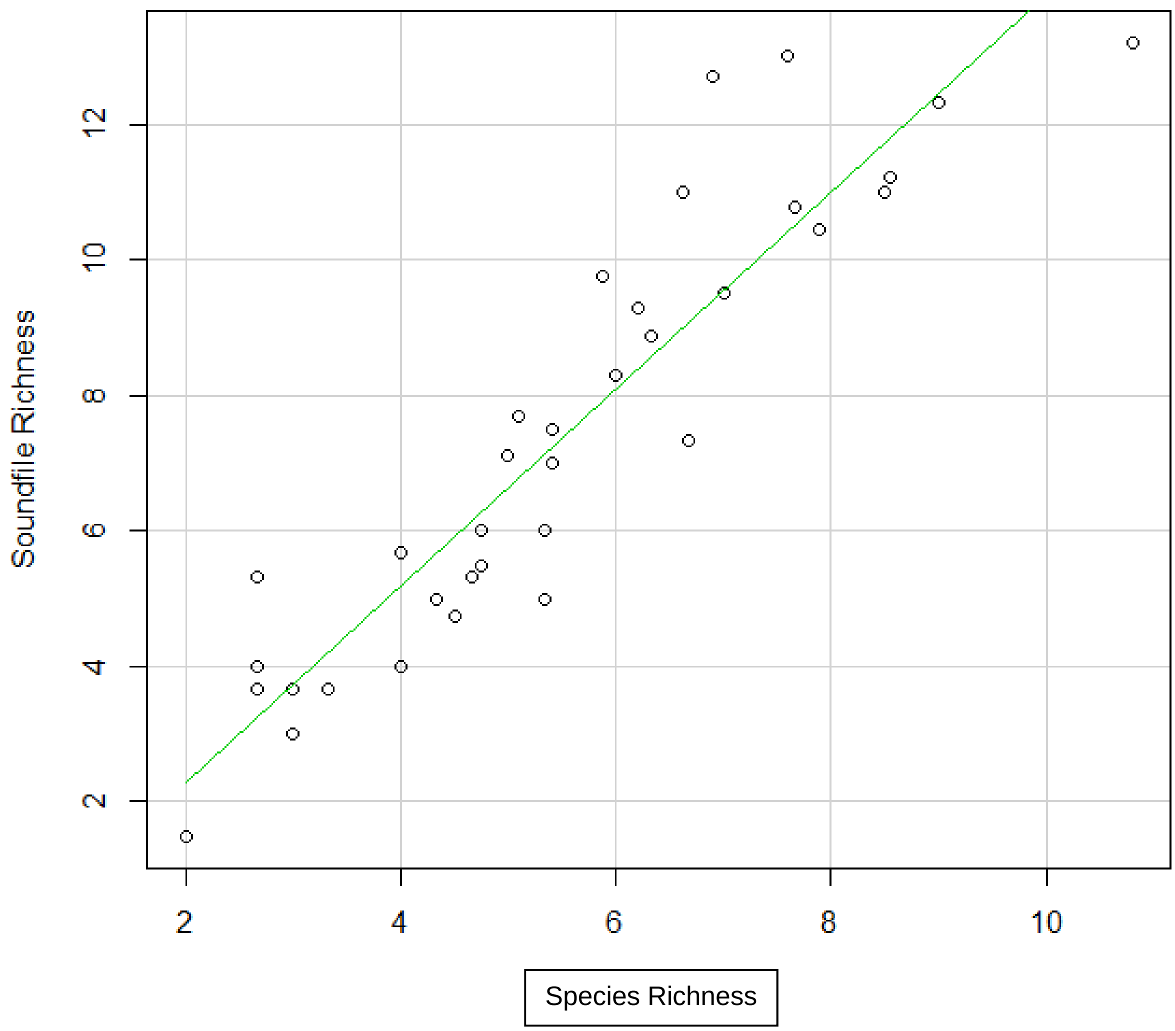

Figure 2: Relationship between NDSI values and Shannon's diversity values from point counts for both morning (open circles, dashed line) and evening (closed circle, solid line).

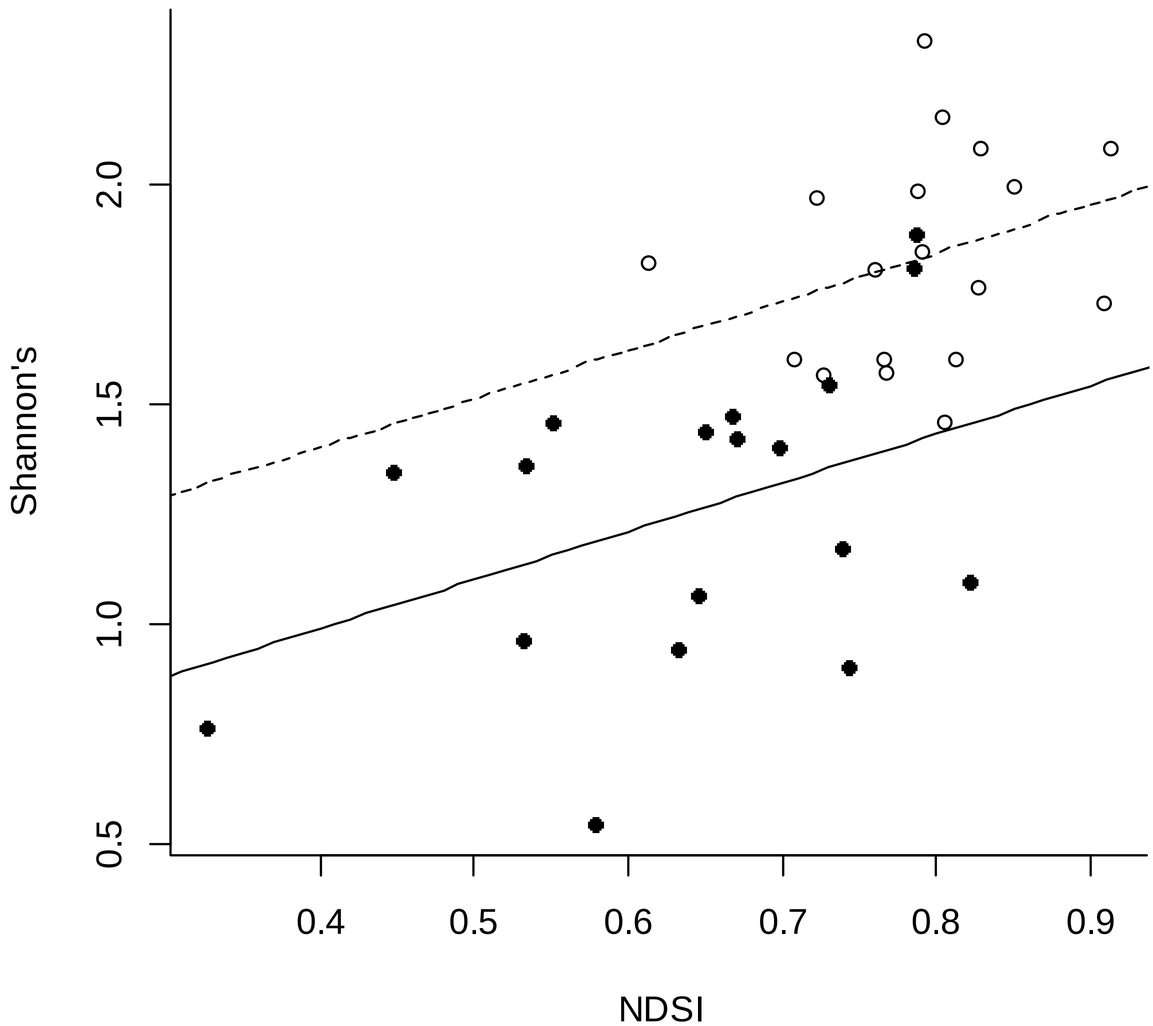

Figure 3: Relationship between NDSI values and species richness from point counts for both morning (open, dashed) and evening (closed, solid) choruses.

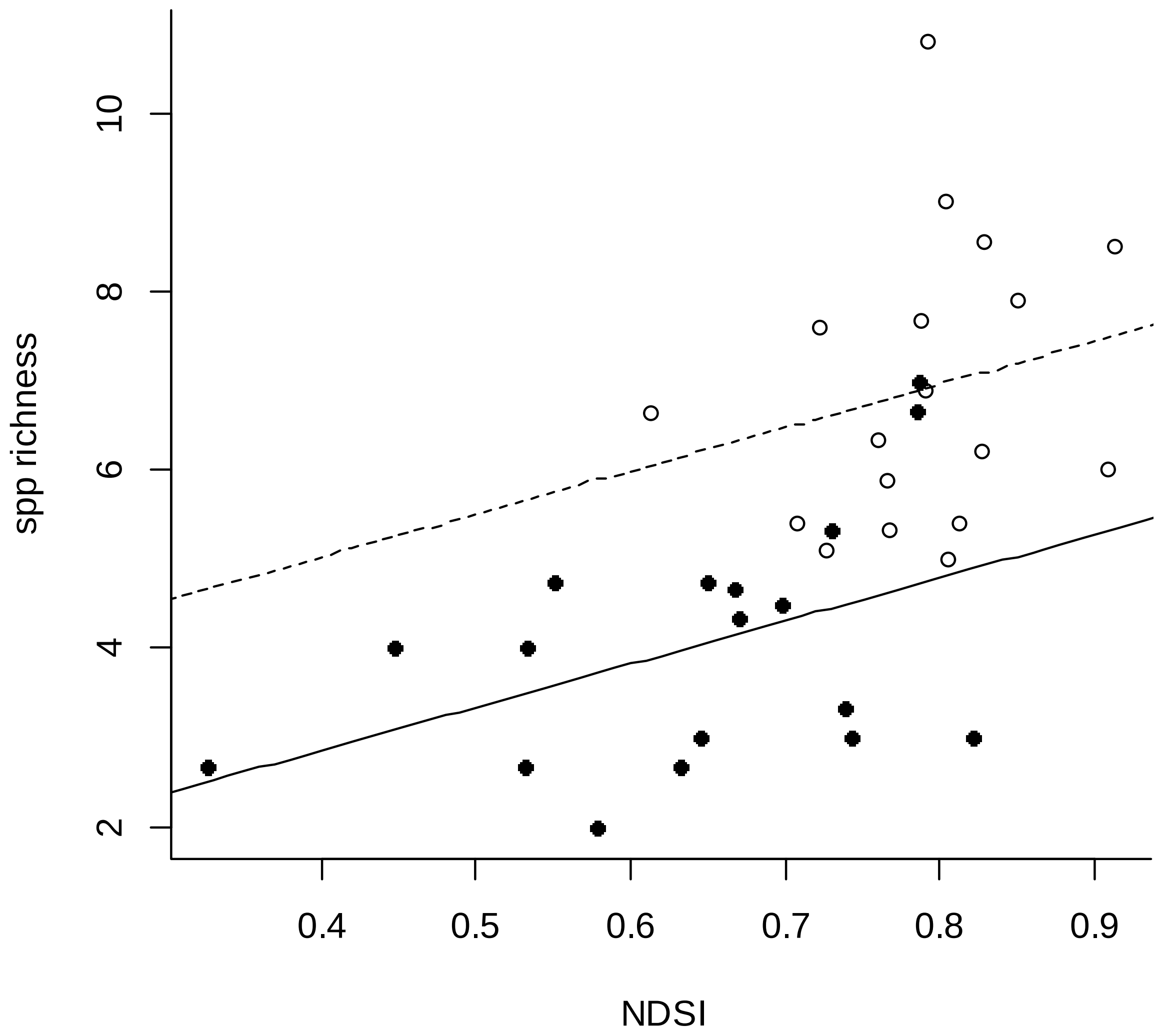

Figure 4: Relationship between technophony values and Shannon's diversity index from point counts, including both morning (open, dashed) and evening (closed, solid) choruses.

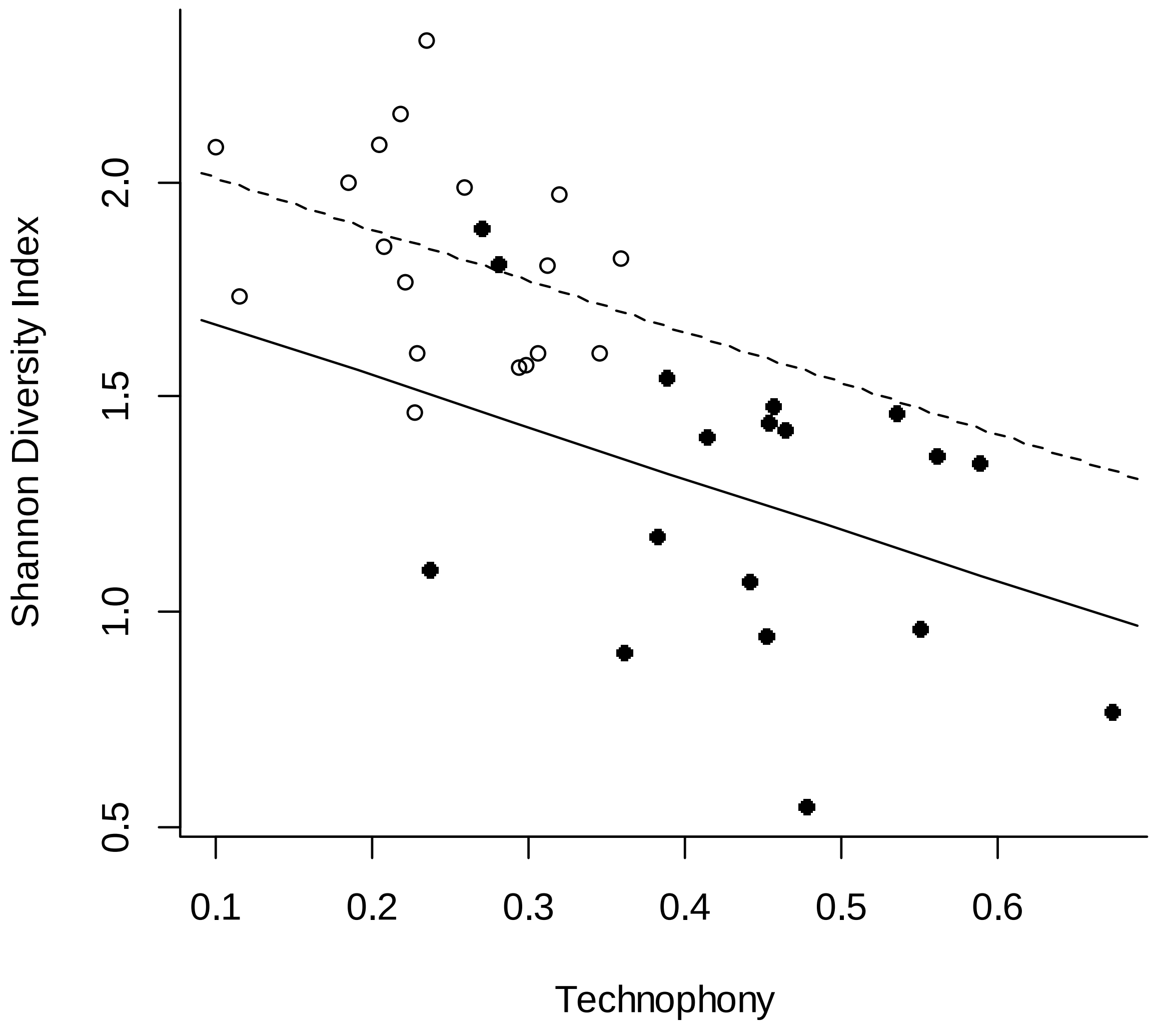

Figure 5: Relationship between technophony values and species richness from point counts for both morning (open, dashed) and evening (closed, solid) choruses.

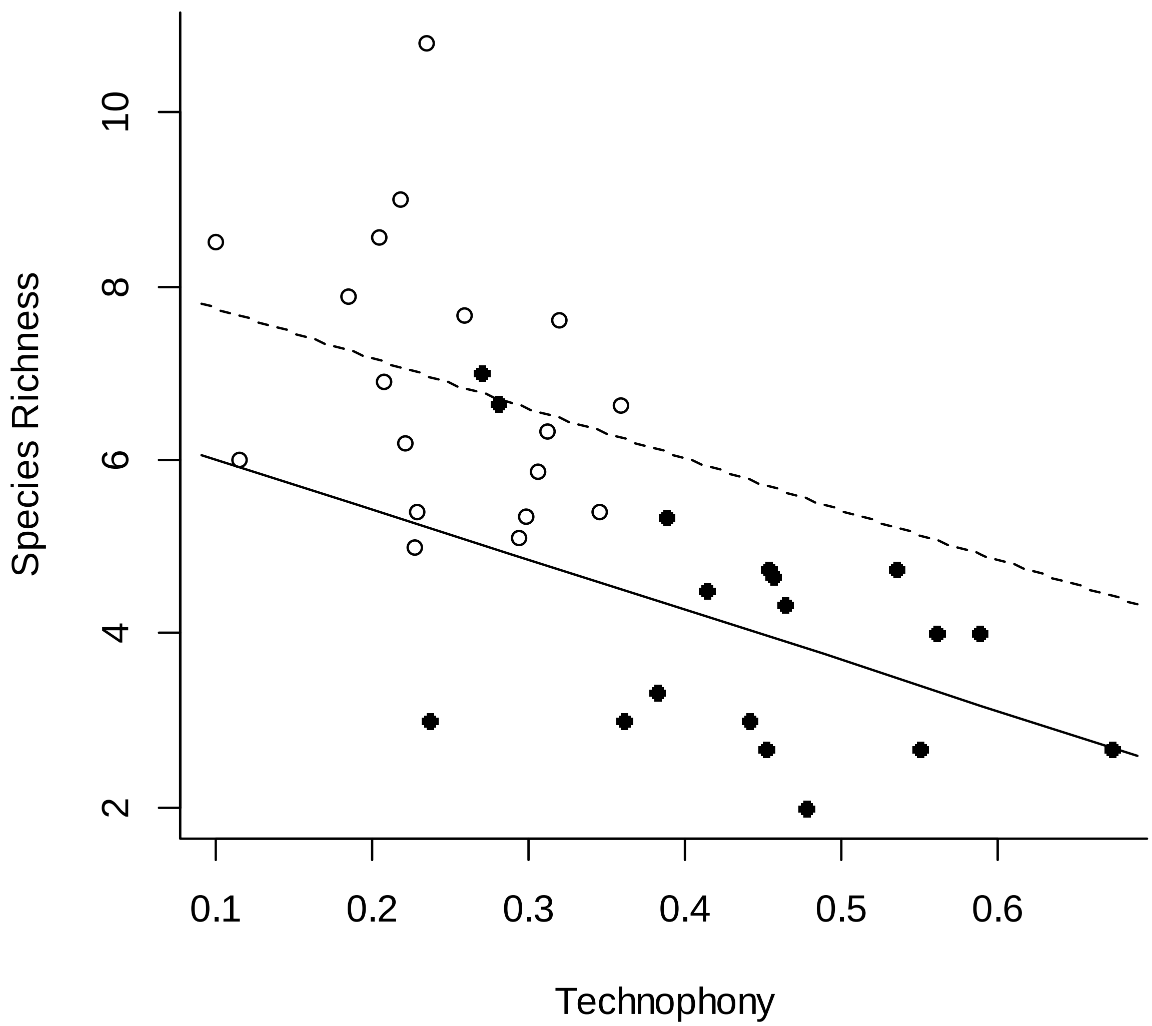

Figure 6: Relationship between NDSI values and species richness values from sound files.

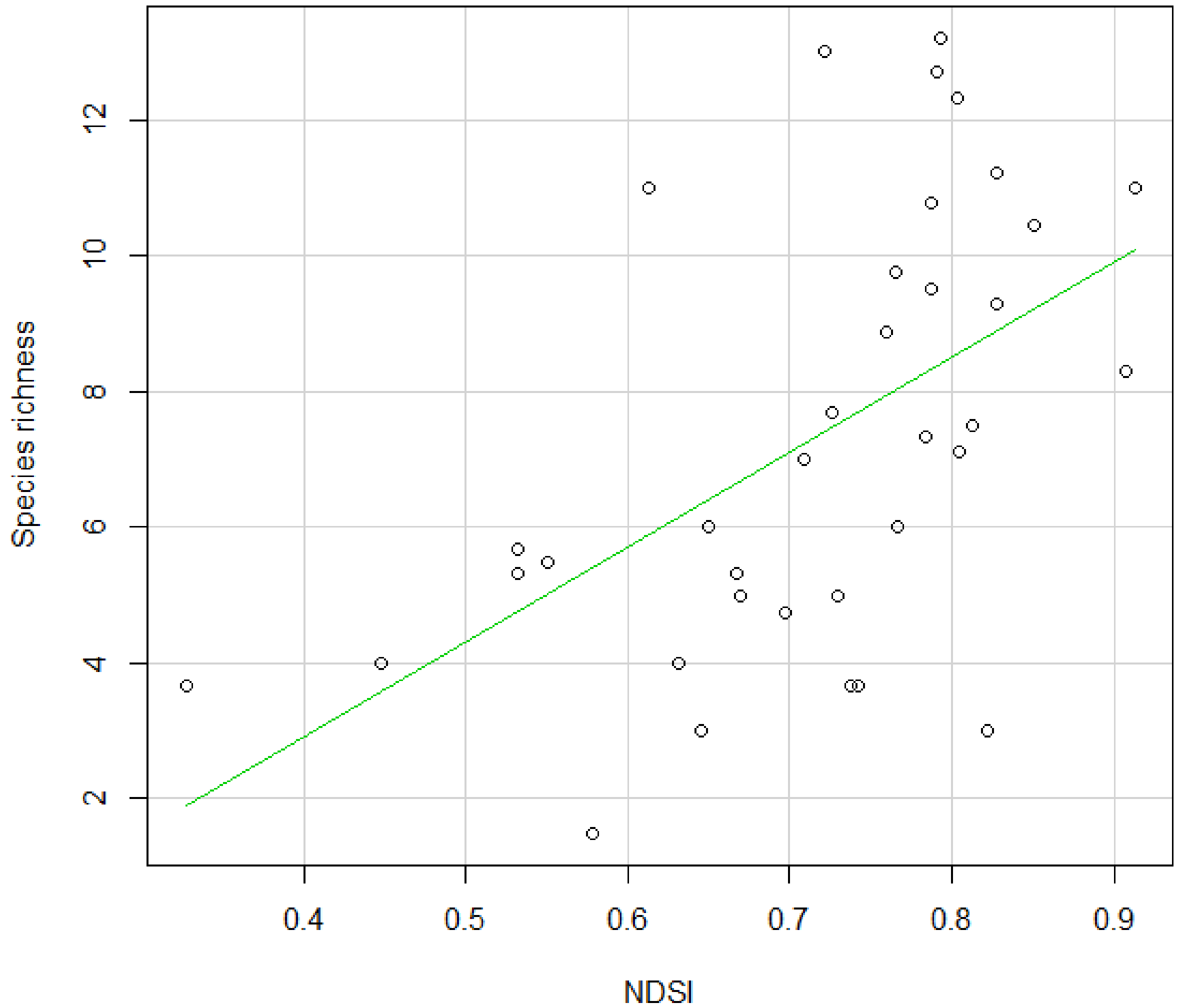

Figure 7: Relationship between technophony and species richness from sound files.