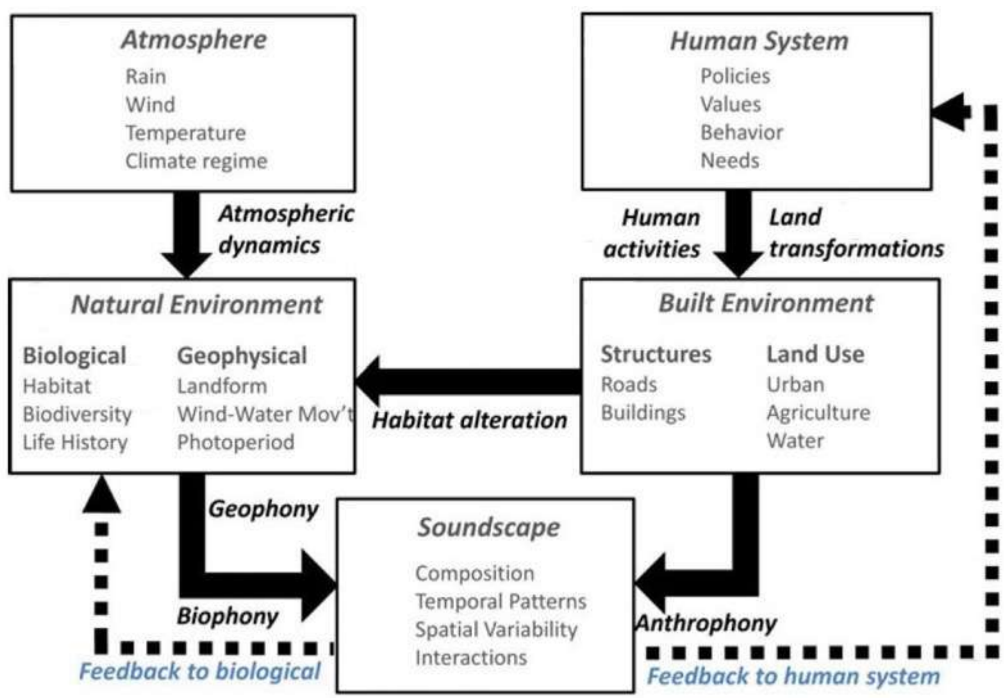
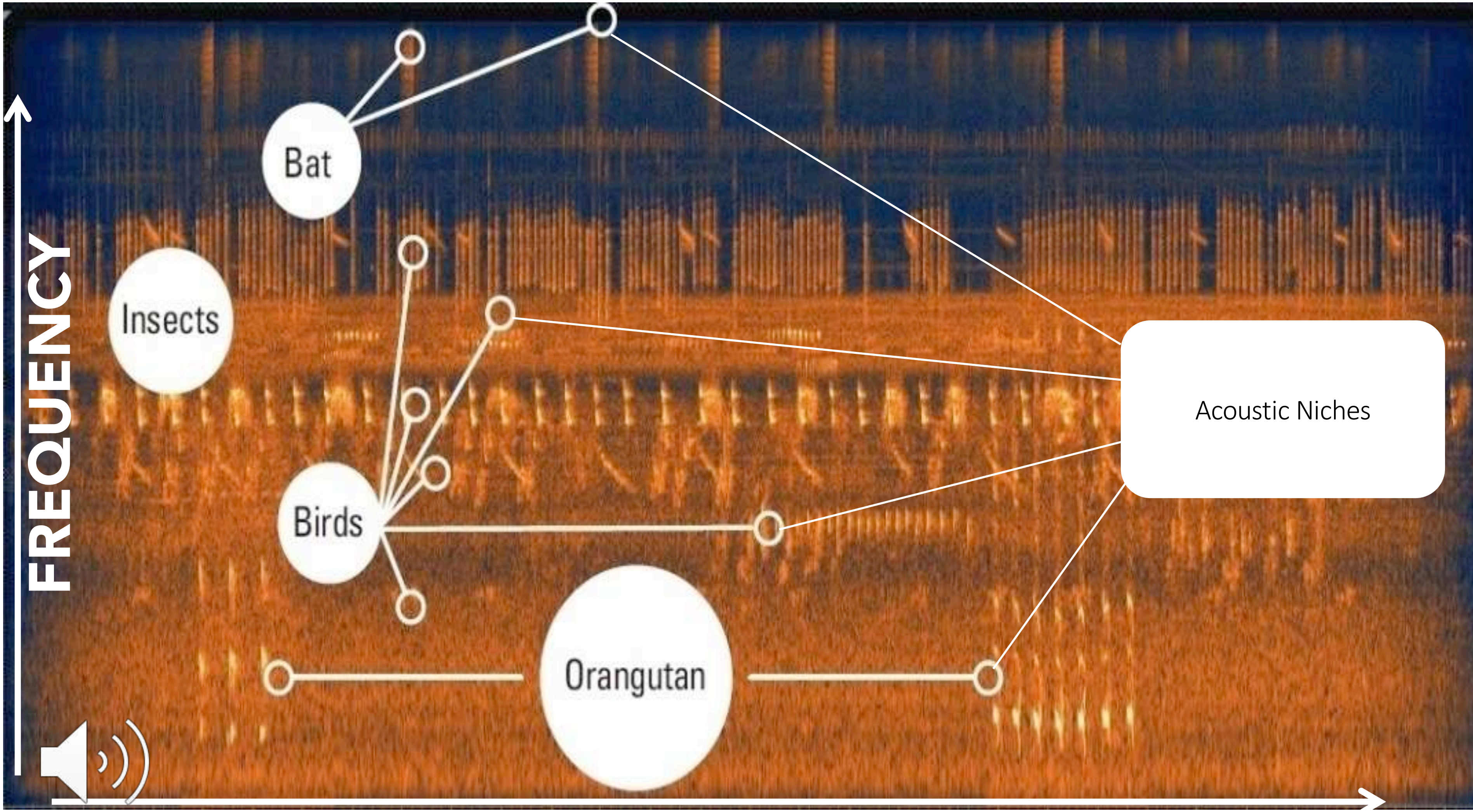

SOUNDSCAPES
@abr_eco

What is Soundscape Ecology?

- New field since 2009
- Soundscape = biophony + anthrophony + geophany
- Soundscapes are an extension of, and thus related to, the landscape that produces them



Processes contributing to soundscape creation and character (Pijanowski *et al.*, 2011)



Credit – Bernie Krause

@abr_eco

Freshwater Soundscape

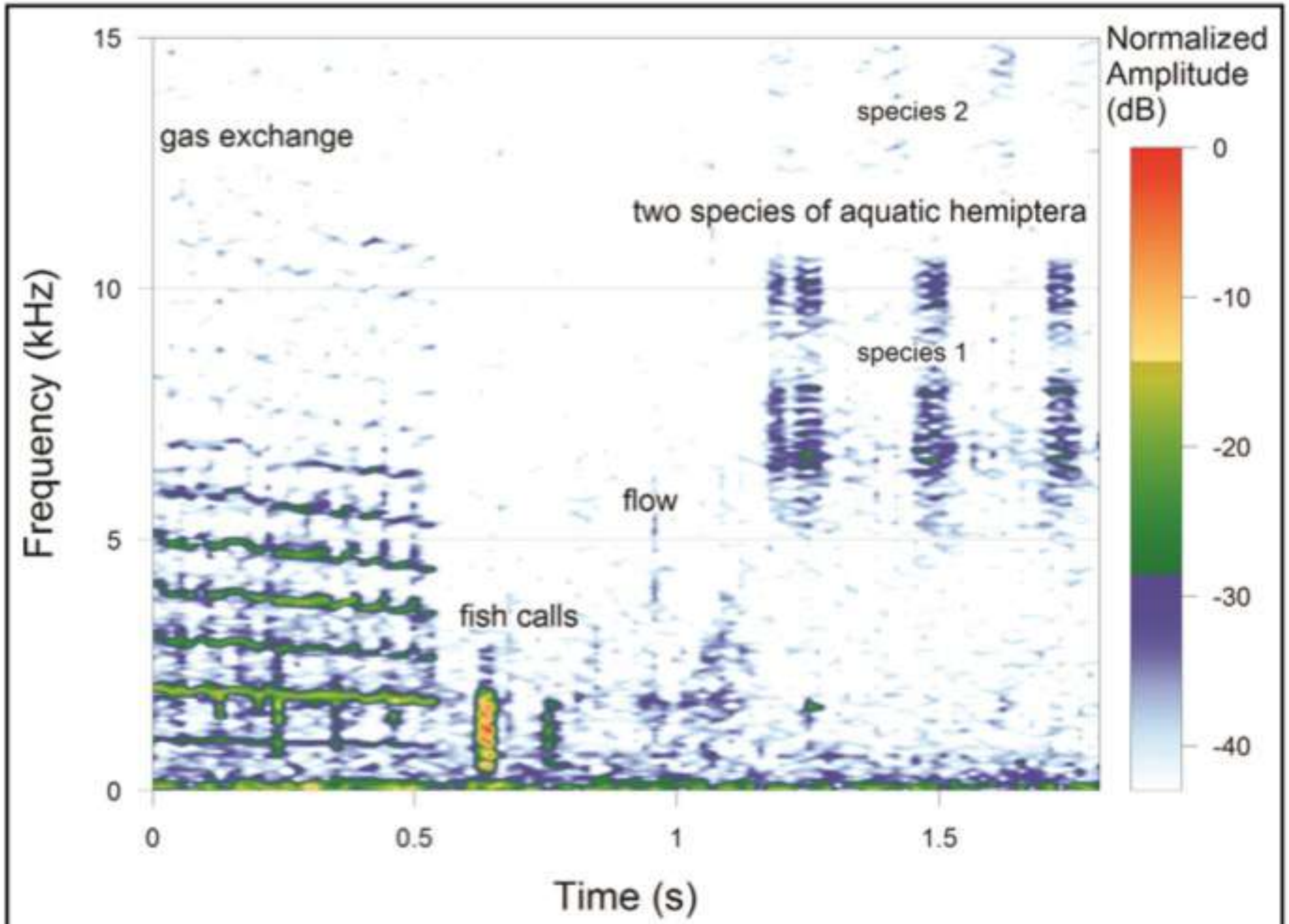


Figure 3. *Whole-ecosystem monitoring: a spectrogram from the Einasleigh River, North Queensland, Australia, featuring sediment gas exchange, fish calls from* Leiopotherapon unicolor, *flow turbulence, and two species of aquatic Hemiptera.*

@abr_eco

Natural Sounds

A Symphony of Trees, Grasses, Birds and Streams

Acoustic Indices

Normalised Difference Soundscape Index (NDSI)

Spectral Entropy (*H*[s])

Signal-to-Noise Ratio (SNR)

Acoustic Dissimilarity Index (ADI)

Acoustic Evenness Index (AEI)

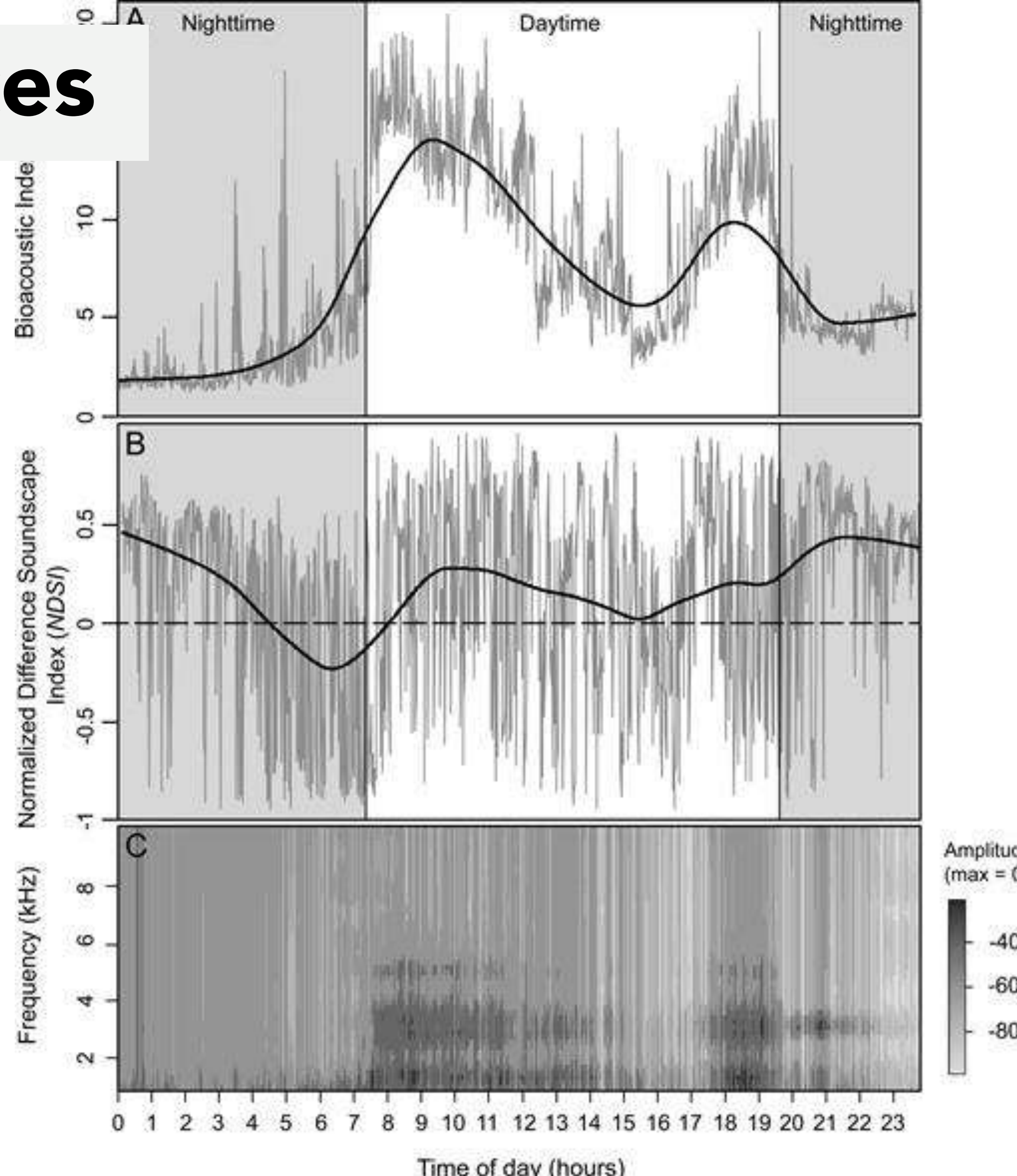
Acoustic Richness Index (AR)

Acoustic Complexity Index (ACI)

Acoustic Diversity Index (ADI)

Spectral Diversity

Bioacoustic Index (BI)



https://doi.org/10.1642/AUK-16-124.1

@abr_eco

alpha indices	
ACI	Acoustic Complexity Index
AR	Acoustic Richness index
M	Amplitude index
roughness	Roughness of a curve (a time wave or a spectrum)
rugo	Rugosity of a time wave or time series
th	Temporal entropy
fpeaks	Frequency peaks detection
H	Total entropy
NDSI	Normalized Difference Soundscape Index
roughness	Roughness of a curve (a time wave or a spectrum)
sfm	Spectral Flatness Measure
specprop	Spectral properties
beta indices	
diffenv	Difference between two amplitude envelopes
diffcumspec	Difference between two cumulated frequency spectra
diffspec	Difference between two frequency spectra
diffwave	Difference between two time waves
itakura.dist	Itakura-Saito distance
kl.dist	Kullback-Leibler distance
ks.dist	Kolmogorov-Smirnov distance
logspec.dist	Log-spectral distance
simspec	Similarity between two frequency spectra

NDSI

- NDSI calculates the ratio of human-generated (anthropophony) to biological (biophony) acoustic components
- Anthropophony is 1-2 kHz frequency bin and the biophony as the 2-8 kHz frequency bin
- NDSI is computed according to:

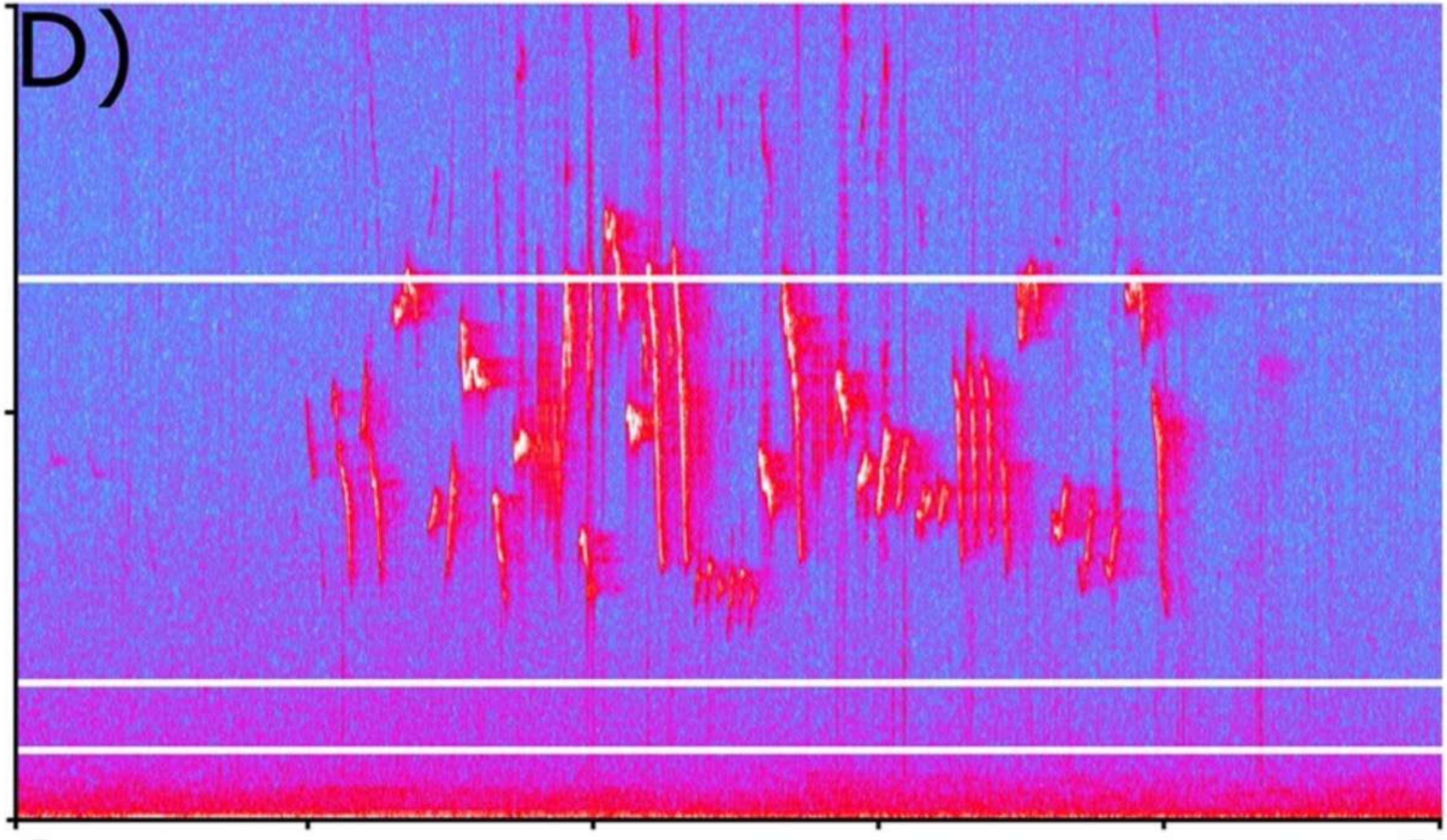
NDSI = (biophony - anthropophony) / (biophony + anthropophony)

- NDSI varies between -1 and +1, where +1 indicates a signal containing no anthropophony.

```
## Note that 'tico' is not a soundscape recording...
data(tico)
spec <- soundscapespec(tico, plot=FALSE)
NDSI(spec)
```

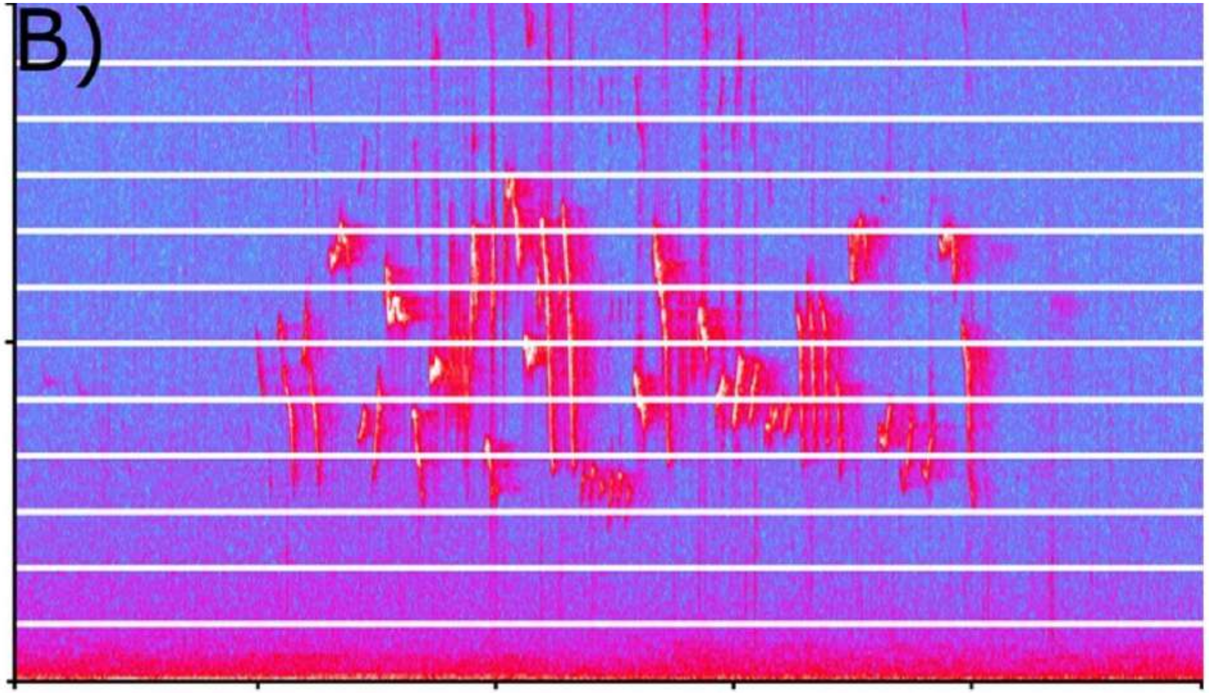
Normalised Difference Soundscape Index (NDSI) (Kasten et al., 2012).

NDSI



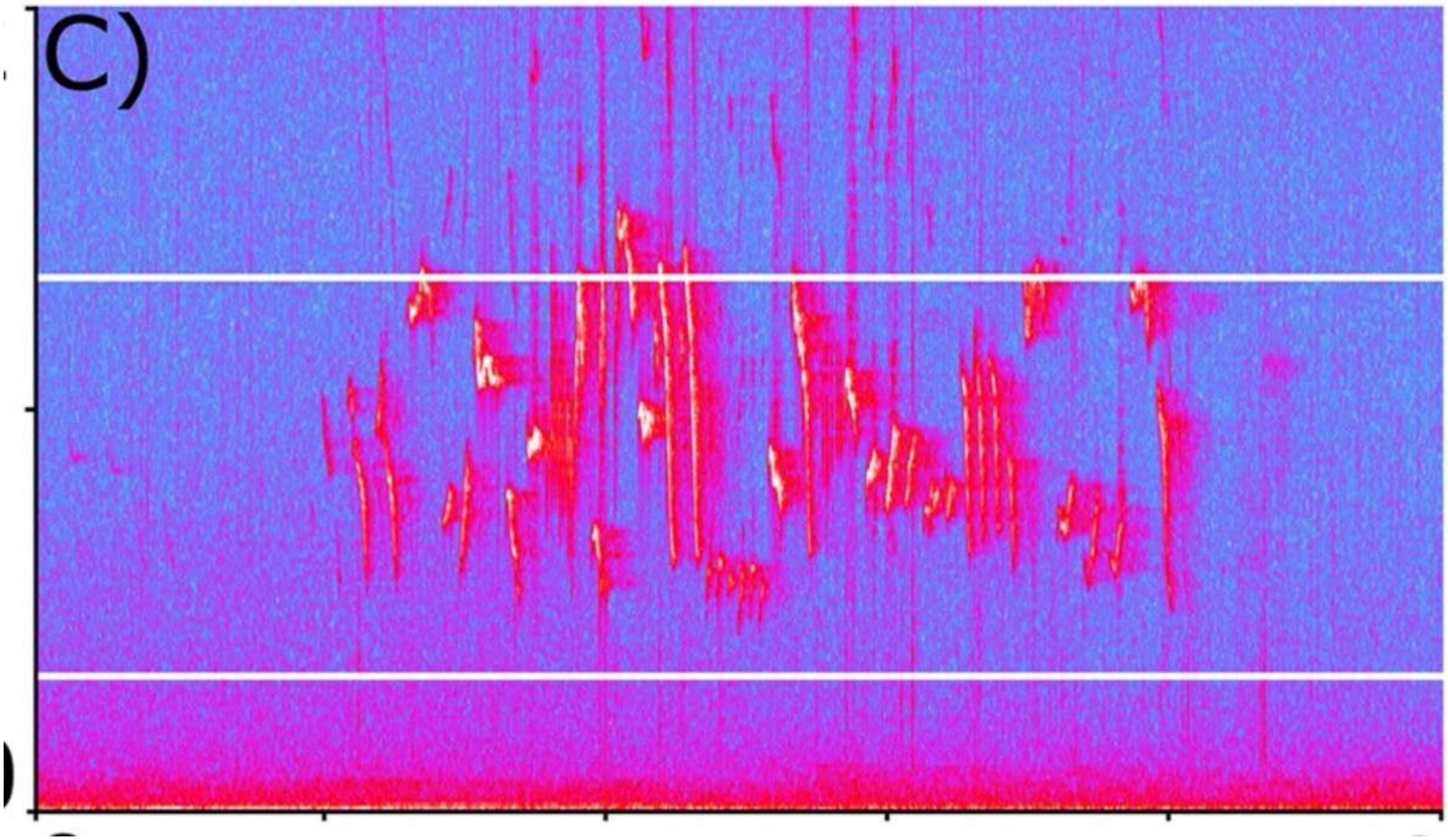
Acoustic Diversity Index (ADI)

- ADI_l is calculated as the Shannon's diversity index for each recording based on the signal power occupancy of each 1 kHz frequency ban



Acoustic Diversity Index (ADI) (Villanueva-Rivera et al., 2011)

Bioacoustic Index

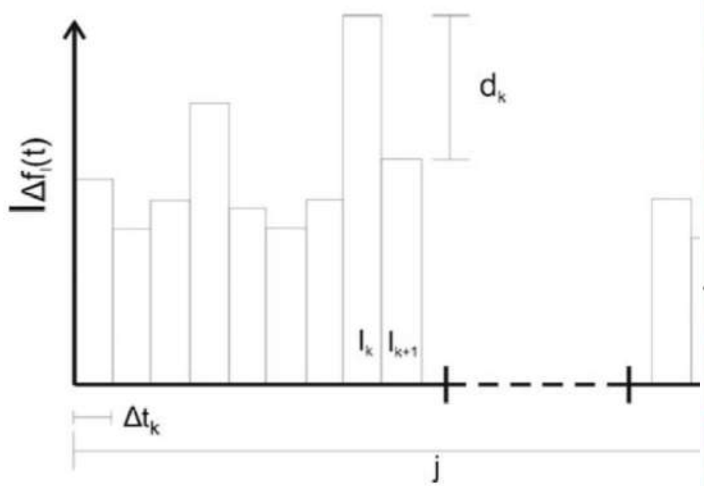


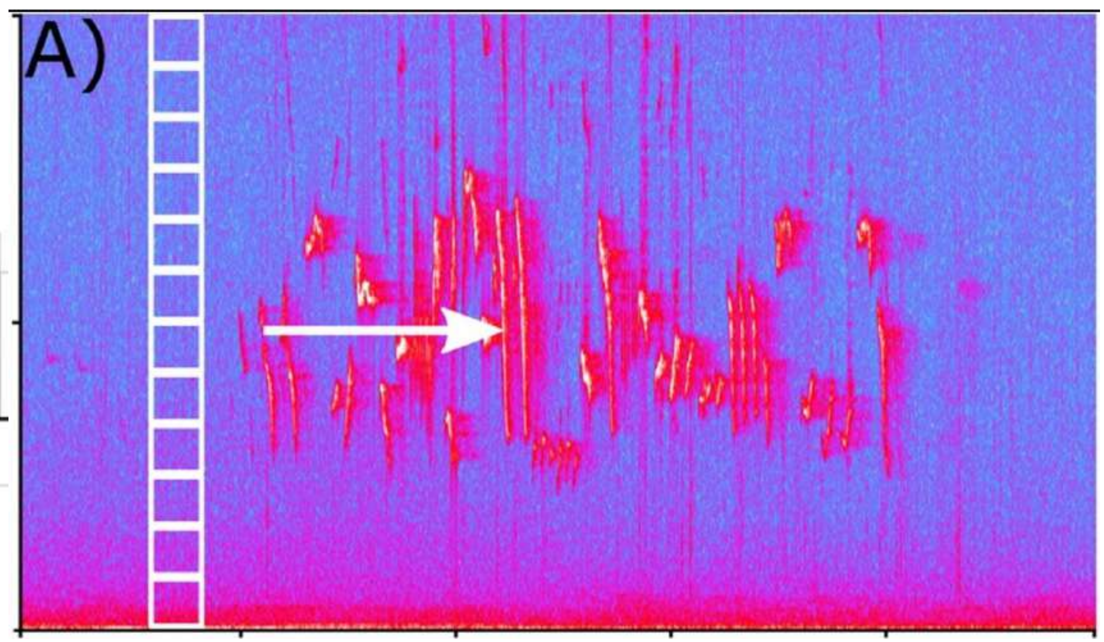
BI_l calculates the signal power within 2–8 kHz frequency band of recording

Bioacoustic Index (BI) ([Boelman et al., 2007]())

Acoustic Complexity Index (ACI)

“significant correlation between the ACI values and the number of bird vocalizations… efficient in filtering out anthrophonies” Pieretti et al

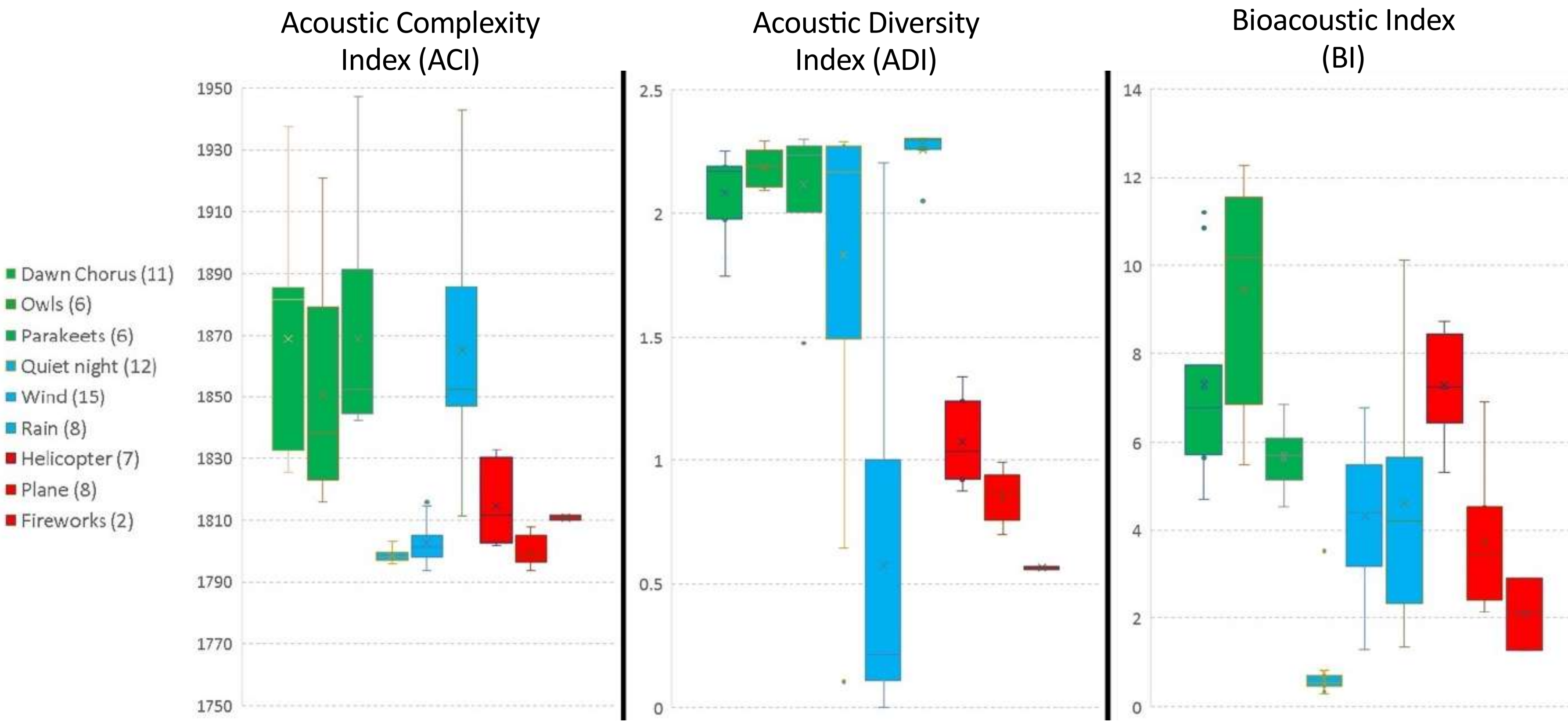




Acoustic Complexity Index (ACI) (Pieretti et al., 2011)

What Can Acoustic Indices Tell Us?

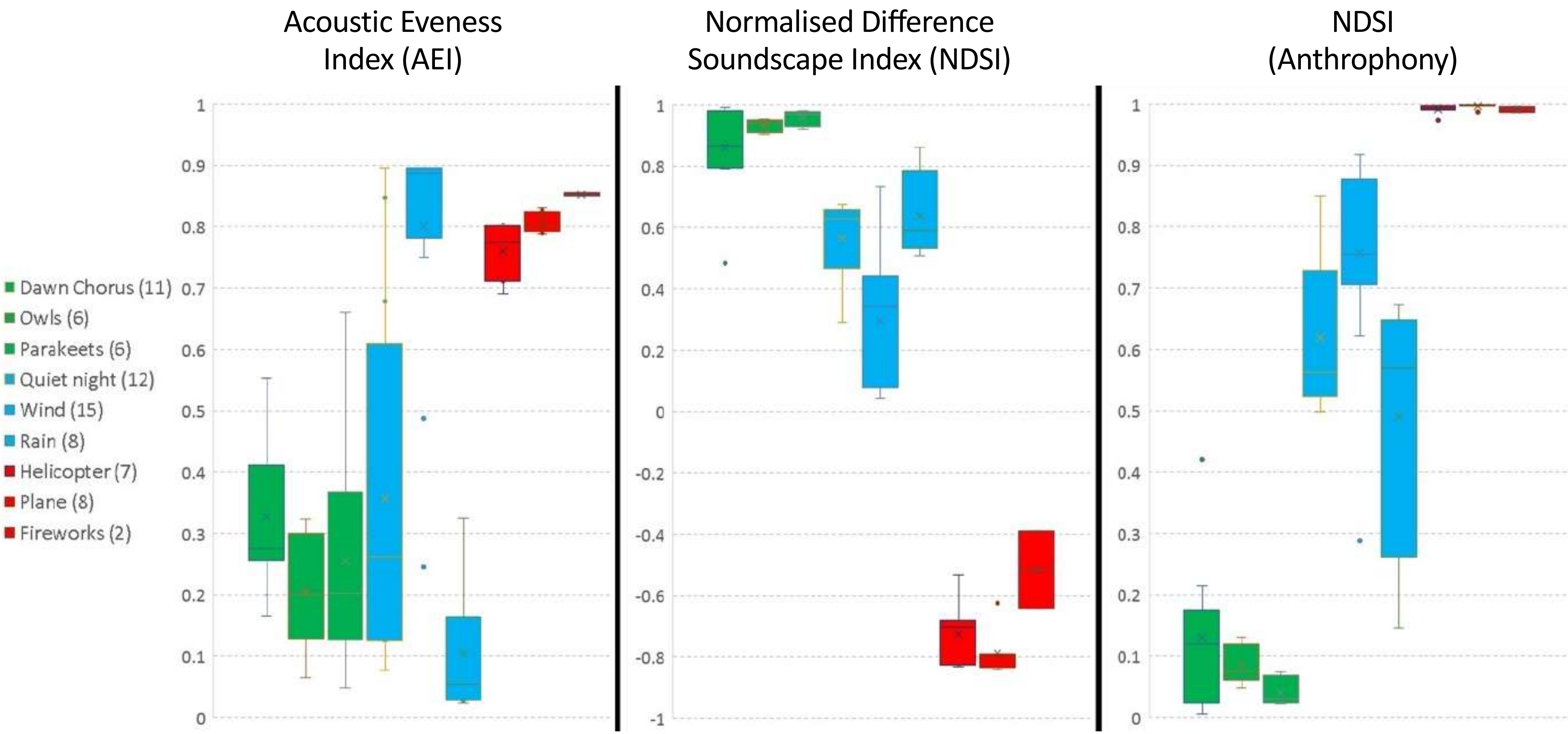
Acoustic indices can provide indications of bio-acoustic activity & species diversity, but more work is needed



@abr_eco

What Can Acoustic Indices Tell Us?

Acoustic indices can provide indications of bio-acoustic activity & species diversity, but more work is needed



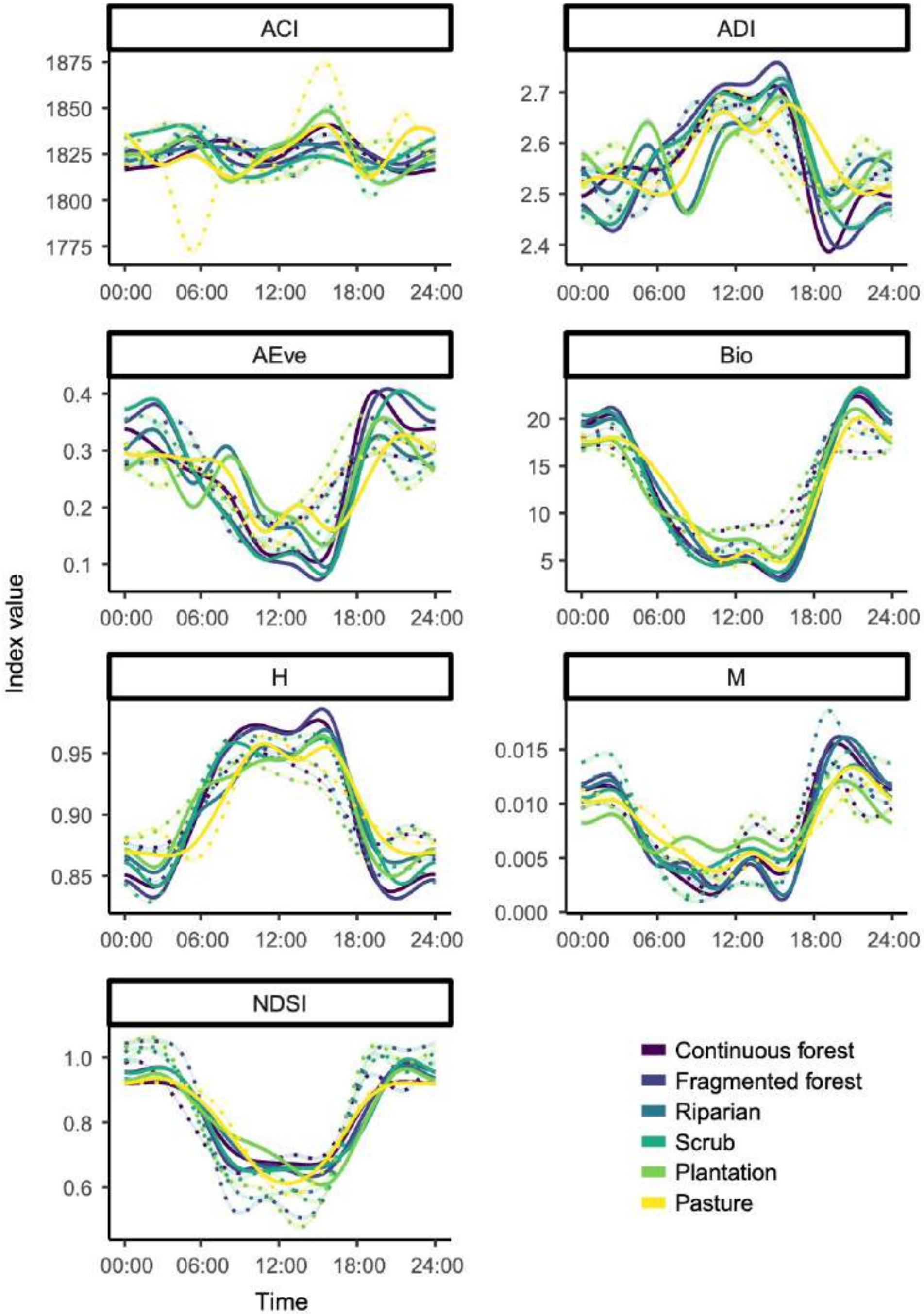


FIGURE 5 Diel patterns in mean acoustic indices, with predicted values and standard errors from GAM output for each habitat. Solid line shows dry season values, dashed line wet season. Values calculated for each 10-min recording window over 24 hr, from 154 recording sets

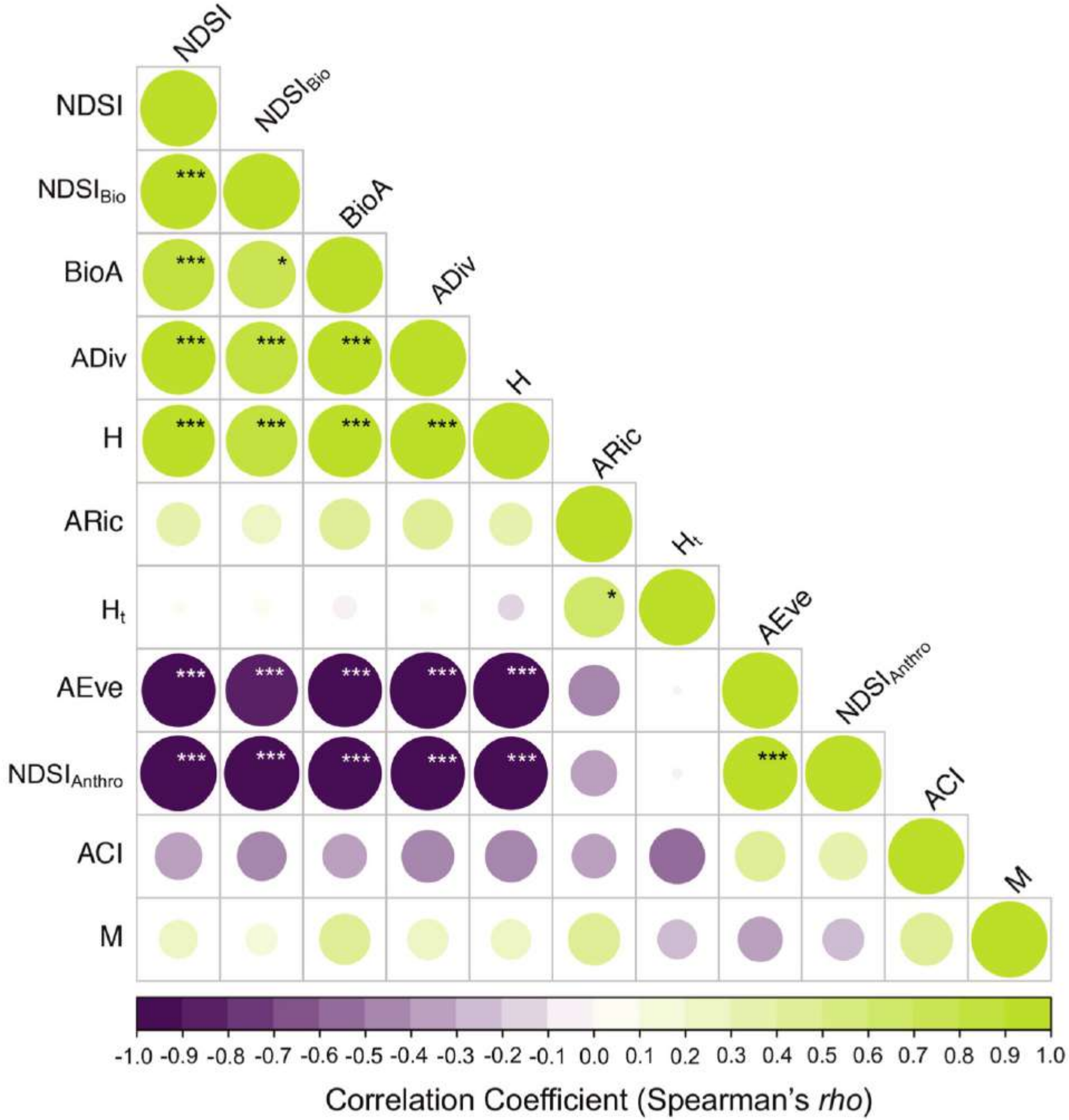


Fig. 1. Pairwise relationships between acoustic indices. Size and colour of circles represents the correlation coefficient (Spearman's *rho*) between pairs of acoustic indices. Significance level of pairwise correlations is represented with * ($P < 0.05$), ** ($P < 0.01$) and *** ($P < 0.005$). We found one main suite of positively correlating indices, comprising NDSI, NDSI$_{Bio}$, BioA, ADiv, H, AEve, and NDSI$_{Anthro}$.

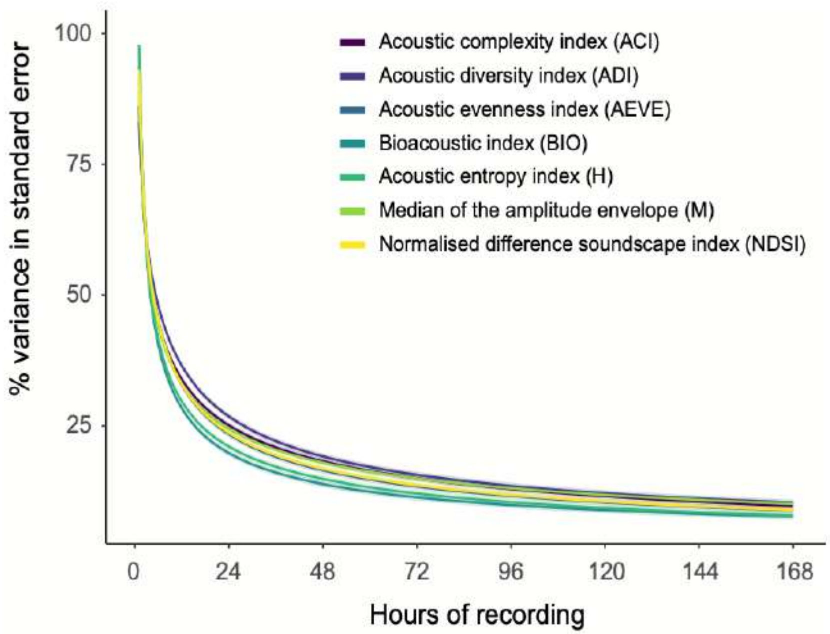


FIGURE 2 Reduction in variance of standard errors for seven acoustic indices, from a total of 154 recordings sets. Curves for each index show predicted values from nonlinear regression models with a Weibull distribution ± 1 *SD*

3 | RESULTS

3.1 | Minimum quantity of recordings and recording schedules

Standard errors rapidly shrank with increasing deployment time; all

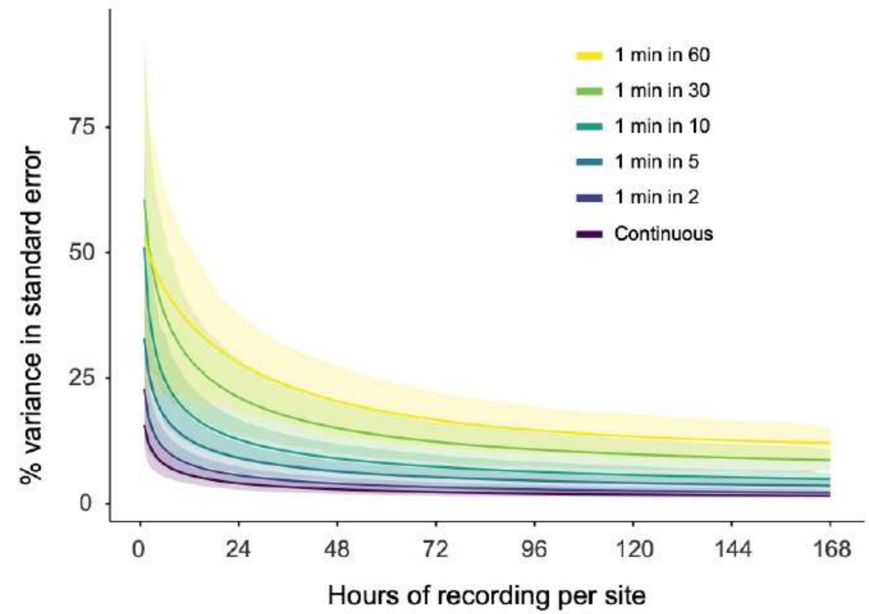


FIGURE 3 Effect of collecting audio recordings on a schedule. Reduction in variance of standard errors for six temporal recording schedules with increasing lengths of recording. Total dataset includes seven acoustic indices from 154 recording sets. Curves show predicted values from nonlinear regression models with a Weibull distribution ± 1 *SD*

Table 1
Recommendations for acoustic index use under different sonic conditions. Recommended acoustic indices based on the results of this study and others when handling audio data including different conditions: presence of geophony, anthropophony, broadband insect stridulations, or study designs including different seasons. All/unknown is when not specifically considering any of the above conditions, but all may be present in the study design, hence the recommendations in this category are conservative recommendations for where sonic conditions are highly variable.

Study Conditions	Recommended Indices	Details
All/unknown	H_t, ARic, $NDSI_{Anthro}$, NDSI	Across all sonic conditions, H_t and ARic performed best, followed by $NDSI_{Anthro}$. NDSI performed less well but was insensitive to all three sonic conditions. Bradfer-Lawrence et al., (2020) found that species rich sites exhibit temporally variable soundscapes, and we observed this pattern in our study.
Anthropophony	H_t, ARic, $NDSI_{Bio}$	ARic and H_t were related significantly to richness in the presence of anthropophony in our study and in that of Depraetere et al., (2012). $NDSI_{Bio}$ was insensitive to anthropophony here and elsewhere (Fairbrass et al., 2017; Kasten et al., 2012).
Geophony	H_t, ACI	H_t was related significantly to richness in the presence of geophony in our study. ACI was insensitive to geophony here and in Sánchez-Giraldo et al. (2020), but did not correlate with richness.
Broadband Insects	BioA	BioA was least sensitive to insect stridulations in our study. Eldridge et al., (2018) found BioA largely ignores high-frequency insect noise.
Multiple Seasons	H_t, ARic, NDSI, H	H_t and ARic did not differ largely between seasons in their performance. NDSI was not significantly affected by any sonic conditions when considering seasons. We found H was fairly robust to seasonality, as did Mammides et al., (2017). NB: seasonal effects likely differ among studies.

TABLE 1 Summary of the indices used in this study, the general soundscape patterns they reflect, and examples from this study. Further information including how the indices are calculated is detailed in Table S2

Index and reference	Soundscape patterns	Patterns in this study
Acoustic Complexity Index (ACI) (Pieretti, Farina, & Morri, 2011)	Based on difference in amplitude between one time sample and the next within a frequency band, relative to the total amplitude within that band. Designed to quantify the inherent irregularity in biophony, while being relatively impervious to persistent sound of a constant intensity.	High values indicate storms, intermittent rain drops falling from vegetation, stridulating insects, or high levels of bird activity. Lowest values came from recordings with consistent cicada noise that fills the whole spectrogram.
Acoustic Diversity Index (ADI) (Villanueva-Rivera et al., 2011)	Increases with greater evenness across frequency bands. An even signal (either noisy across all frequency bands or completely silent) will give a high value, whereas a pure tone (i.e. all energy in one frequency band) will be closer to 0.	Highest values were from recordings with high levels of geophony or anthrophony (wind, helicopters or trucks) blanketing the spectrogram with noise, or from very quiet recordings with little variation among frequency bands. Lowest values reflect dominance of a narrow frequency band, usually by nocturnal insect noise.
Acoustic Evenness (AEve) (Villanueva-Rivera et al., 2011)	Higher values indicating greater unevenness among frequency bands, when there is a greater sound intensity in a restricted range of frequencies. Acoustically rich habitats may produce low values because there is little variation in intensity among frequency bands in saturated soundscapes.	Reverse of ADI patterns. High values identify recordings with dominance by a narrow frequency band of insect noise. Low values are associated with windy recordings with many occupied frequency bands, or near silent recordings with no acoustic activity.
Bioacoustic Index (Bio) (Boelman, Asner, Hart, & Martin, 2007)	A function of both amplitude and number of occupied frequency bands between 2 and 11 kHz. Value is relative to the quietest 1 kHz frequency band; higher values indicate greater disparity between loudest and quietest bands.	Highest values produced by blanket cicada noise, with high amplitude and minimal variation among frequency bands. Low values arise when there is no sound between 2 and 11 kHz, although there is sometimes insect biophony outside these bounds.
Acoustic entropy (H) (Sueur, Pavoine, et al., 2008)	Increases with greater evenness of amplitude among frequency bands and/or time steps. Returns a value between 1 (an even signal, either noisy across frequency bands or completely silent) and 0 (a pure tone with all energy in one frequency band).	Highest values come from near-silent recordings, with no wind, and only faint bird calls. Lowest values produced when insect noise dominated a single frequency band.
Median of the amplitude envelope (M) (Depraetere et al., 2012)	Reflects the amplitude of a recording. Louder recordings will give higher values, reflecting noisier soundscapes.	Highest values associated with high levels of geophony, particularly storms. Low levels of M produced by very quiet recordings, with little biophony or geophony.
Normalized Difference Soundscape Index (NDSI) (Kasten, Gage, Fox, & Joo, 2012)	Relies on a theoretical frequency split between anthrophony (1–2 kHz) and biophony (2–11 kHz). The ratio of the two components give values of −1 to +1, with +1 indicating no anthrophony in the soundscape.	High values reflect high levels of insect biophony, with minimal noise in the 1–2 kHz range. Low values arise when insect biophony dominates the 1–2 kHz band.

Carsington ACI Exercise