Analysis of massive acoustic sampling (in ecology)

Jérôme Sueur

MUSÉUM
NATIONAL
D'HISTOIRE
NATURELLE

28/11/2013
Journées du Centre Blaise Pascal
Data analysis and modelling in life sciences

Layout

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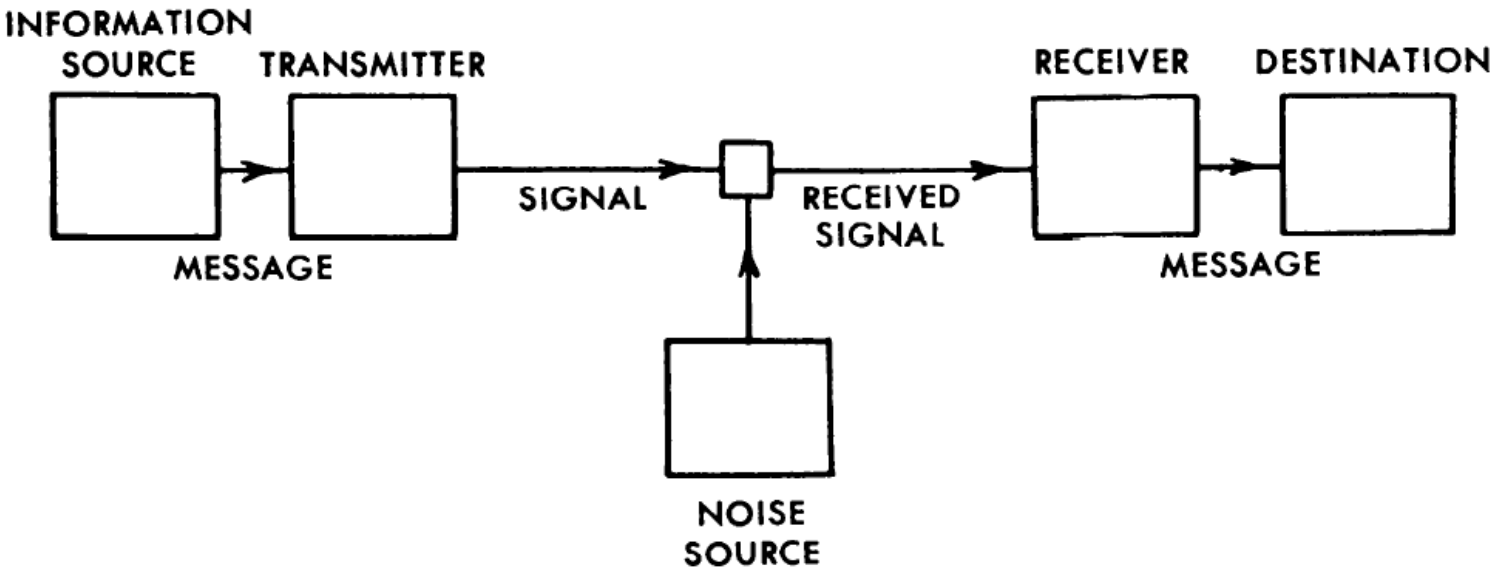
Bioacoustics and ecology

Definition

Bioacoustics is a section of life sciences that is in charge of understanding the

emission,
propagation
and **reception** of sound by animals



CE Shannon & W Weaver (1949) *The mathematical theory of communication*.

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Bioacoustics and ecology

Definition

C. Curé

Some questions addressed in bioacoustics:

- What is the vocal repertoire of *Piou piou*?

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- How did sound signals evolved in a *Piou* group?

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- ...

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Bioacoustics and ecology

Definition

Bioacoustics can be considered therefore as:

interdisciplinary ethology, neurology, biomechanics, evolution, paleontology, ...

species-centered organ, individual, population, species

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A SINGLE SINGING SPECIES

Drawing by Jean Poinsignon

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ACOUSTIC GUILD OR ACOUSTIC COMMUNITY OR SOUNDSCAPE

Drawing by Jean Poinsignon

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Breakdown the species-centered framework of bioacoustics to investigate ecological questions with sound

Breakdown the species-centered framework of bioacoustics to investigate ecological questions with sound

~~Individual~~	$\rightarrow$	Guild
~~Population~~		Community
~~Species~~		Landscape

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Bioacoustics and ecology

Change of scale

Three important challenges linking acoustics and ecology:

1. to assess and monitor animal diversity

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Bioacoustics and ecology

Change of scale

Three important challenges linking acoustics and ecology:

1. to assess and monitor animal diversity
2. to understand animal species interactions

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Bioacoustics and ecology

Change of scale

Three important challenges linking acoustics and ecology:

1. to assess and monitor animal diversity
2. to understand animal species interactions
3. to measure and mitigate human noise pollution on animal vocalisations

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Bioacoustics and ecology

Change of scale

1. to assess and monitor animal diversity

- Who are you?
- Where are you?
- When are you there?
- How many are you?
- What do you do?
- ...

K-H Frommolt

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2. to understand animal species interactions

- Do you interact acoustically?
- If so, do you compete or collaborate through sound?
- How do you share the acoustic ressource?
- What is the size and shape of your acoustic niche?
- What are the dynamics of your acoustic interactions?
- ...

namesofbirds.net

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3. to measure and mitigate human noise pollution on animal vocalisations

- Do you care about noise?
- Does noise change your behaviour / your physiology / your survival rate?
- Can we reduce the impact of noise in natural habitats?
- ...

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These challenges imply a change of scale in:

- sampling

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These challenges imply a change of scale in:

- sampling
- sample analysis

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These challenges imply a change of scale in:

- sampling
- sample analysis
- data analysis

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Sampling

Recording at a large scale

Species-centered bioacoustics to record a specific individual of a targeted species: shotgun microphone or parabola

P. Aimar

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Sampling

Recording at a large scale

No more fore and background sound. To record as much as possible sound.
Omnidirectional microphones covering the **widest area** during the **longest time period**

G. Pavan

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise
- high data storage capacity

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise
- high data storage capacity
- fully programmable

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise
- high data storage capacity
- fully programmable
- resistant to harsh weather conditions

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise
- high data storage capacity
- fully programmable
- resistant to harsh weather conditions
- remotely accessible

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Recording at a large scale

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- remotely accessible
- ...

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Sampling

Recording at a large scale

Passive Acoustic Monitoring (PAM)

- low energy consumption
- low internal noise
- high data storage capacity
- fully programmable
- resistant to harsh weather conditions
- remotely accessible
- ...
- at a low cost!

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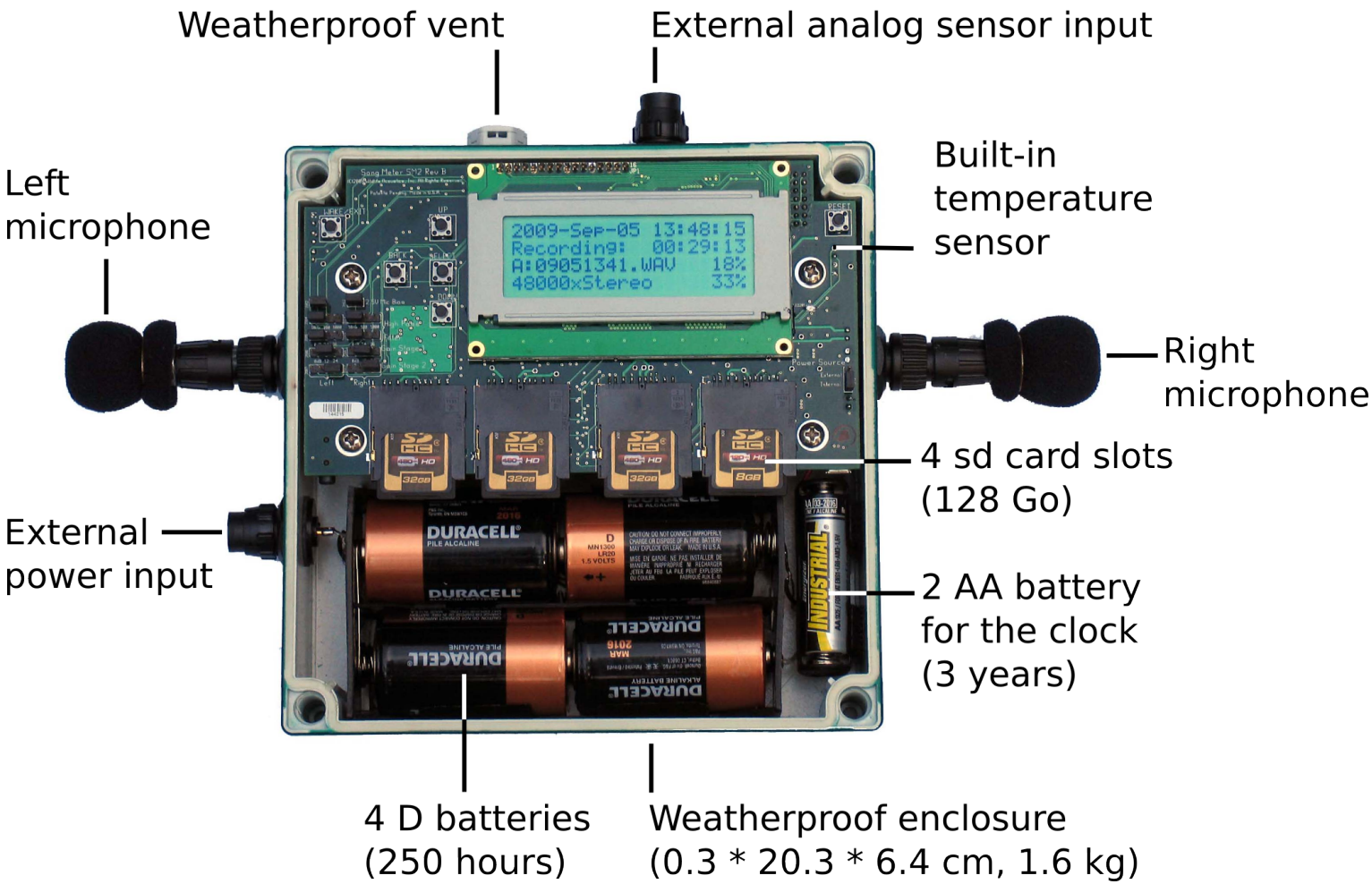
Microphone recording station (SM2)



©Wildlife Acoustics

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Sampling

Recording at a large scale

Monitoring of a mediterrenean soundscape (University of Urbino, Italy)

Farina & Pieretti, 2011

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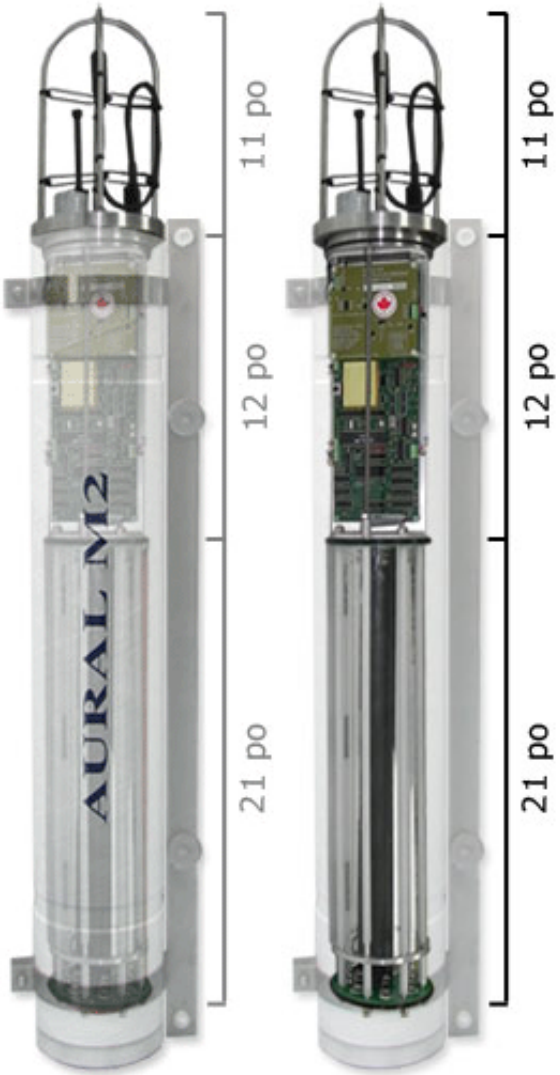
Sampling

Recording at a large scale

Hydrophone recording station (AURAL M2)



©Multi-Electronique

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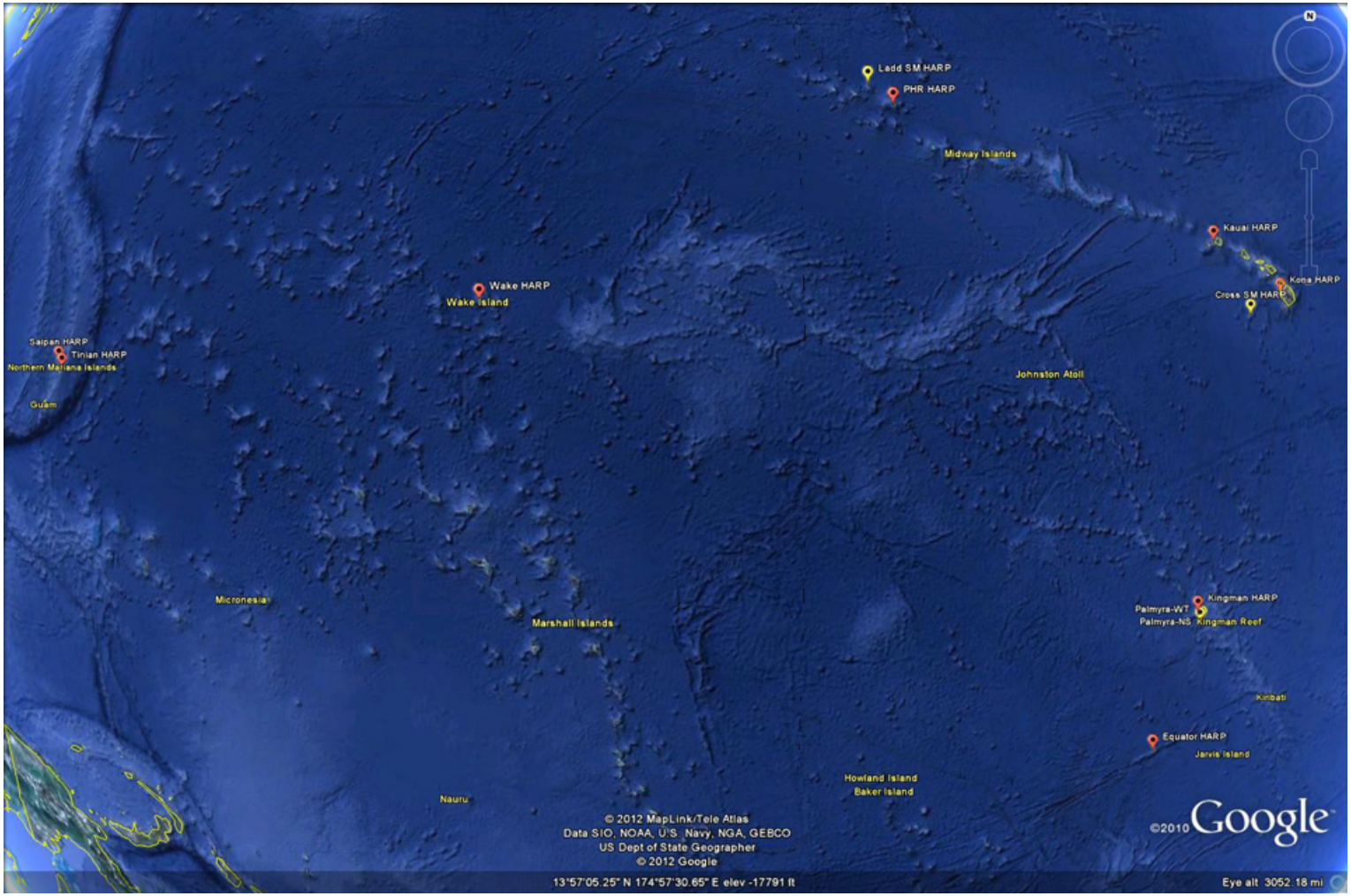
Sampling

Recording at a large scale

Cetacean occurrence and seasonality monitoring in the Pacific Islands Region (NOAA, USA)



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Sampling

Recording at a large scale

Research and money...

OCEAN SCIENCE CONSULTING

Contact OSC to discuss your Passive Acoustic Monitoring requirements

Name

Email

Tel

Enquiry

PASSIVE ACOUSTIC MONITORING (PAM) SYSTEMS

Passive acoustic monitoring (PAM) systems are underwater hydrophones (either towed arrays or static moored systems), top-end processing units and software that detect and process underwater sound.

Deployment and setup of one of Ocean Science Consulting's passive acoustic monitoring equipment on streamer sliding collars.
© OSC 2011.

Ocean Science Consulting (OSC) Ltd. uses specialised passive acoustic monitoring systems to detect the vocalisations of whales, dolphins, porpoises and other marine mammals, during seismic, pile-driving, drilling, naval exercises or other anthropogenic (man-made) industrial activities that produce loud underwater noise.

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Sampling

Files

Quite big datasets...

- $10 - 10^2$ recorders
- $10 - 10^5$ files
- $10 - 10^3$ Go

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Sampling

Files: file managing

shell	R
cd	`setwd()`
rm	`file.remove()`
cp	`file.copy()`
mv	`file.rename()`
ls	`dir()`
any command	`system()`

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Sampling

Files: file metadata

File name:

`K-XI_20101112_013000.wav`

K-XI : recorder ID

20101112 : recording date [yyyymmdd]

013000 : recording time [hhmmss]

File characteristics:

`@left` : left channel

`@right` : left channel

`@stereo` : stereo/mono

`@samp.rate` : sampling rate (f.i. 44100 Hz)

`@bit` : digital depth (f.i. 16 bit)

$\Rightarrow$ categorization, selection, sort

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Layout

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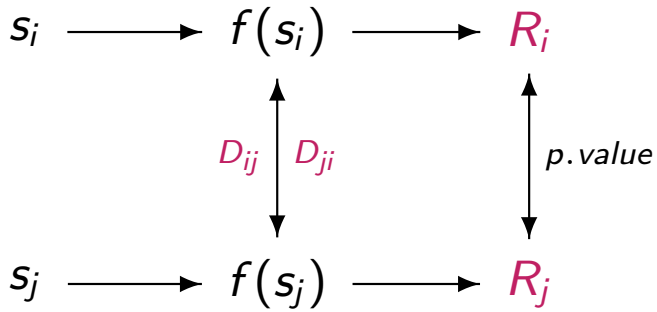
Sample analysis

Sound parametrization

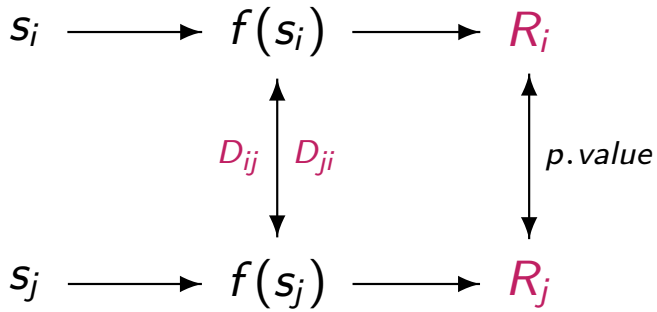


with:

s signal

Sample analysis

Sound parametrization



with:

- s signal
- f transform

Sample analysis

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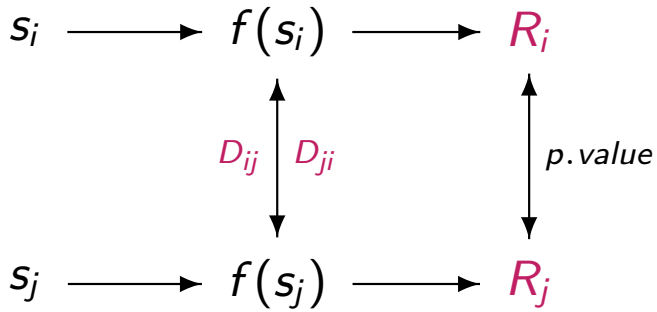
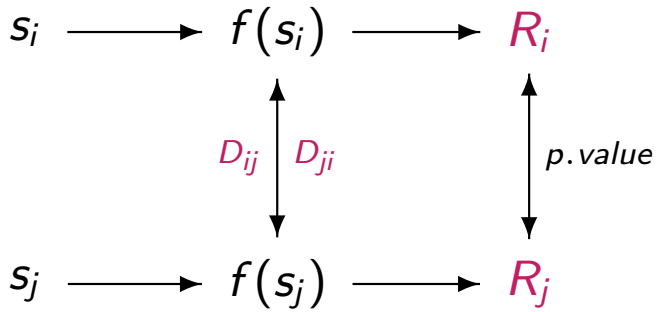


with:

- s signal
- f transform
- D (dis)similarity index – β diversity

Sample analysis

Sound parametrization



with:

- s signal
- f transform
- D (dis)similarity index – β diversity
- R richness / evenness index – α diversity

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Sample analysis

Tools

- `tuneR`: to read in/out `.wav` files

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Sample analysis

Tools

- `tuneR`: to read in/out `.wav` files
- `seewave`: for the parametrization of sound

  - since 2008
  - $>$ 110 end-user functions
  - time and frequency analysis (Fourier decomposition, etc)
  - sound visualization
  - sound synthesis

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Sample analysis

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  - since 2008
  - $>$ 110 end-user functions
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  - sound synthesis
- `ade4` for the analysis of ecological data

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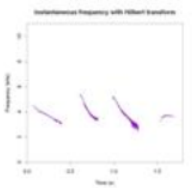
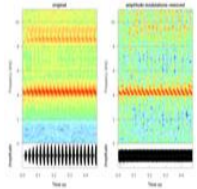
Sample analysis

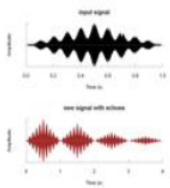
Tools

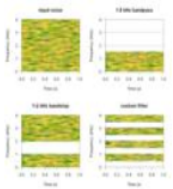
seewave

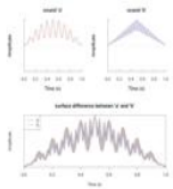
DESCRIPTION INSTALLATION DOCUMENTATION EXAMPLES CITATIONS LIST

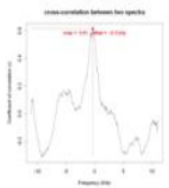

Instantaneous frequency (Hilbert transform)

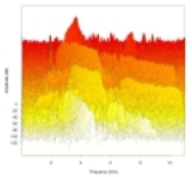

Removing amplitude modulations

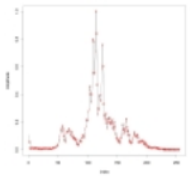

Generation of echoes

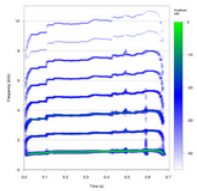

Frequency filter (FIR)

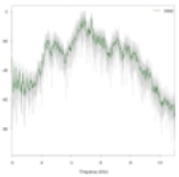

Envelope comparaison

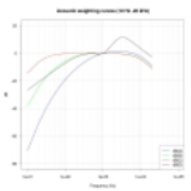

Spectrum cross-correlation

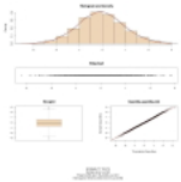

Waterfall plot

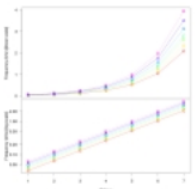

Symbol analysis

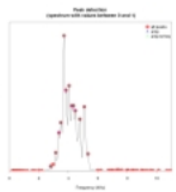

Changing the color palette

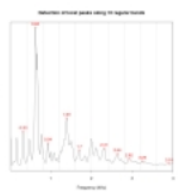

Computing specific spectra

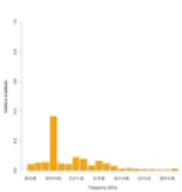

dB weightings

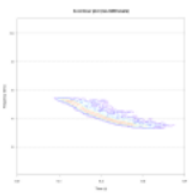

Quantitative data multi-plot

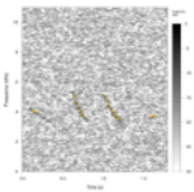



Peaks


Local peak


Animated


Contour


Dominant frequency track

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Sample analysis

Tools

- bioacoustics (frogs, fish, birds, insects, mammals)

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Sample analysis

Tools

- bioacoustics (frogs, fish, birds, insects, mammals)
- soundscape ecology

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Sample analysis

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- bioacoustics (frogs, fish, birds, insects, mammals)
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- city noise pollution

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Sample analysis

Tools

- bioacoustics (frogs, fish, birds, insects, mammals)
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- medical sciences (detection and prediction of alzheimer diseases)

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Sample analysis

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- speech analysis

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Sample analysis

Tools

- bioacoustics (frogs, fish, birds, insects, mammals)
- soundscape ecology
- city noise pollution
- medical sciences (detection and prediction of alzheimer diseases)
- psychology (emotion regulation)
- speech analysis
- musicology (timber analysis in musical acoustics)

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Sample analysis

Tools

Code example:

```
> library(tuneR)
> library(seewave)
> files <- dir('mydirectoy', pattern='*.wav')
> n <- length(files)
> results <- numeric(n)
> for i in (1: length(files)){
+ s <- readWave(files[i])
+ results[i] <- sh(meanspec(s))
}

> head(results)
> [1] 0.88 0.72 0.88 0.90 0.55 0.00
```

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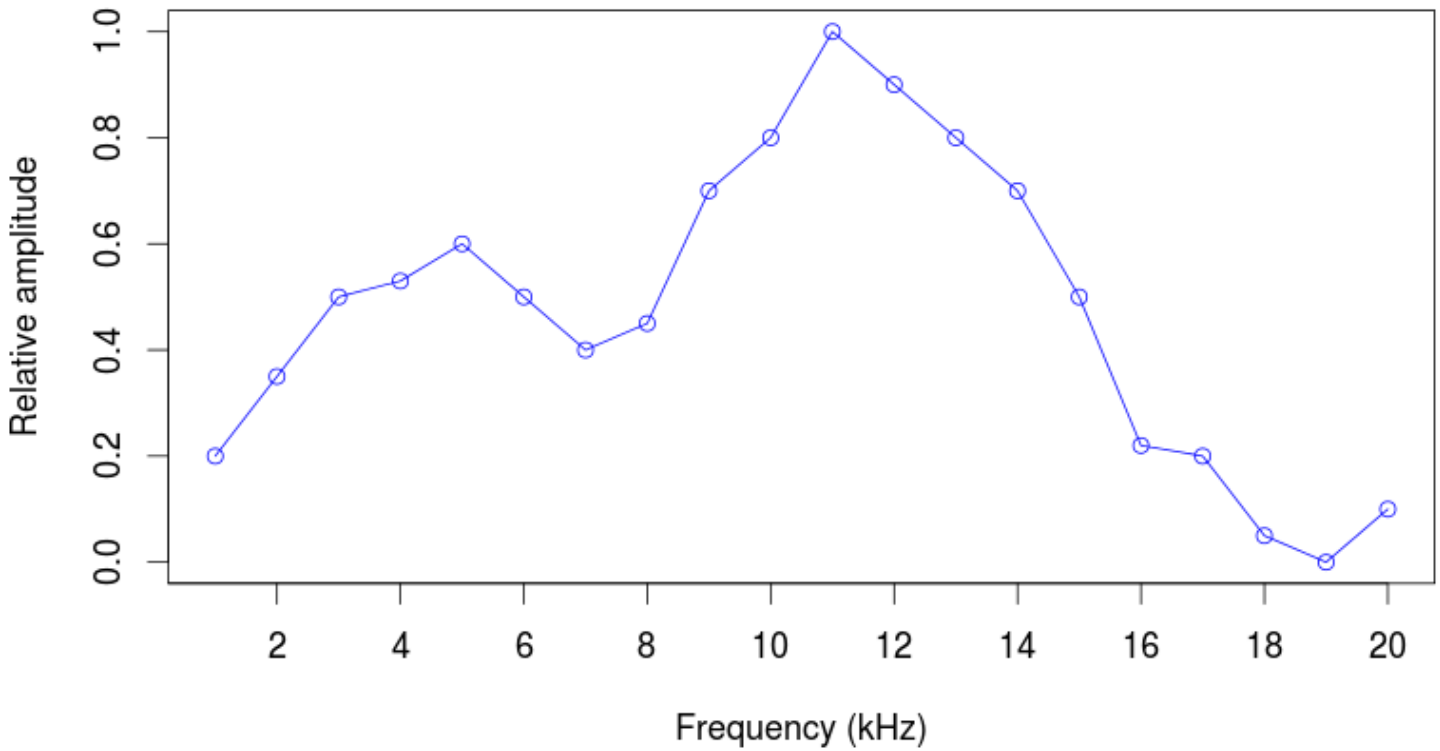
Sample analysis

Indices

α indices to parametrize a single sample

- entropy-like: H, H_f, H_t, AR, H', AEI, ADI
- complexity: ACI
- spectral: $NDSI$, $bioPeak$, ρ, NP
- amplitude: L_x, M



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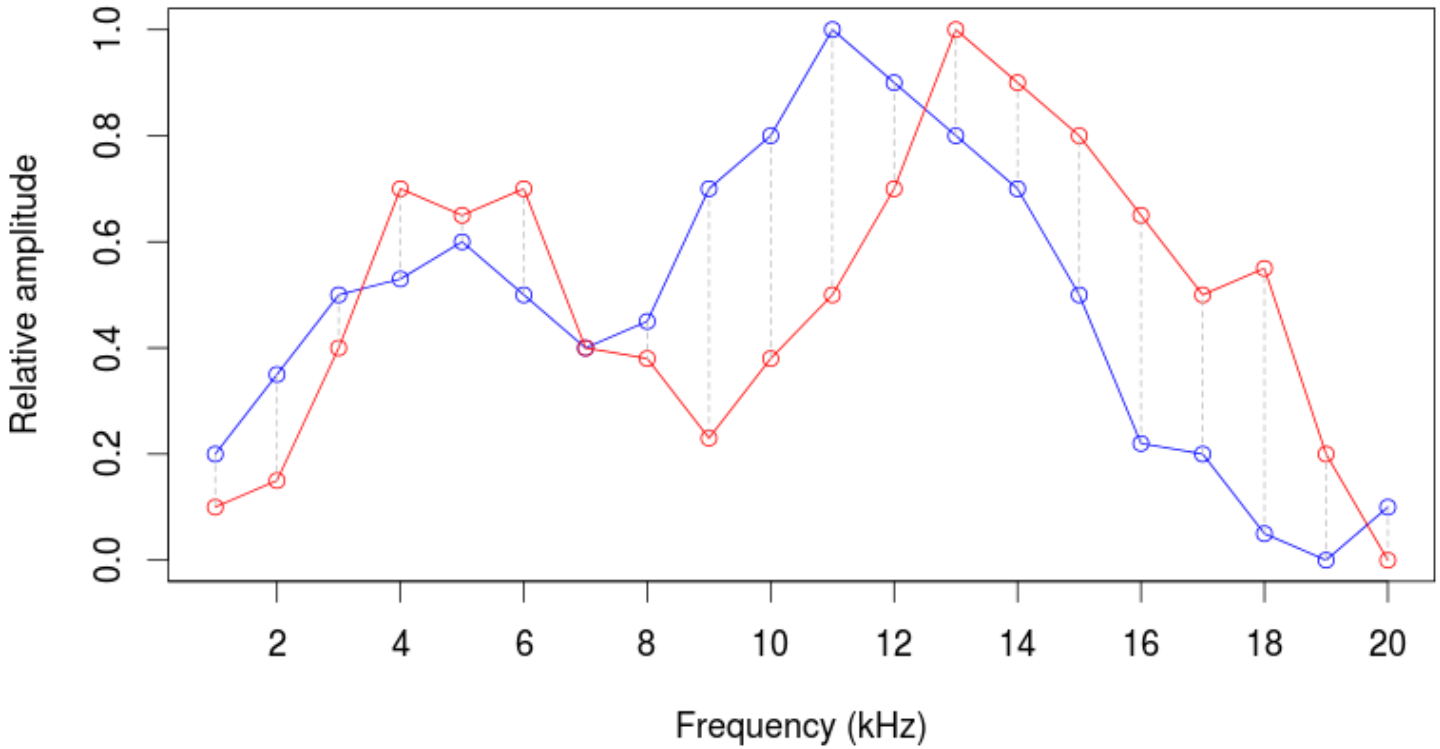
Sample analysis

Indices

β indices to comapare a pair of sample

- D, D_f, D_t, D_{cf}, KS, KL, ...
- KV



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Layout

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SongMeter

Spatial sampling

mature forest

young forest

forest edge

field crop

MUSÉUM NATIONAL D'HISTOIRE NATURELLE

Spatial sampling

mature forest

young forest

forest edge

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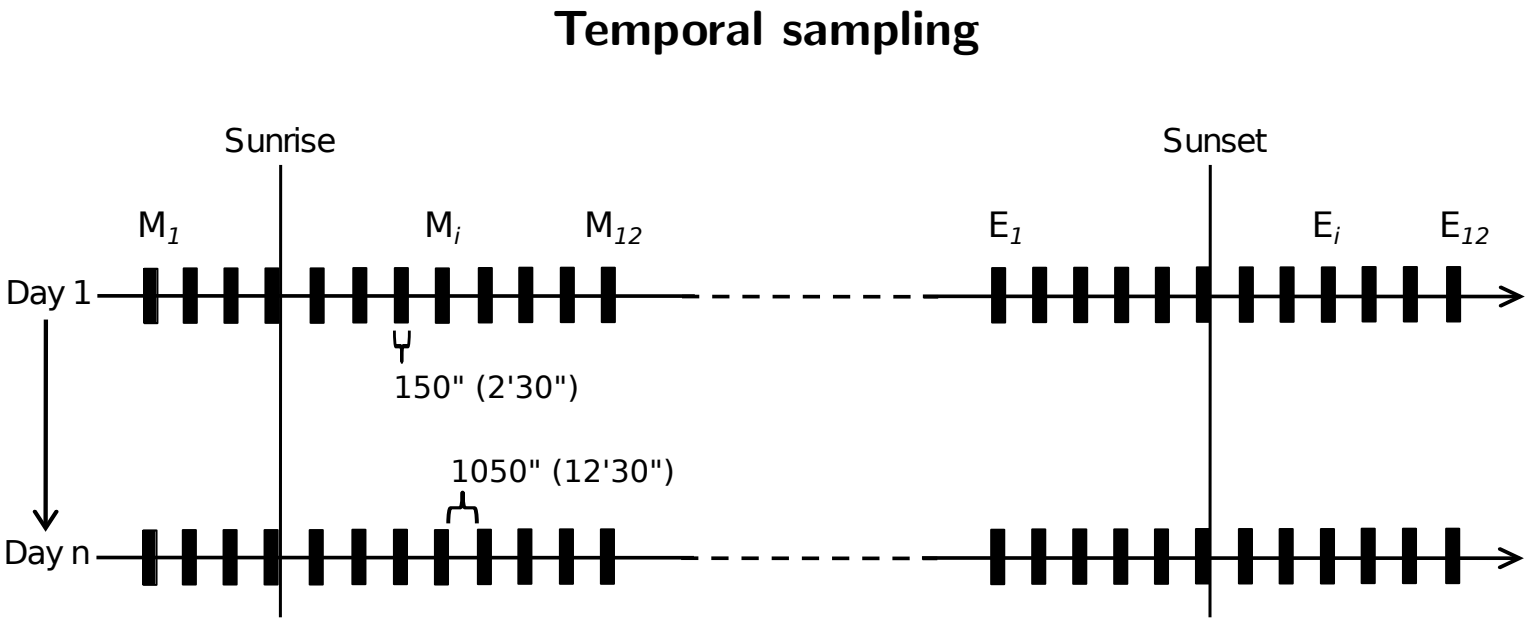
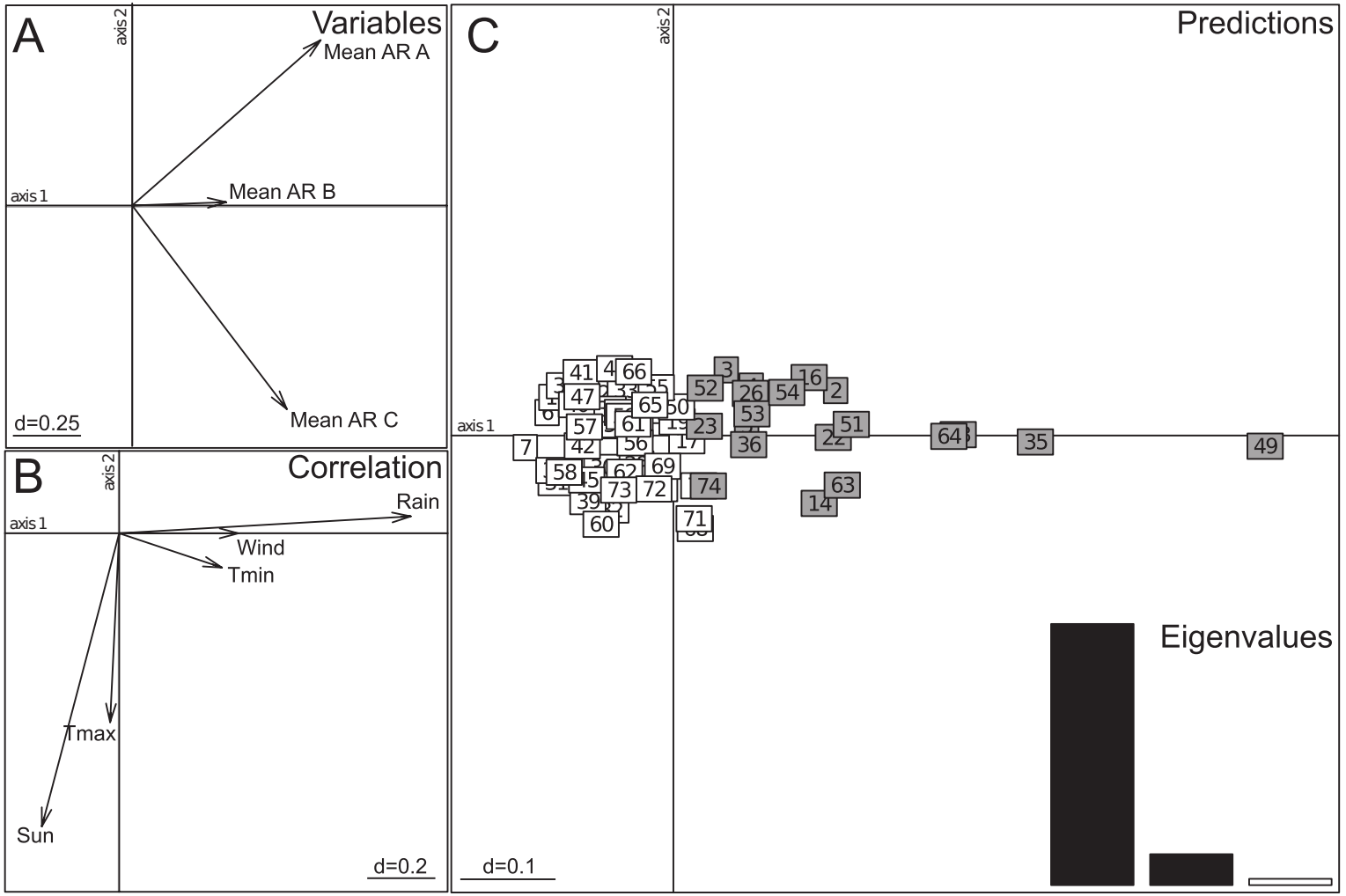

Temporal sampling
Sunrise
Sunset
M_1
M_i
M_{12}
E_1
E_i
E_{12}
Day 1
150" (2'30")
1050" (12'30")
Day n

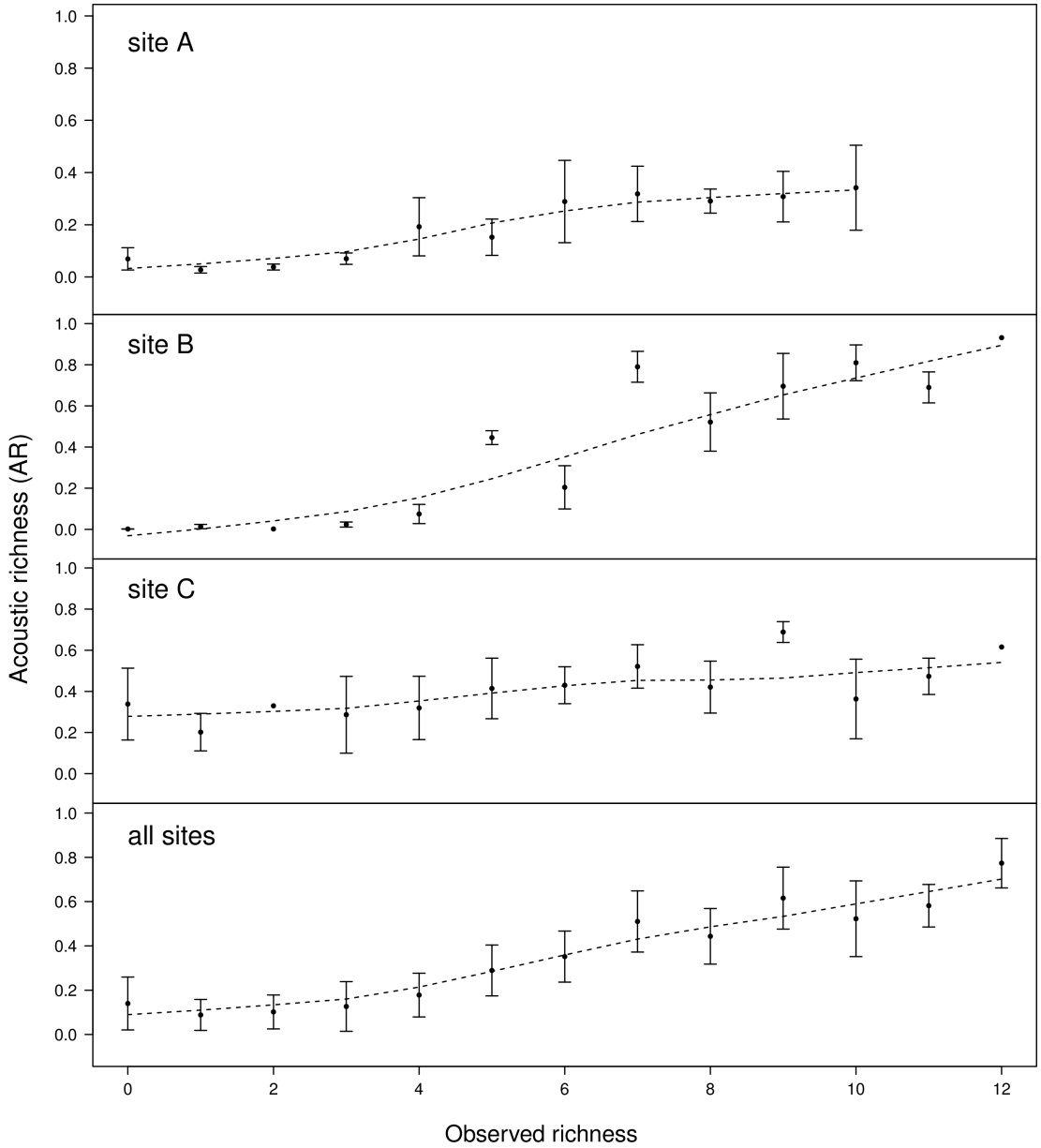
Data analysis (some results)

Uni-dimensional analysis



Data analysis (some results)

Uni-dimensional analysis



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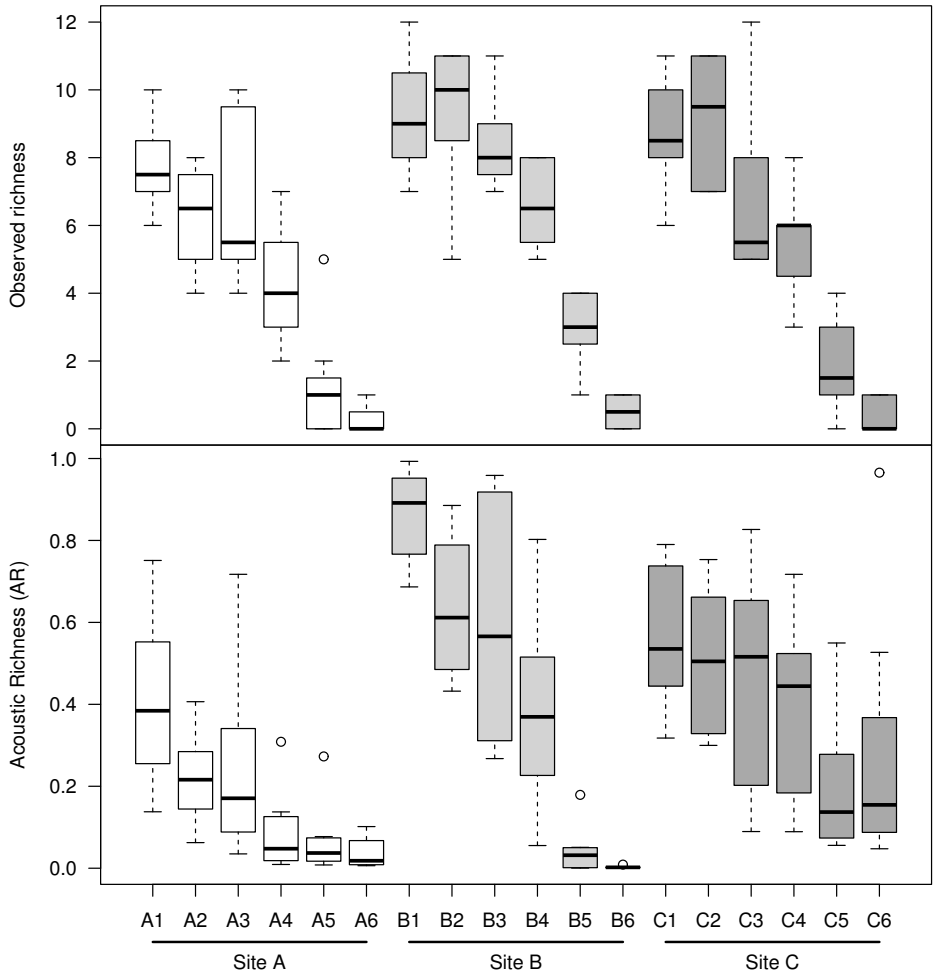
Data analysis (some results)

Uni-dimensional analysis



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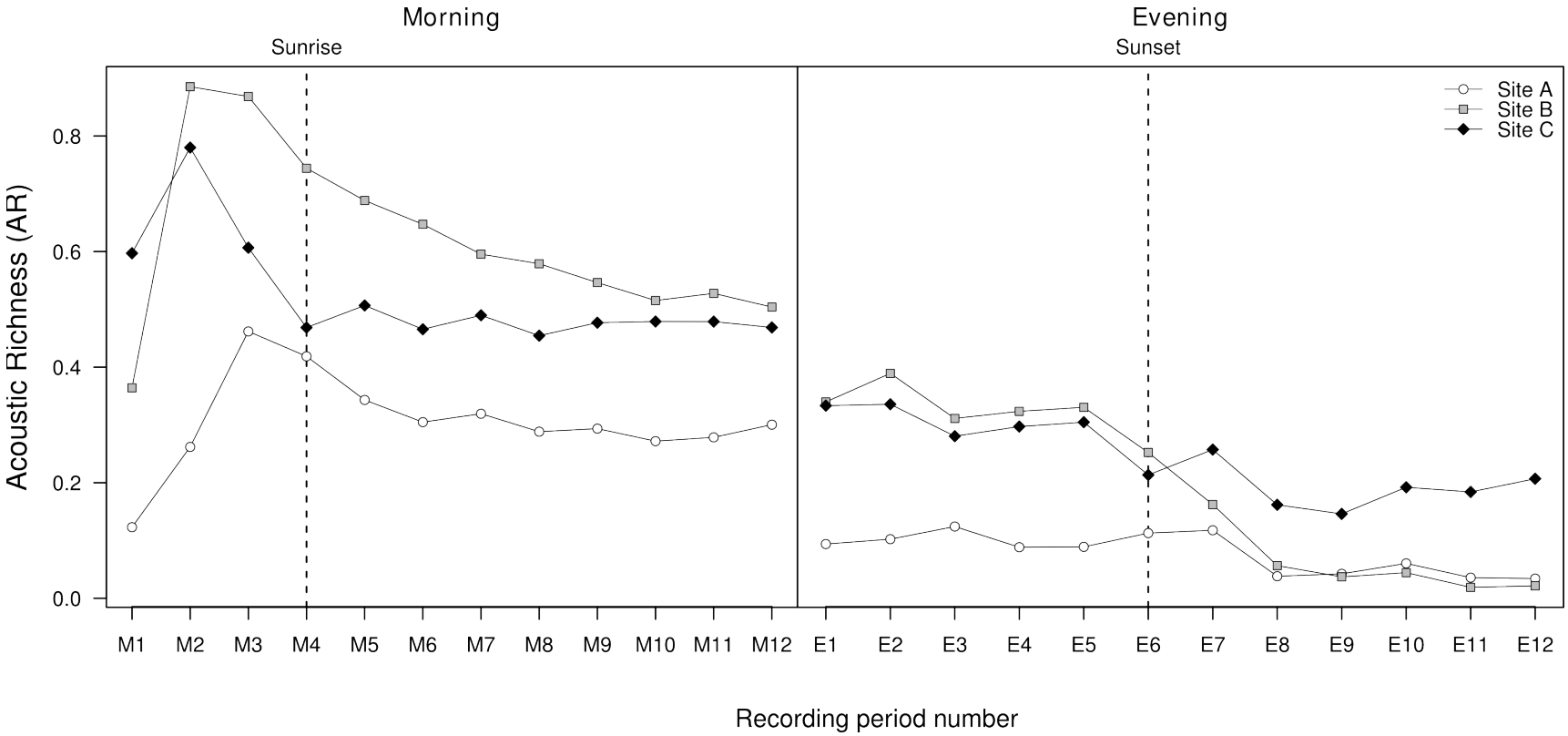
Data analysis (some results)

Uni-dimensional analysis



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Data analysis (some results)

Multi-dimensional analysis

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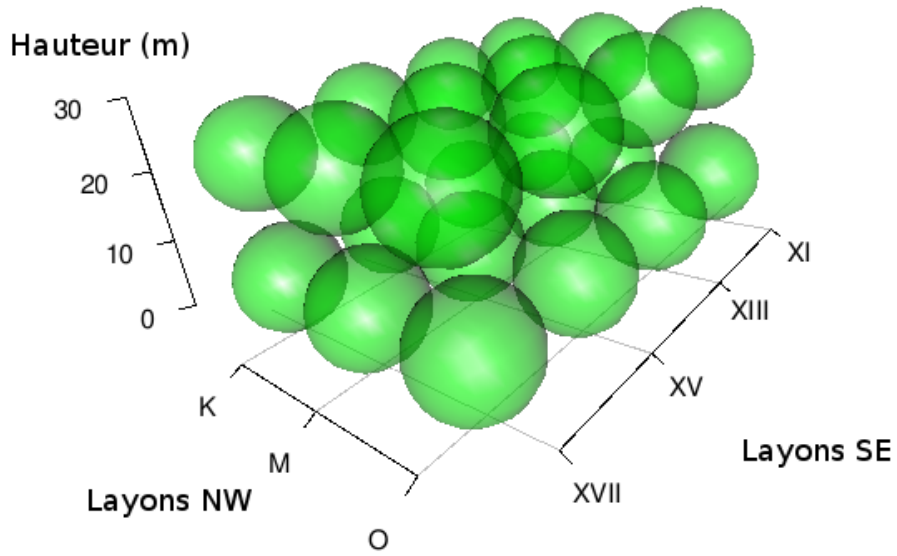
Data analysis (some results)

Multi-dimensional analysis

CNRS research station (French Guiana)



$600 \times 1200 \times 20$ m

24 microphones

1' every 15' – 32 days

49,733 audio files – 910 hours of recording – 522 Go of data

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Data analysis (some results)

Multi-dimensional analysis

Multi-dimensional analysis with `ade4`:
Recipice:

1. Computation of a $10,731 \times 10,731$ distance matrix

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Data analysis (some results)

Multi-dimensional analysis

Multi-dimensional analysis with `ade4`:
Recipice:

1. Computation of a $10,731 \times 10,731$ distance matrix
2. Principal Coordinate Analysis (PCO) on the matrix

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Data analysis (some results)

Multi-dimensional analysis

Multi-dimensional analysis with `ade4`:
Recipice:

1. Computation of a $10,731 \times 10,731$ distance matrix
2. Principal Coordinate Analysis (PCO) on the matrix
3. Principal Component Analysis on the PCoA coordinates with respect to instrumental variables

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Data analysis (some results)

Multi-dimensional analysis

Multi-dimensional analysis with `ade4`:
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   - time of recording (understory / canopy)

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Data analysis (some results)

Multi-dimensional analysis

Multi-dimensional analysis with `ade4`:
Recipice:

1. Computation of a $10,731 \times 10,731$ distance matrix
2. Principal Coordinate Analysis (PCO) on the matrix
3. Principal Component Analysis on the PCoA coordinates with respect to instrumental variables
   - time of recording (understory / canopy)
   - vertical position (understory / canopy)

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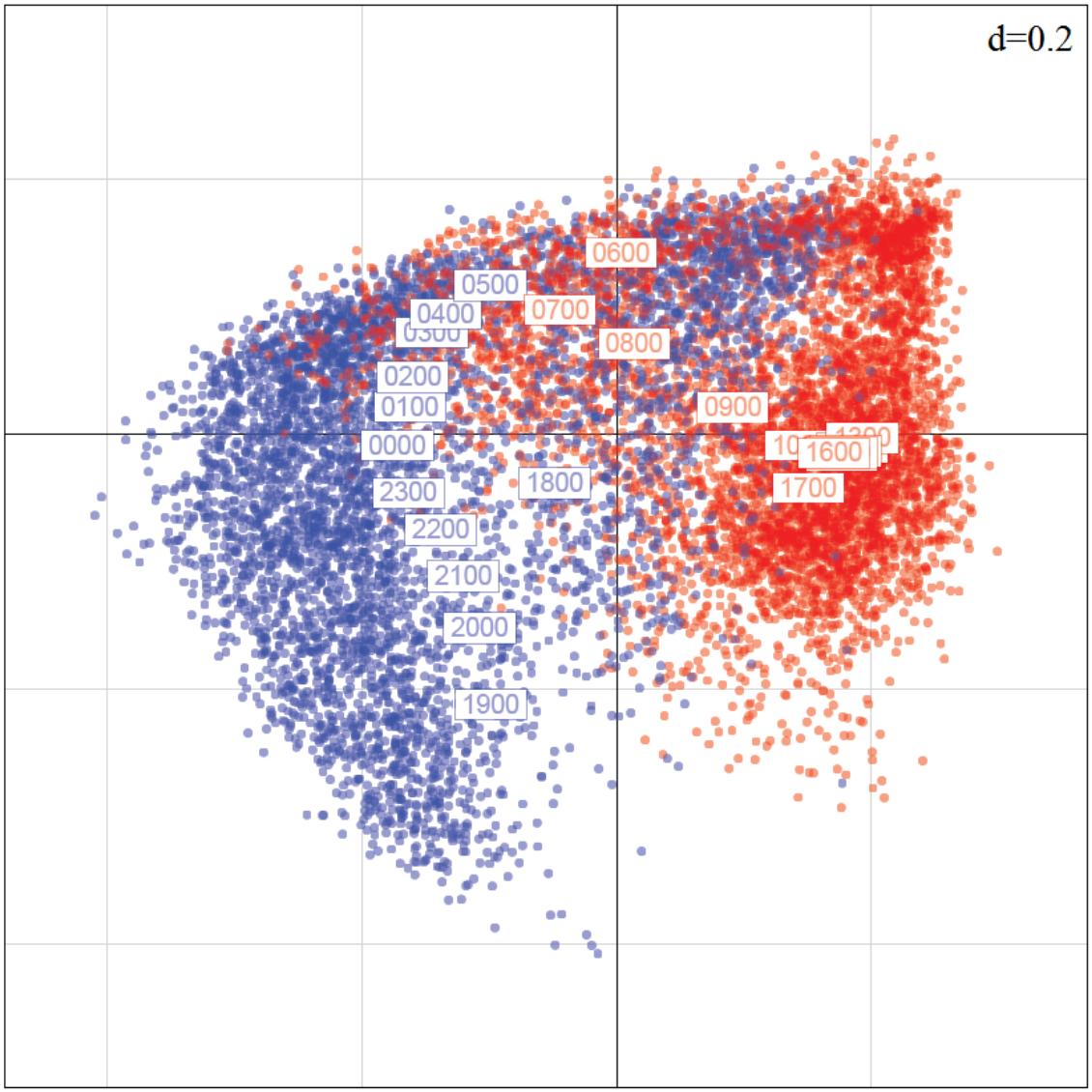
Data analysis (some results)

Multi-dimensional analysis



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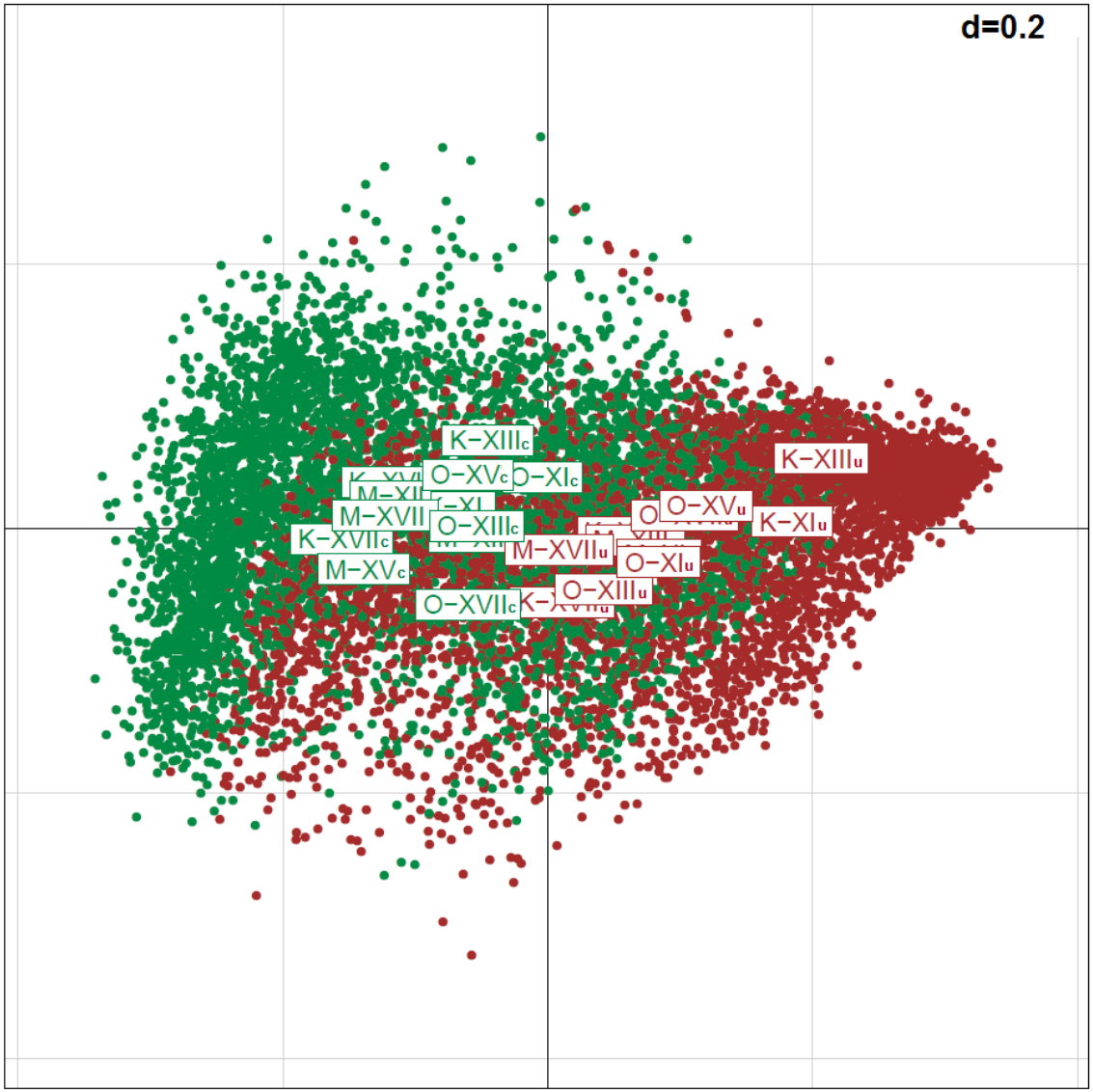
Data analysis (some results)

Multi-dimensional analysis



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Layout

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Conclusion

Improvements required

Upstream

- equipment (smartphones, tablets)
- sampling (wireless network, national recorder network)
- management of files (and of over-sampling...)
- automatic selection of uncorrupted audio files

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Conclusion

Improvements required

Upstream

- equipment (smartphones, tablets)
- sampling (wireless network, national recorder network)
- management of files (and of over-sampling...)
- automatic selection of uncorrupted audio files

Downstream

- signal analysis (filters, relevant audio parameters identification)
- indices (resistant to noise, higher reliability)

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Conclusion

- change of scale is not inherent to bioacoustics
- transfer of techniques and knowledge towards any acoustic environment (natural or not)
- CNRS MASTODONS grant: Scaled Acoustic BIODiversity platform [SABIOD, PI H Glotin]

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INEE

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merci pour votre écoute !

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