From Brain Connectomes to Soundscape Connectomes: A Graph-Based Unsupervised Approach for Acoustic Heterogeneity Identification

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IBAC 2025
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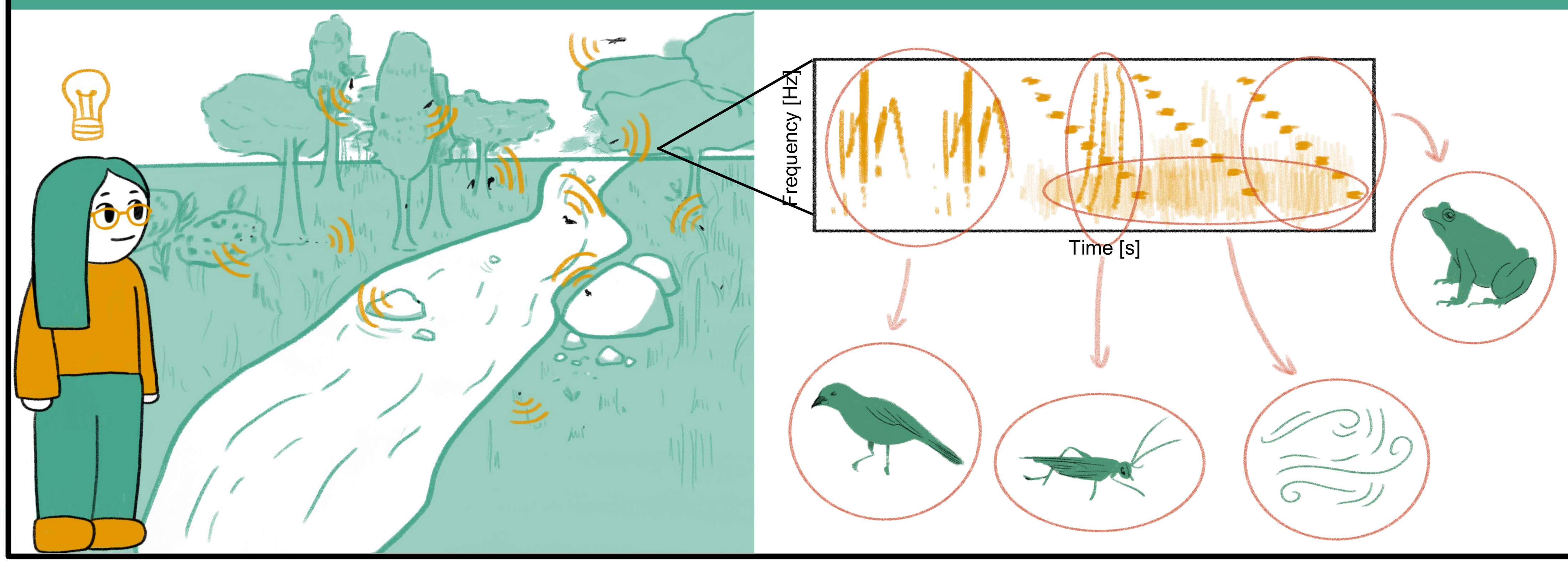
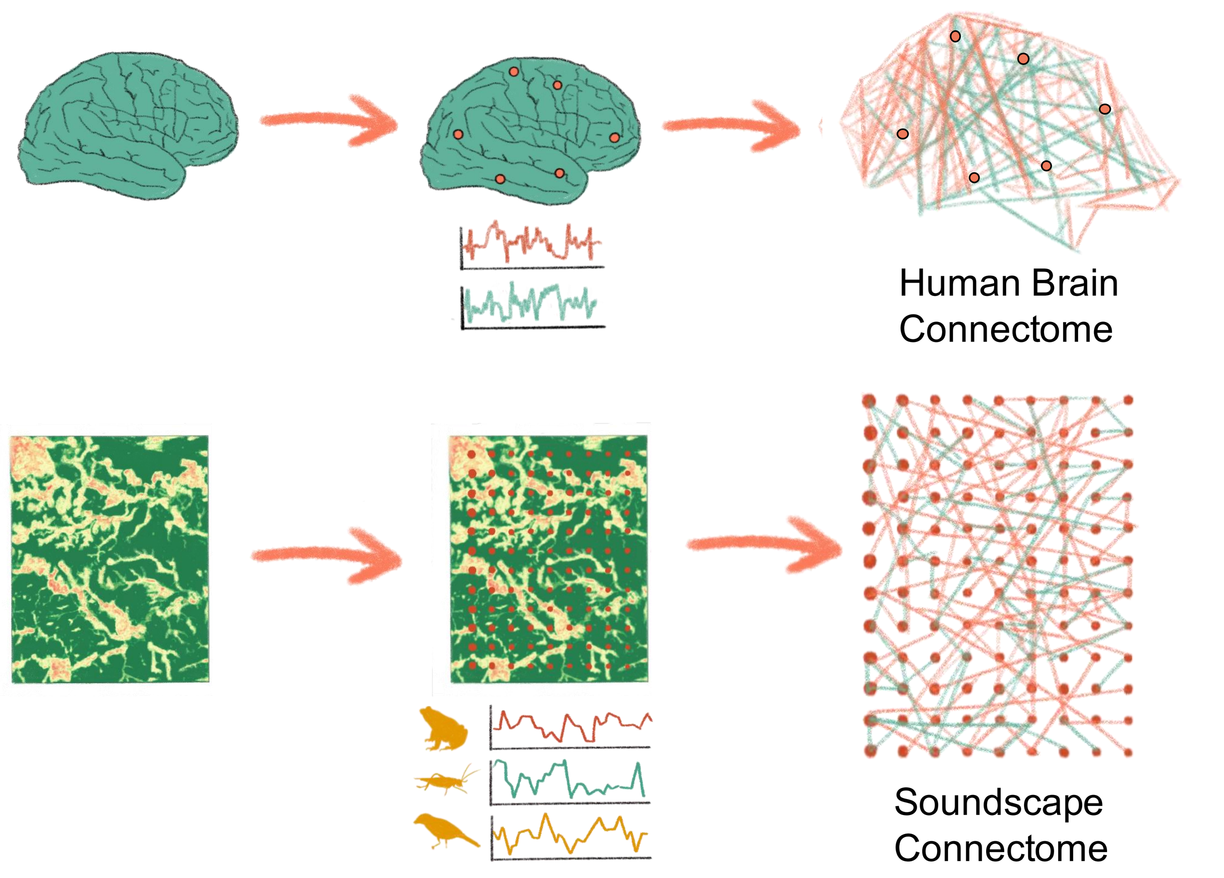
Motivation:



Ecosystem sounds encode which species are present, when they are active, and how they respond to environmental change; comparing per-site acoustic signatures lets us ask whether sites that "sound alike" are ecologically comparable or deserve similar conservation attention.

Passive Acoustic Monitoring (PAM) records the biophony present at each location and is cost-efficient because recorders can be deployed for long periods across wide areas. Processing those continuous recordings can yield valuable information about biophony behavior (e.g., activity rhythms, calling rates) and reveal shared acoustic patterns among sites.

Proposal:

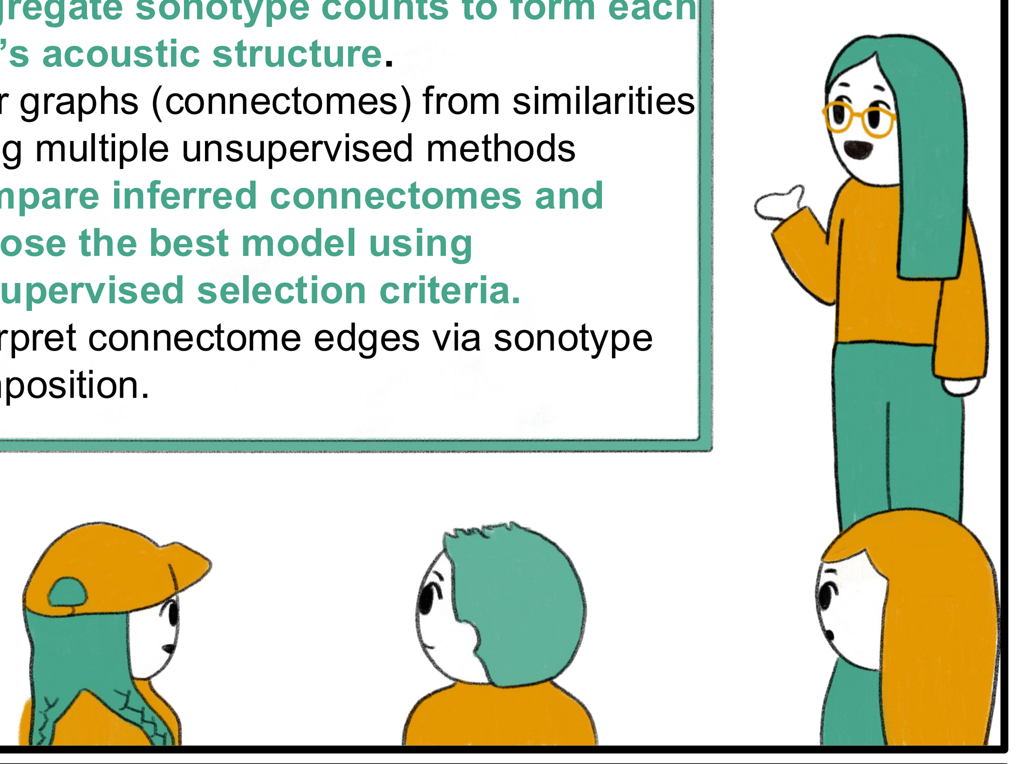


Network maps (connectomes) compactly summarize complex systems by linking units through data-driven relationships. In neuroscience this perspective transformed the study of function and disease.

We adapt this idea to ecoacoustics and define **soundscape connectomes**: graphs whose **nodes** are sites and whose **edges** encode acoustically driven relations derived from each site's biophony.

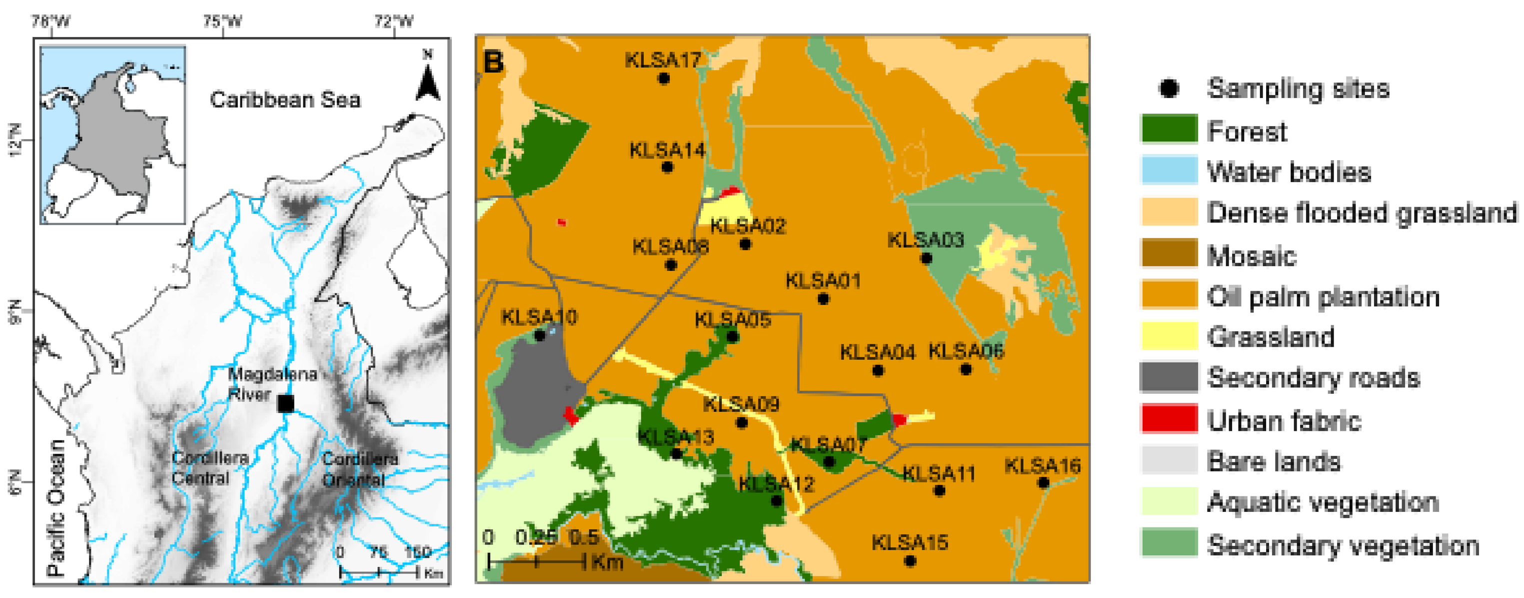
Methodology

1. Decompose recordings into sonotypes (acoustic units).
2. **Aggregate sonotype counts to form each site's acoustic structure.**
3. Infer graphs (connectomes) from similarities using multiple unsupervised methods
4. **Compare inferred connectomes and choose the best model using unsupervised selection criteria.**
5. Interpret connectome edges via sonotype composition.



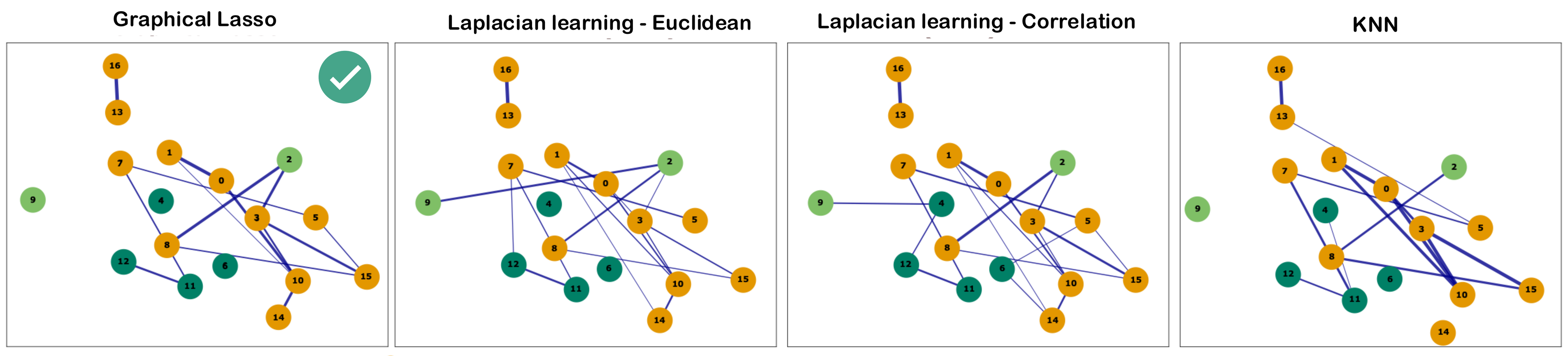
Acoustic dataset:

The dataset consists of 19.598 audio recordings collected over 10 days in March 2021 (dry season) from 17 sites in Colombian landscape. A Song Meter Mini device (Wildlife Acoustics, Inc.) was used for data collection in each sampling site, programmed to record one minute every ten minutes with a sampling rate of 48 kHz. Each recorder was placed at a minimum distance of 300 m from one another.



Soundscape connectome model:

Problem: Many ways to infer a graph. Without ground truth or labels, **how do we choose the model?** We need an unsupervised way to choose the graph method.

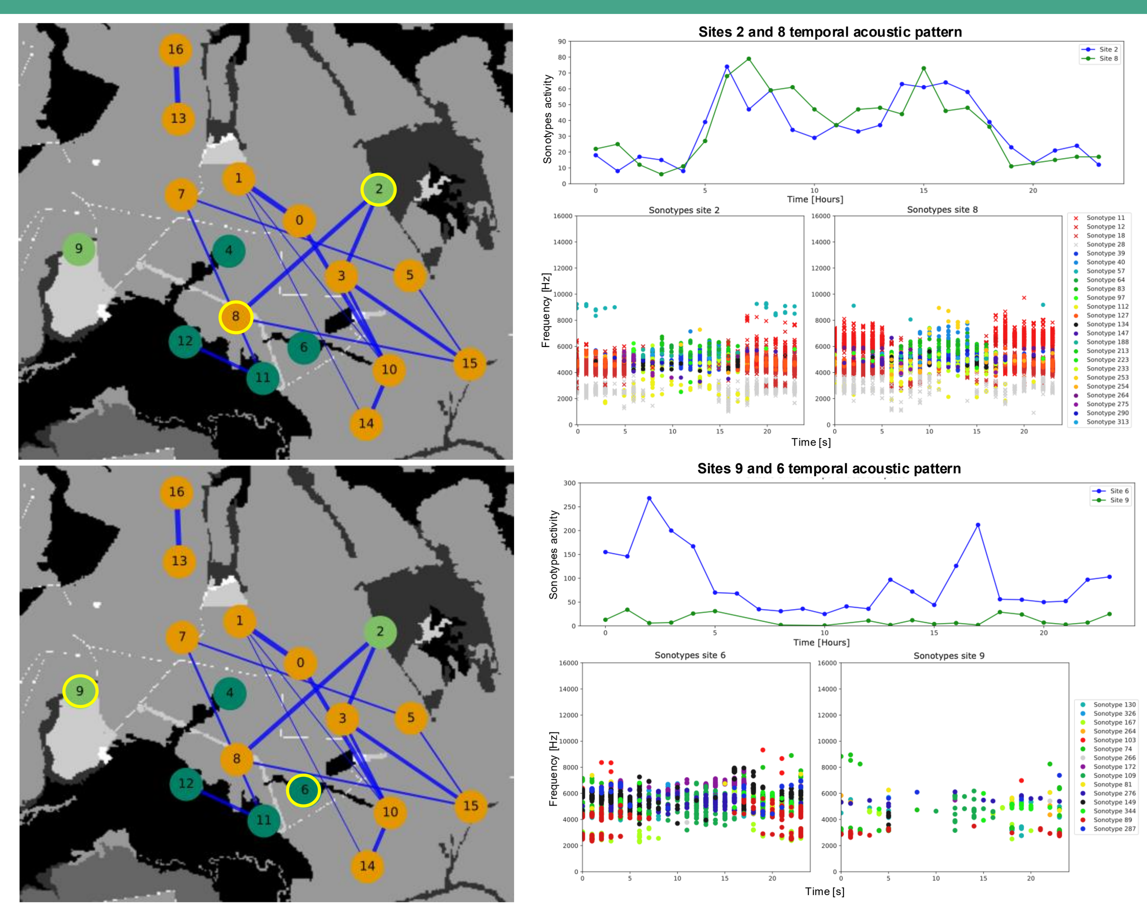


Idea: Treat each site's acoustic structure (site-by-sonotype counts) as a signal on the graph. A good graph lets us **rebuild a hidden site from its neighbors** (smoothness).

Score: Normalized reconstruction error NMSE = $\frac{\|X-\tilde{X}\|_F^2}{\|X\|_F^2}$ – **lower is better**

Graph Method	Avg NMSE ↓
Graphical Lasso	**0.494 ± 0.045**
Laplacian learning - Euclidean	0.527 ± 0.053
Laplacian learning - Correlation	0.506 ± 0.056
KNN (K=3)	0.526 ± 0.051

Model interpretation:



Visualization of acoustic patterns of representative sonotypes in two different site pairs. This visualization captures the diversity and temporal distribution of sonotypes within the soundscape of each site pair.

Conclusions and perspectives:

- A soundscape connectome is a map of acoustic connections among sites, exposing non-obvious (cross-cover) links driven by shared sonotypes and synchronized daily activity.
- It complements remote sensing, enabling label-free, scalable monitoring with PAM to prioritize sites.
- All methods recover a similar core; Glasso has the lowest Avg NMSE. Practical label-free choice.
- Future work includes developing a stable and reproducible unsupervised methodology, incorporate temporal analyses to capture dynamic site patterns and scale to larger datasets (91 sites/49,000 clips; 63 sites/91,993 clips).

Acknowledgment:

This work was supported by Universidad de Antioquia – CODI and the French Embassy in Colombia (SSHN 2024)

The recordings were collected by the Grupo Herpetológico de Antioquia (GHA).

Illustrations by: Isabel Correa-Franco @ren.artista