PURDUE UNIVERSITY
Discovery Park

ACOUSTIC SURVEY DESIGN

BEST PRACTICES IN DATA MANAGEMENT

CENTER FOR GLOBAL SOUNDSCAPES

COLOMBIA ACOUSTICS WORKSHOP 2019

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THE CENTER FOR GLOBAL SOUNDSCAPES

About Us

The Center for Global Soundscapes is home to a diverse group of researchers, scholars and educators endeavoring to better understanding nature and human-nature interactions through the lens of sound. We have training in disciplines including ecology, music, and education, and we record and analyze soundscapes in ecosystems around the world.

Our Mission

The world around us is full of amazing sounds that are often ignored by humans. Unfortunately, many of these sources of these sounds are actually in danger of being destroyed by human activities. Our mission is to study soundscapes in all of the major biomes of the world and to use this information to both understand how ecosystems are changing but also to bring nature to people through our recordings and research.

Where We Go

The work presented here is the result of dozens of studies conducted on nearly every continent and nearly every major biome. Our work spans from the tops of mountains to the depths of our oceans.

Acknowledgements

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PURDUE UNIVERSITY Discovery Park

CENTER FOR GLOBAL SOUNDSCAPES

A GUIDE FOR

ACOUSTIC SURVEY DESIGN

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01.

INTRODUCTION

INTRODUCTION

AN INTRODUCTION TO ACOUSTIC SURVEY DESIGN

Doing effective monitoring of natural resources and biodiversity is a very important part of doing effective conservation work. As part of this monitoring, it is important to identify methods and best practices that can be applied at broad spatial and temporal scales, ideally at a very low cost. Acoustic sensors present a valuable component of this type of monitoring scheme. Because of the relative new-ness of using acoustics to monitor biodiversity, and the variety of contexts in which acoustic sensors have been employed, there is still a great need to standardize methods and identify best practices.

Recording natural sounds for their own sake can be a useful and rewarding process. However, acoustic research is successful when a sensor is placed in a carefully planned design. There are many acoustic survey designs that can be considered, allowing research on many types of ecological problems. Passive acoustic sensors have several key strengths that make them well-suited for answering this broad variety of ecological problems. One of these strengths is that passive acoustic sensors have the duty-cycling capability to be deployed in one place for an extended period, allowing for greater power to detect temporal trends (Deichmann et al., 2018). Additionally, many models of sensors are small and light enough to be easily moved from place to place, allowing examination of ecological gradients at a variety of spatial scales.

In this document, we discuss best practices for designing, developing, and implementing an acoustic survey design that maximizes the ability to generate useful ecological information. The aim of this guide is to provide researchers with a set of useful principles for an initial acoustic study, as well as new methods to help broaden current practices. This guide will enable a researcher to translate their biological or ecological questions into an effective plan of acoustic survey and analysis, and then turn their survey and analysis into useful ecological information.

The guide will additionally provide an ontology of acoustic survey designs, principles for developing sensor deployment and analysis plans.

We describe how survey designs can be conducted and organized in both space and time in order to cover a given area or accomplish a given survey goal.
This guide is a project of the Center for Global Soundscapes at Purdue University, a center dedicated to creating a universal and accessible soundscape library and sett of visualization tools, for research and education both at Purdue and around the world.

ACOUSTIC SURVEYS CAN TAKE PLACE IN ALL BIOMES.

02.

MONITORING PARADIGMS

MONITORING PARADIGMS

A DISCUSSION ABOUT THE PROCESS OF ACOUSTIC MONITORING

We consider two acoustic monitoring paradigms: Passive and Active; additionally, we summarize a broader conceptual paradigm that can be applied to acoustics: Adaptive Monitoring. It is worth noting, however, that these paradigms are not mutually exclusive, and a given study may incorporate some combination of passive and active methods and adaptive frameworks.

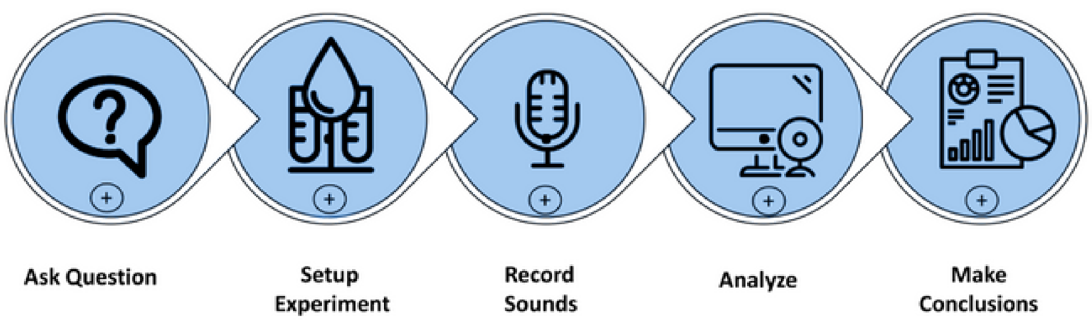
Passive and Active Monitoring

Most acoustic monitoring is passive. Passive monitoring involves listening to a natural system. This is largely done with a stationary acoustic recorder deployed for an extended period. Researchers will interact with the sensor only on deployment and retrieval, so the location and parameters of each recorder must be carefully considered. Active monitoring involves a trained observer in the field making notes of species they hear, or a researcher walking a transect in the field with a handheld recorder to capture sounds of interest.

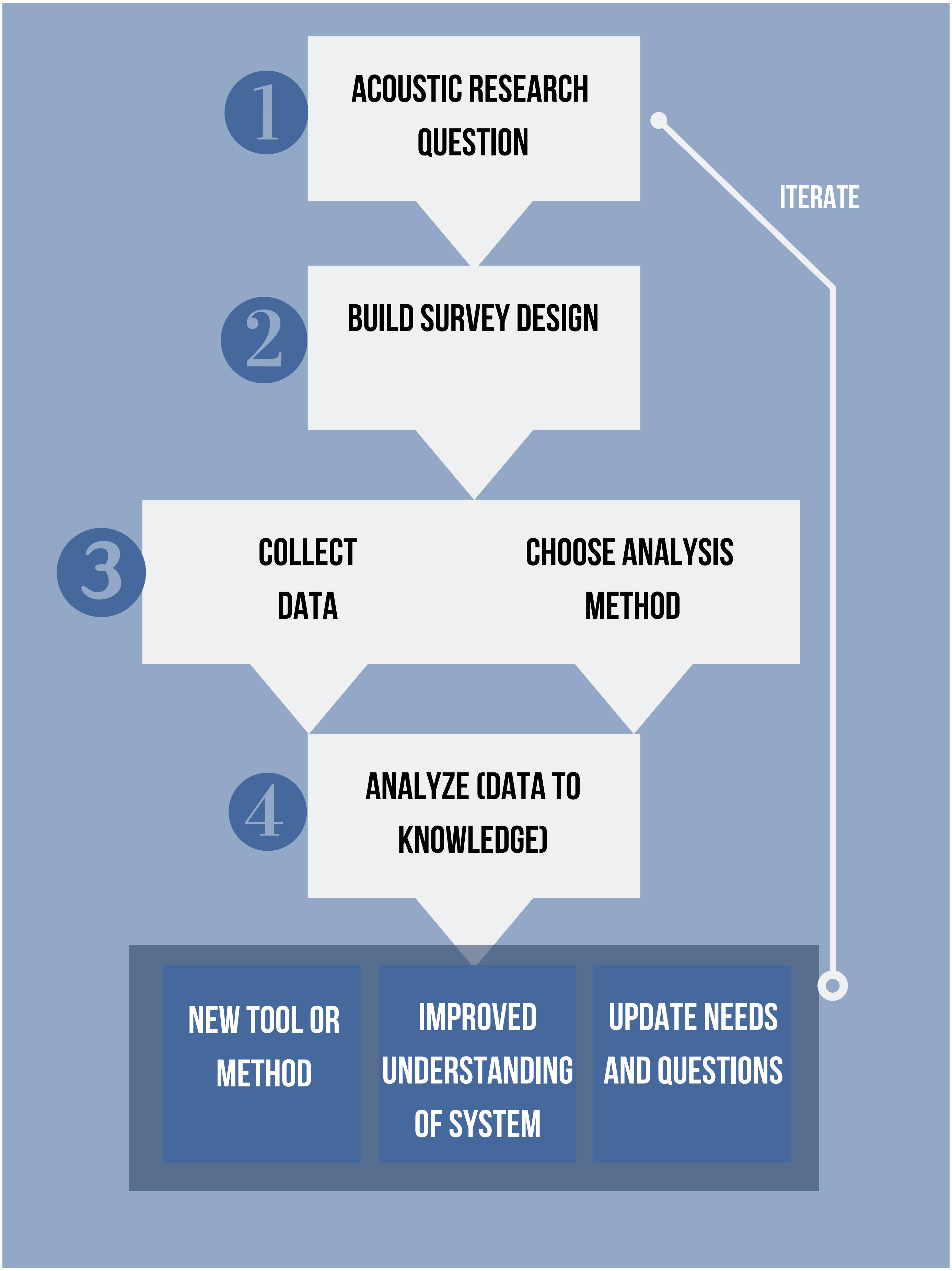
Adaptive Monitoring

Adaptive monitoring is a relatively new paradigm (Lindenmayer & Likens, 2009; Lindenmayer, Likens, Haywood, & Miezis, 2011) intended to be applied to very long-term monitoring processes (on the order of years to decades). Adaptive monitoring relies on beginning with a clear set of research questions and a conceptual model of the system to be monitored. This type of monitoring uses interim analyses to develop new ecological questions in an iterative process. Any monitoring program that is not likely to last long enough for an iterative process of developing new questions is not suitable for an adaptive monitoring paradigm, though some principles set out in the literature around adaptive monitoring may still be useful.

A NON-ITERATIVE MONITORING APPROACH



ADAPTIVE MONITORING FRAMEWORK



03.

GRADIENTS

GRADIENTS

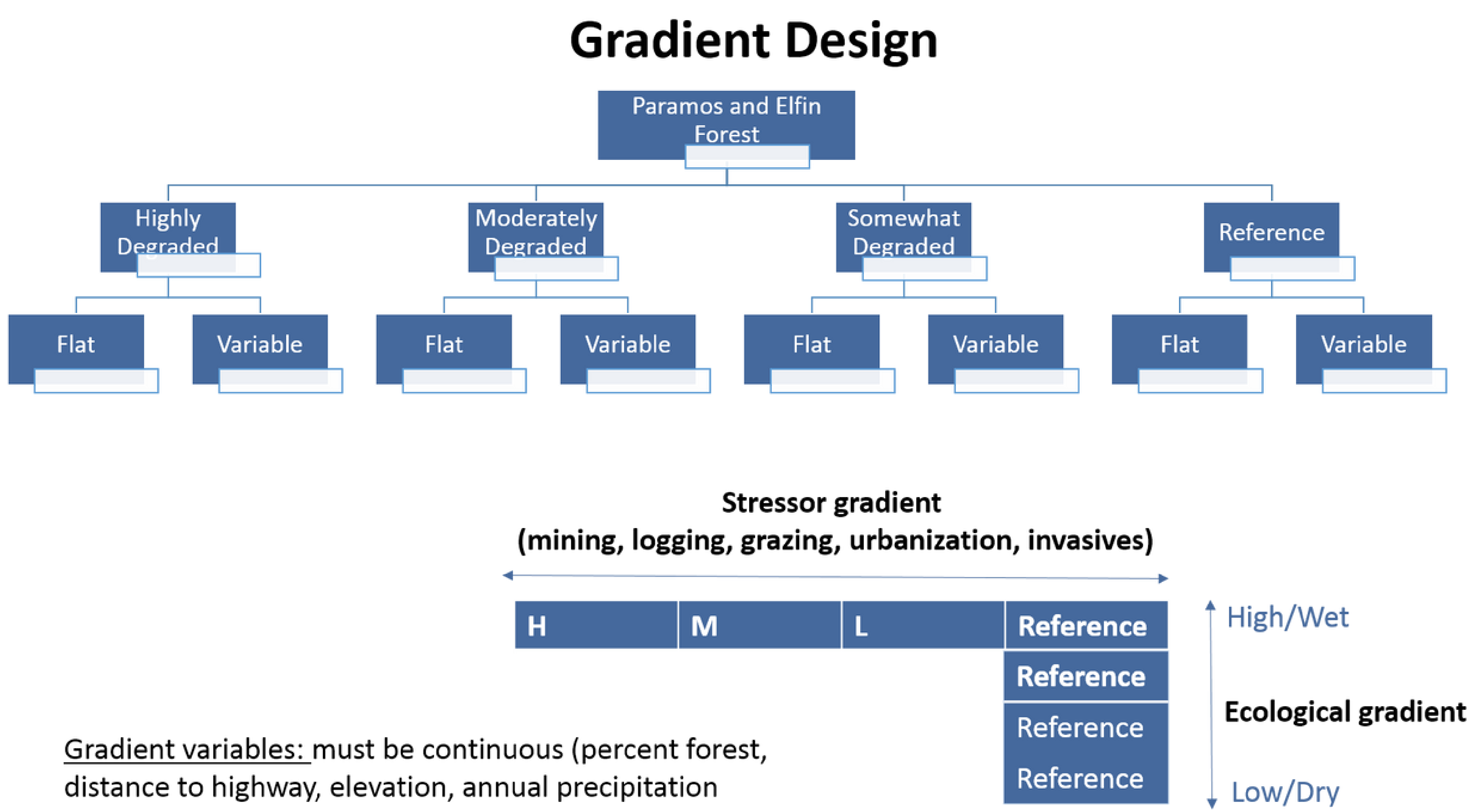
A KEY CONCEPT IN ACOUSTIC SURVEY

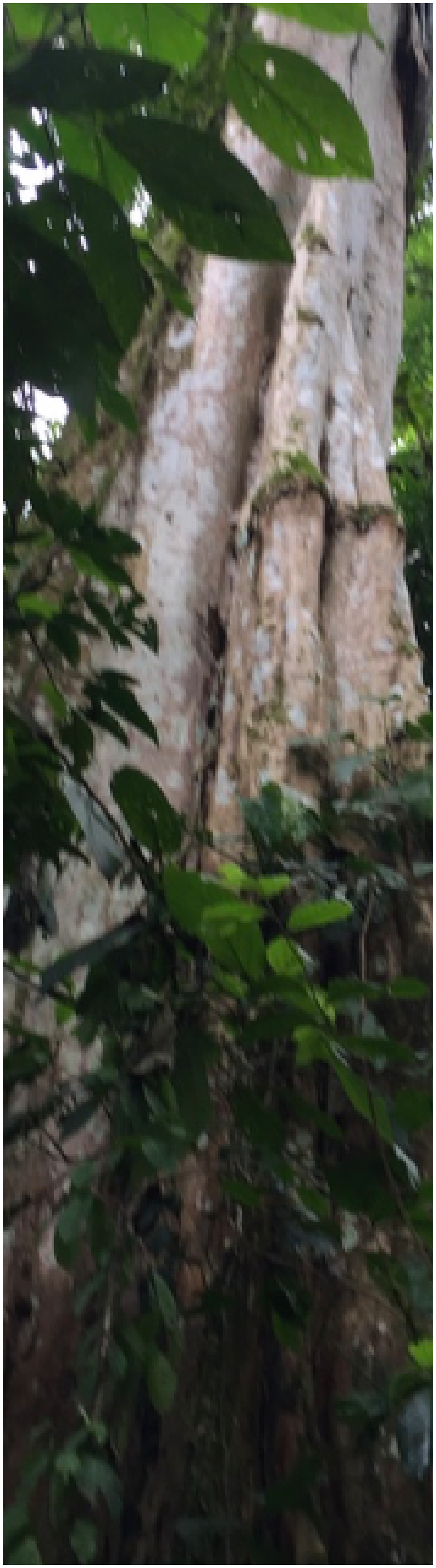
One of the key ecological concepts that acoustic methods can be used to evaluate is that of the gradient, a gradual trend in some variable, whether biotic or abiotic. Gradients can be temporal (such as recency of disturbance), spatial (such as distance from a road or from a water body) and can be defined both qualitatively and quantitatively. Gradients that have been studied at the Center for Global Soundscapes include fire responses in Arizona(Gasc et al., 2018), grazing intensity in Mongolia, agroforestry practices in Colombia, protected area status in California, disturbances in paleotropical rainforests in Borneo(VanSchaik, Gasc, Bellisario, & Pijanowski, 2017), and others.

A key concept to consider when using gradient for an acoustic study, which inherently involves a finite number of survey points, is endpoints. In a traditional gradient study, there are a finite number of survey points along the gradient.

In an acoustic study, where a researcher has a limited number of sensors to deploy, sensor locations should span the entire gradient while controlling for other ecological variables. For example, in a very dynamic topography where disturbance is the primary gradient of interest, a researcher should look to deploy sensors at sites that are roughly comparable in terms of slope, aspect, elevation, and projected climate conditions (rainfall, temperature, etc). In ecological studies, finding perfectly comparable sites may be difficult due to the inherently variable nature of the system. The goal of the researcher should still be to deploy all of their sensors in locations that are as similar as possible to each other except along the gradient of interest.

Record the relevant non-gradient variables as carefully and accurately as possible. These records will enable a researcher to control for these variables in future analysis. However, the need to control for variables that are not the variable of interest can be filled by an increased number of survey points.


Gradient Design
Paramos and Elfin Forest
Highly Degraded
Moderately Degraded
Somewhat Degraded
Reference
Flat
Variable
Flat
Variable
Flat
Variable
Flat
Variable
Stressor gradient
(mining, logging, grazing, urbanization, invasives)
H
M
L
Reference
Reference
Reference
Reference
High/Wet
Ecological gradient
Low/Dry
Gradient variables: must be continuous (percent forest, distance to highway, elevation, annual precipitation



GRADIENTS

SENTINELS

1 MIN / HR

HUMAN GRADIENT

ECOLOGICAL GRADIENT

10-60 MIN / HR

TRANSECT 1

TRANSECT 2

TRANSECT 3

least disturbed

most disturbed

04.

ANALYSIS METHODS

ANALYSIS METHODS

AN OVERVIEW OF KEY ACOUSTIC ANALYSIS TECHNIQUES

In this guide, we present two considerations for the choice of an analysis paradigm. The first consideration is the resources and capabilities available to a researcher or institution. The second consideration is the specific question that the researcher is trying to answer.

On the one hand, a researcher working at a large university with a lot of resources and expertise at their available might choose a set of analyses making best use of those extensive tools and capabilities. However, a researcher who works at a small conservation organization with minimal resources might use a different set of analyses. In the former case, developing an automated detection system may be more useful while the latter may call for a soundscape-level approach.

Audio analysis methods in ecology can be placed on a rough gradient of how much of the analysis is done manually by humans. At one end of this spectrum is manual review and tagging of every recording, for example to listen for a gun-shot or the call of a particular species. While such a method is likely to result in a very detailed and rigorous dataset, it is very time-intensive and relies on a degree of expertise and familiarity with the relevant signals that some institutions may not have access to. Manual review can require up to a 1:1 ratio of recording time to analysis time, if every recording is reviewed by listening to it in its entirety. However, tools do exist to improve the speed of manual review, such as by visually scanning and tagging a spectrogram (Truskinger, Cottman-Fields, Eichinski, Towsey, & Roe, 2014).

At its most rigorous, manual review may warrant multiple observers independently labelling the same recording to minimize observer error. This latter technique is suitably only in circumstances where each individual detection is of paramount importance, often because it will lead to some kind of legal or financial consequences.

At the other end of the manual analysis gradient is fully automated processes where some kind of computational process turns audio into information, whether in the form of an ecoacoustic index (Fuller, Axel, Tucker, & Gage, 2015; Pieretti, Farina, & Morri, 2011; Sueur, Pavoine, Hamerlynck, & Duvail, 2008; Villanueva-Rivera, Pijanowski, Doucette, & Pekin, 2011), some audio measurement such as sound pressure level, or the algorithmic detection of the presence or absence of a specific acoustic signal(Brauer, Donovan, Mickey, Katz, & Mitchell, 2016; Klein, Mckown, & Tershy, 2015; Zhao et al., 2017; Zwart, Baker, McGowan, & Whittingham, 2014). Most analysis workflows will occur somewhere in the middle of this gradient, involving some degree of human decision-making and evaluation, and some degree of computational processing.

For example, it takes some level of human review and classification of audio data to build a training and testing dataset that can then be applied to a machine learning algorithm, and some workflows call for a human to review the output of a machine learning process to identify false positives or false negatives(Klein et al., 2015; Young et al., 2019). If a detector performs poorly, automated detection can still be useful in identifying the portion of audio that can be safely ignored by a human reviewer and highlighting those recordings that are most likely to contain a signal of interest. Even in the calculation of Sound Pressure Levels or Ecoacoustic Indices, some human input is usually desired in order to determine the optimal parameters for each of these processes.

Another consideration in choosing an analysis paradigm is how the researcher wishes to distribute effort over time. Some methods, such as an automated detection and classification model, require significant up-front investment(Goyette, Howe, Wolf, & Robinson, 2011) but become much more efficient as they are used repeatedly.

Analysis Type	Pros	Cons	Examples
Manual Review	• Detects novel sounds • Used in any context, even where automated systems do not exist	• Time-intensive • Labor-intensive • Requires expertise in relevant signals	(Gottesman et al., 2018; Rocha, Ferreira, Paula, Rodrigues, & Sousa-Lima, 2015)
Acoustic Indices	• Calculated quickly on large datasets • Used broadly throughout the literature • Reveal broad biodiversity trends	• Uninformative about specific signals • Performance varies based on parameters of recording and calculation • Determining the right index can be difficult	(Burivalova et al., 2017; Fuller et al., 2015; Gasc, Sueur, Pavoine, Pellens, & Grandcolas, 2013a; Pieretti et al., 2011; Sueur et al., 2008; VanSchaik et al., 2017)
Automated Signal Detection	• Scales with repeated use • Accelerated with powerful computers	• Time and labor intensive to start • Not always able to detect novel signals or events • Risk of false positives	(Britzke, Murray, Heywood, & Robbins, 2002; Klein et al., 2015; Swiston & Mennill, 2009; Zhao et al., 2017)

Building sufficiently large, diverse, and accurately labeled training and testing datasets, and then using those datasets to build a model that performs well, takes a lot of work (Klein et al., 2015). However, if model performance remains consistent over time, the same model can be used repeatedly, minimizing work in further years once it has been built. On the other hand, manual labeling or index calculation require roughly the same amount of work to handle a given amount of data regardless of how many times they are used.

05.

ANALYSIS PARADIGMS

ANALYSIS PARADIGMS

THINKING ECOLOGICALLY ABOUT ACOUSTICS

The previously-described analysis methods are useful in turning recordings into a useful dataset, whether that dataset consists of indices and measurements or observations of specific sounds or species. However, those datasets still need to be applied to a relevant ecological question. These questions are generally determined at the beginning of the survey effort. However, it is possible that questions may change during a survey if some disturbance or event of interest occurs. Some ecological questions may be answered relatively simply, for example whether the prevalence of a given species is greater inside or outside a protected area. On the other hand, acoustic analyses can also be applied to far more complex questions.

In any acoustic analysis program, it is important to consider the variability of the acoustic signal, both spatially and temporally. This is important not only to understand the spatial and temporal dynamics of an ecosystem, but also to build appropriate sampling schemes and analysis units.

Soundscapes can vary dramatically both over the course of a day (think of the dawn and dusk choruses), and over the course of weeks, months, or years(Krause, Gage, & Joo, 2011). There are many potential drivers of this long-term temporal variation, including species starting or ending their mating season, arriving or leaving as part of a migration cycle, or even becoming completely extirpated from a site. Even anthrophonic or geophonic sources can change dramatically over time, as a region experiences seasonality in its climate, seasonality in human behavior, or becomes increasingly developed. None of these trends can be captured acoustically without a long-term monitoring scheme to establish a baseline. This is a key reason to implement “sentinel” sites, a term used to refer to sites that record continuously and that are deployed for a year or more. These sentinels are useful to track long-term trends in a soundscape, and to provide baseline data for comparisons with shorter deployments.

It can also be very important to explicitly establish links between the acoustic data that the researcher wishes to collect, and the ecological question of interest. This is especially important when a long-term acoustic monitoring program is proposed for a specific species. While many studies have successfully used acoustic indices to evaluate broader biodiversity or disturbance level, (Gasc, Sueur, Pavoine, Pellens, & Grandcolas, 2013b; Gómez, Isaza, & Daza, 2018; Sueur et al., 2008), acoustics as monitoring tools for specific species must still be established, especially when it comes to evaluating the correlation between rates of acoustic activity and population. For example, suppose that the goal of the program is to determine whether a given conservation action is effective in terms of increasing population in a given area. To accomplish this using acoustics, researchers need to establish a correlation between the acoustic measurement of species activity that they are using and the actual population of the species in question. This can be done through a variety of methods, such as using camera traps or human observers at the same sites at the same time as the acoustic monitoring is taking place.

06

CHARACTERIZING SITES

CHARACTERIZING SITES

DESCRIBING A LOCATION TO MAXIMIZE ANALYSIS POWER

Because acoustic sensors are usually deployed, then left for a time and recovered, it is vital to compile as accurate a characterization of each sensor's location as possible, both for the researcher's own use and for the use of any other researchers who may make use of the same data in the future. This goes beyond making sure that one has accurately recorded the sensor's latitude, longitude, elevation, and directions on how to get to it for recovery. Ensuring an accurate characterization of the spatial location of each sensor is still very important—acoustic sensors can be small and cryptic and can be easy to misplace, leading to the loss not only of the sensor but of the data that the sensor had collected. Each sensor must be placed into an ecological context in a way that the researcher can reference when they return to the lab with their data to begin the analysis process.

Key to thinking about the characterization of sites in ecological terms is a simple question: If other work calls the researcher away from this project, and they revisit this data after several years, have they documented it enough to still generate useful ecological thinking about the dataset. We recommend collecting whatever notes and observations are practical during the process of sensor deployment, which can then be referred to later (Cook, Olson, Kanciruk, & Hook, 2001; Jones, Schildhauer, Reichman, & Bowers, 2006; Michener, 2006). Photographs, videos, and handheld audio recordings can let a researcher note points of interest in the broader landscape context of a site. Noting any relevant species observed during deployment can be useful in future analysis. Even something as simple as a panoramic photograph of the site taken with a mobile phone can provide vital context when, a year or more later, a researcher may simply be looking at a long list of file names.

In many cases, it is useful to collect this data in multiple formats. For example, while it is useful to record the latitude and longitude of a sensor on a spreadsheet, it can provide an added layer of security to begin each sensor deployment with five minutes of spoken audio notes that can provide a backup copy of that sensor metadata in event of data loss or confusion during the analysis process. An example script for this recording might be:

"This is [Researcher Name] with [Institution]. It is [Date and Time]. I am deploying sensor [Sensor Prefix] at location [Site Name]. The coordinates are [Latitude] and [Longitude]. Our sensor is located at [Brief description of the site]."

Another important consideration in site documentation is data sharing. If there is a possibility of providing data to collaborators, and both groups are not working in the same standardized data-organization scheme, it is important to have a site description that is as complete as possible. Not only is a complete description important, but it is also vital to be able to explain how this data is structured. Such a description could be as simple as a text document describing each column of a spreadsheet, or a complex XML or database schematic. In any case, the key goal should be to ensure that collaborators have enough contextual information to use the data. Generally, a flatter data structure (that is, fewer levels of folders) will be more adaptable to alternate data organization systems that collaborators may be using.

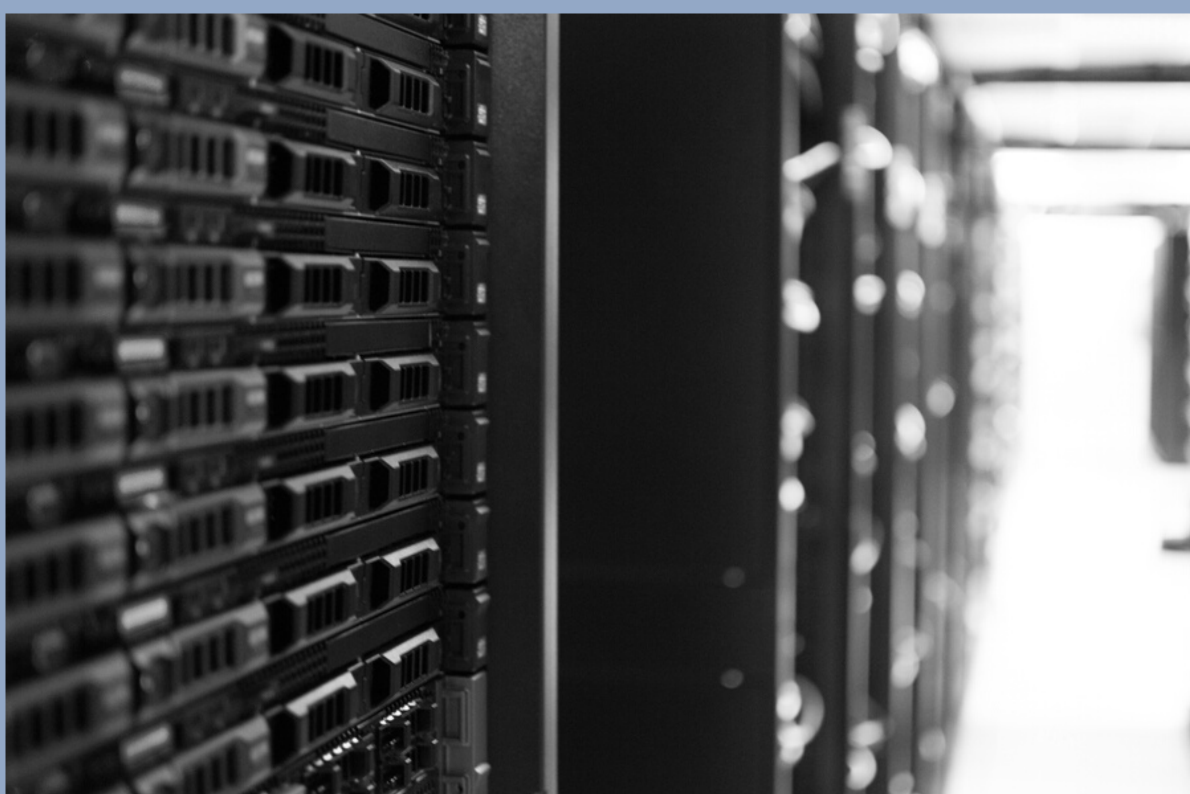
A CHECKLIST FOR SITE DOCUMENTATION

- Site Name
- Sensor Prefix
- Date Deployed
- Date Retrieved
- Name of Researcher Deploying Sensor
- Name of Researcher Retrieving Sensor
- Latitude of Site
- Longitude of Site
- Elevation of Site
- Site Notes and Observations
- Variables relevant to the survey design (such as disturbance level)

Some site information can be collected well before, or even after, deployment. This consists mainly of remotely sensed information. GIS software can be used to build a more complete understanding of key aspects of a site such as slope, aspect, elevation, and can be used to integrate a location with available data about climate and weather, if such data is available for a remote area, which is not always the case. Other geospatial remote-sensing data is also available, including a wide variety of satellite imagery that is very useful for understanding and tracking vegetation patterns across space and time, and placing a given sensor, or a given recording, into these contexts.

07.

DATA STORAGE AND ORGANIZATION



DATA STORAGE AND ORGANIZATION

HOW AND WHY TO STRUCTURE AN ACOUSTIC INFORMATION SYSTEM (AIS), AND AN OVERVIEW OF THE CHORUS TOOL

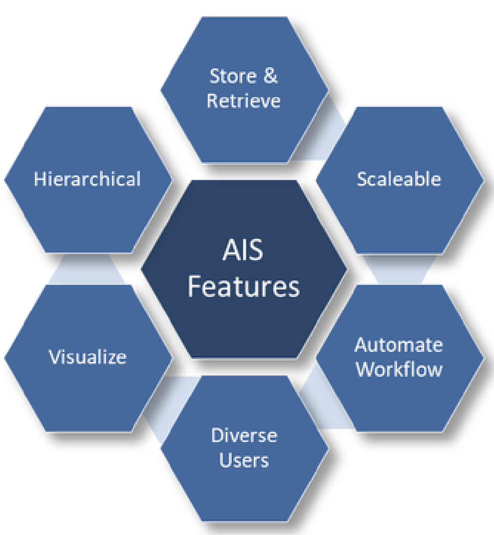
Organization is vital for any dataset. This is especially important with a data source such as acoustic sensors where dataset sizes can range from hundreds of gigabytes to terabytes, and the number of individual files can be in the hundreds of thousands to millions. A well-planned organizational scheme will make analysis, data sharing, and integration with external data much easier (Cook et al., 2001; Jones et al., 2006; Michener, 2006). While there are many institutions engaging in acoustics research, they tend to use a wide variety of data organization schemes. This can create problems for collaborative acoustics research because significant amounts of time and effort must be spent in translating data from one organizational scheme to another. Additionally, errors can occur during this translation process leading to potentially misleading results. Organizational schemes can follow a variety of models.

Some institutions catalog their acoustics data using an existing scheme for storing biodiversity data, focused on observations of a specific species at a specific time and place, for example using the Darwin Core system (Wieczorek et al., 2012). This system may be suitable if the researcher is interested in the prevalence of a specific species or signal. However, if a researcher is more interested in broad-scale community or biodiversity patterns, as expressed in soundscapes,a better analog for their acoustic data might be that of spatial data: LIDAR, GIS layers, satellite images, etc. In fact, the usage of landscape principles was a major driver behind the early development of soundscape ecology, and many landscape indices have led to the development of acoustic indices (Pijanowski et al., 2011). Any system of data organization should be able to keep track both of individual recordings (.wav, .flac, .mp3) as well as placing them into appropriate context.

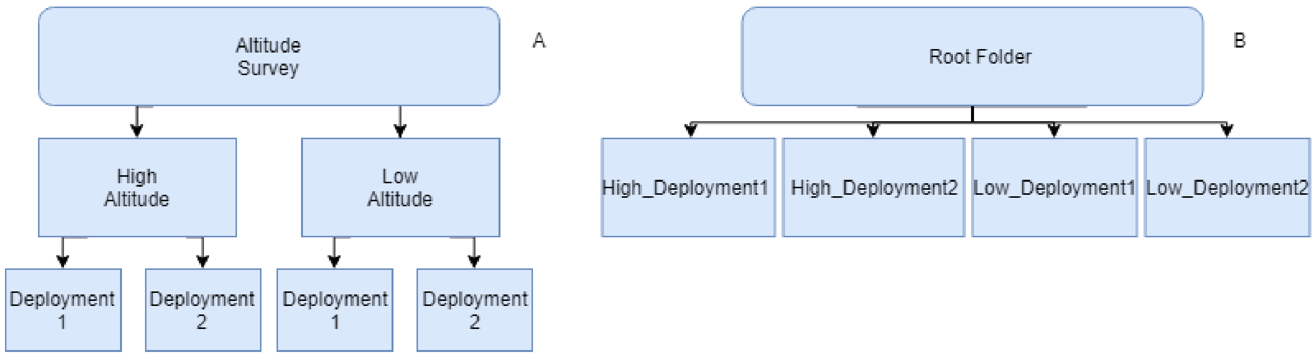
Such a system should be implemented in a way that is useful for researchers with a wide variety of technical competency. A graphical user interface may be suitable for researchers who are interested in exploring sounds, but can potentially be unnecessary or even slow down researchers who may be more technically proficient with command-line utilities such as SQL queries. Such a tool should have several key capabilities:

- **Store and Retrieve Data and Metadata.** Acoustic data contain enormous amount of information, much of it is extracted and stored (acoustic complexity, mean frequencies). Other information about the data file, such as the senor ID that created it, the location, date, time, elevation, etc.
- **Be Scaleable.** Be able to scale to large datasets, on the order of hundreds of gigabytes to petabytes. This scaling is necessary because a researcher may wish to load the results of a study all at once, if they have been in the field for an extended period and returned with months of data, which is a relatively common scenario in acoustics research.
- **Automate Workflow.** Provide automated data organization, filetype conversion, backup, and calculation of acoustic indices. Often, a significant portion of the process of bringing recordings into a system is spent waiting for a researcher to implement the next step in a pipeline. Automating this process should save significant amounts of time, and can include automated checks for errors.
- **Visualize data.** Both to prompt new ecological thinking and to allow the researcher to identify poor recording quality (dead microphone, clipping, etc). These visualizations could take the form of spectrograms, or of plots of acoustic indices. Visualizations can also include spatial information, such as maps of locations where sensors have been deployed.
- **Be hierarchical.** An AIS should track information like total data size and number of files for each deployment of a sensor, each sensor in a study, and each study. It is even useful to look at data at the “collection” level, where multiple distinct studies may have been conducted in the same general area.

- **Enable Online Access.** Be easily accessible through a web portal. When researchers are travelling and wish to explore data, or demonstrate a dataset to a collaborator, it is important to have a user-friendly web portal for data exploration and visualization without having to install or load a complex set of tools.
- **Support Diverse UXs.** Given that there are multiple uses of acoustic data that span those that require custom queries by scientists and to those who are interested in just experiencing these sounds online, an ideal AIS should provide these diverse set of users with different means of accessing the information along with specific permissions.



- **·Archive and Manage "Silent" Data.** The "silent" data referred to here consists of data associated with recordings that do not contain sounds. Such data might include spreadsheets of sensor information, field notes, photographs of the site, videos taken during deployment, geospatial data such as DEMs, remote sensing information like a MODIS NDVI dataset, or climate and weather data. See the "Site Characterization" section for more complete details.
- **Provide Tools to Annotate and Tag Features.** A researcher, or even a member of the general public, should be able to identify specific sound sources or attributes present in a recording. Whether this is a tag representing the acoustic activity of a specific species, the presence or absence of an anthrophonic or geophonic signal like thunder or car noise, or even the emotional sentiment that a sound inspires. Building these tagged data-sets over time will improve training data for machine learning, as well as steadily improving the data available to researcher for other analysis.



This figure shows two possible data organization schemes for a hypothetical study examining altitude. Scheme A involves a hierarchical directory structure, where information about the survey, the site, and the deployment are contained in the folder names and structures. Scheme B is a flatter directory structure, where information is saved in a separate table. Scheme B is much better-suited to data sharing, because it is easier to fit these directories into an alternate organizational scheme that may be used by a collaborator.

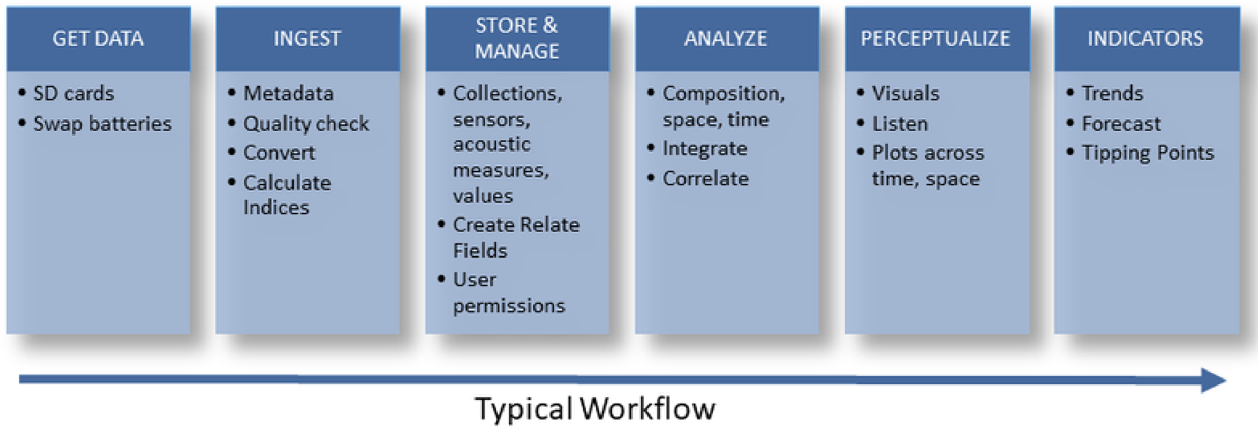
CYBERINFRASTRUCTURE CONSIDERATIONS

An Acoustic Information System will rely on powerful computer hardware to run efficiently. However, there are several distinct options that such a system could employ, each with its own positive and negative points:

Cloud Platforms, such as Amazon Web Services or Microsoft Azure. These provide excellent data redundancy and can be easily accessed from anywhere in the world. However, when dealing with large acoustic datasets, the network bandwidth that is required to move data into a cloud platform can be a limiting factor

A central "clearinghouse" for data. This allows tighter control of a system by its developers, and potentially more rapid iteration and improvement on tools, but may limit opportunities for data sharing.

Distributed systems. Unlike a cloud platform, each institution acts as a 'node', storing and sharing their data on a networked system. This system allows for easy data sharing, but is susceptible to one party making changes to their system that may impact the broader network.



A TYPICAL ACOUSTICS WORKFLOW

A comprehensive acoustic information system should have the following data processing steps as part of its overarching design (see figure). The major components include:

Retrieve Data. This may involve retrieving the sensor at the end of a study, or may involve removing the old batteries and SD cards and installing new ones while the sensor remains in one place.

Ingest Data. This is the process by which data moves from an SD card on a sensor into a system where it is ready for analysis. During this step, metadata about the sensor and site should be incorporated into the dataset. Data can be converted to a compressed format (such as FLAC or MP3) to improve storage efficiency. This is also the step at which quality-control measures should be taken, such as checking for empty files, dead microphones, clipping, or other issues. During this step, any calculations that are needed can also be implemented, such as acoustic indices or sound pressure levels.

Store and Manage Data. The data must be stored in a systematic manner, with multiple copies made to ensure availability in the event of system problems. This is also the step where relationships between data can be established, such as survey design, biome type, or spatial information. The data management phase is where any user permissions are established so that, for example, citizen scientists can read and tag data but cannot move it.

Analyze. During this step, a researcher looks for patterns and correlations in their data in order to answer their research question. This can involve statistical analyses on data, manual review and tagging, or the use of machine learning to detect signals of interest.

Perceptualize. This is the step where a researcher turns their analysis into visualizations. These can be useful in detecting trends or determining where further analysis may be useful. These visualizations may explore trends across space, time, or some ecological gradient of interest.

Generate Indicators. Indicators are how the analysis and visualization products are turned into something that is useful for decision-making. This may include identifying trends and tipping points, or generating forecasts based on projected future influences such as climate change or land use transformation.

A CONSIDERATION OF STANDARDS

There are several issues that should be considered regarding standards as it relates to the management of acoustic data. First is that each file should be created with a metadata for files that allows others to track important information regarding its creation, content and custodian. At present, there is no standard for acoustic sensor data files although there are some industries, mostly in the music and film industry that have established metadata file standards. Unfortunately, these often do not include important scientific information like lat-long of the recording station.

There should also be standards for how sensor networks are set up. Some large scale monitoring programs, such as the USDA Slow the Spread project, established strict protocols for how sensor networks are set up and how they are described in metadata. Thus, a sensor network standard could be developed for acoustic monitoring. Labelling sensors per a network design would help to organize data across similar projects.

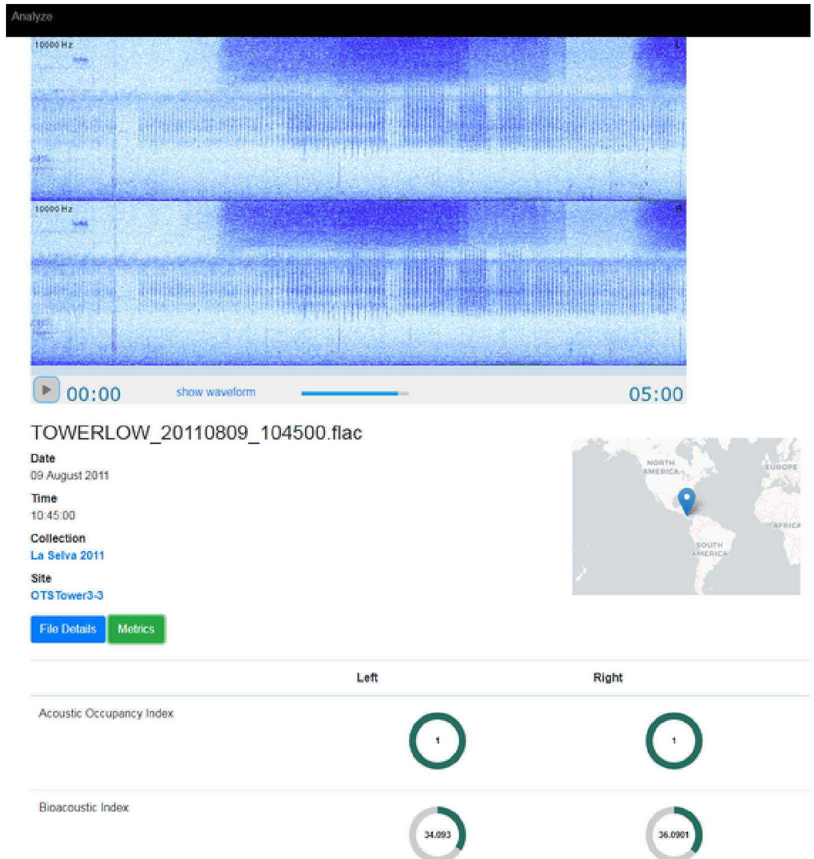
Location based metadata is critical for any acoustic monitoring study. Location information could include: major land cover class that the sensor is located in, distance to nearest road, length of roads within a certain radius, the biome descriptor, soil type, etc. Geospatial data standards for spatial attributes should also be considered and aligned to those for geospatial data (e.g., U.S. FDGS).

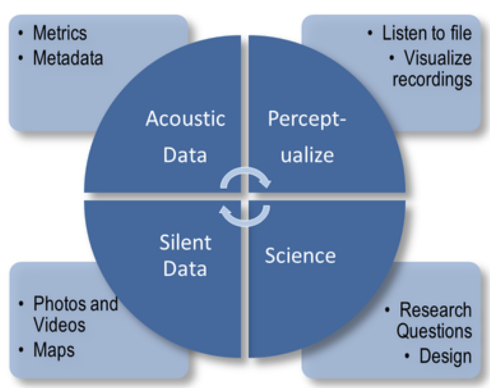
Finally, standards could be considered for how research is described and stored in the database. For example, if sensors are arranged to study a disturbance compared to an undisturbed location, the study could be described as a test-control experimental design with X number of replicates. Therefore, experimental design standards should be considered, especially if large sensor networks are established or many studies are conducted. The added benefits to developing these standards, or adopting those at the US National Institutes of Standards and Technologies (NIST) is that customized routines could be developed for any set of experimental design standards furthering the automation of large scale data processing.

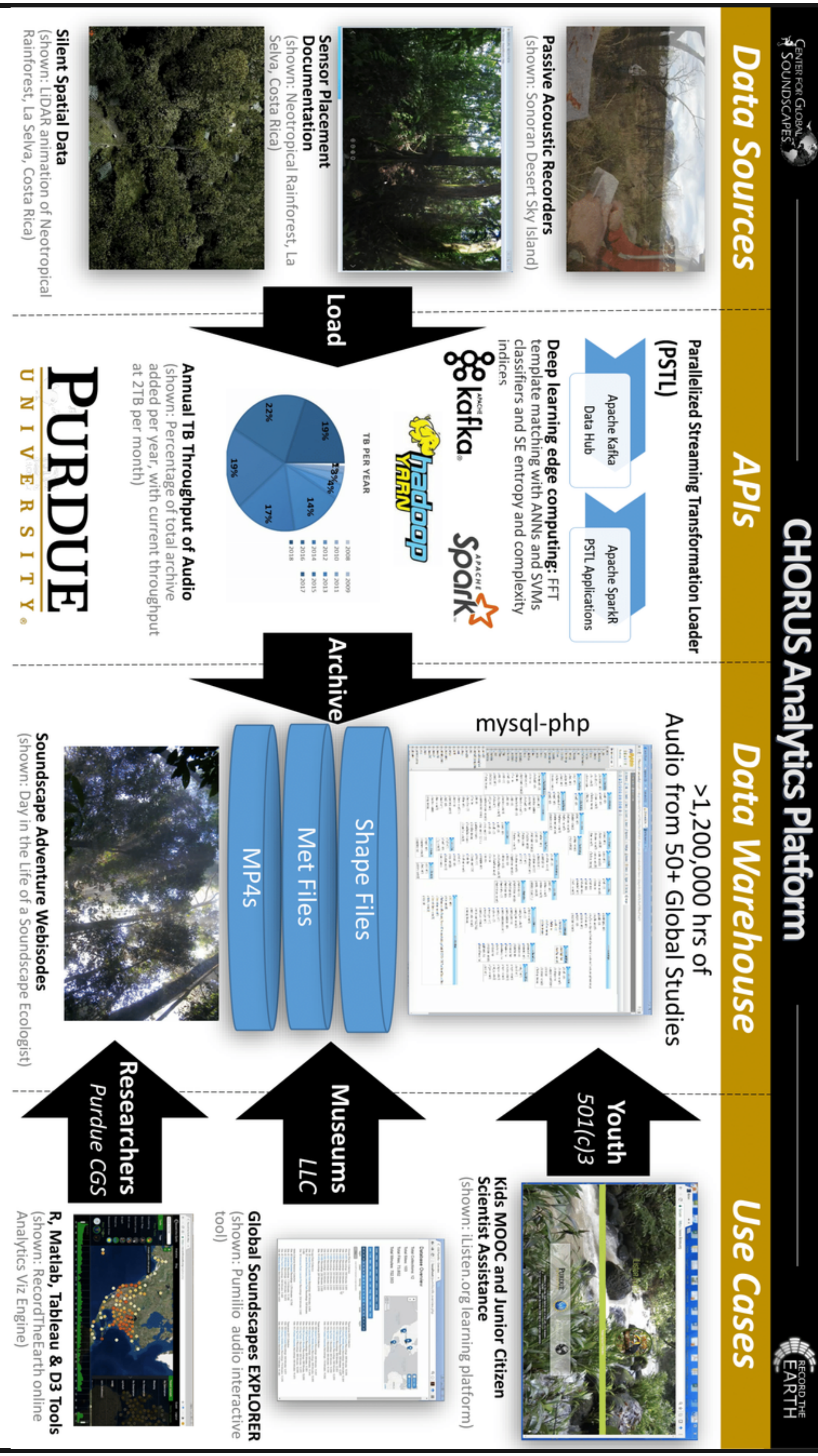
PURDUE'S ACOUSTIC INFORMATION SYSTEM: CHORUS4NATURE

As part of an effort to improve data storage, tracking, and analysis, the Center for Global Soundscapes at Purdue University has developed Chorus4Nature.io, often referred to as "Chorus", the second generation of the Pumilio database system (Villanueva-Rivera & Pijanowski, 2012). This system will enable a researcher, or even a member of the public, to visualize and listen to the entirety of the Center's audio library, as well as providing:

- The location of a collection of studies, including a description of the site, relevant ecological variables such as Koppen-Geiger climate classification, key threats and ecological challenges, research partners, and summaries of the studies contained in the collection
- Photographs and videos that were taken at the site or are relevant to the studies included in the collection
- A list of sounds in the collection, with spectrograms and temporal information on each
- File information, including size, format, channels, duration, sampling rate, spectrogram settings, sensor used, and information about the specific site
- Visualizations showing the acoustic indices that have been calculated for that file






CHORUS Analytics Platform
Center for Global Soundscapes
Record the Earth
Data Sources
APIs
Data Warehouse
Use Cases
Passive Acoustic Recorders
(shown: Sonoran Desert Sky Island)
Sensor Placement Documentation
(shown: Neotropical Rainforest, La Selva, Costa Rica)
Silent Spatial Data
(shown: LiDAR animation of Neotropical Rainforest, La Selva, Costa Rica)
Load
Parallelized Streaming Transformation Loader (PSTL)
Apache Kafka Data Hub
Apache SparkR PSTL Applications
Deep learning edge computing: FFT template matching with ANNs and SVMs classifiers and SE entropy and complexity indices
kafka
hadoop YARN
Spark
TB PER YEAR
Annual TB Throughput of Audio
(shown: Percentage of total archive added per year, with current throughput at 2TB per month)
PURDUE UNIVERSITY
Archive
>1,200,000 hrs of Audio from 50+ Global Studies
mysql-php
Shape Files
Met Files
MP4s
Soundscape Adventure Webisodes
(shown: Day in the Life of a Soundscape Ecologist)
Youth
501(c)3
Museums
LLC
Researchers
Purdue CGS
Kids MOOC and Junior Citizen Scientist Assistance
(shown: iListen.org learning platform)
Global Soundscapes EXPLORER
(shown: Pumilio audio interactive tool)
R, Matlab, Tableau & D3 Tools
(shown: RecordTheEarth online Analytics Viz Engine)

08.

RECORDING PARAMETERS

RECORDING PARAMETERS

HOW TO SET UP A SENSOR

It is important to keep parameters as consistent as possible across a sensor network. Not only does this enable the most effective comparisons between sensors, it also enables the re-use of any pre-existing analysis and data management tools. This re-use can minimize the new work that a researcher must do in the process of turning their acoustic data into meaningful ecological information. Furthermore, because many researchers are now applying machine learning to acoustic analysis, maintaining consistency is important in ensuring the consistent performance of a model, detector, or classifier. A model built using training data from a sensor with parameter set A will have degraded performance on a dataset from a sensor with parameter set B. Some of the key parameters to keep in mind:

Bit Depth: Bit depth is a measurement of the audio resolution of a recording. In an acoustic monitoring context, it is relevant mostly in terms of audio storage efficiency. 16-bit is commonly used in acoustic monitoring, and is sufficient for most tasks. Many acoustic sensors do not allow this parameter to be changed (for example, the Wildlife Acoustics SM4 is 16-bit only).

Sample rate: The sample rate of the recording should be determined in part by any particular species of interest, and in part by logistical needs. Generally, the sampling rate should be more than double the frequency of the highest-frequency expected sound of interest. There are also data storage concerns, both on and off the sensor platform. For example, on a Wildlife Acoustics Song Meter S4 a continuous recording schedule at 48000Hz will fill a 32GB SD card in just under two days, while a continuous recording schedule at 22050Hz will fill that same 32GB SD card in just over four days.

File Format: most recorders store data in WAV format. This is an uncompressed format that is commonly used and can be read by a variety of software packages. Many modern sensors, such as the Wildlife Acoustics SM4 and the OpenAcousticDevices AudioMoth record only in WAV (Hill et al., 2018). Some older sensors from Wildlife Acoustics may record in .WAC, a proprietary audio compression format developed by Wildlife Acoustics. Converting from .WAC to .WAV requires the use of Wildlife Acoustics' Kaleidoscope software, though it can be accomplished without using the paid version. Recording in .WAC can improve data storage efficiency by roughly 60%, depending on other parameters. Once a .WAV has been recorded, data can be converted after the fact to make storage more convenient. This can be done to either a lossy compression format (eg .mp3) or to a lossless compression format (eg .flac) depending on the needs of the researcher and the data storage capabilities of their institution.

Band Filters (High-Pass or Low-Pass): These can be used to minimize the impact of sounds above (low-pass) or below (high-pass) a given frequency. These are most commonly used when there is a constant source of background noise that the researcher wishes to minimize in their recordings. For example, a high-pass band filter may be desirable in a very windy environment, to prevent wind noise, which generally occurs below 2KHz, from causing clipping in the recordings.

Gain: Gain refers to the degree to which a sensor will amplify signals in the environment that it records prior to the recording being saved to storage, and is usually measured in decibels. Gain may be necessary to boost a low intensity signal in order to increase its signal to noise ratio. However, setting the gain too high risks clipping the signal which would permanently distort the recording.

Duty Cycle: The term "duty cycle" refers to when a sensor is, and is not, recording. This can be set based on a clock, dynamically calculated based on sunrise and sunset, or even triggered by an acoustic event. While some researchers and publications may refer to duty cycles using terminology such as "10 minutes every 30 minutes", we find that "10 minutes on 20 minutes off" communicates the same information with less room for confusion, since some might interpret "10 minutes every 30 minutes" to mean 10 minutes on, 30 minutes off. Some commonly used duty cycles follow:

o 10 minutes on, 50 minutes off: This is useful for short-term studies of one month or less, but provides a good ratio of days of recording to gigabytes of data

o 10 minutes on, 20 minutes off: This schedule is also useful for shorter-term studies, though it provides a finer temporal resolution than 10 on, 50 off.

o 1 on 9 off: This is similar to 10 minutes on, 50 minutes off but it provides a better view of the daily patterns in activity. This is a very widely used duty cycle in ecoacoustics research.

o 59 off, 1 on. This should be treated as close to a continuous recording schedule, since continuous back-to-back 60 minute recordings can end up taxing a sensor's processor as it tries to simultaneously write file 1 to the SD card and simultaneously record file 2. This is useful for long-term "sentinel" sites, as well as those where events of interest may be very rare, and recording every single one is a key objective. This may also be desirable where battery power, SD card space, and the logistics of visiting a sensor to swap batteries and cards are minimally intrusive.

o Sunset to Sunrise: This is a useful recording schedule when one is interested in a nocturnal species, such as bats, owls, or some seabird species. Sunset to Sunrise can be incorporated with any of these other duty cycles (for example, 10 minutes on 20 minutes off sunset to sunrise).

TIPS

AN INTRODUCTION TO ACOUSTIC SURVEY DESIGN

- Sample size is key. Each study should use at least five sensors to try to cover a useful range of the ecological gradient or phenomenon of interest
- Sentinels must be stationary. Moving a sentinel risks making its data significantly less useful. This is vitally important in studies where one is working with a partner organization that may be less experienced with acoustic data. This is a problem that we have seen in the past when organizations have interns who will be doing work on acoustic sensors and do not understand the importance of the sensor remaining in one place for its complete deployment duration.
- Have a clear idea of the research question you are attempting to address before deploying your sensors, or even planning where to deploy them (Lawrence et al., 2014). Using a framework of survey designs such as the one outlined in this document can be helpful in making the connection between a research question and its relevant survey design, but some questions may merit other designs, especially those that are focused on single species monitoring.
- Adopting a set of parameters that can be re-used for automated script-based analysis and data management. It is comparatively easy to build a script to handle 3-5 distinct possibilities for expected recording length, gain, bit depth, file size, number of channels, and other parameters. If every survey you conduct has one 10 minute recording every hour, it is much easier to build tools that can be used repeatedly than if some surveys have 10 minute recordings every hour, some surveys have 3 minute recordings every 5, some have 1 minute recordings every 10 minutes, et cetera.

09.

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APPENDIX

AN ONTOLOGY OF SURVEY DESIGN: TERMS

Design type: The conceptual experimental design behind the study. A given sensor can have multiple design types.
Generally a given recorder deployment will be put out as part of some design. Later, in analysis, it may be applied to one of several studies.

SiteID: unique identifier for a specific location. One sensor could be at several sites over time, or a site could contain multiple sensors

Treatment Types: a list of treatment classes. This will generally be a sub-class of the design type

SensorID: prefix of the sensor, which will show up on all recordings. Often the serial number of the sensor, may be a merge field in databases

ReplicateName: identifies a specific site in a treatment. Many treatment-subtreatment combinations will have one replicate, sometimes there are multiple replicates

Subtreatment: Used mostly within nested design types, subcategory of treatment types, may be used for within-vs-between comparisons

EndMembers/Class: type of treatment or subtreatment in a factorial design

APPENDIX

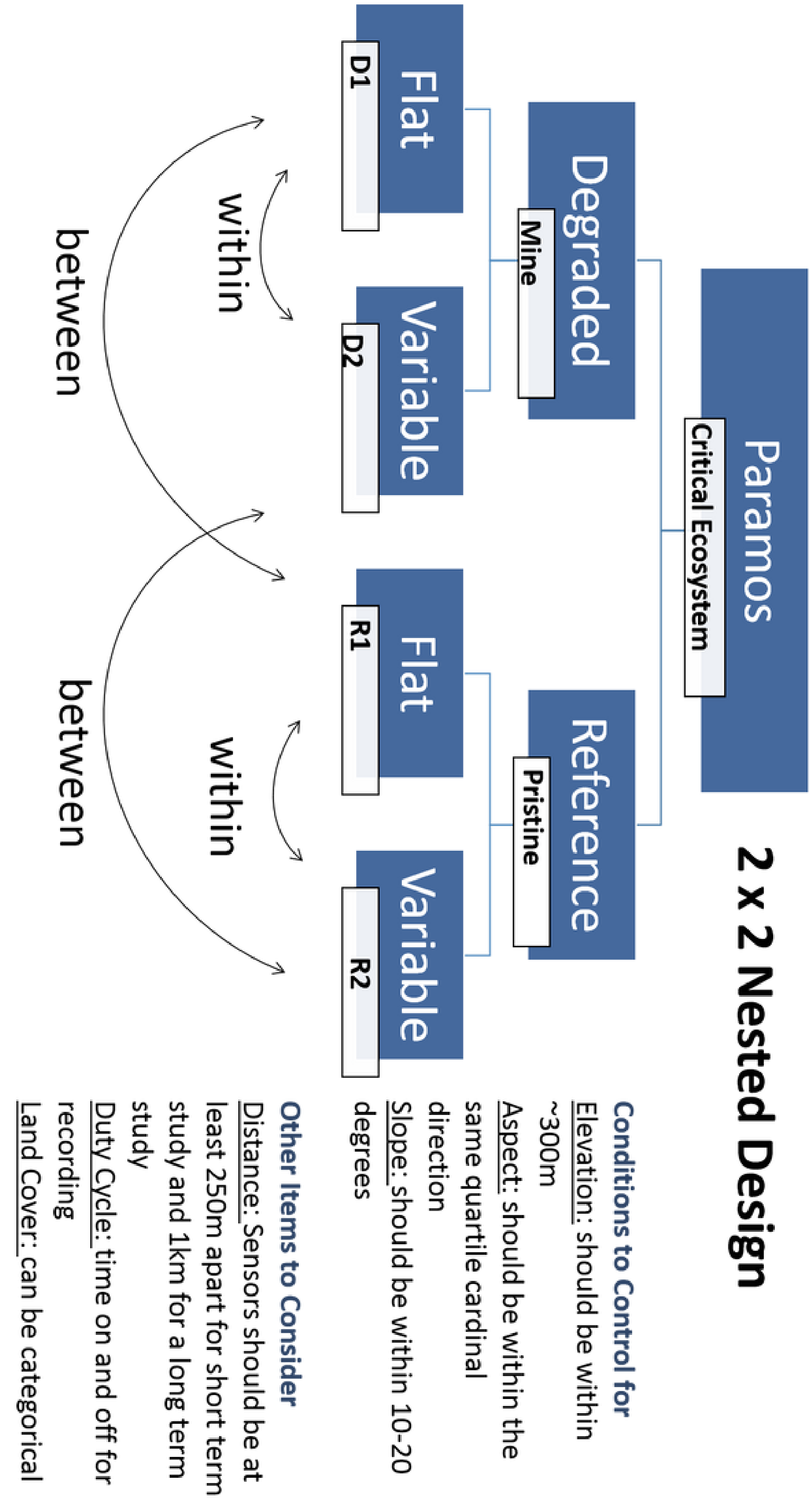
AN ONTOLOGY OF SURVEY DESIGN: SURVEY TYPES

- **Gradient**
- Places sensors along some kind of ecological gradient. Generally relies on more than just endpoints for that gradient
- Tries to control for as many other factors as possible while varying the gradient
- Many types of gradients can be considered

- **Sentinel**
- Long-term deployment (> 1 year)
- Seasonal or longer-term changes and phenology
- Long-term disturbances if deployed at the same site for a multi-year period
- Baseline of long-term variability, so other deployments can be conducted over time while avoiding or minimizing the effects of deployment time

- **Nested**
- Looks at two distinct factors (eg topography and disturbance)
- Needs to deploy a sensor per combination of two or more nested factors
- Can be compared to fractional factorial or full factorial designs in industrial experiment design

- **Full-Spectrum**
- Tries to record outside the audible spectrum
- Generally relies on at least two microphones, with different frequency sensitivities
- Often tries to incorporate aquatic recordings, so a common setup may be ultrasonic + sonic + hydrophone



AN EXAMPLE OF A 2X2 NESTED SURVEY DESIGN USED FOR SENSOR DEPLOYMENT IN PNN CHINGAZA, COLOMBIA

APPENDIX

AN ONTOLOGY OF SURVEY DESIGN: SURVEY TYPES

- **Species**
- Designed to look for the presence/absence, or behavioral patterns, of a specific species
- Can be deployed as some combination of single, grid, or gradient but may be focused on a specific habitat type or on known colonies

- **Grid**
- Regular spatial interval, from meters to kilometers
- Commonly a 3x5 or 5x5 grid
- Used to get at very fine-scale spatial variation in soundscape characteristics

- **Single**
- Single sensor deployed by itself
- Can sometimes be used for testing sensors
- Sometimes used when an opportunity presents itself
- Describes the use of handheld recorders by researchers in the field, where those researchers are not necessarily following some determined sampling protocol