Exploring acoustic dynamics at Pfynwald:
The soundscape of a xeric forest ecosystem

Bachelor Thesis
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Martin Rüegg

Supervisor ZHdK: Marcus Maeder, Institute for Computer Music and Sound
                     Technology (ICST), ZHdK
Supervisor ETHZ: Prof. Dr. Felix Kienast, Landscape Ecology Group, ETH
                     Zürich/WSL

ETH zürich   **D** USYS   **Z** hdk
Zürcher Hochschule der Künste

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Abstract

Usually we look at a landscape with our eyes. Yet the animals living there also produce a variety of sounds. This thesis tries to combine what we hear with what we see. In order to get a holistic picture of the Pfynwald soundscape four entirely different sites were described. One located in the forest, one near a mountain-stream known for debris flow, one near the river Rhone and one next to a pond.

Each site was described visually focusing on landform and landcover, and auditive. Here we distinguished between anthrophony, biophony and geophony. In addition, also classifications for keynote sounds, sound signals and soundmarks were made.

At each location a recorder takes recordings every 10 minutes for 20 s. Based on this data, the acoustic complexity index (ACI) was calculated, leading to a time series with one year worth of data. This data was analyzed for seasonal and diurnal dynamics and patterns.

At Pfynwald different seasons show different diurnal patterns. In spring the ACI is at its peak at dawn and in summer the ACI peaks during the night. Generally the ACI increases in spring, decreases by the end of spring, increases in summer and then decreases again in autumn. The main cause for increasing ACI values are birds in spring and crickets in summer. The site next to the pond is an exception in that there the ACI doesn't increase in summer.

Aside from biophony also anthrophony and geophony can lead to a high ACI. Therefore, a filter was applied to identify recordings with clippings (mostly due to wind but also due to airplanes) and rain. Especially in autumn and winter many recordings were affected. This aligns well with meteorological data. In summer there was hardly any rain and in autumn and winter storms kicked in.

During this thesis we realized that besides looking at the ACI time series it is also important to listen to the actual recordings. The ACI highlights acoustic events but doesn't give further information about the things hearable in the recording. For further research we suggest to conduct statistical analysis of the existing data, collection of additional data and the application of supplementary indices.

Terminology

ACI:	Acoustic complexity index (Pieretti, Farina and Morri, 2011)
Anthrophony:	Anthrophonies are man-made noises. They are produced, for example, by cars, airplanes, machines and musical instruments. (Farina, 2014)
α-index:	α-indices are based on the number of objects and their relative frequency in the examined parameter. Objects usually refer to species. (Sueur et al., 2014)
β-index:	β-indices try to estimate the similarity between lists of objects recorded at different locations. Objects usually refer to species. (Sueur et al., 2014)
Biophony:	Biophonies are non-human sounds of biological origin. (Farina, 2014)
Dawn chorus:	Singing activity of birds is at its peak at dawn.
Geophony:	Typical sources for geophonies are wind, rain, volcanoes, waves, earthquakes, etc. They are strongly influenced by the geographical and climatic characterstics of a site. (Farina, 2014)
Keynote sounds:	Keynote sounds are sounds that are heard constantly or frequent enough by a society to form a background against which other sounds are perceived. When one doesn't actively look for it one doesn't hear it. (Schafer, 1977)
Soundmarks:	Soundmarks are sounds that are unique to a particular soundscape. (Schafer, 1977)
Soundscape:	Similar to the term "landscape", there are different definitions for soundscape. Simply put soundscape is the result of intentional or unintentional overlapping of different sounds of physical or biological origin. Soundscape is an extension of the concept of landscape. The geographical landscape is the spatial dimension in which all populations, communities and ecosystem processes occur. (Farina, 2014)
Sound signals:	A sound signal is a sound that is consciously perceived by humans. (Schafer, 1977)

Acknowledgements

1. Introduction

Landscape ecology uses ecological theories and geographical analyses to understand processes and patterns in a landscape. Similarly, soundscape ecology uses these theories to understand processes that generate sound patterns (Almo Farina, 2017). Soundscape ecology can thus be seen as a part or extension of landscape ecology. This is a relatively young research discipline with great potential in the environmental field. It can be used to assess the quality of parks and nature reserves, urban planning, ethnology and anthropology, and for the long-term monitoring of the effects of climate change in geophysical (glaciers) and biological (reproductive phenology) contexts (Farina, 2014).

In recent years the interest in soundscape Ecology has grown strongly. Due to the technical progress of the last years, especially concerning computing power and the affordability of recording technology, new possibilities arose, which advanced the discipline strongly. However, it is still impossible to automatically identify every type of sound (Farina, 2014).

The consequence of this limitation is that not all components of a soundscape can be identified and the possibilities for efficient evaluation are limited (Farina, 2014).

New approaches make it possible to measure acoustic diversity in the form of frequencies. This can be used to estimate the complexity of a site or habitat. However, there is no direct correlation between acoustic and biological diversity. Nevertheless, a high acoustic diversity is associated with a specific accumulation of species (Farina, 2014).

The collection of ecological data, such as the preparation of a biodiversity assessment, is one of the greatest challenges that ecologists and conservation biologists face. Quantifying biodiversity is mainly based on species inventories, which are both expensive and time-consuming to create (Sueur et al., 2008). These methods are often invasive because they depend on the direct collection or capture of plants and animals (Depraetere et al., 2012).

Acoustic methods can help here. They potentially allow the collection of data over longer periods of time, in a less intrusive way and at lower cost. In some cases, comparisons have shown that acoustic surveys can be more accurate than traditional surveys, as researchers were able to identify more species while listening to the recordings in the lab than in the field (Mammides et al., 2017).

For a better understanding of the relationship between acoustic diversity and the accumulation of species, various indices have been proposed. A distinction is made between α- or within-group and β- or between-group indices (Sueur et al., 2014).

α indices are based on the number of objects and the relative frequency of the objects in the examined parameter. β indices try to estimate the similarity between lists of objects that have been included in different locations. Objects are mostly species (Sueur et al., 2014). The greatest challenge for such indices is the separation of biophony, geophony and anthrophony. This is where the proposed indices differ the most. Geophonies can be identified by separate records of weather data (wind, rain,...) and the corresponding time periods can be deleted (Depraetere et al., 2012).

Anthrophonies are harder to identify. They must be avoided by carefully positioning the recorder and the use of filters (Gasc et al., 2015).

In this thesis we work with one of these indices, the ACI (Acoustic complexity index). The ACI is a way

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to reflect the acoustic diversity of a site. The aim is not to identify individual species, but to determine whether there are dynamics in biodiversity and environmental noise at the site under investigation. The data for this is taken from the Pfynwald forest, a region in which major changes are imminent: It is facing increasing drought as a result of climate change and a motorway is to be built through the area (Amt-für-Nationalstrassenbau, 2019). This study is part of the „Ecodata - Ecomedia -Ecoesthetics" project funded by the Swiss National Science Foundation (SNSF). This project investigates the role of technologies and scientific methods in art for the perception of ecological contexts (Volkart, 2017).

2. Research questions and objectives

The aim of this thesis is to analyze soundscape data from four locations at Pfynwald as timeseries. We investigate how environmental sound changes in the course of the year as well as during the day. Furthermore, we would like to identify and document the sound sources as thoroughly as possible. Therefore, a description of each recording site was made, containing auditive and visual observations. In addition, this work is an inventory (before the construction of the motorway) and examines whether/how the particularly warm summer of 2018 manifests itself in the data. We hypothesize that with increasing temperatures in summer the biophony and therewith the ACI will decrease.

We are interested in the following questions:

- Is there a dynamic in biophony? How is it characterized?
    - Are there seasonal differences?
    - Are there differences in the time of day?
- Is there a dynamic in geophony? How is this characterized?
    - Are there seasonal differences?
    - Are there differences in the time of day?
- Are there acoustic similarities between the locations?
- Are there spatial differences?

We'd like to answer these questions by specifically listening to and viewing the acoustic data. We document conspicuities and try to explain them with observations we make at the recording sites. However we explicitly refrain from a direct comparison of acoustic diversity with biodiversity.

3. Context

3.1. Pfynwald

Pfynwald (Canton Valais; 46° 18' N, 7° 36' E, 615 m ASL) is the largest continuous pine forest in Switzerland. With an annual average temperature of 9.2 °C and a yearly accumulated precipitation of 657 mm (average 1961-1990) it is located in one of the driest regions of Switzerland. The pines are about 100 years old and 10.8 m high (Rigling and Schaub, 2019; Rigling et al., 2019).

In the 70ties and 80ties the trees were exposed to fluorine emissions by the local aluminum-industry. After the installation of filters this problem vastly disappeared (Dyttrich, 2007; Bellwald, 2010). Today, drought is a major driver of forest development, leading to increased mortality in dry years. Pfynwald is located on a debris cone. Water that does not evaporate percolates quickly (Giuggiola et al., 2013). Climate Change intensifies the problem up to the point where the pine trees reach their eco-physiological limits. In the long run this means that trees will die and vegetation zones will shift (Lévesque et al., 2013). Due to a dry period between 1996 and 2004, in some parts of the forest 2/3 of all pines died (Schaub et al., 2019). In light of this a team of WSL researchers installed a long-term irrigation experiment in order to better understand the effects of climate change on trees. For our research we can use their infrastructure. Today, Pfynwald is part of a regional nature park of national importance (Pfyn-Finges, 2019).

3.2. Recording sites
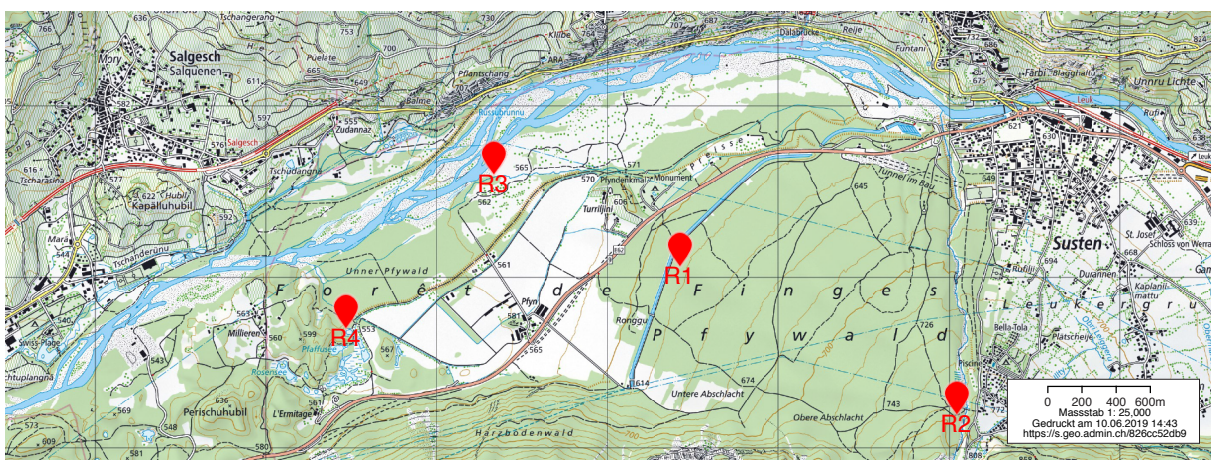
Figure 1: Recording sites (Swisstopo, 2019a)

Recordings were made in four different locations. One of our recorders (Figure 1, R1, LAT: 46.30349, LONG: 7.61279) is located by the WSL research station at Pfynwald. An other one (R2) is placed next to the Illgraben, a mountain stream known for debris flow (LAT: 46.29567, LONG: 7.63381). Recorder 3 (R3, LAT: 46.30831, LONG: 7.59866) is near the river Rhone, one of the few remaining freely flowing river sections in Switzerland (Bellwald, 2010), and recorder 4 (R4) is situated next to a pond in a hilly landscape (LAT: 46.30035, LONG: 7.58755).

These locations were chosen for their differing biotope characteristics and for their geographic distribution in order to get a holistic picture of the soundscape Pfynwald.

4. Methods

4.1. Fieldwork

For this thesis we visited the recording sites on three separate occasions. Each time, SD cards were changed and batteries replaced if necessary. In total we spent five days there, maintaining the recorders and documenting the recording sites. For that purpose we looked at and listened to the surroundings, took pictures and notes. Additionally we studied satellite imagery. Sounds were classified using two different systems. On one hand we used the concept pioneered by Bernie Krause, dividing the soundscape into anthrophony, biophony and geophony (Krause, 2008). On the other hand we used Murray Schafers approach of distinguishing between keynote sounds, signal sounds and soundmarks (Schafer, 1977).

For the visual description of the different sites we mainly looked at the landform and landcover. Land use was also an issue but since all recording sites are located in a natural reserve this aspect isn't of such importance. All our visits to Pfynwald took place in spring or summer with good weather conditions. Visits in different circumstances might have lead to a different result. Sometimes already a weekday can have an impact. For instance a heavily frequented road leads through the valley. On weekends much fewer lorries use this road. Instead there are more motorcycles, leading to a different soundscape.

4.2. Acoustic equipment and setup

The recordings used in this study were made with a SONG METER SM4 ACOUSTIC RECORDER developed by wildlife acoustics. It is a compact, waterproof acoustic recorder with two channels capable of long-term monitoring. It allows up to 400 hours of recording time using internal batteries. In sleeping mode between scheduled recordings it uses hardly any electricity and therefore enables stand-alone recordings over a long period of time (Wildlife-Acoustics, 2019).

For our purposes we took recordings every 10 minutes for 20s with a sampling rate of 44100 Hz and a bit rate of 32 bits. The recordings were saved in a .wav format.

Figure 2 SM4 Acoustic Recorder

The recorders were mounted on trees as displayed in Figure 2 approximately 150 to 200 cm above ground. The recorder at site number 4 (Ponds) was equipped with a hydrophone. The hydrophone was placed in shallow water in approximately 40 cm depth. As a consequence only one channel (right) could be used to make recordings above ground. For all the other locations stereo files are available. This isn't a problem as the index used in this work is extracted from a mono file. In order to stay consistent in the study we decided to always use the right channel for computation.

In addition to the SM4 recorders we placed an AudioMoth recorder next to each SM4 recorder over the course of eight weeks. On one hand this allowed us to have an additional control and on the other hand we had the opportunity to try out a new piece of equipment. AudioMoths are small, low-cost and full-spectrum acoustic loggers (Open-Acoustic-Devices, 2019). In this study we didn't use the recordings made with AudioMoths but explored their potential for further projects in the chapter "Outlook".

4.3. Data set

4.3.1. Acoustic data

For this study we looked at one year worth of data with a temporal resolution of 10 minutes. Starting on March 30 2018. Two recording sites have data available for the entire year and two sites show significant gaps in autumn.

Recorder 1 lacks data between 2018-10-02 04:50:00 and 2018-10-21 09:30:00

Recorder 4 lacks data between 2018-08-30 13:30:00 and 2018-10-21 08:00:00

This results in 139-140 recordings each day. Since each recording takes 20 seconds there is a time shift. Recordings don't always happen at the same time. This has the advantage that events occurring always at the same time (such as church bells) aren't represented too heavily.

4.3.2. Meteorological data

The meteorological data used in this study originates from the long-term irrigation experiment Pfynwald which is part of the Swiss long-term forest ecosystem research program LWF (www.lwf.ch).

Since their weather stations aren't located in the exact same spot as our recorders we only use data from sensors above the tree canopy. We cannot make a statement about the microclimate for each recording site specifically but nevertheless this enabled us to get a general overview of the weather conditions in the entire region.

We used data from the following sensors specifically:

Precipitation: Pfynwald-02-12.precipitation.ch6

Relative air humidity: Pfynwald-02-12.sht-humidity.ch3

Air temperature: Pfynwald-02-12.sht-temperature.ch3

Wind speed: Pfynwald-02-12.wind-speed.ch2

The temporal resolution for the meteorological data used is 10 minutes.

4.4. Acoustic complexity index (ACI)

The acoustic complexity index (ACI) as described by Pieretti et al. (2011) is based on the observation that many biophonies are characterized by temporal variability of amplitudes whereas geophonies and anthrophonies are represented by more constant amplitude values (Farina, 2014).

This means that more individuals and/or species are present when the acoustic information expressed by the ACI is greater (Farina et al., 2016).

The ACI can be calculated in the following way:

First the absolute difference (dk) between two adjacent amplitude values (Ik and I(k+1)) in a single frequency bin (Δfl) are calculated, based on a Matrix of amplitudes extracted from the spectrogram and divided into temporal steps and frequency bins (Pieretti, Farina and Morri, 2011).

$$d_k = |I_k - I_{(k+1)}|$$

Then all of the absolute differences (dk) are added together.

$$D = \sum_{k=1}^{n} d_k$$

This result is then divided by the total sum of amplitude values in order to obtain the relative intensity and to reduce the influence of the distance between microphones and vocalizing organisms (Pieretti, Farina and Morri, 2011).

$$ACI = \frac{D}{\sum_{k=1}^{n} I_k}$$

In the following two steps the calculated values are added together for all frequency bins (Δfl) and temporal clumps (j) (Pieretti, Farina and Morri, 2011).

$$ACI_{(\Delta fl)} = \sum_{j=1}^{m} ACI \qquad \text{for: m = number of j in the entire recording}$$

$$ACI_{tot} = \sum_{l=1}^{q} ACI_{(\Delta fl)} \qquad \text{for: } \Delta f = \sum_{l=1}^{q} \Delta f_l \; ; q = \text{number of } \Delta f_l$$

The size of the frequency bins depends on the sampling frequency and the chosen FFT window (Farina et al., 2016). The size of j can be chosen. Higher clumping will represent more recurrent amplitudes better whereas smaller clumping highlights singularities (Farina et al., 2016).

For our research we chose a window length of 512 as this seems to be a reasonable compromise between resolution in time and frequency and is widely used (Farina, 2014). This means the signal sequence gets divided into 256 frequency bands and 1722 time blocks, each 0.012 seconds long. (Our recordings are just short of 20 seconds)

For j we chose a value of 1 second. Resulting in 19 clumps. (As the recordings are just short of 20 seconds only 19 seconds could be used).

Instead of calculating the sum of frequency bins and temporal clumps inspired by the work of X. Guo (2018) we decided to take the average for both steps leaving us with a more comparable index within the range of 0 to 1. A low value in ACI means little acoustic diversity and a high ACI means high acoustic diversity.

Otherwise the resulting ACI would be highly dependent on the length of the recording (longer recordings would have a higher ACI) and a comparison between different sites would be difficult. Having said this, we are very much aware that the ACI is a α- or within-group-index. Even though we're also looking at spatial differences, the main focus of this study is looking for seasonal and diurnal differences and dynamics in biodiversity and environmental noises, which are better represented through α-indices. Many papers advise to use several indices to depict biodiversity in a soundscape. However, for reasons of time and proportionality, we only calculated one index.

4.5. Data processing and visualization

4.5.1. R Studio

All computations were conducted using the statistical software R, a software commonly used in ecoacoustics. It has the advantage of flexibility. Several packages have been developed for acoustic analysis. We're using tuneR, soundecology and seewave (Sueur J, Aubin T, 2008; Ligges Uwe, Krey Sebastian, Mersmann Olaf, 2018; Pijanowski, 2018).

The packages ggplot2, dygraphs, and shiny were used for data visualization (Ishimaru et al., 2014; Wickham, 2016; Vanderkam Dan, Shevtsov Petr, Allaire JJ, Owen Jonathan, Gromer Daniel, Thieurmel Benoit, 2018).

Furthermore, the following packages were used: maptools, Rmisc, Lubridate, plyr, reshape, zoo (Hope, 2013; H. Wickham, 2016; Spinu et al., 2018; Wickham, 2018; Bivand et al., 2019; Zeileis et al., 2019)

4.5.2. SAS Lab

All spectrograms displayed in this study were created using Avisoft SASLab Pro (Bioacoustics, 2011).

4.5.3. Dealing with noise e.g. wind and rain

While working with the data we realized that many recordings have clippings due to wind or anthropogenic activity. With the following command line applied in a macOS Terminal we were able to identify these recordings.

```
for i in *; do echo $i `sox $i -n --norm -R gain 0.1 2>&1`; done |grep
clipped
```
(Tnovelli, 2016)

`gain 0.1` is optional and catches anything almost clipping. It was added since the function isn't exact. For it to work one has to install "SoX - Sound eXchange", a cross-platform command line audio tool, beforehand (Cbagwell, Robs and Uklauer, 2015).

Another challenge were rain-events. Rain leads to high ACI-values and had to be excluded manually. We tried to exclude it automatically using precipitation measurements. A method that turned out not to be exact enough due to the delayed reaction of rain gauge sensors on the one hand, and due to the impossibility to measure low precipitation amounts with this method on the other hand. In addition to that, the rain sensors aren't in the exact same spot as the recorders, meaning that small scale rain events may get registered by a recorder but not by the rain gauge.

4.5.4. Line graphs

The biggest challenge was the massive amount of data. It is impossible to listen to all recordings and line graphs of one year of data are too crowded to identify patterns. For that reason we looked at the data in two week intervals with a resolution of one hour (Aggregation with mean). For each peak identified we listened to the underling recording and classified it as biophony, anthrophony or geophony depending on the sound dominating. Geophony was further divided into rain and wind events.

This classification was also used to exclude rain events from the dataset. (Figure 3)
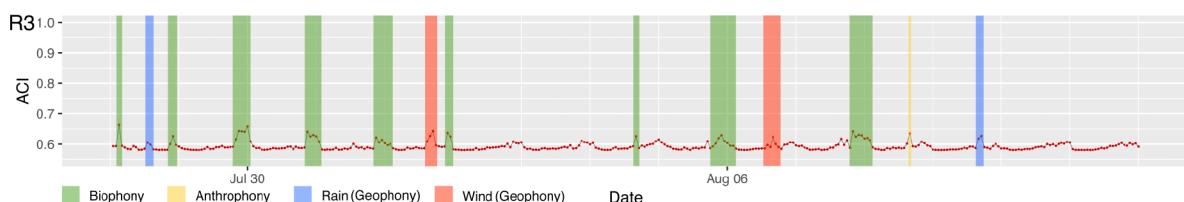
Figure 3: Classification of peak values. R3 stands for the recorder by the riverside (Recorder 3)

In order to look at the data in a finer resolution an interactive app of line graphs developed by X. Guo (2018) was adapted. (Figure 4)
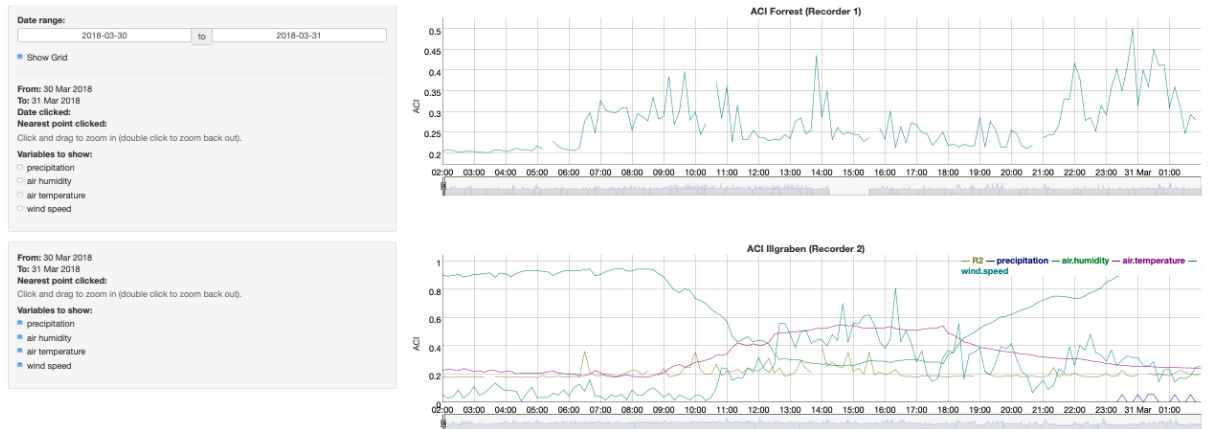
Figure 4: Screenshot of the interactive line graph app. Aside from ACI precipitation, air humidity, air temperature and wind speed can also be displayed. All variables are rescaled to a 0-1 range.

4.5.5. Trendlines

To better see patterns over the course of the year we plotted the entire data and added a trendline using the function geom_smooth with method = loess and span = 0.3 from the R package ggplot2 (Wickham, 2016). For those time series with gaps (recorder 1 and recorder 4) two groups were made. Small gaps resulting from wind and rain removal were ignored.

4.5.6. Different daytimes

As ACI values also follow diurnal patterns (Lin et al., 2017) we decided to look at how the ACI changes throughout the season for specific daytimes. Inspired by the work of B. Krause et al. (2011) we distinguished morning, midday, evening and night. For each category we averaged one hour of data. Midnight and noon were defined as specific times (11:40 – 12:30). Morning and evening change with the seasons (sunrise, sunset). This was achieved using the R package "maptools" (Bivand et al., 2019).

5. Results

5.1. Recording sites

5.1.1. Forest

Figure 5: Recording site 1

Landform: The recording site (displayed in Figure 5) in the forest is located by the WSL research station. It's at the foot of a debris cone piled up by Illgraben. The terrain is relatively flat with a tilt towards the bottom of the valley. It is exposed towards north-north-east. West of the recorder there is a tiny valley.

Landcover: The vegetation is rather monotonous. In the tree layer, pine (Pinus sylvestris) clearly dominates. Many of the trees are dead or show signs of decay. Almost all of them are infested with mistletoe. The trees are roughly 10 m high and 100 years old (Rigling and Schaub, 2019). If one looks closely one can also spot a birch (Betula pendula) and a common whitebeam (Sorbus aria).

The shrub layer is much more diverse: Aside from several bushes (Vibrunum lantana, Ligustrum vulgare, Lonicera xylosteum, Berberis vulgaris, Rosa cannina) there are some downy oaks (Quercus pubescens), birches (Betula pendula), aspen trees (Populus tremula), common whitebeams (Sorbus aria) and a mountain-ash (Sorbus aucuparia) growing.

The herbal layer is composed of bearberries (Arctostaphylos uva-ursi), grasses, some small downy oks (Quercus pubescens), common junipers (Juniperus communis), common whitebeams (Sorbus aria) and many other herbs. Otherwise the floor is covered with mosses. The site is xeric and has shallow soil, occasionally some stones emerge from the soil. One can find mostly limestone but also some quartzites with interbedded dolomites and schists (Berger, McArdell and Schlunegger, 2010).

The sun reaches the floor much later then sunrise as the tree cover is relatively dense.

Land use: This part of the forest is used for research purposes. On the one hand this means there is no disturbance in the form of logging but on the other hand this means that there is lots of sound activity due to researchers maintaining their experiments.

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Anthrophony: As one can see on the satellite image in Figure 6, next to the research station there is a channel that feeds water to a powerplant. From the recording site itself one cannot see or hear it. Also invisible but clearly hearable is the road nearby. This can be classified as a keynote sound. An interesting observation is that the amount and type of noise coming from the road not only varies between day and night but also between working days and weekends. During the week lorries dominate with a rather constant and high pitch sound. On weekends the road is quieter but there are more motorcycles producing a less constant lower pitched tone. Other anthrophonies observed at this location include airplanes and choppers but also strollers walking along the channel and occasionally researchers working at the station.

Figure 6: Satellite image site 1 (Swisstopo, 2019b)

Biophony: The biophony at Pfynwald changes with the seasons. During the time this thesis was written (spring 2019) one could mostly hear birds. Having been there multiple times at different daytimes we can say that they are most active in the morning and appear to be quieter when there is lots of wind. Un-fortunately we could not identify the different species. Bird calls qualify as sound signals. Other biophonies observed came mostly from insects such as wasps and flies. Occasionally one can also hear a dog barking, but one could also argue that this should be categorized as anthrophony instead of biophony. From listening to the recordings we know that in summer in the evening and during the night crickets are strongly present at this location. Depending on how one argues the sound produced by crickets can be classified as a signal or as a keynote sound. Since the main difference between the two categories is whether the sound is perceived consciously or not this highly depends on the listener.

Geophony: Wind is heavily present in the entire Rhone valley. It can produce a variety of sounds. One hears a constant rushing but also varying sounds coming from gusts starting far away and then coming closer at different velocities. Wind also leads to things falling to the ground which then produces a noise.

5.1.2. Illgraben

Figure 7: Recording site 2

Landform: Recording site 2 is located next to Illgraben. A mountain stream known for its debris flow. It is the same stream that piled up the debris cone where recording site 1 is located. The material originates from Illhorn and is composed of limestone and quartzites with interbedded dolomites and schists (Berger, McArdell and Schlunegger, 2010). The site is located on a ridge and again exposed towards north-north-west but this time with the recorder facing uphill. East of the recorder is the Illgraben. The terrain on this side drops steeply. West of the recorder there is a slight drop and then it is relatively flat before there is a steep climb. It is apparent that there were times when Illgraben also flowed through here. The area as a whole is tilted towards the bottom of the valley but is steeper than the recording site located near the WSL research station and shows much more structure in the east-west axis.

Landcover: Near Illgraben the trees are much smaller and the forest seems much younger than at the WSL research station. There is a lot of pioneer vegetation but in the tree layer pine (Pinus sylvestris) still dominates. In comparison to site 1, one can frequently find birch (Betula pendula) and aspen trees (Populus alba). Some of the pines are infested with mistletoe and a substantial amount of them is dead and chipped by snow (see Figure 7). As a result, there is quite a lot of deadwood both standing and lying on the ground. In the shrub layer we find downy oak (Quercus pubescens), common whitebeams (Sorbus aria), spruce (Picea abies), larch (Larix decidua) and fly honeysuckle (Lonicera xylosteum).

In many places the ground is bare, only covered by pine needles. In many parts of the recording site stones emerge from the soil. One can find limestone and quartzites with interbedded dolomites and schists. It generally seems more xeric then at the WSL research station. Nevertheless a herbal layer exists and in some parts the ground is covered with mosses. We found downy oak (Quercus pubescens), spruce (Picea abies), birch (Betula pendula), barberry (Berberis vulgaris), fly honeysuckle (Lonicera xylosteum), ash (Fraxinus excelsior), field maple (Acer campestre) and even a silver fir (Abies alba).

Anthrophony: Whenever we were at this recording site we could mostly hear the cars, lorries and motorcycles from the road with noises made by the cars and lorries qualifying as a keynote sound. At this location one can also hear the train from the other side of the valley. Choppers and airplanes were observed as well. Since there is a small airport nearby in Sion there is a remarkable amount of small propeller airplanes. They fly by much more frequent at weekends with nice weather whereas the frequency of airliners stays more or less the same. On the recordings we could also hear military jets whose noise could actually cause the recordings to overdrive.

As one can see in Figure 8 on the other side of Illgraben there are settlements and some areas with agriculture and also a campsite. Depending on the acitvity there one can hear cardoors, lawn mowers, caralarms and cowbells. Depending on the time churchbells can be heard as well. Except for the lawn mower these are all sound signals. Sometimes one can also hear voices but as there are some hiking trails in the area as well it is not always clear where exactly these noises come from. Whether one can hear these sounds also depends on the direction and intensity of the wind.

Figure 8: Satellite image site 2 (Swisstopo, 2019c)

Biophony: At site 2 one can mostly hear birds singing, dogs barking and insekts humming. A funny thing about insects is that they rerely fly close to your ear but frequently close to the microphone. As a result, if you listen to the soundscape with headsets through a microphone you'll percieve it differently. Flies, for instance, can be quite loud.

Dog barking is quite frequent. This can be explained by the fact that a hiking trail is nearby leading towards the "Bhutanbrücke", a popular attraction in the region also visible on the satellite image (Figure 8). Working there we've also seen squirrels but we never heard a noise produced by them other than a rustle in the trees.

Geophony: Sounds qualifying as geophonies are mainly caused by wind. Of course there is the sound of wind itself whether it blows constantly or squally. But wind also causes things to fall to the ground and bends branches or even entire trees, again producing a noise. An interesting thing about wind in this location is that there are patches with broad-leafed trees dominating and patches with conifers dominating. Wind blowing through broad-leafed trees produces a different kind of sound than wind blowing through a coniferous stock. This location unites both. Depending on the wind direction and where exactly one stands one can better hear the coniferous stock or the broad-leafed trees.

Another geophony is the mountain stream Illgraben. Depending on how much water it carries it produces louder or quieter noises. Illgraben not only produces keynote sounds but also a sound signal that actually could be classified as a soundmark. We never saw it happening but on two occasions our recorder actually caught debris flows, one on July 25 and one on August 8. A debris flow produces incredibly loud noises and leads the recorder to overdrive heavily.

5.1.3. River

Figure 9: Recording site 3

Landform: Recorder number 3 is located next to the river Rhone. The terrain on which it is standing has clearly been formed by the river. Among all of the four recording site it is the only one where there are no stones emerging from the soil. Instead the soil is covered with sand, on top of which we find a layer of pine needles and cones. The terrain has a wavelike form as if shaped by water. There are tiny hilltops and valleys. A bit further north of the recorder there is a small trench with a little brook. Just south of the recorder there is a slight drop towards what once could have been a path. The recorder itself is facing westwards.

Landcover: In the tree layer we find mostly pine (Pinus sylvestris), again infested with mistletoe but also cherry trees (Prunus avium) and aspen trees (Populus tremula). The location is very bushy. In the shrub layer we found pine (Pinus sylvestris), fly honeysuckle (Lonicera xylosteum), wild privet (Ligustrum vulgare), old man's beard (Clematis vitalba), common whitebeam (Sorbus aria), roses (Rosa spp.), common hawthorn (Crataegus monogyna), barberry (Berberis vulgaris), juniper (Juniperus communis), downy oaks (Quercus pubescens), wayfarers (viburnum lantana), aspen trees (Populus tremula), black

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locust (robinia pseudoacacia), cotoneaster (Cotoneaster tomentosus), dogwood (Cornus sanguinea) and field maple (Acer campestre).

The herb layer consists of raspberry (Rubus idaeus), old man's beard (Clematis vitalba), pine (Pinus sylvestris), black locust (robinia pseudoacacia), grasses and many other herbs.

Even though the microphones are located in the forest the landscape here is almost like a steppe. If one moves towards the road (south) there are fewer trees and the environment becomes drier. If one moves towards the river one will find some very wet but also very dry places. There are hardly any trees but many bushes, especially salix. In that sense recorder number 3 is located on a vegetational boundary. Another boundary with the same orientation seems to be the path-like structure described earlier in the section "Landform". On its northern side (left of the recorder in Figure 9) the trees are higher and on its southern side (right of the recorder in Figure 9) trees seem to have been knocked off (maybe due to occasional flooding) leaving space for rejuvenation. In fact there is so much deadwood and the vegetation is so dense that one can hardly navigate through the area.

Figure 10: Satellite image site 3 (Swisstopo, 2019d)

Anthrophony: In terms of anthrophony one can mostly hear airplanes and choppers. Traffic both from the road and the railway can only be heard when the river has little water and therefore is quieter. Sometimes one can also hear the voices of strollers. On the satellite image (Figure 10) further upstream we can also see a gravel plant. Although we never heard it when we were there one can detect it in some recordings.

Biophony: Even though site number 3 is one of the most diverse in terms of landcover only little bio-phony was detected here. Of course there are birds making sound signals but not as many as in the other places. Looking through the recordings it was the first site where we detected crickets. Here they start chirping earlier in the year than in the other places.

Geophony: The main characteristic of this location are geophonies. Of course there is the river producing a constant noise that qualifies as a keynote sound, but there is also wind. Wind here is much more present than in the other locations and leads to lots of clippings in the recordings. It has such an important effect that one could argue to categorize it as a soundmark. Even though one single wind event isn't unique itself, the entirety of all wind events here is. Wind leads to branches cracking and judging from what we see even knocked some trees down. Again, things falling to the ground due to wind make sounds as well. An interesting thing about the river is that when one listens to many recordings in a row (for instance one recording of each day) one can detect the amount of water changing. After a rain event or during snowmelt in spring it is much louder than during the drought period in summer 2018.

5.1.4. Ponds

Figure 11: Recording site 4

Landform: The fourth recorder is located next to a pond in a rather hilly landscape. The recorder is facing the pond and therefore facing east. West of the microphone the terrain is going up quite steeply. The recording site resembles some sort of a half open basin with the pond in its lowest part and open and flat on the other side of the pond. As one can see on the satellite image (Figure 12) there are also some other ponds nearby. The hills here were formed by a landslide therefore the stones one can find on the ground have a different origin than the ones we find at location 1 and 2.

Land cover: The vegetation here is quite dense (see Figure 11). Depending on which season one visits, it is rather difficult to reach the recorder. There are many knocked over trees and other forms of deadwood. In summer identifying the tree layer can be difficult as one can't see very far. There are some pines (Pinus sylvestris), birches (Betula pendula) and a cherry tree (Prunus avium). The pines here are taller than at the other locations but they tend to stand at an angle.

The shrub layer is very prominent with hazels (Corylus avellane) dominating. Other species found include sycamore maple (Acer pseudoplatanus), pine (Pinus sylvestris), downy oak (Quercus pubescens), wayfarer (Viburnum lantana), barberry (Berberis vulgaris), birch (Betula pendula), Ash (Fraxinus excelsior), fly honeysuckle (Lonicera xylosteum), dogwood (Cornus sanguinea), walnut (Juglans regia), aspen tree (Populus tremula), common whitebeam (Sorbus aria), alder buckthorn (Frangula alnus) and several Salicaceae.

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In the herbal layer we find old man's beard (Clematis vitalba), blackberry (Rubus fruticosus), ash (Fraxinus excelsior), dogwood (Cornus sanguinea), pine (Pinus sylvestris), birch (Betula pendula), downy oak (Quercus pubescens), raspberry (Rubus idaeus), grasses and other herbs. At the pond there is also a lot of reed, up to the point where one cannot see the pond anymore.

Figure 12: Satellite image site 4 (Swisstopo, 2019e)

Anthrophony: This recording site is the one with the least anthrophony. Of course one can still hear airplanes and the road but it is quieter than at the other locations. The main reason for that are the hills. They somehow protect the area from noise. Occasionally one also hears strollers with or without dogs. Some of them even climb down and come next to the recorders.

Biophony: The main difference to the other locations in terms of biophony are frogs. They are only active in spring and produce a noise that exceeds all of the other sounds. They can be classified as a soundmark. Then again there are also birds singing, insects humming and dogs barking. Crickets seem to be less active here. As there is less noise-pollution in this area than at the other recording sites, biophony is more evident here.

Geophony: Due to the hills the recorder itself is more or less protected from wind. But the wind still has an important effect. When blowing it moves the reed which produces a different sound as when it blows through the trees. A noise that is unique to this place (compared to the other locations) are things falling into the water. Frogs and fishes jumping out of the water can also be heard. This could also be classified as biophony. One geophony we didn't mention so far is rain. It never rained when we visited but on the recordings one can hear it clearly.
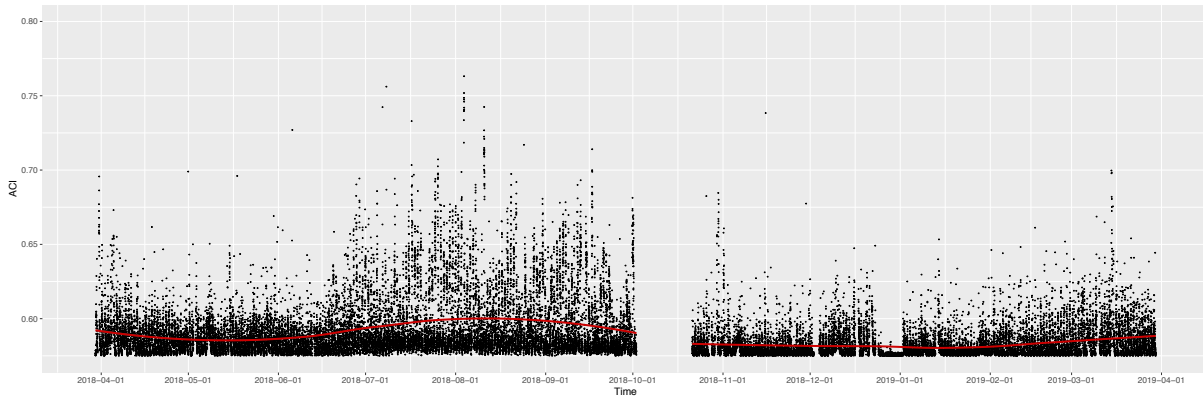
5.2.1. Forest (Recorder 1)

Figure 13: ACI values and general trend in the forest after the removal of recordings containing rain or clippings

As shown in Figure 13 the ACI has a clear late winter-early spring peak and a summer peak: It increases in February and March followed by decreasing values in April and May before increasing again in June, July and August. The fall months show decreasing values marking the beginning of a quieter season.

In Figure 13 recordings affected by clippings and rain have been removed. Wind is responsible for most of these clippings. Figure 14 shows the trendlines for different levels of filtering. Yellow contains all data points, blue is based only on data without clippings, green excludes rain events and red displays only values affected neither by clippings nor by rain. Red therefore is the same trendline as the one in Figure 13. During summer the trendlines are aligned quite nicely. This clearly represents the fact that in Valais the summer of 2018 was very dry and hot with hardly any precipitation. Winter months on the contrary show quite some variation. Clearly there was more precipitation and wind during this time of the year. Especially fall/winter storms or snowfall during November and December seem to have affected ACI measurements quite heavily.

Figure 14: Effects of wind and rain (yellow = all data, blue = no clippings, green = no rain, red = no clippings and no rain)

Initially we expected the ACI to decrease during summer. When listening to the recordings in 24 hour intervals we noticed that they got quieter (especially around noon). But when one looks at Figure 13 and Figure 14 this clearly is not the case for the recording site in the forest. The main reason for that are crickets. They are highly active in the evening and during the night. The noise they produce is represented quite well by the ACI as it has a wide frequency range and gets repeated regularly. This becomes visible in the spectrogram (Figure 15).
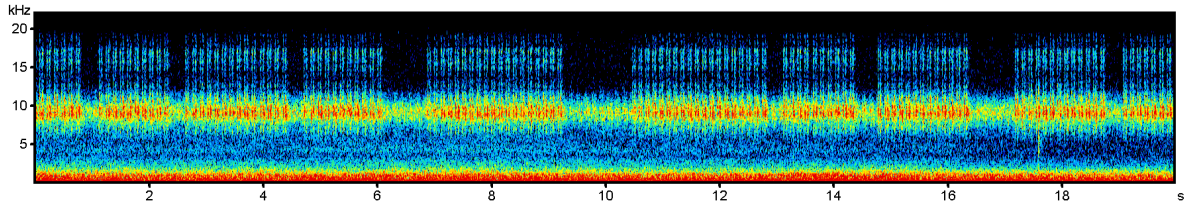
Figure 15: Spectrogram of a recording of crickets

A distinction between different daytimes confirms this effect. The graphs in Figure 16 clearly show higher values during summer months for sunset and midnight but not for sunrise and noon. Hence, for sunrise our hypophysis (decreasing ACI in summer) seems to be true: ACI values decrease during summer and have their peak in spring. During spring, bird activity is at its peak. Birds are most active at sunrise (dawn chorus). As a result they are represented best when only looking at recordings in the morning.
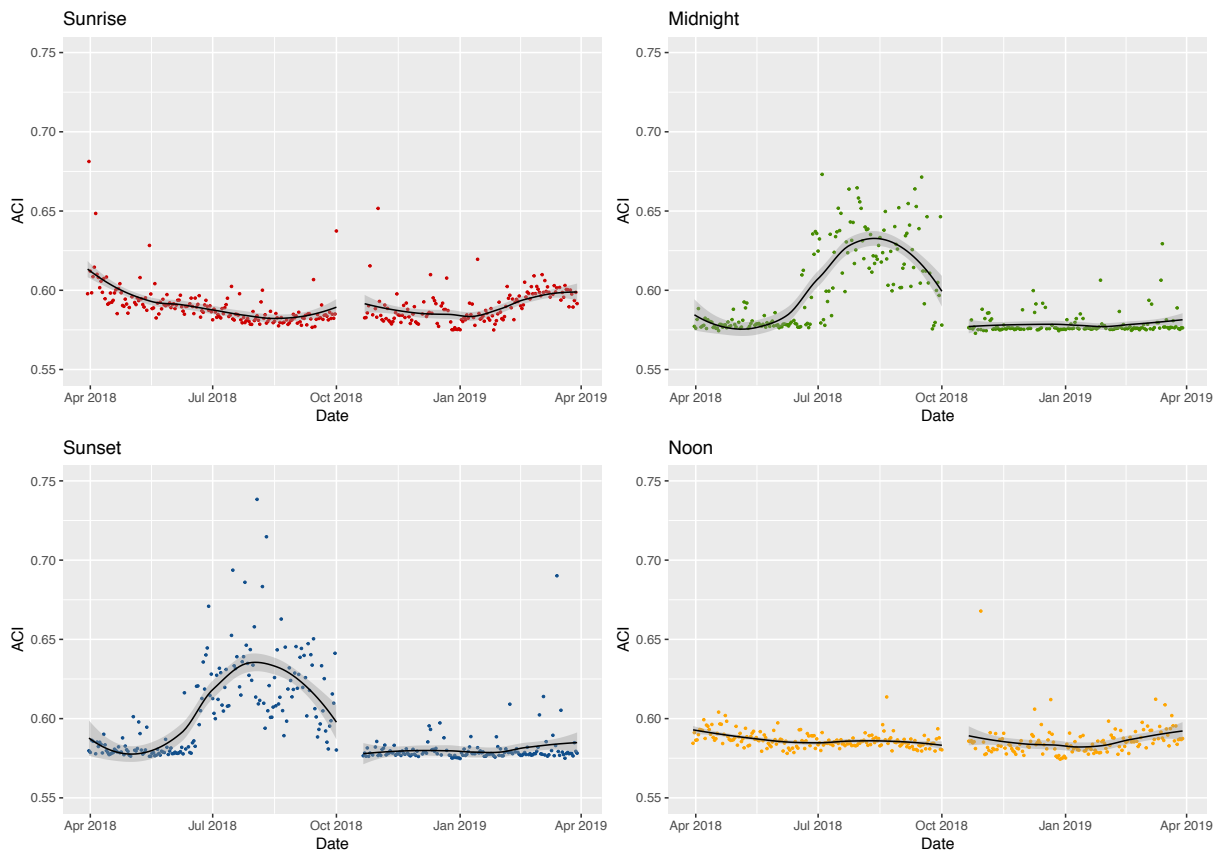
Figure 16: ACI values at different daytimes

Figure 17 shows a spectrogram of bird calls. As one can see, compared to crickets most of the activity is within the 2 to 10 kHz frequency range, meaning that birds aren't as strongly represented by the ACI as crickets are.
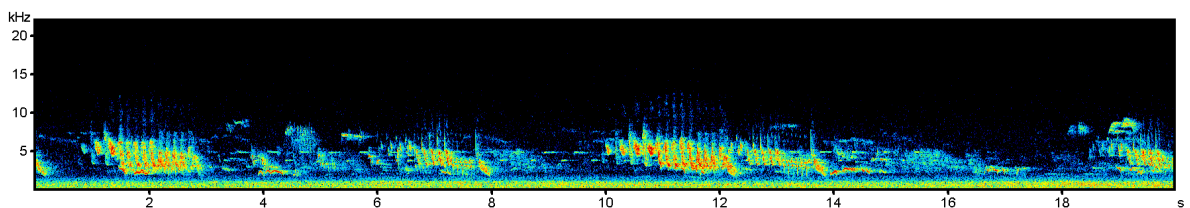
Figure 17: Spectrogram of a recording of birds

5.2.2. Illgraben (Recorder 2)
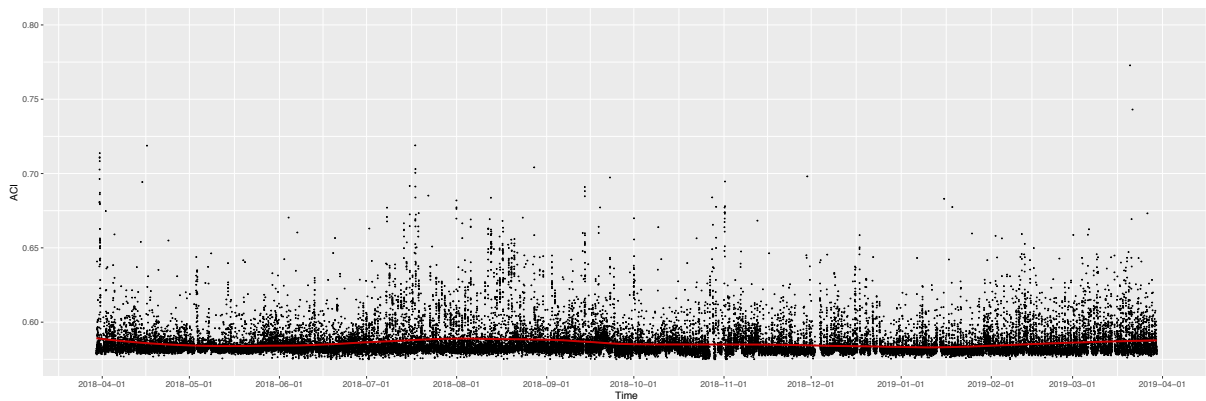
Figure 18: ACI values and general trend by the Illgraben after the removal of recordings containing rain or clippings

Compared to recorder 1 in the forest the values retrieved from recorder 2 at Illgraben are generally lower and show much smaller fluctuations. Yet the trends stay roughly the same (Figure 18). Again the ACI increases in February and March followed by decreasing values in April and May before increasing again in June, July and August. The fall months show decreasing values marking the beginning of autumn and winter.

Figure 19 shows the trendlines for different levels of filtering. Yellow contains all data points, blue is based only on data without clippings, green excludes rain events and red displays only values effected neither by clippings nor by rain. Red therefore is the same trendline as the one in Figure 18.

Again weather phenomena are clearly visible, showing almost no effect in summer but leading to a huge amount of geophonies in autumn and winter.
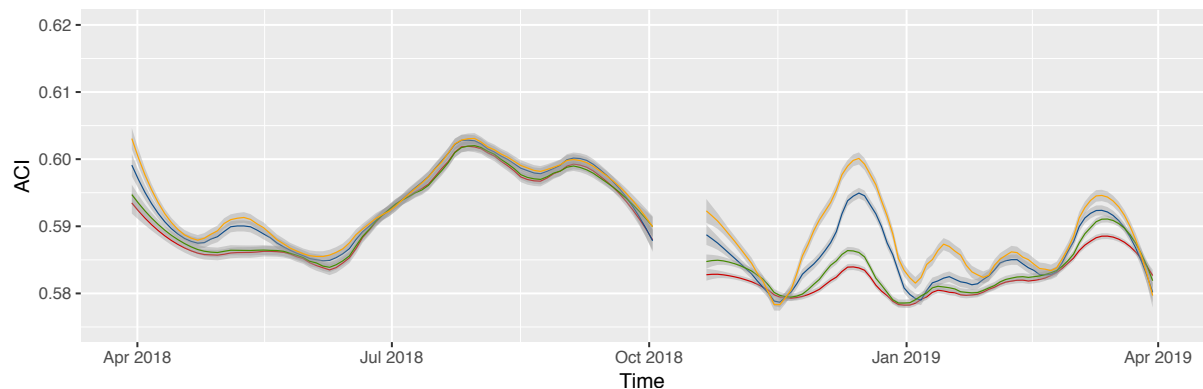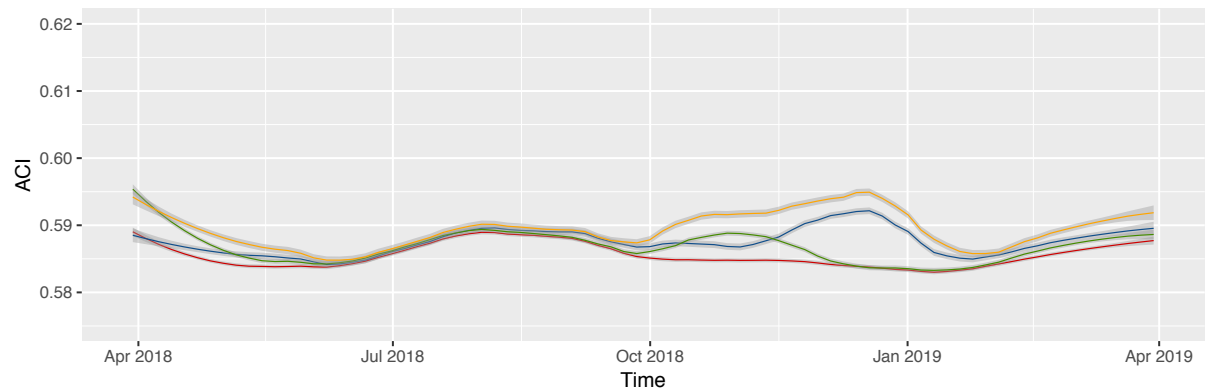

Figure 19: Effects of wind and rain (yellow = all data, blue = no clippings, green = no rain, red = no clippings and no rain)

Crickets seem to be less dominant than at the recording site by the WSL research station, as the ACI doesn't increase as sharply in summer. Yet their effect is still present as one can see in Figure 20. The dynamic caused by bird activity is weaker as well but the distinctive pattern in spring is still visible.
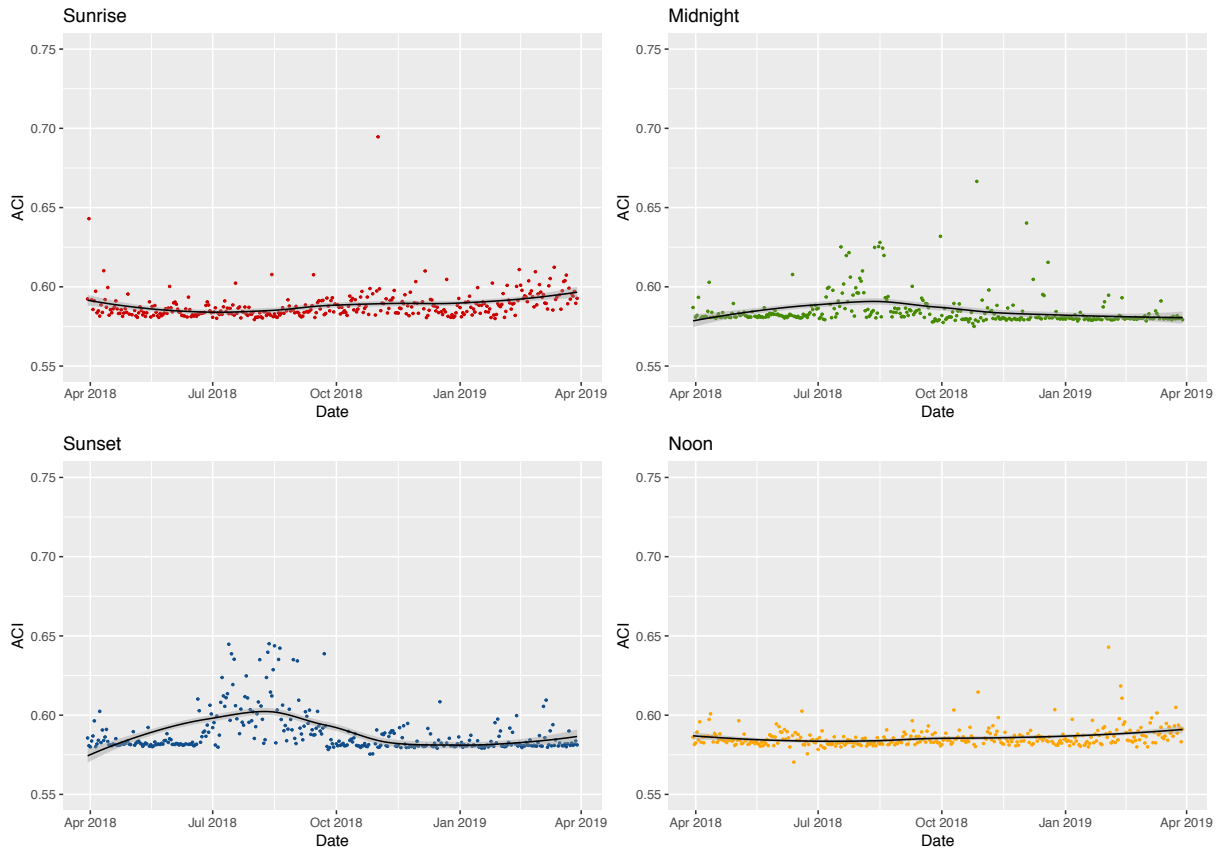
Figure 20: ACI values for different daytimes at Illgraben

5.2.3. River (Recorder 3)

Figure 21: ACI values and general trend by the river Rhone after the removal of recordings containing rain or clippings

Figure 21 shows the seasonal changes of the ACI values after the recordings contaminated by clippings or rain have been removed. Again the highest values can be found in spring and in summer.

Recorder 3 is the one mostly affected by geophonies. Especially wind blowing through the valley gets represented quite heavily. It results in clippings as displayed in Figure 22. Each black line across the entire frequency spectrum is the result of clipping. These interruptions combined with high amplitudes across the entire spectrogram lead to high ACI values. (The highest ACI values in our data come from recordings with clippings).
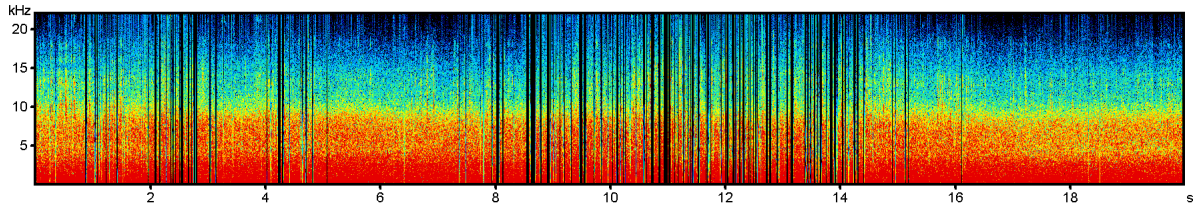
Figure 22: Wind clippings represented in a spectrogram retrieved from recorder 3

The fact that recorder 3 is the one most exposed to wind also becomes visible when one compares Figure 23 with Figure 19 or Figure 14. It is the only one where the removal of data with clippings has a bigger impact then the removal of data with rain.

Figure 23: Effects of wind and rain (yellow = all data, blue = no clippings, green = no rain, red = no clippings and no rain)

Nevertheless, rain has a huge impact. Figure 24 shows its spectrogram. The combination of all raindrops together creates a kind of noise that causes high ACI values.
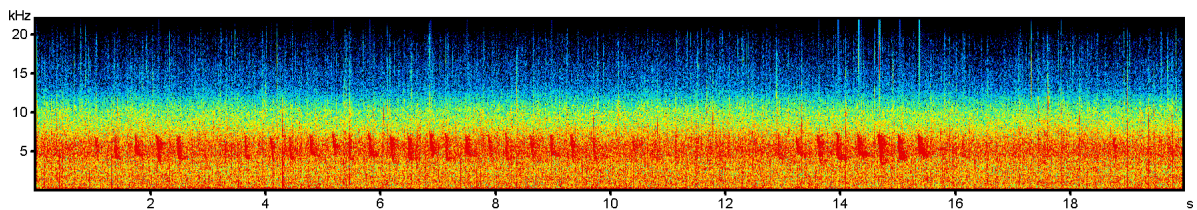
Figure 24: Rain displayed in a spectrogram retrieved from recorder 3

The rushing of the river (Figure 25) on the other hand doesn't seem to lead to high ACI values. Therefore, we also don't see a change of ACI around noon in Figure 26. Noon should be reprehensive of dynamics in geophonies resulting from the river as it is the time of day we noticed animals to be least active throughout the entire year.
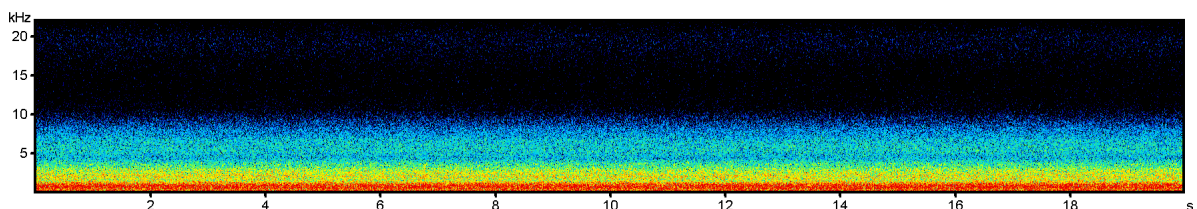
Figure 25 Spectrogram of the noise made by the river

Figure 26 shows that the observation for ACI during summer is also true for the measurements made by the river Rhone. Crickets-activity during the night leads to high ACI values in summer and bird-activity at dawn raises ACI values in spring.

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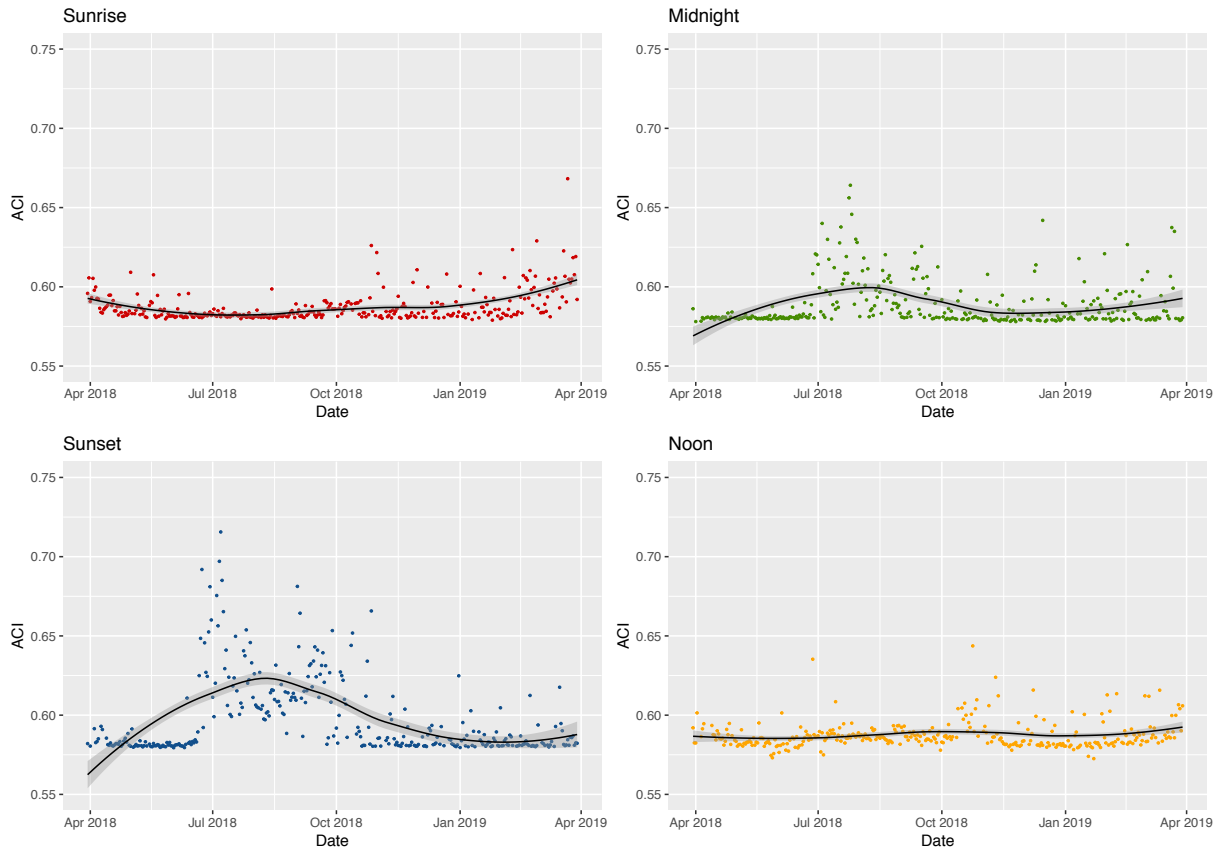
*Figure 26: ACI values for different daytimes at the river Rhone*

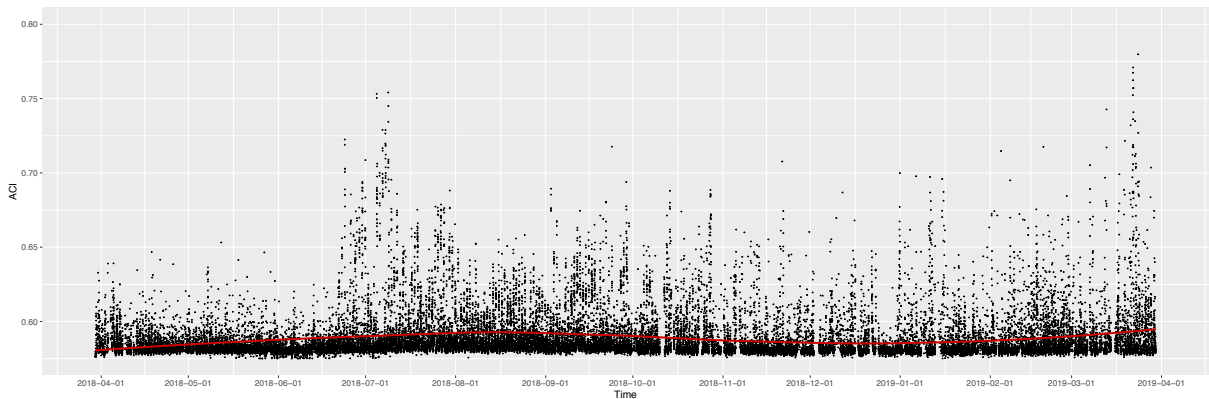## 5.2.4. Pond (Recorder 4)
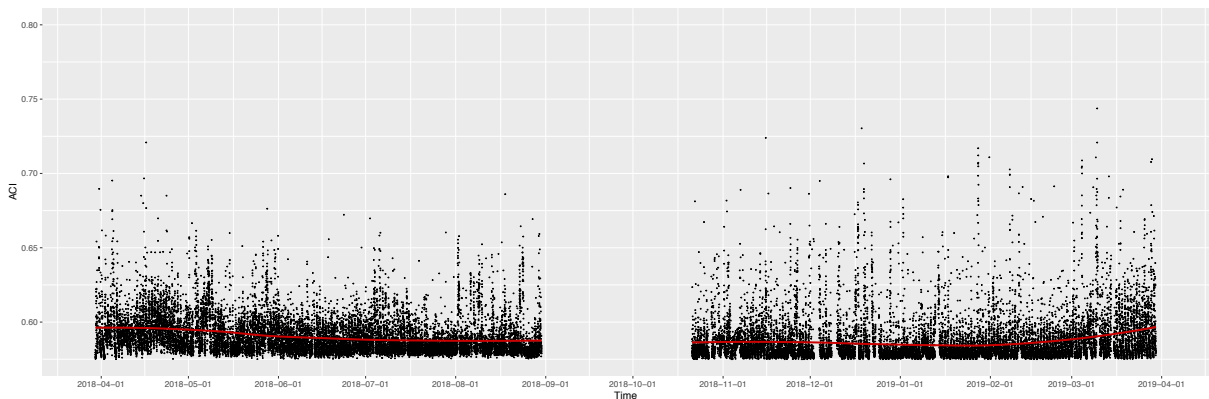
Figure 27: ACI values and general trend by the pond after the removal of recordings containing rain or clippings

According to Figure 27 the recordings made by the pond are the only ones aligning with our hypothesis that the ACI decreases in summer. In fact after the removal of rain and clippings the ACI only increases during spring starting in February and ending in April. For the rest of the year it decreases or stays at a low level.

A possible explanation is the fact that the microphone is placed next to a pond. A significant part of its surroundings is therefore covered by water. Furthermore around the pond it's much more humid then at the other recording sites, meaning it's a less suitable habitat for crickets. Therefore, its summer nights are quieter than in the other locations.

This also becomes visible in Figure 28. The high values in summer for sunset and midnight we observed at the other recording sites we cannot see in Figure 28.
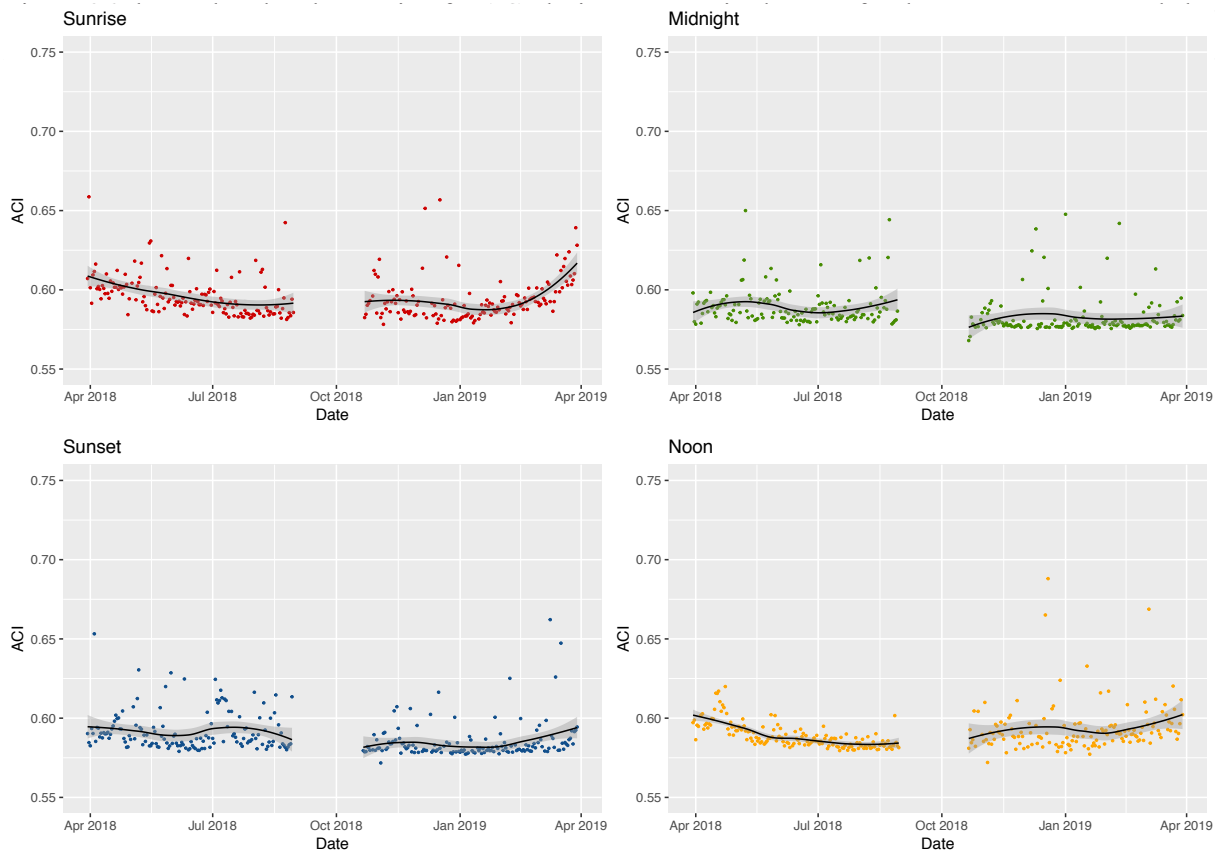
Figure 28: ACI values for different daytimes by the pond

In addition to that, values in spring are probably higher due to frogs. They are highly active in spring during the entire day as this is their mating season. Figure 29 shows a spectrogram of frogs squawking.
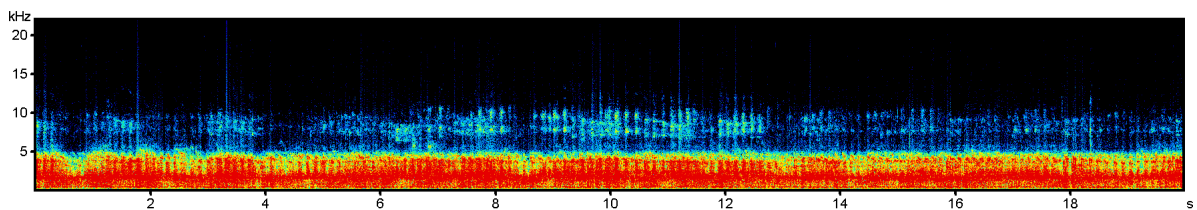
Figure 29: Spectrogram of a recording of frog squawking retrieved from recorder 4

Recorder 4 is located between small hills. As a result it isn't affected by wind as much as the other locations. This becomes quite visible in Figure 30. There is hardly any difference between the two trendlines "rain removed" and "clippings and rain removed". Yet "clippings removed" is still lower than "original data". This doesn't have to be a contradiction as not just wind but also rain and human activity can be the source of clippings.

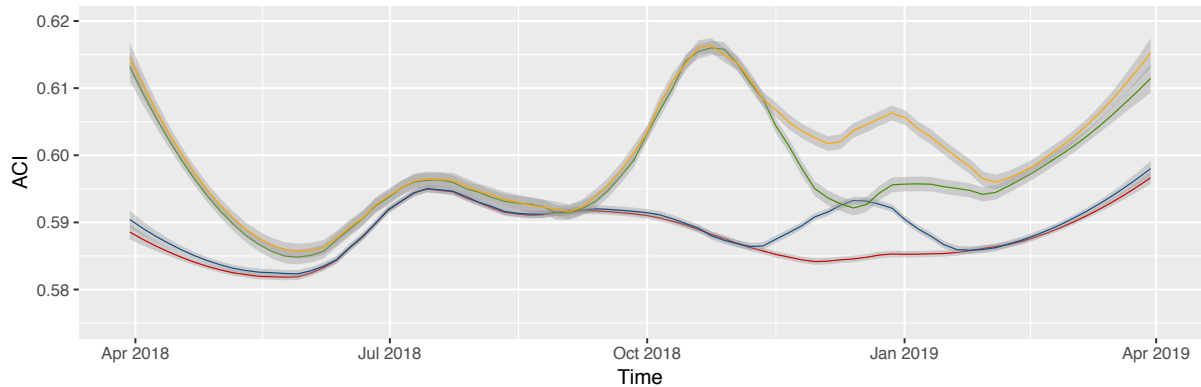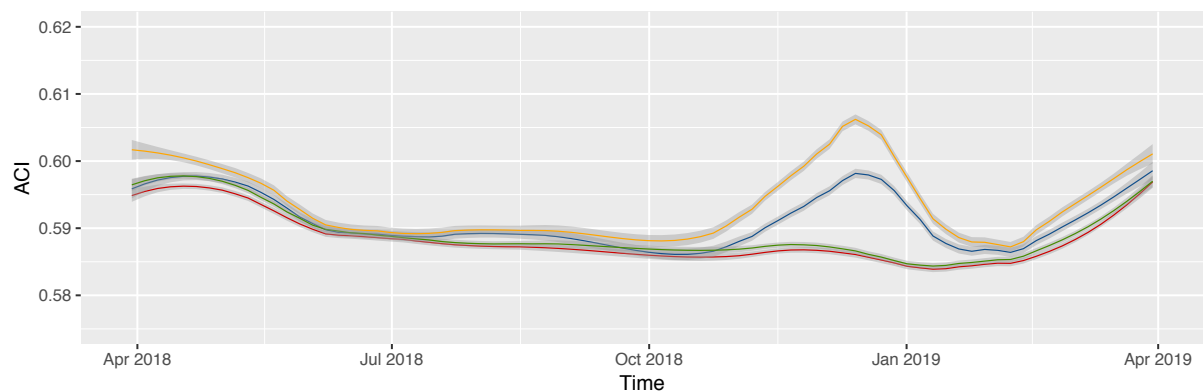*Figure 30: Effects of wind and rain (yellow = all data, blue = no clippings, green = no rain, red = no clippings and no rain)*

5.3. Daily trends and patterns

Every day shows different ACI values. Yet there are some distinct patterns. The most striking ones occur in spring and summer (Figure 31). In spring the ACI jumps to a higher level simultaneously with the sunrise and then slowly decreases during the day until it has reached its minimum again by nighttime. During summer this trend seems to be inverted. The ACI starts to increase in the evening and reaches its maximum in the middle of the night. And then just before dawn the ACI decreases sharply. Days in autumn and winter do not show such distinctive patterns. Yet day and night are clearly distinguishable as the ACI tends to be higher during daytime.
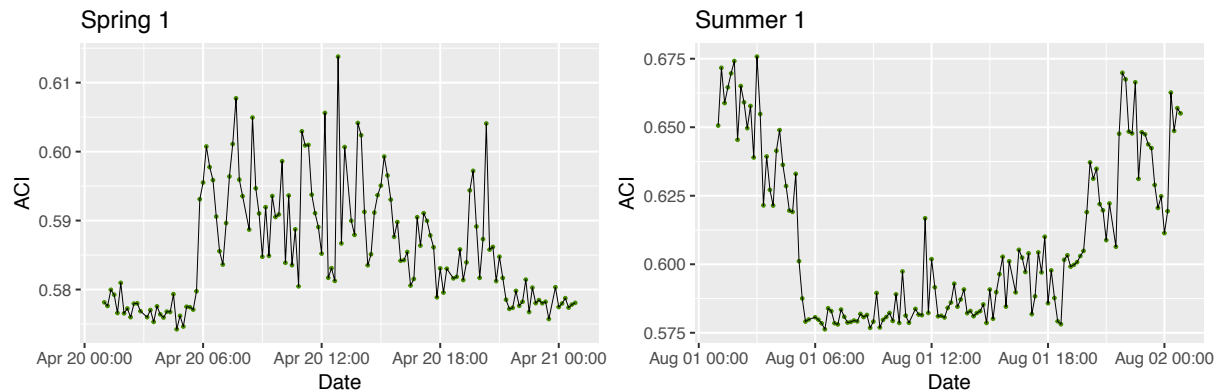
Figure 31: ACI for distinct days in spring and summer (recorder 1 forest)

5.3.1. Patterns throughout the year

The patterns described in Figure 31 repeatedly occur in spring or summer respectively (Figure 32 and Figure 33). But not at all recording sites to the same extent. At site number 4 for instance the summer pattern caused by crickets only occurs between July 3 and July 12. Whereas for the other areas it starts already in mid-June and continues up until the end of September. On recording site number 3 this pattern can be observed even until mid-October.
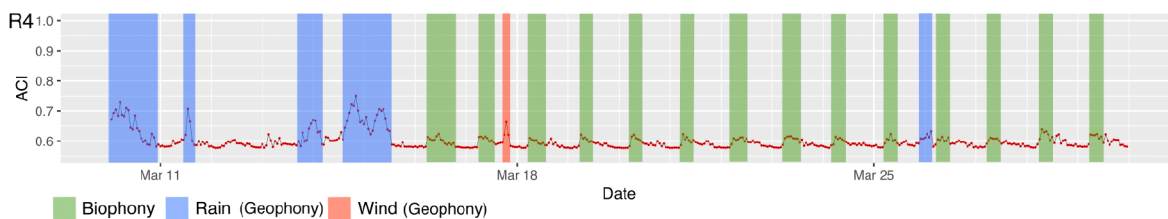
Figure 32: Spring pattern, birds, Recorder 4 (There was no peak with anthrophony in this time period)
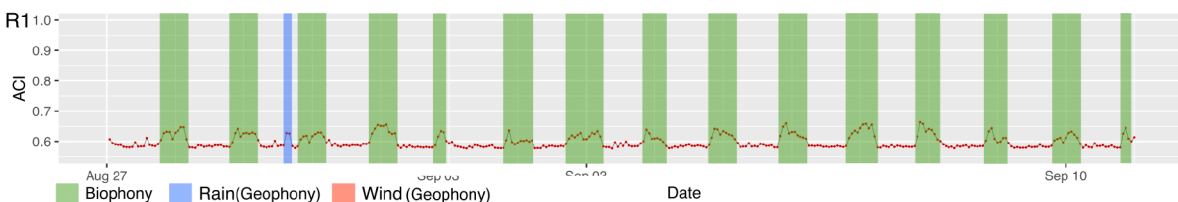
Figure 33: Summer pattern, crickets, Recorder 1 (There was no peak with anthrophony in this time period)

But there are also seasonal patterns aside from biophony. Events classified as wind or rain occur much more often in autumn and winter as well as in the beginning of spring. Sometimes wind events occur almost periodically. It is possible that these are daily patterns caused by mountain-valley wind regimes (Zardi and Whiteman, 2013).

5.4. Differences and similarities between the locations

Figure 34 shows the general trends in ACI for all recording sites twice. In the uppermost row all data is used and in the lowest line recordings containing rain and/or clippings were removed. The rows in between show the precipitation rate, air temperature and windspeed for the area of Pfynwald.

The different sites show quite some variation. Especially site R4 is different from all the other sites. Rain seems to have a strong impact. A peak in precipitation correlates with a peak in ACI. Interestingly enough, this is mostly true for site R1 and R4 but not for site R2 and R3. R3 seems to respond more to wind than to rain. This really corresponds with the observations we made at the location. But the effects of wind speed have to be seen differentiated, also taking the wind direction into account.

R2 doesn't show as strong fluctuations as the other recording sites do. Maybe this is caused by the higher altitude and a more balanced microclimate than in the lower valley. Additionally, the recording site is better protected from wind. For the most frequent wind direction the recorder is positioned on the lee side.
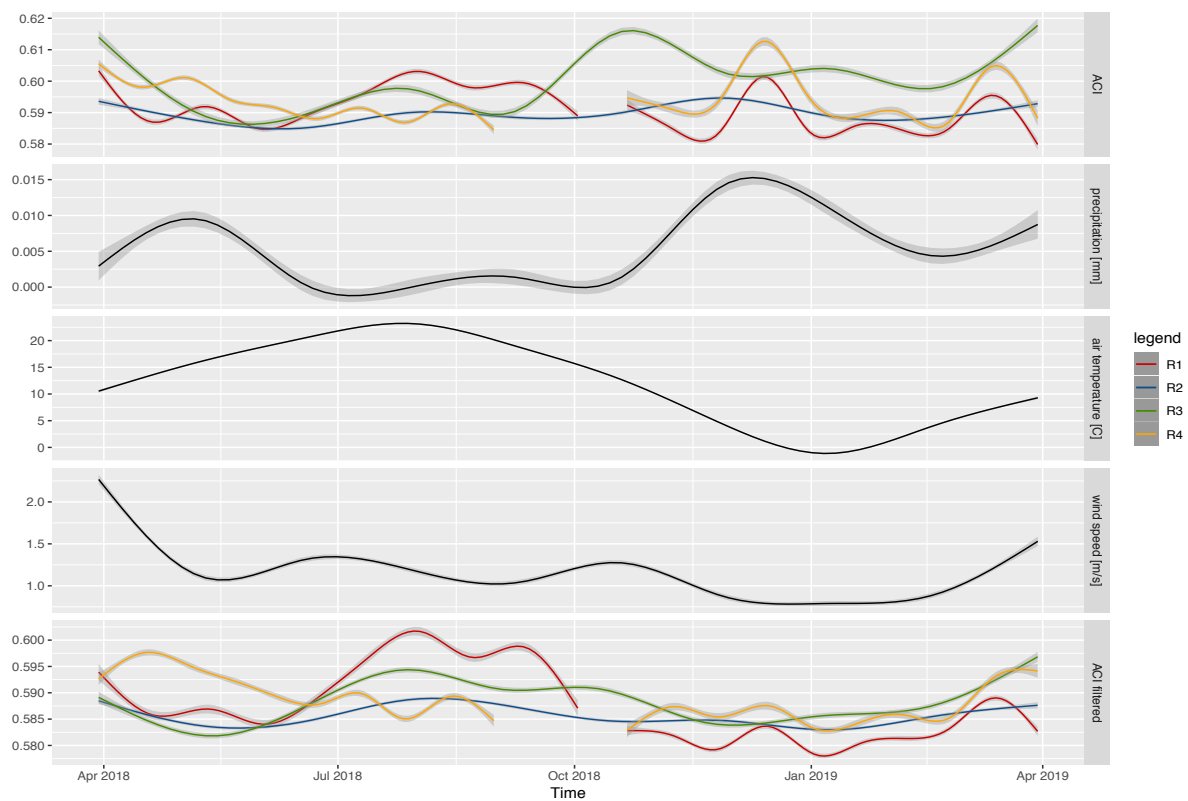
Figure 34: ACI of all recording sites and meteorological data

All stations except for R4 show higher values during summer. In summer temperatures are higher and crickets are active mostly in the evening and during the night. R4 is located next to a pond. High values in spring can be traced back to frogs squawking. This might also be an explanation for why values in summer aren't that high. Parts of the recorders' surroundings are covered by water and therefore it is a less suitable habitat for crickets. Additionally, R4 is somewhat protected from wind and anthrophony as it is surrounded by hills.

Even though crickets seem to have the highest impact in location R1, we first observed them in the recordings by the river (R3). R3 is probably the driest and hottest of all locations covered. Here, summer kicks in earlier and therefore crickets can be heard earlier in the year.

6. Discussion and outlook

6.1. Dynamics in biophony

Having viewed and listened to the data it can be said that there are dynamics in acoustic animal activity. They can be detected both as an overall increase in ACI over the course of different seasons and as a repetition of diurnal patterns. With the exception of site R4 this means a peak in ACI in the morning in spring decreasing throughout the day and high ACI values during summer nights with little activity during the day. R4 shows high ACI values in spring but not in summer. The diurnal patterns are still very much visible but not as explicit as in the other locations. ACI values in spring get amplified by frog activity and in summer crickets aren't as active as in the other locations.

6.2. Dynamics in geophony and anthrophony

An overall dynamic in geophonies can be observed as there is much more rain and wind in the winter months. Especially November, December, April and May show high precipitation rates. Wind seems to have its greatest impact in February and April. For rain no diurnal patterns could be detected. Wind sometimes shows similar patterns in ACI for several days in a row. Usually leading to high values starting around 10 a.m. and stopping a few hours after sunset.

Anthrophonies vary between weekdays. We couldn't detect this looking at the ACI timeseries but by listening to the recordings and visiting the different sites. On weekdays more lorries can be heard on the road than on weekends. On weekends with nice weather conditions the amount of motorcycles and small airplanes increase.

6.3. Summer of 2018

The summer of 2018 was the third summer in a series of summers with temperatures far above the average. Together with the summers of 2017, 2015 and 2003, with a nationwide temperature of 15.3 °C it stands out clearly from all the other summers since the beginning of measurements in 1864. On the south side of the Alps, temperatures reached more than 30 °C already in July on a regular basis (Meteoschweiz, 2019). In addition to that there was hardly any rainfall. From the beginning of June until the end of August only 1.8 mm rain has been measured at Pfynwald.

As a result of this hot and dry weather we anticipated animal activity to be low. This we hoped to see in the soundscape. With the index we used this wasn't the case, quite the opposite. Except for one recording site (site number 4) summer ACI values were higher than during the other seasons, mainly because of crickets that were active during the night. A distinction of different daytimes (sunrise, noon, sunset, midnight) confirmed the strong influence of crickets. It also suggested that our hypothesis (decreasing ACI in summer) might be true if one excludes recordings made in the evening and during the night. Particularly, the values at sunrise have their peak in spring and decrease over the course of the summer. As birds are most active in the morning and many species return from bird migration in spring it would be interesting to see whether this dynamic in ACI is the same for every year or whether the extreme conditions during the summer of 2018 have led to either a more intense or a weaker dynamic.

6.4. ACI

The acoustic complexity index is a reasonable figure to monitor biophony in a landscape, yet it is still far from perfect. As it is hard to find much information on which soundscapes or even signals get represented in which way, we decided to share our experience here:

The ACI claims to avoid anthrophonies and geophonies by suppressing constant noises. This works quite well. We calculated the ACI twice, once without a threshold and once only with frequencies higher then 2 kHz. With a few slightly different values the outcome was the same. But in our experience, anthrophonies and even more so geophonies are often not constant. Wind and rain in particular lead to a high ACI. Wind leads to clippings and can be filtered using algorithms, whereas rain needs to be removed manually. This is no solution for large amounts of data. Generally the huge amount of data is a problem. At some point it becomes impossible to look at the individual datapoints and displaying all the data becomes too crowded. False-color spectrograms, as described by M. Towsey et al. (2014), might be a promising solution but weren't further explored in this thesis.

Not all species get represented the same. Crickets, for instance, repeatedly cover a wide frequency range and therefore get represented much stronger than birds. Depending on what the research question is, this could be a problem. A possible solution might be to set a cut-off at 10 or 15 kHz. Judging from the spectrograms in Figure 15, Figure 17 and Figure 29, crickets are active in almost the entire frequency range while frogs and birds only cover the range up to 10 or 15 kHz. A cut-off in frequencies would give less weight to insects (>15 kHz) in comparison to other biophony and therefore could be a more realistic representation of the daily/temporal distribution of biophony in a soundscape (Farina, Pieretti and Piccioli, 2011). However, this might be a human bias as we tend to give more weight to animals like birds than to insects.

The ACI function lets you chose the size of j (temporal clumps). Small clumps are supposed to highlight singularities and higher clumps should represent more recurrent amplitudes better (Farina et al., 2016). We tried out 1s and 5s long clumps and took their sum (as in the original ACI) and their average (as suggested by X. Guo 2018). After scaling them to the same range they showed hardly any differences. Maybe this becomes more apparent when choosing substantially bigger values for j, such as 20s/30s/60s. But as our recordings are only 20 s long this wasn't an option.

An initial goal of this thesis was to get an estimate of biodiversity through an acoustic index such as the ACI without having to know all the occurring species. At a first glance it seems that the ACI isn't suitable to make such assumptions. The main reason for this is that it is hard to rank. Currently there is no such thing as a reference. What type of landscape/ecosystem shows which values? How does a healthy environment sound? Even comparing the four closely located sites proved to be difficult. Clearly, more experience and data in this area needs to be gathered.

A good way to gain knowledge could be the AudioMoths we tested. They'd enable one to make recordings not only in a few locations but rather in many places, at fixed distances and time-synchronized. Such arrays would give a better special resolution and one could observe how the soundscape changes from location to location. For our test site, for instance, it might be interesting to see at which distance the road gets less important or at which point it's drowned out by the river. This would also allow one to

observe how the ACI changes with distance. One could compare two recordings next to each other but also two values retrieved from microphones further apart, learning about changes in acoustic diversity along spatial gradients.

However, the tests made with the AudioMoths turned out poorly. Two out of four AudioMoths didn't record at all (one because probably during the installation the SD card popped out) and two stopped recording for no obvious reason (One also had an SD card popped out by the time of removal). In addition to that they're not weather resistant. Yet these are all problems that could be solved.

Besides a general lack of experience, another reason why it might be hard to compare different sites based on the ACI is the fact that it is an α- or within-group-index (Sueur et al., 2014), meaning that it is good for comparison at the same site and therefore perfect for monitoring biodiversity at only one site but not suited for comparisons between different sites.

Nevertheless, we think a comparison between different sites using the ACI can be done. Efforts to gather experience in this field do exist. A good example is the project "sounding soil" where recordings in soils with different forms of cultivation and uses are made with the aim to develop a tool to monitor soil quality/health (Mäder, 2019).

In conclusion it can be said that the ACI is a good tool to detect acoustic events in a soundscape but then it is essential to actually listen to the recordings of these events.

6.5. Further research objectives

In this thesis only one index was used, yet for acoustic biodiversity assessments to work it might be wise to use several complementary indices at the same time for the same recordings. In fact, as Sueur et al. (2014) state: "[…] it is highly probable that a single index will never cover all biodiversity facets and be reliable in all contexts."

In addition to that, further statistical analysis should be performed. This is something that might lead to new results using the existing data especially for the comparison of the different recording sites, but also for the changes in seasonal dynamics and patterns. To compare the different recording sites, one could look at the variation of ACI for different daytimes within and among different sites using boxplots. This has been done by J. Sueur et al. (2008) .

To analyze seasonal and diurnal dynamics, one could perform a multilevel regression analysis (MLA). B. Krause et al. (2011) used MLA to examine temporal patterns of biophony at four locations in Sequoia National Park. Biophony was used as a dependent variable, and temporal variables included four times of day and four seasons as fixed effects. Biophony wasn't expressed using the ACI. Instead, they used the arcsine of values measured as PSD (Power Spectral Density) between 2 and 8 kHz (Krause, Gage and Joo, 2011). This analysis could also be performed using the data from Pfynwald.

As we have seen in our analysis, variability can have differing patterns at different scales such as weeks, months and years. It is important to look at the data at different scales. To further examine such patterns, one could perform a multiresolution analysis (MRA) using the Haar MODWT (maximum overlap discrete wavelet transformation) wavelet transform (Ghosh et al., 2007). During the research for this thesis we could find only very few soundscape-papers applying wavelet transformation (Ulloa et al., 2018). Yet it can be said that it has huge potential in this field as it becomes increasingly popular for analyzing

environmental time series (Ghosh et al., 2007).

For our analysis we have already filtered the data for recordings with clippings and rain. Further spectral filtering and noise/signal extraction techniques could be explored and applied.

In addition to further analysis of the already existing data, collecting new data is of great importance. The recording period analyzed in this thesis lasts for only one year and contains an unusually warm and dry summer. It would be interesting to make a comparison with "normal" summers. This would enable one to make a statement about how drought manifests itself in the soundscape and therefore make an educated guess about the effects of climate change on the acoustic environment.

In turn of anthrophony there are big changes to come as a motorway will be put in place. A large part of it will be underground. Therefore, noise pollution from the existing road will probably decrease sharply. Again, extending the recording period would be interesting as it would allow a comparison of the soundscape before, during and after construction. An investigation that, as far as we know, would be unique.

6.6. Art and science

In this thesis we focused on the scientific analysis of acoustic data. Yet many artists have done and are still doing pioneering work within the field of soundscape. In fact it is a perfect example for how art and science can come together. It is not just about proving art scientifically, but even more so about opening up science artistically.

It is about how data is presented and being aware of the fact that the chosen medium influences our perception of the data. Both, art and science, increasingly use the same media exploring new ways to display and understand data. For science it has become a necessity in order to cope with ever increasing numbers of data whereas art explores new media out of curiosity. Science tries to state facts as clean as possible. But when scientific findings are communicated to the public, emotions are key. Especially if it's about the environment, a field almost everybody feels somehow attached to. On top of that we should recognize that even though we try to leave them out of the scientific process they are still present.

Art tries to evoke emotions. When artists and scientists work together the presence of emotions becomes more apparent and new questions emerge. Artists can help scientist not just to get their point across but also to be aware of their own personal bias. Science on the other hand enables artists to explore new fields and allows them to work also based on facts. Technology has equipped mankind with new senses, and art can try to make them tangible. In this thesis we mostly looked at line graphs. Yet the data we looked at are sound recordings. Actually listening to them lead to many additional insights. We should use not just our eyes but all our senses to make science.

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8. Appendix
8.1. R Code

8.1.1. ACI Function

```
# The code for the following function is based on the function acoustic_complexity() from the package
# soundecology. Which intrun refers to a paper by Pieretti(2011).
# As I 'll run this function in a loop I don    't want all notifications included.
# I still want to keep them though for better understanding. Therefore I included them as comments.

funcACI  <-  function   ( soundfile  ,  min_freq  = NA,  max_freq  = NA,  j  = 5,  fft_w  = 512,  ovlp  = 0,
                  plot  = FALSE,  ylim = NULL,  main = NULL,  return_spec  = FALSE)
{
  if   ( is.na  (max_freq)) {
    max_freq  <-  soundfile  @samp.rate  / 2
#     cat(paste("\n", "max_freq  not  set,  using  value  of:", max_freq,
#                "\n\n"))
  }
  if   ( is.na  (min_freq)) {
    min_freq   <-  0
#     cat(paste("\n min_freq  not  set,  using  value  of:", min_freq,
#                "\n\n"))
  }
  if   ( is.numeric   ( as.numeric  (min_freq))) {
    min_freq   <-  as.numeric  (min_freq)
  }
  else   {
    stop ( " min_freq  is  not  a  number."    )
  }
  if   ( is.numeric   ( as.numeric  (max_freq))) {
    max_freq   <-  as.numeric  (max_freq)
  }
  else   {
    stop ( " max_freq  is  not  a  number."    )
  }
  if   ( is.numeric   ( as.numeric  (j))) {
    j   <-  as.numeric  (j)
  }
  else   {
    stop ( " j  is  not  a  number."    )
  }
  if   ( is.numeric   ( as.numeric  (fft_w))) {
    fft_w   <-  as.numeric  (fft_w)
  }
  else   {
    stop ( " fft_w  is  not  a  number."    )
  }

# create   a function   to calculate   the absolute   difference   of  the  spectrum  and  add  together   all
the  differences

  get_d  <-  function  ( spectrum ,  freq_row ,  min_col ,  max_col)  {

    D = 0
    for   (k  in  min_col : (max_col   -   1))   {
      D = D + abs (spectrum[freq_row,      k]  -  spectrum[freq_row,
      k  +  1])
    }

    return  (D)
  }
```

```r
# Ensure that the Nyquist-Shannon sampling theorem isn't violated by max_freq choosen.
  samplingrate <- soundfile@samp.rate
  duration <- length(soundfile@right)/soundfile@samp.rate
  nyquist_freq <- (samplingrate/2)
  if (max_freq > nyquist_freq) {
    cat(paste("\n WARNING: The maximum acoustic frequency that this file can use is ",
              nyquist_freq, "Hz. But the script was set to measure up to ",
              max_freq, "Hz. The value of max_freq was changed to ",
              nyquist_freq, ".\n\n", sep = ""))
    max_freq <- nyquist_freq
  }


  wlen = fft_w

# All the data used is stereo. One recorder though has a hydrophone pluged in.
# Therefore I only use the other channel (right).
# To be consistent across the study I decided to only use the right channel for the other sites
as well.

  if (soundfile@stereo == TRUE) {
#    cat("\n This is a stereo file. Results will be given for each channel.\n")
    right <- channel(soundfile, which = c("right"))
#    cat("\n Calculating index. Please wait... \n\n")

    # create a spectogram
    spec_right <- spectro(right, f = samplingrate, wl = wlen, ovlp = ovlp,
                          plot = FALSE, norm = TRUE, dB = NULL, scale = FALSE,
                          wn = "hamming")

    specA_right <- spec_right$amp # retrieve the amplitudes from the spectrogram


    min_freq1k = min_freq/1000
    max_freq1k = max_freq/1000

    # make sure to only include values within the defined frequency range
    which_min_freq <- which(abs(spec_right$freq - min_freq1k) ==
                              min(abs(spec_right$freq - min_freq1k)))
    which_max_freq <- which(abs(spec_right$freq - max_freq1k) ==
                              min(abs(spec_right$freq - max_freq1k)))
    if (which_min_freq < 1) {
      which_min_freq = 1
    }
    if (which_max_freq > dim(specA_right)[1]) {
      which_max_freq = dim(specA_right)[1] - 1
    }

    specA_right <- spec_right$amp[which_min_freq:which_max_freq, ]

    rm(spec_right)
    rm(right)
```

```r
    # prepare the variables for the calculation
    specA_rows <- dim(specA_right)[1]
    specA_cols <- dim(specA_right)[2]
    delta_fl <- (max_freq - min_freq)/specA_rows  # define single frequency bin
     # define single time fraction
    delta_tk <- (length(soundfile@right)/soundfile@samp.rate)/specA_cols
     no_j <- floor(duration/j) # number of windows into which the file is diveded
    I_per_j <- floor(j/delta_tk) # number of intensity values per j
    ACI_right_vals <- rep(NA, no_j)
    ACI_fl_right_vector <- rep(NA, no_j)
    ACI_right_matrix <- data.frame(matrix(NA, nrow = specA_rows,
                                          ncol = no_j))

    for (q_index in 1:specA_rows) {
      for (j_index in 1:no_j) {
        min_col <- j_index * I_per_j - I_per_j + 1
        max_col <- j_index * I_per_j
        D <- get_d(specA_right, q_index, min_col, max_col)
        # sum of absolute differences between adjacent values of intensity
      } sum_I <- sum(specA_right[q_index, min_col:max_col])
        # sum of intensity values registered in j
    }   ACI_right_vals[j_index] <- D/sum_I
        ACI_right_matrix[q_index, j_index] <- D/sum_I
    if (plot) {
      ACI_fl_right_vector[q_index] <- mean(ACI_right_vals) # mean instead of sum

    }

      plot(colMeans(ACI_right_matrix), type = "l", main = main, xlab = "Time [s]", ylim = ylim)
      abline(h =mean(colMeans(ACI_right_matrix)), lty = 2)


    ACI_tot_right <- mean(ACI_fl_right_vector)  # mean instead of sum
#   cat(paste("\n", "   Right channel: ", sep = ""))
#   cat(ACI_tot_right)
#   cat("\n\n")
  }

  return(ACI_tot_right)
}
```

8.1.2. Calculating the ACI

```r
# The following code is adapted from Xianda Guo (2018)
# Load libraries
library(tuneR)

library(seewave)

library(soundecology)

# Set working directory
setwd("/Volumes/data pfynwald 1/Ecodata_Pfynwald/Recorder1/Data")

################# Calculate ACI values #################

#### define an empty data frame
aci.kontr.10min.sep <- data.frame()

#### obtain the audio files one by one, and calculate ACIs saved into the data frame
### Every name has the same format (e.g. PFYNWALD1_20180326_092355.wav).
### The date and time insures that it is unique.
### I use "paste" to compose the date of every loop
# per year
for (i in 2018:2019) {
  # per month
  for (j in 1:12){
    # per day
    for (k in 1:31) {
      # per hour
      for(l in 0:23) {
        # per 10 minutes (recordings took place every 10 minutes)
        for(m in 0:5) {
          unique.name <- paste(i, sprintf("%02d", j), sprintf("%02d", k), "_", sprintf("%02d", l),
                               m, sep = "")
          # the function will extract the audio file from the current work directory
          audio <- list.files(pattern = unique.name)
          # deal with missing values (skip)
          if (identical(audio, character(0))) next
          # if there are 2 audio files within 10 minutes, choose the first one
          if (length(audio) > 1) {
            audio <- audio[1]
          }
          # read data.wav. For audio with multiple channels, set toWaveMC = TRUE to get a
            WaveMc-class object
          wave <- readWave(audio)
          # calculate ACI, with some argumets of frequency and cluster size, and etc.
          aci <- funcACI(wave, j=1)
          # make the caluation as a dataframe with unique name defined above
          aci <- as.data.frame(t(aci), row.names = unique.name)
          # combine the "aci" data frame to the outputing data frame
        } aci.kontr.10min.sep <- rbind(aci.kontr.10min.sep, aci)
      }
    }
  }
}


#### define the column of time
aci.kontr.10min.sep$Time <- as.POSIXct(paste(rownames(aci.kontr.10min.sep),
                                       0, sep = ""),format = "%Y%m%d_%H%M")

colnames(aci.kontr.10min.sep)=c("ACI","Time")

# save data
save(aci.kontr.10min.sep, file = "ACI_10min.RData")
```

8.1.3. Organizing the ACI values

```r
###### As a list ######

# Set working directory
setwd()

# Load data
load("ACI_10min.RData")

#### organizing the data in a list (one dataframe for each day)
aci.daily <- list()
for (h in 2018:2019){
  for (i in 1:12){
    for (j in 1:31){
      a<-grep(paste(h, sprintf("%02d", i), sprintf("%02d", j), sep = ""),
              row.names(aci.kontr.10min.sep))
      Day <- aci.kontr.10min.sep[a,]
      aci.daily[[length(aci.daily)+1]] <- Day
      names(aci.daily)[[length(aci.daily)]] <- paste(h, sprintf("%02d", i), sprintf("%02d", j),
                                                     sep = "")

    }
  }
}

# remove nonexisting days (such as 0231)
aci.daily <- aci.daily[sapply(aci.daily, function(x) dim(x)[1]) >20]

# save list
save(aci.daily, file = "dailyR1.RData")

###### All data in one file ######

Sys.setenv(TZ='Etc/GMT-1')

# Set working directory and load data
setwd()

load("ACI_10min.RData")

R1 <- aci.kontr.10min.sep
# Set working directory and load data
R1$Time <- as.POSIXct(paste(rownames(R1), 0, sep = ""), format = "%Y%m%d_%H%M")
setwd()

load("ACI_10min.RData")

R2 <- aci.kontr.10min.sep
R2$Time <- as.POSIXct(paste(rownames(R2), 0, sep = ""), format = "%Y%m%d_%H%M")


# Set working directory and load data
setwd()

load("ACI_10min.RData")
```

```r
R3 <- aci.kontr.10min.sep
R3$Time <- as.POSIXct(paste(rownames(R3), 0, sep = ""), format = "%Y%m%d_%H%M")

# Set working directory and load data
setwd()

load("ACI_10min.RData")

R4 <- aci.kontr.10min.sep
R4$Time <- as.POSIXct(paste(rownames(R4), 0, sep = ""), format = "%Y%m%d_%H%M")

# merge the data into one data frame
all.aci <- merge(R1, R2, by = "Time", all = TRUE)

all.aci <- merge(all.aci, R3, by = "Time", all = TRUE)

all.aci <- merge(all.aci, R4, by = "Time", all = TRUE)

colnames(all.aci)=c("Time","R1", "R2", "R3", "R4")

# save data
save(all.aci, file = "allaci.RData")
```

8.1.4. Four Daytimes

```r
##### Define the different daytimes #####

# load libraries
library(maptools)
library(lubridate)

# set timezone
Sys.setenv(TZ='Etc/GMT-1')

# define coordinates (different for each recording site)
crds <- c(-7.58742,46.30027)

# retrieve sunrise and sunset for each day
hels <- matrix(crds, nrow=1)
Hels <- SpatialPoints(hels, proj4string=CRS("+proj=longlat +datum=WGS84"))
d180330 <- as.POSIXct("2018-03-30", tz="Etc/GMT-1") # define starting date

Hels_seq <- seq(from=d180330, length.out=365, by="days")
up <- sunriset(Hels, Hels_seq, direction="sunrise", POSIXct.out=TRUE)
down <- sunriset(Hels, Hels_seq, direction="sunset", POSIXct.out=TRUE)

# combine the data to one data.frame
sun <- cbind.data.frame(up[,2], down[,2])
colnames(sun) <- c("sunrise", "sunset")
rm(up, down, hels, Hels, Hels_seq, crds, d180330)

### set start and adding noon & midnight

# starting 30 min before sunrise
sun$sunrise <- round_date(sun$sunrise, unit="10 minutes") - 1800
# starting 30 min before sunset
sun$sunset <- round_date(sun$sunset, unit="10 minutes") - 1800
sun$noon <- as.POSIXct(paste(round_date(sun$sunrise, unit = "1 day"),"11:30:00", sep = " "))
sun$midnight <- as.POSIXct(paste(round_date(sun$sunrise, unit = "1 day"),"23:30:00", sep = " "))

# export csv
write.csv(sun, file = "sunR2.csv", row.names = FALSE) # filename differs for each site

##### Prepare the data ##### (needs to be done for each recording site)

# set timezone
Sys.setenv(TZ='Etc/GMT-1')

# set working directory
setwd()

# importing the data
sun <- read.csv("sunR2.csv", header = TRUE)
load("dailyR2.RData")

# set sun to POSIXct
for (i in 1:4){
  sun[,i] <- as.POSIXct(sun[,i])
}
rm(i)
```

```r
#### extracting ACI values for sunrise (1h average)
morn.date <- data.frame()
aci.morning <- data.frame()
for (h in 2018:2019){
  for (i in 1:12){
    for (j in 1:31){
      morn <- sun$sunrise[grep(paste(h, sprintf("%02d", i), sprintf("%02d", j), sep = "-"),
                               sun$sunrise)]
      datum <- paste(h, sprintf("%02d", i), sprintf("%02d", j), sep ="")
      a <- which(aci.daily[[datum]]$Time > morn & aci.daily[[datum]]$Time <= morn +3600)
      b <- mean(aci.daily[[datum]][a,"ACI"])
      if (!is.na(b) == TRUE) {
        aci.morning <- rbind(aci.morning, b)
        morn.date <- rbind(morn.date, morn)}
    }
  }
}

aci.morning <- cbind(aci.morning, as.Date.POSIXct(morn.date[,1]))

colnames(aci.morning)=c("ACI sunrise","Date")

rm(a, b, datum, h, i, j, morn, morn.date)

#### extracting ACI values for sunset (1h average)
aci.evening <- data.frame()
evn.date <- data.frame()

for (h in 2018:2019){
  for (i in 1:12){
    for (j in 1:31){
      evn <- sun$sunset[grep(paste(h, sprintf("%02d", i), sprintf("%02d", j), sep = "-"),
                             sun$sunset)]
      datum <- paste(h, sprintf("%02d", i), sprintf("%02d", j), sep ="")
      a <- which(aci.daily[[datum]]$Time > evn & aci.daily[[datum]]$Time <= evn +3600)
      b <- mean(aci.daily[[datum]][a,"ACI"])
      if (!is.na(b) == TRUE) {
        aci.evening <- rbind(aci.evening, b)
        evn.date <- rbind(evn.date, evn)}
    }
  }
}

aci.evening <- cbind(aci.evening, as.Date.POSIXct(evn.date[,1]))

colnames(aci.evening)=c("ACI sunset", "Date")

rm(a, b, datum, h, i, j, evn, evn.date)
```

```r
#### extracting ACI values for noon (1h average)
aci.noon <- data.frame()
noon.date <- data.frame()
for (h in 2018:2019){
  for (i in 1:12){
    for (j in 1:31){
      noon <- sun$noon[grep(paste(sprintf("%02d", i), sprintf("%02d", j), sep = "-"), sun$noon)]
      datum <- paste(h, sprintf("%02d", i), sprintf("%02d", j), sep ="")
      a <- which(aci.daily[[datum]]$Time > noon & aci.daily[[datum]]$Time <= noon +3600)
      b <- mean(aci.daily[[datum]][a,"ACI"])
      if (!is.na(b) == TRUE) {
        aci.noon <- rbind(aci.noon, b)
        noon.date <- rbind(noon.date, noon)}
    }
  }
}


aci.noon <- cbind(aci.noon, as.Date.POSIXct(noon.date[,1]))

colnames(aci.noon)=c("ACI noon", "Date")]

rm(a, b, datum, h, i, j, noon, noon.date)

#### extracting ACI values for midnight (1h average)
aci.midnight <- data.frame()
mid.date <- data.frame()
for (h in 2018:2019){
  for (i in 1:12){
    for (j in 1:31){
      mid <- sun$midnight[grep(paste(sprintf("%02d", i), sprintf("%02d", j), sep = "-"),
                          sun$midnight)]
      datum <- paste(h, sprintf("%02d", i), sprintf("%02d", j), sep ="")
      a <- which(aci.daily[[datum]]$Time > mid & aci.daily[[datum]]$Time <= mid +3600)
      datum2 <- gsub("-", "", as.character(as.POSIXct(datum, format = "%Y%m%d")+86400))
      c <- which(aci.daily[[datum2]]$Time > mid & aci.daily[[datum2]]$Time <= mid +3600)
      b <- mean(c(aci.daily[[datum]][a,"ACI"], aci.daily[[datum2]][c,"ACI"]))
      if (!is.na(b) == TRUE) {
        aci.midnight <- rbind(aci.midnight, b)
        mid.date <- rbind(mid.date, mid)}
    }
  }
}

aci.midnight <- cbind(aci.midnight, as.Date.POSIXct(mid.date[,1]))

colnames(aci.midnight)=c("ACI midnight", "Date")

rm(a, b, datum, h, i, j, mid, mid.date)

# merging the dataset
aci.difftime <- merge(aci.morning, aci.noon, by = "Date", all = TRUE)
```

```r
aci.difftime <- merge(aci.difftime, aci.evening, by = "Date", all =TRUE)

aci.difftime <- merge(aci.difftime, aci.midnight, by = "Date", all =TRUE)

# exporting the dataset
save(aci.difftime, file = "4daytimes2.RData")

##### Plot the data ##### (needs to be done for each recording site)

# Load libraries and set working directory
library(ggplot2)
library(Rmisc)
library(plyr)

setwd()

# load data
load("4daytimes2.RData")

# identify data gaps
aci.difftime$group <- c(0, cumsum(diff(aci.difftime$Date) > 3))

# prepare the plots
a <- ggplot(aci.difftime, aes(x = Date, group = group)) +
  geom_point(y = aci.difftime[,"ACI sunrise"], colour="#CD0000", size=0.5) +
  geom_smooth(aes(y = aci.difftime[,"ACI sunrise"]), method = loess, span = 0.3, size = 0.5,
              color = "black") +
  ylim(0.55, 0.75) +
  ylab("ACI") + xlab("Date") +
  ggtitle("Sunrise")

b <- ggplot(aci.difftime, aes(x = Date, group = group)) +
  geom_point(y = aci.difftime[,"ACI sunset"], colour="#104E8B", size=0.5) +
  geom_smooth(aes(y = aci.difftime[,"ACI sunset"]), method = loess, span = 0.3, size = 0.5,
              color = "black") +
  ylim(0.55, 0.75) +
  ylab("ACI") + xlab("Date") +
  ggtitle("Sunset")

c <- ggplot(aci.difftime, aes(x = Date, group = group)) +
  geom_point(y = aci.difftime[,"ACI midnight"], colour="#458B00", size=0.5) +
  geom_smooth(aes(y = aci.difftime[,"ACI midnight"]), method = loess, span = 0.3, size = 0.5,
              color = "black") +
  ylim(0.55, 0.75) +
  ylab("ACI") + xlab("Date") +
  ggtitle("Midnight")

d <- ggplot(aci.difftime, aes(x = Date, group = group)) +
  geom_point(y = aci.difftime[,"ACI noon"], colour="#FFA500",size=0.5) +
  geom_smooth(aes(y = aci.difftime[,"ACI noon"]), method = loess, span = 0.3, size = 0.5,
              color = "black") +
  ylim(0.55, 0.75) +
  ylab("ACI") + xlab("Date") +
  ggtitle("Noon")

# plot all data
multiplot(a, b, c, d, cols=2)
```

8.1.5. Trendlines

```r
##### Filtering the data for rain and clippings #####

### Clippings

## Set working directory
setwd()

## Load the data
load("ACI_10min.RData")

clippings <- read.table("R1.txt")

# Recordings with clippings were identified outside of R and saved in a files called "R1.txt",
# "R2.txt", "R3.txt", "R4.txt". The following steps are made with "R1.txt"
# and need to be done separately for each recording site

## mark recordings with clippings
clippings$V1 <- as.character(clippings$V1)

clippings$V1 <- substring(clippings$V1,first = 11, last = 22)

clippings$V1 <- as.POSIXct(paste(clippings$V1, 0, sep = ""), format = "%Y%m%d_%H%M")
clippings <- clippings[-c(1:4, 1434:1552),]
clippings <- as.data.frame(clippings)
colnames(clippings)<-"Time"
clippings$clippings <- 1

R1 <- merge(aci.kontr.10min.sep, clippings, by = "Time", all = TRUE)
R1$clippings[is.na(R1$clippings)] <- 0
R1 <- na.omit(R1)

## save the data
write.csv(R1, file = "R1.csv", sep = ";")

### Rain was marked manually (outside of R) and saved in files called "R1.csv", "R2.csv",
"R3.csv","R4.csv"

##### Generate plots with datapoints and a trendline #####

### Needs to be done for each recording site separately (Variable names and working directory
need to be adjusted)

## Set working directory, system time and load libraries
setwd()

Sys.setenv(TZ='Etc/GMT-1')
library(ggplot2)

## Load the data and make sure it has the right format
R1 <- read.csv("R1.csv", header = TRUE, sep = ";")
R1$Time <- as.POSIXct(R1$Time, format = "%d.%m.%Y %H:%M")
```

```r
## Plot the data
# The datafiles already contain a grouping variable. If not then there was no grouping needed and the parameter
group has to be deleted
ggplot(R1[-c(which(R1$clippings == 1 | R1$m.rain == 1)),], aes(x=Time, y = ACI, group = group))+
   geom_point(color = "black", size = 0.1)+
   scale_x_datetime(date_breaks = "1 month")+
   geom_smooth(method = "loess", span = 0.3, color = "#CD0000", size = 1)+
   ylim(0.575,0.8)

##### Generate plots only with trendlines for each location #####
## Set working directory, system time and load libraries
setwd()

Sys.setenv(TZ='Etc/GMT-1')
library(ggplot2)

## Load the data and make sure it has the right format
R1 <- read.csv("R1.csv", header = TRUE, sep = ";")
R1$Time <- as.POSIXct(R1$Time, format = "%d.%m.%Y %H:%M")


## Plot the data
# The datafiles already contain a grouping variable. If not then there was no grouping needed and the parameter group
has to be deleted.
ggplot()+
   geom_smooth(data=R4[-c(which(R4$clippings == 1 | R4$m.rain == 1)),],
               aes(x=Time, y=ACI),
               colour="#CD0000", size=0.3, method = "loess", span = 0.3)+
   geom_smooth(data=R4[-c(which(R4$clippings == 1)),], aes(x=Time, y=ACI),
               colour="#104E8B", size=0.3, method = "loess", span = 0.3)+
   geom_smooth(data=R4[-c(which(R4$m.rain == 1)),], aes(x=Time, y=ACI),
               colour="#458B00", size=0.3, method = "loess", span = 0.3)+
   geom_smooth(data=R4[,], aes(x=Time, y=ACI),
               colour="#FFA500", size=0.3, method = "loess", span = 0.3)+
   coord_cartesian(ylim = c(0.575,0.62))

##### Generate plots only with trendlines for all locations #####
## Set working directory, system time and load libraries
setwd()

Sys.setenv(TZ='Etc/GMT-1')
library(ggplot2)

## Load the data and make sure it has the right format
R1 <- read.csv("R1.csv", header = TRUE, sep = ";")
R1$Time <- as.POSIXct(R1$Time, format = "%d.%m.%Y %H:%M")
```

```r
R2 <- read.csv("R2.csv", header = TRUE, sep = ";")

R2$Time <- as.POSIXct(R2$Time, format = "%d.%m.%Y %H:%M")

R3 <- read.csv("R3.csv", header = TRUE, sep = ";")

R3$Time <- as.POSIXct(R3$Time, format = "%d.%m.%Y %H:%M")

R4 <- read.csv("R4.csv", header = TRUE, sep = ";")

R4$Time <- as.POSIXct(R4$Time, format = "%d.%m.%Y %H:%M")

## Plot the data with rain and clippings removed
ggplot()+
  geom_smooth(data=R1[-c(which(R1$clippings == 1 | R1$m.rain == 1)),],
              aes(x=Time, y=ACI, group = group),
              colour="#CD0000", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R2[-c(which(R2$clippings == 1 | R2$m.rain == 1)),],
              aes(x=Time, y=ACI),
              colour="#104E8B", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R3[-c(which(R3$clippings == 1 | R3$m.rain == 1)),],
              aes(x=Time, y=ACI),
              colour="#458B00", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R4[-c(which(R4$clippings == 1 | R4$m.rain == 1)),],
              aes(x=Time, y=ACI, group = group),
              colour="#FFA500", size=0.5, method = "loess", span = 0.3)+
  coord_cartesian(ylim = c(0.575,0.62))

## Plot all data
ggplot()+
  geom_smooth(data=R1[,], aes(x=Time, y=ACI, group = group),
              colour="#CD0000", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R2[,], aes(x=Time, y=ACI),
              colour="#104E8B", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R3[,], aes(x=Time, y=ACI),
              colour="#458B00", size=0.5, method = "loess", span = 0.3)+
  geom_smooth(data=R4[,], aes(x=Time, y=ACI, group = group),
              colour="#FFA500", size=0.5, method = "loess", span = 0.3)+
  coord_cartesian(ylim = c(0.575,0.62))

##### Generate plots with trendlines of ACI and meteo data #####
## Set system time and load libraries
Sys.setenv(TZ='Etc/GMT-1')
library(ggplot2)

### Load ACI data
## Set working directory
setwd()

## Load the ACI data and make sure it has the right format
R1 <- read.csv("R1.csv", header = TRUE, sep = ";")
R1$Time <- as.POSIXct(R1$Time, format = "%d.%m.%Y %H:%M")
```

```r
R2 <- read.csv("R2.csv", header = TRUE, sep = ";")

R2$Time <- as.POSIXct(R2$Time, format = "%d.%m.%Y %H:%M")

R3 <- read.csv("R3.csv", header = TRUE, sep = ";")

R3$Time <- as.POSIXct(R3$Time, format = "%d.%m.%Y %H:%M")

R4 <- read.csv("R4.csv", header = TRUE, sep = ";")

R4$Time <- as.POSIXct(R4$Time, format = "%d.%m.%Y %H:%M")

### Load meteo data

## Set working directory
setwd()

## load data
env.var <- read.csv("2835_Pfynwald-0_Pfynwald-02-0_Pfynwald-02-1_Pfynwa_1522360800-1553900400.csv"
                    sep = ",", header = TRUE)

env <- env.var[,c(1,5,9,12)]

env$Timestamp <- as.POSIXct(env$Timestamp, format = "%Y-%m-%d %H:%M:%S")

colnames(env) <- c("Time", "precipitation","air temperature", "wind speed")

## separate the data and add facetting variable (a)

# ACI data
R1$a <- 1
R2$a <- 1
R3$a <- 1
R4$a <- 1

R1.2 <- R1[-c(which(R1$clippings == 1 | R1$m.rain == 1)),]
R2.2 <- R2[-c(which(R2$clippings == 1 | R2$m.rain == 1)),]
R3.2 <- R3[-c(which(R3$clippings == 1 | R3$m.rain == 1)),]
R4.2 <- R4[-c(which(R4$clippings == 1 | R4$m.rain == 1)),]

R1.2$a <- 5

R2.2$a <- 5

R3.2$a <- 5

R4.2$a <- 5

# meteo data
rain <- env[,1:2]
temp <- env[,c(1,3)]
```

```r
wind <- env[,c(1,4)]

rain$a <- 2

temp$a <- 3

wind$a <- 4

## Prepare labels
labels <- c(
  `1` = "ACI",
  `2` = "precipitation [mm]",
  `3` = "air temperature [C]",
  `4` = "wind speed [m/s]",
  `5` = "ACI filtered"
)

## Prepare plot
sp <- ggplot()+
  geom_smooth(data=R1, aes(x=Time, y=ACI, group = group, colour = "R1"),
              size=0.5)+
  geom_smooth(data=R2, aes(x=Time, y=ACI, colour = "R2"),
              size=0.5)+
  geom_smooth(data=R3, aes(x=Time, y=ACI, colour = "R3"),
              size=0.5)+
  geom_smooth(data=R4, aes(x=Time, y=ACI, group = group, colour = "R4"),
              size=0.5)+
  geom_smooth(data=R1.2, aes(x=Time, y=ACI, group = group, colour = "R1"),
              size=0.5)+
  geom_smooth(data=R2.2, aes(x=Time, y=ACI, colour = "R2"),
              size=0.5)+
  geom_smooth(data=R3.2, aes(x=Time, y=ACI, colour = "R3"),
              size=0.5)+
  geom_smooth(data=R4.2, aes(x=Time, y=ACI, group = group, colour = "R4"),
              size=0.5)+
  geom_smooth(data=rain, aes(x=Time, y = precipitation), colour = "black",
              size = 0.5)+
  geom_smooth(data=temp, aes(x=Time, y = env$`air temperature`), colour =
                "black", size = 0.5)+
  geom_smooth(data=wind, aes(x=Time, y = env$`wind speed`), colour =
                "black", size = 0.5)+
  scale_colour_manual(name = "legend",
                      values = c("#CD0000","#104E8B","#458B00","#FFA500"))

## Plot
sp + facet_grid(a~., scales = "free", , labeller = as_labeller(labels))
```

8.1.6. Diurnal patterns

```r
## set working directory and system time and load libraries and data
setwd()

Sys.setenv(TZ='Etc/GMT-1')
library(ggplot2)
library(Rmisc)
load("ACI_10min.RData")

## Choose the day
spring_1 <- aci.kontr.10min.sep[2928:3066,]
summer_1 <- aci.kontr.10min.sep[17281:17420,]

## Prepare plots
a <- ggplot(spring_1, aes(x = Time, y = spring_1$ACI)) +
  geom_point(colour="#458B00",  size=0.5) +
  geom_smooth(method = loess, span = 0.1, size = 0.5, color = "black")+
  ylab("ACI") + xlab("Date")+
  ggtitle("Spring 1")
b <- ggplot(summer_1, aes(x = Time, y = summer_1$ACI)) +
  geom_point(colour="#458B00",  size=0.5) +
  geom_smooth(method = loess, span = 0.1, size = 0.5, color = "black")+
  ylab("ACI") + xlab("Date")+
  ggtitle("Summer 1")

## Plot
multiplot(a, b, cols=2)
```

8.1.7. Interactive line graphs

```r
# The following code is adapted from Xianda Guo (2018)

# libraries for plotting and mada manipulation
library(ggplot2)
library(lubridate)
library(reshape)
library(zoo)
# libraries for interactive plots
library(shiny)
library(dygraphs)

# set working directory and load data
setwd()

load("allaci.RData")

setwd()

load("ACI_10min.RData")

setwd()

env.var <- read.csv("2835_Pfynwald-0_Pfynwald-02-0_Pfynwald-02-1_Pfynwa_1522360800-1553900400.csv",
                    sep = ",",header = TRUE)

env <- env.var[,c(1,5,6,9,12)]

env$Timestamp <- as.POSIXct(env$Timestamp, format = "%Y-%m-%d %H:%M:%S")

colnames(env) <- c("Time", "precipitation", "air humidity","air temperature", "wind speed")

#### Prepare the data

### R1

# organize new data frames, like make a new data frame for all values to be displayed on one graph
x0 <- merge(all.aci[,c(1,2)], env, by = "Time", all = TRUE)

# data Scaling of each column: x <- (x - min(x)) / (max(x) - min(x)) to  make all data
between 0 and 1
x1 <- data.frame(apply(x0[,-1], MARGIN = 2, FUN = function(X) (X - min(X, na.rm = TRUE))/
              (max(X, na.rm = TRUE)-min(X,na.rm = TRUE))))

# add the time column back
comb.irr.R1 <- cbind(x0$Time, x1)

## make it become time-series data
comb.irr.R1.zoo <- zoo(comb.irr.R1[, 2:6], order.by = comb.irr.R1[,1])
```

```r
### R2

# organize new data frames, like make a new data frame for all values to be displayed on one graph
x0 <- merge(all.aci[,c(1,3)], env, by = "Time", all = TRUE)

# data Scaling of each column: x <- (x - min(x)) / (max(x) - min(x)) to make all data between 0 and
x1 <- data.frame(apply(x0[,-1], MARGIN = 2, FUN = function(X) (X - min(X,na.rm = TRUE))/
                (max(X, na.rm = TRUE)-min(X,na.rm = TRUE))))

# add the time column back
comb.irr.R2 <- cbind(x0$Time, x1)

## make it become time-series data
comb.irr.R2.zoo <- zoo(comb.irr.R2[, 2:6], order.by = comb.irr.R2[,1])

### R3
# organize new data frames, like make a new data frame for all values to be displayed on one graph
x0 <- merge(all.aci[,c(1,4)], env, by = "Time", all = TRUE)

# data Scaling of each column: x <- (x - min(x)) / (max(x) - min(x)) to make all data between 0 and
x1 <- data.frame(apply(x0[,-1], MARGIN = 2, FUN = function(X) (X - min(X, na.rm = TRUE))/
                (max(X, na.rmTRUE)-min(X,na.rm = TRUE))))

# add the time column back
comb.irr.R3 <- cbind(x0$Time, x1)

## make it become time-series data
comb.irr.R3.zoo <- zoo(comb.irr.R3[, 2:6], order.by = comb.irr.R3[,1])

### R4

# organize new data frames, like make a new data frame for all values to be displayed on one graph
x0 <- merge(all.aci[,c(1,5)], env, by = "Time", all = TRUE)

# data Scaling of each column: x <- (x - min(x)) / (max(x) - min(x)) to make all data between 0 and
x1 <- data.frame(apply(x0[,-1], MARGIN = 2, FUN = function(X) (X - min(X,na.rm = TRUE))/
                (max(X, na.rm = TRUE)-min(X, na.rm = TRUE))))

# add the time column back
comb.irr.R4 <- cbind(x0$Time, x1)

## make it become time-series data
comb.irr.R4.zoo <- zoo(comb.irr.R4[, 2:6], order.by = comb.irr.R4[,1])

# set the date range to be displayed
date_earlist <- min(as.Date(aci.kontr.10min.sep$Time))

date_latest <- max(as.Date(aci.kontr.10min.sep$Time))
```

```r
### App

# user interface --------------------------------------------
ui <- fluidPage(
  # Some custom CSS for a smaller font for preformatted text
  tags$head(
    tags$style(HTML("
                    pre, table.table {
                    font-size: smaller;
                    }
                    "))
  ),
  # to display all the sensors, 3 panels are vertrically arranged
  verticalLayout(
    # the first panel for R1
    sidebarLayout(
      sidebarPanel(
        # when clicked on, calendars will show up for users to select dates.
        dateRangeInput("daterange", "Date range:",
                       start = date_earlist + 1, end = date_earlist + 2,
                       min = date_earlist, max = date_latest,
                       #format = "mm/dd/yy",
                       separator = " to "),

    checkboxInput("showgrid", label = "Show Grid", value = TRUE),
    hr(),
    # the control panel below line graphs for zooming in or out
    div(strong("From: "), textOutput("from1", inline = TRUE)),
    div(strong("To: "), textOutput("to1", inline = TRUE)),
    div(strong("Date clicked: "), textOutput("clicked", inline = TRUE)),
    div(strong("Nearest point clicked: "), textOutput("point1", inline = TRUE)),
    helpText("Click and drag to zoom in (double click to zoom back out)."),
    # the side panel for users to choose what to be displayed
    checkboxGroupInput("variable1", "Variables to show:",
                       c("precipitation" = "precipitation",
                         "air humidity" = "air.humidity",
                         "air temperature" = "air.temperature",
                         "wind speed" = "wind.speed"))
    ),
    # the main line graph
    mainPanel(
      dygraphOutput("dygraph1")
    )
  ),
```

```r
# R2
sidebarLayout(
  sidebarPanel(
    div(strong("From: "), textOutput("from2", inline = TRUE)),
    div(strong("To: "), textOutput("to2", inline = TRUE)),
    #div(strong("Date clicked: "), textOutput("clicked", inline = TRUE)),
    div(strong("Nearest point clicked: "), textOutput("point2", inline = TRUE)),
      helpText("Click and drag to zoom in (double click to zoom back out)."),
      checkboxGroupInput("variable2", "Variables to show:",
                    c("precipitation" = "precipitation",
                      "air humidity" = "air.humidity",
                      "air temperature" = "air.temperature",
                      "wind speed" = "wind.speed"))
  ),
  mainPanel(
    dygraphOutput("dygraph2")
  )),

# R3
sidebarLayout(
  sidebarPanel(
    div(strong("From: "), textOutput("from3", inline = TRUE)),
    div(strong("To: "), textOutput("to3", inline = TRUE)),
    #div(strong("Date clicked: "), textOutput("clicked", inline = TRUE)),
    div(strong("Nearest point clicked: "), textOutput("point3", inline = TRUE)),
    helpText("Click and drag to zoom in (double click to zoom back out)."),
    checkboxGroupInput("variable3", "Variables to show:",
                  c("precipitation" = "precipitation",
                    "air humidity" = "air.humidity",
                    "air temperature" = "air.temperature",
                    "wind speed" = "wind.speed"))
  ),
  mainPanel(
    dygraphOutput("dygraph3")
  )),

  # R4
  sidebarLayout(
    sidebarPanel(
      div(strong("From: "), textOutput("from4", inline = TRUE)),
      div(strong("To: "), textOutput("to4", inline = TRUE)),
      #div(strong("Date clicked: "), textOutput("clicked", inline = TRUE)),
      div(strong("Nearest point clicked: "), textOutput("point4", inline = TRUE)),
      helpText("Click and drag to zoom in (double click to zoom back out)."),
      checkboxGroupInput("variable4", "Variables to show:",
                      c("precipitation" = "precipitation",
                        "air humidity" = "air.humidity",
                        "air temperature" = "air.temperature",
                        "wind speed" = "wind.speed"))
    ),
    mainPanel(
      dygraphOutput("dygraph4"))
  )
)
)
```

```r
# server ------------------------------------------------
server <- function(input, output) {
  ############### render dygraph plot

  output$dygraph1 <- renderDygraph({
    dygraph(comb.irr.R1.zoo[, c("R1", input$variable1)],
            main = "ACI Forrest (Recorder 1)",
            ylab = "ACI") %>%
      dyOptions(drawGrid = input$showgrid, digitsAfterDecimal = 4
      ) %>%
      dyRangeSelector(dateWindow = input$daterange) %>%
      dyHighlight(highlightCircleSize = 3,
                  highlightSeriesBackgroundAlpha = 0.2,
                  hideOnMouseOut = FALSE)    %>%
      dyLegend(width = 500)
  })


  output$dygraph2 <- renderDygraph({
    dygraph(comb.irr.R2.zoo[, c("R2", input$variable2)], main = "ACI Illgraben (Recorder 2)",
            ylab = "ACI") %>%
      dyOptions(drawGrid = input$showgrid, digitsAfterDecimal = 4
      ) %>%
      dyRangeSelector(dateWindow = input$daterange) %>%
      dyHighlight(highlightCircleSize = 3,
                  highlightSeriesBackgroundAlpha = 0.2,
                  hideOnMouseOut = FALSE)    %>%
      dyLegend(width = 500)
  })


  output$dygraph3 <- renderDygraph({
    dygraph(comb.irr.R3.zoo[, c("R3", input$variable3)],
            main = "ACI River (Recorder 3)",
            ylab = "ACI") %>%
      dyOptions(drawGrid = input$showgrid, digitsAfterDecimal = 4
      ) %>%
      dyRangeSelector(dateWindow = input$daterange) %>%
      dyHighlight(highlightCircleSize = 3,
                  highlightSeriesBackgroundAlpha = 0.2,
                  hideOnMouseOut = FALSE)    %>%
      dyLegend(width = 500)
  })


  output$dygraph4 <- renderDygraph({
    dygraph(comb.irr.R4.zoo[, c("R4", input$variable4)],
            main = "ACI Pond (Recorder 4)",
            ylab = "ACI") %>%
      dyOptions(drawGrid = input$showgrid, digitsAfterDecimal = 4
      ) %>%
      dyRangeSelector(dateWindow = input$daterange) %>%
      dyHighlight(highlightCircleSize = 3,
                  highlightSeriesBackgroundAlpha = 0.2,
                  hideOnMouseOut = FALSE)    %>%
      dyLegend(width = 500)
  })
```

```r
  ############ sidebarpanel control
  output$from1 <- renderText({

    strftime(req(input$dygraph1_date_window[[1]]), "%d %b %Y")
  })

  output$to1 <- renderText({
    strftime(req(input$dygraph1_date_window[[2]]), "%d %b %Y")
  })

  output$point1 <- renderText({
    paste(input$dygraph1_click$x_closest_point, "\n", input$dygraph1_click$y_closest_point)
  })

  ############### sidebarpanel 2
  output$from2 <- renderText({
    strftime(req(input$dygraph2_date_window[[1]]), "%d %b %Y")
  })

  output$to2 <- renderText({
    strftime(req(input$dygraph2_date_window[[2]]), "%d %b %Y")
  })

  output$point2 <- renderText({
    paste(input$dygraph2_click$x_closest_point, "\n", input$dygraph2_click$y_closest_point)
  })

  ########### sidebarpanel 3
  output$from3 <- renderText({
    strftime(req(input$dygraph3_date_window[[1]]), "%d %b %Y")
  })

  output$to3 <- renderText({
    strftime(req(input$dygraph3_date_window[[2]]), "%d %b %Y")
  })

  output$point3 <- renderText({
    paste(input$dygraph3_click$x_closest_point, "\n", input$dygraph3_click$y_closest_point)
  })


  ########### sidebarpanel 4
  output$from4 <- renderText({
    strftime(req(input$dygraph4_date_window[[1]]), "%d %b %Y")
  })

  output$to4 <- renderText({
    strftime(req(input$dygraph4_date_window[[2]]), "%d %b %Y")
  })

  output$point4 <- renderText({
    paste(input$dygraph3_click$x_closest_point, "\n", input$dygraph4_click$y_closest_point)
  })
}

# excuate the app

shinyApp(ui = ui, server = server)
```

ETH

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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