UNIVERSITEIT TWENTE.

# SMART ENVIRONMENTS PROJECT

## DOCUMENTATION REPORT

**The Rangers**

*Bas Reterink 3006360*
*Xinran Zhi 2874695*
*Maryna Bielik 2878291*
*Max Vroomans 3077691*
*Jona Patig 2920158*
*Luuk Jansen 3072681*
*Anna Ridala 2987538*

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# Chapter 0: Introduction

**Version 1**
Bird calls play a crucial role for means of communication, navigation, and territory defense. However, the increasing levels of noise pollution caused by human activity make it difficult for wildlife researchers to accurately hear and identify these calls in the wild. This problem is particularly acute in urban and suburban areas, where the sounds of traffic, construction, and other man-made noises often drown out the sounds of birds.

To address this challenge, this team presents Tweak, a ready-to-deploy solution that utilizes artificial intelligence to isolate bird calls from other noises. Tweak is designed to help researchers accurately hear and identify bird calls in a variety of environments. In addition, Tweak can recognize the species and an estimation of the amount of birds heard, providing valuable data for researchers studying the behavior and populations of different bird species.

In this research paper, the technology behind Tweak and its potential impact on the field of wildlife research will be described. The potential benefits of using Tweak for bird conservation efforts, as well as its potential applications in other areas of environmental research shall also be looked at. By providing a reliable and accurate way to hear and identify bird calls, Tweak has the potential to significantly advance our understanding of bird behavior and ecology. Tweak will be used in collaboration with a group monitoring cats. This means that the relationship between the amount of birds and cats can also be further explored. With the help of the data gathered more educated decisions in regards to protection and conservation of these important species can be made.

# Chapter 1: Literature Review

## Exploring the ecology of suburban wildlife

Some of the highest rates of development in the world occur on the outskirts of cities and on rural estates nearby. This may result in significant changes to the landscape, altered ecological processes, and a decline in biodiversity. Native plants and animals are facing a severe challenge with the loss of habitat and open space, which poses threats to biodiversity and quality of life. [1]

## Application of risk concepts to wildlife management: Special issue

A study on how wildlife management processes can be improved based on how people respond to risks related to the environment. A range of problems for both humans and wildlife could arise from interactions between the two. Knowledge from different disciplines must be merged to the extent that human dimensions research can improve comprehension of management results. This article gives deep information on significant risk-related theories and demonstrates how risk can be used to guide applied research in the field of wildlife. [2]

## Creating coexistence between humans and wildlife

The article is about ideas that are provided by experts around the world to set a global policy agenda for protected areas. It provides information about rules that would create coexistence between humans and animals and also for humans in general, since human-wildlife conflict often involves human-human conflict. Another point in reaching this goal is studying biology science. [3]

## The effects on plastic pollution on aquatic wildlife: Current situation and future solutions.

The amount of consumer products of plastic materials that are produced today are equal to the size of the ocean. Qualities of plastic that are useful for people can be very harmful to wildlife. It is believed that once this huge mix of garbage reaches the uninhabited, they may cause death to various species. The problem now is trying to be solved by different technologies that are used to monitor and gather the plastic. Scientists are thinking of a solution that will help reduce the amount of plastic used everyday as it has a dangerous effect on the ecosystem. [4]

## Visual Informatics Tools for Supporting Large-Scale Collaborative Wildlife Monitoring with Citizen Scientists

This article contains different means of monitoring wildlife, such as GPS-tracking, satellite tracking, and sensor networks. More on, it talks about computer based learning techniques to analyze images captured by camera-traps. This way, you can determine the species of the photographed animal. [5]

## Towards a New Opportunistic IoT Network Architecture for Wildlife Monitoring System

This article contains information about energy conservation by processing information in wildlife monitoring systems before transmitting it to a main server. This way small-scale monitoring (which are more likely to be more labor-intensive) becomes more efficient and sustainable. [6]

## Trends in Ecology & Evolution

This article proposes that all surveillance-monitoring should be changed to monitoring with a purpose. A monitoring system should be put in place according to certain predetermined goals. This would make things much more efficient and problem oriented. [7]

## Are unmanned aircraft systems the future of wildlife monitoring? A review of accomplishments and challenges

For wildlife monitoring, regular abundance surveys are required to adaptively manage the wildlife populations. Drones enable much more frequent fly-overs than planes, making the data less dated. The main non-technological problem right now is legislation, since many countries are creating laws to decrease drone usage. Technology-wise, the drones still have very limited flight endurance compared to planes and the sensors used need to be much lighter. [8]

## Comparison of Aerial Thermal Infrared Imagery and Helicopter Surveys of Bison (Bison bison) in Grand Canyon National Park, USA

In theory, thermal detection of wildlife should be more accurate than human observers in a high-density vegetation environment. This paper compares a typical helicopter survey (human observers) with a TII (thermal infrared imagery) helicopter survey.
TIR is less accurate than helicopter flights and about 3 times more expensive. However, the safety for the passengers is much higher. The decreased accuracy from the TIR group was mostly caused by them not finding a major herd, which the helicopter group did find. [9]

## Technological advances in biodiversity monitoring: applicability, opportunities and challenges

The main issues for satellites are; the availability of data and the resolution of the camera's. On the other hand, cost is the main issue for cameras. For acoustic devices, the available sound data is the main issue. Lastly, there is limited research on environmental DNA but the main issue is probably the small area covered. [10]

## Automatic Fungi Recognition: Deep Learning Meets Mycology

This paper is about an AI that can detect fungi based on images alone with a 93% accuracy. The researchers developed a new AI that is even more accurate. The AI is used in an application which is free for everyone to use. Inside the application, experts verify the information by using the images provided, increasing efficiency. However, this only applies to

Danish fungi, as the researchers use the Danish fungi atlas as a basis for the AI to train on. [11]

## Tools and Technologies for the Monitoring, Controlling and Surveillance of Unwanted Catches

In The European Landing Obligation book, remote Electronic Monitoring (EM) is used as a means of monitoring and managing unwanted catches at sea. This method is also relatively easy to implement and cheap compared to other monitoring and management methods. [12]

## Automatically detecting the wild giant panda using deep learning with context and species distribution model

The infrared camera trap is an effective tool for automatically detecting the wild giant panda. Compared to conventional methods, camera traps are non-invasive for wildlife. However, giant pandas positions within the images may affect detection performance. The ideal position is when pandas face the camera. [13]

## Precision wildlife monitoring using unmanned aerial vehicles

Unmanned aerial vehicles(UAVs) are a great way to accurately monitor wild animals. UAVs have been used in applications as diverse as monitoring in their short history. Moreover, according to the analysis of the model, UAVs are a more precise technique than others. [14]

## Benthic Habitats, as Derived from Classification of Side-Scan-Sonar Mapping Data, Are Important Determinants of Reef-Fish Assemblage Structure in the Eastern Gulf of Mexico.

Side-Scan-Sonar and camera trap are two methods used to monitor reef-Fish Assemblage Structures in the Eastern Gulf of Mexico. Side-Scan-Sonar is used to measure a wide range of coral habitat types such as Pothole, ledges. Camera trap monitor function is used for measuring taxa, taxonomic richness, and taxonomic diversity. [15]

## Agriculture and wildlife: A two-way relationship

Around 30% of all wildlife habitat land is agricultural land in Canada, showing the crucial role it plays in wildlife monitoring and conservation. 49.9% of wildlife on agricultural land is in woodlands and wetlands, displaying the secondary purpose of the land itself. While agricultural land needs certain environments to survive, pollinators are crucial in sustaining a healthy and efficient farming cycle. Finally, “buffer zones” are set aside around large bodies of water like streams, rivers, and lakes on farmland in order to prevent sediments and contaminants from leaking into the most crucial zones of wildlife habitat on agricultural land. Contaminated water leads to dying wildlife, and thus dying pollinators, which can lead to unhealthy agricultural land. [16]

## The Princeton ZebraNet Project: Sensor Networks for Wildlife Tracking

The current technologies for tracking wildlife herds are VHF Triangulation and GPS tracking, both of which come with their own problems (error prone and collar retrieval required due

to GPS' high energy consumption). In order to solve this problem, the methods are combined in order to complement each other and be more accurate. Zebra herds are tracked with a GPS tracker within the male (they travel in harems (1 male + multiple females)), and the other zebra's locations are based off of triangulation and signal strength to the main zebra, using low energy trackers. Findings of this method reveal daily routines and migration patterns, movement speeds, and the herd's reactions to natural events such as floods or droughts. The data displays that rapid moves hurt the herd in general, and chaos leads to less reproduction. [17]

## A GPS-Less Localization and Mobility Modelling (LMM) System for Wildlife Tracking

The idea of the paper is a project to attempt to replace GPS tracking with another method: LMM (Localization and Mobility Modeling). The method uses low range low energy simple sensors in order to reduce the overall energy required, and make the entire process of wildlife tracking simpler. Sensors are attached to animals, using peer to peer triangulation to determine movement speeds and direction. It is said that traditional GPS collars affect the animal's movement patterns more than they would naturally move by themselves. In order to fail proof the system, sensors can be set up on trees and bushes in order to ensure the possibility for triangulation at all times, as the sensors only have a range of a few kilometers. [18]

## Non-traditional data and innovative methods for autumn climate change ecology

Most data found on wildlife analyzes species and plants over the entire year, or longer periods of time which doesn't give a very good sample of how seasons and climate change affect the patterns. The paper presents methods of extrapolating and using novel data sets from previous broader studies in order to cross reference and draw more information out of the data, specifically on how the wildlife and habitats behave during autumn. [19]

## Quadcopter applications for wildlife monitoring:

A quadcopter (a drone) can be compact and can be equipped with different types of cameras, depending on how high you fly and how much you can interrupt nature with sound without leaving a negative impact on the area. When a drone vibrates, to make high quality photos you need a damper. Getting the equipment right for the purpose means as little possible flight time while gathering as much data as you can. Weight is a huge influence on flight time. [20]

## Managing and monitoring birds using point counts: standards and applications:

Random locations that are not on boundaries between habitat types should be used. While roads can be logistically appealing, you should avoid them. Mainly use tertiary and secondary roads or trails because these have less of an effect on their surrounding habitat. More than 10 min should not be spent at each point and each point has to be at least 250 meters apart. [21]

### A comparison of camera trap and permanent recording video camera efficiency in wildlife underpasses

Monitoring wildlife that go through highway underpasses may be underestimated. Camera traps failed to record more than 40 percent of animal passes and about 17 percent of large animal passes. These numbers can be improved by making sure the mammals are in front of the camera for longer. Also adding another camera at the end of the underpass can help in double checking if there was a mammal. [22]

### Integrating Remote Sensing into Wildlife Monitoring for Conservation

Remote sensing creates more possibilities to gather data than ever before. With so much technology there is to use, the excitement over this tech may lead researchers to first decide what tech to use before they know what they will be measuring. Remote sensing therefore should only be used in appropriate situations. Constantly examining what went good and bad is key to success. [23]

### Coral Reef Monitoring, Reef Assessment Technologies, and Ecosystem-Based Management

Accessible, reliable data of changes in coral reefs can help researchers map out the level of pollution and the state of global warming the rest of the ecosystem/planet is experiencing as coral reefs are global indicators. New methods of monitoring, such as structure from motion image processing and acoustic techniques, are modernizing the field. To determine the most important characteristics for gauging the health of coral reefs and developing methods to transmit those data the Essential Ocean Variable (EOV) and Essential Biodiversity Variable (EBV) frameworks have been adapted. Consistency in data measurement and recording are now the main priority for the new age of coral reef monitoring. [24]

### BearCam: automated wildlife monitoring at the arctic circle

Remote wildlife monitoring can lessen the negative impacts of nature based tourism as, the animals are less likely to come into contact with humans. The article looks at the development and usage of the “BearCam” in the arctic circle. The camera system consists of good enough camera equipment to withstand the harsh conditions of the arctic climate and an algorithm for detecting motion of bears. The algorithm was developed in order to lessen the amount of data collected by the BearCam. [25]

## Chapter 2: Identification of General Problems and Challenges

**1:** GPS High range collars disturb wildlife, and new methods should be found. A lot of energy (inefficient and unsustainable) is used.

**2:** Novelty areas of wildlife research have not been analyzed as much as they could be, and modern sensors and methods could be applied to old research in order to narrow down information.

**3**: A lack of regulations in measurement and a unified database can lead to miscommunication by the scientists and a lack of consistency in the data collected.

**4:** Data takes a lot of space and it is difficult to leave equipment in an area that is difficult to reach for a long time. Often visiting the same area can disturb the wildlife in the area.

**5:** In countries where wildlife management is most needed(Africa, south-america), it is usually still cheaper to employ humans than to use current technology solutions.

**6:** For drone-based observation, the main issues are cost and legislation.

**7:** It is still very unclear what environmental variables cause species growth and decay. The relationship is vague.

**8:** GPS tracking and sensor networks don't provide any images, so ecologists can't gain any insight in any behavioral properties of animals, and image based wildlife tracking is not very energy efficient.

**9:** Through machine learning, the camera can recognize animals or plants by the characteristics of the species. Developing machine learning is difficult.

## Chapter 3: Identification of Relevant Problems

**1**: There is not enough research on what the effect of water-based environment variables is on land-based wildlife. [28]

**2:** Wildlife monitoring equipment is too expensive for the countries which need it the most. [26]

**3**: A detector (camera trap, sensors) covers only a small surface area [27].

**4:** Sensors get dirty from pond water. --> Longevity of monitoring equipment when left alone in the wild for a lasting period of time. [30]

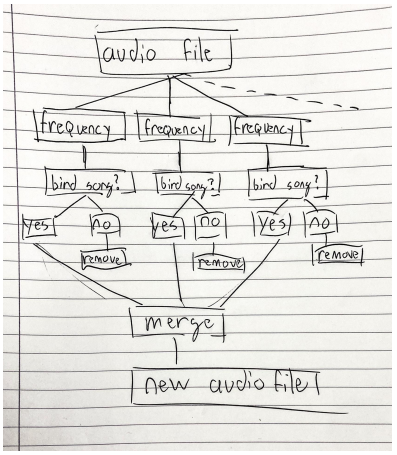
**5:** Data being clouded by noise and resolution restrictions frequently make it challenging to monitor the quality of inland water bodies. [29]

## Chapter 4: Problem Selection and Motivation

How can bird noises be isolated in environments with a lot of background noise?
It is difficult for researchers to study birds in noisy areas because it's a lot harder to determine how the bird actually sounds [31]. If these sounds were more clear, researchers would be better able to study how birds sound and communicate. For instance, a call to tell each other that a predator is near, or a tweet to locate a source of food. And does a noisy environment (by man-made noise) make these communications more difficult?
It has been found that, especially in densely populated countries like the Netherlands, noise pollution is a big problem to wildlife monitoring, as it disturbs sensors and animals [32]. The solution to this problem will hopefully allow researchers to collect bird noises in any area, including near highways or roads that would otherwise drown out data. It is a more feasible solution to a problem that is local to us, meaning it will be possible to test different methods to the solution. Primary data can be collected from the local environment, instead of having to base everything off of papers that were created far away.

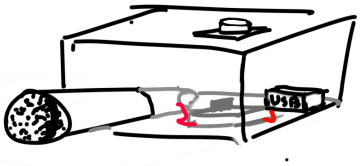
# Chapter 5: Potential Solutions

**Digital filtering**



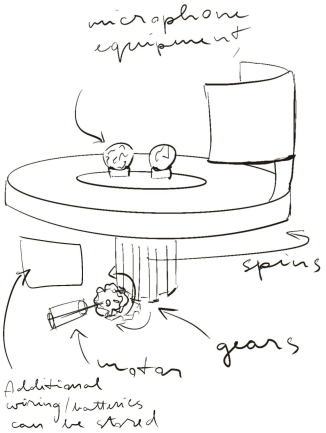

This solution consists of an omnidirectional microphone and an arduino. The microphone records the sound when a button is pressed. When the button is pressed again, the microphone stops picking up sound and the recorded audio is saved, creating an audio file. The file consists of all frequencies that were there when it was recorded. The Raspberry Pi will start processing the audio-file. It will get rid of certain background-noise frequencies we do not want. Therefore just leaving the bird noise. The Raspberry Pi writes the new processed audio to an attached USB-stick and plays it on the 5mm headphone jack.

The processing of the audio will be done with Python and an appropriate sound processing library, as part of the team has experience with this. The sound will be analyzed using external tools, such as reaper or audacity. The solution could be tested by playing sample audio from a separate computer.




**Active analog filtering (“shield” that moves around)**

Monitoring the direction of the sound and using a rotating disc that blocks sounds that are not bird calls. This solution would be useful in a noisy area as it would allow for blockage of sound. If the “larger” sounds get blocked the microphone has better potential to pick up on the bird noise.

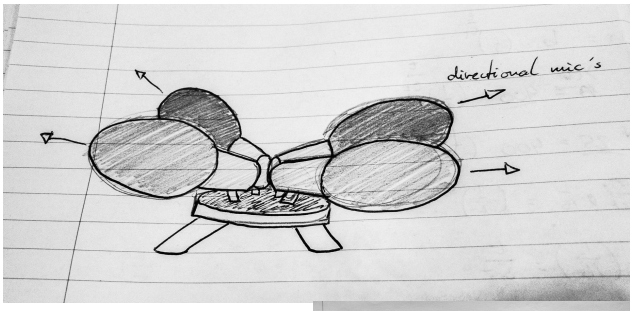


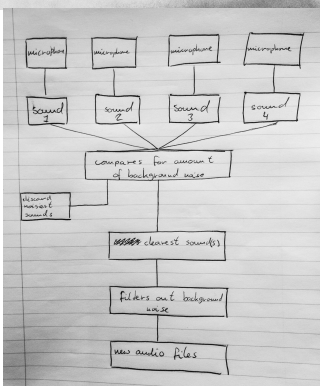

The mechanism would rotate around the microphone equipment standing on a pole. Several different materials for the optimate blockage of noise can be tested. If several microphones are used the mechanism could also help with determining the direction of the bird song/noise.

The umbrella and shield are connected into a 90-degree arc. The outside of the cover is porous material for noise absorption. The inner surface is smooth and reflects sound

**Microphone Array**

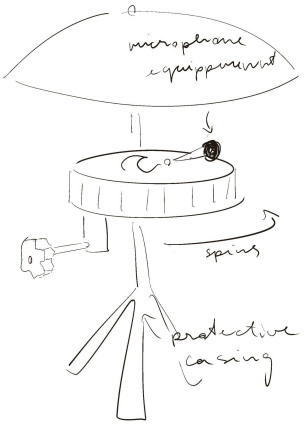
Through the use of multiple unidirectional (minimum 4) microphones, it's possible to single out the direction of a bird sound. Using this data, a final sound file can be recorded that is a mix of the single sound streams, with mixing depending on the frequencies of each microphone. For example, if one sound stream primarily records a constant background noise, the final sound file will only take this sound stream at a much lower volume compared to the others, in order to single out the specific noises. This creates a final output file which only contains bird chirps with the occasional cracking of a stick, or something of the sorts.

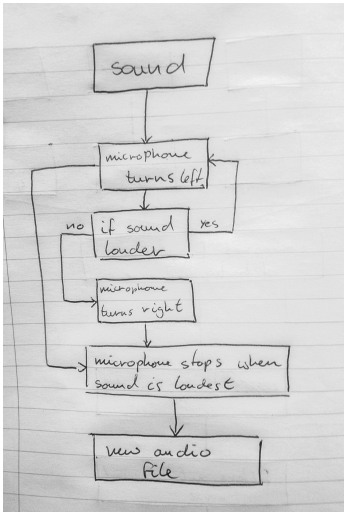



**Orientational microphones?**

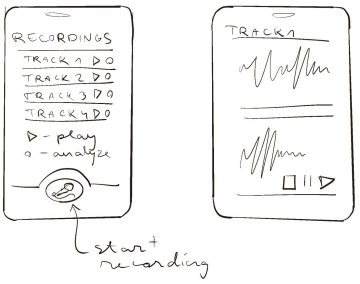
This solution includes an unidirectional microphone that determines where the most prominent bird sound is coming from. It does this by recording short snippets from every direction and then calculates which direction contains the most bird noise. It then turns the microphone towards the sound. When the optimal stance is achieved, the microphone creates a new audio file, which is stored on an usb stick.




**Phones**

For this solution, an app is created which allows users to record and filter their own audio recordings. By using the hardware of the phone, more power can be devoted toward processing, using machine learning to filter out certain bird frequencies. Users are able to record a new track, play back the original, play back the processed version (after the recording is finished), and finally compare the sound files of the two tracks. While there isn't a dedicated device (physical aspect) of this solution, it also makes it the most accessible to the general public, as anyone with a phone with a microphone is able to use the software.



# Chapter 6: Solution Selection

The solution will use **digital filtering** and **active analog filtering**.

The term “Digital filtering” represents blocking frequencies that are not bird noises with software. This solution is optimal for multiple reasons.
-Some team members have experience in analyzing and filtering frequencies.
-The solution uses  an arduino, off grid, so battery life and reliability is important. This part of the setup is energy-efficient and reliable, providing functionality even if the hardware solution fails.
-The process is automated, making it easy and time-efficient to use.
-Software is free, so this part of the product will be cheap and scalable.

active analog filtering will also be used. Think of a moving shield that blocks noise from the most noisy direction. This is useful for multiple reasons.
-Very loud background noise can be removed so the microphone only picks up sound from a certain direction, making digital filtering easier because there is less to filter.
-This idea is feasible and the team members like hardware design.

The proposed final solution therefore consists of 4 modules:
-An arduino with all the required software
-A moveable shield with the motors, hooked up to the arduino
-The microphone, hooked up to the arduino
-An encasing, on a stand, with batteries. It should hold up in nature.

# Chapter 7: Methodology

The product has an **input**, which is the microphone (physical (sound) to digital transducer). The information gathered by the microphone is processed, digital filtering is taking place here, and **output** to the usb-port or speaker. This means it is a computing-based solution for a problem that humans (researchers) encounter. There are two possible routes the team can take: recognizing the species and recognizing the amount of birds in an area. Both would involve data processing and would have to rely on applicatory mathematics. The combination of the analog microphones, the processing of data, and the combination of the processed data with a dataset of cats in the same area shall contribute to a smart device to be used in given research field. The data will be collected near birds that need to be monitored near a noisy sound source that disrupts the listening experience.

The equipment would not be used in a controlled environment and would be influenced by weather conditions. This means that the equipment would need to be waterproof. A suitable material for this would be a thin plastic/latex that would still let through sound. Another option would be waterproof speaker fabric. This would have a similar effect as the plastic, but let more sound through. As temperature proofing the equipment without having to worry about sound would prove difficult, this group has decided to focus on choosing low temperature resistant equipment rather than trying to encase it from the cold. The product would not be suitable for use in extreme weather conditions.

Microphones

The microphone used will require proper calibration so that it is able to document and reproduce the **exact** sound that it picks up. Using a sample sound with a known frequency and amplitude, it is possible to test the microphone by determining if it records and reproduces the exact sample sound. If not, changes in the microphones settings can be made in such a way that the resulting sound file matches the sample sound. The recorded sound will be sent to a computer. Because omnidirectional microphones are not available for this project, we may implement a tube around the microphones, which will act as an acoustic barrier. This way, the microphones will be omnidirectional to a certain extent: the microphone will pick up sound mainly from one direction.

BirdNET

For the data processing,  an open source machine learning tool will be used. This is a very new development, only made available in the past couple of years, but it shows great promise The AI being used is called BirdNET. [33] It is a ResNet neural network, a relatively new type of Convolutional Neural Network first created in 2016. [34] The ResNet architecture enables the effective usage of many more layers than a standard ConvNN, providing more precise results. The architecture of BirdNET's ResNet is mostly based on the wide ResNet architecture, with minor tweaks by subsequent research. [35]

BirdNET analyzes monochrome spectrograms generated from audio files. The spectrograms created have a high temporal resolution, are capped around the frequencies mostly used by birds (150Hz to 15 KHz) and are compressed in the frequency dimension. This was done as a trade-off between precision and processing speed.

The data used to train BirdNET consists of the following:
• 7000H+ community-curated recordings from xeno-Canto, a repository for labeled bird calls.
• 750.000+ recordings of birds from a sound library in the USA.
• Non-event recordings to train the network to ignore other sounds, such as geophysical, animals, humans, recorder noise and human activity such as cars or construction.
• A list of the most common north-american species using eBird.

Overall, BirdNET is not a very novel approach to this problem, but a very well-executed approach of the current best practices. This makes the performance metrics very close to optimal for what is currently possible. This was tested and confirmed by the authors, who tested their neural network against other neural networks made specifically for BirdCLEF, a competition to identify birdcalls. BirdNET got a very competitive score.
This high performance, the ease of use of this library and the relatively low resource use made BirdNET ideal for the purposes.

Number of birds
Using the microphones and BirdNET, a good estimation of the amount of bird calls per species detected can be made. In research, it has been shown that using birdNET counts can approximate human-counted bird counts, but it seems like this does not always work exactly as expected.[1] For tracking changes in patterns however, this should be less of an issue.

Sewing the waterproof material
Sewing with waterproof material can be a bit more challenging than working with traditional fabrics, but it is certainly possible. The team found an acoustic fabric produced by Aukustikstoff. This fabric is designed to let through sound, while being waterproof. Therefore making it an ideal solution for TWEAK.

When working with waterproof fabric, it is essential to use a waterproof thread and a new, sharp needle. This will ensure that your seams are as secure as possible and will not come apart in wet conditions. Additionally, it is important to use a sewing machine that can handle the thickness of the material. Some machines may struggle with the added bulk, so it's worth testing your machine with a scrap piece of fabric before starting your project.

Another important step in working with waterproof material is the use of a seam sealer. This is a special product that is applied to the seams of the fabric after they have been sewn. It helps to seal the seams so that water cannot penetrate them, making the finished project completely waterproof. It's important to take care when applying a seam sealer as it can be messy, so it's best to do it in a well-ventilated area and to wear gloves to protect your hands. The group has decided to opt out of using a seam sealer as in this case a completely waterproof product isn’t necessary.

[1] Kahl, S., Wood, C. M., Eibl, M., & Klinck, H. (2021). BirdNET: A deep learning solution for avian diversity monitoring. In Ecological Informatics (Vol. 61, p. 101236). Elsevier BV. https://doi.org/10.1016/j.ecoinf.2021.101236

Validation

To validate if the gathered data is correct multiple actions can be taken. Firstly, consistency checks. To check if one data set is valid, you can run another one. If several data sets produce the same result, you can be sure that that first dataset is correct. (This is to see if the filtering is done right.) Secondly, exclusion. If the bird noise is isolated correctly, for example in proximity of a highway, the bird noise should sound the same as if the bird was recorded in a silent environment. For validating the amount of birds, we can play an audio file with bird noise, of which we know the amount of birds that make noise. If the approximation is close, let's say within 15% of the exact amount of birds, we can say that this part of the product is valid.

If the methodology is properly executed, the end result will be a product that filters out background noise from recordings of bird songs and through those recordings determines the amount and species of the birds.

**Equipment the team will require:**

-Arduino
-Raspberry PI
-Microphone
-Casing material (waterproof)
-material for 3D printing the case skeleton

To fabricate all modules we need an Arduino, microphones, waterproof material (shield and chassis) and tools. Tools can be found in the DesignLab and at SmartXP.

## Ambitious vs. basic scenario

The group wants the project to turn out as good as possible in the time slot provided whilst still keeping the work realistic. For this purpose, several scenarios shall be considered. The basic scenario would guarantee a working solution that can be presented and fit the criteria of the assignment. An ambitious scenario shall also be considered. This scenario would come into play in case the team has time to work on it. The ambitious scenario would improve the project.

**Basic**

Isolate sound digitally by using an Arduino which gets input from a microphone. By isolating the bird calls and using the open source AI (birdNET) the team would be able to determine the species of the birds nearby. This would be useful for tracking the areas in which certain species of birds exist.

**Ambitious**

The ambitious scenario would build upon the basic scenario. The main ambitious scenario that the team is aiming to achieve is to estimate the amount of birds in an area. This could be done by identifying the amount of bird calls going on at all times and calculate an average taking into account other factors that could be influencing it. Similarly, placing several of the microphone devices in separate locations (same as the cat-data collection stations) would help the team identify in which location there are ”more” birds. Other ideas include GPS

pinpointing and bird identification. GPS pinpointing could be implemented to document where certain data was recorded. Specific bird identification may be done with AI, though knowledge beyond the scope of this group may be required.

## Solution modules

-An arduino with all the required software
-The microphone, hooked up to the arduino
-An encasing, on a stand, with batteries. It should hold up in nature.

## Task assignment

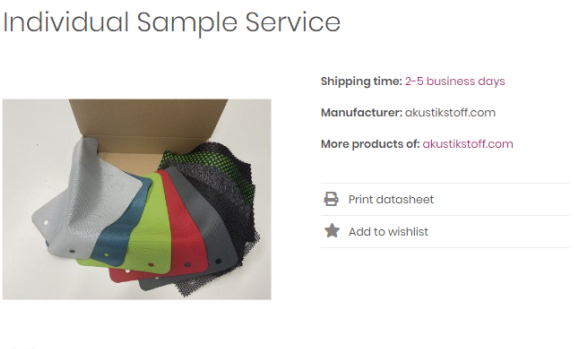
In general, all team members help each other. However, each person will have a main responsibility and this should be their focus.

Important note: the roles were changed after the winter holiday as the group realized more people had to be assigned to the programming department. This is what the roles looked like in the end:

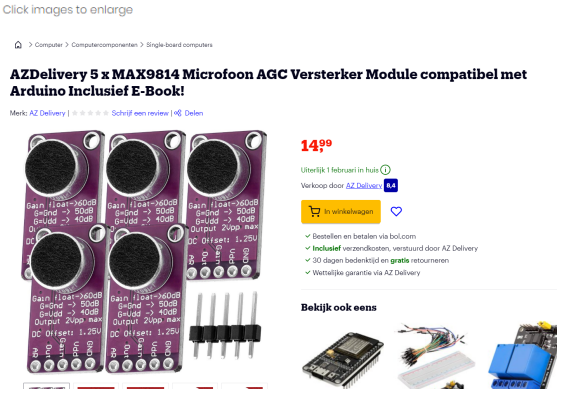
| **Person** | **Main responsibility** | **Helps with** |
|---|---|---|
| Anna | Team leader | Encasing |
| Jona | AI for species recognition | Software determining amount of birds/arduino |
| Xinran | Hardware | Software determining amount of birds/arduino |
| Max | Encasing | Hardware |
| Luuk | Documentation/research | Hardware |
| Marina | Infographic and logo | Finance and encasing |
| Bas | Software determining amount of birds/arduino | AI for species recognition |

# UNIVERSITEIT TWENTE.

## Shopping list:

- 

Akustikstoff cloth 2.0 (sample set)

- 

AZDelivery 5 x MAX9814 (8 pcs)

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# UNIVERSITEIT TWENTE.

## Time plan

| Month | Week # | Weekday | Date | Arduino & Rasp. Pi | Microphone | Casing | General | | Notes |
|---|---|---|---|---|---|---|---|---|---|
| **December** | **Week 5** | Thursday | 15/12/2022 | | | | Specification | | |
| | | Friday | 16/12/2022 | | Decide what mic to use/purchase | Sketches and decide on material | | | |
| | | Saturday | 17/12/2022 | | | | Voluntary home-research | | |
| | | Sunday | 18/12/2022 | | | | Voluntary home-research | | |
| | **Week 6** | Monday | 19/12/2022 | Ideate on software design | | Create design with materials and dimensions | Order parts 1 | | |
| | | Tuesday | 20/12/2022 | | | | | | |
| | | Wednesday | 21/12/2022 | | | | | | |
| | | Thursday | 22/12/2022 | Work on software | Test ordered parts for quality and directionality | Test ordered materials for sound distortion | Write Introduction | | |
| | | Friday | 23/12/2022 | Work on software | Test ordered parts in nature | Start working on building | | | |
| | | Saturday | 24/12/2022 | | | | | | |
| | | Sunday | 25/12/2022 | | | | | | |
| | **Vacation** | Monday | 26/12/2022 | | | | | | |
| | | Tuesday | 27/12/2022 | | | | | | |
| | | Wednesday | 28/12/2022 | | | | | | |
| | | Thursday | 29/12/2022 | Online meeting | Online meeting | Online meeting | Meeting with all | | |
| | | Friday | 30/12/2022 | | | | | | |
| | | Saturday | 31/12/2022 | | | | | | |
| **January** | | Sunday | 1/1/2023 | | | | | | |
| | | Monday | 2/1/2023 | | | | | | |
| | | Tuesday | 3/1/2023 | | | | | | |
| | | Wednesday | 4/1/2023 | | | | | | |
| | | Thursday | 5/1/2023 | | | | | | |
| | | Friday | 6/1/2023 | | | | | | |
| | | Saturday | 7/1/2023 | | | | | | |
| | | Sunday | 8/1/2023 | | | | | | |
| | **Week 7** | Monday | 9/1/2023 | | | | | | Bas is not there this week |
| | | Tuesday | 10/1/2023 | Work on software | | Work on building the casing | | | |
| | | Wednesday | 11/1/2023 | | | | | | |
| | | Thursday | 12/1/2023 | | | | | | |
| | | Friday | 13/1/2023 | First software version finished and testing | | First casing ready | meet in the afternoon, work on | | |
| | | Saturday | 14/1/2023 | | | | | | |
| | | Sunday | 15/1/2023 | | | | | | |
| | **Week 8** | Monday | 16/1/2023 | | | | Testing and fixing | | |
| | | Tuesday | 17/1/2023 | | | | | | |
| | | Wednesday | 18/1/2023 | | | | | | |
| | | Thursday | 19/1/2023 | Testing | Testing | Testing | | | |
| | | Friday | 20/1/2023 | Fixing | Fixing | Fixing | Put everything together + testing | | |
| | | Saturday | 21/1/2023 | | | | | | |
| | | Sunday | 22/1/2023 | | | | | | |
| | **Week 9** | Monday | 23/1/2023 | Testing + debugging | Problems? | Problems? | What works and what doesn't | | |
| | | Tuesday | 24/1/2023 | Debugging | Make changes? | Make changes? | Make things work better if neccessary | | |
| | | Wednesday | 25/1/2023 | Final tests | Final tests | Final tests | Test everything | | |
| | | Thursday | 26/1/2023 | | | | Create project presentation | | |
| | | Friday | 27/1/2023 | | | | Project Presentation | | |

# Chapter 8: Validation

Validate your results through some tests and/or some scientific evaluation process

<To be prepared the 8th to 9th week>

Hypothesis: Tweak can isolate bird noise and use this to count and recognise birds.

If TWEAK works properly, it should pass all tests. These tests are ran:

- Sound isolation test
- Count test
- Recognition test
- Fabric test
- Microphone test
- Software-hardware combination

NB! Due to restrictions in time from when TWEAK was built to when the documentation had to be handed in not all tests were performed. The author's chose the most suiting tests to increase efficiency.

| Test: | TWEAK passed the test! | TWEAK did not pass the test |
|---|---|---|
| Sound Isolation test | unknown | unknown |
| Count test | unknown | unknown |
| Bird recognition test | TWEAK passed! | |
| Fabric test | TWEAK passed! (the water-test) | Acoustic-test unknown |
| Microphone test | TWEAK passed! | |

## Sound isolation tests

To test if the bird noise isolation works we can use two speakers. One speaker will play a general sound with bird noise. The other speaker will play background noise, think of highway or wind noise. TWEAK will be placed near the speakers. If TWEAK filters out the background noise from the bird noise, that means TWEAK is working.

Also, by playing with the volume of the 'background noise' speaker we can test the range of 'background noise' volume in which TWEAK will work.

Sound samples:
General bird noise sound: Birds singing in the woods *

*TWEAK should be able to pick out bird sound in a forest, therefore this test is conducted with the use of forest sound.
Background noise: Highway noise, Construction - and city noises

Common forest volume is around 32dB [37]. So this will be the volume at which we play the forest sound. A common highway sound level is around 70 to 80dB, at a distance of 15 meters [38]. If TWEAK works at 'background noise' levels that are this loud, it is functioning! TWEAK working means that it is filtering out the background noise, so bird noise can be heard clearer.

The amount of decibels can be measured with an app on a phone. The volume should be measured at the same distance as where TWEAK is placed.

| Bird noise level (dB) | Background noise level (dB): | TWEAK works? |
|---|---|---|
| 32dB | 60dB | Should work |
| 32dB | 70 dB | Should work |
| 32dB | 80 dB | |
| 32dB | 90 dB | |

Did TWEAK pass this test? YES/NO!

## Count tests

The count test has the same approach as the isolation test. For the counting test two (or more) sound samples are needed. One sound sample should have more bird calls then the other one. That way, the only difference is the amount of bird calls. The amount of bird calls are in sync with the amount of birds. So, TWEAK should show the difference in the amount of bird calls.

| Sample sounds: | YouTube link: |
|---|---|
| Sample with NO bird calls | https://www.youtube.com/watch?v=1t7g690boao&t=4s |
| Sample with fewer bird calls | https://www.youtube.com/watch?v=PyFN_FYwqvc |
| Sample with more bird calls | https://www.youtube.com/watch?v=wKnS8VPxpHI |

| Used sample | Expected results | Does TWEAK match the expected results? |
|---|---|---|
| [1] Sample with NO bird calls | TWEAK should show that there are no birds. | YES/NO |

| | | |
|---|---|---|
| [2] Sample with some bird calls | TWEAK should show that there are birds. | YES/NO |
| [3] Sample with more bird calls | TWEAK should show that there are more birds than in the second sound sample. | YES/NO |

* Take into account that there will always be a fault margin, the value of this fault margin is unknown.

Did TWEAK pass this test? YES/NO!

## Recognition tests:

Testing if TWEAK can recognise birds is done by bird call sounds that are already known. If TWEAK links the sound to the correct bird, TWEAK is working. If TWEAK recognises at least two birds, the author's consider the test a success.

Bird sample sounds:

1. Turdus Merula
2. Turdus Viscivorus

Did TWEAK pass this test? YES

## Fabric test:

The microphones will be covered from the elements by a fabric. This fabric needs to hold up to two requirements. First of all it should be water resistant. TWEAK should be able to record data under rainy weather conditions. Secondly, the fabric cannot block incoming sound. This way, the microphones will catch the most accurate sound from the area and insure that bird sound will not get distorted. The fabric used is made by Akustikstoff, and called Acoustic Cloth 2.0.

**Water test**

The fabric which will be used is Akustikstoff. This company claims that their product is 'Liquid-Repellent'.

| Test | Result | Wanted result? |
|---|---|---|
| Does water get through when spraying the fabric with water, as if it is raining? | NO | YES |
| Does water go through the fabric? | YES | NO |
| Does water water go through after coating it with 'water-repellant' spray? | NO | YES |

The coating of the fabric solved the main problem of water sticking to the fabric.

Did TWEAK pass this water test? YES

**Acoustic test**

Akustikstoff claims that their fabric delivers so-called ‘acoustic transparency’. This is interpreted as if the cloth does not mess with the through-coming sound. To test this you can play audio and record audio. Record one time in front of the speaker, and another time with the fabric between it.

| | Noise level (dB) |
|---|---|
| Decibelmeter in front of speaker | |
| With fabric between speaker and decibel meter. | |

Did TWEAK pass this acoustic test? YES/NO

# Microphone test:

**The microphones in TWEAK: AZDelivery 5 x MAX9814**

Microphones need to be tested to make sure that they are functional. Each of the six microphones is hooked up to an arduino. Their output is plotted to the serial plotter. If the serial plotter shows a wave the microphones are working. Waves were also checked with an app that lets the user choose a wave to show. E.g. when a sine wave was chosen, you saw a clear sine wave on the serial plotter.

| Do the microphones work? (mic#. YES/NO) | | | | | |
|---|---|---|---|---|---|
| 1. YES | 2. YES | 3. YES | 4. YES | 5. YES | 6. YES |

**Microphone distance test:**

For this test a microphone was placed on a table. Then respectively a podcast and bird noise was played at different distances from the microphone. In the chart, it is indicated if the audio was still audible at a certain distance. The results of this test are in the chart below.

| Distance (m) | Is it audible (podcast) | Is it audible? (bird noise) |
|---|---|---|
| 1 | yes | yes |
| 2 | yes | yes |
| 4 | yes | yes |
| 8 | yes | yes |
| 16 | no | yes |

*All max. volume on iPhone SE2 (2022)
*This testing is done inside for ideal circumstances. (No wind etc.)

**Unidirectional microphone test:**
To make omnidirectional microphones unidirectional, tubes were placed on the microphones, see fig.1. The same concept as a shotgun microphone. To test the functionality the serial plotter (Arduino) was used to plot 6 graphs (because TWEAK uses 6 microphones). When playing a sound, the microphone that pointed in the direction of the sound clearly showed a bigger amplitude. By that, showing that the ‘tubes’ were doing what was intended. Also, see fig.1 and see that one graph has a greater amplitude, this is the graph of the microphone pointing towards the sound. (It might be hard to see, there is a video recording showing it more detailed)

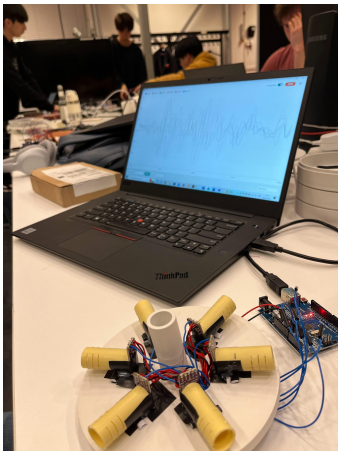


*fig 1.*

TWEAKS' microphones were able to record clear audio of birds from quite a distance. Also, the tubes on TWEAKS' microphones turned the omnidirectional microphones into unidirectional microphones successfully. Therefore TWEAK passed this test. Also, bird recognition has been done successfully on this same audio file!

Did TWEAK pass this test? YES

## Software and hardware

Things that are working and validated:

- Birdnet → does output .vsc file
  It did successfully recognise birds by their bird calls. See recognition test above.
- The microphone records and the software puts out a .wav file.
- Microphone frequencies were tested:
  - fig. 1
- The casing has been 3D printed, the fabric has been sewn together in the shape of a bird (for aesthetic purposes), and the fabric (after being sprayed with waterproofing spray) has proven to be waterproof.

# Chapter 9: Results and Conclusion

TWEAK should be able to isolate bird sound and use this to recognise and count birds.
*Please note that not all results are confirmed just yet. Therefore they are left blank. If there is no clear result, the results are not confirmed.

## Results:

***Bird noise isolation results:***

TWEAK can/cannot isolate bird noise from background noise. Background noise such as a highway or city center. Verification is done by comparing the sound we got from TWEAK with the original sound.

| Location: | Successful noise isolation? |
|---|---|
| Near a highway | YES/NO |
| City center (exact location needed) | YES/NO |

In the validation part of bird noise isolation different circumstances were tested. The results above show that TWEAK works near a highway and in a city center.

***Bird recognition results:***

TWEAK can recognise birds.

| What birds did TWEAK recognise? | |
|---|---|
| Bird # | Bird name: |
| 1. | Turdus Merula (A.K.A. Blackbird; in dutch: Merel) |
| 2. | Turdus Viscivorus (A.K.A. Mistle Thrush; in dutch: Grote Lijster) |

***Bird counting results:***

TWEAK can/cannot count birds in the real world. Results will be based on if TWEAK gives a representative representation of the amount of birds. Verification will be done by researchers listening to multiple original sound files, and comparing that to what TWEAK shows. If TWEAK works, it should give the same results as the researchers.

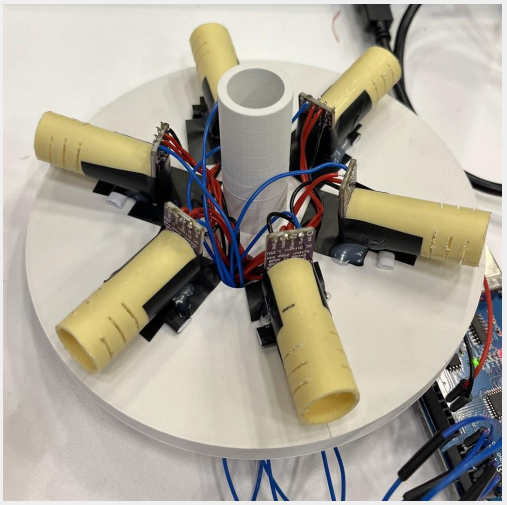
Sample 1: *(location, time, date, more/fewer birds then sample 2)*
Sample 2: *(location, time, date, more/fewer birds then sample 1)*

| Which sample has more birds in it? | |
|---|---|
| Researcher results: | Sample 1 / 2 (has more birds) |
| TWEAK results: | Sample 1 / 2 (has more birds) |
| Do the researchers' and TWEAK results match? | YES/NO |

***Fabric***

After testing the fabric the results did not meet the requirements. Although water did not go straight through, the cloth absorbed the water. The solution was water-repellent spray. After coating the fabric with this, the fabric is able to repel water. This way, the fabric will stay dry in humid and rainy environments.

***Hardware design***

| The microphone array in TWEAK: | To make TWEAK look beautiful, a team member created a phenomenal looking fabric bird that sits on top of TWEAK: |
|---|---|
|  fig.2 |  fig.3 |

***Software***

TWEAK contains software that can isolate* bird noise sound, software that can recognise birds and software that can count* birds.

*For now this is now the case

## Findings:

Team members used both open-source software and coded software themselve to make TWEAK work. This may sound straight forward, but it was the opposite. Members ran into

problems which took a lot of time to solve. Working with a Raspberry Pi, Arduino, microphones and AI turned out to be a million piece puzzle.

3D printing took a long time. Especially for TWEAK because it is quite the contraption.

## Conclusions:

Ideal conclusion for TWEAK: *TWEAK can isolate bird noise, and with that recognise and count them.*

Because of the fact that we did not get TWEAK to run in time, the conclusion cannot be complete. However, there are things that we can conclude.

| Function: | Pass? |
|---|---|
| Bird sound isolation | |
| Bird recognition | Pass! |
| Bird counting | |

Things that can be concluded:

- We can see which microphone picks up the most sound. The tubes convert omnidirectional microphones into unidirectional microphones which is successfully proven fig.1. The mic in which sound is directly pointed shows the highest amplitude.
- We can get sound in a .wav file. This is necessary for further processing of the audio in TWEAK.
- BirdNet (bird recognition) does work. After running some tests BirdNet dit recognise birds.
- The fabric does what it is supposed to do. It is water-repellant and this is tested.
- Soldering the microphones for a connection with Arduino is working.
- Everything fits in the encasing

The problem is that individual things do work. TWEAK does not work on its own for now. Getting the software to work is the main problem. At this point in time TWEAK is 90% a working product.

## Bibliography


[1] S. DeStefano and R. M. DeGraaf, “Exploring the ecology of suburban wildlife,” Frontiers in Ecology and the Environment, vol. 1, no. 2, pp. 95–101, Mar. 2003, doi: 10.1890/1540-9295(2003)001[0095:eteosw]2.0.co;2.

[2] M. L. Gore et al., “Application of Risk Concepts to Wildlife Management: Special Issue Introduction,” Human Dimensions of Wildlife, vol. 14, no. 5, pp. 301–313, Sep. 2009, doi: 10.1080/10871200903160944.

[3] F. MADDEN, “Creating Coexistence between Humans and Wildlife: Global Perspectives on Local Efforts to Address Human–Wildlife Conflict,” Human Dimensions of Wildlife, vol. 9, no. 4, pp. 247–257, Dec. 2004, doi: 10.1080/10871200490505675.

[4] M. Sigler, “The Effects of Plastic Pollution on Aquatic Wildlife: Current Situations and Future Solutions,” Water, Air, & Soil Pollution, vol. 225, no. 11, Oct. 2014, doi: 10.1007/s11270-014-2184-6.

[5] Z. He *et al*., "Visual Informatics Tools for Supporting Large-Scale Collaborative Wildlife Monitoring with Citizen Scientists," in *IEEE Circuits and Systems Magazine*, vol. 16, no. 1, pp. 73-86, Firstquarter 2016, doi: 10.1109/MCAS.2015.2510200.

[6] E. D. Ayele, N. Meratnia and P. J. M. Havinga, "Towards a New Opportunistic IoT Network Architecture for Wildlife Monitoring System," *2018 9th IFIP International Conference on New Technologies, Mobility and Security (NTMS)*, 2018, pp. 1-5, doi: 10.1109/NTMS.2018.8328721.

[7] James D. Nichols, Byron K. Williams, Monitoring for conservation, Trends in Ecology & Evolution, Volume 21, Issue 12, 2006, Pages 668-673, ISSN 0169-5347, https://doi.org/10.1016/j.tree.2006.08.007.

[8] Linchant, J., Lisein, J., Semeki, J., Lejeune, P. and Vermeulen, C. (2015), A review of UASs in wildlife monitoring. Mammal Review, 45: 239-252. https://doi.org/10.1111/mam.12046

[9] Hennig JD, Schoenecker KA, Terwilliger MLN, Holm GW, Laake JL. Comparison of Aerial Thermal Infrared Imagery and Helicopter Surveys of Bison (*Bison bison*) in Grand Canyon National Park, USA. *Sensors*. 2021; 21(15):5087. https://doi.org/10.3390/s21155087

[10] PJ Stephenson. Technological advances in biodiversity monitoring: applicability, opportunities and challenges, in Current Opinion in Environmental Sustainability, 2020; 45, 36-41, https://doi.org/10.1016/j.cosust.2020.08.005.

*[11]* Picek L., Šulc M., Jeppesen T. S, Heilmann-Clausen J., Matas J., Lind E. Automatic Fungi Recognition: deep learning meets mycology. Sensors . 2022;22(2). 633. https://doi.org/10.1155/2022/2276318

[12] James, K. M., Campbell, N., Viðarsson, J. R., Vilas, C., Plet-Hansen, K. S., Borges, L., González, Ó., M van Helmond, A. T., Pérez-Martín, R. I., Taboada Antelo, L., Pérez-Bouzada, J., Ulrich, C., James, K. M., Campbell, N., Viðarsson, J. R., Plet-Hansen, K. S., Ulrich, C., Borges FishFix, L., Ó González, B., … T M van Helmond, S. A. (2019). Tools and Technologies for the Monitoring, Control and Surveillance of Unwanted Catches. In The European Landing Obligation (pp. 363–371). https://doi.org/10.1007/978-3-030-03308-8_18

[13] Wang, H., Zhong, J., Xu, Y., Luo, G., Jiang, B., Hu, Q., Lin, Y., & Ran, J. (2022). Automatically detecting the wild giant panda using deep learning with context and species distribution model. *Ecological Informatics*, *72*, 101868. https://doi.org/10.1016/J.ECOINF.2022.101868

[14] Hodgson, J. C., Baylis, S. M., Mott, R., Herrod, A., & Clarke, R. H. (2016). Precision wildlife monitoring using unmanned aerial vehicles. *Scientific Reports 2016 6:1*, *6*(1), 1–7. https://doi.org/10.1038/srep22574

[15] Switzer, T. S., Tyler-Jedlund, A. J., Keenan, S. F., & Weather, E. J. (2020). Benthic Habitats, as Derived from Classification of Side-Scan-Sonar Mapping Data, Are Important Determinants of Reef-Fish Assemblage Structure in the Eastern Gulf of Mexico. Marine and Coastal Fisheries, 12(1), 21–32. https://doi.org/10.1002/MCF2.10106

[16] Sarah Jeswiet and Lisa Hermsen, "Agriculture and wildlife: A two-way relationship," *Statcan.gc.ca*, 2014. https://www150.statcan.gc.ca/n1/pub/16-002-x/2015002/article/14133-eng.htm (accessed Nov. 24, 2022).

[17] Martonosi, M. (2004). The Princeton ZebraNet Project: Sensor Networks for Wildlife Tracking. Princeton University, 2-7.

[18] A. Naureen, N. Zhang, S. Furber and Q. Shi, "A GPS-Less Localization and Mobility Modelling (LMM) System for Wildlife Tracking," in IEEE Access, vol. 8, pp. 102709-102732, 2020, doi: 10.1109/ACCESS.2020.2997723.

[19] A. Naureen, N. Zhang, S. Furber and Q. Shi, "A GPS-Less Localization and Mobility Modelling (LMM) System for Wildlife Tracking," in IEEE Access, vol. 8, pp. 102709-102732, 2020, doi: 10.1109/ACCESS.2020.2997723.

[20] Radiansyah, S., Kusrini, M.D. and Prasetyo, L.B. (2016) *Quadcopter applications for wildlife monitoring*, *IOPscience*. IOP Publishing Ltd. Available at: https://iopscience.iop.org/article/10.1088/1755-1315/54/1/012066 (Accessed: November 24, 2022).

[21] Ralph, C.J., Droege, S. and Sauer, J.R. (1995) *Managing and Monitoring Birds Using Point Counts: Standards and Applications*, *Forest Service USDA*. Available at: https://www.fs.usda.gov/research/treesearch/31755 (Accessed: November 24, 2022).

[22] J. Jumeau, L. Petrod, and Y. Handrich, "A comparison of camera trap and permanent recording video camera efficiency in wildlife underpasses," *Ecology and Evolution*, vol. 7, no. 18, pp. 7399–7407, 2017.

[23] P. J. Stephenson, "Integrating Remote Sensing into Wildlife Monitoring for Conservation," *Environmental Conservation*, vol. 46, no. 3, pp. 181–183, 2019.

[24] D. O. Obura, G. Aeby, N. Amornthammarong, W. Appeltans, N. Bax, J. Bishop, R. E. Brainard, S. Chan, P. Fletcher, T. A. C. Gordon, L. Gramer, M. Gudka, J. Halas, J. Hendee, G. Hodgson, D. Huang, M. Jankulak, A. Jones, T. Kimura, J. Levy, P. Miloslavich, L. M. Chou, F. Muller-Karger, K. Osuka, M. Samoilys, S. D. Simpson, K. Tun, and S. Wongbusarakum, "Coral Reef Monitoring, Reef Assessment Technologies, and ecosystem-based management," *Frontiers*, 01-Jan-1AD. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fmars.2019.00580/full. [Accessed: 20-Nov-2022].

[25] J. Wawerla, S. Marshall, G. Mori, K. Rothley, and P. Sabzmeydani, "BEARCAM: Automated Wildlife Monitoring at the Arctic Circle - machine vision and applications,"

*SpringerLink*, 10-Apr-2008. [Online]. Available: https://link.springer.com/article/10.1007/s00138-008-0128-0. [Accessed: 24-Nov-2022].

[26] P. Stephenson, "Technological advances in biodiversity monitoring: applicability, opportunities and challenges," *Current Opinion in Environmental Sustainability*, vol. 45, pp. 36–41, Aug. 2020, doi: 10.1016/j.cosust.2020.08.005.

[27] Zwerts, J. A., Stephenson, P. J., Maisels, F., Rowcliffe, M., Astaras, C., Jansen, P. A., van der Waarde, J., Sterck, L. E. H. M., Verweij, P. A., Bruce, T., Brittain, S., & van Kuijk, M. (2021). Methods for wildlife monitoring in tropical forests: Comparing human observations, camera traps, and passive acoustic sensors. *Conservation Science and Practice*, *3*(12). https://doi.org/10.1111/CSP2.568

[28] Hill, M. J., Greaves, H. M., Sayer, C. D., Hassall, C., Milin, M., Milner, V. S., ... & Wood, P. J. (2021). Pond ecology and conservation: research priorities and knowledge gaps. Ecosphere, 12(12), e03853.

[29] L. Yang, J. Driscol, S. Sarigai, Q. Wu, C. D. Lippitt, and M. Morgan, "Towards Synoptic Water Monitoring Systems: A Review of AI Methods for Automating Water Body Detection and Water Quality Monitoring Using Remote Sensing," Sensors, vol. 22, no. 6, p. 2416, Mar. 2022, doi: 10.3390/s22062416.

[30] Johnson, K.S. *et al.* (2007) *Chemical Sensor Networks for the Aquatic Environment*, *ACS Publications*. Available at: https://pubs.acs.org/doi/full/10.1021/cr050354e (Accessed: December 1, 2022).

[31] V. Lostanlen *et al.*, 'BirdVox: Machine listening for bird migration monitoring', *bioRxiv*, p. 2022.05.31.494155, Jan. 2022, doi: 10.1101/2022.05.31.494155.

[32] Duquette, CA, Loss, SR, Hovick, TJ. A meta-analysis of the influence of anthropogenic noise on terrestrial wildlife communication strategies. J Appl Ecol. 2021; 58: 1112– 1121. https://doi.org/10.1111/1365-2664.13880

[33] Kahl, S., Wood, C. M., Eibl, M., & Klinck, H. (2021). BirdNET: A deep learning solution for avian diversity monitoring. In Ecological Informatics (Vol. 61, p. 101236). Elsevier BV. https://doi.org/10.1016/j.ecoinf.2021.101236

[34] He, K., Zhang, X., Ren, S., & Sun, J. (2016). Deep residual learning for image recognition. In Proceedings of the IEEE conference on computer vision and pattern recognition (pp. 770-778).

[35] Zagoruyko, S., & Komodakis, N. (2016). Wide residual networks. arXiv preprint arXiv:1605.07146.

[36] *Sewing with Waterproof Fabrics*. (n.d.). Twig + Tale. https://www.twigandtale.com/blogs/sew-alongs/sewing-with-waterproof-fabrics

[37] D.H. Kyon, M.J. Bea and J.H. Lee, *An analysis of the acoustic characteristics of forest sounds*, in Acoustical Society of America, 2014 https://asa.scitation.org/doi/pdf/10.1121/1.4896145

[38] Chris Corbisier, *Living with noise*, US Department of Transportation - Federal Highway administration, July/August 2003. https://highways.dot.gov/public-roads/julyaugust-2003/living-noise#:~:text=Levels%20of%20highway%20traffic%20noise,to%20carry%20on%20a%20conversation.