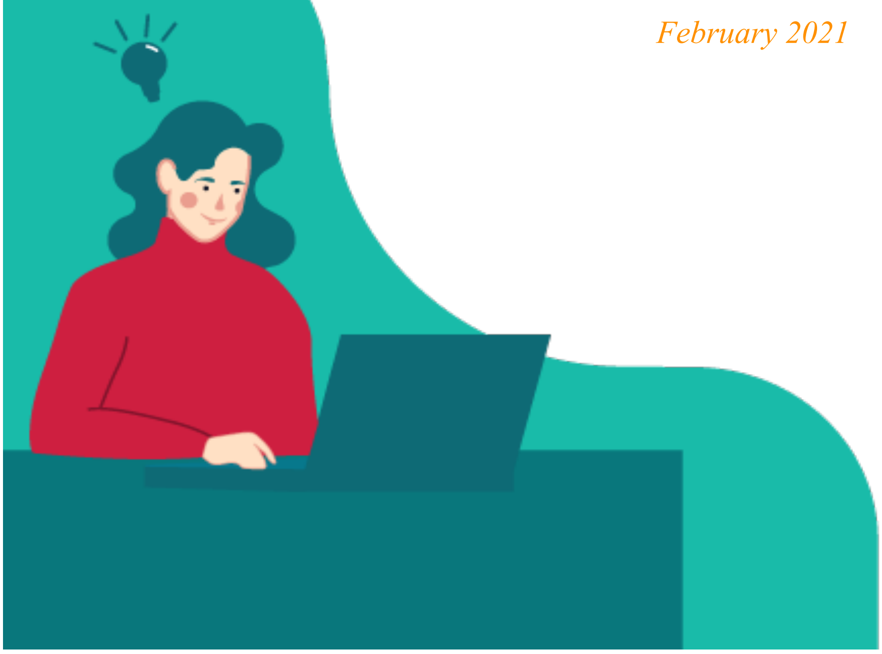
BIOBORD
PLATFORM

ANALYSIS OF REMOTE SENSING TECHNOLOGIES

for monitoring of large bodied wild-animals and free-ranging livestock

February 2021



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Editor
Inese Suija – Markova

Authors
Agris Brauns
Alekss Vecvanags
Annie Loosen
Barbara Zimmermann
Dainis Jakovels
Halgrim Breie
Jevgenijs Filipovs
Juho Pirttiniemi
Markku Paananen
Riika Kumpulainen
Tadeusz Peczek
Thomas Vogler

www.biobord.eu

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1. Context, objective and tasks carried out

1.1. Context

This study is conducted in the frame of the Baltic Sea Region Interreg project "ConnectedByBiobord – Biobord open innovation platform connecting bioeconomy developers in BSR" (hereinafter – ConnectedByBiobord).

ConnectedByBiobord is an extension stage project for the Flagship project to EUSBSR PA Bioeconomy named "RDI2CluB: Rural RDI Milieus in transition towards smart bioeconomy clusters and innovative ecosystems". The goal of RDI2CluB has been to support smart, sustainable and inclusive growth of the bioeconomy in rural areas of the Baltic Sea Region.

ConnectedByBiobord is building upon outputs of the RDI2CluB project, including the Joint Action Plan (Illustration 1) and the Biobord Platform for transnational innovation cooperation.

OBJECTIVE #1
Exchange, development of KNOWLEDGE
1.1. Exchange, development of TECHNOLOGICAL KNOWLEDGE
    1.1.1 Digitalisation for sustainability and productivity
    1.1.2 Technologies for natural resources management
    1.1.3 Technologies for bioenergy production
    1.1.4 Technologies for low emission building
1.2. Exchange, development of KNOWLEDGE STREAMLINING INNOVATIVE BUSINESS
    1.2.1 Renewing operations of traditional bio-based SMEs with new business and cooperation models
    1.2.2 Exchange of knowledge and experience for development of natural resources-based services in tourism, well-being and other areas

OBJECTIVE #2
Development and renewing of SERVICES and TOOLS used to upscale/improve regional INNOVATION ECOSYSTEMS
2.1. Establishment of active network of bioeconomy innovation hubs with a joint model and platform for innovation management
    2.1.1 Developing and testing a joint innovation management model for the network of bioeconomy innovation hubs in BSR
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2.3. Access to skilled workforce for rural SMEs
    2.3.1. Development of smart lifelong learning paths to support bioeconomy SMEs

OBJECTIVE #3
Raising awareness of bioeconomy stakeholders and society on bioeconomy, smart and sustainable exploitation of bioresources
    3.1.1 Development and dissemination of joint online knowledge base for awareness-raising
    3.1.2 Raising awareness of stakeholders and society

Illustration 1. Snapshop of the Joint Action Plan developed in RDI2CluB Project. Available on http://rdi2club.eu

In ConnectedByBiobord, the partnership implements transnational innovation pilots derived from the Joint Action Plan. One of the innovation pilots is devoted to new technologies for monitoring large-bodied wild animals and free-ranging livestock (Tech Innovation Pilot).

The main objectives of Tech Innovation Pilot are: 1. to design and test practices for building co-creation dialogue and developing open innovations in the transnational context; 2. to increase knowledge about prospective bioeconomy sub-sectors and promising interfaces for developing higher added-value bioeconomy products, services and knowledge-intensive jobs.

The Tech Innovation Pilot is implemented by partners from five countries:

- JAMK University of Applied Sciences in Finland.

- Krinova Incubator and Science Park in Sweden.
- Inland Norway University of Applied Sciences in Norway.
- Foundation “Institute for Environmental Solutions” in Latvia.
- Foundation “Pro Civis” in Poland.

This report has been co-written by a group of authors representing the above-listed partner organisations.

We would like to express our gratitude to stakeholders (Table 1) who contributed their time and knowledge in letting us gain more in-depth understanding on the current and future needs and challenges related to the monitoring and management of wildlife and free-ranging livestock.

Finland	Latvia	Norway	Poland
- Finland hunters’ association - The Finnish Wildlife Agency - Haukanmaan riistamiehet ry - Keljon hirvimiehet ry, - Vesangan Erämiehet ry - KSN Metsä Oy - LUKE, The Natural Research Institute of - Finland’s Forest Centre - Kaldoaivi reindeer cooperative - Näkkälä reindeer cooperative	- SIA “Forest Owners Consulting Center” - SIA “Tilbe” - SIA Sodra Latvia - State Forest Service - JSC “Latvia's State Forests	- NJFF Sentralt - NJFF Hedmark - Statskog - Sollia Fjellstyre	- Research Unit of Polish Hunting Association - Świętokrzyski National Park for Landscape Protection - Świętokrzyski National Park - Main Directorate of State Roads and Motorways - Mr. Pietrasik Waldemar, Expert - Institute for Mammals Biology in Białowieża - SmallGIS, Ltd. - State Forests, Office for Forest Husbandry and Planning - Institute for Nature Protection PAN - Institute of Zoology PAN, - Association of All Alive Creatures - Association Wolf

Table 1. The list of surveyed stakeholders.

1.2. Objective of the study

The primary objective of the study is to review existing capabilities of various remote sensing technologies and assess their potential for monitoring of large-bodied wild animals, free-ranging livestock and their habitat.

The report will focus on:

- dominant, large-bodied ungulate species in the countries of Baltic Sea Region and Norway, including elk (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), white-tailed deer (*Odocoileus virginianus*), reindeer (*Rangifer tarandus*), and wild boar (*Sus scrofa*).
- free-ranging livestock and semi-domestic reindeer *(Rangifer tarandus*).
- effective and remote data acquisition technologies with minimal human involvement from a data acquisition perspective.

1.3. Tasks undertaken

The scope of the study was defined as comprising the following tasks:

1. To explore existing and future challenges of wildlife monitoring and management in the BSR context.
2. To review and assess currently used approaches and methods for monitoring of wild animals, free ranging livestock and their habitats.
3. To collect and conduct an analysis of stakeholder needs in every partner country.
4. To review existing capabilities of various remote sensing technologies for monitoring of large-bodied wild animals, free-ranging livestock and their habitats.
5. To identify opportunities for development of innovative, technology-based solutions for monitoring of large-bodied wild animals, free-ranging livestock and their habitats.
6. To elaborate recommendations for further implementation of Technology Innovation Pilot.

1.4. Structure of the report

This report presents the results and recommendations from the study. It is laid out as follows:

- **Section 2** provides our analysis of current challenges related to monitoring of large-bodied wild animals, free-ranging livestock and their habitats, based on literature review and stakeholder interviews.
- **Section 3** presents the analysis of remote sensing technologies and opportunities for innovations.
- **Section 4** provides our conclusions and steps for further implementation of Technology Innovation Pilot as a part of the ConnectedByBiobord project.

2. Current needs and challenges of monitoring wild animals, free ranging livestock and their habitat

2.1. Global and European contexts

Globally, humans and livestock make up the majority (96 %) of mammalian biomass (Bar-On et al. 2018). Our global demand on resources pits us against wild animals and their resource needs for survival. Additionally, we are faced with a human-induced extinction crisis that requires immediate conservation action for certain species to persist. For successful conservation action, we must monitor wildlife distribution and density to understand their responses to a changing climate.

Europe's natural resources have been subject to changes for many centuries. Agriculture has taken over forested lands, and roads and human settlements have fragmented the landscape into a mosaic of fields and forest patches. Many wildlife species have become locally reduced or even extinct, partly because they lost their habitat, and partly because they were persecuted by humans for food and fur or because they were considered a pest and threat to livestock production.

In recent years, however, Europe experiences a come-back of wildlife populations to a degree that overcomes any expectations. The main reason for this is changed legislation in favor of conservation, and the increased productivity of forests and fields due to silviculture and agricultural practices, i.e., clear-cutting and fertilizing. Many wild ungulate populations are today by far denser than what the pre-agricultural habitat could have sustained. These wild ungulates share fields and forests with livestock, and together, these animals make up a strong herbivore guild. As a consequence, large carnivores are returning at an ever-growing speed to most of Europe (Chapron et.al., 2014).

The rewilding of Europe comes at benefits and costs. While people value the presence of natural environments that sustain wildlife for recreation, hunt and ethical and aesthetic reasons, wildlife behaviour triggers conflicts of interest connected to natural resource use, management and conservation. Although, according to the Food Agriculture Organisation, wild ungulates are a valuable natural resource with annual contribution of above €394 million to the EU economy through game meat production, wild ungulate expansion is connected to damages exceeding several €100 millions to agricultural crops and forests. Furthermore, an average of 750000 vehicle collisions with ungulates per year has been reported (Langbein et al., 2011) in Europe indicating also a problem related to the safety on roads. In addition, wildlife can transmit diseases to livestock and humans, and vice versa.

Sustainable adaptive wildlife management (Apollonio et al., 2017) is a potential solution to mitigate losses but requires reliable information on wildlife densities and distribution for proper decision making. Wildlife census and monitoring based on remote sensing technology should be considered as an efficient, cost-effective, and reliable option.

2.2. Baltic Sea Region context

From 15 October to 15 December 2020, CBB partners in Finland, Latvia, Poland and Norway analyzed the currently used approaches and methods for monitoring of wild animals, free ranging livestock and their habitats and the needs of various stakeholder groups connected to this topic. The partners carried out desk-studies and conducted semi-structured stakeholder interviews. The framework of stakeholder interviews is enclosed in the Annex of this report.

Below we present the key findings.

The following **stakeholder groups** were identified to be connected with the topic of wildlife monitoring:

- National and/or regional wildlife management institutions
- Land use management organizations (forestry, agriculture)
- Nature conservation and protection institutions
- Hunters community (individuals, clubs, associations)
- Veterinary services
- Owners of free-ranging livestock
- Research institutes
- Technology developers
- Infrastructure developers (e.g., roads, airports, railroads, large electric systems etc.)
- Operators of hunting tourism

Table 2 summarises some of the stakeholders’ needs revealed during the interviews.

Stakeholders	Needs
Wildlife management, hunters, landowners	- More precise estimates of animal populations (e.g., deer, moose, reindeer) - Tracking of wounded animals after traffic accidents and non-successful hunts - Monitoring of reproduction and survival of wildlife
Conservation, veterinary services	- Wildlife census in general, e.g., monitoring of invasive species - Spreading of diseases and parasites, e.g., ASF, CWD - Migration and health conditions of animals responsible for transmitting diseases to farms
Land use management (forestry, agriculture)	- More precise estimates of animal populations - Setting of hunting quotas based on more precise data - Browsing assessments - Monitoring of free-ranging livestock – animal welfare
Infrastructure development	- Animal migration patterns to avoid traffic accidents and to ensure proper planning and construction of large-scale public infrastructure (roads, airports, railroads, large electric systems, etc.)
Technology developers	- Development of new technology-based services to supplement or replace time- and resource-consuming methods - Development of the best strategies for data collection not to scare away or disturb animals - Training of algorithms for automated data analysis - Combination and fusion of various data sources, for example, airborne data with the data collected by citizens (e.g., ScanCam in Norway and Finland), camera traps (e.g., hunting clubs in Finland), LIDAR and satellite data (e.g., Foodscape) - Development of techniques for extraction of specific parameters – species specific signatures and shapes; habitat types.

Table 2. Stakeholders' pains, needs and desires

The interviewed stakeholders mentioned several large-bodied **animal species** to be of high interest for the development of remote sensing technology-based monitoring approaches, including:

- Elk (*Alces alces*)
- Red deer (*Cervus elaphus*)
- Roe deer (*Capreolus capreolus*)
- White-tailed deer (*Odocoileus virginianus*)
- Reindeer (*Rangifer tarandus*)
- Wild boar (*Sus scrofa*)

Free-ranging livestock and semi-domesticated reindeer *(Rangifer tarandus*).

A vast array of remote sensing **technologies and data management tools** are currently used to monitor and characterise wild animals and their habitats in the CBB partner countries.

The list below summarizes the technologies which are already used for the monitoring of wildlife either for research purposes or as a supplementary data source to national inventories. It has to be emphasised that the majority of these tools has greater potential and requires further tests and validation.

- Airborne observations (manned aircrafts, e.g., helicopters, airplanes)
- Drones with thermal and multi-spectral cameras.
- Satellite and airborne images.
- Airborne LIDAR data.
- Wildlife cameras.
- Sound detection technologies.
- Biosensors.
- Movement / vibration sensors.
- GPS collars.
- GPS tags (for free-ranging livestock).
- Mobile applications.
- IoT based tracking devices.
- Citizen science activities (snow tracking, camera traps, line tracking of birds).
- Artificial intelligence for software development.
- Transport vehicles as support in data collection or verification.

The above-listed technologies are used to detect, test and extract various **parameters** which can be grouped into three categories – animals-related, environment-related and technology-related.

Animals-related

- Population estimates.
- Animal species, sex, age.
- Reproduction and survival (number of mothers and calves, survival rates).
- Animal health condition.
- Animal migration pattern.
- Detection of injured / killed animals.
- Grazing behavior.
- Animal disturbance.
- Species distribution.
- Animal threats.

Environment-related

- Land use / land cover change detection.
- Vegetation diversity.
- Biomass assessment.
- 3D terrain and surface models.
- Assessment of browsing damages (e.g., browsed tree-tops and stems in young forest stands).
- Monitoring of fences built around forest stands.
- Presence of people / illegal activities (snow-scooters) in the areas of interest.

Technology-related

- Data collection strategies and protocols (e.g., avoid animal disturbance, detect objects of interest).
- Integration of data from various sources, data fusion, use of different data bases (e.g., forest data).

- Development of algorithms and workflows for <u>automated</u> data processing and analysis.
- Development of algorithms for data and image classification, discrimination of objects.
- Hardware development (drone batteries; drone noise regulation (lowering and increasing)).
- Management and processing of big data.
- GPS signal in blind spots.
- Improved protocols for citizen science activities.

According to the knowledge of CBB partner organizations and stakeholder interviews, in all countries the need for research and innovation activities for the development of remote sensing technology-based solutions for monitoring of wild animals and domestic animals, and their environment is driven by several **challenges and opportunities**, such as:

- Aging of observers.
- Standard animal monitoring methods are resource-intensive and laborious.
- Track counts on snow are becoming more difficult due to te climate change-related decrease in snow cover.
- There are limited studies on selection and adaptation of the best counting methods for each species or a group of speciess (e.g., invasive species such as wild-boar in Norway, small ungulates)
- Remote sensing technologies have the potential to supply data which were hard or impossible to obtain before.

Further, we present **a country-specific summary** of stakeholder interviews.

Finland

- Moose is the most important game animal in Finland, and moose population is rather well-estimated.
- Although private hunters and hunters' clubs use game cameras to monitor and identify animals, government agencies are careful to use images obtained with camera traps due to strict legislation of information security and data collection.
- There is not a systematic deer population inventory system in use, and there is not an established methodology for monitoring of wild boar. As a result, there are remarkable uncertainties in knowledge about the populations and their changes.
- There is high interest about wild boar population, because of the threat to pig industry due to potential transmission of the African Svine FeverASF. It might be relatively easy to attract public funding for wild boar studies.
- Waterfowl populations are monitored by counting individual birds at specific observation points and specific time. There are remarkable uncertainties in knowledge about the populations and their changes.
- There are some uncertainties in knowledge about predator populations, e.g., brown bear, wolf, wolverine, lynx. Researchers use GPS collars, collection of excrements and public observations to study these animals.
- Monitoring of free-ranging livestock (e.g., reindeer) is done by GPS tags (length of battery and blind spots are issues), IoT tracking devices (in a test phase), and drones (e.g., for controlling the movement of herd, detecting of animals (e.g., injured/dead animals)).
- Drones and cameras (active infrared and thermal images) are gaining interest among many groups of stakeholders.
- Main challenges:
    - Imprecise population estimates.
    - Data on species with sparse population (wild boar, wolf, lynx, brown bear) are difficult to obtain.

    - Need for new monitoring methods of waterfowl species and small ungulates to supplement existing methods.
    - Crossing data on animals with other databases, for example, forest data to improve knowledge on relationship between animal densities, grazing behavior and different environments.
    - Management of big data is laborious, requires clear split of responsibilities and data ownership among various institutions.
    - To find a paying customer.

Latvia

- All the stakeholders interviewed admitted that the number of wild animals was increasing.
- The observation data provided by hunters is far from reliable.
- The current animal census approach is resource-intensive and inaccurate.
- Most of the stakeholders have limited in-house capacity to develop advanced data analysis tools.
- The stakeholders interviewed are interested in remote-sensing technology testing and allocation of test-sites.
- Remote sensing-based solutions can support monitoring of some parameters relevant for wildlife management.
- Only few stakeholders have expressed willingness to buy the potential service.

Norway

- Drones with RGB and thermal sensors are used to collect images and count (manually) wild reindeer herds in the mountainous areas.
- Citizen science (line transects for birds, snow-tracking and camera traps) is also applied for animal monitoring.
- Challenges:
    - Manual analysis of drone data.
    - Labor intensive reindeer identification and counting (with snow scooters and binoculars).
    - Estimation of population densities of big game to set hunting quotas
- Desired developments:
    - Counting reindeer: post flight analysis of drone images (automation of counts).
    - Finding and tracking reindeer herds.
    - A method for estimation of big game species for management purposes (setting quotas).
    - Increase knowledge base on area usage, migration patterns to improve management of big game.
    - Map available winter and summer browse for moose and assess browsing damage in young pine stands.
    - Development of methods to monitor small games species (roe deer, hares). So far, no reliable estimates.
    - Development of methods / protocols to use thermal sensors for tracking injured animals (after game-vehicle collisions).
    - Tracking of immigration of invasive species (wild boar).
    - Monitor illegal use of snow scooters in the mountains, reduce disturbance for wildlife.

Poland

- Most popular technologies used for wild animals-monitoring are all kinds of cameras, GPS telemetry, collars and chips with transmitters.
- LIDAR, satellite images are used as a supportive tool to describe habitats.
- Planes, ultra-light planes and drones are also used as supportive tools and a transport.
- Current barriers for technology uptake:
    - Limited information on technologies and potential.
    - Good hardware and rather limited software.
    - Weak cooperation between technology providers and researchers.
    - Use of newest technologies is expensive.
    - Limited capacity for integration of data collected by various technologies.
    - Low level of awareness among policy and decision makers, and society. More communication and education are needed).
    - Investment in brand-new technology is a high-risk business.
- Desired developments:
    - Up to date, quick and permanent data collection and analysis.
    - Technologies that allow extending spectrum of collected data, and support personal observations and studies (e.g., drones)
    - Chips with transmitters to follow animal migrations and observe preferred habitats.
    - Increased knowledge on animal lifestyle for better protection and support during the most sensitive life periods (pregnancy, maternity, winter).
    - Monitoring of animal health status in correlation with to the environmental and climate changes as well as in correlation to rapid changes in agriculture
    - Up to date and comparable data / monitoring technologies to assess the effectiveness of environmental investments and make evidence-based investment decisions
    - Integrated use of various technologies to provide more accurate data and analysis.
    - More research is needed in relation to animal genes transmission (location of animal habitats, migration routes and scales, intensity, times of migration, animal species, distance between animals, activity, body temperature, threats).

3. Review of remote sensing technologies

3.1. Camera traps

Camera traps are remotely triggered cameras that automatically take pictures of subjects that can be used for monitoring or research processes. A recent practical guide (Molloy, S.W., 2018) gives a concise list of pros of using camera traps:

- Cheap (typically EUR 200-500) and easy to deploy.
- Reliable.
- Able to be deployed for months at a time.
- Non-invasive.
- Easy to operate.
- Able to be used in situations which can be hazardous for people.
- No licensing required (can depend on local jurisdiction).

The most modern camera traps use a combination of passive infrared (PIR) ad motion sensors to minimize the chances of false negatives (animal walking by and camera not detecting) while also trying to reduce the chances of false positives (empty detections). Reducing the number of false negatives is more important than reducing the number of false positives for species monitoring or research purposes.

Cognisys Inc. offers active sensors which use a transmitter-receiver that triggers a video camera or DSLR whenever the infrared beam between the sensors is interrupted. The pros are fewer chances of false negatives, very fast trigger speeds, better image quality and the possibility to locate the camera at a different location from the sensor system allowing for better images. The cons are very high costs and more complicated deployment. The cost limitations make it less useful for research/monitoring purposes, where simply adding more cheaper PIR camera traps to the study site could be more beneficial.

Camera models come with different specifications and features, some which can be adjusted and some of which cannot. Although some features have different behaviours in various climates/target sites/habitats, according to Rovero et al., 2013 and after the experience in field testing the most important ones are:

- *Trigger speed* - one of, if not the most important feature in a camera. Trigger speeds can play a large role in detecting individuals that are walking at a pace or/and are closer to the camera. Slower trigger speeds can lead to the animal not being recognizable due to partly or completely walking out of the camera's field of view. Trigger speed can be less necessary if the target is attracted to a feeding station or lure. Trigger speeds tend to vary from 0.2 s - 0.8 s for PIR cameras. Slow trigger speeds can be compensated by having a larger detection zone (moving the camera farther away), but it is not always possible in field conditions.
- *Image quality*- high quality is necessary for animal detection, recognition, feature extraction, and can play a large role in the detection of individuals. Image quality differs for day and night-time photos/videos. For many models, trigger speeds can be changed depending on if the target animals tend to be fast or slow-moving.
- *Flash range* - in areas with a viewshed flash range it is important to reduce the chances of a presumed false positive due to the animal being detected by the PIR + motion sensor, but not being visible in the picture/video. The flash is usually the brightest in the centre of the photo. The effects of a smaller flash range can be negated by placing the camera closer directly facing where the animal is most likely to be.
- *Data transmission (optional)* - Cameras with data transmission capabilities send a picture and/or video files over the 3G or 4G mobile network. This allows for automatic data storing, classification and analysing in almost real-time. It saves human resources for manually acquiring the SD cards of the camera and storing the data and reduces the anthropogenic disturbance in the research area. The downsides of data transmission are that it requires extra battery life to transmit files, and video files take up a lot of space, so the most commonly transmitted files are images.

Advances in computer vision technology also improve the efficiency of working with camera trap data. Although all cameras tend to produce false positives in certain conditions which can take up a lot of expert resources to sort through and analyse, especially in large scale studies, machine learning models can remove empty images and classify different animal species (Tabak et al., 2018). Machine learning technologies can resolve the issue of estimating population densities and total abundance of unmarked individuals (Gilbert, 2020) with feature extraction re-identification. Feature extraction, like human face detection, is frequently used and can re-identify a human with near-perfect accuracy. This technology can potentially be used to successfully re-identify animals beyond the capabilities of a human observer (Schneider, 2020).

3.2. Wearable sensors

Applying electronic tags to individual ungulates is an invasive and cost-intensive monitoring method because the animals need to be caught and often also immobilized in the first hand. Tagging animals results in large datasets with high spatial and/or temporal resolution but from only a limited sample of the animal population. The representability of the sampled animals for the entire population depends on individual variation and age- and sex-specific behaviour. Because ruminants (wild ungulates, cattle and sheep) are large-bodied species, electronic tags can be provided with relatively large batteries, enabling the tags to run for a long time and collecting and eventually also transmitting a lot of data.

3.2.1. Positioning

Tags to locate animals is the most common electronic application in wildlife monitoring and extensive farming. For ruminants, these tags are usually mounted on collars, but there are also small tags available that can be mounted on earmarks. Starting in the 1960s, VHF and UHF radio-transmitters were used to triangulate the animals' position (Kenward, 2001), either from the ground, from the air or by satellites. At the beginning of the 1990s, the Global Positioning System GPS was developed by the US Army for military use. It consists of a GPS device that receives signals which are continuously emitted by more than twenty satellites orbiting the earth at a distance of roughly 20.000 km (Van Diggelen, 2009). From the signals received by at least three satellites, the device calculates its own position on the globe. As soon as this system was opened for civil use in the mid-nineties, it was adopted by wildlife biologists and livestock farmers for animal monitoring. GPS technology has developed a lot during the past twenty years, and there is now also alternative global satellite navigation systems GNSS available, e.g., GLONASS developed by Russia and Galileo developed by the EU. The newest location devices usually combine several GNSS and therefore increase the positioning accuracy and precision.

The first wild species reported to be monitored with GPS was moose (*Alces alces*) in North America (Rempel et al., 1995). A review on the use of GPS in applied ecology tracks the methodological development which made the tags ever more precise, energy-effective and durable (Zimmermann 2013). The success of animal positioning depends not only on the device itself but also on the landscape topography, vegetation and weather conditions, which all can contribute to weaken, bend or block the satellite signals. Today's GPS devices have an accuracy of about 20 m (Bradshaw et al., 2007).

An important improvement happened when transmission systems were integrated into the devices, allowing the positioning data to be downloaded remotely while the collar still is on the animal. These systems use either VHF, UHF, satellite or GSM links, and the data is usually stored on servers and directly displayed on online maps. This technology opened up for studies where animals could be followed in real-time to record habitat selection and behaviour in recent locations in the field.

The market for GPS tags in wildlife ecology is very limited, and there are only a few commercial providers, e.g., Vectronic GmbH in Germany, Followit AB in Sweden, Ecotone in Poland, GPS-Collars in Norway, see Table 3. For livestock farming, however, there is an ever-growing market of national and international providers. Livestock tags come at much lower prices, partly due to the bigger market, and partly because livestock collars can more easily be replaced and therefore do not need the same robustness and battery life length.

Provider	GPS tags for wild ungulates and costs
Vectronic GmbH, Germany	Survey, Vertex Lite and Vertex Plus collars, with increasing complexity. Survey collars contain a GPS module and the options of satellite

https://www.vectronic-aerospace.com/	communication for re-programming and data download, and drop-off. Vertex Lite includes additionally an activity and mortality sensor and more communication options. Vertex Plus contains additionally the options for tri-axis accelerometry (up to 32 Hz), a UHF-reader for proximity studies and communication with implants, and virtual fence programming. The collar can also be purchased with an integrated camera. Costs of a collar suitable for moose are about 1800 euro for Vertex Plus, excluding communication and sensor options
Followit AB, Sweden https://www.followit.se/	Six different size Tellus GPS collars could be purchased. Medium Plus collar is suitable for red deer and costs ~1900 euro. Remotely activated drop-off function could be purchased for an additional 200 euro. Data transfer through GSM network costs an additional 144 euro per year. Position data is transferred via SMS and is stored in the cloud that is accessible through both desktop and mobile app. Radio tracking of Tellus GPS collars is possible and VHF transmitter/receiver could be purchased for additional ~1200 euro.
Ecotone, Poland http://www.ecotone-telemetry.com/index.php/en	Ecotone produces GPS tags and collars for different sized animals, all the way down to birds and up to bisons.
GPS-Collars, Norway https://www.gps-collars.com/	Four different size CellTraX GPS/GSM/UHF collars could be purchased. 450 g collar is suitable for red deer and costs ~650 euro. EarTraX GPS tag for ear costs ~600 euro. Remotely activated drop-off function isn't available. Data transfer through GSM network costs an additional 216 euro per year. Data is preferentially downloaded through GPRS/3G and is available through a web application. Radio tracking of CellTraX GPS collars is possible and UHF transmitter/receiver could be purchased for additional ~1200 euro.

Table 3. Most popular European providers of GPS tags for wild ungulate

GPS-tags are often combined with other dependent or independent tags, and in the following comes a list of different sensors.

3.2.2. Accelerometry

An accelerometer measures the fine-scale movements of the body in different directions. If an accelerometer is integrated into a GPS-collar, it will measure neck movements along two or three axes. Measurements may be as frequent as 100 times per second (100 Hz), but more common are accelerometers of 4-32 Hz. By observing an animal and recording its behaviour, and so match these behaviours in time with the accelerometer data, it is possible to find the accelerometry signature for different behavioural states. In other words, the accelerometry data can be used to assess the sequence of behaviours of a given individual and to calculate how much time an animal uses for specific behaviours. This has been successfully done for livestock, e.g. (Alvarenga et al. 2016, Tofastrud et al. 2018, Van Nuffel et al., 2015), but to a lesser extent for wildlife, e.g. (Heurich et al. 2012), because wild animals are harder to observe.

3.2.3. Mortality

Electronic tags usually contain a mortality sensor that warns a researcher, a manager or a farmer if the animal is dead or inactive over a long period. Mortality sensors can be coupled to the accelerometer, i.e., if there is no movement registered in x consecutive hours. Alternatively, some mortality sensors are triggered by a sudden drop in body temperature. Mortality estimation using GPS-tags is increasingly being studied over last decade, thus offering novel insights into the functioning and health of animal populations and markedly advancing the efficiency of management plans for species affected by illegal, conflictual, or cryptic sources of mortality (Sergio et al., 2019).

3.2.4. Reproduction

Reproduction is often monitored by using a vaginal implant (Sakatani, 2019). This is an electronic tag that is expelled during birth. It so emits a signal if the temperature drops or if the accelerometer does not report any movements. Vaginal temperature and electrical conductivity sensors are also used for estrus detection in cows (Andersson et al., 2016).

3.2.5. Cameras and acoustic tags

For large animals which can carry some weight, cameras and acoustic tags can be mounted on a GPS-collar (Brockman, 2017). This allows us to identify their behaviour at a given place, and it can also be used to measure the behavioural response on e.g., human disturbance and infrastructure.

3.2.6. Interactions and proximity

Collars can contain a device that makes the tags from different animals to communicate with each other. This can be useful to observe the distance between mother and calf, herding behaviour, or interactions between predators and wild or domestic prey. Similar applications are proximity devices that e.g., change the positioning schedule or send a warning as soon as the animal enters the emission zone of a physically placed tag. In extensive livestock farming, GPS-collars with virtual fences are getting even more common (Umstatter, 2011). Once an animal approaches the virtual fence, a sound is emitted, and if the animal continues, it will receive an electric shock from the collar. After a short learning period, the animal will be conditioned on the sound and stop moving before it receives the electric shock.

3.2.7. Biosensors

To measure the physiological state of an individual, there is a variety of biosensors to measure e.g., body temperature and heart rate. Biosensors can be implanted in the rumen (no need for surgery) or subcutaneously, or they can be applied outside. Most GPS tags come with a temperature sensor. However, this tag measures the ambient temperature rather than the body temperature. External heart rate loggers are common in livestock monitoring but have limited applicability in wild ruminants.

The global growth of the wearable sensors sector between 2017-2027 has been predicted to soar from \$0.91 billion to \$2.6 billion (Harrop et al., 2016). The market of wearable sensors in livestock farming is much larger in comparison to wild animals. Monitoring of livestock health is of high interest due to high potential economic impact. Therefore, advanced sensor systems have been applied primarily for livestock monitoring. In the case of wild animal monitoring, only GPS position is often measured due to difficult sensor installation procedure as well as limited battery capacity. Nevertheless, it is expected that different sensors currently used only for livestock monitoring will be applied also for wild animals. Development of improved batteries and more efficient data transfer options for remote areas might be triggers for the adaptationof livestocksensors in wild animal monitoring.

3.3. Acoustic sensors

Acoustic sensors have been widely used to record many different taxa with loud and distinct sound signatures, such as birds, bats, amphibians, insects, marine mammals, and wolves. Although many ungulates produce social sounds during the year, these are usually rare and hard to detect with microphones. The exception is during the breeding season, when many ungulates, especially from the *Cervidae* family, emit loud calls to protect their territory and attract females, which allows the adult males to be detected and their activity researched or monitored (Rusin, 2019).

Autonomous recording units (ARU) that can be left in the field for prolonged periods of time are an emerging technology that can be used to survey sound producing animals even better than human observers (Darras, 2019). Cheap technologies are being developed that allow these methods to be deployed at a large scale.

AudioMoths created by *Open Acoustic Devices* are affordable ARU's ($59.00) that run on 3 AA batteries and are able to record frequencies from 8,000 kHz to 384,000 kHz and have customizable schedules that let them conserve memory space and battery life (Hill et al., 2019). They also provide an IPX7 casing for 34.99$. *Open Acoustic devices* also have created an even smaller model - the µMoth for specific acoustic surveying needs. Raspberry-Pi solutions like AURITA (Beason et al.,2019) have also been created, that can be customized and tweaked after use, with differing costs. These solutions often aren't commercial and don't come with weather-resistant casing, so more manual work needs to be put in creating and deploying them.

Sound localization is also possible by placing multiple time synced ARU's in a grid and quantifying the time difference of arrival, which is reviewed in a recent publication by (Rhinehart et al., 2020). Commercial units SM4TS are by *Wildlife Acoustics* for 1 099$ that have a GPS attached which synchronizes to the GPS clock, allowing for near perfect time synchronization. CARCAL is a non-commercial ARU that offers localization capabilities for a cheaper cost (manufacturing costs of ~200$), but it is open sourced and has to be hand crafted (Wijers et al., 2019).

3.4. DNA collection

An integral part of wildlife conservation research and management is nowadays genetic sampling. Animal DNA has been traditionally obtained invasively, from blood or other tissues, however public concerns over animal welfare require that animals are affected as little as possible during research (Miriam, 2019).

Traditionally, DNA samples have been obtained invasively, from blood or other tissues, which sometimes involves euthanization of the animal. Recently, wildlife genetics studies have been revolutionized by innovative non-invasive sampling techniques. Non-invasively obtained genetic samples allow for data collection without the need for killing or even handling the animal (Waits et al., 2005).

Another obstacle that might be preventing the wider uptake of non-invasive methods is limited awareness of alternatives and more ethical approaches to research due to lack of education and discussion about animal ethics and animal welfare in ecological research (Bekoff, 2002).

The quality and quantity of DNA that can be isolated from commonly encountered biological sources frequently varies and depending upon different environmental conditions. Tissue, blood and semen are the best source to obtain a DNA profile, whereas other biological fluid like gastric fluid, fecal matter, vomit, bone and hair, etc. have less percentage to isolate DNA and comparatively difficult to generate a genetic profile (Linacre et al., 2013).

Various factors are responsible for DNA degradation and affect the ability of DNA typing. A main leading factor which affects DNA includes sample quantity, time, temperature, humidity, sunlight, UV light, different substrate, chemical exposure, contamination (from bacteria or micro-organisms).

Prolonged exposure of biological sample to the environment cause DNA degradation and become unsuitable for further scientific analysis. So, importantly, the prime goal during handling (both collecting and preserving) of biological evidence to halt the degradation process have already in progress and limit any further future deterioration (Semikhodskii, et al., 2007; Trace, 2015).

The main serious issue related to the handling of the biological DNA sample is the risk of contamination. There is always a high risk of DNA contamination during collection and transportation. So, it is necessary to take preventive attention to reduce possible contamination during collecting and preserving DNA evidence. The main contamination in DNA is due to other biological source getting mixed with relevant or with surface contamination that come in contact with the sample or improper collection and preservation cause a high risk of biological activity (like microorganism or bacterial activity) will destroy the DNA authenticity (NCJRS, 2015).

Animal feces contain cells from the intestines of the animal, and these cells can be used to identify the DNA of individual animals. Together with the information on where and when the feces sample was taken, one can estimate population densities using capture-recapture analysis, and also obtain information on animal space use, such as seasonal migration. While molecular methods for monitoring wildlife is well established for large carnivores (Bischof et al., 2020), there are only a few attempts done for ungulates. This difference between taxa may be explained by the higher need of the management to monitor conflicting, threatened species, such as large carnivores. Also, carnivore DNA is better maintained than DNA in ungulate feces. This is due to the high microbial activity in ruminant intestines (Bischof et al., 2020), leading to a high rate of DNA dissolution. Also, there is a high cost per sample for DNA-analysis, and because ruminants are much more numerous than carnivores, many more samples would need to be analysed. There is a need for developing cost-effective methods because ruminant feces are easy to collect and sampling an area for feces could give absolute estimates of the population size.

3.5. Aircrafts and airborne sensors

Wang et al. (2019) reviewed studies of wild animal surveys based on satellites, manned aerial aircraft platforms, and unmanned aircraft systems with a focus on data usage and animal detection methods. They summarized that manned aerial vehicles have a longer endurance flight time, allowing wild animal surveys on remote, large-scale areas. Manned aerial imagery for wild animal monitoring can be collected with significantly higher resolutions compare to satellite passive sensor image data and are more independent from cloudy sky conditions.

Vehicles like helicopters are preferred in studies of terrestrial animals over smaller areas, while fixed-wing airplanes over remote locations and marine environments. The main disadvantage of manned aerial surveys is very high operational costs, especially for the real-time missions where usually data collection is performed by trained observers as employed professionals. However, in some cases manned areal systems should be considered as the most cost-efficient technique, especially if the survey mission is planned to be on the high geographical scales. Franke et al. (2012) on their research missions have used silent, slow-flying microlight airplanes like S-Stol which have very low operating costs. The aircraft operation without technical equipment is approximately 100 €/h, compare to the helicopter or twin-engine turboprop aircraft where operational costs without technical equipment are about 1000 €/h. For example, single-engine land class aircraft like Cessna 172 consume around 250 €/h.

Manned aerial fixed-wing aircraft and helicopters for monitoring wild animals have been used since the last century. Monitoring missions of wild animals can be divided into two main categories: real-time surveys, where target species are counted in situ by trained humans, and photographic surveys, where wild animals are counted from RGB and emitting energy-sensing data (Wang et al., 2019). Primarily surveys were mainly real-time missions of monitoring wild animals in low abundance large-scale areas. The terrestrial animals included polar bears (Ursus maritimus) (Wiig, Ø. and Bakken, 1990), red kangaroos (Megaleia rufa) and sheep (Caughley et al., 1972), buffalos (Syncerus caffer), elands (Taurotragus oryx), elephants (Loxodonta africana), and giraffes (Giraffa camelopardalis) (Stoner et al., 2007), and pronghorns (Antilocapra americana) (Smyser et al., 2016).

The photography data like still RGB images or videos acquired from manned areal aircraft have been used to count animals for decades (Martin et al., 2016). Several benefits over the real-time survey missions provide the photography-based method, including high altitudes flights, collection of significantly high-resolution photography data (up to 2.5 cm), post-observations of imagery and videos after flights, and developing automatic algorithms for separation of animal counts (Descamps et al., 2011; Chabot et al., 2018; Groom et al., 2013; Hollings et al., 2018).

Infrared thermography has also been widely tested for several decades (Graves et al., 1972; Potvin and Breton, 2005; Kissell and Nimmo, 2011). Franke et al., (2012) surveyed wild animals over large-scale geographical areas with a significant temperature difference from the background environment, such as red deer (Cervus elaphus), fallow deer (Dama dama), roe deer (Capreolus capreolus), wild boar (Sus scrofa), foxes, wolves, and badgers. They have used a computer-linked nadir-looking camera system consisting of a JENOPTIC® infrared camera (640 x 480 pixels) and a Canon 5D Mark 2 high-resolution RGB camera (5,616 x 3,744 pixels). The infrared camera used was an uncooled microbolometer detector that is sensitive to wavelengths of 7.5–14 µm with sensitivity to temperature differences of 0.08 Kelvin.

Manned aerial surveys using a combination of thermal and visible light cameras allow remote observation of wildlife over large geographical areas and have been widely studied (Franke et al., 2012; Millete et al., 2011; Havens and Sharp, 2015) resulting in recommendations for sampling conditions and technological setup. The canopy cover is the main limitation of aerial surveys as the detection possibility of animals could go from 100% in open areas to <50% in closed-canopy forests. The thermal imager is often used as a primary sensor for the detection of animal shapes similar hot-spots but higher-resolution visible light imaging data could be used for the reduction of false-positive detections. Oishi et al., (2018) have studied the capabilities of sika deer (Cervus nippon) detection with airborne thermal images collected with a TABI-1800 sensor (Itres Research Limited). Images were acquired twice at an altitude of 1000 and 1300 m. The pixel resolutions of obtained imagery were 40 cm and 50 cm after data pre-processing. They concluded that such resolution thermal images can be used only on movings hot-spot recognition level without the species identification by revisiting the target area. However, flights on lower altitudes can increase the pixel resolution of TABI-1800 images and in combination with a high-resolution RGB sensor have a huge potential in the detection of large-bodied wild animals on large-scale geographical areas.

Thermal high-resolution photography imagers that can be mounted on manned aircraft:

- TABI-1800 **-** thermal imaging sensor has been developed by Itres Research Limited. It is a push frame cooled MCT thermal broadband sensor covering a spectral range from 3.7 to 4.8 microns, 40 degrees total field of view with 1800 spatial imaging pixels, resolving temperature differences less than 50mK, operable at -10 degrees to 40 degrees of Celsius. It has a changeable filter system with the ability to cut out unwanted parts of detecting spectral range. The price of this sensor is approximately 300000€.
- microTABI640 - portable thermal imager for air and ground use developed by Itres Research Limited. It is a push frame cryo-cooled broadband sensor covering a spectral range from 3.7 to 4.8 microns, 40 degrees total field of view with 640 spatial imaging pixels, resolving temperature differences less than 30mK, operable at -10 degrees to 40 degrees of Celsius. It can be mounted on high payload UAVs and low-cost single-engine manned aircraft. The price of this sensor is approximately 90000€.
- FLIR SC7000 series – a portable thermal imager for air and ground use developed by FLIR Systems. It is a frame cooled MCT broadband sensor covering a spectral range from 3.0 to 5.1 microns, 640x512 spatial imaging pixels, resolving temperature differences less than 30mK, operable at -20 degrees to 150 degrees of Celsius. Because of the high frame rates, it can be mounted on low-cost single-engine manned aircraft. The price of this sensor is approximately 100000€.

- VarioCAM HD head 900 – computer vision thermal imager for air and ground use developed by InfraTec GmbH. It is a frame shooting uncooled microbolometer focal plane array sensor camera covering a spectral range from 7.5 to 14 microns, at full frame (30 Hz) it has 1024x768 spatial imaging pixels (the sub-frame formats are available), resolving temperature differences up to 20mK. The price of this sensor is approximately 50000€.

RGB high-resolution photography imagers that can be mounted on manned aircraft:

- Trimble Aerial 60 megapixel camera – digital RGB camera for areal applications. It has Rodenstock Apo-Sironar 60mm f/4.0 lens, 53.9 mm x 40.4 mm effective pixel CCD sensor, 8924x6732 spatial imaging pixel resolution, electronically controlled leaf shutter.
- PhaseOne iXM-100 megapixel camera – digital RGB camera for areal applications. It has optional changeable lenses, 43.9 mm x 32.9 mm effective pixel CMOS sensor, 11664x8750 spatial imaging pixel resolution, electronically controlled leaf shutter.

3.6. Drones

Unmanned aircrafts (UAV), here drones, are still underused in wildlife management, despite the wide range of potential applications (Burke et al. 2019, Koh et al. 2012, Linchant et al. 2015). They are currently being tested for counting wild reindeer in the open mountain habitats (Ruud & Hagen, 2019) and ungulates in pine and beech forests in Poland (Witzcuk et al., 2019). Drones have the advantage that they are cheaper than manned aircrafts and that they can be operated on the spot and at lower heights and sound, and their use is independent of daylight. As technology develops and the market increases, drones become affordable for wildlife managers, landowners and other stakeholders involved in wildlife management.

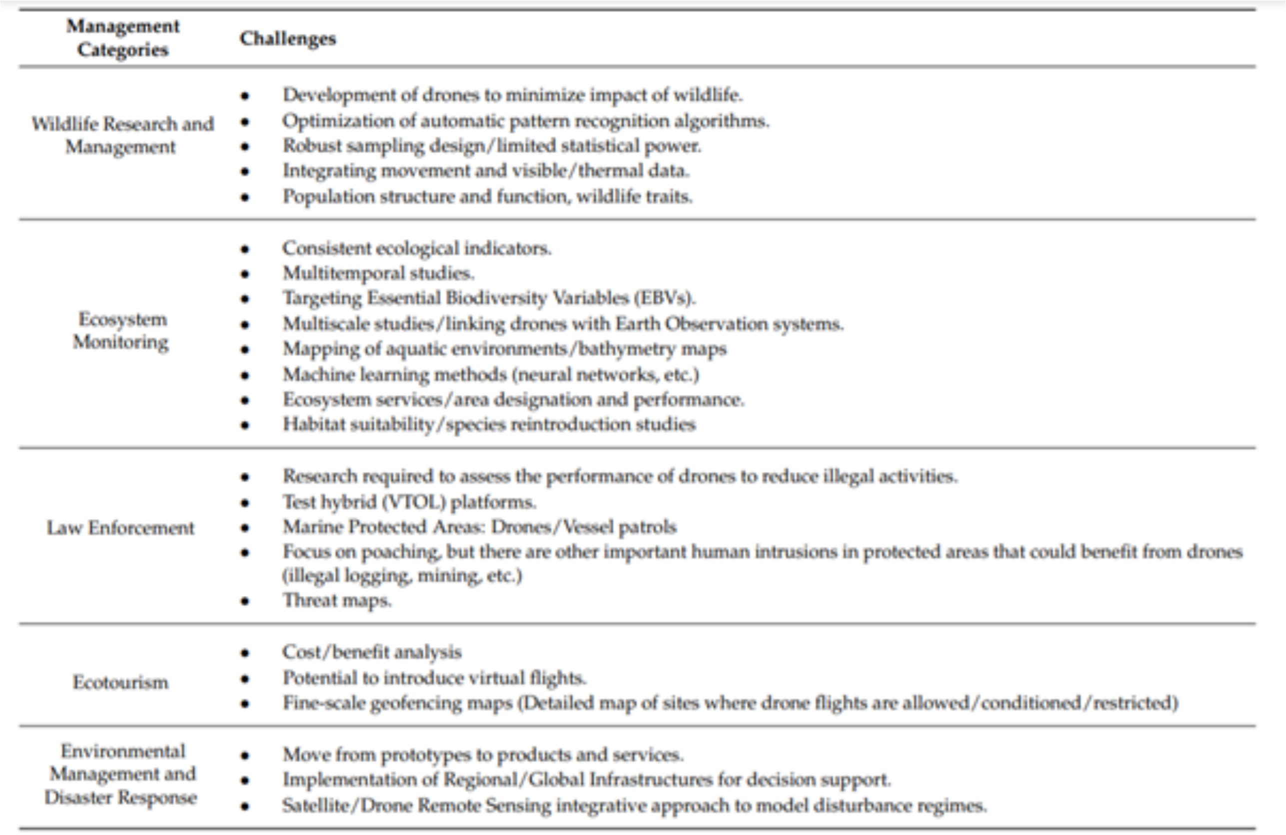
It is not the drones themselves, but rather the cameras mounted on the drones that determine the usefulness. For monitoring of homoeothermic animals, thermal infrared cameras (TIR) that register heat emitted from the body can be more successful than optical cameras (RGB) that record the light reflected by the body, especially if the species is elusive and hard to optically distinguish from the surroundings (Burke et al., 2019, Havens & Sharp, 2015, Cilulko et al., 2019). Detection success using TIR depends on flight height, camera angle, temperature and humidity of the surroundings and the atmosphere, the skin/hair temperature of the animal, and its behaviour and selection of habitat (Havens & Sharp, 2015, Cilulko et al., 2019, Israel, 2015).

For vegetation surveys, multispectral cameras that in addition to RGB measure near-infrared NIR are useful for estimation of e.g., the normalized difference vegetation index NDVI to capture information about live green vegetation biomass of a given plant or vegetation plot (Peñuelas & Filella, 1998). Here too, ambient temperature and humidity, as well as flight height, define the success and resolution of the measurements. In agricultural vegetation mapping, pictures must overlap usually around 70 % so that high quality maps can be created (Daponte et al., 2019). Changes in light conditions during data collection can cause serious errors to vegetation maps, often seen as stripes on a map, and must be considered during data processing (van der Merwe et al., 2020)

The term UAVs or drones include various types and sizes of equipment from a weight of only a few hundred grams to thousands of kilograms. The military use of UAVs has been the driving force for technical development for a long time but especially during last decades the agricultural, meteorological and nature resources related users have started to utilize UAVs more and more (Springer, 2013, Krisna 2018). The most suitable types for nature conservation and wildlife monitoring are multi-rotor drones and fixed-wing drones (van Gemert et al., 2015, Boon et al. 2017). Multi-rotor drones offer the possibility for vertical take-off and landing with good data accuracy because of the ability to control position and orientation of the camera precisely. Limited speed and flying time restrict their use in wide area monitoring. Fixed-wing drones have longer flight time due to efficient power use and they are usually flown higher than multi-rotor drones to cover larger areas at the same flying time. Downsides are their inability to hover without movement at one spot, need for runway or catapult at take-off and specific landing equipment such as parachute (Boon et al., 2017). Both types can be programmed to follow specific predetermined flying routes.

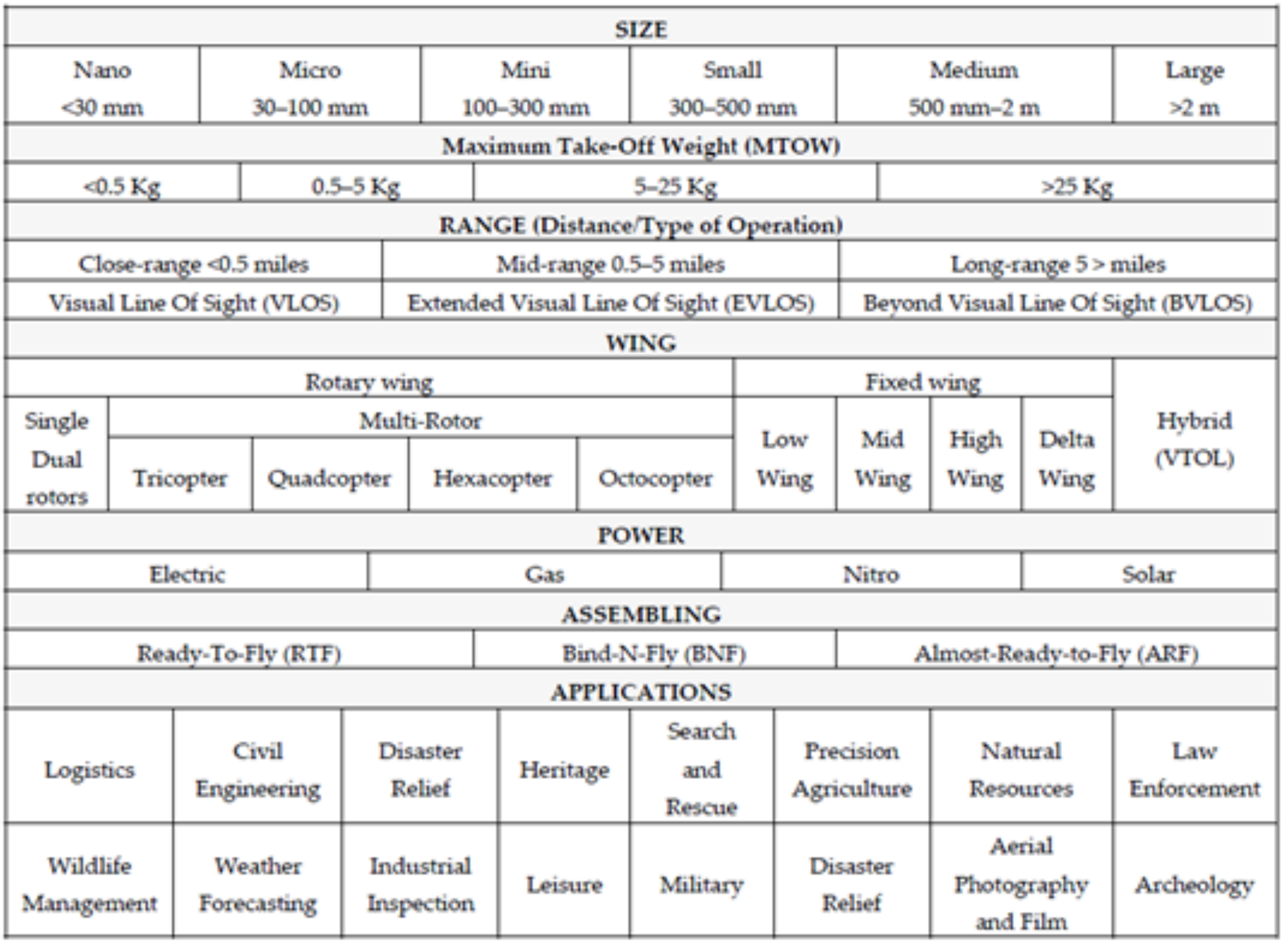
Recent developments in UAVs or drones, artificial intelligence and miniaturized thermal imaging systems made it more flexible, affordable and accurate for aerial surveillance of ungulates (Witczuk et al., 2018; Chretien et al., 2016; Gonzalez et al., 2016; Christie et al., 2016). It has been estimated that the UAV-based survey of 100 ha large territory is ~10 times less time-consuming in comparison to analogous surveys based on traditional field visits (Witczuk et al., 2017). By reviewing different studies, Hodghson et al. (2018) has concluded that drones count wildlife more accurately and precisely than humans. However, in most cases, animal counting from aerial surveys is still performed manually, the need for automatization of data processing is visible. Automatization could also help using different monitoring systems reliably together as nowadays manual counting can lead to a significant difference in population density results. In Australia, macropods (kangaroos) were counted in both helicopter and drone with optical camera and as a result drone offers much lower macropod density versus helicopter (3.2 vs. 53.8 animals km2 respectively) (Gentle et al. 2018). Research gap analysis on African swine fever performed by the European Food Safety Authority (EFSA, 2019) has identified drones (especially the ones equipped with thermal cameras) as an important data source.

UAVs have become increasingly popular tools for wildlife research; research gaps and challenges have been identified in several review studies. Lopez & Mulero-Pazmany (2019) reviewed drone applications for conservation in protected areas, highlighted potential challenges that can help to guide future research in the field, provided a brief classification of platforms according to characteristics and application and the overall overview of sensors and devices that can be coupled to drones, see Illustrations 2, 3 and 4. Recommendations on observing strategies for monitoring animals using UAVs equipped with thermal cameras have been collected by Burke et al., 2019. Early morning is recommended for thermal surveys due to the maximal contrast between the target object and background. Witczuk et al. (2017) have identified the main challenges of UAV thermal-data-based method - difficulties in species identification due to relatively low resolution of thermal cameras, regulations limiting drone operations to visual line of sight, and high dependence on weather. For the test flights, Witczuk et al. (2017) have used two types of UAVs. Daylight flights were conducted with a fixed-wing AVI-1 airplane (Taxus SI, Warsaw, Poland) with a wingspan of 3.5m, electrical propulsion, and 90 min maximum flight time and to minimize financial loss due to potential crash while operating in the dark for the night flight, have used an inexpensive fixed-wing Skywalker X8 Flying Wing (Skywalker Technology Co. Ltd., Wuhan, China) with a wingspan of 2.1 m, electrical propulsion, and 40 min maximum flight time. Barnas et al. (2020) have proposed a standardized protocol for reporting methods when using drones for wildlife research. It is recommended that protocols are structured in at least six sections - project overview, drone system and operation details; payload, sensor, and data collection; field operation details; data post-processing; and permits, regulations, training, and logistics.



Management Categories	Challenges
Wildlife Research and Management	• Development of drones to minimize impact of wildlife. • Optimization of automatic pattern recognition algorithms. • Robust sampling design/limited statistical power. • Integrating movement and visible/thermal data. • Population structure and function, wildlife traits.
Ecosystem Monitoring	• Consistent ecological indicators. • Multitemporal studies. • Targeting Essential Biodiversity Variables (EBVs). • Multiscale studies/linking drones with Earth Observation systems. • Mapping of aquatic environments/bathymetry maps • Machine learning methods (neural networks, etc.) • Ecosystem services/area designation and performance. • Habitat suitability/species reintroduction studies
Law Enforcement	• Research required to assess the performance of drones to reduce illegal activities. • Test hybrid (VTOL) platforms. • Marine Protected Areas: Drones/Vessel patrols • Focus on poaching, but there are other important human intrusions in protected areas that could benefit from drones (illegal logging, mining, etc.) • Threat maps.
Ecotourism	• Cost/benefit analysis • Potential to introduce virtual flights. • Fine-scale geofencing maps (Detailed map of sites where drone flights are allowed/conditioned/restricted)
Environmental Management and Disaster Response	• Move from prototypes to products and services. • Implementation of Regional/Global Infrastructures for decision support. • Satellite/Drone Remote Sensing integrative approach to model disturbance regimes.

Illustration 2. Challenges for the effective implementation of drones in protected areas (Lopez & Mulero-Pazmany, 2019).

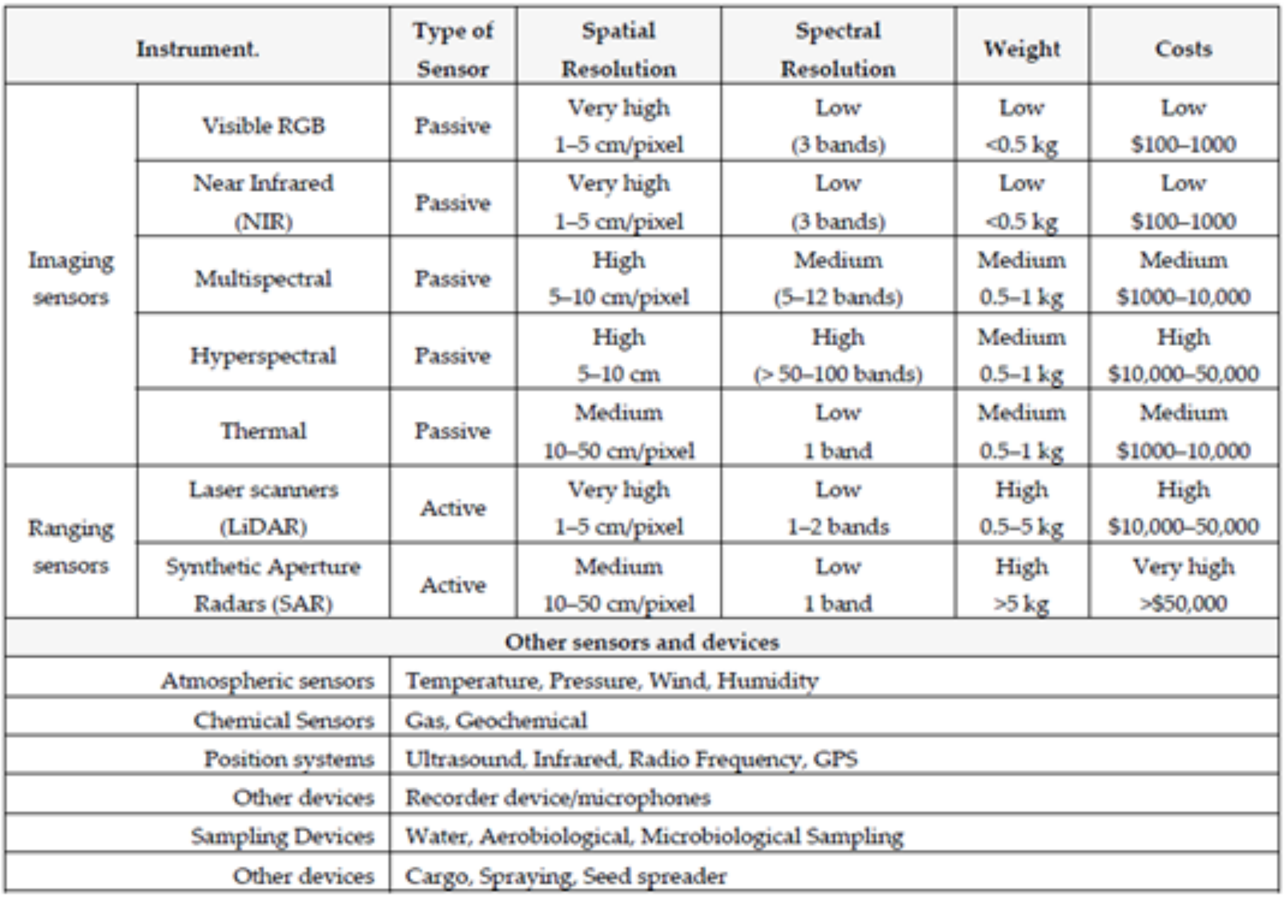


<table>
<tr><th colspan="10">SIZE</th></tr>
<tr><td>Nano
<30 mm</td><td colspan="2">Micro
30–100 mm</td><td colspan="2">Mini
100–300 mm</td><td>Small
300–500 mm</td><td colspan="3">Medium
500 mm–2 m</td><td>Large
>2 m</td></tr>
<tr><th colspan="10">Maximum Take-Off Weight (MTOW)</th></tr>
<tr><td colspan="2"><0.5 Kg</td><td colspan="2">0.5–5 Kg</td><td colspan="3">5–25 Kg</td><td colspan="3">>25 Kg</td></tr>
<tr><th colspan="10">RANGE (Distance/Type of Operation)</th></tr>
<tr><td colspan="3">Close-range <0.5 miles</td><td colspan="3">Mid-range 0.5–5 miles</td><td colspan="4">Long-range 5 > miles</td></tr>
<tr><td colspan="3">Visual Line Of Sight (VLOS)</td><td colspan="3">Extended Visual Line Of Sight (EVLOS)</td><td colspan="4">Beyond Visual Line Of Sight (BVLOS)</td></tr>
<tr><th colspan="10">WING</th></tr>
<tr><td colspan="5">Rotary wing</td><td colspan="4">Fixed wing</td><td rowspan="3">Hybrid
(VTOL)</td></tr>
<tr><td rowspan="2">Single
Dual
rotors</td><td colspan="4">Multi-Rotor</td><td rowspan="2">Low
Wing</td><td rowspan="2">Mid
Wing</td><td rowspan="2">High
Wing</td><td rowspan="2">Delta
Wing</td></tr>
<tr><td>Tricopter</td><td>Quadcopter</td><td>Hexacopter</td><td>Octocopter</td></tr>
<tr><th colspan="10">POWER</th></tr>
<tr><td colspan="3">Electric</td><td colspan="2">Gas</td><td colspan="3">Nitro</td><td colspan="2">Solar</td></tr>
<tr><th colspan="10">ASSEMBLING</th></tr>
<tr><td colspan="4">Ready-To-Fly (RTF)</td><td colspan="2">Bind-N-Fly (BNF)</td><td colspan="4">Almost-Ready-to-Fly (ARF)</td></tr>
<tr><th colspan="10">APPLICATIONS</th></tr>
<tr><td>Logistics</td><td>Civil Engineering</td><td>Disaster Relief</td><td>Heritage</td><td>Search and Rescue</td><td colspan="2">Precision Agriculture</td><td colspan="2">Natural Resources</td><td>Law Enforcement</td></tr>
<tr><td>Wildlife Management</td><td>Weather Forecasting</td><td>Industrial Inspection</td><td>Leisure</td><td>Military</td><td colspan="2">Disaster Relief</td><td colspan="2">Aerial Photography and Film</td><td>Archeology</td></tr>
</table>

Illustration 3. Classification of drones according to characteristics and applications. (Lopez & Mulero-Pazmany, 2019).

UAVs have been used for wild ungulate studies. Baldwin (2019) evaluated white-tailed deer (*Odocoileus virginianus*) population survey methods and browsing pressure in a North Carolina State Park and reached 97% accuracy for quantification of the captive population of deer using a fixed-wing Ritewing Drak aircraft equipped with the 640 × 480 pixels non-radiometric thermal infrared imager (FLIR Vue Pro 640, 13-mm lens, 45° horizontal FOV, 30Hz; FLIR Systems, Inc., Wilsonville, OR, USA). Atuchin et al. (2020) have demonstrated detection of elk in Siberian winter forests using a drone plane Supercam S250 (Unmanned Systems LLC, Izhevsk, Russia). Its take-off weight is 7.5–9.5 kg, which allows for 1.5 kg of payload, e.g. a camera and a thermal imager. The drone plane can operate at wind velocity of up to 15 m/s and air temperature from –50°C to +45 °C. The aircraft was equipped with a visible camera Sony RX1R II is a full-frame camera with no crop factor, which makes it possible to cover a wide area without additional maneuvering and a compact, low power ATOM500 thermal imaging camera. Liang et al. (2020) used a UAV equipped with a standard RGB camera to study seasonal variation in herd composition of the Formosan sika deer (Cervus nippon taiouanus) in a forest-grassland mosaic habitat of southern Taiwan. The photographs and videos collected by UAV were used for manual identification of the age and/or sex of each individual recorded, and for the generation of data on deer group size, sex ratio, the age-group ratio for each herd, and solitary animals. Two models of multi-rotor UAV or drone, the Typhoon H (Yuneec, Shanghai, China) and the Phantom 4 Pro (DJI, Shenzhen, China), were used in this study. Barasona et al. (2014) used the UAS platform which was built using the foam fuselage of a radio-controlled model Easy Fly plane (St-models, China) propelled by a brushless electrical engine. The embarked systems are an on-board video camera used for First Person View Flight (FPV), a GPS (10 Hz, Mediatek, model

FGPMMOPA6B), an Ikarus autopilot (Electronica RC, Spain) which provides flight stabilization, On-Screen Display (OSD), a Panasonic Lumix LX-3 digital photo camera 11MP (Osaka, Japan).



Instrument.		Type of Sensor	Spatial Resolution	Spectral Resolution	Weight	Costs
Imaging sensors	Visible RGB	Passive	Very high 1–5 cm/pixel	Low (3 bands)	Low <0.5 kg	Low $100–1000
	Near Infrared (NIR)	Passive	Very high 1–5 cm/pixel	Low (3 bands)	Low <0.5 kg	Low $100–1000
	Multispectral	Passive	High 5–10 cm/pixel	Medium (5–12 bands)	Medium 0.5–1 kg	Medium $1000–10,000
	Hyperspectral	Passive	High 5–10 cm	High (> 50–100 bands)	Medium 0.5–1 kg	High $10,000–50,000
	Thermal	Passive	Medium 10–50 cm/pixel	Low 1 band	Medium 0.5–1 kg	Medium $1000–10,000
Ranging sensors	Laser scanners (LiDAR)	Active	Very high 1–5 cm/pixel	Low 1–2 bands	High 0.5–5 kg	High $10,000–50,000
	Synthetic Aperture Radars (SAR)	Active	Medium 10–50 cm/pixel	Low 1 band	High >5 kg	Very high >$50,000
Other sensors and devices						
Atmospheric sensors		Temperature, Pressure, Wind, Humidity				
Chemical Sensors		Gas, Geochemical				
Position systems		Ultrasound, Infrared, Radio Frequency, GPS				
Other devices		Recorder device/microphones				
Sampling Devices		Water, Aerobiological, Microbiological Sampling				
Other devices		Cargo, Spraying, Seed spreader				

Illustration 4. Summary classification of sensors and devices that can be coupled to drones (Lopez & Mulero-Pazmany, 2019).

The UAV platform high-resolution images were used for studying the spatial abundance of ungulates concerning the spatial epidemiology of tuberculosis (TB) in the ungulate community of Doñana National Park (South-western Spain).

UAV caused disturbance to wildlife has been studied by different research groups. Mulero-Paznamy et al. (2017) have found that wildlife reactions depended on both the UAV attributes (flight pattern, engine type and size of aircraft) and the characteristics of animals themselves (a type of animal, life-history stage and level of aggregation). Target-oriented flight patterns, larger UAS sizes, and fuel-powered (noisier) engines evoked the strongest reactions in wildlife. Animals during the non-breeding period and in large groups were more likely to show behavioural reactions to UAVs, and birds are more prone to react than other taxa. Rebolo-Ifran (2019) used the information available from the scientific literature on the effects of drones on wildlife and complement it with Internet (YouTube) information to evaluate whether recreational activities using drones produce behavioural responses from wildlife. They concluded that many species presented behavioural responses to drone overflights, furthermore, 26% of the species that were disturbed are included in one of the International Union for Conservation of Nature categories of threat. Brunton et al. (2019) have investigated the potential impacts of drone monitoring on a large terrestrial mammal, the eastern grey kangaroo (Macropus giganteus). They observed that drone altitude is a key consideration for minimizing disturbance of large terrestrial mammals - kangaroos were most likely to flee from a drone flown at an altitude of 30 m and lover, but drone flights at an altitude of 60–100 m above ground level will minimize behavioural impacts. A single quadcopter (UAV DJI Phantom 3

Advanced) was used with a video and IR camera attached. Mesquita et al. (2020) have studied the effect of drone flights on the behavior of great dusky swifts (Cypseloides Senex) and white-collared swifts (Streptoprocne zonaris). The drone model used was a DJI Mavic Pro quadcopter, black color, with a diagonal size of 335 mm, 743 g weight, ± 77 dBA noise level, the maximum flight speed of 65 km / h, and 20 min average flight autonomy, that carried a camera with a 1/2.3″ (CMOS) and sensor with 12.35 effective megapixels. They concluded that 50 m distance is the threshold value where significant disturbance effect could be observed - at distances >50 m the disturbance percentage does not exceed 20%, at <40 m the disturbance percentage increase to > 60%. Ditmer et al. (2019) flew an Iris+ model quadcopter UAS (3D Robotics, Berkeley, CA, USA) and experimentally tested the impact of repeated UAV exposure to American black bears (Ursus americanus) habituate as well as tolerance levels persistence during an extended period without UAV flights. They observed that the capacity of a large mammal to become and remain habituated to a novel anthropogenic stimulus in a relatively short time (3–4 weeks). In the case of ungulates, UAV caused disturbances on Formosan sika deer (*Cervus nippon taiouanus*) could be observed in the video published by Liang et al. (2020), however, the effect wasn't measured quantitatively. Schroeder et al. (2020) used Phantom 4 Advance (DJI, Shenzhen, China), a small quadcopter with an onboard 20-megapixel camera for a study on the UAV-caused disturbance effect on wild guanaco (*Lama guanicoe*) and observed that higher height and lower UAV speed reduced disturbance, except for large groups, which always reacted.

In contrast to well-studied animal counting possibilities from single overpass aerial surveys (Havens and Sharp, 2015), repeated overpasses for change detection Oishi et al. (2018) and overlapping (stereo) image data acquisition for extraction of 3-D information (Sorensen et al., 2018) seems to be directions with unexplored potential. Brinkman & Garcelon (2020) have proposed to use UAVs for remote delivery of anesthetic darts into larger wildlife species, thus, avoiding the restriction of being close enough to use traditional rifle-based darting. Söderqvist (2019) tested drones as one of the options for scaring the wild boar from agricultural lands showing a significant decrease in crop damage. Fischer et al. (2019) used a UAV equipped with a multispectral imager for quantification of damage in agricultural areas caused by wild boar. The overall accuracy of damage estimates to cornfields ranged from 74% to 98% when using visible and near-infrared information, compared to 72…94% with visible information alone. Solo multirotor UAS (3D Robotics, Berkeley, CA, USA) was used equipped with a RedEdge multispectral sensor (MicaSense Inc., Seattle, WA, USA). The RedEdge sensor captured reflectance data in 5 discrete spectral bands: blue, green, red, red edge, and near-infrared, cantered on 475, 560, 668,717, and 840 nm, respectively.

Wildlife monitoring studies are usually performed with commercially available UAVs and thermal cameras. DJI drone with FLIR thermal camera is the most popular option, however, some alternatives exist on the market. The most popular options for thermal drone imaging are reviewed below.

- FLIR System Inc is the global leader in the design and manufacture of thermal cameras for different applications. They have several thermal cameras options suitable for drones:
- FLIR Vue Pro – a thermal camera (7,5 – 13,5 µm spectral) with on board recording and flight controller integration; sensor resolution - 336x256 or 640x512 pixels; full frame rate – 9 or 30 Hz; field of view options – 32…45°; price range from $2149 (336x256 pixels, 9 Hz) to $3849 (640x512 pixels, 30 Hz);
- FLIR Vue Pro R – similar to FLIR Vue Pro but with temperature calibration option form radiometric data; price range from $3149 (336x256 pixels, 9 Hz) to $4849 (640x512 pixels, 30 Hz);
- FLIR Duo Pro R – dual-sensor thermal and visible light imager; high definition 4k color video camera for visible light imaging; FLIR Vue Pro R for thermal imaging; price range from $4499 (336x256 pixels, 9 Hz) to $6599 (640x512 pixels, 30 Hz);
- Zenmuse XT – FLIR Vue Pro equipped with a gimbal compatible with DJI drones (Inspire 1 and Matrice 100, 200, 300 RTK and 600 series); price range from $3199 to $5299.

- Zenmuse XT2 - FLIR Duo Pro R, hi equipped with a gimbal compatible with DJI drones (Inspire 1 and Matrice 100, 200, 300 RTK and 600 series).
- Zenmuse H20t - FLIR Duo Pro R equipped with object tracking 20 MP zoom camera, laser rangefinder and gimbal compatible only with DJI Matrice 300 RTK.

The starting price of the carrier drone could vary in range from 3400 euro (Inspire 2) up to 9000 euro (Matrice 300 RTK) without accessories. Therefore, a complete drone setup with thermal and visible light imagers could exceed 17000 euro. Less expensive dual-camera systems are also available. Customized DJI Mavic 2 equipped with FLIR 640 Boson thermal camera costs ~$7200 and Autel Robotics EVO 4K with FLIR 640 Boson thermal camera costs ~$6900, however, synchronization of both sensors might be a challenge. Thermal sensor resolution is the main limiting factor in wildlife monitoring using dual-camera, therefore, systems with lower thermal were not reviewed. Currently, 640x512 pixel thermal sensors are the best available option in the affordable price range. Thermal data resolution could be increased either by flying at lower altitudes or using a lens with a narrower field of view.

- Workswell has produced higher-resolution dual-cameras WIRIS Security, where thermal sensors have 800x600 pixel resolution as well as better zoom option, however, the price of such a dual-sensor system is ~$20000 without gimbal and drone.
- Shenzhen Viewpro is a Hi-tech manufacturer specialized in R&D and manufacturing of zoom gimbal cameras for industrial and commercial Unmanned Aerial Vehicle. An impressive range with single-sensor and dual-sensor that are compatible with their produced drones and can be mounted on other UAVs with PSDK (Payload Self Development Kit). They have several dual-sensor cameras that are already compatible with some of the DJI UAVs. An available list of the payloads with technical specifications can be found at http://www.viewprotech.com/index.php?ac=article&at=list&tid=127.
- DJI PSDK Series – single-sensor, dual-sensor thermal and visible light imagers with a gimbal compatible with DJI drones (Matrice 200, 210, 210RTK). Prices range from $5400 for Z10TL-DJI 3-axis, 10x optical zoom visible light gimble camera with 300m IR Laser Light to $18460 for WK10TIRM-DJI high-precision professional 3-axis gimbal 4 lens, 10x optical zoom camera and IR+EO dual-sensor object tracking with GPS location resolving.
- Single and Dual-Sensor Tracking Series - single, dual-sensor thermal and visible light imagers. Prices range from $1900 for Q10T 10x Time Optical Zoom EOS Camera gimbal with build-in auto-tracking to $23000 for Q30TIR-1352 powerful 3-axis gimbal, visible light and thermal imager object tracking with EO 30x optical zoom and high resolution dual thermal zooming camera.
- IR Laser Illumination Series - dual-sensor IR laser illumination and visible light imagers. Prices range from $4600 to $5750
- GPS Location Resolving Series – dual-sensor visible light imager with object racking and GPS location resolving. Prices range from $4600 for Z30TM LRF optimized 3-axis camera gimbal, GPS location resolving, 30x optical zoom object tracking camera to $25200 for Q30TIRM pro3-axis gimbal, 30x optical zoom SONY camera, IR+EO Dual Sensors Object Tracking GPS Location Resolving.
- Rotary-wing, airplane and VTOL UAVs are available in stock of Shenzhen Viewpro. The above-mentioned sensors series are compatible depending on the take-off weight parameter. An available list of UAVs with technical specifications and prices can be found at https://www.viewprouav.com/.
- Rotary-wing UAVs – helicopters and Tri, Quad, Hexa multi-rotor UAVs. Prices range from $3200 for QS600K Multi-purpose small multi-rotor UAV quad, high precision locating DUL RTK to $10160 for HM1600P 120min Endurance HEXA UAV 15KM KM Image data transmission remote patrol surveillance investigation and mapping UAV.
- AIRPLANE & VTOL UAVs – fixed-wing, VTOL Quad and Duo tailsitter UAVs. Prices range from $297 for ASV 1800 Fixed-wing UAV VTOL drone three-axis tilt Rotor UAV Long-range mapper to $

35220 for AHY3800P Petrol-electric power VTOL UAV Large wheelbase 4 hours flight time support load 15KG

In summary, UAVs are becoming popular for wildlife monitoring due to relatively large coverage in a short time. UAVs equipped with high-resolution colour or/and thermal cameras are usually used for data acquisition. Thermal sensor resolution is the main limiting factor in wildlife monitoring using dual-camera where 640x512 pixel thermal sensors are the best available option in the affordable price range. Thermal data resolution could be increased either by flying at lower altitudes or using a lens with a narrower field of view. Early morning or late evening are recommended for data acquisition due to maximal contrast between target animal and background in acquired image data. Flight altitude above 50 m is recommended to minimize the disturbance of animals. Best practices for data acquisition planning have been proposed, however, the golden standard is still under development.

3.7. Satellites

Wang et al. (2019) has published a comprehensive review of studies regarding wild animal surveys based on multiple platforms, including satellites, manned aircraft, and unmanned aircraft systems (UASs), and focuses on the data used, animal detection methods, and their accuracies. Their conclusions show that submeter very-high-resolution (VHR) spaceborne imagery has potential in modelling the population dynamics of large (>0.6 m) wild animals at large spatial and temporal scales, but has difficulty discerning smaller (<0.6 m) animals at the species level, although high-resolution commercial satellites, such as WorldView-3, have been able to collect images with a ground resolution of up to 0.31 m in panchromatic mode.

Spaceborne remote sensing has the unique advantage of assessing the dynamics of wild animals and their habitats. The numbers of large animals or colonies can roughly be estimated from VHR satellite imagery, such as QuickBird and WorldView. Although higher~~-~~ spectral, ~~-~~ temporal and ~~-~~spatial resolution imagery collected by satellites~~-~~will improve the ability to detect small animals and should continue to receive attention, it is almost impossible to detect individuals and capture the details of small-sized species in satellite imagery, even if the resolution greatly improves in the future.

Low-spatial resolution spaceborne imagery has primarily been used for characterizing and assessing changes in wild animal habitats, and VHR satellite imagery has been used only for directly monitoring large-sized (>0.6 m) individual animals, such as wildebeests, zebras (Yang et al.,2014), and southern right whales (Fratwell et al., 2014), or estimating the populations of animals that are colonial or congregate in groups, such as penguins (Fratwell et al., 2012). Notably, most previous VHR surveys have used 0.4~~-~~m to 1~~-~~m~~-~~ resolution imagery. Recently, only a limited number of studies have used the higher-resolution WorldView-3 data (e.g., Fretwell, et al., 2017 and Cubaynes, et al.,2019). Satellite imagery offers several potential advantages over aerial imagery collected using manned aircraft or UASs, including larger geographic coverage and regular data collection. Satellite imagery has the potential for modelling past, present, and future populations of large-sized wild animals. An additional advantage for satellite surveys require little regulation or logistical effort, are safe and do not disturb the target animals. With the continuous improvement of the satellite imagery resolution in the future, it could increase the number of potential species to be monitored from space. Although revisit times may improve with additional satellite launches, satellite imagery will not entirely replace conventional aerial surveys in the near future because of the significantly lower resolution (Abileah, 2001). Even for the highest resolution satellite imagery, such as WorldView-3, the resolution is still not sufficient to discern small (<0.6 m) animals (Yang et al.,2014) at the species level. An animal must occupy two or more pixels in the imagery to avoid information loss. Target animals that occupy only 1–2 pixels in the VHR imagery cannot be discerned as being different species, especially when the target species have similar colours and body size~~s~~ characteristics. Also, open habitat landscapes and high colour contrasts between the target organisms and the landscape are necessary for using VHR imagery in the estimation of animal abundance (LaRue et al.,2017). Currently, the cost of VHR satellite images limits the usage and further development of animal monitoring with this data type.

Currently, the highest spatial resolution from the satellites whose data are available free of charge is Sentinel-2 (10-60m/pix with 5 day revisit frequency) and Landsat-8, and Landsat-7 (15 – 30m/pix with revisit times of 16 days each). And these characteristics are more suitable for wild animal habitat mapping as the resolution is suitable for monitoring the changes in the habitat or food base (clear-cuts, changes in the grasslands, agriculture management). Modelling approaches for assessment of target animal habitats and living space capacity are usually divided into expert knowledge-based approaches with well-known variable value ranges and machine learning approaches where the relation between reference data and available variables is empirically estimated (Bradley et al., 2012; Dettki et al., 2003). It is suggested that continuous remote sensing variables should only be included in habitat models if authors can demonstrate that their inclusion characterizes potential habitat rather than actual species distribution (Bradley et al., 2012). Ecological-Niche Factor Analysis (ENFA) is often used as an empirical approach for habitat suitability assessment (Hirzel et al., 2002). However, more advanced machine learning-based models have found their application also for habitat suitability modelling, e.g., random forest (Li et al., 2017), Bayesian networks (MacPherson et al., 2018), probabilistic neural networks (Munoz-Mas et al., 2018).

4. Conclusions and next steps

The need for remote sensing technology-based solutions for monitoring of wild large-bodied animals, free-ranging livestock and their habitats is driven by several challenges and opportunities.

The currently applied standard animal monitoring methods are resource-intensive and laborious and, to large extent, rely on voluntary work of hunting clubs or citizen science. The population of hunters is aging, and younger generations are not interested in this spare time activity, thus alternative ways of animal monitoring is demanded. Some animal counting techniques such as track counts are also becoming difficult to apply due to decrease in snow cover. In all of the surveyed countries, there is a need for more precise estimates of wild animal populations, and there have been limited studies on the selection and adaptation of the best counting methods for each species or family of the animals.

All in all, the importance of wildlife monitoring and more reliable estimates of wild animal populations is increasing due to the need for sustainable management of natural resources, climate chang,. conflicts of interest (e.g., forestry, agriculture due to animal-caused damage), traffic accidents, diseases (e.g., ASF, CWD), and invasive species (e.g., wild boar in Finland and Norway). As demonstrated in the technology review above, remote sensing tools have potential to address many of the current challenges of wild animals monitoring; however, further research and innovation activities are required.

Our study revealed that the research sector had been more active in exploring different kinds of remote sensing technologies for wildlife monitoring than the public management or private industry sector. We want to address this issue by implementing a series of transnational innovation activities to demonstrate and test remote sensing potential for monitoring of large-bodied wild animals and free-ranging livestock and do it in close collaboration and engagement of various stakeholder groups.

Based on the information gathered through the analysis of scientific and professional literature, practical experience and stakeholders' interviews, we have defined the scope of technology demonstration events to be implemented in Latvia, Norway and Finland in the period from February till April 2021 (see Annex

2). At the end of April and the beginning of May, the transnational online stakeholders' meet-up will be organised to share the lessons learnt, present the results and gather the feedback for further required developments. Although physically, the technology demonstration activities will be carried out in Latvia, Finland and Norway, the scope of activities will address the needs and interests of more countries, e.g., Poland.

To learn more about the ConnectedByBiobords project and to follow the progress of Technology Innovation Group's activities, join the Biobord platform – www.biobord.eu .

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Annexes

Annex 1: THE ASSESSMENT OF TECHNOLOGICAL DEVELOPMENT NEEDS OF STAKEHOLDERS RELATED TO WILD ANIMAL AND FREE-RANGING LIVESTOCK MONITORING ISSUES

Interview framework

1. GENERAL INFORMATION

Name of an organisation	
Address	
Legal status	
Number of employees	
Contact details of the interviewed person	**Name, surname, position:** **Telephone number:** **E-mail:**

2. INFORMATION ON ACTIVITIES

2.1. What are the main activities of your organisation?

2.2. How are your organisation's activities related to wild animals and free-ranging livestock?

2.2. What is your main need / interest in relation to wild animals and free-ranging livestock – data, knowledge, a nature management solution, a new/improved technology, other? Be as specific as possible!

3. TECHNOLOGICAL DEVELOPMENT NEEDS

3.1. What is your experience in applying modern remote sensing technologies for getting information related to wild animals and free-ranging livestock? What purpose did you use them for? What challenges did you face, if any?

Technology	Purpose and user experience
Camera traps	
GPS collars, tags	
Biosensors	
Drone-based sensors	
Aircraft-based sensors	
Airborne LIDAR	
Satellite images	
Passive acoustic sensors (microphones)	
Data from citizen science activities	
Any other technology	

3.2. What value / opportunities do you see in using modern remote sensing technologies in relation to wild animals and free-ranging livestock?

3.3. What challenges do you see both within your organisation and in the external environment which are slowing down or stopping technology uptake in your operations / decision making?

3.4. If you had an opportunity to test the capabilities of the before-mentioned technologies, which technology would you focus on and what for?

3.5. Recommended other links related to this topic?

Annex 2: PRELIMINARY SCOPE OF TECHNOLOGY DEMONSTRATION ACTIVITIES

Title: **Development of non-invasive remote sensing methods for monitoring of wild large-bodied animals and free-ranging livestock and assessing their impact on ecosystem services**

Objectives of demonstration activities:

Finland	Latvia	Norway	Poland
1. To demonstrate capability of technologies for monitoring animals: detect / identify animals, coverage / efficiently, cost-effective methods.	1. To demonstrate the capability of drones for the assessment of deer and moose population in a target area.	1. To make reindeer management more effective	
2. To wake up stakeholders' interest in innovative technologies	2. To validate results using other reference methods and present them to stakeholders.	2. To detect individual moose by drone	
3. To deepen discussion of possibilities, challenges and development focus of innovative technologies and monitoring methods	3. To test different data acquisition regimes and animal reactions to define the protocol for animal counting with drones.	3.To test whether drones scare moose.	

Primary stakeholders:

Stakeholder groups	Finland	Latvia	Norway	Poland
National and/or regional wildlife management institutions	X	X	X	X
Land use management organizations (forestry, agriculture)		X		
Nature conservation and protection institutions				X
Hunters' community (individuals, clubs, associations)	X	X	X	X
Veterinary services				X
Owners of free ranging livestock	X			
Research institutes	X	X	X	X
Technology developers	X			X
Infrastructure developers (e.g., roads, airports, railroads, large electric systems etc.)				X
Operators of hunting tourism	X		X	

Target animal species

Species	Finland	Latvia	Norway	Poland
Elk	X	X	X	X
Deer	X	X		X
Row-deer	X	X		
Reindeer	X		X	
Wild boar	X	X		X
White-tailed deer	X			

Primary technologies

Technologies used for animal monitoring and characterization of environments	Finland	Latvia	Norway	Poland
Helicopter or airborne observations		X		X
Drones with thermal and multi-spectral cameras	X	X	X	X
Satellite and airborne images		X	X	
Airborne LIDAR data				
Game cameras / camera traps		X		
Sound detection technologies	X			X
Biosensors			X	X
Movement / vibration sensors				
GPS collars		X	X	X
GPS tags (for free-ranging livestock)				
Mobile applications				
IoT based tracking devices.				
Citizen science activities (snow tracking, camera traps, line tracking of birds)	X			
Artificial intelligence for software development		X		X
Transport vehicles as support in data collection or verification				X

Other data sources ___________________				

Primary parameters of interest

Animals-related parameters	**Finland**	**Latvia**	**Norway**	**Poland**
Population estimates	X	X	X	X
Animal species, sexes, age	X	X	X	X
Reproduction and survival (number of mothers and calves, survival rates)	X			
Animal health condition	X			X
Animal migration pattern	X	X	X	X
Detection of injured / killed animals.	X			
Grazing behavior	X	X	X	X
Animal disturbance	X	X		
Species distribution	X	X	X	
Animal threats	X			X

Environment-related	**Finland**	**Latvia**	**Norway**	**Poland**
Land use / land cover change detection.		X	X	X
Vegetation diversity	X	X	X	X
Biomass assessment				X
3D terrain and surface models		X		
Assessment of browsing damage (e.g., browsed tree-tops and stems in young forest stands)	X	X		
Monitoring fences built around forest stands.		X		
Presence of people / illegal activities (snow-scooters) in the areas of interest	X		X	X

Technology-related	**Finland**	**Latvia**	**Norway**	**Poland**
Data collection strategies and protocols (e.g., avoid animal disturbance, detect objects of interest)		X	X	X
Integration of data from various sources, data fusion, use of different databases (e.g., forest data)		X		X
Development of algorithms and workflows for automated data processing and analysis		X	X	X
Development of algorithms for data and image classification, discrimination of objects		X	X	
Hardware development (drone batteries; drone noise regulation (lowering and increasing)	X			
Management and processing of big data		X		X
GPS signal in blind spots				
Improved protocols for citizen science activities				X

Primary challenges / opportunities to be addressed by pilot activities

Challenges and opportunities	Finland	Latvia	Norway	Poland
Aging observers			X	X
Standard animal monitoring methods are resource-intensive and laborious.	X	X	X	X
Footprint observations are becoming difficult due to a decrease in snow-cover.		X	X	X
There are limited studies on selection and adaptation of the best counting methods for each species or a family of animals (e.g., invasive species such as wild-boar, small ungulates)	X	X	X	X
Remote sensing technologies have potential to supply data which was hard or impossible to obtain before	X	X	X	X

Expected impact of pilot activities

Impact	Finland	Latvia	Norway	Poland
Increased knowledge of higher precision wildlife management	X	X	X	X
Use of technology to obtain data that has not been available up to now.	X	X	X	X
Use of technology to reduce manual labor to ensure cost-efficiency.	X	X	X	X

Priority elements and items

Finland

1. **Drone based methods:** performance of drone monitoring in various terrains and environments, functionality such as flying height, monitoring wideness and range, use of IR and thermal cameras, cost-effectiveness of data collection, game-counting triangle done with drones.
2. **Sound detection:** detection of animal species and distance observations, algorithms of detection of vocal sounds and even sound of steps
3. **Game camera data collection:** citizen science data to a common platform, deer species identification

Norway

1. Pilot 1: Automatic detection and counts of wild reindeer from drone images, detecting reindeer herds from satellite images

2. Pilot 2: Using GPS positions of collared moose to test detection probability using drones equipped with thermal cameras in different habitats
3. Pilot 3: Flying the drones over GPS-collared moose at different heights and thereafter analyse the movement pattern from the GPS-positions and activity from acceleration sensors

Latvia

1. Pilot 1: Demonstration of the capability of drone for the assessment of deer and moose population in a target area

Steps to organize pilot activities

Finland

1. Common structure for all pilots (a manuscript) and plan how to invite other partners and stakeholders to participate via internet.
2. The two main pilots are implemented in Latvia and Norway; some tests are also performed in Finland. Finnish partners are interested in testing a game-counting triangle both with drones and human observation and comparing the results.

Norway

Pilot 1: Wild reindeer
The first step is the acquisition of both drone images of reindeer herds as well as cloud free satellite images of the area the reindeer herds were observed. Further, drone images will be analysed using automatic and supported classification. The herds then need to be identified on satellite images and the process of finding the herds needs to be automated on a suitable platform for use by management.

Pilot 2 and 3 Moose detection and disturbance
These two pilots can be combined in time and space. The activities will take place in Finnskogen, where there currently are 9 moose with GPS-collars that continuously send positioning data remotely to a map server (Figure 1). Three of these moose (E2001, E2002, E2003) are collared with GPS including acceleration sensors, whose collars will be retrieved in beginning of March to access the acceleration data. The field experiment has to take place before that, sometimes in February. We will for the field day change GPS-positioning from the regular hourly positions to positions every 10-15 minutes and so fly the drone at different heights over the most recent position of the moose. We will use two drones, our own with camera xx and the drone of IES. This will allow us to compare image quality.

Latvia

- Step 1: Develop a joint protocol that should be tested in all countries.
- Step 2: Define comparable test sites in all countries involving stakeholders.
- Step 3: Perform test flights with drones during different conditions (daytime, weather), including animal disturbance tests.
- Step 4: Perform reference data acquisition using a standard method for validation.

- Step 5: Demonstrate results to stakeholders during the international stakeholders' meet-up.

Poland

1. Presentation of Polish stakeholders technologies and data collection methods
2. Knowledge exchange with other partners
3. Networks development for future cooperation
4. Events organized in the form of webinar to get ready for international cooperation and to disseminate results of pilots