Handbook

Drones in Biomonitoring

From Buy To Fly

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IMPRESSUM

This handbook is the main output of the research project 'DROHNEN IM BIOMONITORING' (*DRONES FOR NATURE* - short *DroBio*) - research period 2020 – 2022.

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The legal statements are based on the author's research. No legal examination has been conducted as part of the project.

All recommendations regarding the mentioned hardware and software are based on the author's research and experiences. The technical developments in hardware and software, as well as changes in legal frameworks that, among other things, may affect availability and usability are subject to high dynamics. Therefore, the statements made may no longer be entirely accurate at a later date.

Therefore it´s essential to conduct own examinations and research on the current circumstances, conditions and legal framework.

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GLOSSARY AND ABBREVIATIONS

ASP *(Artenschutzprogramm)*	species conservation program
BAB *(Bundesautobahn)*	German federal highway
BMDV *(Bundesministerium für Digitales und Verkehr)*	Federal Ministry of Digital Affairs and Transport
BVLOS	**B**eyond **V**isual **L**ine of **S**ight
COLORED INFRA-RED (CIR) IMAGES	*CIR* imagery uses a portion of the electromagnetic spectrum known as *near infrared* that ranges from 0.70 µm to 1.0 µm, just beyond the wavelengths for the color red. CIR imagery is good at penetrating atmospheric haze and for determining the health of vegetation.
DB *(Deutsche Bahn)*	German Railroad
DFS *(Deutsche Flugsicherung)*	German Air Traffic Control Agency
DEM *(Digital Elevation Model)* ***DSM*** *(Digital Surface Model)*	earth surface with objects on it
DTM *(Digital Terrain Model)*	earth surface without objects on it
DOP	**D**igital **O**rtho**p**hoto
Drone	here synonym for ***RPAS*** = Remote Piloted Aerial System ***UAV*** = Uncrewed Aerial Vehicle ***UAS*** = Uncrewed Aerial System (flight platform + sensors
Double-Grid	mission of two raster flights flown in an angle of 90° to each other
FFH area *(Natura2000 area)*	area of the *NATURA 2000-NETWORK* of protected areas in the EU
FFH species	species of the *HABITATS DIRECTIVE* of the EU
FVA *(Forstliche Versuchsanstalt)*	Forest Research Institute Baden-Württemberg
Grid- *or* ***Raster flight***	a flight mission, where parallel flight lines, overlapping each other in adjustable percentages, are planned and flown over an area
Ground Control Point *(GCP)*	geodetic surveyed control point for georeferencing an ortophoto without flying in *RTK* mode
GROUND TRUTHING	verification of the objects detected in aerial photos by control sampling on the ground

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GNSS *(Global Navigation Satellite System)*	generic term for the totality of worldwide satellite navigation systems (American GPS, Russian GLONASS, European GALILEO, Chinese BeiDou, Japanese QZSS, Indian NAVIC)
HFR *(Hochschule für Forstwirtschaft Rottenburg)*	University of Applied Sciences Rottenburg
HSWT *(Hochschule Weihenstephan-Triesdorf)*	University of Applied Sciences Weihenstephan
AI	Artificial Intelligence
Kp-Index	Measurement of the magnetic effect of solar particle radiation (energy input from solar winds) → can influence navigation (compass influence) and control of drones
LAG *(Länderarbeitsgemeinschaft der Vogelschutzwarten)*	State Working Group of Bird Conservation Centers
LBA *(Luftfahrtbundesamt)*	German Federal Aviation Agency
LfU Bayern *(Bayerisches Landesamt für Umwelt)*	Bavarian State Office for Environment
LNV *(Landesnaturschutzverband)*	State Conservation Association
LUBW *(Landesanstalt für Umwelt Baden-Württemberg)*	Baden-Württemberg State Institute for the Environment
LuftVO *(Luftverordnung)*	German Air Regulation
NABU *(Naturschutzbund)*	Nature And Biodiversity Conservation Union
NDVI	***N****ormalized* ***D****ifference* ***V****egetation* ***I****ndex*
NOTAM *(Notice to Airmen)*	Notifications of changes, e.g. short-term and urgent orders, procedures and information for conducting a flight at the respective location. They appear irregularly and at short notice as required and inform about temporary flight restriction areas.
ORTHOPHOTO	a distortion-free and true-to-scale image of the earth's surface, created with the aid of photogrammetric methods from several individual aerial or satellite images
Overlap	overlapping of the photos to be taken in the direction of flight (front lap) and sideways (side lap) - necessary for photogrammetric processing

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Payload	physical add-ons such as additional or replaceable sensors
PHOTOGRAMMETRY	Measurement methods and evaluation procedures to indirectly determine the position and shape of objects by image measurement and to describe their contents by interpreting the images.
PPK *(Post Processing Kinematic)*	subsequent correction of the GPS signal by stored satellite position data
RGB *(**R**ed **G**reen **B**lue)*	the 'normal' color spectrum of conventional cameras
RTK *(**R**eal **T**ime **K**inematic)*	real-time correction of common errors of the GNSS signal via corrected satellite position data from a network of base stations - used in official surveying tasks
Spotter	observer of the air sapce and the drone supporting the pilot
SRTM *(**S**huttle **R**adar **T**opography **M**ission)* ***height***	a height model generated from satellite remote sensing data with a resolution of roughly 30 m (1 arcsecond - resolution of a height tile on the equator). Some flight planning apps can download these height models for terrain height-adjusted flying.
Terrain Awareness	terrain adapted flying at the same altitude above ground
VTOL *(Vertical Takeoff and Landing)*	a fixed-wing drone with vertical start and landing capabilities

For simplicity, the widely used term drone is used as a substitute for the terms ***UAV/UAS*** (Unmanned/Uncrewed/Unoccupied Aerial Vehicle/System), ***RPAS*** (Remotely Piloted Aircraft System), or similar.
It always refers in this text to a civilian aircraft, usually equipped with a sensor, mostly a camera.

PERSONAL THANKSGIVING

I would like to dedicate this manual to my father and dear family, who always support me
and especially to my wife, who allowed me all the heaps of time to write this manual.

Thanks also to several drone colleagues who critically reviewed the manual in advance - especially Tamara Wiesel for her particularly meticulous proofreading.

Herzlichen Dank!
Much obliged!
Steffen

MOTIVATION

"One only loves what one knows, and one only protects what one loves."

(Konrad Lorenz)

In a world where changes are progressing rapidly, it is of great importance that we are innovative in order to preserve our planet and especially our living conditions. The use of drones can contribute in many ways to increasing the effectiveness of environmental monitoring, reducing costs, and minimizing disturbances.

Only through the use of effective and cost-effective methods for data collection and analysis can we meet the increasing demands for diversity, quality, and evidence of monitoring data.

For this reason, this manual was developed to support nature conservation and facilitate tasks related to monitoring for authorities, planning offices, and field ecologists. The goal is to provide them with practical information and guidance on how to effectively utilize drones for their tasks and to help them fully leverage the potential of drone technology by offering tips for flight planning, sensor selection, data processing, and more.

The manual presents practical steps and provides recommendations for drone applications in biomonitoring, with the aim of ensuring that drone projects can be conducted efficiently and successfully from the beginning.

THE NEED OF MONITORING

Since the UN Conference in Rio de Janeiro in 1992, the global community has set a goal to significantly limit or mitigate processes that lead to biodiversity loss and to halt overall species extinction. Many countries, such as EU member states and Germany with its federal states, have been developing strategies and concrete concepts to achieve this goal.

The availability of real and up-to-date data on the current status of species or areas is a prerequisite for meaningful action. This can only be achieved through thorough initial assessment and subsequent regular monitoring of conditions, populations, and habitats.

Additionally, there has been a significant increase in the "demand for reliable data" for compatibility assessments, landscape management plans, strategic environmental assessments, environmental impact assessments, and specifically for the monitoring obligations according to Article 17 of the Habitats Directive (PRÖBSTL-HAIDER, 2013).

In addition, there are many new monitoring tasks such as mapping of open landscape biotopes, FFH mowing meadow mapping, HNV monitoring, insect monitoring etc. and often not enough personnel or resources for it (JEDICKE ET AL., 2024).

To ensure that the usually limited financial and human resources for monitoring are used efficiently and effectively, according to needs and requirements, it is essential to optimize (methodologically and financially) and standardize the applied monitoring methods (SCHMELLER ET AL., 2009).

The use of drones can contribute in various ways to increase the effectiveness of monitoring by reducing costs and often minimizing disturbances.

MONITORING-POSSIBILITIES WITH DRONES

The following publications provide a good overview of the diverse possibilities of using drones for conducting monitoring tasks:

- (ELTNER ET AL., 2022),
- (DUFFY ET AL., 2020),
- (JIMÉNEZ LÓPEZ & MULERO-PÁZMÁNY, 2019),
- (MANFREDA ET AL., 2018),
- (WHITEHEAD & HUGENHOLTZ, 2014),
- (WHITEHEAD ET AL., 2014).

During the research project *DroBio*, several of these deployment possibilities were examined. These examples are described in more detail below.

For each presented task, simple workflows were developed, and recommendations for successful implementation are provided.

MONITORING-CALENDER

The self-developed calendar (*Fig. 1*) is intended to provide a brief overview of possible monitoring topics according to the season. Depending on the time of year and phenological state, different tasks arise and/or the currently prevailing conditions should be captured.

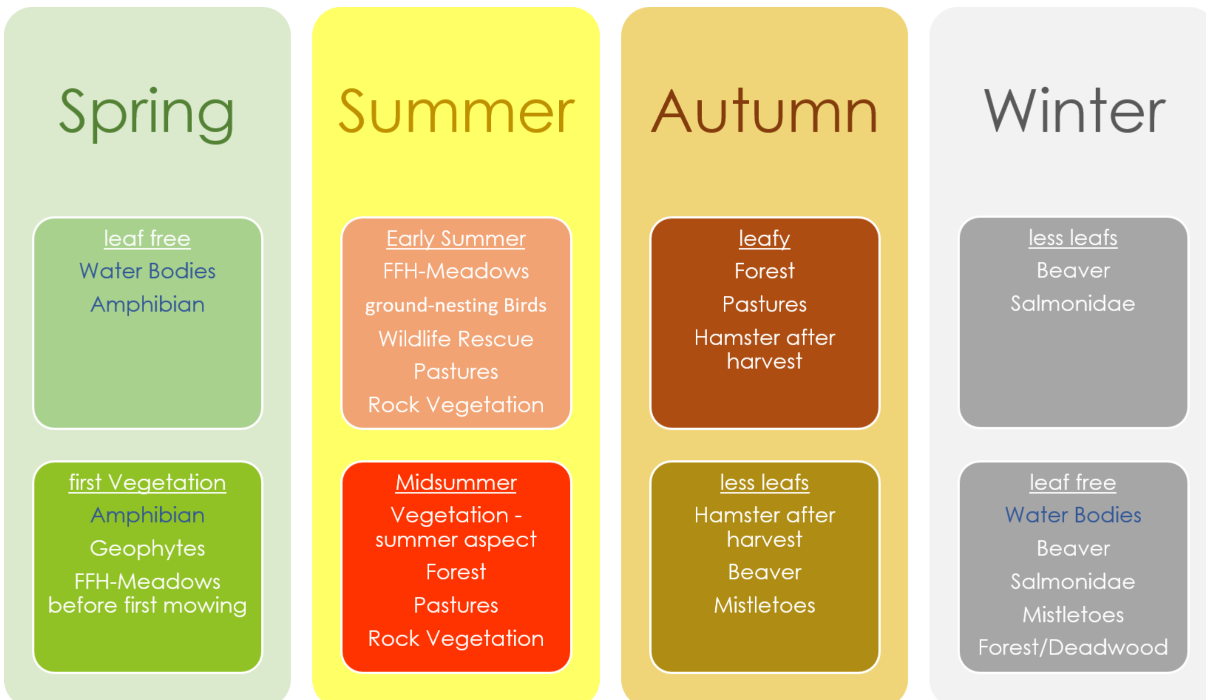

Fig. 1: Monitoring calendar (Döring, 2022)

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OVERVIEW

This manual aims to provide a comprehensive yet simple presentation of the necessary steps for the successful integration of drones in various applications of biodiversity monitoring.

In the more extensive *FINAL PUBLIC REPORT*, the information on many aspects is further expanded and enriched with additional details, explanations, examples, and discussions, including some challenges.

Fig. 2 illustrates the sequence of data collection using drones. The manual is largely structured based on these steps.

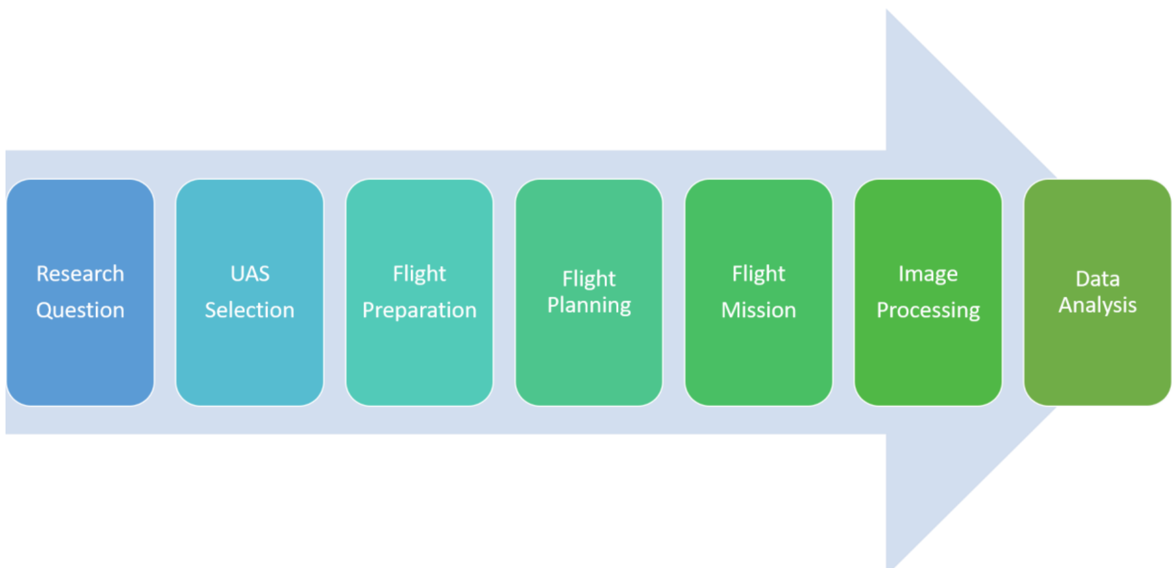

Fig. 2: Workflow of Drone monitoring (Döring, 2021)

01 BUY

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Before starting with drone monitoring, it is important to acquire the appropriate equipment.
The first step is to consider where and for what purpose the drone will be used, how much money can be invested, and what sensors are needed. These factors are crucial in choosing the drone model and its associated equipment.
The following chapter provides a brief introduction to the key points that should be considered when purchasing a drone with suitable equipment that best meets the specified requirements.

REQUIREMENTS ANALYSIS

At the beginning of the considerations for purchasing a drone, it is advisable to conduct a thorough needs analysis. All interested colleagues (from other departments as well) should be involved to ensure that the best possible equipment can be acquired to cover a wide range of use cases.

The following questions can help and should be largely answered before making the final decision to purchase and deploy a drone or a specific model – created following DUFFY ET AL. (2020, S. 24 FF.).

How big is the average survey area?

If the average study areas are large, one must first make a fundamental decision between multicopters with limited flight time and less area covered (or need of more batteries) and fixed-wing aircraft with vertical take-off and landing (*VTOL*) capabilities and long flight times covering large areas.

Multicopter

Fixed-Wing/VTOL

Fixed Wing - VTOL
(SKYSCRAB, 2023)

Tailsitter - VTOL
(Dempewolf, 2023)

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How big are the smallest objects to survey?
Which resolution of the camera sensor is necessary for it and which flight height is intended or possible?

For the monitoring of very large areas, the combination of drone data with other remote sensing data such as satellite scenes or orthophotos from manned surveys - e.g. the national surveys - is recommended. However, the latter have in any case a lower temporal resolution - they are usually renewed only every 2 - 3 years.

The high-resolution drone data can be used to validate lower-resolution images - see (HORN, 2021), (FASSNACHT ET AL., 2021), (KIT, 2020).

If you want or need to fly as high as possible to get as much ground coverage as possible, you need a higher resolution camera on a more expensive carrier platform (*Multicopter* or *VTOL*) for the same ground resolution.

If you can also fly lower to improve resolution, a small 'off the shelf' drone will often suffice.

Multicopter  or Fixed-Wing, VTOL or hired crewed flights ?

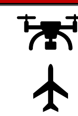
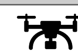
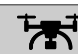
Scale/Size	the smalllest object to survey determines the resolution (area/pixel) and thereby flght height and ground coverage	
Area size	the bigger →	
Resolution	the higher →	
Area geometry	the tricky (e.g. narrow valleys) →	
	long small corridors (e.g. rivers, pipelines) and big 'easy' areas → often more ecomic →	
Time	the faster →	
Flight conditions	If homogenous survey conditions (time, light, water level etc.) are necessary for big areas and the survey has to be realized in short time →	
Tender offer or own flights, that is the big question here!		

Fig. 3: Decision support for choosing carrier platform (Döring, 2022, free Icons from UXWING)

Which absolute position accuracy is needed for the data?
Is the GNSS positioning system of 'normal' drones with 2 - 4 m position accuracy sufficient, or do you need surveying accuracies in the centimeter range?

For the latter a RTK/PPK-GNSS system is needed on the drone.

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Alternatively ground control points (*GCPs*) can be surveyed to georeference the drone images (*PIX4D, 2022B*).
For good elevation accuracies, there is no way around a RTK/PPK-GNSS system with direct or post processed correction capability and an accurate geoid model for the photogrammetry software (in Germany, the *GCG2016 OF THE BKG*).
Do you need different sensors /payload like RGB, multispectral or thermal on a regular basis?
If you want to alternate different sensors or even fly two different sensors at the same time on the same drone, you need a more expensive carrier platform - e.g., the *DJI M300* (DJI, 2022A).
But maybe it's better to take several of the small off-the-shelf drone models with only one fixed sensor system, which are cheaper, smaller, lighter and easier to handle and better to transport.
Which sensors do you really need - esp.in the beginning?
Often, the potential of 'normal' *RGB* images (red-green-blue color spectrum of conventional cameras) is not really exploited (*LARRINAGA & BROTONS, 2019*). RGB images can already be used to create a number of meaningful indices (see *VEGETATION MONITORING*), which are sufficient for many questions (*AGAPIOU, 2020*). In these two publications, (*L3HARRIS, 2022*) and (*SKYGLYPH, 2022*), there are descriptive compilations of different indices.
How necessary is the easy transportability of the equipment?
If the drone is often taken on foot into rough terrain for mapping work, then it should be as small and light as possible.
Carrier systems with more diverse sensor options are usually only transportable by car, as they are very large themselves and often require bulky accessories.
How much do you want to or can you spend?
For authorities or nature conservation associations, the acquisition of their own drones is recommended if there is little or no budget to hire external aerial services and if the expertise of their own staff can/should be expanded. The most economical use of drones is by the field ecologists/mappers themselves, as they can directly carry out the necessary ground truthing (= verification on the ground of the objects recorded from the air) in addition to the aerial surveys. **Is your budget big enough for** • **Drone** + equipment (esp. enough batteries + fireproof boxes, backpack, tablet or smartphone etc.), • most notably **costs + working time** for   ○ **education & training** (pilot licenses, flight training, software use and more)

  - **maintenance & management of the equipment** (battery & hardware service etc.)?

    These items should not be underestimated. Depending on the task and situation, the legal implications are considerable and the use of drones must be discussed intensively with the responsible parties (bosses, legal department etc. - since 07/2022 also concerning the authority agencies), so that the pilots + team are not only solely liable in case of irregularities.

    However, this requires at least one 'drone officer' who is well trained (legally and technically), keeps up to date and keeps the equipment in good shape - all of course in his working time as part of his fixed duties. He also takes care of the education and regular training of the colleagues/pilots - also calculated as working time.

- the necessary **Software** for flight planning, data processing etc., which can be expensive?
- the necessary often expensive **Hardware** (PC, Workstation or similar) **for data processing** (the more power, the better - *PHOTOGRAMMETRY-PROGRAMS*) and
- sufficient **data storage**?

Can the investment costs eventually be justified by better outputs or amortized by further orders e.g. from different departments?

Is there a potential clientele with potential demand in the targeted field of activity (conservation/other biomonitoring, surveying, construction)?

Opportunities for earnings, payback potential (by passing costs on to customers), and expanding markets for drone service providers are currently found primarily in construction, surveying, agriculture, and slowly increasing in the forestry environment.

The potential demand for drone services in biomonitoring, which predominantly includes government and conservation tasks, is currently rather rare. Since nature conservation does not generate profits, only (very) limited budgets are available.

What other departments or divisions within agencies or organizations may have a need for high resolution and often actual remote sensing data? Can the costs for acquisition for a drone, its equipment and its usage be shared among several interested parties?

First, it would be a good idea to conduct an interdepartmental needs assessment for remote sensing data in order to jointly procure the necessary equipment or commission flights.

By working together, the equipment is usually better utilized, which could increase the chances of approval for the acquisition.

DRONE TECHNOLOGY

Once you have decided to buy and deploy a drone, you need to decide which type of drone would be most appropriate for your intended purpose from a technical point of view.

Detailed explanations can be found e.g. in ELTNER ET AL. (2022, S. 37 FF.) or TMUŠIĆ ET AL. (2020).

Tab. 1: Classification of uncrewed flying platforms (Döring, 2022 after TMUŠIĆ ET AL., 2020)

<table>
<tr><th>Platform</th><th>Advantages/Disadvantages</th><th>flight time/
ground coverage</th></tr>
<tr><td colspan="3">Multicopter (electrical) - classic drone with 3 to 12 rotors (see above)</td></tr>
<tr><td rowspan="9">simple to handle,
off-the-shelf</td><td>high flexibility, quick deployable</td><td rowspan="9">flight time between ca. 20 to 40 min
ground coverage: several hectars - depending on flight height

Fig. 4: DroBio project drone (Döring, 2020)</td></tr>
<tr><td>high stability</td></tr>
<tr><td>easy handling</td></tr>
<tr><td>good transportability (e.g. backpack)</td></tr>
<tr><td>flexible height and speed envelope</td></tr>
<tr><td>hovering capable</td></tr>
<tr><td>less area coverage</td></tr>
<tr><td>wind sensitivity</td></tr>
<tr><td>Costs: ca. 500 - 6,000 €</td></tr>
<tr><td rowspan="6">different payload possible,
up to 25 kg</td><td>payload up to 10 kg</td><td rowspan="6">flight time depending amongst others on the payload – ca. 10 to 60 min
ground coverage: several hectars - depending on flight height
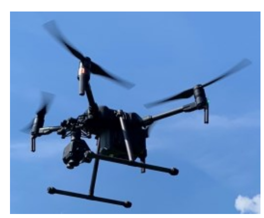
Fig. 5: LfU project drone (Mitterbacher & LfU Bayern, 2021)</td></tr>
<tr><td>versatile due to changeable sensors</td></tr>
<tr><td>heavier and bulkier - car necessary for transport</td></tr>
<tr><td>more permissions necessary</td></tr>
<tr><td>good planning recommended</td></tr>
<tr><td>Costs: ca. 10,000 - 40,000 €</td></tr>
<tr><td colspan="3">Fixed Wing aircraft (electrical) - similar to known model planes</td></tr>
<tr><td rowspan="5">depending on model - 2 or more sensors parallel deployable</td><td>in the style of conventional model airplanes with minimum 1 propeller for propulsion</td><td rowspan="5">flight time > 1 to several hours
ground coverage: several km² - depending on flight height</td></tr>
<tr><td>good ground coverage</td></tr>
<tr><td>hand launching possible</td></tr>
<tr><td>+ - higher flight speed necessary</td></tr>
<tr><td>enough landing place necessary</td></tr>
</table>

	flight planning more complex	 *Fig. 6: Fixed-wing aircraft (M. Paetzold)*
	more experienced pilot necessary	
	Costs: ca. **10,000 - 30,000 €**	
Hybrid *VTOL* (**V**ertical **T**ake-**O**ff and **L**anding)	3 up to 5 rotors for vertical, 1 to 3 propellers for horizontal propulsion	flight time **> 1 to several hours**, mostly less than simple fixed-wings through higher weight and air drag ground coverage: **several km²** - depending on flight height  *Fig. 7: VTOL (Skyscrab, 2020)*
	Vertical Take-Off and Landing	
	good ground coverage	
	hovering capable	
	flight planning more complex	
	more experienced pilot necessary	
	mechanical complex sytems	
	Costs: ca. **20,000 - 50,000 €**	

Various properties and elements of a drone are interrelated and determine both the price and the classification into different drone weight and price classes. The resolution, the quality and type of payload (esp. the additional weight of the sensors) increase the cost of transport and permissions, as well as the weight and price (see *Fig. 8*).

Fig. 8: Interrelations of different parameters with the drone type (Döring, 2021)

FOLDABLE MULTICOPTER -MODELS

The aim of the *DroBio* research project was to investigate the use of drone models that are quite affordable, as easy to use as possible, lightweight, legally less demanding, and easy to transport.

For this purpose, a foldable *DJI Mavic 2 Pro* was rented. Rented because no new equipment was budgeted in the project and in the rental price a warranty and the needed insurance were included.

Advantages of foldable drones

small + easy to transport (foldable, fit in small shoulder bags like a binocular)
easy **handling**
Sensors - are sufficient for most of the purposes envisaged here (the sensor size and thus the respective model must be selected according to the use cases)
legal less problematic through weight and size - see e.g. HERE or here FAA.GOV

Tab. 2 presents a selection of foldable copter models with their most important specifications. The websites with the complete specifications are linked in the headlines.

Tab. 2: Specifications of three foldable drone models (Döring, 2022)

	DJI Mavic 2 Pro	DJI Air 2S	DJI Mini 3 Pro
Weight	907 gr.	595 gr.	249 gr.
Camera	• 1" CMOS • Resolution: 20 MP	• 1" CMOS • Resolution: 20 MP	• 1/1,3" CMOS • 48 MP effective
Photo Formats	• JPEG • DNG (RAW)	• JPEG • DNG (RAW)	• JPEG • DNG (RAW)
Law	EU Drohnenverordnung für DJI Mavic 2 PRO / Zoom		• **under 250 gr/0.55 lb** → legal less demanding (drohnen.de, 2022b) or (FAA, 2024b) • e.g. visitor management
Particularities	end of life → successor model **Mavic 3** - the first drone model certified as **EU drone law compliant**	• obstacle sensors in all four directions • better for rock inspections	• small but good camera • tested by a survey company (Dannenbauer, 2022) with a good performance → suitable for survey and monitoring tasks
Alternative Models	Autel (EVO models) or Parrot (Anafi models) occasionally found in scientific publications. For DJI Alternativen no scientific publications have been found, nor are there any field reports from colleagues.		

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MODELS WITH OTHER SENSORS

The following drone models are also well suited for monitoring tasks in nature conservation, as they are easy to operate, light, transportable and still relatively affordable (< 10,000 €).
Some of them also allow to extend the spectrum of research possibilities by attaching other sensors with different wavelengths.
The less expensive models below 3,000 € are mostly all equipped only with RGB cameras.

Models up to about 6,000 € often have either a thermal or a multispectral camera plus an additional RGB camera for visual alignment installed.
Only from about 10,000 € onwards you can find carrier models where sensors and other payload can be exchanged - see SENSORS AS PAYLOAD.
There are only alternative models described which are in a similar price range below 10,000 €.

DJI Phantom 4 RTK

The *DJI Phantom 4 RTK* (*P4 RTK*) has been designed as a survey drone with its highly accurate satellite positioning system (*GNSS system*) and a 1" RGB camera. It enables to take photos with a positional accuracy of ≤ 5 cm horizontally and vertically, which mostly meets the requirements of survey data accuracy.
The position coordinates are corrected in real time in *RTK* (*Real Time Kinematic*) mode during the flight, but can also be corrected afterwards in a so-called post-processing kinematic (*PPK*) with the recorded satellite data.

More of correction methods in the publication "*UAVs for the environmental sciences*" (ELTNER ET AL., 2022, S. 87 FF.).
With a price of around 6,000 € it was not expensive for a survey grade tool (PRZYBILLA & BÄUMKER, 2020). Especially, because theoretically no control points are needed and therefore a lot of time for measuring can be saved.
However, it is recommended to always survey geodetically a few checkpoints for quality control.
In Tab. 3 the *P4 RTK* is compared with its successor the *DJI Mavic 3E*.

Tab. 3: DJI Phantom 4 RTK compared with Mavic 3E (after DJI, 2022*)*

Parameter	Phantom RTK	Mavic 3E
Survey accuracy	It fullfills the den ASPRS Class III accuracy standard for digital orthophotos. The actual accuracy depends on e.g. the light conditions, the flight height, the used software and other parameters.	1 cm + 1 ppm (horizontal), 1,5 cm + 1 ppm (vertical) Some user experiences • DJI-MAVIC-3-ENTERPRISE-RTK-REVIEW • DJI-MAVIC-3E
Ground solution (*GSD*)	flight height **100 m** = **GSD 2.3 cm**	flight height **100 m** = **GSD 2.7 cm**
Sensor	1" CMOS; 20 MP Pixel size = 2.4 µm	4/3" CMOS; 20 MP Pixel size = 3,3 µm Tele: 1/2" CMOS, 12 MP

high precision RTK GNSS	GPS: L1/L2 GLONASS: L1/L2 BeiDou: B1/B2 Galileo*: E1/E5a	GPS + Galileo + GLONASS + BeiDou Dual band L1 + L2
all Specifications	HTTPS://WWW.DJI.COM/PRODUCTS/CAMERA-DRONES#PHANTOM-SERIES	HTTPS://WWW.DJI.COM/PRODUCTS/CAMERA-DRONES#MAVIC-SERIES
Alternative	e.g. YUNEEC H850 RTK	

DJI Phantom Multispectral RTK

This drone, equipped with multispectral sensors, is, like the previous *Phantom RTK*, also a cost-efficient alternative for much more expensive carrier systems, where the multispectral or other sensors have to be purchased separately. (see SENSORS AS PAYLOAD).

It is relatively easy to operate, even for inexperienced users, and its integrated *RTK* system delivers highly accurate images (DI GENNARO ET AL., 2022). Its broad sensor spectrum (*multispectral*) is provided by six individual sensors (red, green, blue, red edge, near infrared - NIR, RGB).

It enables further research questions to be addressed, especially for vegetation studies (chlorophyll content, plant health etc.).

In Tab. 4 the *P4 Multispectral* is again compared to its successor the *DJI Mavic 3M*.

Tab. 4: DJI Phantom 4 Multispectral compared with Mavic 3M (after DJI, 2022)

Parameter	Phantom Multispectral	Mavic 3M
Sensors	**Sensors**: 6 × 1/2,9-Zoll-CMOS Pro Sensor: 2.08 MP (2.12 MP in total)	**RGB**: 4/3 CMOS, 20 MP **Multispectral:** 1/2,8" CMOS, 5 MP
Filters	Blue (B): 450 nm ± 16 nm Green (G): 560 nm ± 16 nm Red (R): 650 nm ± 16 nm Red Edge (RE): 730 nm ± 16 nm *NIR*: 840 nm ±26 nm	Green (G): 560 ±16 nm; Rot (R): 650 ±16 nm; Red Edge (RE): 730 ±16 nm; *NIR*: 860 ±26 nm;
high precision RTK-GNSS	GPS: L1/L2; GLONASS: L1/L2; BeiDou: B1/B2; Galileo [2]: E1/E5	GPS + Galileo + GLONASS + BeiDou alle Dualband L1 + L2
Ground solution (GSD)	(H/18,9) cm/pixel, H = flight height in relation to the surveyed area (unit: m)	
all Specifications	HTTPS://ENTERPRISE.DJI.COM/PHANTOM-4-RTK?SITE=ENTERPRISE&FROM=NAV	HTTPS://ENTERPRISE.DJI.COM/MAVIC-3-M?SITE=ENTERPRISE&FROM=NAV
Alternatives	Other solutions consist of a carrier model and an interchangeable or additional multispectral camera.	

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DJI Mavic 2 Enterprise Advanced - thermal drone

Until recently, the *DJI Mavic 2 Enterprise Advanced* (M2EA) was THE drone for wildlife monitoring and thermal inspections. It had only recently closed the gap between the former also quite cost-intensive systems with low-resolution thermal cameras (2,500 to 5,000 €) and the high-end systems, which still cost double and triple (10,000 € to 15,000 € and more).

At about €6,000 without accessories, it had established itself as a popular drone for wildlife rescue, in part because it is not difficult to operate and has the highest freely available resolution (640 × 512) with a high frame rate of 30 Hz. It has small dimensions, is foldable and easy to transport.

It was replaced by the new *DJI Mavic 3T* at the end of 2022.

In *Tab. 5* the *M2EA* is again shown side by side with its successor *DJI Mavic 3T*.

Tab. 5: DJI Mavic 2 EA compared with Mavic 3T (after DJI, 2022)

Parameter	Mavic 2 EA	Mavic 3T
Size (L × B × H)	folded: 214 × 91 × 84 mm unfolded: 322 × 242 × 84 mm	folded: 221 × 96,3 × 90,3 mm unfolded: 347,5 × 283 × 107,7 mm
Thermal-Sensor	uncooled VOx Microbolometer	uncooled VOx Microbolometer
Lens	ca. 9 mm - equivalent to 35 mm format: ca. 38 mm	equivalent to 35 mm format: 40 mm
Sensor resolution	640 × 512 mit 30Hz	640 × 512 mit 30Hz
RGB-camera	1/2"-CMOS Sensor with 48 MP Zoom: 32-fach	Tele: 1/2" CMOS, 12 MP Zoom: 8x (56x Hybridzoom) wide, tele- und thermal sensor better zoom - digital and thermal
Advantages COMPARISON	batteries of all Mavic 2 models interchangeable	longer flight time more security: object detection and distance sensors in all directions - omnidirectional binocular vision system compatibel wit the FLIGHTHUB 2 - real time and online streaming of the data (e.g. to the smartphones of the helpers during wildlife rescue) - quick intervention possible
all Specifications	HTTPS://WWW.DJI.COM/SUPPORT/PRODUCT/MAVIC-2-ENTERPRISE	HTTPS://ENTERPRISE.DJI.COM/MAVIC-3-ENTERPRISE?SITE=ENTERPRISE&FROM=NAV
Alternatives	DJI: MATRICE 30, Autel: EVO II DUAL 640T, EVO MAX 4T	

SENSORS AS PAYLOAD

However, if you opt for a higher-priced drone model with interchangeable sensors - e.g. DJI INSPIRE 2, DJI MATRICE 300 RTK, MATRICE 350 RTK, YUNEEC H850 RTK or drones made in Germany like from MICRODRONES, COPTING, CADMIC, MULTICOPTER , VECTORBIRDS oder EXABOTIX, you still have to choose the right sensor.
In a detailed meta-analysis two scientist compared the most used sensors with their respective specifications (JIMÉNEZ LÓPEZ & MULERO-PÁZMÁNY, 2019).
Each sensor has its individual resolution, bandwidth etc. which must be known in order to use it correctly and most effectively.
Most sensors are passive cameras with different spectral coverage ranges (Tab. 6).

Tab. 6: Sensors - costs and use cases (Döring, 2022), following JIMÉNEZ LÓPEZ & MULERO-PÁZMÁNY (2019) and TMUŠIĆ ET AL. (2020)

Spectrum	Type	Costs	possible use
RGB (camera) visible spectrum, 3 spectral bands (red, green, blue)	passive	50 – 50.000 € (e.g. Phase 1, 100 MP)	Aerial photography, (habitat) mapping, orthophotos, 3D modeling, inspection, wildlife observation (identification), landslide mapping, single tree mapping, videos ...
Thermal (camera) middle to long wave thermal infrared (MWIR, LWIR)	passive	3.000 - 6.000 €	Animal monitoring/searching, nest searching, forest fire detection, inspection, ground temperature, water temperature, soil water content, volcanology, plant stress, urban heat island mapping, monitoring/protection of objects or areas
Multispectral (camera) near infrared (NIR) 3 - 12 Bands	passive	3.000 - 6.000 €	Plant vitality, vegetation indices, water quality, geological surveys, classification studies
Hyperspektral (camera) many spectra - up to 100 bands	passive	several 10.000 €	Vegetation monitoring, plant physiology, plant phenotyping studies, biophysical surveys, ecological processes, forest/plant health, chlorophyll content, water quality, minerals mapping, insect infestation,
Laserscanning (*LiDAR-Scanner*) 1 - 2 spectra	active	12.000 - 250.000 €	3D models, topographic elevation models, forest inventory (structure, biomass, tree volume, crown/canopy height, leaf area index ...), erosion studies
see also - DRONE TECHNOLOGIES FOR CONSERVATION - (DUFFY ET AL., 2020, S. 24 FF.)			

SENSOR RESOLUTION

Especially when mapping with *RGB* sensors, often a high level of detail is important.

The Ground Solution Distance (*GSD*) indicates how many centimeters edge length a raster cell on the ground has in the resulting image.

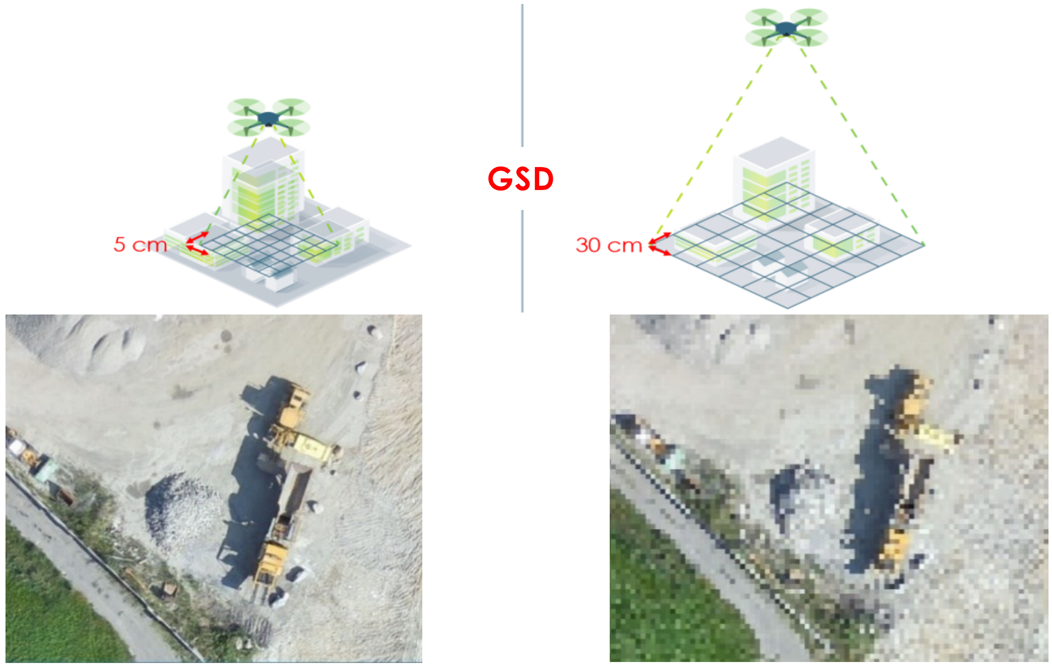

Fig. 9: Correlation between flight height and GSD (modified from PIX4D, 2019)

The resolution affects the representation of individual objects and generally the 'sharpness' of the image.
In *Fig. 9,* the machine, recorded with a GSD of 5 cm, is visible with clear details.

With a GSD of 30 cm, however, details are blurred.
This leads to the following conclusions for the same sensor:

lower flight height	**higher ground solution**
less efficiency through **more flight time per area →**	less ground coverage/battery
higher flight height	**less ground solution**
more efficiency through **less flight time per area →**	more ground coverage/battery

Objects that are smaller than the ground resolution (GSD) are only displayed with/in one pixel. That means they are no longer recognizable as individual objects. This plays a role, for example, when you want to identify plants with the drone at species level.
One single object should be represented at least by 3 or more pixels.

In *Tab. 7*, the resolutions of the cameras of the foldable drones described above are compared at certain flight heights with that of the *Zenmuse P1* from *DJI*, representing a higher-resolution RGB sensors. This allows an estimation of the flight height and camera resolution required for the intended investigation.

Tab. 7: Resolution of drone sensors at different flight heights (Döring, 2021)

Drone / Sensor	Sensor Size	25 m	50 m	75 m	100 m
DJI Zenmuse P1 coverage	35.9 × 24 mm	**0.30 cm** (25 × 16 m)	**0.60 cm** (49 × 33 m)	**0.90 cm** (74 × 49 m)	**1.21 cm** (99 × 66 m)
DJI Mavic 2 Pro coverage	13.2 × 8.8 mm	**0.56 cm** (31 × 21 m)	**1.13 cm** (62 × 41 m)	**1.69 cm** (93 × 62 m)	**2.26 cm** (124 × 82 m)
DJI Air 2 S	13.2 × 8.8 mm	0.72 cm	1.44 cm	2.16 cm	2.88 cm
DJI Mini 3 Pro	9.7 × 7.3 mm	0.89 cm	1.79 cm	2.68 cm	3.57 cm
DJI Mini 2	6.3 × 4.7 mm	0.90 cm	1.80 cm	2.70 cm	3.60 cm

As you can see, even the smaller cameras already have a relatively high resolution and allow high-quality data to be recorded.
A big advantage of higher quality cameras is the size of their sensor. The larger the sensor, the more sensitive the camera is to light. But a larger sensor usually increases the data volume of the captured images by a considerable factor. This in turn has an effect on the storage space to be kept available and the processing (time and PC power) of the images.
Under adequate conditions with good light (see PARAMETERS FOR GOOD IMAGES), the smaller sensors are sufficient for most of our research.
At the end of the topic an example is given, which shows the relations between sensor (camera) and its resolution, the flight height and the possible ground coverage (*Tab. 8*).
The sensor described is one inch in size, the same like from the *Mavic 2 Pro*.

Tab. 8: Parameters of DJI Phantom 4 RTK (modified from AEROTAS, 2022A)

Flight height [m]	Resolution (GSD) [cm Pixel size]	Area coverage [ha]	horizontal accuracy [cm]	vertical accuracy [cm]
30	0,85	2,4	< 3	3
60	1,7	8	4	6
90	2,55	10	6,4	9
120	3,4	24	8,5	12

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NOTE

If here the information about models of the company DJI (Shenzhen DJI Sciences and Technologies Ltd.) predominates, this is not meant to be an advertisement. However, you can't avoid this company if you are looking for cost-efficient, reliable and easy-to-use drone models.
In recent years, the market for semi-professional drones (prosumer drones) with good quality and (semi-)professional usable cameras has tilted towards the Chinese manufacturer DJI - with 76% market share of commercial drone sales and 94% of the private customer sector. (*SIMMIE, 2021*).
The range of different models is wide (*KOPTER-PROFI, 2022C*) and in the price-performance ratio largely unbeatable (*BENOWITZ, 2021*). DJI is the global market leader, followed by four other companies (*STATISTA, 2022*). Some smaller provider together account for the remaining 11.2 % (Tab. 9).

Tab. 9: Drone manufacturer und market shares (following STATISTA, 2022)

Hersteller	Marktanteil 2021
DJI	76 %
Intel	4.1 %
Yuneec	3.6 %
3D Robotics	2.6 %
Parrot	2.5 %
Andere	11.2 %

EXCURSUS - DJI REMOTE CONTROL

For automated mapping tasks, you should definitely **buy the simple remote control** for the 'normal' DJI drone **models in conjunction with a smartphone or tablet → third-party apps for easy-to-plan grid flights only run on this control!**
Only the Enterprise models have DJI's own app *DJI Pilot* enabled on the smart remote controls/controllers with the option **for raster flights (mapping)**.
The installation 'via detours' and use of **external apps** (like e.g. *Litchi*) **on a 'normal' DJI smart controller can lead to the loss of warranty and insurance liability!**

USEFUL ADDITIONAL HARDWARE

The aircraft with its direct accessories is usually not sufficient to carry out all flying tasks effectively and comfortably.

The following equipment has proven its worth over the last few years in private and professional use and can be recommended without reservation:

Transport bag of **Fly More-Kits** - in the *DroBio* project the *Mavic 2 Fly More-Kit* (DJI, 2022b) was used and can be recommended.

The shoulder bags or whole kits are available for almost all DJI consumer drones. The bags are not much bigger than the drones themselves and allow to hang the drone, together with 2 additional batteries and the remote control, simply over the shoulder.

Backpack - most of the prosumer drones presented together with the necessary equipment can be taken well in a backpack and carried on foot.

These two have well-proven themselves in continuous use: the *Aviator Drohnen Rucksack D1* (Manfrotto, 2022) and the *DroneGuard Pro 450* (Lowepro, 2022)

Ground targets - for the measurement of ground control points briefly described above. Of this selection e.g. - *Ground targets for surveys* - the model *RSL512* can be recommended. It is painted on both sides and you can use either the dark or the brighter side according to the light conditions. They still fit in the backpacks and can even be used for takeoff and landing on uneven surfaces if necessary.

A **high accuracy multi-frequency GNSS** device is needed to survey the ground targets so that they can be used for georeferencing the photos when using a 'normal' drone without an RTK/PPK system.

One of the most econmic GNSS systems on the market is the *RTK Handheld Surveyor Kit* or the *RTK Calibrated Surveyor Kit* from ArduSimple (2022).

In Fig. 10 you can see a selfmade housing and velcro fixing to a smartphone of the original breakout board.

For surveying with RTK connection the free *SW Maps* or other apps are recommendable - *https://www.ardusimple.com/compatible-software*.

Fig. 10: GNSS-System (Döring, 2021)

- Of course, you should also think of enough **batteries** + **car charger** + **firesafe transport bag(s)** +
- one or more **powerbanks** to charge/operate the remote control or charge the smartphone on a long flight day +
- possibly a **sun protection visor** for the smartphone or tablet (used with the 'normal' remote control) should be thought of.

  DJI remote controls with their own monitor are normally bright enough to be read in full sunshine.

02 PREPARATIONS

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PREPARATION OF THE FLIGHTS

In June 2021, the rules for drones were standardized throughout Europe and the LUFTVO IN GERMANY was amended accordingly. Since it is part of the required proof of knowledge for all drone models that are suitable for monitoring, it is assumed to be known.

The quick guide "SCHNELL IN DIE LUFT" ("*Quick in the air*") on the new digital platform for unmanned aviation (***DIPUL***) of the German Federal Ministry of Digital Affairs and Transport (BMDV, 2022) provides the user with an easy introduction to the requirements for flying a drone in Germany.

Therefore, here (*Tab. 10*) shows only a brief overview of the most important rules (since 07/2022 also valid for all PUBLIC ADMINISTRATION AGENCIES):

Tab. 10: The new LUFTVO - short overview (Döring, 2022)

NEW	**Theory test + registration for drones > 250 grams** absolutely required)
	Liability insurance absolutely necessary!
	Uninterrupted unaided visual contact with the drone necessary.
NEW	Flight height up to **maximum 120 m** above ground level (*AGL*)
	Control zones/geozones must be checked in apps or on the PC and, if necessary, permits must be applied for (also valid AUTHORITIES)
NEW	depending on the weight - **Category 'Open' Operations** A1- A3 o A1: near persons o A2: secure distance to persons o A3: greater distance to persons
NEW	max. weight UAS = max. 25 kg

Checklists to remind you of the most important points, have been created for the stages leading to a successful flight mission. They can be printed, successively worked through and checked off.

All checklists have been created for further use and may be used without restrictions if the correct author information is given. The short versions for printing are attached at the end.

The first of the checklists provides guidance and recommendations on the general requirements for drone operations.

For regulations in many other countries, you can take a look on the site e.g. –

- GLOBAL DRONE REGULATIONS DATABASE or
- DRONEMADE | COUNTRY DRONE LAWS or
- UAVSYSTEMSINTERNATIONAL.COM.

For the **USA** there is the FAA website - GETTING STARTED | FAA.GOV with the most useful informations.

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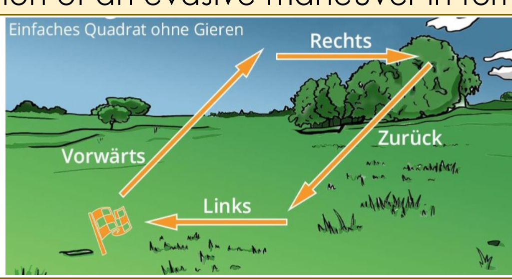
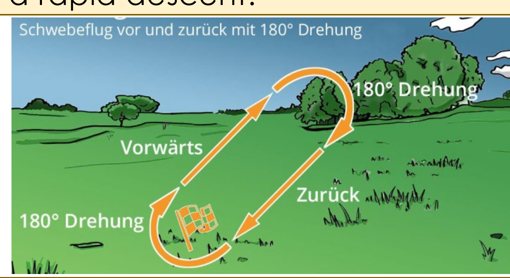
CHECKLIST - GENERAL REQUIREMENTS

CHECKLIST - GENERAL REQUIREMENTS	OK
The **EU proof of online training A1/A3** is basically required for drones > 250 gr. - but generally recommended for ALL drones to get started safely. The A1/A3 training can be taken with an online exam - *HTTPS://LBA-OPENUAV.DE.*	
The *EU A2 Pilot Certificate* can be taken at all *certified testing centers* in Germany, at some of them also online - see e.g. *DROHNEN.DE (2022C)* or for the USA - *The Recreational UAS Safety Test (TRUST)* (FAA, 2024A) The **A2 Pilot Certificate** builds on the A1/A3 certificate and can be **highly recommended** to more ambitious and professional pilots, as it can facilitate a lot in terms of flight opportunities!	
The obligatory registration of the **pilot/operator** can be made here – for Germany - *UAS-REGISTRATION.LBA* or for the USA - *FAA DroneZone (2024)*→ Drones have to be marked with the Operator-ID or **sending a Remote ID**!	
Liability insurance is in Germany required by law for all drones suitable for monitoring. Comparisons and offers can be found on the Internet - e.g. here bei DROHNEN.DE *(2024)* oder bei *KOPTER-PROFI (2024)*. However, for many operators in Germany, **a commercial liability insurance for the drone is recommended**- see *Versichertedrohne Magazin (2022)*. All activities (e.g. monitoring or fawn rescue) that are not for pure recreational activities can be understood as commercial by insurance companies or in general - for the USA see (*FAA, 2024C*).	
It is always necessary to train yourself to control the drone safely! For this purpose, it is mandatory that the pilot is well acquainted with the manual and the control commands for the drone, in order to be able to take over and land the drone manually in case of unforeseen incidents. For the A2 Pilot Certificate however a **practical self-training** is obligatory in Germany and has to be affirmed with a signature (*LBA, 2024*). **The ability to manually take over the drone must always be given** - e.g. in the always possible appearance of a helicopter and the necessary initiation of an evasive maneuver in form of a rapid descent!	





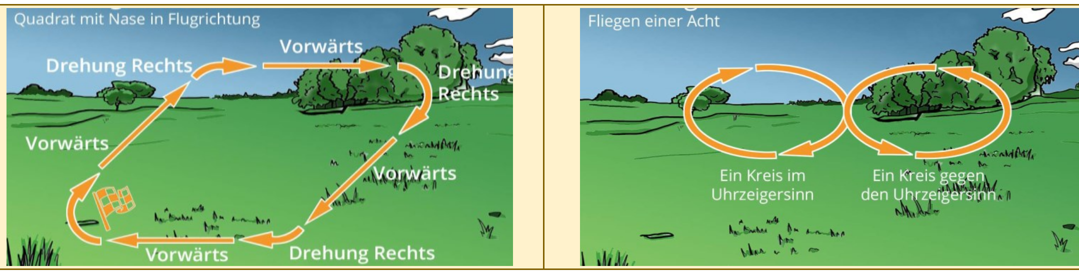


Fig. 11: Practical Flight Training (with permission of KOPTER-PROFI, 2021)

It is advisable to keep a **flight log** - for self-organization and as proof of flights made, which may be relevant for insurance issues. In Thuringia, for example, a flight log must be kept as part of a general order.

- **Flight log apps** - e.g. *AIRDATA UAV*, *DRONE LOGBOOK*, *KOPTER PROFI APP* (KOPTER-PROFI, 2022A), *DROHNEN FLUGBUCH - APP STORE* (APPLE, 2020)

PREPARATIONS OF A FLIGHT MISSION

In the context of specific surveys that are to be addressed through drone flights, meticulous mission planning is of paramount importance. The following checklist outlines essential aspects and measures to be considered when professionally preparing for a drone flight.

CHECKLIST - MISSION PREPARATION

Checklist - Mission Preparation	OK
Define the area of operation - e.g. a KML file from Google Earth! Useful • **to apply for permits**. • for flight planning - **can be loaded into most drone flight computers.** • **for wildlife rescue.** The area to be mowed can often be exported from the official agriculture GIS - **necessary for the common application** (in BW e.g. out of *FIONA*) **-** as ***SHP* file** and converted via *UAV editor* into a ***KML* file** for different drones - see chapter *WILDLIFE RESCUE*.	

Check the Geo-Zones! **PC** • The official Geoportals of the German federal states are the most reliable source of information on protected areas - see GEOPORTALS OF THE FEDERAL STATES. • The new website of the German Federal Ministry of Digital Affairs and Transport (*BMDV*) + *DFS (= German Air Traffic Control Agency)* DIPUL offers, among other things, a map tool and, according to the BMDV, **is legally compliant with regard to the location and number of geozones.** • FLYNEX is a private online map tool which equally offers the location and number of geozones, but without warranty. It can be used on a PC or as a handy app - MAP2FLY. • in the **USA** - B4UFLY | FEDERAL AVIATION ADMINISTRATION (FAA.GOV) **Smartphone Apps** • Two more apps - DRONIQ and KOPTER-PROFI. • in the **USA** - B4UFLY | FEDERAL AVIATION ADMINISTRATION (FAA.GOV)	
Check permission requirements! • Some German federal states have handed over approval authority to the Federal Aviation Authority (*LBA = Luftfahrtbundesamt*). You can see them in white fields in the table - LIST OF THE STATE AVIATION AUTHORITIES. • USA - GETTING STARTED | FAA.GOV • **Apply for permits in time!** Approval may need to be sought from the following entities (since 07/2022 also valid for all GERMAN PUBLIC ADMINISTRATION AGENCIES): • the responsible **nature conservation authorities** for flights in protected areas below 100 m • the **Operators of power grids** near high-voltage power lines • the **Railroad administration** near railway lines or • the **Highway administration** near high/freeways and • for **other protected airspaces the respective responsible authorities** - see DROHNEN.DE (2021)	

Contact local nature conservation area managers or associations!
• **For flights in protected areas, the responsible area managers should be involved,**
  o to promote acceptance,
  o to obtain important information about the area,
  o to get the necessary data and
  o to learn about the common survey methodology and to be able to tie in with it.	

Make the necessary methodological arrangements with clients! • If possible, tie in with existing methodology. • Research further necessary information. • Prepare **ground truthing** (checking on the ground the elements seen in the air - such as plant and animal species or other objects).	
Define the research questions well! • **Defining the size of the smallest object to be detected** → this **defines the necessary ground resolution (*GSD*)** – PIX4DCALCULATOR (recommendations for flight heights) → and helps to choose the necessary camera resolution and height • **Defining the Output**! o only 2D or in addition o 3D object models → then thinking of additional *oblique photos* (camera tilted downward in a angle of e.g. 75°)	
Define the sensor according to the research question. • **RGB, multispectral, thermal, resolution etc.**	
BAXTER & HAMILTON, (2018) already have summarized a number of these preliminary considerations and also taken into account economic considerations.	

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FLIGHT PLANNING ON THE PC

A significant part of the preparation of flight missions can be done at home or in the office.

The following steps are required and a few useful programs and websites are briefly presented, which we often used in the preparation.

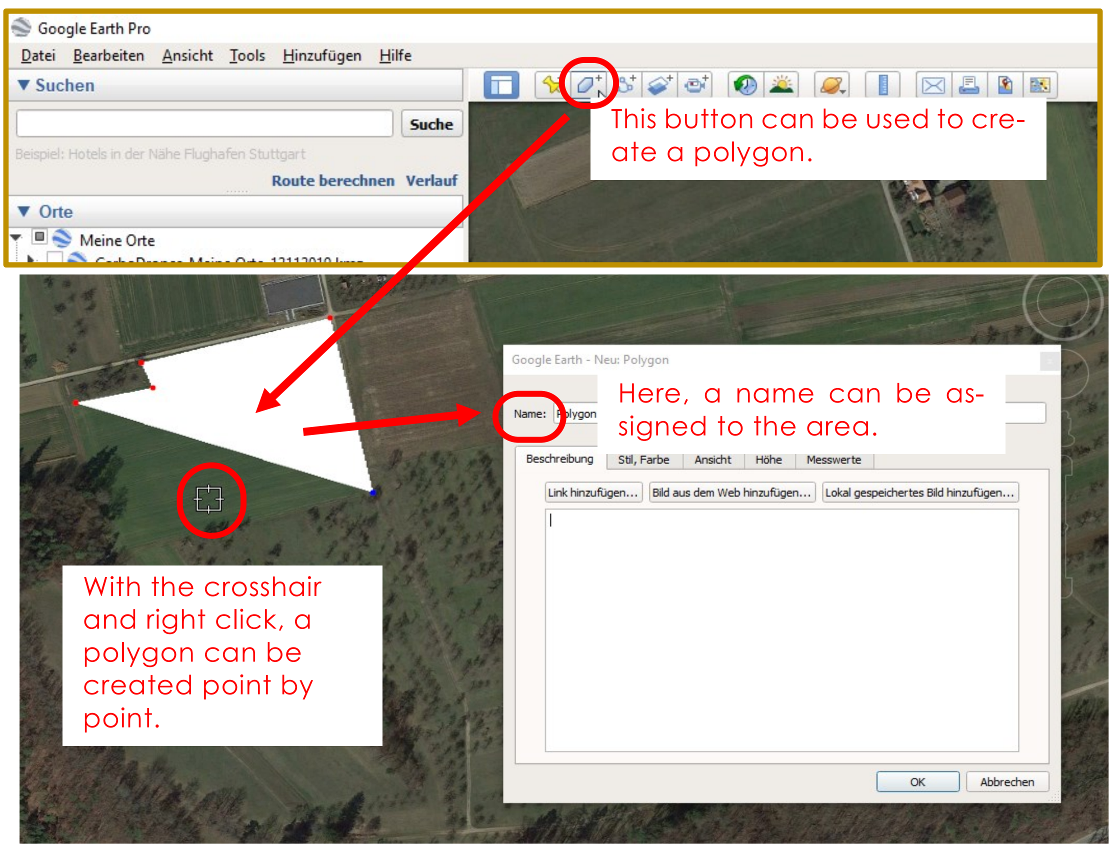
DEFINING THE FLIGHT AREA

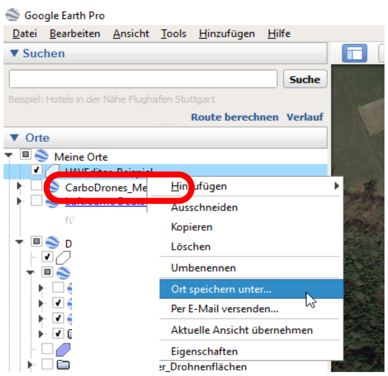
There are two simple ways to digitize the area of the survey area and export it in *KML* format.

A *KML* generated in this way can be imported into several flight planning apps and used as a basis for the planning.

Google Earth

With the cost-free GOOGLE EARTH e.g., survey areas can be created quite easily online (*Fig. 12*). These areas can then be exported in *KML* format for further use in flight planning - see also detailed instructions in the LBA GUIDE TO DIMENSIONING.





Right-click on the desired object under ***My Places*** (**Meine Orte** - outlined in red in Fig.12) to export the area as *KML*.

Right click

→ Save location as ...

→ select *KML* format

→ select desired folder

→ Save

Fig. 12: Screenshots from Google Earth (Döring, 2023)

QGIS

The cost-free open-source software QGIS can also be used to create areas for flight planning. The areas can then be exported as *KMLs* as well.

For this purpose, an area polygon is created and then the layer is exported with **Right-click → Export → Save vector layer as *KML***.

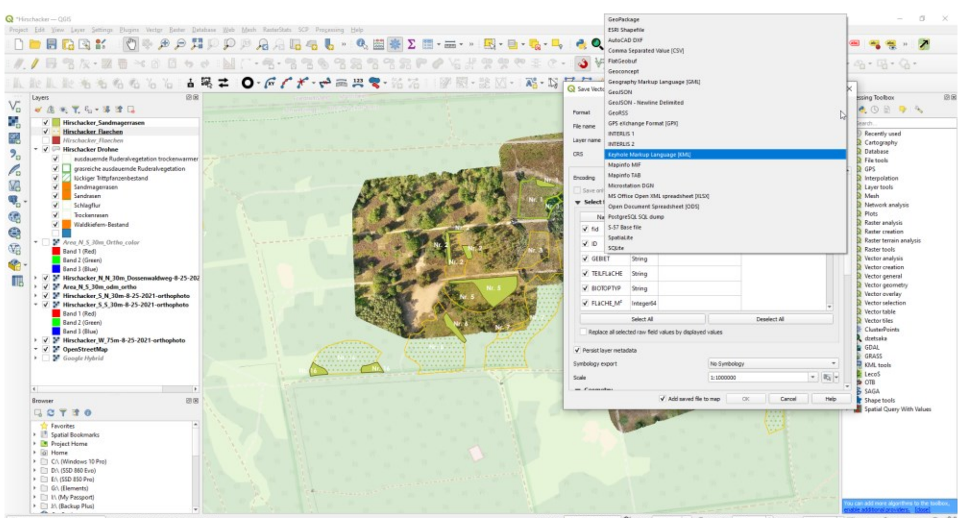


Fig. 13: QGIS – export layer as KML (Döring, 2021)

CHECKING GEOZONES

The next step is to check if the flight area is located in a **geozone** (geographical area of restricted airspaces) and therefore subject to legal restrictions.
There are several portals/websites to perform the check on the PC.
Not all information is displayed in the same way in all German portals (e.g. some portals or apps show less power lines than really exist in the area).
Since the transfer of information from official sources to private portals can vary in time, the actuality of the data in these portals also varies.
It is absolute recommendable to always consult several portals or websites to get more complete image of the reality in the operation area and to be safe.

Geoportals of the federal state environmental agencies

The geoportals of the federal states represent the most legally secure and up-to-date sources of information for protected areas, which are particularly relevant in biomonitoring. It is normally mandatory that they are always kept up to date.
The following list (*Tab. 11*) is intended to facilitate access to the geoportals.

Tab. 11: List of the official German States geoportals (Döring, 2021)

Baden-Württemberg	https://udo.lubw.baden-wuerttemberg.de/public/
Bayern	https://geoportal.bayern.de/bayernatlas/?lang=de&topic=ba&catalogNodes=11&bgLayer=atkis
Berlin	http://www.stadtentwicklung.berlin.de/geoinformation/fis-broker/
Brandenburg	https://geoportal.brandenburg.de/de/cms/portal/start/map/32
Bremen	https://www.gis.umwelt.bremen.de/webappbuilder/apps/15/
Hamburg	https://geoportal-hamburg.de/geo-online/
Hessen	https://www.geoportal.hessen.de/
Mecklenburg-Vorpommern	https://www.geoportal-mv.de/gaia/login.php
Niedersachsen	www.umwelt.niedersachsen.de
Nordrhein-Westfalen	https://www.geoportal.nrw/themenkarten
Rheinland-Pfalz	https://geodaten.naturschutz.rlp.de/kartendienste_naturschutz/
Saarland	https://geoportal.saarland.de/mapbender/frames/index.php?lang=de&gui_id=Geoportal-SL-2020&WMC=2988
Sachsen	https://geoportal.sachsen.de/cps/karte.html?showmap=true&service=https://geodienste.sachsen.de/iwms_gsz_schutzgebiete/guest?
Sachsen-Anhalt	https://lvwa.themenbrowser.de/UMN_LVWA/php/geoclient.php?name=naturschutz
Schleswig-Holstein	https://danord.gdi-sh.de/viewer/resources/apps/Anonym/index.html?lang=de#/
Thüringen	Karte: Karte Schutzgebiete - Kartendienst des TLUBN (thueringen.de)

dipul

The digital platform for unmanned aviation - DIPUL - is the new 'drone portal' of the German Federal Ministry of Digital Affairs and Transport. It is intended to bundle all relevant information on the subject of unmanned aviation - i.e. drones.

The site provides a map tool (a map page) on which the respective flight locations can be searched for and all geo zones relevant to them can be queried in accordance with § 21 h of the new German Air Traffic Regulations (*LuftVO*) (*Fig. 14*).

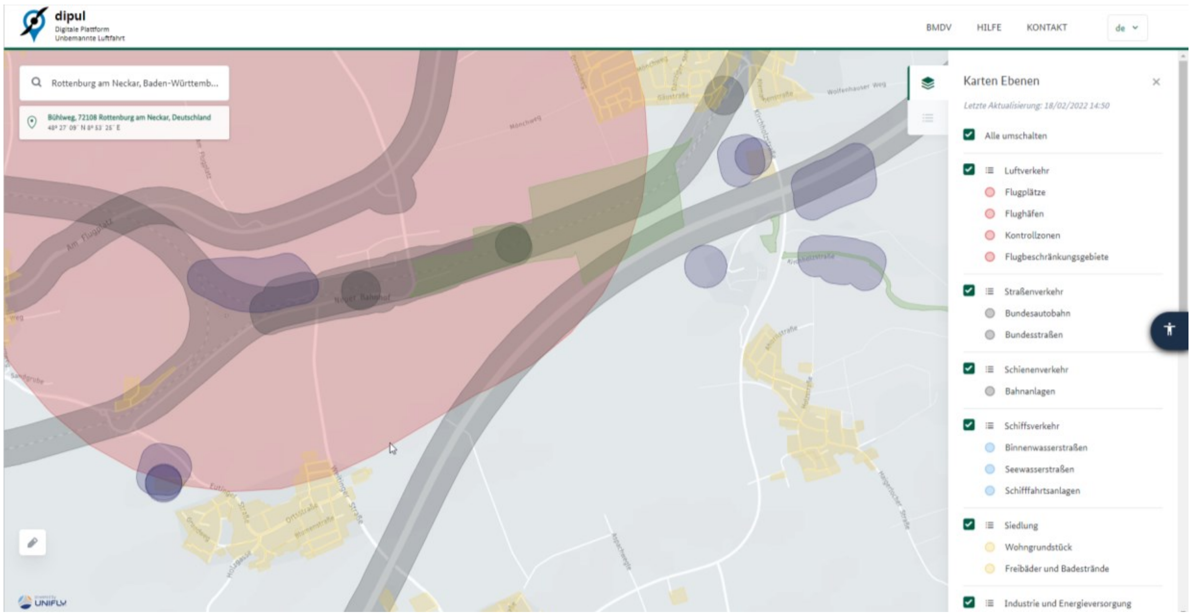


Fig. 14: dipul - Map tool for Geozones (DIPUL, 2024)

flynex

The private platform FLYNEX provides a similar map tool page where the respective flight locations can be searched and the relevant geo-zones can be queried.

Smartphone-Apps for Geozones

To be on the safe side, the geozones should be checked again in the field via smartphone apps.

The following apps for example are useful (*Tab. 12*):

Tab. 12: Apps for Geozones (Döring, 2022)

Map2Fly - MAP2FLY – GOOGLE PLAY - Desktop FLYNEX
Droniq - DRONIQ APP – GOOGLE PLAY – only App
Kopterprofi - KOPTER-PROFI APP – GOOGLE PLAY – only App
USA: B4UFLY | FEDERAL AVIATION ADMINISTRATION (FAA.GOV) – Apps & Desktop

List of the Aviation Authorities of the German federal States

Further information, e.g. on applications for ascent permits, can be viewed and submitted on the respective websites of the German aviation authorities of the federal states (*Tab. 13*).

Tab. 13: List of the Aviation Authorities of German federal States (Döring, 2021)

Graphical overview with applications: ENTRY INTO GEOGRAPHICAL ZONES | DIPUL	
Baden-Württemberg	LANDESLUFTFAHRTBEHÖRDE BADEN-WÜRTTEMBERG
Bayern	LANDESLUFTFAHRTBEHÖRDE BAYERN
Berlin	LANDESLUFTFAHRTBEHÖRDE BERLIN
Brandenburg	LANDESLUFTFAHRTBEHÖRDE BRANDENBURG
Bremen	LANDESLUFTFAHRTBEHÖRDE BREMEN
Hamburg	LANDESLUFTFAHRTBEHÖRDE HAMBURG
Hessen	LANDESLUFTFAHRTBEHÖRDE HESSEN
Mecklenburg-Vorpommern	LANDESLUFTFAHRTBEHÖRDE MECKLENBURG-VORPOMMERN
Niedersachsen	LANDESLUFTFAHRTBEHÖRDE NIEDERSACHSEN
Nordrhein-Westfalen	LANDESLUFTFAHRTBEHÖRDE NORDRHEIN-WESTFALEN
Rheinland-Pfalz	LANDESLUFTFAHRTBEHÖRDE RHEINLAND-PFALZ
Saarland	LANDESLUFTFAHRTBEHÖRDE SAARLAND
Sachsen	LANDESLUFTFAHRTBEHÖRDE SACHSEN
Sachsen-Anhalt	LANDESLUFTFAHRTBEHÖRDE SACHSEN-ANHALT
Schleswig-Holstein	LANDESLUFTFAHRTBEHÖRDE SCHLESWIG-HOLSTEIN
Thüringen	LANDESLUFTFAHRTBEHÖRDE THÜRINGEN

For the federal states in white boxes, the *Luftfahrt-Bundesamt* (*LBA*) is directly responsible for the application.
"Local jurisdiction is based on the applicant's principal place of residence in the case of natural persons, and on the applicant's registered office in the case of legal entities." (*LBA, 2023*)

International Regulations

A **list of international flight regulations** can be found on this website –

- GLOBAL DRONE REGULATIONS DATABASE , DRONEMADE | COUNTRY DRONE LAWS or UAVSYSTEMSINTERNATIONAL.COM

for the **USA** esp. here

B4UFLY | FEDERAL AVIATION ADMINISTRATION (FAA.GOV).

CHECKLIST - DIRECT FLIGHT PREPARATIONS

Checklist - Flight Preparations still in the office	OK
Copter Check • **Are software and firmware actual and concordant?** Technically ok? • **After updates, the basic settings must be checked in the remote controller!** (max. flight height, return to home (*RTH)* height - for save returning after the flight or when pressing the RTH button, sensors etc.)	
Load batteries and put them in a firesafe box. If necessary, battery car re-charger packed?	
Prepare the *KML* (and eventually a height model) **of the survey area** and loading it on the controller´s SD card.	
Cache the background map of the flight planning app - if there is an internet connection (in the office or in the field), it is possible to cache the map by zooming in and out (so that all the necessary tiles are loaded into the temporary memory at different zoom levels).	
Insert SD cards (controller and drone) and pocket **reserve** ones.	
Prepare (and pocket) **the log book** - paper book or prepare an app (DRONELOGBOOK, AIRDATA, KOPTER-PROFI …)	
Pocket licenses, insurance documents and **permissions.**	
Check the weather - on PC or in apps • UAV FORECAST - Wind data, GEOMAGNETIC DISTURBANCES (Kp-Index) - PC/App • KACHELMANNWETTER.COM - esp. Wind data - PC • WETTERONLINE.DE - 'simple' Wind data - PC • KOPTER PROFI APP - e.g. Geo zones, Kp-Index • USA – e.g. with weather forecast - App AUTOPYLOT.IO/B4UFLY/ or App/Desktop UASIDEKICK.COM/B4UFLY_LAANC/	
Pay attention to NOTAMs = NOTICE TO AIRMEN = news of potential hazards along a flight route or at a location that could affect the flight • Germany - e.g. AIS.DFS.DE or in DRONIQ-APP • USA - e.g. UASIDEKICK.COM/B4UFLY_LAANC/	
Pack further equipment (landing pads, barrier tape …)	
Pack *Ground Truthing* equipment and, if necessary, **survey equipment** (GNSS receiver, ground targets …)	
If necessary, **notify the nature conservation authority**, that has issued a permit of the flight, the day before by e-mail - especially to possibly reassure concerned citizens who ask, why someone is flying a drone in a protected area.	
Emergency contact list prepared and packed?	

FLIGHT LOGBOOK

WEATHER REPORT

Flight weather recommendations – s. PARAMETERS FOR GOOD IMAGES

- best uniform overcast (= uniform illumination, Sun means also shadows)
- low to no Wind speed
- Do NOT fly in high wind, rain, high Kp-Index (the electronics can be disturbed) or very low temperature (battery life)
- if possible, not with highly varying illumination (changing cloud coverage)

Useful Websites and Apps

- ***UAV FORECAST*** - Wind data, *GEOMAGNETIC DISTURBANCES* (Kp-Index) - **PC/App**
- *KOPTER PROFI APP* - Geozones, KP-Index - **App**
- *KACHELMANNWETTER.COM* - Wind data - **PC**
- *WETTERONLINE.DE* - 'simple' Wind data - **PC**

CHECKLIST - FLIGHT PREPARATIONS ON-SITE

Checklist - Flight Preparations on-site	OK
Check Geozones once more on-site via Apps: • in Germany e.g. MAP2FLY, KOPTER PROFI, DRONIQ • in the USA - B4UFLY | FEDERAL AVIATION ADMINISTRATION (FAA.GOV).	
Get an overview of the terrain and memorize it - of power-supply lines, obstacles (e.g. trees, buildings) … - in addition to the online maps or data. **Take the terrain** (hills, trees …) **into account** when setting the flight heights (RTH = return to home, mission height …).	
Choose and secure the starting place. • If possible, start from the highest point to have always enough distance to the ground and from obstacles! • Pay attention to the changing GSDs! • If necessary, secure the starting place yourself or arrange for necessary closures!	
Instruct your **team** and inform **present persons** of your flight plans!	
If an **airfield** is **nearby**, contact the control office by phone and, if requested, sign in and out for each flight.	
Prepare the drone. **Check the settings again** - esp. after updates: max. flight height, (*RTH* for safe return to home height after flight or by pressing the *RTH* button), sensors ...	

CHECKLIST - DURING THE FLIGHT

Checklist - During the Flight	**OK**
Keep the **hands always on the remote control**!	
Keep the **drone and the surrounding airspace always in sight**!	
Control the **flight parameters on the screen** (battery data, height ...)!	
In case of **danger** immediately take over **manual control** and **lower the drone** (e.g. on tree height when a Heli approaches) or bringing it back home!	
If a **bird attacks** steer the drone sharply upward and backward away from the bird and land if necessary!	
Manual control can be regained with DJI models by moving the flight mode lever (on the side) of the remote control quickly back and forth. This interrupts the mission and gives full control access again.	

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CHECKLIST AFTER THE FLIGHT

Checklist - After he Flight	OK
Remove closures of the **starting place**.	
Sign out by the **airfield control**.	
Fill in the **logbook** and noting **special occurrences**.	
If possible, save and **synchronize the flight plan** for further use.	
If necessary, sign out with the **nature conservation authority**.	

03 METHODOLOGY

METHODOLOGICAL CONSIDERATIONS

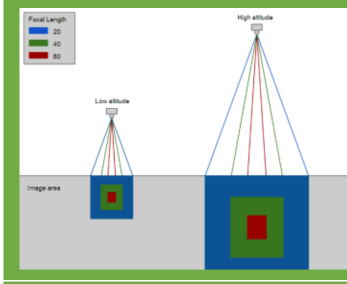
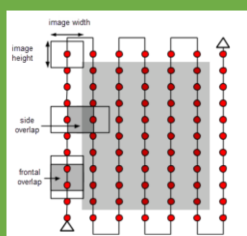
During the preparations, methodological considerations should be made and, if necessary, agreements reached with the clients. If possible, already established methods for the respective monitoring objective should be adopted or linked to. The following points (*Tab. 14*) should help to define the general conditions for the planned flights.

Tab. 14: Methodological considerations (Döring, 2022)

Conditions	Concrete Parameters
Time of the year	• Under which **phenological conditions** should be surveyed? • Plays the **flowering time** of certain plants a role? • Are the data better recorded in **leafy or in non-leafy conditions**?
Time of the day & Sun position	• For landscapes etc. it is best to fly around **midday** when the sun is highest = less shadows (e.g. cast by trees or objects). • Be aware that the **position of the sun** depends on the time of the year and the time of day! • For **thermal flights**, it is recommended that the temperature difference between the environment and the objects is as high as possible → flights recommended especially in the early morning hours!
Size of the flight area	• How many **batteries** are needed for the mission? • Should the flight area be divided, or does the flight app **remember the last point** before coming to change the battery and then return there? • The **starting point** should be chosen according to the terrain. If possible, you should start from the highest point to avoid getting into trouble on the return flight. → If you cannot automatically fly at a constant altitude above ground (***terrain following***), different flight heights will have a negative effect on the resolution of the orthophotos! • In order to keep the drone constantly in sight, it may be necessary to move the home (starting) point during the flight → most apps **update the home point** (pilot position) automatically.
Geozones	• Are **permissions** necessary in the area? • Is there an **airfield** or an **airport** near the flight area? Must the flight height be reduced?
Equipment	• Is **extra equipment** necessary - e.g. for *Ground Truthing* or for surveying of *GCPs*?

PARAMETERS FOR GOOD IMAGES

Tab. 15: Parameter for good images (Döring, 2022)

Parameter	Recommendations
Height 	• For highest possible **efficiency**, fly **as high as possible and as low as necessary**!
	• **Above forest and dense vegetation**, fly **as high as possible** in any case. The perspective distortion is then lower and similarities between the overlapping photos (*tie points*) are better detected = better photogrammetric results.
	• The **flight height** should be **adapted to the smallest object** being surveyed - see SENSOR RESOLUTION.
Overlap 	• For **Mapping missions** there should always been set at least 75 % frontward and 60 % sideward **overlap.**
	• Surveying **forests and dense vegetation** the **overlap** should set higher (**≥ 80 to 85 %**) for taking into account the complex and fine geometries of branches and leaves = better photogrammetric results.
	• When flying over relatively **monotonous structures** such as grassland, cornfields, lakes, sand, snow → choose **> 80 % overlap** = better or even primordial for getting any photogrammetric results at all.
	• In the case of **rivers and lakes**, always **include shoreline areas or some prominent structures** if possible. → Photos of pure water surfaces with strong reflection and waves can usually not be photogrammetrically assembled into an orthophoto.
Flight Speed  specified mostly in m/s (4 × m/s) - 10 % ≈ km/h	• The **flight speed** plays a major role, especially using cameras with an electronic shutter with line or column exposure (ROLLING-SHUTTER - as in most of the drones presented here). The movement of the drone can cause distortions (stretching of the objects or smearing effects) in the images. • The faster the drone flies and the worse light conditions or wind are, the stronger are the distortions.
	• Especially under **unfavorable conditions** (little light, wind etc.) the **speed** should be **reduced**!
	• Under optimal conditions the speed could be increased again.

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Weather	A good contrast in the photos should always be seeked.
	• Best flying with a uniform overcast sky.
	• A **cloudless and sunny sky** = often hard contours, shadows and wind.
	• **Partly cloudy** = most unfavorable through irregular illumination and cloud shadows in the photos.
	• **Best** to fly in **little to no wind** - especially when easily moving landscape elements (grasses, fine branches ...) are the focus of the survey!
	• Do NOT fly in high wind, rain, high Kp-Index (the electronics can be disturbed) or very low temperature (battery life).
Light	**There must always be enough light to produce good photos!**
	• **Too much and too bright light** can cause overexposure of the photos, many reflections, but also hard shadows, which can cause problems especially in the automated evaluation of orthophotos. → Therefore, the **camera settings** for the **white balance** should always be set in the apps to **cloudy or sunny** according to the current conditions.
	• If there is too little light during flights in twilight, the ISO values are set too high in automatic mode. This leads to noise (= grainy texture) in the photos and can impair the analysis. → **If possible, an ISO value as low as possible around 100 should be achieved.**
	• **The less light, the longer the shutter speed must be** (*Drones Made Easy, 2021*). But this can lead to distortion and smearing problems due to the airspeed.
	• Photos should be taken with the **shortest possible exposure time** and
	• with **sufficient and as uniform light as possible** or
	• preferably with **diffuse light on evenly cloudy days** (overcast sky) or
	• **on sunny days** mainly **around noon** (shortest shadows) **and without clouds** - because of larger shadows when the sun is lower (especially in winter).
	However, all these conditions can rarely be met surveying larger areas and with tight schedules → compromises have to be made!
	For further camera settings you should definitely know what you do, in order to really achieve better results!

OBLIQUE PHOTOS

Oblique images can help to improve the photogrammetric results.
For the high-priced drone models, oblique images are part of the flight missions, e.g. the 3D photogrammetry mission of the DJI Phantom RTK (Fig. 15). For this mission, one raster flight with the camera pointing 90° downward (*nadir*) and four more flights with the camera at a downward angle (*oblique*) are automatically performed. These ensure a lot of different views of the same object and thus its high accurate 3D reconstruction.
Oblique images can also be used to better capture steeply sloping terrain surfaces, canopy volumes in forests, vertical surfaces such as rock faces or the facades of buildings.

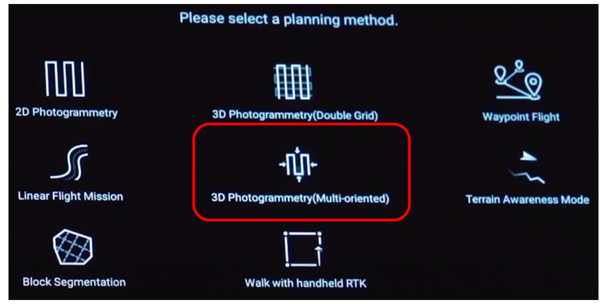

Fig. 15: Mission Options in the Phantom 4 RTK App (Döring, 2022)

Furthermore, they can also contribute to further stabilization of the image bundle (PRZIBYLLA, 2020) and to more height accuracy (DJI & KRULL, 2020).

Tab. 16 shows a number of possible application scenarios for oblique images.

Tab. 16: Application scenarios for oblique images (Döring, 2022)

Application scenarios	Advantages
Forest or **high Vegetation Monitoring**	• better structure recognition, volume and height estimation due to more 'insight' into the crown space (REDER; WAßERMANN & MUND., 2019) • detection of understory vegetation (PERROY; SULLIVAN & STEPHENSON., 2017)
Rock Monitoring	• Insight into niches, angles and platforms tilted backwards (STRUMIA ET AL., 2020)
River Monitoring	• better river bank view under vegetation (RUSNÁK ET AL., 2018)
3D-Models	• more viewing angles of complex structures like e.g. facades or rock walls (NESBIT & HUGENHOLTZ, 2019), (DRONEDEPLOY, 2022)
General Surveys	• For **more stable/accurate altitudes** a few oblique shots are often sufficient (DJI & KRULL, 2020). For example, one option on the DJI Phantom 4 is called ***RTK Altitude Optimization***. With this setting the drone flies from the end point of the mission into the center of the flight area and takes a few photos at an angle of 75°. These few shots are enough to achieve more stable and accurate altitudes.

APPS FOR FLIGHT PLANNING

Apps are required for any automated flight planning and often differ considerably in their scope of services. Most of the following apps were tested during the project, but MAP PILOT was mostly used during the flights (Tab. 17).

In comparison, this app has the most professional setting options with the best price-performance ratio.

Tab. 17: Flight Planning Apps (Döring, 2021)

Name	Costs	Handling	Website
MAP PILOT PRO	CA. 150 €/ YEAR PRO VERSION	• iOS & Android • VERSATILE + PROFESSIONAL USABLE: Terrain Awareness online (terrain adapted flying at the same altitude above ground), Corridor flight planning • Desktop Portal with area and flight administration • Online synchronization of the flights	HTTPS://WWW.MAPSMADEEASY.COM/MAP_PILOT/I HTTPS://APPS.APPLE.COM/US/APP/MAP-PILOT-PRO/ID1546656014
PIX4D-CAPTURE	ONLY A RESTRICTED DISCOVERY VERSION IS STILL COST-FREE.	• new Pro subscription version with more FEATURES: Terrain Awareness, Corridor missions … • PC planning	PIX4DCAPTURE PRO - PIX4D DOCUMENTATION
DRONELINK	CA. 299 €/YEAR BUSINESS STARTER	• FEATURES: Terrain Following, facade inspections • PC planning	https://dronelink.com/
DRONE HARMONY	FROM 33 $/MONTH STARTER VERSION	• VERSIONS: Android & iOS • FEATURES: Terrain Following, corridor missions, facade inspections • PC PLANNING	Test: https://www.remotevision.ch/der-grosse-drohnen-flug-planungs-app-vergleichstest/
DRONE DEPLOY	FROM $ 329/MONTH INDIVIDUAL VERSION	• Android & iOS • Features: Corridor missions, facade inspection, AI integration • PC planning, drone/pilot management • Online processing of the photos	https://www.dronedeploy.com/pricing.html

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04 PRAXIS

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After all the preparations, the first missions can finally be flown.
In order to facilitate the use of drones for monitoring tasks, this chapter compiles practical experiences on various issues from our own flights and scientific publications. In the conclusion of each example, recommendations are given to simplify the implementation of similar surveys.

DISTURBANCE ECOLOGY OF DRONE FLIGHTS

All flights in the project were coordinated with the responsible nature conservation authorities and decisions were made on the basis of the diagram in *Fig. 16* and in consultation with the responsible area administrations and area managers.
Particularly in the case of lower flight altitudes for certain monitoring scenarios, it is necessary to consider well

- at which time should be flown? In breeding, molting or other sensible seasons, the heights recommended in the disturbance ecology basic rules should be observed as far as possible.
- However, drone flights can even help to reduce disturbances compared to terrestrial survey methods and are even advocated by the German *State Working Group of Bird Conservation Centers (Länderarbeitsgemeinschaft der Vogelschutzwarten)*: "Positive aspects of drone technology should be actively used or advocated for nature conservation in compliance with nature conservation regulations." (*LAG VSW, 2023*).

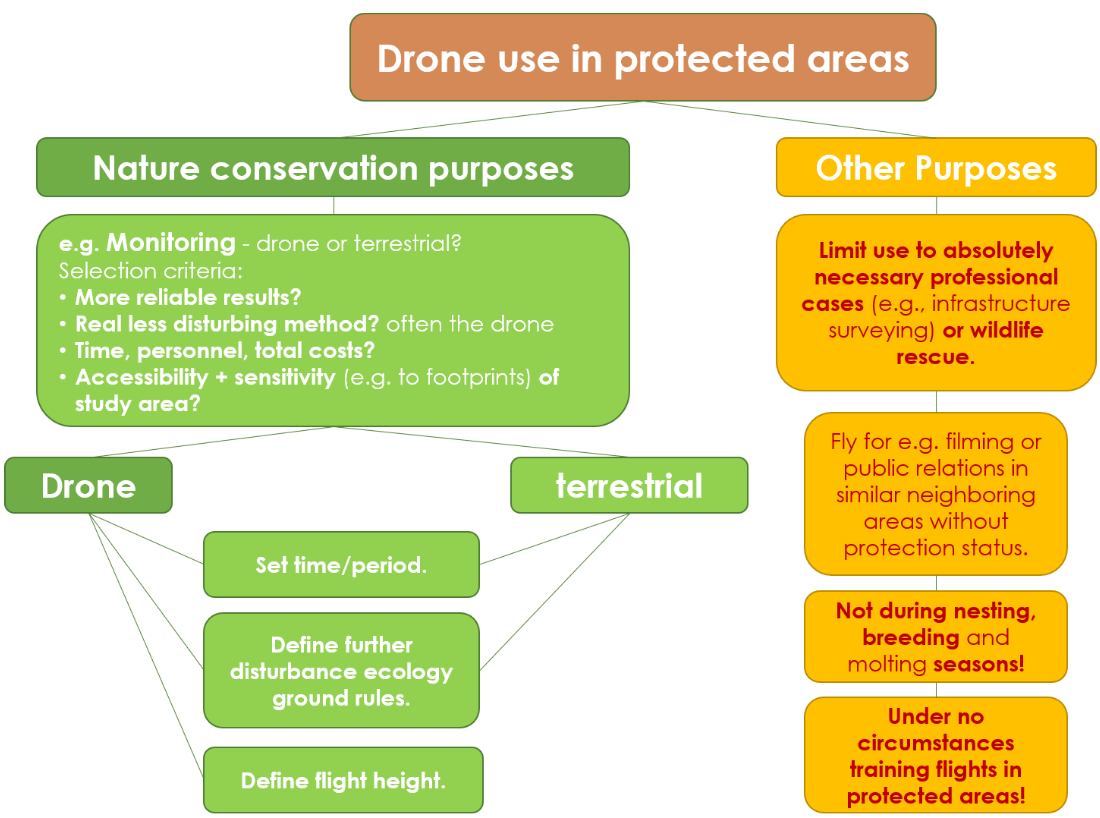

Fig. 16: Decision tree for drone flights in protected areas (Döring, 2022)

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DISTURBANCE ECOLOGY - BASIC RULES

Especially in protected areas, the following basic rules of disturbance ecology should ALWAYS be observed (Tab. 18**).**

These disturbance-ecological rules were compiled in cooperation with a colleague of the *Bavarian Bird Protection Institute* and external sources. They are published together with examples and further information in a document on the homepage of the Bavarian State Office for the Environment (*DÖRING & MITTERBACHER, 2022*).

The new position paper of the above mentioned *LAG* is based on this document and equally provides information and recommendations for the careful use of drones, especially for bird protection (*LAG VSW, 2023*).

All aerial surveys in protected areas, or for nature conservation purposes in general, should always be coordinated with the respective nature conservation authorities and area managers.

In this way, methods can be harmonized, standardized and cooperations promoted.

In the end, this will **contribute to a growing acceptance of professional drone operations for nature and species conservation**.

Tab. 18: Important rules for careful drone flights (DÖRING & MITTERBACHER, 2022)

The drone is used in protected areas exclusively for the purpose of nature conservation monitoring or the rescue of fawns, small game and ground nesting birds and preferably a training for Nature Conservation needs!. → **Flights for documentation purposes** (e.g. landscape surveys, vegetation monitoring) should be carried out, **if possible, only outside of nesting, breeding and molting seasons** (the latter: ducks/geese) **from August to January** (to be adapted to your area) and **away from visible bird concentrations!** → **Exceptions**: Strictly necessary professional use cases like e.g. infrastructure surveys (e.g. power line inspections) **with special permissions** from the nature conservation authorities **and a training course for Nature Conservation needs!** → **NEVER touch nests of ground nesting birds, only mark them** (e.g. *SIGNAL POLES*) and report them to the area managers!
Drone flights in protected areas, should be limited to the absolutely necessary extent of time and space. → **If possible, limit the areas to be flown over** by asking hunters or other knowledgeable persons about species occurrences or sightings. This helps to avoid unnecessary flights and reduces possible frustration due to a lack of detection success. → Areas that anyway are excluded from mowing or similar activities during the breeding season or areas in a contract nature conservation program (with measures such as later mowing, etc.), should not be flown over unnecessarily.
Only Drones as small as possible, quiet and electrically operated should be used.

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Quiet flight patterns with regular and smooth trajectories at a constant altitude are least disturbing.

→ **Avoid sudden changes of direction and rapid flight maneuvers near animals!**

→ **Direct approaches to animals must be avoided at all costs!**

In case of visible reactions of animals (nervousness, flight, attack, etc.), distance must be sought immediately and the drone flight aborted if necessary.

→ **In the event of attacks (e.g. by birds of prey), the drone must be quickly steered upwards and backward away from the bird**! If necessary, the drone flight in this area should be aborted for the moment. **Birds of prey** often hunt in a dive, so they are very fast downward, but normally cannot follow quickly upward.

Drone flights should be conducted at the maximum possible flight height at which the target species or objects can still be detected safely and effectively.

→ From a disturbance ecology and technical point of view, ≥ 40 m flight height is recommended so far – see (*LAG VSW, 2023*).

→ If it is necessary **to fly lower for methodological reasons** (e.g. detection of plants at species level), these flights should **preferably NOT** take place **during critical times such as molting or breeding periods** and/or should be **well coordinated with the area administration**.

If possible, the drone should take off and land only in less sensible areas that are already regularly frequented by people (roads, field paths, parking areas, etc.).

Flights for **landscape monitoring** or similar, which can be carried out on weekdays, **should**, if possible, **NOT** be carried out **on weekends, public holidays or during vacation periods** in areas with high visitor frequency in order **to reduce the risk of unauthorized imitation**.

→ **For wildlife rescue, however, only the time of mowing is decisive** - if this falls on a weekend due to weather conditions, of course it can be flown then as well.

Interested people passing-by should be actively informed about the special sense and purpose of drone flight for wildlife rescue or monitoring and **be made aware that drone flights in protected areas are absolutely prohibited for recreational purposes** or absolutely **require a permit** for other purposes.

Collaboration between the Nature Conservancy people and wildlife rescuers who have and use drones is highly recommended.

PRELIMINARY NOTE

For all of the following examples, further and more detailed information is available in the public final report of the associated research project - see the final research report DRONES IN BIOMONITORING.

OPEN LANDSCAPE MONITORING

INTRODUCTION

Capturing landscapes from drone imagery is one of the most widespread uses of drones in biomonitoring.

The following selection of topics for drone applications in landscape monitoring illustrates the wide range of possible uses: COASTS (MANGROVES) and MARINE HABITATS, GRASSLAND, SAVANNAS, WETLANDS, MOORLAND, RIVER-/RIVULET ECOSYSTEMS, GLACIERS, POLAR REGIONS, WASTE MONITORING IN THE OCEANS.

The most topics are cited out of the metaanalysis 'DRONES FOR CONSERVATION IN PROTECTED AREAS: PRESENT AND FUTURE' (*JIMÉNEZ LÓPEZ & MULERO-PÁZMÁNY, 2019*).

In our project 'Drones in Biomonitoring' (*DroBio*) different landscape types such as agricultural or semi-open pasture landscapes, rock faces, wetlands and bogs, water bodies and forests have been investigated with the help of drone imagery. Especially their status quo and structural changes among other objectives have been analyzed.

All flights in the project were coordinated with the responsible nature conservation authorities and respective area managers.

Grasslands are globally recognized as some of the most biodiverse ecosystems, with certain types, such as some limestone grasslands in Romania, rivaling the biodiversity of tropical rainforests on a small scale (WILSON ET AL., 2012). Unfortunately, many ecologically valuable grassland areas have been converted into urban development, agriculture, or forests in recent decades. Simultaneously, the remaining meadows and pastures have become less diverse in species due to intensive land use. To provide habitat for as many plant and animal species as possible, meadows and pastures should be mown or grazed sparingly and managed extensively, with little or no fertilization. Overuse or neglect can lead to the loss of these valuable habitats (*GIERCZAK, 2021*). Grassland soils also sequester a significant

amount of carbon, provide erosion protection, and contribute to groundwater protection (LAZBW, 2022).
Since the EU agricultural reform in 2013, the preservation of permanent grassland has been regulated through requirements for area-based direct payments. However, these obligations apply only to farms receiving direct payments. Some federal states, including Schleswig-Holstein, Mecklenburg-Western Pomerania, and Baden-Württemberg, have enacted their own legal regulations, known as grassland conversion bans, to prevent the conversion of grassland. Violations are subject to administrative penalties. However, only in Natura 2000 areas is there an absolute prohibition on conversion and plowing (UBA, 2022). Some grassland types are as priority habitat types directly protected under the EU Habitats Directive), such as the *lowland hay meadows* (6510 - p. 80) and the *mountain hay meadows* (6520 - p. 81). These habitats are subject to legal monitoring obligations, and the directive prohibits their deterioration.
Gilan et al. (2020) focused on developing indicators for assessing pastureland using RGB data and images from a multispectral camera mounted on the commonly used and cost-effective DJI Phantom drones. They compared the indicators derived from drone data, including vegetation height, coverage, and canopy gaps, with terrestrial observations of North American sagebrush steppe. The similarities were promising, and they provided recommendations for the effective use of drones in pastureland monitoring. They concluded that while drone data may not completely replace traditional methods, they do offer a cost-effective and easily deployable complement or alternative for many research questions. Moreover, they can capture new aerial perspectives and parameters, especially for larger areas, which are typically not covered comprehensively by terrestrial observations.
2019, the conference "Production-Integrated Compensation Measures" took place at Anhalt University of Applied Sciences, during which Pietsch et al. (2020) gave a presentation on the "Applications of remote sensing data in the monitoring and management of nature conservation measures on agricultural land." In their presentation, they emphasized the importance of:

- Monitoring changes within a vegetation period or over longer periods,
- Assessing plant populations in terms of quality, potential damage, causes thereof, species composition, etc.,
- Using surface models to derive developmental stages of existing vegetation units (e.g., heathlands, flower strips)

They were able to depict both the structural richness and plant diversity of fallow land and flower strips using UAV image data, based on the determination of flower colors. However, it also became clear that supplemental terrestrial vegetation surveys are indispensable for capturing selected target species that are difficult to discern in dense plant stands and determining their coverage levels.
Various publications on drones and grassland also deal with the remote sensing measurement of grassland yield. For instance, Bareth (2018), Lussem et al., (2019) and Lussem et al. (2020) achieved good photogrammetric height measurement results with conventional DJI Phantom drones. This enabled the estimation of grassland yields without physical contact (no trampling of the meadow compared to the rising plate method). Of course, factors such as species composition and mowing time play a role, making yield

predictions more challenging. However, the approach is promising, and the methodology will continue to be pursued. Similar approaches are also being pursued in the DiWenkLa project at the University of Hohenheim in the Southern Black Forest (DIWENKLA, 2022).
For an international overview, LYU ET AL. (2022) present a summary of application trends of UAV remote sensing in grassland ecosystem monitoring with the common UAV platforms and sensors. They reviewed the grassland application scenarios from five aspects: vegetation monitoring, animal surveys, soil physical and chemical monitoring, degradation monitoring and environmental disturbance monitoring. At the end, they summarize the momentary limitations and identify future development directions.

CONCLUSIONS

Tab. 19: Open Landscape monitoring - synopsis (Döring, 2021)

Open Landscape Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
Survey of • **Conditions** • **Structures** • **Changes** • **Habitats** • **Vegetation** - limited useful down to species level • **Control** flights	o **Raster flights** o **as high as possible**, as low as necessary to detect the smallest necessary object o **different flight altitudes** if necessary o **different sensors** o **eventually low-flying photos for species recognition** → to verify the species in orthophotos from a higher flight altitude	• high def. actual **Orthophotos** • **permanent Documentation** • **saves time** • **exact positioning** with multifrequency GNSS • **Multispectral-Analysis** possible • **3D-Point clouds** possible	o **Photos** - RGB, Multispectral, Thermal o **Orthophotos** o **3D-Models** o **Laserscans**

Tab. 20: Open landscape monitoring - recommendations (Döring, 2021)

Method/Parameter	Reason
It is essential to observe the DISTURBANCE ECOLOGY - BASIC RULES (especially in breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The PARAMETERS FOR GOOD IMAGES should always be observed.	
Most effective flight mode = **programmed grid flights** → Overlap = min. 75 % forward and 60 % sideways	A certain overlap is always required for usable orthophotos. - see PARAMETERS FOR GOOD IMAGES
Always fly as high as possible to avoid disturbances. → Additional photos flown at low altitudes can be used to detect and address species in photos from a larger and more effective flight height (verification of species). → If for methodological reasons (e.g. detection of plants at the species level) it is necessary to fly much lower, these **flights should preferably not take place in critical times such as nesting, breeding or molting periods and/or should always be well coordinated with the area conservation managers**.	The height should of course always chosen conform to the size of the smallest object to be examined. An object should be represented by at least three image/pixels to be recognizable at all. The efficiency increases with higher flight altitude, because the ground coverage becomes higher. see SENSOR RESOLUTION. Minimizing disturbance should be a priority. However, drone flights can even help to reduce disturbance compared to terrestrial survey methods (e.g. in wetlands) - see DISTURBANCE ECOLOGY OF DRONE FLIGHTS.
In the case of **monotonous structures** such as tall grass (land) - e.g. flower meadows with many overgrowing grass or cornfields, lakes, sand and snow, the **overlap should be increased** to **at least** → **85 % forward** and **70 % sideward**. → Ensure good contrast in images!	Photogrammetry programs often have problems, because they do not find clear connection (tie) points between the individual images in the case of very uniform structures. - see (PIX4D, 2022A) Therefore, include as much 'structure' as possible, such as bushes or trees in or at the edge of the area. Fly in good weather conditions - see PARAMETERS FOR GOOD IMAGES.
In the case of **rivers and lakes**, a section of the shore area should always be included if possible.	Pure water surfaces are also too uniform, reflect too strongly and/or have moving waves. Therefore, they usually do seldom allow orthophoto creation.

MOOR MONITORING

INTRODUCTION

Until the 17th century, peatlands were hostile and inaccessible to humans and remained largely untouched wilderness. During industrialization, peatlands were increasingly drained to make them useable for agriculture or forestry. Today, the remaining peatlands are highly endangered and hence equally the habitats of many typical and highly specialized animal and plant species. (BfN, 2022)

Many peatlands have been placed under protection due to their severe decline and continued endangerment. The national biodiversity strategy explicitly states the conservation and restoration of peatlands as a declared goal. With these protection efforts, a large part of the moors could be preserved, but most of the moors are strongly degraded and in many places their water balance is disturbed. Therefore, extensive maintenance and development measures are necessary in order to preserve and promote the biodiversity of the moors in the future. (Moorschutz in Deutschland; BfN, 2022)

The use of drones is an ideal supplementary method for moor monitoring. With drones, a contact-free and thus low-disturbance exploration and image recording of an entire area is possible. Well recognizable vegetation units can be recorded, differentiated, digitized and examined in further analyses.

However, to verify the objects captured by aerial photography, an accompanying terrestrial inspection by experts, known as ground truthing, must always be carried out.

It is most economical if these experts also carry out the aerial surveys themselves.

By using a self-configured drone, researchers have been able to develop a detailed guide for the detection, description and analysis of vegetation patterns in drone imagery for vegetation ecology questions. During aerial surveys of the Hörfeld marsh in 2016, different vegetation patterns were detected and classified (Hecke et al., 2018).

They differentiated

- intrinsic or species-immanent patterns of selected vegetation types on the basis of their growth form (e.g. tuft formation), intraspecific competition or the specific dispersal strategy of a species.
- The temporally different development of vegetation units and species in the seasonal course also revealed phenology-related patterns.
- Further site-related patterns could be detected by zonation at eco-logical gradients like humidity, by abiotic environmental factors like wind, water currents, (solar) radiation or mechanical disturbance (e.g. by avalanches).
- Furthermore, patterns due to extrinsic factors such as animal feeding, storage traces or excrement input and associated nutrient displacement were recognizable.
- Of course, anthropogenic use of the landscape such as mowing of meadows, afforestation and deliberate (fertilization, drainage, etc.) or accepted changes (e.g. nutrient inputs) of the ecological site factors also play a role.

Since 2012, an association in England has been using drones to protect moors and to study and map mountain moors in Yorkshire (*IUCN UK, 2020*). They use **high-resolution drone data to generate precise elevation models for analyzing surfaces and erosion processes, for hydrological modeling of runoff and cross-sections, and for planning re-watering measures**. The success of these measures is monitored after their implementation - again with the help of drone data. High-resolution RGB photos are used to create 3D models, for (automatized) vegetation monitoring and for planning intervention measures.

The peatland conservationists thus exploit the full range of classical methods of analyzing drone data. **Acquiring a drone and generating their own high-resolution data was cheaper for them and yields higher-quality data** than could be acquired commercially at a high price.

While the amount of data is a challenge in terms of storage and management, it is worth the effort as it allows the peatlands to be mapped and studied in previously impossible quality and depth. **According to the association, the use of drones has revolutionized the way it restores raised bogs.**

Groundwater connection is the goal of many wetland restoration projects. *Harvey et al., (2019)* in the USA used **a drone with a thermal camera to monitor restoration measures**, specifically to detect the necessary leakage of groundwater.

The flights were carried out in winter to map the temperature contrast between the cold surface water and the warmer groundwater that rises to the surface due to its lower density. With these so-called *TIR* (*Thermal InfraRed*) mappings, they were able to demonstrate the distribution of groundwater infiltration, its course and influence on already restored channels. **They recommend this technique for the planning and success control of renaturation measures.**

In Australia in 2018, an off-the-shelf *DJI Phantom 4 Pro* was used **to generate reliable elevation models to create hydrologic surface models** (*De Roos et al., 2018*). These were used **to plan the protection and regeneration of damaged peat moss stands (*Sphagnum*)**. These contribute essentially to the resilience of peatlands.

Also in 2018, *Liu & Abd-Elrahman (2018)* were able to improve **object-based image classification to analyze land cover in wetlands based on high-resolution**

drone imagery, yielding more accurate results.

High-resolution multisensorial drone data allowed Beyer & Grenzdörffer (2018) in Germany **to precisely classify the vegetation of a peatland using modern classifiers**. The multisensorial dataset, consisted of 14 individual datasets - namely RGB and multispectral, thermal images, a digital surface model (DEM) and several vegetation indices. Using an automated random forest classification approach, an overall accuracy of approximately 89% was achieved. The study showed that drones enable new data at the scale level between leaf and stand levels that are superior to conventional satellite and aircraft-based surveys.

Using an automated image classification approach and high-resolution drone data, Pande-Chhetri et al. (2017) in the U.S. successfully **analyzed wetland vegetation** already in 2017. However, the investigations were very time-consuming and required expert knowledge to calibrate the results.

Already in 2013, high-resolution Chabot & Bird (2013) used image **data from aerial surveys with a fixed-wing drone of wetlands for the protection of the American Little Bittern** (*Ixobrychus exilis*). They could identify and analyze relevant vegetation structures both visually and automatically. As a result, they recommended the use of drones for wetland monitoring.

As drone technology and its regulations and applications rapidly advance, it is difficult to provide simple and definitive practical guidance and action recommendations on the use of drones for mapping and monitoring wetlands. Therefore, Justyna Jeziorska (2019) has compiled a **recommendable overview reporting on drone hardware and software, regulations, scientific applications and procedures for data acquisition and processing in the context of wetland monitoring and hydrological modeling**.

In another very detailed study, **the status quo and emerging opportunities for drone operations in wetland surveys** were elaborated (Dronova et al., 2021). The focus was on **ecosystem management and the necessary scientific and technical research methods and data requirements**. *Dronova et al.* analyzed 122 case studies from 29 countries to determine how drone technology could best support monitoring and management objectives. The **analysis workflows** used for the drone data were also analyzed and systematically mapped.

CONCLUSIONS

Tab. 21: Moor Monitoring - synopsis (Döring, 2021)

Moor /Beaver Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
• **Area management** • **Change detection + documentation** • **Vegetation surveys** • **Renaturation of moors** • **Water body + Canal controls** • Beaver monitoring	○ **Manual flights** for video recordings ○ Automatic flights for entire area ○ **fly as high as possible** (≤ 120 m) for effective area coverage ○ **fly lower if necessary** for smaller study objects or close-up inspections ○ **Observe breeding and especially molting times!**	• **saves time** - compared to wading and BELLY-boating • **more effective and efficient** • **better overview** - especially over non-accessible areas • **less + shorter disturbance than terrestrial inspection** • permanent documentation	○ **Photos** - RGB, Multispectral, Thermal ○ **Videos** ○ eventually. Orthophotos

Tab. 22: Moor Monitoring - recommendations (Döring, 2021)

Method/Parameter	Reason
It is essential to observe the DISTURBANCE ECOLOGY - BASIC RULES (especially breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The PARAMETERS FOR GOOD IMAGES should always be observed.	
Most effective flight mode = **programmed grid flights** → Overlap = min. 75 % forward and 60 % sideways	A certain overlap is always required for usable orthophotos. - see PARAMETERS FOR GOOD IMAGES.
For pure inspection of dams or other infrastructure, manual flights are recommended - eventually with video recording or single photos. 	Manual flights allow a quicker inspection, since only a visual inspection is carried out - if necessary, a 'proof photo' can be shot. Individual objects can be approached more flexibly for closer inspection.

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Always fly as high as possible. → If necessary, lower flights can be made for closer inspection or for the investigation of smaller objects. → If you have to fly very low for methodological reasons (e.g. detection of plants at species level or beaver structures), these flights should preferably not take place during critical times such as moulting or breeding periods and/or should be well coordinated with the area managers.	The efficiency increases with higher flight altitude, because the ground coverage becomes higher. The altitude of course must be chosen according to the smallest object to be examined, which should be represented by at least 3 pixels - see SENSOR RESOLUTION. **Minimizing interference should be prioritized**. But drone flights may even contribute to the reduction of disturbance compared to terrestrial survey methods - e.g. in wetlands (MCKELLAR ET AL., 2021) or in general (LAG VSW, 2023).
For certain problems, the use of **multiple sensors** may be necessary.	Additional thermal or multispectral images can help generate better analyses and classification models.
Different camera angles → 90° Nadir and → approx. 75° tilted forward The professional *DJI Enterprise models* have their own 3D flight plans.	OBLIQUE PHOTOS can be used to better determine **volumes** of structures and to create better **3D models**. In addition, they contribute to better stabilization of the image bundle block and to greater **height accuracy** - important for accurately recording **dams**, **fill levels**, etc. in peatlands.

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FOREST MONITORING

INTRODUCTION

The possibilities for the use of drones in forest areas are very diverse and are already being tested/used more and more. Remote sensing in German forests initially began with the evaluation of satellite and aircraft data in connection with the forest dieback of the 1980s. In Germany it was mainly driven by the working group of forest aerial photograph interpreters (*AFL*) with members of different forest research institutions (*FVA, 2023*).

The use of drones as a tool for 'NEAR remote sensing' has gained a lot of momentum in recent years. Increasingly **dry summers** and **more frequent bark beetle infestations** make it **imperative to record stressed trees** or whole **stands**. Drones can facilitate this work and there are many projects and service providers on this topic.

In the Nationalpark (NP) *Bayerischer Wald* e.g. Drones have already been used since 2014 for research and monitoring tasks, especially of the bark beetle infestations (*keep.eu, 2014*). Using multisensorial UAV data from hyperspectral and thermal cameras and from laser scanners, stressed/bark beetle infested trees are detected and infestation progression is analyzed (*NP Bayerischer Wald, 2020*).

Good overviews of recent developments in the use of drones for forest health are provided by two publications - one from Germany *Ecke et al. (2022)* and another from Portugal *Duarte et al. (2022)*.

Ecke et al. analyzed 99 papers, Duarte et al. evaluated 49 publications. Many of the papers entail the use of small and off-the-shelf drones.

However, there is a tendency towards multisensorial solutions - with the use of multispectral cameras up to laser scanners, which in turn require heavier and more expensive carrier platforms (drones). There is also a trend towards increasingly complex evaluation methods.

Dempewolf et al. (2017) measured successfully the **tree height increment during the growing season** via surface models created from drone imagery of an older of-the-shelf drone (*DJI Phantom 3*).

The *DSMs* were used to calibrate forest growth models for research and management purposes.

Until now, the **recognition of tree species** from high-resolution drone photos has been a major challenge. By means of **artificial intelligence** (*AI*) such as e.g. in Schiefer et al. (2020) this method is constantly being refined and developed further in the direction of operationality.

The **proportion of deadwood in forests** is an important criterion for forest nature conservation. In the Hainich Nationalpark, Thiel et al. (2020) successfully surveyed the proportion of deadwood using high-resolution drone data. The method proofed more favorably than terrestrial surveys.

The **forest condition survey** (***WZE*** = Level I program of the Europe-wide and nationwide annual forest monitoring) and the use of drones for the collection of the data is the research topic of a cooperation project of the Bavarian State Institute for Forests and Forestry (*LWF*) together with the University of Applied Sciences Weihenstephan-Triesdorf (*HSWT*) (*LWF, 2020*). The health condition of the tree crowns is recorded by the percentage of leaf and needle loss, and represents a great financial and organizational challenge. The data are collected by specialized persons in week-long forest walks. The aim of the research project is to determine the economic efficiency of the use of drones, in order to make the conventional recording method more efficient.

Further projects of *LWF* & *HSWT* deal with topics such as the possible supplementation or substitution of parts of the equally time-consuming and expensive **forest inventory** (*LWF, 2019*), the assessment of **damage to black pines** (*Pegelow et al., 2021*), **drone-assisted plant seeding** in forests (*Meinhold & Göttlein, 2022*) and the use of **fixed-wing drones for monitoring in mountain forests** (*LWF, 2023*).

The Forest Research Institute (*FVA*) Baden-Württemberg has as well launched several drone projects. A study on the **derivation of forest inventory parameters** compared the analysis of **tree heights**, **crown radius** and **crown attachment height** from aerial images of different aircraft (airplane, gyrocopter, *UAV*) and *LiDAR* data (*UAV*) (*Ganz; Käber & Adler, 2019*). Tree height and crown radius could be reliably derived and the differences between the results from laser and photogrammetric data were smaller than expected. Since high point density is an important factor for successful derivation of individual tree attributes in photogrammetric data, the best results were obtained with the drone data due to the higher resolution. The results show that drones are powerful tools for the small-scale assessment of forest and tree properties and can at least complement existing remote sensing methods (*FVA, 2018*).

A **drone-based detection of forest dynamics** was developed in collaboration with the project "*Walddrohne*" ("*Forest Drone*") (*FVA, 2019*). The aim was to demonstrate the extent to which high-resolution drone imagery allows **accurate measurement of regeneration and ground vegetation heights**, often with very fine and complex structures.

In the **project "*NotRufDrohne*"** ("*EmergencyCallDrone*"), investigations are being carried out to support the forest rescue chain in forest areas with insufficient mobile phone coverage. A drone shall automatically ascend in forest areas with poor or non-existent ground reception, position itself above the canopy and make an emergency call. Furthermore should it be possible from the air to establish a mobile radio connection between first responders and rescue services ([FVA, 2020]).

The newest research project "***5G-Förster-Innendrohne***" (*"5G-ForesterDrone"*) deals with the automated use of drones for all possible forestry work processes in combination with 5G technology ([FVA, 2022]). Also being tested is the use of fixed-wing drones, which allow large-scale surveys of forest stands.

Already in 2014, **forest gaps** down to 1 m² in size could be detected from drone images . Thus, [GETZIN ET AL. (2014)] demonstrated a cost-efficient method for biodiversity monitoring in forests.

Gaps are important structural parameters and allow conclusions about the state of biodiversity in forest stands ([ZIELEWSKA-BÜTTNER ET AL., 2016])

For some time now, the Brandenburg State Forestry Office (*LFB*) has been regularly **using drones in its operational activities** and has established a professional drone management system.

With the help of drone data, it has already been possible to successfully answer a number of diverse questions. The worked-on topics include

- the survey of forest structures in fir, red oak and wild fruit trees
- multispectral aerial surveys of ash experimental plots
- systematic monitoring of leaf emergence, flowering and fructification of oak, European beech, bird cherry, wild service tree, wild pear and apple, pine, (Norway spruce)
- monitoring of stand establishment success (first afforestation)
- nursery surveys
- regular surveys of extensive forest damage (forest fire, windthrow, lightning)
- verification of clear-cutting
- Polter-/Timber pile surveys (3D)
- survey image flights on wildlife overpasses (green bridges)
- wildlife detection
- the use for *ASP* carcass search (*ASP* = African swine fever)

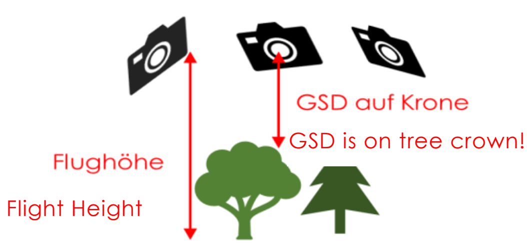
CONCLUSIONS

Tab. 23: Forest Monitoring - synopsis (Döring, 2021)

Forest Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
• **Forest** conditions, structure surveys, inventories, evaluations • Bark beetle infestation	o **raster flights** o **as high as possible** - otherwise problems with photogrammetry o Take **tree heights** into account! o **High overlap > 80%** for both directions	• **saves time** • **higher area coverage** compared to random sampling in terrestrial inventories • **multispectral analyses** → vegetation indices	o **Orthophotos** o **Images** - RGB, Multispectral, Thermal

• Tree species identification • Tree/plant seeding • Mistletoe monitoring • …	o **different camera angles** - 90° nadir and approx. 75° oblique - better 3D view of tree crowns and volume estimation o **without wind** (if possible) o **spotter** (if possible)	• **volume** and **mass** calculations • **precise localization** with multi-frequency GNSS • **permanent documentation**	o **Point Clouds** o **3D-Models** o **Laserscans**

Tab. 24: Forest Monitoring - recommendations (Döring, 2021)

Method/Parameter	Reason
It is essential to observe the **DISTURBANCE ECOLOGY - BASIC RULES** (especially breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The PARAMETERS FOR GOOD IMAGES should always be observed.	
Most effective way of flying = **programmed grid flights** Forest canopies often look like monotonous structures → **overlap min. 80 % in both directions** → **no wind if possible** → pay attention to **good contrast** in images	For usable orthophotos, a certain overlap is always needed - see PARAMETERS FOR GOOD IMAGES. Trees and dense vegetation have very complex structures due to their geometries (many branches, twigs and leaves), which makes it difficult for photogrammetry programs to find key points between the individual images - see (PIX4D, 2022A)
You should always fly as high as possible - see SENSOR RESOLUTION → **Take tree heights into account!**  	Efficiency is higher due to greater ground coverage. With greater flight height, perspective distortion is reduced and vegetation appears less complex. This makes it easier for the photogrammetry software to identify commonalities between overlapping images and define key (tie) points. For the **calculation of the resolution (GSD) on the canopy**, the **tree height must be subtracted from the flight height**.
Different camera angles	OBLIQUE IMAGES can be used to better capture crown spaces or more sloped

→ 90° Nadir and → approx. 75° tilted forward The professional DJI *Enterprise* models have their own 3D flight plans.	terrain surfaces. They are also useful for better volume determination and for better 3D models. Likewise, they contribute to further stabilization of the image bundle and height accuracy (DJI & KRULL, 2020).

Visibility plays a special role in forest monitoring (*Fig. 17*). The drone quickly gets out of sight in the forest, which is prohibited under normal circumstances according to the German Air Traffic Regulations (*LuftVO*).

If you want to increase the visibility (*Fig.* 18), you can, for example, **raise your position**. In the Hainich, researchers used the **viewing platform of the tree top trail** for this purpose (*HESE ET AL., 2019*).

Other scientists achieved similar things **using a cherry picker** (*QUANTUM SYSTEMS, 2018*). A third option that is (will be) possible according to the new EU regulations is the *APPLICATION* **to operate a drone beyond visual range (*BVLOS*) in the** *SPECIFIC CATEGORY*.

These measures can be used to fulfill the requirements during forest surveys with a drone.

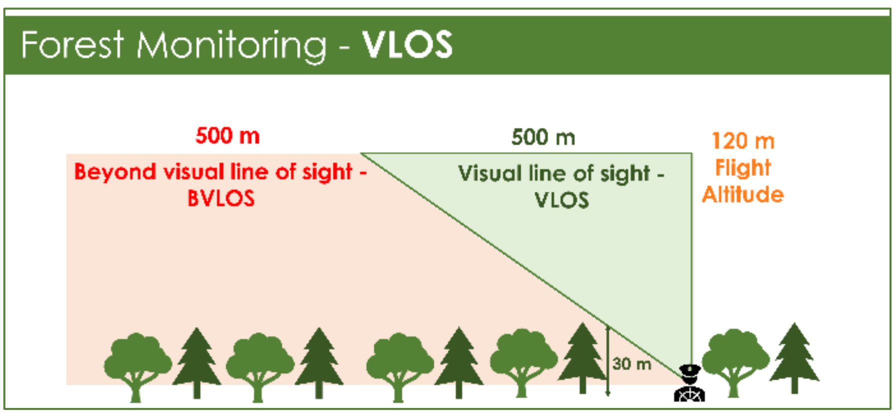


Fig. 17: Visibility of drones in the forest (Döring, 2022)

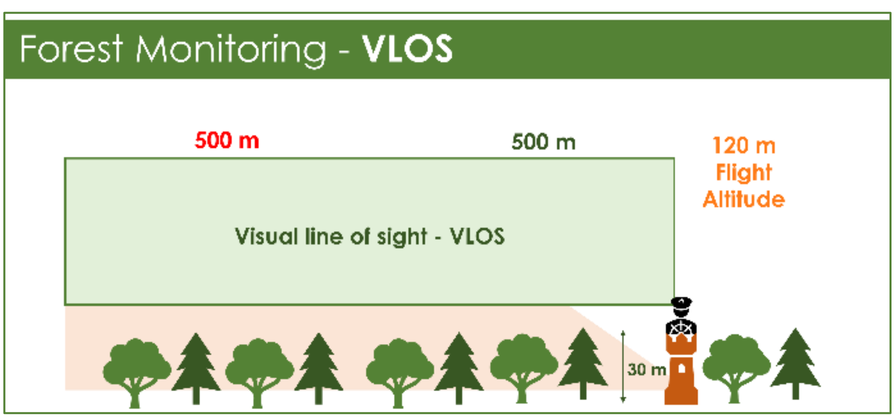


Fig. 18: Increasing drone visibility in the forest (Döring, 2022)

WATER BODY MONITORING

INTRODUCTION

The EC Water Framework Directive (*WFD*) was the first ecologically oriented directive in water protection in 2000. It aims to achieve a good ecological and chemical status of surface waters and a good ecological potential of morphologically heavily modified or artificial water bodies (*EU-RL 2000/60/EG*).

In Germany, surface waters and groundwater are regularly probed for control purposes as part of national and international monitoring programs (*UBA, 2017*).

The ecological status of surface waters is assessed in the *WFD* mainly according to the condition (presence, quality) of the respective natural habitat-typical biotic communities, i.e. the biological quality elements. Hydromorphological and physico-chemical characteristics are used to support the assessment (*UBA, 2022*).

The following parameters can be used to support the monitoring of water bodies by drone images:

- ***Biological quality elements*** *(such as* *Phytoplankton*, *Macrophytes / Phytobenthos*, *Macrozoobenthos* *and the* *Fish fauna*) *- especially the* ***mapping of macrophytes*** (*UBA & BuLAG Wasser, 2022a*).
- ***Hydromorphological quality elements*** - morphology, water balance and continuity - especially the width variation (the depth variation only to a limited extent) (*UBA & BuLAG Wasser, 2022c*).
- ***Structure and substrate of the river bed:*** *run development, flow velocities, substrate conditions*
- **Structure of the riparian zone:** structure and conditions of the riparian areas

Although these parameters are not primarily decisive for the assessment of stream status, their quality must be such that the biological quality elements can achieve a good status. Many fish species show a distinctive migratory behavior, as they have different demands on environmental factors such as flow, temperature and substrate depending on their life stage - reproduction, feeding, growth or hibernation (*RP Tübingen, 2019*).

The morphological condition of a watercourse is mainly determined by **mapping the structure of the watercourse**. **This mapping can be supplemented in many parts by drone data** and possibly even replaced in some cases. Finally, the deviation of the current from the potential

natural characteristics of the water structure is evaluated (UBA, 2017).
With the help of the "overview procedure" or the "on-site procedure" (UBA & BuLAG Wasser, 2022c) the level of deviation of the morphological condition from the potentially natural condition of a watercourse is divided into structural classes for small to medium-sized watercourses. For this purpose, particularly relevant structural elements with certain indicator properties are recorded (UBA, 2017).
In *Fig. 19* the structural parameters (red framed) can be easily recorded and evaluated with a drone - always provided that the bank vegetation allows the view from above! **Therefore, plan aerial flights in the foliage-free period!**
As always, recording with a drone has the advantage that a permanent and objectively measurable data basis is created.
For some of the questions, methods have already been developed. However, some of them are often only conditionally applicable, since their implementation would probably rather complicate the application and lead to an increase in costs. In a manual for high-resolution drone mapping of riverine landscapes the procedure was described in five steps (Rusnák et al., 2018):

- **Site reconnaissance on PC** together with **proof of compliance with legal requirements.**
- **Pre-flight field work**, if necessary, for high-precision measurement of ground control points for georeferencing of the drone images.
- The **actual flight mission** with automated and manual flights at different altitudes and the combination of nadir, oblique and horizontal images (for

Components Anne+B22+A+A3:C19 Art 1.1.1 WRRL (European Waterframework Directive)	Criteria Annex V, Art. 1.2.1 WRRL	Single parameter of the LAWA-Structure mapping small to medium sized Water Courses (LAWA 2019)
Structure of the Stream Bed	Development of the water course	course bending
		curvature erosion
		special course structures
	Flow Rate	current diversity
		backwater
		transverse benches.
Substrate of the riverbed	Substrate Conditions	substrate diversity
	Structure and substrate of bed	longitudinal benches
		special riverbed structures
Width Variation	Width variation	riparian strip
		profile type
		width variance
Depth Variation	Depth variation	profile depth
		depth variance
		lateral erosion
Structure of the riparian zone	Structure and Conditions of the riparian zone	riparian vegetation
		bank fixation
		special riparian structures

Fig. 19: Individual parameter of the quality component "Morphology" (UBA & BuLAG Wasser, 2022c)

better self-calibration of the camera and higher precision of the results - especially of the shore areas). This procedure requires a multiple of flight time.

- **Processing of the captured images** and subsequent quality check.
- **Analysis of the data** by classification of the point clouds and semi-automatic image classification using a training data set. However, this method requires a large effort, especially for non-specialists - see AUTOMATED ANALYZING TOOLS.

With the developed methodology, morphological structures, changes, the riparian areas and even relatively small dead wood of the river could be successfully recorded in the less vegetated areas and partially classified automatically.

English researchers compared in 2016 the resolution of drone data (orthophotos, elevation models and point clouds) with respect to their use in an automated classification model for hydromorphological data (specifically for use in the official ecological watercourse surveys discussed above). The resolution had a significant effect on the number of detected structures and objects as well as on the accuracy of their identification. (RIVAS CASADO ET AL., 2016). The following structures and objects were successfully detected and classified: Riparian banks, erosion areas, riffles/rapids/riffles, well-flowed stream channels, pools, shallow water zones, vegetation, and shadows.

Detailed definitions of the structures with explanatory pictures can be found here (GESCHÄFTSSTELLE GEWÄSSERÖKOLOGIE, 2022) or here (POTTGIESSER & MÜLLER, 2012).

Note: With our *Mavic 2 Pro* project drone, described above, the resolution of < 5 cm in the publication of Rivas-Casado et al. can be easily achieved or even undercut (usually rather < 3 cm) and thus the structures and objects described can be detected even better.

In an Italian project, GRACCHI ET AL. (2021) used a small drone to generate high-resolution data (elevation model, orthophotos and 3D models). These data allowed the successful, inexpensive and minimally invasive **detection of geomorphological changes** caused by stream dynamics **and vegetation changes** on an Italian river.

After a **dam removal**, in the context of a **river restoration**, EVANS ET AL. (2022) used images from an older commercial drone with a simple RGB camera (*DJI Phantom 3*) to represent the **changes at the landscape scale** more reliably than it would have been possible by terrestrial and moreover more cumbersome sampling in transect surveys alone. Even changes were recorded (more area covered) that would not have been detected at all due to the sampling character and the limited area coverage of the terrestrial surveys. This shows the importance of more flexible and new methods in monitoring at different scales as well.

In another study on hydromorphological issues, WOODGET ET AL. (2017) could show again that even for less experienced people and with commercially available drones, **continuous and high-resolution data acquisition of rivers** is relatively easy and cost-effective. In the study you can find a lot of advice on data acquisition and processing especially for remote sensing of water bodies and many other resources on the subject.

As described above, the biological quality elements are the main assessment parameter for the ecological status of surface waters. For this purpose, the habitat of invertebrates, fish, macrophytes and phytobenthos as well as that of the phytoplankton is assessed.

Macrophytes and **algae** could be successfully recorded by *Kislik et al. (2020)* with an off-the-shelf *DJI Phantom 4 Pro*, even underwater and in non-wadeable waters. In clear water macrophytes could be detected down to depths > 1 m Moreover, the data could be analyzed automatically. However, only the individual images could be used for this purpose, since the creation of orthophotos was problematic due to the large water areas - see *Conclusions*.

In Scotland, *Biggs et al. (2018)* surveyed also successfully macrophytes as key elements in river systems. Their extent, blocking effect and the plant size are important for river management in terms of habitat shaping, water resistance, sedimentation and monitoring of restoration measures. Terrestrial survey methods are time-intensive and therefore often spatially limited. In addition, they often have a lower spatial and detail resolution, which leads to an unsatisfactory data situation of the macrophyte distribution. However, **all mentioned parameters can be efficiently recorded by drone surveys**.

In her Master's thesis, *Sessanna (2019)* was able to demonstrate that the detection of submerged macrophytes of small streams in settlements and the **classification of adjacent land use** is possible using **multispectral data** from **aerial surveys**, digital image processing methods and **machine learning**.

The issue of capturing **moisture gradients** in the landscape has also been addressed by several publications. In their publication, *Araya et al. (2020)* surveyed natural grassland with a drone and a multispectral camera attached. From the RGB-channel images, a ***DEM*** was calculated and various terrain variables were derived from it. At the same time, the **soil moisture content** of the first 4 cm was measured at several control points. Subsequently, these measurements, the **multispectral images**, the **terrain data** and **meteorological data** such as precipitation and potential evapotranspiration (*PET*) were **combined** to program a **machine learning model**. This should eventually be able **to predict soil moisture** from the variables - naturally WITHOUT the measurements. The hydrological variables precipitation and *PET* turned out to be the most important parameters for predicting the soil moisture. However, according to the authors, the distribution of moisture probably depends more on the topographic variables from the *DEM*. The approach is promising, but further research is needed.

The use of drones with multispectral or thermal cameras is promising in water monitoring, but the processing and analysis of these data is not trivial and can hardly be undertaken without expert knowledge.

COMMON THEMES OF WATER BODY MONITORING

In addition to the hydromorphological quality elements of the *WFD* - morphology, water balance and passability (*UBA, 2017*), the following topics have additionally emerged in the course of the research and in contact with different actors:

- **Documentation & Monitoring** of **renaturations**
- **Habitat Mapping of flora + fauna** (e.g. beavers or fish - especially fish habitat

mapping and the search for spawning grounds)
- **Mapping of the course** of riparian lines
- **Recording of driftwood and deadwood** in the river bed

At the *State Fishing Association of Baden-Württemberg*, drones are already being used for various purposes in water inspection, among others:

- Estimation of the **cover of** submerged and also emergent **macrophytes**
- **Structural Reconnaissance** of standing and flowing waters
- **Documentation of the watercourse** of strongly meandering waters and in areas difficult to access
- **Search for spawning grounds** of salmon, sea trout and brown trout - mainly in December
- **Documentation of renaturation** at and in water bodies

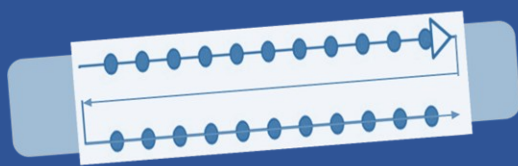
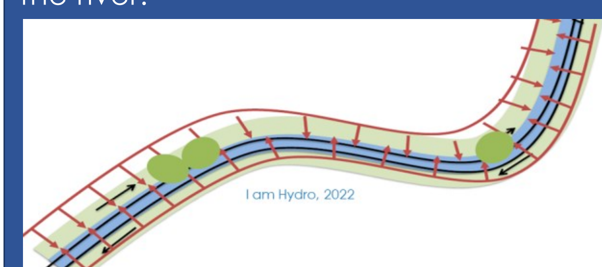
CONCLUSIONS

Tab. 25: Water Bodies/Salmon Monitoring - synopsis (Döring, 2021)

Stream and Salmon Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
• **River inspection** • **Monitoring changes** • **monitoring renaturations** • **Fish habitat monitoring** • …	○ **Corridor flights** ○ **Fly as high as possible** (but ≤ 120 m) ○ **Fly lower** (only if necessary for smaller objects) ○ **Oblique surveys** across the river for embankments ○ **Fly during foliage-free periods** (if possible). ○ **Observe water level** (if necessary) ○ **Eventually use a green laser** for the river bed	• **saves time** • **better overview** from above • **higher resolution** than DOPs of the countries • **Permanent data** for documentation and later analysis	○ **Photos** - RGB, Thermal ○ **Orthophotos** ○ **Videos** ○ **DEMs** ○ **LiDaR-point clouds**

Tab. 26: Water Bodies/Salmon Monitoring - recommendations (Döring, 2021)

Method/Parameter	**Reason**
It is essential to observe the DISTURBANCE ECOLOGY - BASIC RULES (especially breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The PARAMETERS FOR GOOD IMAGES should always be observed.	
Line structures	Linear CORRIDOR FLIGHT PLANNING makes it possible to plan flights over linear

→ automatic **corridor flight planning** - see (PIX4D, 2022A) → The **overlap** should be set to **at least 80 % forward** and **60 % sideward**. → **2 flight lines, better ≥ 3**, are necessary for good orthophotos. 	areas such as rivers, roads, overhead power lines or pipelines simply and effectively, with the shortest possible flight time. In contrast to a raster flight mission, only the strictly necessary areas (riverbed, pipeline corridor, etc.) are flown along a planned line and less images have to be processed. The flight becomes much more economical and efficient. See e.g. DRONESMADEEASY - LINEAR-FLIGHT-PLANNING or PIX4D - IMAGE-ACQUISITION-PLAN.
Fly always **as high as possible**! → but ≤ 120 m (EU)! → Only fly lower when necessary - e.g. for small objects to be surveyed.	The efficiency increases with higher flight altitude, as the ground coverage becomes higher - see **SENSOR RESOLUTION**
In the case of **monotonous structures** such as **water bodies** or tall grass (land) - e.g. flower meadows with many overgrowing grass or cornfields, lakes, sand and snow, the **overlap should be increased** to **at least** → **85 % forward** and **70 % sideward**. → Ensure good contrast in images.	Photogrammetry programs often have problems, because they do not find clear connection (tie) points between the individual images in the case of very uniform structures - see (**PIX4D, 2022A**) Therefore, include as much 'structure' as possible, such as bushes or trees in or at the edge of the area. Fly in good weather conditions - see **PARAMETERS FOR GOOD IMAGES**.
In the case of **rivers and lakes**, a section of the shore area or an island or deadwood should always be included if possible.	Pure water surfaces are too uniform, reflect too strongly and/or have moving waves. Therefore, they usually do often allow no orthophoto creation at all.
You can add **oblique shots** e.g. for the river banks flying perpendicularly across the river. 	Oblique or angled photographs can be used to get a better view under the shoreline vegetation on the river banks. Furthermore, they also contribute to further stabilizing the image alignment and improving height accuracy - see **OBLIQUE-FOTOS**.

Flying during the **leafless season** is particularly advisable for the **shoreline area**.	Without foliage on the trees, you usually get a better view of the shoreline area and may even be able to survey the edges of the embankments.
Under certain circumstances, additional conditions need to be considered, for example (e.g.). → water levels/river stages, → only uniform cloud cover due to possible reflections - possibly using a polarizing filter for the camera lens, → a snow-free river environment.	For certain aerial survey missions, specific requirements must be met to obtain the desired data. If all conditions must be met simultaneously, the time window for flights is significantly shortened. This necessitates particularly careful planning of the flight missions or deployment of fixed wings/VTOLs.
A green laser can be used to capture the **bottom of water bodies** (*Szafarczyk & Toś, 2022*).	Green light penetrates deeper into water compared to other colors in the light spectrum, making it helpful for capturing the bottom of water bodies, especially in shallow waters or clear water. The laser is used to illuminate the bottom, and the reflected beams are then captured by a camera to create detailed images. However, its use requires significantly more expensive equipment and can only be conducted by specialized personnel. The technology is not yet widely available.

ROCK MONITORING

INTRODUCTION

Drones monitoring **parallel** to vertical rock structures - in contrast to 'normal' survey flights **over** rocks - has so far mainly been used for geological or geomechanical questions such as surface roughness of rock discontinuities. (SALVINI ET AL., 2020), for stability-relevant surface modeling of complex vertical rock surfaces (WANG ET AL., 2019) or safety-relevant management issues for rock protection.

To monitor **erosion of near-vertical to overhanging coastal cliffs** in the Normandy, LETORTU ET AL. (2018) compared photogrammetric analyses of drone photos, terrestrially obtained photos, and terrestrial laser scan data. With the drone, larger areas could be surveyed with similar accuracy, more often at regular time intervals, faster, easier and with better visibility even into hidden corners. In a follow-up work, the parameters that could best record the cliffs with drone support were investigated. The best results were obtained with camera angles of 70°, 60° and 50° (JAUD ET AL., 2019).

For the **volume measurement of fallen boulders**, GÓMEZ-GUTIÉRREZ & GONÇALVES (2020) could create very accurate and satisfying 3D models with images flown parallel to the cliff (see CONCLUSIONS) using a commercially available *DJI Phantom 4 Pro*. In addition, flight planning could be automated using the *Drone Harmony* app briefly presented in the methodology section - see APPS FOR FLIGHT PLANNING.

The test flights within our *DroBio* project with the *Drone Harmony* app were carried out in a quarry. On the relatively even and 'smooth' rock faces (like on the previously mentioned cliffs) the vertical flight planning and execution was possible. But at the other surveyed 'real' rocks an automatization was no longer possible, because the frontal surfaces of most rock faces are much too irregular and often trees or bushes grow directly at the bases of the rock faces. This makes automated flight planning for regular photogrammetric flight paths impossible and dangerous and ultimately only allows manual flying.

Only very few works have been found on **rock monitoring with drones for eco-logical questions**.

In one publication, DWYER ET AL. (2020) created **3D models of rock faces** from drone photos in order to be able **to detect potential disturbances of raptor nesting sites** by climbing routes. The models were analyzed visually and recommendations for the disturbance management of climbing routes could be developed.

The aforementioned coastal cliffs are often home to a unique diversity of plant species and are protected as habitat type '*Atlantic rocky coasts and Baltic rocky and steep coasts with vegetation*' (LRT 1230) under the Habitats Directive (Annex I). This means that monitoring and reporting are obligatory. The gathering of monitoring data is a challenge in these habitats, because rock surveys are difficult and time-consuming.

Therefore, Italian scientists looked for alternative monitoring methods. Using drone imagery, they were able to successfully **detect and identify all target species of a coastal cliff** (STRUMIA ET AL., 2020). Identification was easy for 3 out of 5 species, as they either had specific and unique characteristics (such as indistinguishable leaf shapes) or could be recorded at the right time with phenologically unambiguous characteristics.

On much larger and inaccessible **rock faces in a Chinese national park**, ZHOU ET AL. (2021) studied the little-known flora and successfully identified trees, shrubs and vine species (*Fig. 20*).

Fig. 20: Inaccessible rock walls in China (ZHOU ET AL., 2021)

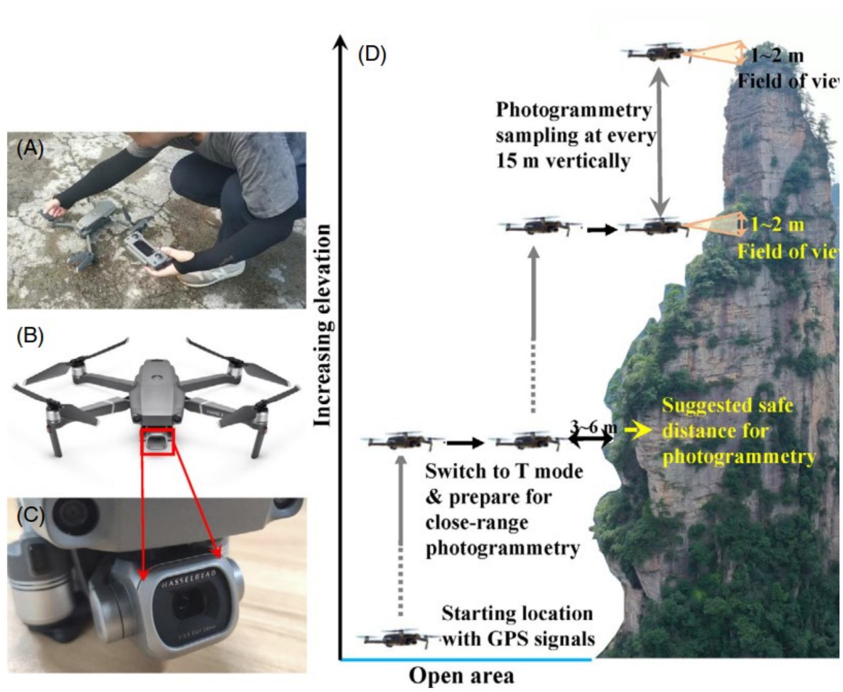


Fig. 21: Investigation of steep rock faces (ZHOU ET AL., 2021)

They flew as close as safely possible vertical parallel to the rock surface (3 - 6 m) and took two to three photos at each stop ca. every 15 m (*Fig. 21*). In this way, the entire rock face was scanned from bottom to top and high-resolution photographs were taken of the woody plants present.

In a brand new published work, TAVILLA ET AL. (2024) were able to capture images with an off-the-shelf DJI Mavic 3 of a Natura 2000 mountain side cliff that is normally inaccessible. They also took the photographs manually and processed them in *WebODM*.

This allowed them to observe the habitat of some species in detail and to discover the reappearance of a *Saxifraga* species, which had not been seen in this area for over 140 years. They concluded, that using drones for botanical research can boost field research, making monitoring easier and more cost-effective over time, especially in Natura 2000 sites.

The photographs in the project were taken in a similar way - but on less high rock faces with regular vertical or horizontal trajectories, always parallel to the rock. This shows a certain logical 'self-evidence' of the method, because the cited works were not yet known at the time of the own flights.

CONCLUSIONS

Tab. 27: Rock Monitoring - synopsis (Döring, 2021)

Rock Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
• **Rock inspection** • **Vegetation monitoring** (if possible) • **Fauna monitoring** (e.g. bats in crevices) • **Decision support for climbing regulations** • …	o **manual flights** - NOT automatic o best with spotter, **utmost attention!!!** o Always an eye on the display! o From time to time point the camera downwards to keep your distance from vegetation! o Fly **parallel to the rock** (sideways or up and down) o Stop-photo-go-stop-photo ... for sharper photos o **Many photos** for good 3D models o Photos at different distances from the rock o **Different camera angles** - horizontal and diagonally downwards	• **Insight into crevices and ledges** • **saves time** - alternative climbing/abseiling • **reduces disturbance** • **Permanent documentation**	o **Photos** o Videos o **vertical orthomosaic** o **facade aspect** o **3D models**

Tab. 28: Rock Monitoring - recommendations (Döring, 2021)

Method/Parameter	Reason
It is essential to observe the ***DISTURBANCE ECOLOGY - BASIC RULES*** (especially breeding and molting periods)!	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The *PARAMETERS FOR GOOD IMAGES* should always be observed.	
Mostly only **manual flights** can be **recommended**. Automatic flights are NOT recommended!	Due to the irregularity of the rocks and the irregular vegetation growth (especially at the base of the rocks), regular and schematic flight planning is not possible.
Always keep an eye on the display and the drone attentively! **Fly best with a spotter!**	It must be flown very close to the rocks with utmost attention! In **sunny and windy weather turbulences** makes the drone noticeably unsteady close to the rocks.
Fly backwards into the space from time to time and point the **camera downwards** to estimate the distance to the vegetation!	At the (foot of the) rocks there is often tree- or bush-like vegetation in different heights. To estimate the vegetation (height), the wide angle of the camera can be used to observe the vegetation.
Flight paths → **parallel to the rock** (from side to side and from top to bottom) → **Take many photos for good 3D models** (automatically in intervals or by manual triggering). → **Fly in different distances to the rock surface**. → **Stop-**Photo**-Go-Stop-** Photo **-Go** for sharper photos.	To be able to generate good ortho views and 3D models, you need a sufficient number of photos with appropriate overlap and coverage of the rock surface - see *PARAMETERS FOR GOOD IMAGES*. A large number of photos with many different aspects of the rock surface and taken at different distances from the rock will improve the 3D models. Stopping to take photos avoids possible distortions in the images - but at costs of the flight time.
Take photos on flight paths parallel to the rock with different camera angles - horizontal and oblique downwards.	With different camera angles, you get better views of back-tilted and deeper ledges and into crevices that are often invisible from below with binoculars.

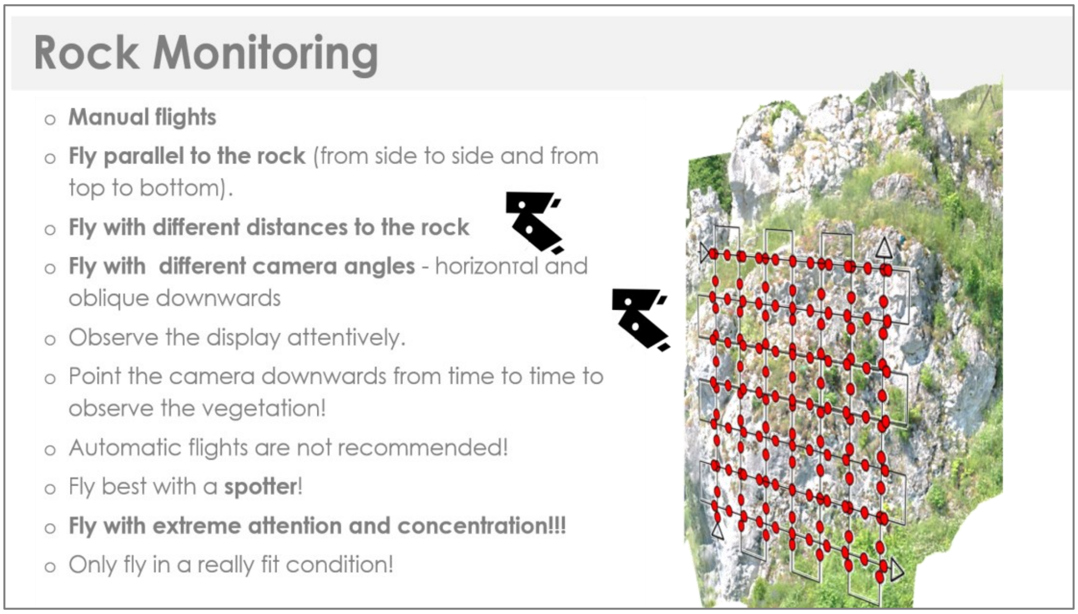


Fig. 22: Rock Monitoring – graphical synopsis (Döring, 2021)

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VEGETATION MONITORING

INTRODUCTION

When zooming into landscapes, plants are the next closest objects to survey. Many of their parameters can be recorded directly or indirectly (see *Conclusions*). In **agriculture**, a number of these parameters have been successfully surveyed with drones already for some time. Subsequently, they have been analyzed to improve cultivation techniques, and the results have been used purposefully, in Germany often only on a trial basis - (*Grenzdörffer, 2017*) or (*LTZ Augustenberg, 2022*), in other countries already operationally across larger farms (*Croptracker, 2023*).

Especially plant groups with clear and easily visible characteristics such as e.g. **tuft grasses** (*Hecke et al., 2018*) or large flowered plants like ***Arnica montana*** (*DBU, 2021*) or ***Colchicum autumnale*** (*Petrich et al., 2020*) can already be detected relatively well with smaller drones and simple sensors. Their population areas can be determined or even the number of individuals can be counted.

For small-flowered plants without easily distinguishable characteristics, however, it quickly became clear during our project that these were reliably only very difficult to identify down to species level. Not even larger and high-resolution sensors are very helpful without much effort, and certainly it cannot be made without adequate *Ground Truthing*.

As early as 2015, Danish scientists tested the use of a commercially available drone with an RGB camera **to detect the flowers of certain wild plants** (*Sørensen; Strandberg & Bak., 2015*). These should serve as indicators for the effects of certain agricultural processes and climate fluctuations. By recording area-wide indicator plants (flowers), a large-scale monitoring of such effects could be possible. It was just a matter of selecting the right indicator plant (in this case a clover species) for quick identification. For the image analysis of the drone photos, the cost-free and powerful open-source image processing and analysis program *ImageJ* was used, with which the flowers could be successfully classified.

Note: *ImageJ* has many, many parameters to adjust and requires an intensive training. Thus like the other classification tools, it is not suitable for 'simple' and quick analyses - see *Automated Analyzing Tools*

In Portugal, an Australian bud wasp was used as a biological control agent to **control the progressive invasion of *Acacia longifolia***. To monitor the progress of the containment, De Sá et al. (2018) developed a method to count the flowers of *Acacia* using digital image classification techniques in drone images (*RGB-* and CIR-Images = *Colored InfraRed images*). Flower counting itself did not perform as well as with terrestrial survey, but the distribution of *acacias* could be determined effectively and cost-efficient.

Wijesingha et al. (2020) used data from drone surveys (RGB and thermal images, stand height models) and automated image classification methods to **detect the invasive *Lupine*** (*Lupinus polyphyllus*) with high accuracy in the *Rhön Biosphere Reserve*. The results deviated only by 5 % from the manually digitized *Lupine* populations in the drone images. The workflows created in the paper are applicable to other areas and species as well.

In a **preliminary study on species-level**, Lopatin et al. (2017) simulated the use of a drone with a hyperspectral camera by mounting a spectrometer on a scaffold 2.5 m above ground to obtain high-resolution data of the study areas. The goal of this preliminary study was to test the feasibility of future drone deployments to more quickly survey large and diverse areas and to automate the analysis of the data. They determined that UAV-based monitoring for classification of individual grassland species is feasible under the following conditions:

- The **resolution** must be high enough to avoid mix pixels with parts from different species. Resolutions of < 1 cm are recommended. It depends on the species present and the complexity of the species composition - see *Fig. 23*.
- The more complex the species composition and structural form of the stands, the more problems arise in the analysis and with the accuracies of the classifications. This reduces the effectiveness compared to terrestrial sampling field surveys.

Fig. 23: Resolution comparison of flower strips (Döring, 2021)

Conclusions of the work is that in very **complex ecosystems** with **high structural heterogeneity** (due to different strata and overlaps of individuals) **aerial surveys and automated evaluation methods are not very effective or even impossible**.

In very patchy vegetation stands or in those with predominantly **homogenic species groups that are hardly mixed, the approach could be quite successful**. The automation of the analysis of drone data in vegetation monitoring is particularly promising if only certain target species are in focus, clearly detectable with as unambiguous characteristics as possible.

In North Rhine-Westphalia, the application *FELM* (remote sensing-based recording of habitat types for FFH monitoring) was developed in 2018. Remotely sensed information (elevation data, digital RGB orthophotos, *RapidEye* and *Sentinel-2* satellite data) will be used to **assess selected Natura 2000 habitat types**. The user can choose between different site-specific indicators. Especially for heathland habitats very good results could be achieved (Buck et al., 2018).

RGB orthophotos from drone data could probably be fed in there as well.

Due to **heavy soil contamination by ammunition residues**, vegetation mapping and soil relief surveys on a heath area of the DBU natural heritage site are also being carried out with the aid of drones (*DBU, 2022*).

Recently, *BASAVEGOWDA ET AL. (2024)* developed an object detection model based on UAV photos and Deep Learning (*DL*) to automate the identification of indicator species for promoting biodiversity in permanent grasslands through sustainable land management. If a certain number of indicator species is found, farmers can apply for a subsidy of the EU organic Eco-scheme 5 ("Result-oriented extensive management of permanent grassland with evidence of at least four regional indicator species") of up to 450 €/ha for this agricultural environmental service.

But a terrestrial identification means a significant monitoring cost in terms of time and money for the farmer - a drone takes the necessary images in short time.

The German company *DRONIQ (2024)* offers the detection of the indicator species in green/grassland with a drone and *AI*-based software from the company *ANYA (2024)* as a brand new service. The drone flies over the green space in just a few minutes and the farmer receives the results a few hours later and can apply for funding. The detection quote of the *AI* is ca. 90 % of 220 possible indicator species of different regions or habitats.

HEATHLAND

To reliably assess the need for and plan landscape management measures and survey their effect in the open countryside, it is necessary to monitor its (conservation) status on a regular basis.

For this purpose, the spatio-temporal changes in landscape development are observed as a function of the natural processes of vegetation dynamics. The aim of the large-scale project *NATEC* in the Kyritz-Ruppiner Heath is to develop feasible workflows and analysis methods for it.

Special emphasis will be placed on the analysis of 'normal' *RGB* images from small and commercially available drones.

Heathland is characterized during the year particularly by different aspects of heather plants (*Calluna vulgaris*), but also the accompanying species such as lichens, mosses and grasses, and the amount of litter. Their colors change with the seasons and can be easily observed, classified and evaluated in drone images. In addition to the different species, **vitality characteristics** in the various stages of heather reproduction and distribution are also visible (*NEUMANN ET AL., 2022*).

The **effects of landscape management measures** and the subsequent development trends can also be analyzed and documented. The appearance of heathland often changes drastically after maintenance interventions, which can also be easily tracked in drone images. According to the evaluation, the management measures can then be readjusted if necessary.

In addition, the **changes of the *Calluna* occurrences** in their growth dynamics and regeneration ability are examined.

In a study on the phenological and distributional aspects of Calluna, it was impressively shown that it is possible to determine from the images of a commercially available DJI Phantom 4 Pro, on the basis of the optical properties of various plants, their **area proportions** and their **condition** (NEUMANN ET AL., 2020). This is even possible with images from a relatively data- and area-efficient flight height of 80 m (NEUMANN ET AL., 2020). Calibration data from field surveys were used for the necessary ground truthing. This ensured that the respective color properties were assigned to the correct objects (here plants). In a subsequent work, NEUMANN ET AL. (2021) could also be record and classify the grass in- and overgrowth using normalized digital surface models (***nDSM***).

> normalized digital surface model (**nDSM**) = digital surface model (***DSM***) minus digital terrain model (***DTM***). (ELTNER ET AL., 2022)

The proportion of grass also plays a decisive role in the evaluation of FFH meadows (LAZBW, 2014).

Grasses – esp. *Calamagrostis epigejos*, which is often very overbearing and therefore has to be removed - are usually forming larger, coherent, flat stands and can therefore be detected and their area extent quantified particularly well.

Calamagrostis could be successfully detected and mapped with *RGB* drone images e.g. in the publications of an avalanche track investigation (JUNGMEIER ET AL., 2016) and of surveys in a river valley marsh (BEYER & GRENZDÖRFFER, 2018).

CONCLUSIONS

Tab. 29: Vegetation Monitoring - synopsis (Döring, 2021)

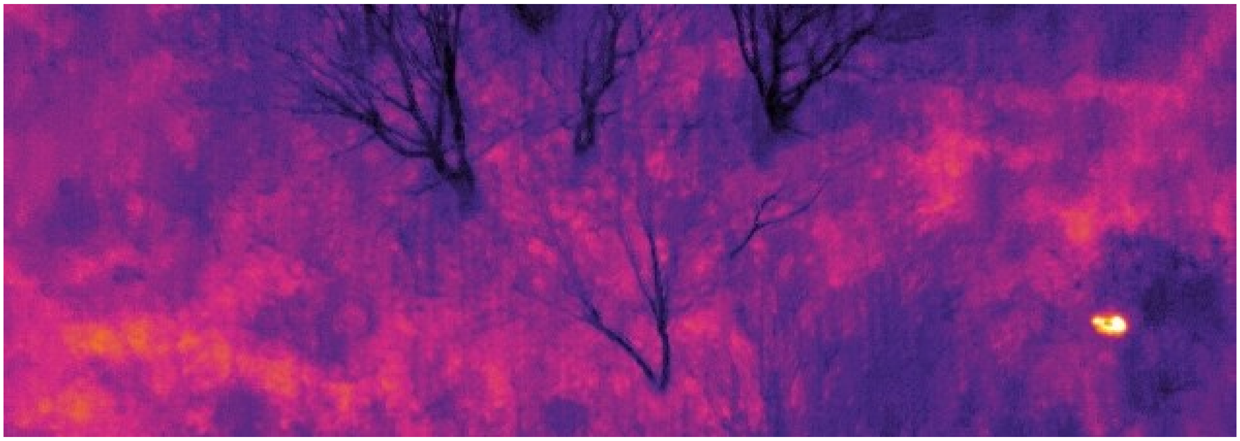
Vegetation Monitoring			
Difficulty / Experience / Benefit			
Aims	**Parameters**	**Advantages**	**Data**
DERIVATION OF PLANT PARAMETERS (often with multispectral cameras) YIELD ESTIMATIONS VIA PLANT HEIGHT PLANT HEALTH PLANT COUNTING PLANT IDENTIFICATION AND SINGLE PLANT MAPPING OVERVIEW	○ **Grid flights at different heights** - vegetation to species level ○ **Flights with different sensors** ○ **Verifying detected species by ground truthing** - (for first simple check e.g. with *Flora Incognita*) – have them verified by an expert! ○ **some oblique photos at 85°** for better height stability	• **high-resolution Orthophotos** • **Multispectral-Analysis** • **Vegetation- Indexes** - equally from RGB photos • **Yield analyses** with height models • **exact localization** with multi-frequency GNSS • **saves time** • **permanent documentation**	○ **Photos** - RGB, Multispectral, Thermal ○ **Orthophoto** ○ **Height models**

Tab. 30: Vegetation Monitoring - recommendations (Döring, 202)

Method/Parameter	Reason
It is essential to observe the *DISTURBANCE ECOLOGY - BASIC RULES* (especially breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
The PARAMETERS FOR GOOD IMAGES should always be observed.	
Most effective flight mode = programmed grid flights → Overlap = min. 75 % forward and 60 % sideways.	A certain overlap is always required for usable orthophotos. - see PARAMETERS FOR GOOD IMAGES.
In the case **of monotonous structures** such as tall grass (land) - e.g. flower meadows with many overgrowing grass or cornfields, lakes, sand and snow, the **overlap should be increased** to **at least** → **85 % forward** and **70 % sideward**. → Ensure good contrast in images.	Photogrammetry programs often have problems, because they do not find clear connection (tie) points between the individual images in the case of very uniform structures - see (PIX4D, 2022A). Therefore, include as much 'structure' as possible, such as bushes or trees in or at the edge of the area. Fly in good weather conditions - see PARAMETERS FOR GOOD IMAGES.
Always fly as high as possible to avoid disturbances - see OPEN LANDSCAPES.	The efficiency increases with higher flight altitude, because the ground coverage becomes higher - see SENSOR RESOLUTION. Minimizing disturbance should be a priority. However, drone flights can even help to reduce disturbance compared to terrestrial survey methods - see DISTURBANCE ECOLOGY OF DRONE FLIGHTS and (LAG VSW, 2023).
Flights at different altitudes could provide images down to species level. **Commercial species detection with *AI*** – e.g. GRASSLAND AERIAL SURVEY BY DRONE TO IDENTIFY SPECIES, ANYA	**Orthophotos from higher flight height** can possibly be **verified by single photos from lower height**. *AI* species detection for agricultural purposes is already in operational progress.
Flight areas could be narrowed to the likely occurrence area of the target species through experience and/or	Narrowing flight areas is recommended to reduce disturbances, conserve resources and minimize frustration.

observations of area managers and species experts.	Searching on suspicion is often not very promising.
Flights with different sensors extend the spectrum for further analyses.	See applications in *Sensors as Payload*.
Ground Truthing For the first simple check of species, e.g. the app *Flora Incognita* can be used.	**Verification** (ground truthing) of detected species by experts is absolutely necessary.
Normal flights can be supplemented by **additional flights with oblique images - about 75° - 85° camera downward angle.**	*Oblique images* can be used to better estimate vegetation heights. Likewise, they contribute to further stabilization of the image bundle and height accuracy (*DJI & Krull, 2020*).

FAUNA MONITORING



INTRODUCTION

Since the beginning of the use of drones for species and nature conservation and for scientific purposes in the early 2000s (GIONES & BREM, 2017), drone missions for wildlife observation, counting and rescue have been among their main uses. They are **a good alternative to the often dangerous manned flights** for wildlife observation. These pose **some of the highest risks to wildlife workers** in the United States. (SASSE, 2003). They are also usually less invasive than conventional methods, esp. compared to terrestrial census where humans are usually an extreme nuisance (JIMÉNEZ LÓPEZ & MULERO-PÁZMÁNY, 2019, S. 8).

In the last cited paper and in those of DUFFY ET AL. (2020) and BARNAS ET AL. (2020) many further publications on the topic of drones and wildlife are mentioned. These publications give a good overview of the large number of possible applications.

Also, the website HTTPS://CONSERVATIONDRONES.ORG provides detailed information on the topic.

Tab. 31 lists animal classes and species with exemplary publications linked that are already being researched using drones.

Tab. 31: Animal classes and drone monitoring (Döring, 2021)

Animal Class	Publications
Mammals	TERRESTRIAL & MARINE
Birds	WATERFOWLS, BIRD COLONIES, GROUND BREEDING CONSERVATION, DISTURBANCE PREVENTION, EAGLE PROTECTION …
Reptiles	CROCODILES, LIZARDS & AI
Fishes	SALMONS, TROUTS, SHARKS, RESEARCH
Insects	BUTTERFLIES, MONITORING

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In Germany, animal-related drone operations are currently mainly limited to **fawn rescue** and **research projects** or **nature conservation association activities** (e.g. ABU-NATURSCHUTZ).
But some wildlife monitoring services are yet operational.
For example, the OGF GMBH (2024) use thermal imaging and zoom cameras for drone-based wildlife monitoring to determine the current wildlife density and for mapping developments in wildlife populations.
Once the general conditions have been determined and possible restrictions have been checked, the survey of the commissioned area can start. At a height of around 100 m above the ground (*AGL*) the survey is carried out in S-shaped paths with a path width that ensures an overlap of the trajectories. This also ensures the detection of heat sources that may be located at the edge of an image (e.g. behind a tree).
"Different types of game react differently to the presence of drones. However, the disturbance is often only slight and the game densities can usually be realistically depicted. In most cases, they are higher than expected." (Tab. 32)
The publication on the **disturbance ecology of drone use** by DÖRING & MITTERBACHER (2022) cites more national and international examples of the use of drones in animal monitoring and wildlife rescue.
More application examples can also be found here WWW.LFU.BAYERN.DE/NATUR/DROHNEN/INDEX.HTM and here in more detail DROBIO RESEARCH REPORT.

Tab. 32: Practical experiences on sensitivity of game species toward drones (OGF GMBH, 2024)

Game Species	Perception on 100 m AGL	Escape reaction	Thermal Visibility 100 m AGL	Estimatiom of method
Roe Deer	rarely	very seldom	very good	very good
Red Deer	yes	Partly	very good	limited
Wild Boar	rarely	very seldom	mostly good	good
Fallow Deer	rarely	seldom	very good	very good
Mouflon	-	-	very good	-
Europ. Hare	No	no	good	good
Wolf	yes	often	mostly good	limited

WILDLIFE RESCUE

According to the German Wildlife Foundation, over 500,000 wild animals die in Germany every year, including around 90,000 fawns, as a result of mowers or machines used in grassland management (DT. WILDTIERRETTUNG, 2022).
Even highly threatened meadow birds such as partridge, lapwing, curlew, black-tailed godwit and harrier often suffer significant losses (GANTEFÖR; KINSER & FREIHERR V.MÜNCHHAUSEN, 2019).
In Bavaria and other federal states there are several drone projects especially for the **protection of ground nesting birds** - see (DÖRING & MITTERBACHER, 2022).
For some time now, various measures have been developed and are sometimes implemented to minimize these losses, including the use of drones - a pioneering work in this area is the doctoral thesis of Martin Israel (ISRAEL, 2015).
Drones are now a proven and even government-approved and funded tool (BMEL, 2020) to find fawns and meadow nesting birds efficiently in agricultural areas.

A few example websites that deal with the topic:

- HTTPS://SCHWABENKITZ.DE/LEITFADEN/LEITFADEN_ZUR_KITZRETTUNG.PDF
- HTTPS://KITZRETTUNG-HILFE.DE
- WWW.LFL.BAYERN.DE/PUBLIKATIONEN/INFORMATIONEN/220360/INDEX.PHP
- WWW.DEUTSCHEWILDTIERSTIFTUNG.DE/CONTENT/3-NATURSCHUTZ/7-REH-STOPPT-DEN-MAEHTOD/3-PRAXISRATGEBER-MAEHTOD/PRAXISRATGEBER-MAEHTOD_DEUTSCHE-WILDTIER-STIFTUNG_2019.PDF
- WWW.UNSEREBROSCHUERE.DE/LANDESJAGDVERBAND/WEBVIEW/
- HTTPS://DOCS.UAVEDITOR.COM/DE//HOW_TO-REHKITZ-RETTUNG_UND_AGRARBEREICH
- DROHNENFÖRDERUNGEN 2022 – EINE KRITISCHE BETRACHTUNG

NOTE: Like stated in the RULES for disturbing-less flying, the collaboration between Nature conservationists which have to give permission for flights in protected areas but could need help with the drones for monitoring tasks and wildlife rescuers who have and use drones but need the permissions, is highly recommended. It is a win-win situation - see the picture below.

Conclusions

Tab. 33: Fauna Monitoring - synopsis (Döring, 2021)

Fauna Monitoring & Wildlife Rescue			
Dificulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
• **Nest Search** (e.g. *Vanellus vanellus, Numenius arquata etc.*) • **Fawn/Wildlife Rescue** • **Eyrie Controls** (e.g. *Aquila chrysaetos*) • **Bird Counts** - esp. colonies • **Beaver Monitoring** • **Field Hamster Monitoring**	○ **Raster flights** ○ **Manual flights** only if not otherwise possible (ineffective) ○ **Thermal cameras** to search for animals, nests and rescue wildlife ○ **Fly as high as possible** ○ Do **not take off and land in the immediate vicinity of birds/animals** and nesting or moulting areas! ○ **Fly very carefully and evenly!**	• **fast and trace-free nest search** • more effective **search via thermal images** • **less disturbance** • **more effective counting of nests/colonies** from the air • **faster** than tree climbing for eyrie control • **permanent documentation** for more reliable counting - even later	○ **Live-Monitor view** for purely visual ad hoc evaluation ○ **Photos** - RGB, **Thermal** ○ if necessary Orthophotos for analysis ○ Videos

Tab. 34: Fauna Monitoring - recommendations (Döring, 2021)

Method/Parameter	**Reason**
• **Always fly as high as possible.** • **Do not take off or land in close proximity to birds/animals or nesting or molting areas.** • **Fly very carefully and steadily.**	Always follow the basic rules for minimizing disturbance and for successful detection and observation - see ***DISTURBANCE ECOLOGY - BASIC RULES***.
The **most effective** wildlife search is by means of programmed **grid flights** (KAUFMANN; HOLLIGER & SON, 2022). Flight planning: e.g. (FLUGMODUS E.V., 2021)	If areas are to be flown for animal search, one wants **to be sure that also the whole area is flown.** Since you usually do not want to create orthophotos, only control photos or videos may be useful or necessary.

→ **For the detection of animals, only a slight overlap of the flight paths is required.** → **Narrow search areas to hot-spot areas with animal occurrences** through experience and/or observations by hunters or other area experts.	Narrowing down the search areas is recommended to conserve resources and minimize frustration. **Searching on suspicion is often not very promising** - see *Disturbance Ecology - Basic Rules*.

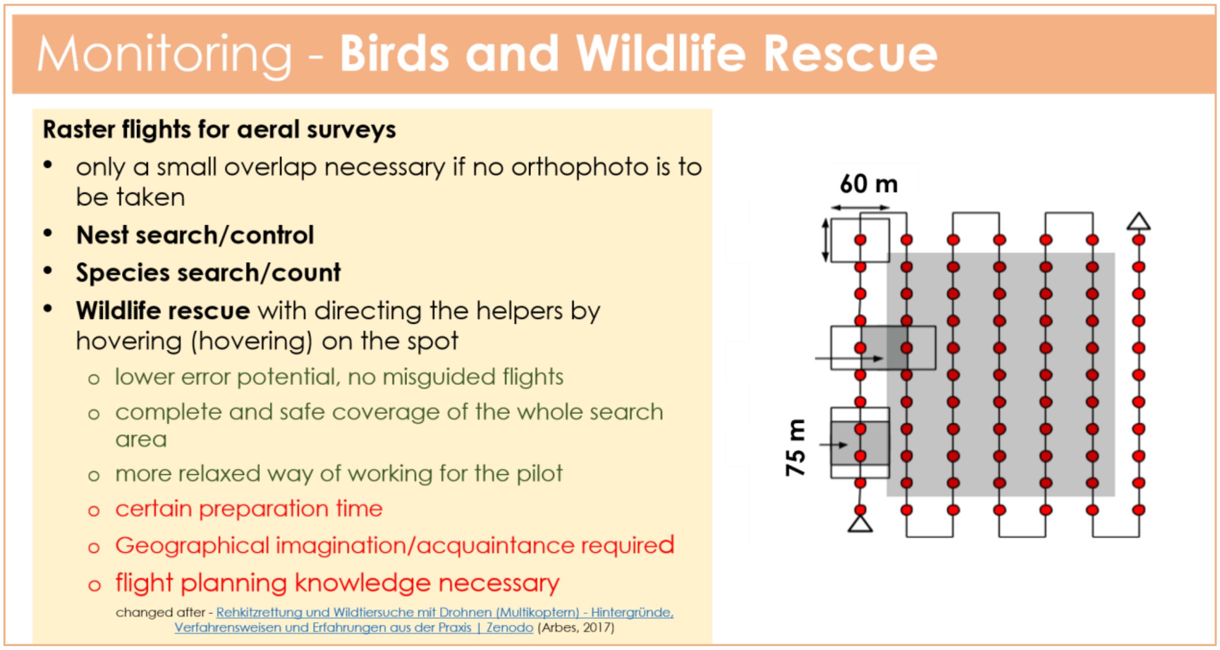

Fig. 24: Wildlife rescue - programmed flights (Döring, 2021 after Arbes, 2017))

Manual flights	
→ e.g. **to check bird nests and colonies** or to **search for animals** on rocks, in streams, etc.	Manual flights are mainly recommended for specific control of objects.
→ For wildlife rescue, they are more ineffective and prone to errors, since usually a whole area is to be flown.	They have a short preparation and setup time, but accuracy stands or falls with the pilot. Safe coverage of the search area is only possible with ideal terrain conditions, knowledge of the area and sufficient experience of the pilot. The potential for error is often high.

Fig. 25: Wildlife rescue - manual flights (Döring, 2021, after ARBES, 2017)

Thermal cameras are recommended or even necessary for animal, nest search and wildlife rescue.

→ Especially in summer or on warm/sunny days, **flying** should be done **in the early morning hours** if possible.

Many animal species are well camouflaged and can be detected more easily or exclusively by thermal cameras - see SENSORS AS PAYLOAD.

The higher the **temperature difference** between the animal's body and the environment, the easier it is to detect the animal.

Detailed info can be found in "***Thermal Imaging Techniques to Survey and Monitor Animals in the Wild:*** *A Methodology*" (HAVENS & SHARP, 2015).

According to new law, a drone can now be flown at night or twilight without special permission.

However, since 07/2022, in Germny it must be equipped **with a green flashing light** - HTTPS://WWW.LBA.DE/DE/DROHNEN/FAQ/01_FAQ_ALLGEMEIN/FAQ_NODE.HTML

Do not touch the nests of ground nesting birds under any circumstances!

Many ground-nesting birds are strictly protected by the German Federal Nature Conservation Act, especially § 44. **Their manipulation may result**

→ Mark only for the farmer to be able to avoid them - e.g. by staking them out with bamboo sticks.

Fig. 26: It´s staked out! (VEREIN THEMA:NATUR, 2024)

in criminal consequences (§§ 69 - 71)**!**

→ see e.g. HTTPS://KITZRETTUNG-HILFE.DE/HELFERINFOS/WENN-GELEGE-GEFUNDEN-WERDEN

Fig. 27: Stake-out of a lapwing nest (Margit Böhm, 2015)

Use synergy effects!

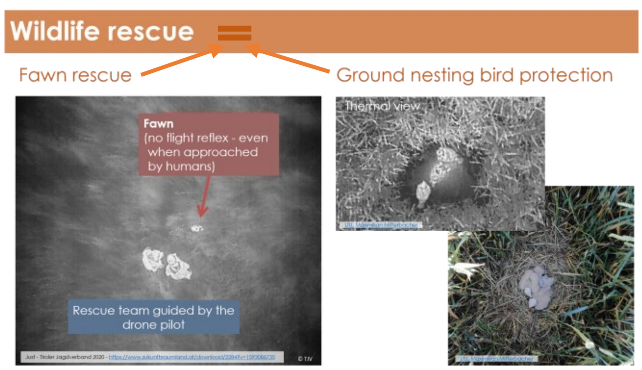

Fig. 28: Wildlife recue synergies (Döring, 2021)

- Fawn rescuers watch out for ground-nesting birds and other animals = **wildlife rescuers**.
- Wildlife rescuers fly also for conservation tasks in exchange for easier permits and reimbursement of expenses.

Cost compensation ideas for drone wildlife rescuers.

- Funding areas are defined for areas with a high occurrence of wildlife (deer, ground nesting birds etc.), in which farmers, disadvantaged by time-consuming scanning of the meadows, receive compensation funding. This is passed on, at least in part, to the volunteer wildlife rescuers for the reimbursement of expenses.
- For hunters who use drones to search for wildlife before mowing, the costs could be offset against the hunting cooperative lease or possible wildlife damage incurred.
- The goal should be to establish wildlife rescue as a value-adding service to guarantee its continuity.
- Farmers save costs for legally required prevention measures by the help of the wildlife rescuers. However, these saved expenses should be passed on (at least in parts) to compensate the expenses of the wildlife rescuers.

SALMON & BEAVER MONITORING

Introduction Salmon Monitoring

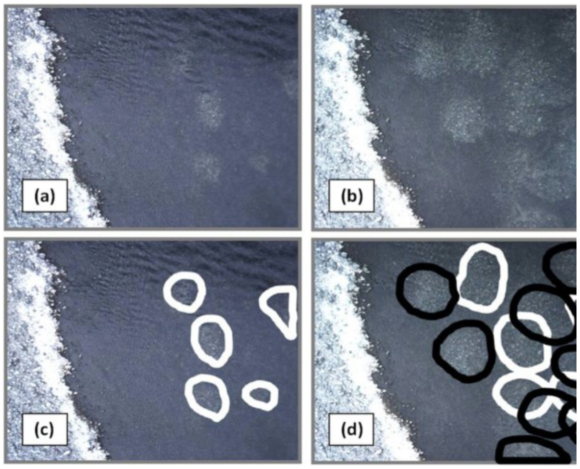

Fig. 29: Salmon spawning pits - Redds (GROVES ET AL., 2017)

According to the International Union for Conservation of Nature (IUCN), the Atlantic salmon is classified on the Red List of Threatened Species as "Endangered". The species is also listed in Annex II of the European Habitats Directive, which requires reporting on its conservation status (*SACHTELEBEN & BEHRENS, 2010*). Once in the reporting period, the inhabited bodies of water should be characterized for habitat mapping and assessment of impairments based on structural, morphological, physical, and chemical features (*BFN, 2011*). Due to the prohibition of deterioration, this also means at the same time the protection of habitats because the Annex II species are equally used as criteria for the selection of suitable protected areas (*WWF, 2007*).

Almost all salmon species worldwide are threatened by human impact on their spawning habitats (due to development, damming, construction, pollution and warming by power plants of many rivers) and are listed as species worthy of protection (*CONNOR ET AL., 2019*).

For their protection, they or their habitats and spawning pits (redds) are regularly counted in many places. In *Fig. 29*, these redds appear as whitish ovals. This is due to the fact that the *Rogner* (female salmon ready to spawn) uses its tail fin to strike a spawning pit about 3 m × 1 m wide and 0.5 m deep into the gravelly substrate of the riverbed.

In the process, many pebbles overgrown with dark algae on the surface are turned over and their white 'belly' is visible in the pit (*Fig. 30*).

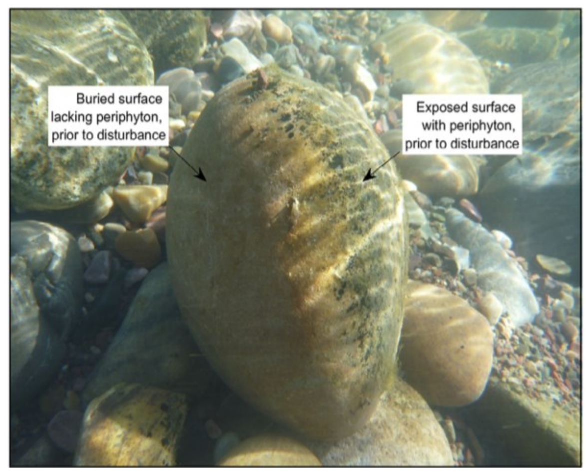

Fig. 30: Colored pebbles (HARRISON ET AL., 2020)

The **spawning pits/redds** are easily visible from the air and are often **counted** from helicopters, especially in the USA and Canada. However, helicopter flights are not without danger and were also less accurate than drone counts (*GROVES ET AL., 2017*).

As early as 2012, *KUDO ET AL. (2012)* **compared** in Japan the use of **a remote-controlled helicopter** (also a drone) **with conventional aerial flights**. The area coverage is lower, but so are the costs, with simultaneous gains in flexibility and accuracy. They postulated that good sample recordings could often be sufficient and sometimes preferable to less accurate complete counts.

2014 in Canada, WHITEHEAD ET AL. (2014) were able to use drones to **observe** entire **schools of salmon** in their spawning grounds and even **individual salmon** at their spawning beds and **count** them in an orthophoto.

In Kodiak, Alaska, the fish agency used the predecessor model of the drone used in the project (a *DJI Mavic*) with a polarizing filter placed in front of the camera to first **find salmon for tagging** and later count the color-coded salmons (ALASKA FISH & GAME, 2018).

Using object-based image analysis (*OBIA*), HARRISON ET AL. (2020) performed automated **redd counting** in both **RGB images** and much more expensive **hyperspectral images**, all from drone flights. Both sensor data have advantages and disadvantages:

The **RGB data** were faster to process and achieved higher positional accuracy, suitable for fast and often repeatable data acquisition.

The **hyperspectral data** allowed more accurate automated detection and counting of redds, depth measurement of the riverbed and other habitat parameters - but at much higher costs of the sensor and the required flight platform.

In general, however, the researchers believe that **remote sensing with drones is in many aspects much cheaper, more efficient and less dangerous than other monitoring methods for salmon**. So far, these have included boating/kayaking, wading, and sometimes even diving/snorkeling.

All these methods are rather time-consuming and therefore expensive, usually limited in space and often, as mentioned before, not without danger (HARRISON ET AL., 2020).

Introduction Beaver Monitoring

Beavers are no longer rare guests in our landscapes. On the contrary, there are often problems with the coexistence of beavers and humans, especially in agricultural and densely populated areas, which require population management. However, they are also protected as an '*Annex Species*' under the European Habitats Directive, so their populations need to be monitored regularly to document their conservation status.

In response to a debate about the reintroduction of beavers in England, PUTTOCK ET AL. (2015) conducted a feasibility study to show that it is possible to effectively **detect beaver activity** and its impact on the ecosystem using a drone. Using a simple digital camera on a *hexacopter* (6 rotor multicopter) and systematic grid flights in winter (in the defoliated state for better 'insights'), all structural changes created by the beaver could be well identified in the high-resolution images and elevation models. They recommend drones as cost-effective tools for monitoring beaver activity.

To compare **heavy metal transport in beaver channels** of American mining areas with 'normal' heavy metal dispersal in beaver-free areas, BRIGGS ET AL., 2019 used a drone to map floodplains and connecting channels of beaver activity. They found an increased distribution of heavy metals in beaver-influenced areas. In their opinion, this should be taken into account especially in these mining areas when considering necessary management decisions.

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Fig. 31: Beaver monitoring in a moor (Döring, 2022)

In 2022, a municipality in Lower Austria used drones for the first time to carry out the **monitoring of the strictly protected beaver**, which is necessary for the **reporting requirements** of the European Habitats Directive (*Großdietmanns, 2022*). "The images taken by drones will then be analyzed for beaver patterns to determine the current distribution and population size." After the method has been successfully applied, the aerial surveys are to be repeated regularly.

To stay in Lower Austria, in 2019, a student focused in her master's thesis on remote sensing methods to derive the **habitat quality of beaver territories by analyzing land cover** (*Schlegel, 2019*). She tested different remote sensing data sets - including orthophotos from a drone - and methods for their suitability on a richly structured stretch of water. With the high-resolution orthophotos (resolution of 3 cm), better automated classification results were achieved than with the lower-resolution aerial photograph of the national survey (a resolution of 20 cm and a low temporal resolution from 2 to 3 years).

In **Ukraine's Slobozhanskyi National Park**, drones have already been used to map beaver activity since 2018 (*Brusentsova, 2018*).

Evidence of beaver presence has also been studied extensively in the southern Tierra del Fuego using public satellite data (*Huertas Herrera et al., 2019*). An off-the-shelf drone was used to verify the satellite data (a form of ground truthing with higher resolution drone data).

The effort resulted in a presence density map of beaver population distribution.

Conclusions

Tab. 35: Salmon and Beaver Monitoring - synopsis (Döring, 2021)

Salmon/Beaver Monitoring			
Difficulty	Experience	Benefit	
Aims	**Parameters**	**Advantages**	**Data**
Salmon Monitoring • **Spawning pit/redd monitoring** of Salmon and Trout • **Fish habitat mapping** • Fish counts (if possible) Beaver Monitoring • **Habitat inspection** • **Mapping tracks and infrastructure** • beaver counting (with a Thermal camera if possible)	○ **Manual flights** - with display support or ○ **Automatic flights** for **area mapping** ○ Fly so high that the entire **river bed can be seen** on the screen. ○ **Ensure line of sight!** ○ If necessary, **descend to examine smaller objects - pay attention to accompanying vegetation!** ○ **Fly in winter without foliage** (if possible)**!**	○ **time-saving** - a section of the river can be inspected from one point ↔ surveying on foot along the river ○ **better overview** (especially at inaccessible river sections) ○ **permanent documentation** with overviewing pictures	• **visual** inspection + counting on the display • **Photos** - taken automated or manual • **Videos** • **Orthophotos**

Tab. 36: Salmon and Beaver Monitoring - recommendations (Döring, 2021)

Method/Parameter	**Reason**
It is essential to observe the <u>DISTURBANCE ECOLOGY - BASIC RULES</u> (especially breeding and molting periods)**!**	Avoidance of disturbance → fewer conflicts with nature conservation concerns
Manual flight - with display support or **automatic flight** for areal mapping with **corridor flight planning** - see <u>CONCLUSIONS</u>.	Often a manual flight is sufficient. If necessary, manually triggered photos or video recordings can be added for documentation purposes. For orthophotos, as always, a certain overlap is required - see <u>PARAMETERS FOR GOOD IMAGES UND CONCLUSIONS</u>

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On smaller rivers, it is possible to fly so high that **the entire width of the riverbed** can be seen **on the screen**. **For beaver monitoring, particularly the riparian areas must be flown.**	This is the most efficient way to fly, since only one trajectory is necessary - see *SENSOR RESOLUTION*. Slides and lodges are often located on the shore.
If possible, its best to fly without foliage to better detect salmon spawning beds and beaver lodges, dams and slides.	Without foliage, it is generally easier to see salmon beds and beaver tracks. If necessary, you can lower the drone to examine smaller objects in more detail.
Fly with even more caution, as riparian vegetation may be in the way when looking for redds or approaching the 'beaver infrastructure elements'.	Only experienced and highly skilled pilots should fly between riparian vegetation to conduct detailed inspections of the structural elements of the salmon or beaver habitats.

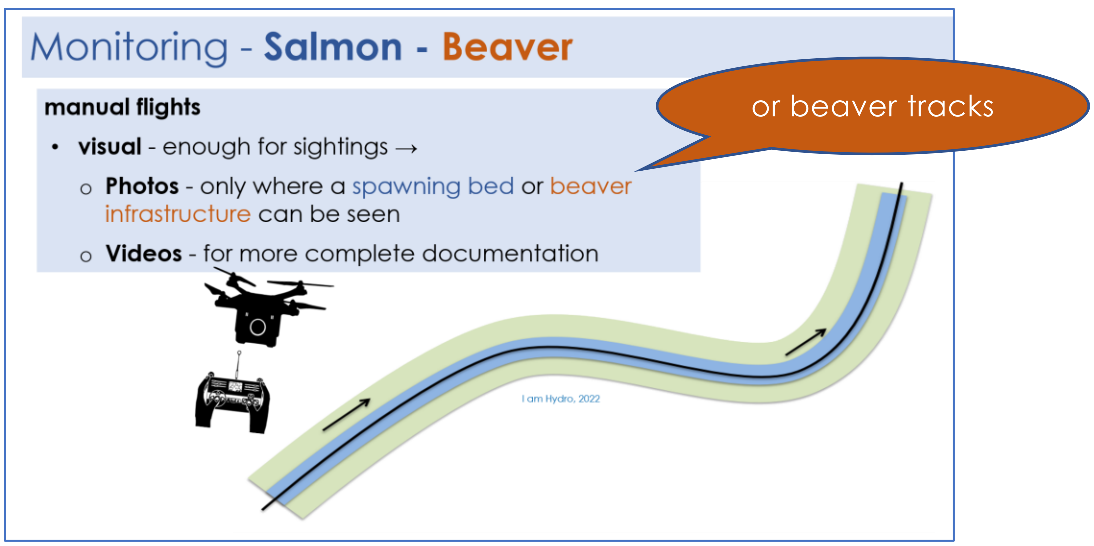

Fig. 32: Manual drone-monitoring of salmon and beaver (Döring, 2022)

05 ANALYSIS

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Once the flights have been successfully completed and all the data are available, the next step is perhaps the most time-consuming one - namely the processing of the images and the subsequent analyses.

From the multitude of possibilities, only those that have been tested by us and thus we can recommend as being easily practicable and cost-effective, will be described here.

PROCESSING OF THE DRONE PHOTOS

The further processing of the captured images into orthophotos is carried out using photogrammetric software. Below, some self-used and recommendable programs will be briefly described along with their main features. But first of all, two methods for the processing of single photos and videos are recommended.

PHOTO/VIDEO PROCESSING

IMAGE PROCESSING WITH GIMP

The free open-source program *GIMP (2022)* is a very powerful image editing program that is almost on a par with its expensive competitors. The large bunch of features, unfortunately also means an equally large amount of time is required to get familiar with. It is also available as a *PORTABLE VERSION*, which can be installed in a folder of the PC or on a USB stick without registration in the operating system.

It was used, for example, to colorize the mistletoe photos differently to make the individual mistletoes more visible (*Fig. 33*). The image was set to Hue -39 (tool **Colors** → Hue-Saturation), which makes the trees appear green-grey and the mistletoe red. It makes them stand out well from the rest of the landscape.

Note: For other photos or tastes other values may be more meaningful and trial and error remains inevitable. The coloring can of course be done with any photo editing software. It is recommended that you use an image editing program you are already familiar with.

With such color changes, automated image evaluation is also easier. Stronger contrasts are both advantageous for the creation of training surfaces for image classification and easier to distinguish for an *AI*.

Fig. 33: Color-modified mistletoe image - mistletoe in light red (Döring, 2021)

COLORED INFRA-RED (CIR) IMAGES e.g. have been used in remote sensing for a long time. They show features of objects (especially vegetation) that have been recorded with special sensors in a non-visible spectrum of the electromagnetic field. ***CIR* photos** are also good for:

- identifying plant species
- estimating biomass of vegetation
- assessing soil moisture
- assessing water clarity (i.e. turbidity)

VIDEO PROCESSING

For videos from aerial flights the easy-to-use program AVIDEMUX (AVIDEMUX, 2022) was used for first cutting.
It is a simple video editing program that can also be run as a PORTABLE VERSION on a USB stick.
CUTTING A VIDEO is done by setting a start and end point to define the section to be cut. Pressing ***DEL*** deletes the selected section. In this way, videos can be shortened relatively quickly for evaluation to the sequences of interest.
The OUTPUT FORMAT should be set to *MP4-Muxer* to get videos in ***MP4 format***, which can be read by most video viewers.
By tapping ***Save*** and specifying a location, the processing (cutting and encoding) of the video is initiated. This can take a while.
Afterwards the free version of the mighty video editing program DAVINCI RESOLVE served as editing program for the prior cut scenes, producing small movies.

PHOTOGRAMMETRY SOFTWARE

Different programs were used to combine individual photos into one overall aerial image (ORTHOPHOTO) and an elevation model. Each program is briefly described below with its advantages and disadvantages.

MAPS MADE EASY

Das Online processing option MAPS MADE EASY (*MME*) is probably the easiest solution to create an orthophoto from the captured single images (*JPGs*). It can be recommended for small offices or freelancers who do not want to purchase expensive hard- and software or do not want to deal with photo processing.
No special knowledge is required to use *MME*, as the images only need to be uploaded to the online server. After assigning a name to the new map and a few more clicks, the processing is initiated and you can move on to other duties. However, there is no possibility to influence the editing process.
Another big advantage is that there is no need to buy an expensive and powerful PC, which is usually necessary for the use of photogrammetry programs. These programs are usually quite resource-hungry and require a certain amount of power to process the images (at least in a reasonable time).

Advanced Output	Download by June 28 Why?
GeoTIFF (TIF)	Download (397.1 MB)
Full Resolution Image (JPG)	Download (35.3 MB)
DEM GeoTiff (TIF)	Download (22.9 MB)
Colorized DEM GeoTIFF (TIF)	Download (16.8 MB)
Colorized DEM (JPG)	Download (1.6 MB)
3D Google Earth (KMZ)	Download (10.7 MB)

Fig. 34: Outputs in MME (Döring, 2022)

As a result, *MME* provides different data formats that can be downloaded after the processing is finished (*Fig. 34*)
The most important data for further processing are mainly geo-referenced GEO-TIFFS, which can be analyzed with their correct geographic position directly in a GIS.
The **KMZ-Format** consists of a zipped file that can be dragged directly in GOOGLE EARTH, where it can be viewed and easily analyzed in a simple way.
This format is also well suited for dissemination due to its smaller size (see *Fig. 34*).
DRONESMADEEASY is the provider of *MME* and the aforementioned flight planning app *MAP PILOT* (see *APPS FOR FLIGHT PLANNING*).
With the *SUBSCRIPTION VERSION* of *Map Pilot Pro* 1 Gigapixel (= 50 photos with 20 MP each or more photos with less MP) can be processed COST-FREE. Only for larger areas with more photos *FEES* will be charged. However, these fees are affordable and can be passed on directly to the customers.
Before uploading the photos for processing a large area, for which fees are incurred, its recommendable to get first a partial area processed without costs, to see if the quality of the resulting orthophoto is sufficient – see below.
The photos for such a partial area can be selected quite easily with the program DRONEDB.
It exists also a prepaid model for image processing, where points can be bought for processing without *Map Pilot* subscription.
All price models can be found here - *HTTPS://WWW.MAPSMADEEASY.COM/PRICING*.

WebODM

For people who have influence on the processing of the photos and want to change processing parameters, the free open source desktop program *WEBODM* = *WEB Open Drone Map* (*WEBODM, 2022*) is recommended.

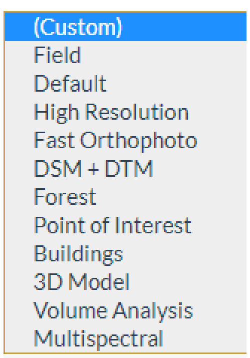

Fig. 35: WebODM Presets (Döring, 2022)

The program offers presets for standard scenarios such as *Field*, *Buildings*, *Forest*, etc. (*Fig. 35*), which already provide useful results. After selecting and uploading the images and assigning a name to the project, all that remains is to click *Start*.
In addition, individual parameters can also be 'fine-tuned'. However, as with any other professional program, this requires a deeper knowledge of the program.
The

- manuals like *ODMBOOK* (TOFFANIN, 2023) and
- *'WEBODM: AN OPEN-SOURCE ALTERNATIVE TO COMMERCIAL IMAGE STITCHING SOFTWARE…'* (PATEL ET AL., 2024) or
- tutorials like e.g. *'PROCESSING DRONE IMAGES WITH WEBODM'* (*GISOPENCOURSEWARE.ORG, 2022*)

are good helpers starting with *WebODM*. Alternatively, you can simply go by try and error. But in all cases you should first process a small subset (see *Fig. 36*) of the images for trials to get the best settings. This keeps the processing time as short as possible after each change of parameters.

Meanwhile, *WebODM* is available as a native Windows program. The INSTALLER for 50 € or 140 € saves a lot of time for 'normal' people, compared to the GITHUB-VERSION, which is otherwise completely costless, but has to be installed by the user from scratch.
An active community constantly drives the further development of *WebODM* and it now delivers a quality that can easily be compared to that of other much more expensive photogrammetry programs.
For this reason, and due to its favorable acquisition costs, it is being used more and more frequently in research and practice.
However, for this as well as for most other photogrammetry programs a powerful PC is needed, which should have (much) more power than a usual office PC - (WEBODM, 2023) see at the end of the website. The necessary several thousand Euros (starting at about 2,000 €) for a work station must therefore be included in the economic calculation.

droneDB

From the same company as *WebODM* is the program *DRONEDB (2022)*, a database software that makes the management and visualization of drone photos and creations of subsets very easy (*Fig. 36*).
This is very useful if you want to process a large area but still need to find out the

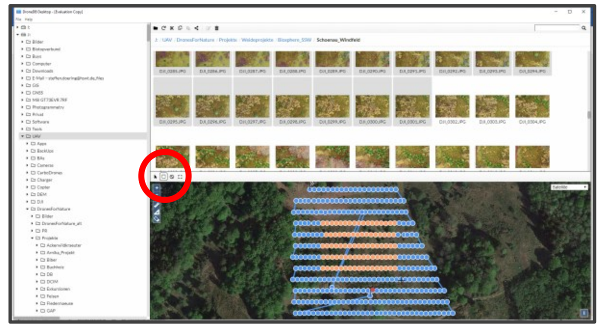

Fig. 36: droneDB - photo selection (Döring, 2021)

optimal parameter settings. For this purpose, as already mentioned, testing on a small area is recommended in order to keep the processing times with repeatedly changed parameters low.
The square button (outlined in red in *Fig. 36*) can be used to select the desired images by drawing a rectangle over them. The selected images are then highlighted in gray in the upper window. With a right click you can copy them into a folder of your own choice.
Previously, the QGIS extension ***Import Photos*** (see SINGLE PHOTO-IMPORT) was used to select the photos for a subarea. With this extension, a point layer of the photo centers can be created in QGIS. By displaying the image names as labels in this point layer, the photos of a certain area section can be found out. However, these must be manually selected in their folder and saved or copied as a subset. This process is much more complicated and time-consuming.

AGISOFT METASHAPE

The vertical ortho views of the rocks were processed with the Russian photogrammetry program AGISOFT METASHAPE, since the other two programs did not yet offer the creation of orthophotos/ orthoviews of vertical structures (like *facade missions*).

In 2020 the *Educational Version* costed 'only' 588 €. But this version may only be used for research and education purposes.
For commercial applications you need the full version, which costs about 3.500 €. This is mostly within the cost

range of many other commercial competitors. However, you have to purchase only once a *Metashape* license with lifetime updates and do not have to pay an annual subscription like for the most competitor programs.

The development of the software is very dynamic and the support for inquiries is fast and courteous.
However, the hardware performance requirements are high and must be taken into account (AGISOFT, 2022).

COMPARISON OF THE USED PHOTOGRAMMETRY SOFTWARE

Tab. 37: Comparison of the used Photogrammetry Software (Döring, 2022)

Program	Specific Properties
MapsMadeEasy (Online - USA)	• completely online • up to 200 photos (20 MP each) free processing for Map Pilot Pro subscriptions • For larger areas, the survey area can be divided into smaller sub-areas with 200 photos each and processed accordingly • Upload images - download results - done • black box without influence
WebODM (USA)	• *Open Source* - installation completely cost-free possible • Windows installer recommended (around 140 € one-time) and saves a lot of time for untrained PC users • easy handling → presets for different purposes → easy to 'click through' • default settings usually already deliver good results • similar 'tuning possibilities' as commercial programs → equally deeper familiarization or training necessary • DTM-DSM preset good compromise between computing time and quality • active *community* • MANUAL available - ca. 30 € • usable with Ground Control Points (GCPs)
Agisoft Metashape (Russia)	• was used specially for vertical orthophotos of rocks, which were not yet possible with *WebODM* and *MME* • one of the most widely used programs • good performance • *default settings* usually already deliver good results • fine tuning of the many possible parameters possible → deeper familiarization or training required • usable with Ground Control Points (GCPs)

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For a comparison of four different photogrammetry programs (***WebODM***, ***Agisoft Metashape***, ***Pix4D***, ***Correlator3D***), five datasets of different drone surveys (vineyard, reef, shoreline/beach, and city) were downloaded from an online platform for drone data (GEONADIR) and processed (PELL; LI & JOYCE, 2022).
Subsequently, the results were compared with each other. There was no clear winner and all programs performed similarly well with the default settings (even the open-source program *WebODM*!).

However, there were noticeable differences in the processing time and the outputs. Therefore, **it is recommended to use the same software with the same settings for monitoring changes and creating multi-temporal time series**.

In *Tab. 38*, in addition to those already presented, some further photogrammetry programs are compared with regard to their price and their processing possibilities.

Tab. 38: Comparison of some photogrammetry programs (Döring, 2022) in terms of price and processing capabilities

			Processing	
Program	**Version**	**Costs**	**Online**	**Offline**
MAPS-MADEEASY	ONLINE	• POINTS per Gigapixel • Processing up to 1 gigapixel free for *Map Pilot Pro* users	fee	yes
WEBODM	OPEN SOURCE - INSTALLER	• Desktop processing completely free • 147 $ on time fee for installer (recommended) • self-installing free of costs	fee	yes
AGISOFT METASHAPE	EINMALIG	• 570 € for educational version • commercial version ca. 3.500 €	yes	yes
REALITYCAPTURE	FREE OR SUBSCRIPTION	• **free to use for students, educators, and hobbyists and for companies making less than $1 million USD/year** • Help tutorial as sidebar • man menus	yes	yes
PIX4D	SUBSCRIPTION	• different subscription models		yes
3DSURVEY	SUBSCRIPTION	• different subscription models		yes
DRONEDEPLOY	SUBSCRIPTION	• different subscription models	directly from App	no

ANALYSES OF SINGLE IMAGES AND ORTHOPHOTOS

After photogrammetric processing, the resulting orthophotos, elevation models and point clouds can be used for various analyses.

The analyses of single images or orthophotos can be done in different software applications and in different degrees of difficulty.

SINGLE IMAGE/VIDEO ANALYSES

Single images or videos can be easily analyzed visually and relevant objects or structures can be counted.

In the meantime, there are more and more *AI*-based solutions (*AI* = Artificial Intelligence) that can automatically recognize animals or objects in images/videos and thus facilitate the analysis considerably.

However, such advanced methods are usually not easy to use, either in terms of their operation or in terms of the hardware and software required.

GIS ANALYSES OF ORTHOPHOTOS

There are several ways to analyze orthophotos in a *GIS* (Geographic Information System).

The simplest method of *GIS* analysis is to import an orthophoto into a *GIS* program and digitize the areas or objects of interest. Thereby, these get measurable properties. For example, areas or distances can be measured or counted.

In this way, changes can be documented, analyzed and objectively quantified.

The data can also be exported e.g. as tables and used for further processing in special statistics programs.

Google Earth

GOOGLE EARTH (GE) is such a well-known (Online-) *GIS* system. In *GE* it is possible to upload georeferenced orthophotos directly or simply drag them in the map area from the corresponding folder.

This way you can

- **Compare** your own **drone orthophotos with *GE* aerial photos from different years**. To do this, one has to tap on the button ***'Show historical images***' (symbol similar to a clock) in the upper toolbar. Afterwards, the available historical views can be compared with the current image using the vertical slider that appears.
- In addition, the **areas or elements** to be examined can be **digitized** using the *orthophoto* loaded into the program. To do this, tap the ***'Add polygon***' button, whereupon a kind of crosshair and a pop-up window appear (see *Fig. 37* and GOOGLE EARTH in FLIGHT PLANNING ON PC). The crosshair can now be used to set the corner points for a polygon. Once the last corner point has been added, the area can be named in the pop-up window, the color etc. can be set and the finished polygon is displayed when the window is closed.
- Under the ***'Measured values***' tab, both the area and the perimeter of the polygon can be read.

- The digitized layers are stored in the data bar on the left and can be modified at any time.
- The data can be organized in **project folders**, which allows a systematic data management.
- A folder can be exported as *KMZ* or *KML* with '***Save location as ...***'.
- For further processing and modification of the individual areas as distinct geometries, they must be converted into other data formats in QGIS using '*Export*' and '*Save as*'.

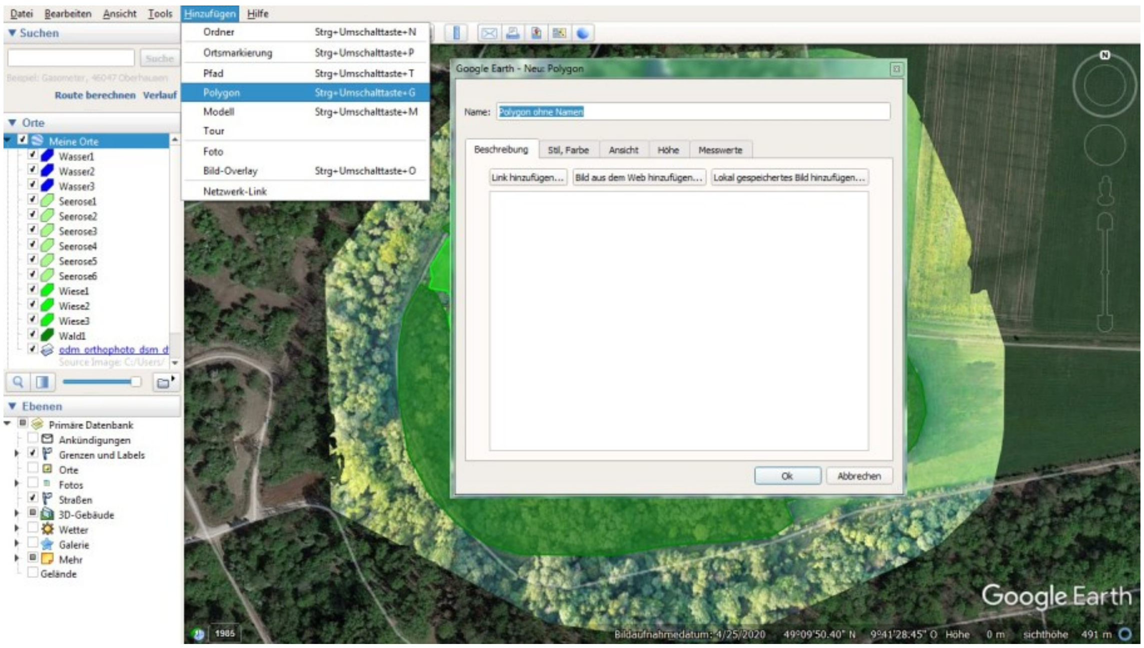

Fig. 37: Importing and editing drone data in Google Earth (Lutz, 2022)

QGIS

[*QGIS*] is a free open-source desktop GIS software and is becoming more and more popular. It can handle the most diverse data formats without any problems. Thus, data can be easily dragged into *QGIS* and, if they have coordinates, are located directly on the 'right place in the world'.

The position of the data can be checked with different integrated background maps - from *Google Earth* over *OpenStreetMap* up to the integration of official maps of the state surveys – see e.g. *OPEN.GIS.LAB (2018)*.

QGIS has a wide range of basic functionalities, but can be supplemented with many plug-ins.

Hereafter, a few plug-ins that were used/tested for the analysis of the drone data:

Single Photo-Import

The ***Import Photos*** tool is well suited for the visual evaluation of orthophotos by sharper single photos.

This icon  appears in the Toolbar of QGIS – see red circle in Fig. 37.

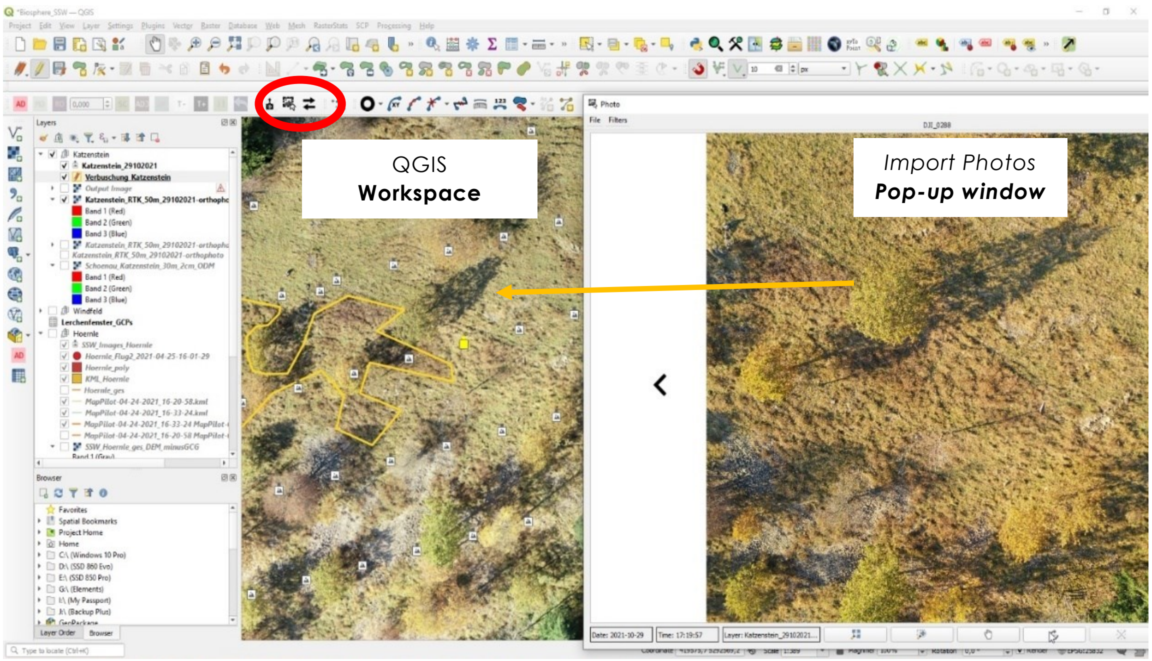

Fig. 38: Example of Digitalization with Import Photos (Döring, 2022)

Pushing the **Camera icon** on the left , a point layer can be created from the image centers of geo-tagged photos (= with coordinates in the *meta* or *exif* data). The desired folder with the corresponding images has to be selected and the execution to be started. The point layer is automatically displayed in QGIS.

In the attribute table of the layer many parameters (like image name, location, the relative path to the images etc.) are stored. When the **image button** in the center of the toolbar is activated, tapping on one of the photo points will display the associated photo, with its date & time and elevation information, in its own pop-up window (right image in *Fig. 38*).

This window can be enlarged or displayed side-by-side to the QGIS workspace.

The double view allows, with the help of the usually sharper respective single photo, a more precise visual inspection of an orthophoto in the workspace. This makes digitizing (*Fig. 38* left) easier and more accurate.

It is also possible to simply match project photos with a background map or other layers. This is especially useful for photos from manual flights. It simplifies the localization and visual/manual evaluation of single photos (e.g. for beaver, salmon, bird monitoring).

In view of the time-consuming set-up and application of automated evaluation methods, this is often the fastest method of analysis.

Automated Analyzing Tools

The classification tool ***dzetsaka*** is suitable **for experienced users for (semi-)automatic image classification**.

- Homepage and manual - [GITHUB.COM/LENNEPKADE/DZETSAKA]
- It can be used to classify the raster data/images to be analyzed using [TRAININGS AREAS]. In these areas, representative digitized objects are assigned to different classes and thus made identifiable. Afterwards various classification algorithms (*Random Forest, KNN and SVM*) can be opted for.

The ***Orfeo Tool Box*** ([OTB]) with a great number of algorithms, tools etc. offers many possibilities to process raster data (images).

- The OTB tool ***ImageClassifier*** is controlled similar to the *dzetsaka* tool by training surfaces and is therefore only as good as the created surfaces.

The ***Semi-Automatic Classification Tool*** ([SCP]) also comes equipped with a variety of algorithms, tools, etc. and is specifically designed for downloading and using satellite data.

Note: Any supervised classification requires adequate knowledge of the objects to be examined and classified ([GROUND TRUTHING]). Therefore, **the training data must be cleanly and accurately created and readjusted for any new changed condition** (light, clouds, phenology etc.).
For the applications propagated in this manual, mostly only *RGB* data (= 'normal' color data) are available, in which each pixel is assigned a color code. These color codes are used for the evaluation.
Accordingly, similar colors, even of different objects, are classified in the same way and thus incorrect. For example, shadows of trees can be interpreted in the same way as similarly color-coded dark stones or ground surfaces.
For these and some other reasons, **the (semi-)automatic image classification tools are not trivial to handle and require experience and always good training data.** Mostly, these **have to be created for each flight again with its new acquisition conditions** (different light conditions etc.).
For people who are not experts in the field and for more effective data processing, this type of automated assessment can currently not be suggested.

Note: On June 14, 2023, the **online AI portal** from [BIODRONE] was presented in the course of a workshop. The service is not cheap, but allows in a simple web interface to **create online *AI* models** for the analysis of own images without the need of special knowledge or hardware.
Own photos are uploaded and subsequently, an orthophoto is created.
Circle or polygon shapes have to be drawn manually around some of the target objects for detection.
Afterwards, an artificial intelligence (*AI*) system can be trained using these annotated shapes. The resulting *AI* model can be enhanced through uncomplicated supplementary digitalization procedures.

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EPILOGUE

In addition to the handbook, training modules for the presented topics were produced during the research project 'DROHNEN IM BIOMONITORING' and the network '*DiB - Drones in Biomonitoring*' was founded. More than 200 UAV specialists, nature conservationists, companies, students etc. are subscribed. It is a platform for the exchange of drone knowledge.

I cordially invite all interested parties to participate in this network. If you are interested in the network or have any questions or comments, please feel free to contact me at DRONESFORNATURE@POSTEO.DE.

The corresponding more detailed and public project report is soon available in English at the following web addresses: HTTPS://DOI.ORG/10.5281/ZENODO.11182157 or at HTTPS://WWW.RESEARCHGATE.NET/PROFILE/STEFFEN-DOERING/RESEARCH. It presents the own carried out project parts for the here mentioned practice examples (04 PRAXIS) in detail and defines problem areas, which could be especially interesting for public authorities.

Furthermore, **I invite all readers to comment eagerly** in order to keep the handbook up to date and to make it better.

Thank you for your reading, hope this helps + best regards!
Steffen

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SHORT CHECKLISTS FOR PRINTING

The following checklists can be printed out and freely used. However, they do not replace the need for customization and supplementation according to your specific requirements!

Checklist – Generel Requirements	OK
EU proof of online training **A1/A3**	
EU A2 Pilot Certificate **A2** + practical self-training	
Registration of the pilot/operator (+ operator-ID on the Drone)?	
Commercial (recommended) **liability insurance?**	
Logbook prepared (recommended)**?**	

Checklist – Mission Preparation	OK
Area of operation defined – e.g. **KML-file saved and uploaded?**	
Geo-Zones proofed - office PC and/or in apps on the smartphone?	
Permission requirements checked?	
Local nature conservation area managers or associations contacted?	
Methodological arrangements with clients made?	
Research questions well defined?	
Sensor defined? - RGB, Multispectral, Thermal, resolution etc.	

Checklist - Flight Preparations still in the office	OK
UAS checked? **Software and firmware** up to date and concordant? All technique ok? **Basic settings** (max. flight height, return to home (*RTH)* height, sensor settings etc.) after updates checked?	
Enough batteries loaded and packed in firesafe boxes? Eventually battery car recharger packed?	
The **KML of the survey area** prepared and loaded on the **controller´s SD card?**	
Eventually **background map of the flight planning app** loaded in cache?	
SD cards in UAS and RC inserted? **Replacement SD cards**?	
Logbook prepared and packed?	

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Licenses, insurance documents and **permissions** packed?	
Weather on PC and/or in apps **checked**? • *UAV Forecast* **- Wind data,** *Geomagnetic disturbances* **(Kp-Index) - PC/App** • *kachelmannwetter.com* **- esp. Wind data - PC** • *wetteronline.de* **- 'simple' Wind data - PC** • *Kopter Profi App* **- e.g. Geo zones, Kp-Index - App**	
NOTAMs checked - e.g. *www.dfs-ais.de* oder in *Droniq-App*?	
Further equipment packed (Landepads, barrier tape, eventually *Ground Truthing*/survey equipment - GNSS receiver, ground targets ...)?	
Nature conservation authority via E-Mail informed?	
Emergency contact list prepared and packed?	

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Checklist - Flight Preparations on-site	OK
Geo-Zones checked again in Apps: e.g. *MAP2FLY*, *KOPTER PROFI APP*, *DRONIQ APP*?	
Got an overview of the terrain – power lines, obstacles (e.g. trees, buildings etc.) – an tried to memorize them? **Terrain undulation** (hills etc.) observed for height settings?	
Starting place choosen and secured if necessary? • **If possible, start from the highest point to have always enough distance to the ground and from obstacles!** Pay attention to the changing *GSDs*! • **If necessary, secure the starting place yourself or arrange for necessary closures!**	
Team instructed (security and methodology) and **present persons** of flight plans informed?	
If an airfield is nearby, the control office by phone contacted and instructions obtained?	
UAS well prepared for take-off?	
Settings checked again – new updates? For example:	
• **max. flight height**	
• **Return to home (*RTH*) height**	
• **Sensor settings**	
• **max. flight distance** (radius oof geo fence)	
• **battery settings**	
• **Alarms (batteries, flight distance etc.)**	
Pilot fit (well rested, healthy, no medicaments or drugs taken)?	

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