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PRACTICE INSIGHTS

SPECIAL FEATURE: INNOVATION IN PRACTICE

Flying high for conservation: Opportunities and challenges of operating drones within the oldest National Park in the Alps

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Abstract

1. Drones have emerged as an essential tool in various conservation applications. Despite the great potential, drone use by protected area managers is still scarce or accompanied by scepticism. The ongoing debate revolves around whether drones are fancy gadgets or if they can effectively guide management strategies and align with the overarching goals of protected areas.
2. Here, we present a practical overview of how novel drone applications contribute to the goals of the oldest national park in the Alps, along with the associated challenges. To do so, we review our seven-year experience as park employees flying drones within the park and its surroundings.
3. First, we provide background information receiving limited attention in the existing literature such as our motivation behind a drone purchase, costs and an overview of our flight operations.
4. Second, we show three examples that demonstrate the potential of drones as a valuable tool in addressing the goals of the park: managing the area, researching natural processes and facilitating communication.
5. Third, we reflect on operational challenges and provide valuable lessons for addressing the specific challenges of flying drones in an alpine and protected environment.
6. *Practical implication*: Our experience supports the benefits of drones for protected area management, but it also highlights the need for certain precautions, increased focus on operational challenges and further research on wildlife-drone interactions.

KEYWORDS

alpine environment, ant mounds, deep learning, flight operations, protected areas, repeat photography, UAS, UAV, visitors, wildlife

1 | INTRODUCTION

Over the past decade, drones, also known as unoccupied aerial systems, have become indispensable tools in various conservation applications (Robinson et al., 2022). They provide a cost-effective means to capture very high spatial resolution data (Marvin et al., 2016; Wich & Koh, 2012), enabling a timely collection of aerial imagery and the derivation of digital elevation models (DEMs, e.g. Guillaume et al., 2021). Drones provide complementary data to satellite sensors, particularly in terms of spatial resolution, time and frequency of acquisition, and viewing angles—attributes that are essential for many applications (Alvarez-Vanhard et al., 2021). Notable applications of drones in conservation, particularly in protected areas, include wildlife monitoring (Linchant et al., 2015), tracking wildfires (Tang & Shao, 2015), monitoring of natural processes (Woodget et al., 2017), detection of illegal activities (Bondi et al., 2018), quantifying human disturbance (Ancin-Murguzur et al., 2020), estimation of plant diversity (Rossi et al., 2022) and mapping invasive species (Gonçalves et al., 2022).

While these studies show that drones can provide high-quality data for effective monitoring and management of protected areas, their usage by park managers remains relatively modest (López & Mulero-Pázmány, 2019; Walker et al., 2023). Many protected area managers maintain scepticism about the application of drones for several reasons, including concerns related to costs, lack of expertise, potential impacts on wildlife (Mo & Bonatakis, 2022), public acceptance (Markowitz et al., 2017), logistics, topography and weather (Duffy et al., 2018). Adding to the prevailing scepticism, it remains debated whether drones are fancy gadgets or if they can effectively guide management strategies and align with the overarching goals of protected areas (Seier et al., 2021).

Drawing on our seven-year experience flying drones over 100 times in the Swiss National Park (SNP) and its surroundings, we provide a practice-based overview of how novel drone applications contribute to the goals and tasks of the oldest national park in the Alps and highlight opportunities and operational challenges that have received limited attention in the existing literature. Our insights provide valuable lessons to assist managers and scientists planning to fly drones in protected areas.

2 | DRONE HISTORY OF THE SWISS NATIONAL PARK

The SNP, founded in 1914, is a category Ia nature reserve (highest protection level—strict nature reserve), encompassing 170 km^2 of rugged alpine terrain with elevations ranging from 1350 to 3170 m a.s.l. (46°34′–46°46′ N, 10°02′–10°18′ E). The goals of the park are threefold: to allow the unhindered development of nature without human interference, to research the ensuing natural processes, and to inform visitors (Baur & Scheurer, 2014). To support the goals of the park, the park management approved the purchase and utilisation of drones in 2016. Traditionally, the park's habitat monitoring, generation of DEMs and survey of infrastructure have been costly and labour-intensive, relying on expensive and externally conducted airborne campaigns or very time-consuming manual measurements with the use of theodolites, total stations, and differential GPS receivers. Manual measurements also require field inspections, which can disrupt highly sensitive alpine ecosystems. Therefore, strong arguments in favour of the purchase of drones were the claimed capability to produce in-house, cost-effective, less intrusive and accurate spatial data for the monitoring of natural processes. The decision was further supported by the growing demand from external researchers for timely and high-resolution spatial data provided by drones. By employing its own drones, the park management opted to (i) eliminate the need for external expertise, recognising the importance of local area knowledge, (ii) have the flexibility to respond to management needs and the survey of natural disturbances promptly, and (iii) build in-house expertise on what and how can be achieved with drones. From a regulatory point of view, Switzerland adopted the EU drone regulation on 1 January 2023 and the SNP is a designated no-fly zone with exceptions allowed for the park administration (Federal Office of Civil Aviation, 2023). To be able to fly drones, we had to take a self-study online training course and exam since our flights are conducted in the open category A3 (for further information see https://www.easa.europa.eu/domains/civil-drones-rpas).

2.1 | Hardware and software costs

To operate drones from 2017 to 2023, we invested approximately 15,000 Euros per year in material and software, including the acquisition of (i) four multi-rotor drones: Falcon 8 octocopter (Ascending Technologies, Krailling, Germany) in 2017, DJI Matrice 210 RTK v2 in 2019, DJI Mavic 3E and DJI Mavic 3T (DJI, Shenzhen, China) in 2023; (ii) their accessories (i.e. controller, batteries, GNSS base station); (iii) different cameras: RGB (Sony NEX-7, Zenmuse X5S) for the generation of high-resolution DEMs, thermal (FLIR Tau 2640) and multispectral (Micasense Altum) for habitat and vegetation health mapping and monitoring; (iv) flight planning software UgCS (SPH Engineering, Riga, Latvia) and photogrammetry software PIX4Dmapper (PIX4D S.A., Prilly, Switzerland); and (v) liability insurance. We opted for multi-rotor drones due to the small area needed for take-off and landing, the ability to hover and simultaneously acquire high-oblique images, reduced potential for wildlife conflicts (Section 4) and significantly lower costs compared to vertical take-off and Landing (VTOL) drones—typically around three times cheaper. Excluded from the reported costs are the infrastructure costs required to handle and store the large amount of data produced (e.g. workstation) and the differential GPS receiver used for measuring the ground control points (GCPs). While at first glance the cost could be perceived as high, drones have greatly facilitated our work, allowing us to meet our mandate more effectively and at the same time reduce the overall disturbance of field inspections (Section 3).

2.2 | Overview of flight campaigns

During the 7 years of drone operations, we have conducted 132 flight campaigns, covering an average of 21 ha per campaign. We carried out most drone flights at a flight altitude between 40 and 80 m above-ground in automated flight mode, producing data with an average spatial resolution of 2.55 cm and an average location accuracy of 0.04 cm in the three coordinate dimensions (coordinate system LV95/LN02). We determined the location accuracy by using an average of nine GCPs per flight campaign, measured with a Trimble GeoXR real-time kinematic GNSS.

Of all flights, 38% were carried out over grasslands to document habitat restoration, estimate plant diversity and map habitat types (Figure 1a). We captured images of rivers in 33% of our drone campaigns to mainly monitor changes before and after artificial floods. The monitoring of mass movements including debris flows, solifluction lobes, rock glaciers and avalanches made up 21% of our drone applications. To a lesser extent, we imaged forests (that is, 5%) for deadwood and tree density, while the remaining image acquisition focused on assisting infrastructure projects, including roads, buildings and dams. Interestingly, we carried out 47% of our flights beyond the park borders (Figure 1b). Therefore, our drone expertise provided an opportunity to interact with different stakeholders such as the adjacent nature park, the hunting and fishing office and private companies engaged in restoration projects, strengthening the park's acceptance within the region.

3 | DRONE APPLICATIONS IN LINE WITH THE GOALS OF THE PARK

The following three examples demonstrate how we took advantage of drones in addressing the goals of the park: managing the area, researching natural processes and informing visitors.

3.1 | Managing the area: Infrastructure planning with point clouds

Our primary use of drones has been for high-resolution topographic surveying with Structure-from-Motion (SfM) photogrammetry (Westoby et al., 2012). The 3D point clouds or thereof derived DEMs generated from overlapping drone images with SfM enabled us to precisely map the landscape. In the SNP, natural processes are strictly protected, allowing nature to thrive unhindered. However, this entails a certain risk for the few infrastructure facilities that lie within the park, requiring regular maintenance. Debris flows in particular resulted in the recurring need of repositioning or rebuilding trails, bridges and staircases. The planning of these infrastructures was facilitated by the availability of point clouds and elevation models displaying the current situation, that is post-natural event. For example, we used Potree (https://potree.github.io/), a free open-source web-based graphics library for point cloud rendering and measurements, to determine the necessary span width for newly required bridges (Figure 2a).

3.2 | Researching natural processes: Ant mounds in thermal images

To analyse the effect of ants on grasslands in the SNP, the abundance and distribution of *Formica exsecta* mounds are surveyed regularly on an 11 ha alpine meadow located in the park (Schütz et al., 2008). Manually surveying the mounds took three people an entire week, which prompted us to test and implement the use of drones to map them. During the course of sunny days in summer, ant mounds heat up on the surface with a difference of up to 10°C compared to surface temperatures in vegetated areas (Wylie et al., 2021). The significant thermal contrast and the rounded shape (Figure 2b) render the identification of ant mounds on thermal images feasible with deep learning (Brodrick et al., 2019). Our workflow involved the generation of thermal orthomosaics with a spatial resolution of 6.77 cm using SfM with images obtained by our thermal camera mounted on the Falcon 8 octocopter. To label, train, validate and classify the ant mounds, we used the deep learning toolset of ArcGIS Pro *v2.7.0*. Specifically, we trained a region based convolutional neural network (R-CNN) with Resnet50 as a backbone model, using a dataset of 300 labelled ant mounds spanning two areas of 1.6 ha in total. We achieved a high model accuracy (*F*-Score = 0.79) with an almost negligible rate of false positives and the only limitation being the non-detection of smaller mounds (diameter < 20 cm). For details on the flight campaign, image processing and mound classification, we refer to Morger (2022). Overall, after an hour of drone-based image acquisition and a couple of

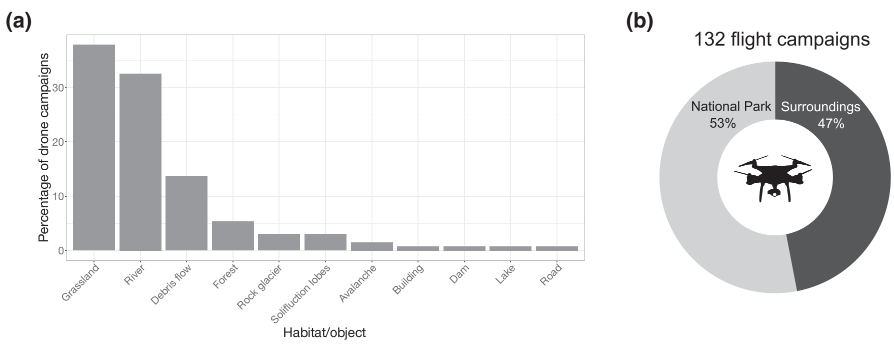

FIGURE 1 Percentage of 132 drone campaigns conducted in the Swiss National Park or surroundings between 2017 and 2023 categorised according to their (a) main ecosystem or object imaged (b) location.

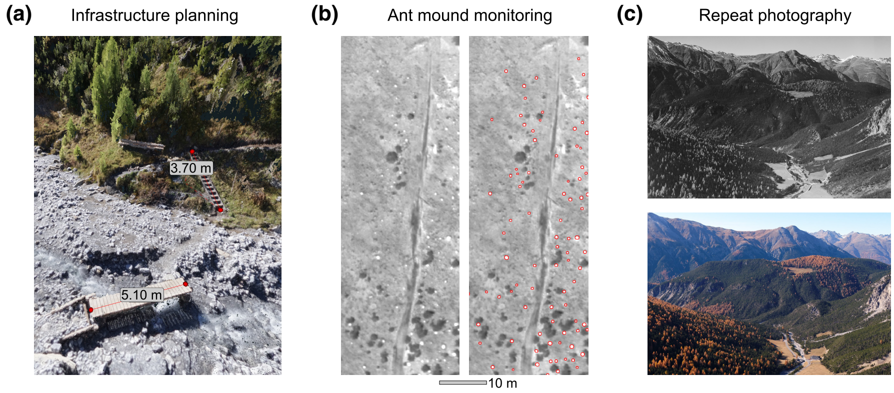

FIGURE 2 Three examples of drone applications in the Swiss National Park: (a) Point cloud derived from drone images with photogrammetry used for infrastructure planning. (b) Drone-based thermal images showing ant mounds in white (left) due to warmer temperatures and automatically classified mounds using deep learning in red (right). (c) Drone-based repeat photography (bottom) of a historical landscape image taken by Werner Friedli in October 1954 from a low-flying aeroplane (top).

hours of mostly unsupervised processing, we identified more than 1600 ant mounds across the entire meadow, minimising disturbing field inspections, saving a week of fieldwork while precisely detecting most of the mounds and estimating their size.

3.3 | Informing visitors: Drone-based repeat photography

Repeat photography is the practice of replicating pre-existing photographs for documenting and quantifying changes over time (Depauw et al., 2022; Hammond et al., 2020). It allows us to document habitat restoration and ecosystem changes in an oblique view, better aligning with how people perceive the world and thus offering a great tool for communication purposes. For example, we have recaptured a historical landscape image of the SNP taken by Werner Friedli in October 1954 from a low-flying aeroplane (Figure 2c). To the best of our knowledge, this marks the pioneering use of drones for repeat photography of historical high-oblique airborne images. Our approach used the monoplotting technique to obtain an estimation of the historical camera position and angle. We estimated the height above-ground at 337.35 m with the camera almost horizontally orientated at an angle of 6.514° downwards and an azimuth angle of −89.211°. Given the flight altitude above-ground level, such a flight is currently only possible with a special permit from the Federal Office of Civil Aviation and a specific operations risk assessment (SORA), a requirement not needed when we conducted the flight on October 28, 2021. During the flight, we had to slightly correct the drone position manually until the shot was properly framed. Once the image was recaptured, the affine matching was performed with the free available software Regeemy *v0.2* (https://regeemy.software.informer.com), employing control points present in both images, such as unchanged rock structures. The historic and new images will be part of an exhibition at the park visitor centre and were already used to visually communicate landscape transformations that have transpired over the course of 70 years within the SNP.

4 | THREEFOLD CHALLENGE OF OPERATING DRONES IN THE PARK

4.1 | Navigating the complex environment

The rugged and steep alpine landscape requires careful flight planning and limits the operational range due to limited flight visibility. While flight planning software accounting for terrain elevation has greatly increased flight operation safety, based on our experience, steep or terrain drops in forested areas remain problematic. In such areas, inaccuracies and coarseness of the digital terrain model used to plan the automatic flight and selecting a flight altitude too close to the tree height can lead to the drone flying lower than tree crowns. A situation that occurred when our DJI Matrice 210 RTK V2 collided with the top of a 55-meter-tall larch tree on a 35-degree steep slope, leading to a crash landing. While the camera survived the fall, the drone suffered total damage. In general, in steep and rugged areas, we recommend being very conservative in the choice of flight altitudes, having good area knowledge, conducting pre-flight checks onsite and having the flight plan crosschecked by another pilot.

At elevations greater than 2500 m a.s.l., we observed air rarefaction affecting the power consumption of our drones. Air density is inversely related to air temperature and decreases with lower air pressure. Another factor influencing battery performance is the wind. Particularly, in the proximity of mountain ridges, the wind can be of high intensity. Under cold and windy conditions, we advise planning flight duration in a way that a certain percentage of the battery capacity remains unused and being prepared for fast battery percentage drops during flights. In particular, we have observed decreases in flight duration at high elevation and windy conditions by as much as 40% compared to the manufacturer's specifications. Furthermore, we strongly discourage flying in cold and humid conditions, that is the presence of low clouds and temperatures below the freezing point. Low temperatures in combination with very humid air cause icing of the propellers with aerodynamic degradation and potentially catastrophic consequences for the drone (Szilder &

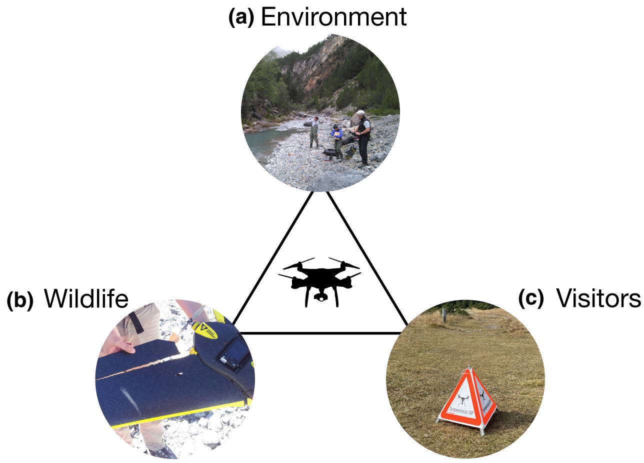

FIGURE 3 Three main challenges of operating drones in protected areas: environment, wildlife and visitors. (a) Drone flight in a remote river gorge. (b) Fixed-wing drone after eagle attack. (c) Warning sign to alert visitors of ongoing drone operations.

Yuan, 2017). At the moment, ice protection systems for drones are under development (e.g. Müller et al., 2023).

Remote areas of the SNP and river gorges (Figure 3a) do not have an internet connection, making higher precision estimates of the drone positions with real time kinematic (RTK) impossible. In such areas, achieving drone products with centimetre accuracy requires laborious GCPs (James et al., 2017) or the additional step of post processed kinematics (PPK), which is currently limited to certain drone models (Li, 2023).

Finally, we advise getting insurance covering the costs of a total loss, in the case such a loss is not affordable. Given the uncertainties involved in drone flights, it is not a matter of if but rather when the drone might encounter an accident.

4.2 | Minimising the disturbance to wildlife

The SNP is known for its large populations of wild ungulates. In addition, five pairs of eagles (*Aquila chrysaetos*) and six pairs of bearded vultures (*Gypaetus barbatus*) nest in the park or its vicinity. Correspondingly, one of our concerns when operating drones is the potential disturbance to these animals. Although ungulate monitoring programmes in the SNP could greatly benefit from drone images as proven by different studies (McMahon et al., 2021; Zabel et al., 2023), we are still sceptical towards flying over animal herds. We think that our scepticism is partly justified (Seier et al., 2021) and operating in a strict nature reserve requires a balance between the goals of minimising human interference and research goals. While drone applications avoid intrusive field inspections and the generated noise can be minimised by choosing an optimal flight altitude (Duporge et al., 2021), ungulates, rodents (e.g. marmots) and birds could still perceive drones as predators or competitors (Egan et al., 2020). However, the effects on animal behaviour can be difficult to determine and further studies need to be conducted. In the meantime, we avoid flying over mammals and use mitigation measures to reduce the potential impact on wildlife (Mo & Bonatakis, 2022). Specifically, we avoid using fixed-wing or VOTL drones due to the negative experiences encountered with territorial eagles, who seem to perceive the fixed-wing drones as competitors. During two early test flights using fixed-wing drones with a bird-like silhouette, the drones were attacked by eagles. In one case, the drone wing was damaged, but an emergency landing was still possible (Figure 3b). The eagles remained unhurt, yet the outcome could have been different, potentially grounding all our future drone endeavours. In the presence of predatory birds, we therefore recommend using lower-flying, less bird-like multi-rotor drones. Overall, to minimise the disturbance, we (i) plan the drone campaigns avoiding the nesting periods of birds and the presence of large ungulate herds, (ii) do not fly in the winter months to avoid triggering additional stress in wildlife and (iii) conduct as far as possible the drone flights in areas already disturbed due to road noise and being adjacent to hiking trails. Crucial in minimising disturbance to fauna is the local area knowledge, in our case directly available by the fact that the park independently plans and carries out drone operations and discusses the flight operations internally, including not just the pilots but also rangers and executive board members.

4.3 | Justification to visitors

From the onset, we were mainly concerned with avoiding disturbance to wildlife, eventually underestimating the conflict potential with visitors. Flying drones in a strict nature reserve can seem like a contradiction to many. While the public support for conservation-related uses of drones is fairly high (Markowitz et al., 2017), park visitors searching for intact and undisturbed nature can get highly irritated by the buzzing drone noise. Accordingly, we had angry visitors, leading to uncomfortable situations when we tried to operate a drone and provide them with information at the same time. It is essential to recognise that confrontations might occur but mitigation measures are possible. For example, we now raise awareness of drone applications in popular science magazines, communicate via social media when large drone campaigns are planned, avoid flying drones during peak season, put up warning signs (Figure 3c) and have an additional ranger in place to communicate with visitors during drone operations.

5 | CONCLUSION

The decreasing costs and increasing safety features of drones (e.g. obstacle detection), open new opportunities for protected areas. Here, we have shown how drones have greatly facilitated our work as protected area managers, extending beyond research scopes and the confines of the park. With the right precautions, protected area managers can greatly benefit from the deployment of drones in managing and monitoring the park, communicating results and fostering collaborations. In taking advantage of drones, we have also faced different challenges regarding the environment, wildlife and visitors. By sharing our experience, we intend to provide insights into best practices for flying drones in protected areas and draw attention to often underreported details. We believe that highlighting challenges and reporting the interaction with wildlife should be essential steps to further enhance indispensable, safe and minimally disturbing drone applications in protected areas.

AUTHOR CONTRIBUTIONS

Christian Rossi conceived the study and led the writing of the manuscript. Samuel Wiesmann contributed to reviewing previous drafts and gave its final approval for publication. Both authors performed most of the drone flights.

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CONFLICT OF INTEREST STATEMENT

Both authors were employed by the Swiss National Park during the study.

DATA AVAILABILITY STATEMENT

There are no data associated with this paper.

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