Remote Sensing in Ecology and Conservation
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ORIGINAL RESEARCH

Drones as a tool to monitor human impacts and vegetation changes in parks and protected areas

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Keywords
Drones, protected areas, recreation ecology, tourism impact, UAVs, visitor management

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Editor: Ned Horning
Associate Editor: Anna Carter

Received: 15 February 2019; Revised: 7 August 2019; Accepted: 12 August 2019

doi: 10.1002/rse2.127

Abstract

Increased visitation to protected areas could have adverse impacts on the conservation values in the protected areas, and therefore effective visitor monitoring methods are needed to meet the complex management challenges that arise. Collecting data on human impacts is highly time consuming, thus requiring more effective tools that allow for high-quality and long-term measurements. In this study, we show how unmanned aerial vehicles (i.e. UAV or drones) could be used to monitor tourism impacts in protected areas. Tourism has boomed in national parks in Norway in recent years, such as in Jotunheimen National Park for which this study applies. We test the use of drones on a site where new tourist facilities will be established to set a baseline to identify future changes. We demonstrate how drones could help protected area management by monitoring visitor use patterns and commonly associated impacts such as trail condition (width and depth), vegetation structure and disturbances, informal trail proliferation, trampling, and trash and other impacts along the trails. We assessed accuracy and reliability compared with intensive field measurements of impacts and found low-cost drones to be effective in mapping the study area with a resolution of 0.5 cm/pixel: drone derived trail measurements were comparable to traditional measurements with a negligible divergence on trail width measurements and a consistent 1.05 cm divergence on trail depth measurements that can be corrected with a few validation points. In addition, we created a high-resolution vegetation classification map that could be used as a baseline for monitoring impacts. We conclude that drones can effectively contribute to visitor monitoring by reducing time spent in the field and by providing high-resolution time series that could be used as baseline to measure tourism impacts on conservation values in protected areas.

Introduction

The number of visitors to parks and protected areas is substantially increasing (Balmford et al. 2015). Protected areas provide opportunities for recreational activities (e.g. hiking, running or biking) and can provide a range of physical, psychological and social benefits, but often require trails and other infrastructure (e.g. parking lots) to ensure safety and enjoyment of natural areas. Without proper management, intensive use of natural sites can result in worsening of trail conditions (Ólafsdóttir and Runnström 2013), and impacting the visitor quality and safety (Tomczyk et al. 2016). Therefore monitoring the state of the trails, such as soil erosion, trail width or informal trails, is a priority that requires constant monitoring to ensure long-term preservation of the landscape and to limit the area directly disturbed by trails (Barros et al. 2013; Tomczyk et al. 2017).

Monitoring trails and the ecological conditions of the natural sites generally requires intensive sampling by fieldworkers who directly measure trail conditions such as depth or width (Olive and Marion 2009), proliferation of informal trails (Barros and Pickering 2017), effects of trampling and campsite formation (Monz et al. 2013), vegetation fragmentation and shifts as a consequence of recreational use (Hammitt et al. 2015) and the distribution of trash and other visitor impacts along the trails (Kuba et al. 2018). These qualities are important to manage, not only for conserving native species and wildlife, but also for providing visitors with a high-quality experience from visiting protected areas. While the current methods for monitoring impacts can be very precise, these approaches rely upon highly skilled workers and careful planning on what parameters that are relevant to measure. Economic and logistic constraints of traditional fieldwork result in temporally and spatially sparse data on conditions in the protected areas hindering effective conservation planning.

An alternative requiring less field work is to use mid-or high-resolution georeferenced imagery, either from aircrafts or satellite imagery (Kim and Daigle 2012). However, the resolution and accuracy of measurements are lower compared to field data. Satellite imagery that are often used for conservation planning could be freely available (e.g. Landsat 8, Sentinel-2), but their low resolution makes them unfit for the purpose of managing protected areas and for detecting small-scale disturbances to the landscape (<1 m). Sub-meter resolution data (e.g. IKONOS), on the other hand, are costly to obtain due to the high prices related to each image download. In addition, temporal resolution is also a challenge when working with remotely sensed data, as it depends on the weather at the time the satellite passes the area of interest, and therefore cannot be pre-determined. While it has been shown that high-resolution satellite imagery (less than 5 m pixel size) can provide more accurate land-cover assessments than medium resolution (30 m pixel size) imagery (Boyle et al. 2014), finding high-quality time series of high-resolution and cloud-free images can be difficult and expensive.

With the advent of affordable unmanned aerial vehicles (i.e. UAVs or drones) capable of collecting high-resolution imagery, several fields of research are using this technology to gather relevant information. Drones have been implemented for many different purposes, such as wildlife detection (Koh and Wich 2012), vegetation mapping (Cruzan et al. 2016; Cunliffe et al. 2016), land cover classification (Kalantar et al. 2017), species reintroduction (Puttock et al. 2015) or forest monitoring (Paneque-Gálvez et al. 2014). These studies show that with little economic investment and easy operability, consumer-level drones can provide high-quality data and time series for effective monitoring and management of medium-sized areas. Weather limitations for flying drones are mostly limited to rainfall during the flights, and the mapped resolution can be adjusted to reflect the available time. Together with an easy set-up of equipment, drones allow for highly effective monitoring of conservation values and threats.

The main outcome of a drone flight mission is multiple high-resolution ground images, which can then be converted to a single high-resolution and large-scale image (i.e. an orthophoto) with photogrammetry tools (Näsi et al. 2015; Cunliffe et al. 2016) and allow the creation of digital surface models (DSM) with a resolution that can be as high as a sub-centimeter level. Trail parameters (width and depth) can be directly measured from orthophotos (trail width) and DSMs (trail depth) using GIS software such as QGIS or ArcGIS by overlaying virtual lines along the trails and extracting the line length and depth profiles. The spatial coverage and desired resolution can be controlled before performing the flight missions by adjusting the height of each flight to the project needs (Anderson and Gaston 2013; Puttock et al. 2015). Another benefit of using drone-derived orthophotos is that landscape-level disturbances such as trampling or vegetation fragmentation can be detected (Tang and Shao 2015), especially in inaccessible areas. Spatially explicit indicators can later be withdrawn from the data, even years after the survey was performed. Flights can be repeated at relevant time intervals, which increases the monitoring opportunities (Turner et al. 2015).

In this study, we assessed the accuracy and reliability of using a consumer-level drone as a high-resolution tool to improve and facilitate monitoring of the impacts derived from recreational use of landscapes by developing a high-resolution map and a digital surface model (DSM). This approach allows measuring trail conditions (width and depth), identifying informal trails and trampling, and creating a supervised land cover classification of the area to detect vegetation composition and habitat fragmentation. We evaluated the use of drones to monitor recreation trails and sites by comparing GIS measurements with systematic and repeated field measurements to assess accuracy and reliability.

Materials and Methods

Study area

The study area is located in the vicinity to Jotunheimen National Park in south-central Norway on the shore of the Gjendes Lake (Fig. 1). This area is a tourist attraction for outdoor recreationists and has also been traditionally used for sheep grazing. The study area is also adjacent to one of the main entrances to the park, containing recreational use cabins nearby, with Gjendesheim across the river as the closest one, and the Besseggen trail as the main attraction of the area receiving 60,000 visitors annually. Our study area was located on a historic cabin site which is important for cultural heritage management and we surveyed an area of approximately 200 × 90 m (1.8 Ha) on this site. This small area is of high interest due to the planned establishment of a bridge that will easen the numerous visitors to Gjendesheim and Besseggen to cross the river, resulting in

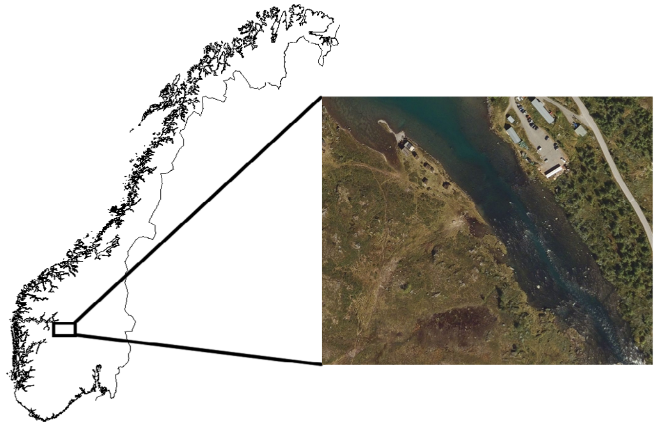

Figure 1. Location of the study area in south-central Norway and aerial picture of the studied site.

higher density of visitors around the historic cabin and potential impacts on the site.

Manual measurements

Ground truth transect lines were established by sampling 17 trail sections every 20 meters, where trail width and maximum depth (i.e. maximum trail incision) were measured to the closest millimeter. For each trail section, we set a pair of 10 × 10 cm square markers indicating the start and end of the trail width and depth measurements in order to visit the exact locations both manually and afterwards in the orthophoto generated after the drone flight. Each trail section was measured five times to assess the manual measurement variability.

Drone flight mission

Images were acquired in August 2017 and 2018 using a DJI Phantom 3 Standard drone (www.dji.com) equipped with a built-in GPS unit and the integrated 12MP camera (4000 × 3000 pixels), with a field of view (FOV) of 94°. The flight mission was planned with the PrecisionFlight app (www.precisionhawk.com): altitude was set to 10 m and flying speed to 2 m/sec yielding a ground sampling distance of approximately 5 mm/pixel. A gray reference card was used to calibrate the images before the flight, and a front and side overlap of 70% was set between the images to ensure that every part of the surveyed area was captured in at least three images. Camera shutter speed was set to be 1/1000th second to avoid motion blur and aperture value was the default f = 2.8.

Image processing

Resulting images were processed using the web-browser based version of OpenDroneMap named WebODM (www.opendronemap.org), a freely available open source photogrammetric software. The 'high resolution' pre-established profile was used to preserve spatial data, and the resolution was manually set to be 0.5 cm/pixel: the image database was split into batches of 100–120 photos for the photogrammetric processing, as the computing requirements for the whole database would be too high, and the resulting layers (i.e. orthophoto and DSM) would be impractical to handle in GIS software. GPS location and orientation parameters (pitch, yaw, roll) were extracted from the EXIF metadata embedded in each image. Image distortion was automatically corrected in the software by means of a pre-established lens calibration profile included in the data pre-processing step of the WebODM routine. The resulting orthophoto and DSM model were aligned to each other and used for the site analyses.

Drone image measurements

We performed the drone measurements in the same fashion as the manual measurements in order to compare the variability between both methods. For that purpose, we created five virtual lines at each of the 17 trail sections using QGIS (QGIS Development Team, 2018) to replicate the manual measurements. Each line started on one side of the trail edge and ended on the opposite side of the trail edge, delimited by the markers set during the manual measurement: the marker edge was identified with a fine scale (between 1:2 and 2:1 scale) to the closest possible pixel. The aim of using multiple lines on the orthophoto was to capture the measurement variability in drone-derived image measurements. The length of each line was measured based on the orthophoto as a measure of trail width, and the lines were overlaid on the DSM to extract the depth profiles for each section. Afterward, trail depth was calculated by overlaying the virtual lines over the DSM and subtracting the altitude at highest side of the trail to the lowest point of the trail section. Trampling and vegetation fragmentation areas were visually identified from the map by assessing vegetation differences (e.g. patches of herbaceous plants within a shrub thicket) and discontinuous patches (either in structure or color) in homogeneously distributed vegetation. In order to assess the applicability of drone measurements for time series, we used an orthophoto captured in August 2017 in the same area with the same flight parameters: the 2017 and 2018 orthophoto and DSM were aligned manually using common landscape elements (e.g. large stones or buildings) as reference. The orthophotos were therefore aligned to the maximum resolution of the orthophoto (0.5 cm), and the DSM error was assessed by subtracting the 2017 DSM to the 2018 DSM. Finally, we performed a supervised classification using the maximum likelihood estimator (MLE) on the orthophoto by means of the semi-automatic classification plygin (SCP) in QGIS to identify the main land cover groups in the study area (i.e. bare soil, heath, juniper shrubs, grasses, stones, buildings and water).

Results

562 and 711 images were taken in August 2017 and 2018, respectively, both in two consecutive flights with a total flight time of approximately 35 to 45 minutes flight, resulting in a 33479*33082 (approximately 1.1 gigapixels) and a 46,948*41,491 pixel (approximately 1.95 gigapixels) georeferenced orthophotos in 2017 and 2018, respectively, with an estimated resolution of 0.5 cm/pixel (Fig. 2A). The DSM was derived from the dense point cloud, resulting also in a 0.5 cm/pixel resolution (Fig. 2B).

The maximum divergence between the trail width measurements using the manual measurements and the drone image based measurements was of 3.1 cm (Fig. 3), with an average divergence of 0.02 cm (1st quartile = −0.3 cm, 3rd quartile = 0.6 cm): only 4 of the 85 measurements had a divergence above 2 cm. The divergence between measurements was non-significant in a *t*-test ($P = 0.81$, 95% CI −0.18; 0.22). Variability in measurements was higher in the manual method than in the drone measurements (Fig. 3).

Maximum trail depth (trail incision) measurements showed a divergence between manual and drone measurements, with a maximum overestimation of 4.49 cm compared to the manual measurement (Fig. 4): 22 of the 85 measurements had a divergence above 2 cm. Drone measurements tended to overestimate the depth by approximately 1.05 cm (1st quartile = −2 cm, 3rd quartile = −0.22 cm). The depth measurements showed a similar pattern in measurement variability as the width measurements (Fig. 4), with the manual measurements being more variable than the drone measurements. Although the difference is statistically significant in a t-test ($P < 0.001$, 95% CI −1.3; −0.79 cm), correcting the drone measurements by the measured divergence resulted in non-significant differences in measurements ($P = 0.99$, 95%CI −0.26; 0.25 cm).

The 2018 and 2017 orthophotos were aligned to the closest 0.5 cm and the same alignment was applied to the DSM. The mean divergence between the two layers was of 15.52 cm. Once the layers were corrected for the systematic divergence (i.e. added 15.52 cm to the 2018 DSM), the divergence between ranged between −0.12 (1st quartile) and 0.09 cm (3rd quartile).

The supervised classification resulted in a high-resolution map where the main land cover categories were clearly distinguished (Fig. 5), allowing to identify the trails with exposed bare soil, and differences in vegetation types (i.e. heath, juniper and grasses).

Visual inspection

The visual inspection of the orthophoto allowed to detect manmade structures such as firepits, as well as highly likely droppings from sheep, which indicates that the method could also be used for monitoring wildlife cues

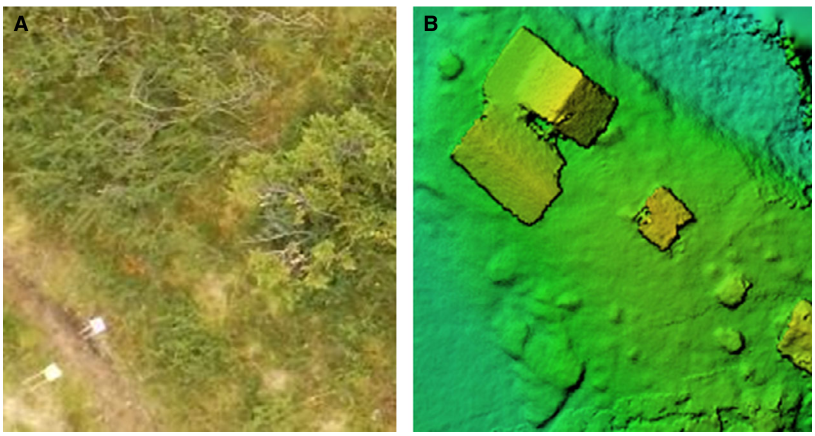

Figure 2. (A) 100% crop of the orthophoto resolution where the bare soil (bottom left side) can be distinguished from the vegetated areas. Juniper shrubs can be identified (upper half of the image) and (B) DSM of the cabins where the roofs are clearly distinct from the ground surface.

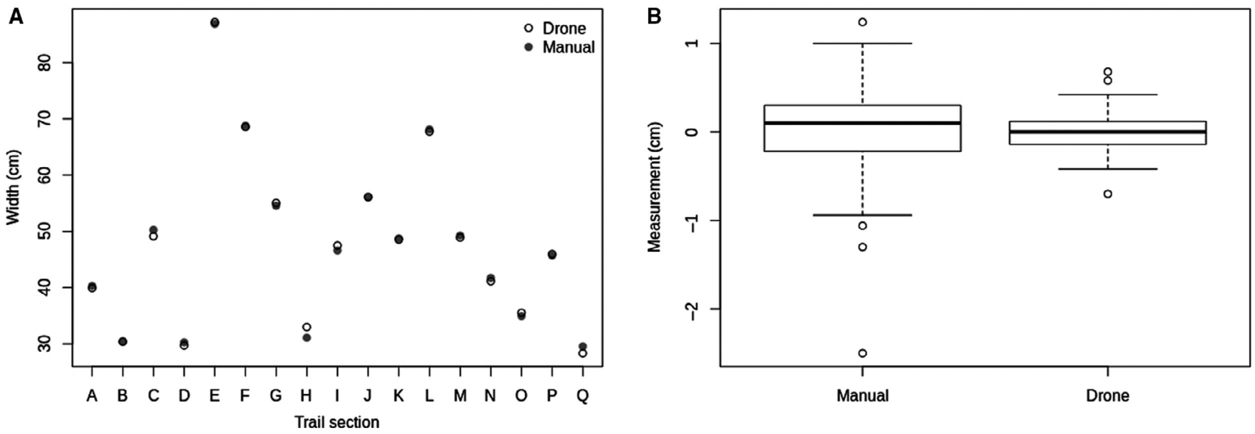

Figure 3. (A) comparison between the drone (hollow dots) and manual (gray dots) width measurements and (B) the variability of the manual (left) and drone image based (right) width measurements.

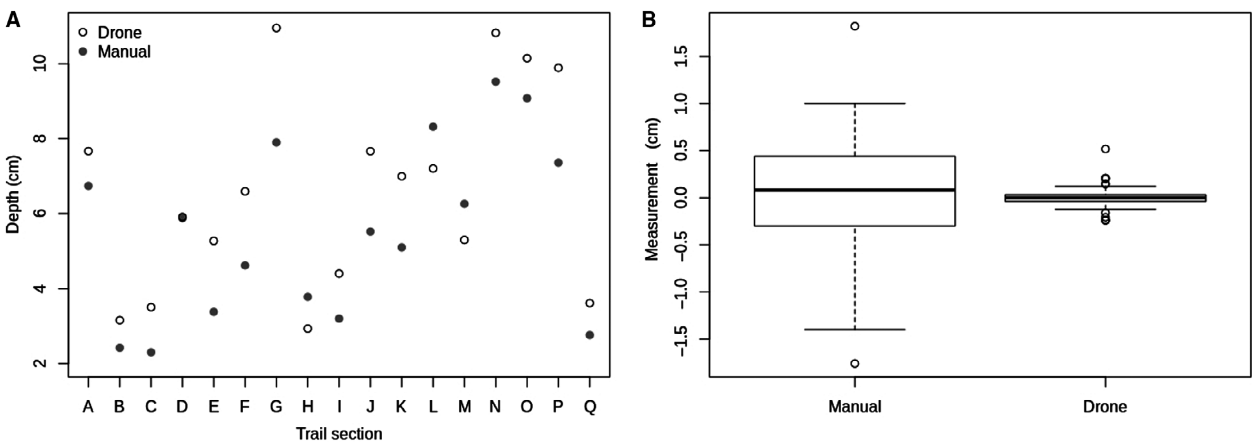

Figure 4. (A) comparison between the drone (hollow dots) and manual (gray dots) depth measurements and (B) the variability of the manual (left) and depth image based (right) width measurements.

(Fig. 6). Vegetation disturbances such as trampling events could also be identified as patches of dead woody structures could be identified in a careful visual inspection (Fig. 6).

Discussion

Our study showed that drones, together with photogrammetric tools, can provide park and protected area managers with reliable tools to monitor recreational impacts in a non-intrusive and efficient manner. Drones can provide measurements of trail parameters, such as width, depth and informal trail proliferation, but also more complex measurements such as vegetation change, soil loss due to erosion or landslides (Turner et al. 2015), water runoff analyses (Barreiro et al. 2014) trash and wildlife cues. We have demonstrated that detailed surveys to map protected areas and measure trail conditions, trampling and effects on vegetation as a consequence of human use can be performed with high spatial and temporal resolution with minimal technical expertise required. The systematic divergence found in the drone depth measurements is corrected by measuring a subset of reference depths or scattering objects with known dimensions in the study area to calculate correction parameters.

We assessed the accuracy and reliability of using drones for monitoring human impacts and vegetation change by intensive field sampling in a protected area, and found that the information retrieved from drones has a low error rate, both compared to the manual measurements and between years. The classified maps provided adds value by helping managers to classify vegetation patches and detect the exposed bare soil in the areas of interest,

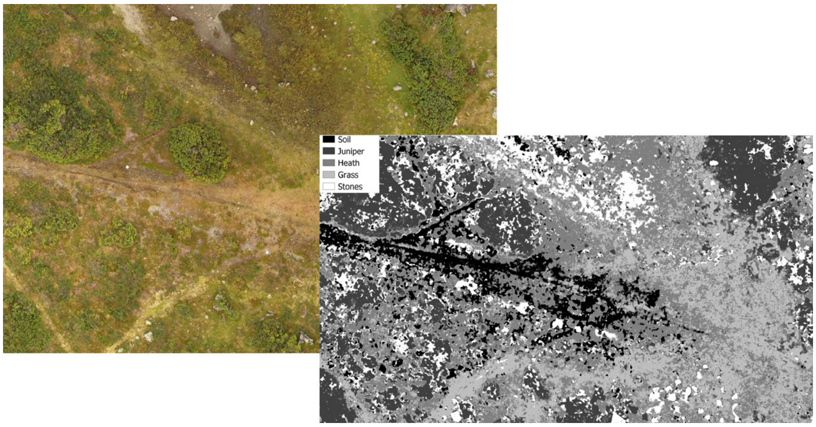

Figure 5. Example of classification on the drone-based orthophoto that allows identifying bare soil against other land cover types such as juniper shrubs, heath or grasses.

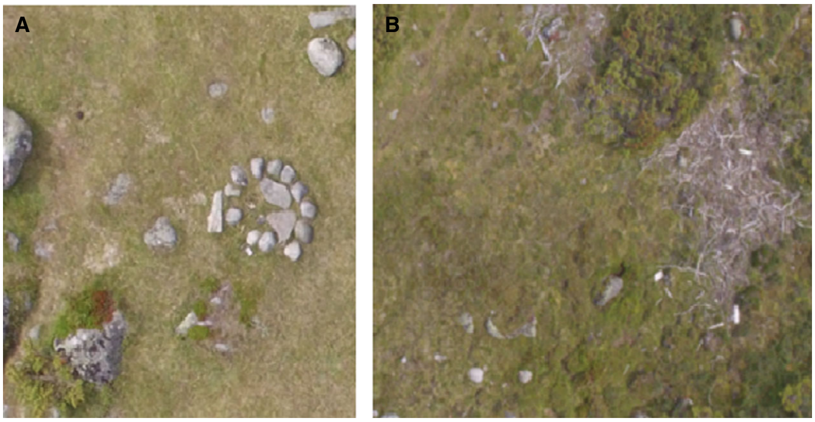

Figure 6. Detailed findings after visual inspection of the orthophoto. (A) Firepit and sheep dropping (delimited by a white circle) and (B) detection of vegetation fragmentation on the edge of a dense juniper patch.

and visual inspection helps identify other human impacts in the area. Using a time-series approach, such as yearly monitoring or inspections after periods with high visitation or catastrophic events (Meyer et al. 2015; Erdelj et al. 2017), this approach can help find how the landscape changes and how in responds to managerial actions. Time series of vegetation classification done in GIS can help managers identify areas with significant changes in vegetation composition as a result of human or wildlife pressure, and enforce management actions accordingly. Even more, drones can be used to assess water runoff (Barreiro et al. 2014), erosion (Ćwiąkała et al. 2017) and a wide range of management relevant landscape parameters (Anderson and Gaston 2013). In summary, drones provide a new toolset for the management of parks and protected areas by applying GIS tools to the drone-derived images.

The high-resolution vegetation classification provides vegetation cover maps and inform decision makers about the landscape and its potential vegetation changes (Cunliffe et al. 2016). Such classification approaches can help identify vegetation shifts (e.g. transitions from shrubs to grasses due to trampling), and can provide tools to detect more sensitive areas in combination with the trail parameters and a DSM (Woodget et al. 2017). Visual inspection of the orthophoto, on the other hand, allows the detection of structures and disturbances that may be difficult to identify through classification approaches, such as fire pits or damaged vegetation areas due to trampling or camping, which can result in unwanted effects on the landscape (Pickering et al. 2018). Such detection, however, may be subject to biases, as the images have a limited resolution and may not provide with necessary information: while we identified apparent sheep droppings in our visual inspection of the orthophoto, such classification is highly subjective and has to be done carefully. The visual inspection of the orthophoto could be considered a virtual fieldwork campaign, where skilled researchers ‘explore’ the landscape to detect structures and disturbances that would not be detected otherwise.

Compared with traditional aerial images, drones are a more flexible tool for monitoring human impacts and vegetation changes (Koh and Wich 2012) as they could be used with very little planning time. The set-up time for a drone flight is short: a flight can be started within less than 5 minutes from arrival in the study area, which makes it very effective at making use at time periods where weather conditions (e.g. rain showers, wind gusts) may disturb the original fieldwork plans, or rapid responses are necessary (Erdelj et al. 2017). However, drone flying is highly regulated in protected areas, and is dependent on dry weather conditions (i.e. no precipitation), which can also result in difficulties to perform the flights at the desired time and place. Despite the limitations, drones are a flexible tool that can help direct work efforts in a more efficient manner and increase the sampling intensity with limited resources needed.

There is a trade-off between desired resolution and the time required for mapping an area. The final resolution of the orthophoto and DSM is dependent on the camera resolution and the flying altitude (Anderson and Gaston 2013; Puttock et al. 2015): surveys requiring lower resolution can be performed at a higher flight altitude, thus reducing the time needed to survey an area. To demonstrate the flexibility of a drone flight to match the resolution needed and adapt it to different time constraints, we performed an additional flight at 50 m height. This flight resulted in a 2 cm/pixel orthophoto resolution based on 31 images (as opposed to the 711 images obtained on the 10 m height flight) taken in a flight duration of 5 min, instead of the 45 min needed for the highest resolution map that required swapping batteries. Flying at altitudes lower than 10 m are more likely to result in accidents such as crashing with infrastructure or trees, thus we suggest that surveys requiring flights under 10 m should be performed manually, or with higher resolution cameras (e.g. a DSLR mounted on a high-end drone) rather than flying at lower heights. Low-resolution surveys can benefit from a high-altitude mission to identify high interest areas (e.g. drastic vegetation changes or erosion) (Meyer et al. 2015) and afterwards fly these areas at lower altitudes to obtain high-resolution information or perform onsite assessments by skilled fieldworkers.

Another way of increasing the value of using drones for monitoring is to upgrade the camera or attach other sensors to the drones to retrieve more information. While use of greenness indices is increasing (Motohka et al. 2010), allowing the use of a standard RGB camera to assess plant health, multi and hyperspectral cameras are nowadays lightweight and more affordable (Näsi et al. 2015), as well as terrestrial laser scanning solutions for high-resolution surface mapping (Lin et al. 2011). Attaching such equipment to a drone would add a new dimension to the measurements with no extra effort for the operator, resulting in a deeper knowledge of a site including hyperspectral information that can provide with information on nutrient status in the plants (Zagajewski et al. 2017), biomass (Bendig et al. 2015) or help identify invasive species (Alvarez-Taboada et al. 2017).

Although high-resolution ground control points (GCPs) are highly recommended for aerial measurements of landscape parameters using high-resolution GPS units (Kachamba et al. 2016), we argue that they are not essential if field measurements validate the drone image based measurements. Even if each individual drone image has an associated geolocation error, a high enough number of images will reduce the georeferencing error to very low rates (Barry and Coakley 2013; Ćwiąkała et al. 2017). The resulting orthophoto will have a very high relative accuracy (i.e. the trail parameters in this study) and a good absolute accuracy (Barry and Coakley 2013), meaning that the measured trail parameters will be very accurate (relative accuracy), although the placement of the orthophoto on a global coordinate system (absolute accuracy) may have a deviation. Furthermore, using reference measurements can help identify and correct potential errors in the trail measurements. Our results show that, despite a difference of 15.52 cm between the DSMs generated in two adjacent years (2017 and 2018), the maps correlate very well to each other, with an error lower than 0.2 cm between the two DSMs after correcting for the bias. These results show that, while the absolute accuracy of the maps may have biases (i.e. orthophotos and DSMs that are not aligned perfectly), these relative errors are simple to correct using georeferencing tools and bias between DSMs can be also measured and corrected. Therefore, we suggest that a high number of images, as a drone mapping survey requires, results in orthophotos and DSMs that can be directly used to assess the trail condition and vegetation changes in the areas of interest.

Despite the advantages this method provides, there are several limitations. First, trails have to be directly visible from the air: tree canopy obstructs the direct view, making it impossible to generate an orthophoto. In addition, the legal requirements (i.e. registrations, permits) have to be met before starting the survey. Furthermore, a safe flight plan needs to be in place, where potential risks are assessed. Duffy et al. (2017) summarized a set of guidelines to establish safe and successful drone surveys (Cruzan et al. 2016). Technical challenges are also critical to the success or failure of a survey. Battery life is a key factor, with an approximate flight capacity of 30 min/battery in most consumer-level drones. Such flight time capacity may require landing the drone several times to replace batteries before finalizing a mission, therefore requiring careful planning of safe landing areas to avoid accidents and disturbing visitors or wildlife. Small electric drones show the least disturbance to wildlife, but are nonetheless foreign to the natural landscape and need to be flown with care (Tablado et al. 2017), thus careful observation of stress signals is necessary when flying close to wildlife to adapt, or even stop, the flight mission.

Conclusion

In conclusion, park and protected area managers would benefit from applying drones for monitoring impacts, which will result in spatially explicit and comprehensive high-quality data at very low cost. Combining orthophotos, DSMs and classified maps provide with high-quality information that can improve the knowledge on the landscape and lead to more efficient management. Furthermore, the low cost of operating a drone, as opposed to traditional fieldwork, allows for more comprehensive assessments, resulting in appropriate temporal and spatial scales. Monitoring of the management actions will also be easier using drones by automating the assessment of land cover changes in the landscape (e.g. by flying the same mission over time) or being able to re-visit the sites retrospectively if needed.

Conflict of Interest

The authors declare no conflict of interest.

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