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Using Drones to Generate New Data for Conservation Insights

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Using Drones to Generate New Data for Conservation Insights

Abstract
Human impact on the environment is driving a decline in biodiversity that heightens the need for informed management of conservation lands. Unmanned aerial vehicles (UAVs), also known as drones, are an increasingly cost-effective tool for generating high-quality data used to map landscape features, analyze land cover change and assess the effectiveness of conservation efforts. Traditional sources of remotely sensed data such as satellites and aircraft can be costly, inflexible and unable to detect fine-scale surface variation. This paper explores the advantages (and challenges) of analyzing data collected by drones to generate useful conservation management insights. We focus on three key considerations. The first is pre-flight planning. This includes FAA regulations, flight control software and study area considerations. The second is acquiring and processing drone captured still images to generate georeferenced map layers. The third is developing GIS models that analyze relationships between drone-derived data layers at multiple scales.

To demonstrate how data collected by UAVs can provide useful conservation insights, we analyze the relationship between fire behavior and landscape features at the Weaver Dunes Preserve in Minnesota. Here, the Nature Conservancy is restoring high quality prairie habitat via a series prescribed burns. Because prairies benefit from "patchy" burns (as opposed to fires that consume the entire burn site), we map landscape features (slope, elevation and aspect) and analyze their correlation with the location and extent of post-burn patches of ash.

Keywords
Conservation, UAVs, prescribed burns, prairie restoration, drones

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1 CONSERVATION CHALLENGES AND THE RISE OF DRONES

Because of increasing habitat loss, pollution, invasive species and climate change, humanity is not on track to meet conservation goals set by the United Nations (SCBD 2014). At current rates, human alteration of the environment is driving a decline in biodiversity that could lead to a sixth mass extinction within 240 years (Barnosky et al. 2011). An increasing body of evidence indicates that species loss plays a key role in limiting ecosystem services to society (Hooper et al. 2012).

There are positive signs, however. The amount of protected lands is increasing by 0.13% per year (Jenkins and Joppa 2009), and nearly a quarter of countries have protected more than 17% of their land area (SCBD 2014). Still, a minority of protected areas benefit from effective management, and we face significant challenges in restoring damaged ecosystems (SCBD 2014). Acquiring and effectively analyzing conservation data plays a key role in protecting biodiversity, and unmanned aerial vehicles (UAVs) show promise in acquiring data that informs conservation science and supports effective restoration strategies (Pimm et al. 2015).

Effective environmental restoration and conservation efforts require delineating high priority conservation areas, creating management objectives and implementing appropriate conservation strategies (Wilson et al. 2009). Air photos support these efforts by providing accurate and timely information about topography, land use, land cover and the distribution of target species. Remotely sensed data is also critical for measuring conservation effectiveness and for tracking the progress of management efforts (Baena et al. 2017). Consequently, one of the goals of the Convention on Global Biodiversity is to refine remote sensing technologies that monitor land cover and make "improvements in analysis and interpretation of data gathered from disparate collecting and monitoring systems" (SCBD 2014: 22).

As recently as 2012, most researchers and land managers were forced to rely on low resolution satellite images, costly aerial surveys and time consuming and expensive ground surveys to acquire conservation data (Koh and Wich 2012). Traditional remote sensing platforms such as satellites and aircraft are also limited by time intervals between images, clouds obscuring the landscape and an inability to detect large-scale surface variation (Lentile et al. 2006). Worse, aerial surveys were a significant cause of work-related mortality for wildlife biologists (Jones et al. 2006).

Drones, however, have several advantages over field surveys, aerial photography and satellite imaging. They generate highly detailed data layers that can be more accurate than aerial surveys (Han et al. 2017). Drones record overlapping images and are able to fly slowly at low altitudes, so they "bridge the gap between terrestrial and traditional aerial image acquisition and are therefore ideally suited to enable easy and safe data collection" (Tscharf et al. 2015: 15). They are inexpensive, require relatively little training to use and can be rapidly deployed (Ivošević 2015; Jones 2006). Drones offer flexibility, ability to operate in hostile environments and ease of use (Grimaccia et al. 2015). They can also be dispatched to photograph the same landscapes multiple times, improving our ability to monitor ecosystem dynamics (Zhang et al. 2016). Not surprisingly, they are increasingly substituted for fieldwork that can be relatively tedious, intrusive, prone to error and time consuming (Jin et al. 2017).

Barriers to the use of drones are falling rapidly. In 2006, a prototype conservation drone system was constructed for $35,000 and researchers predicted that "with a civilian market, mass production of a reliable, effective, durable modular autonomously controllable aircraft might soon be available for under $10,000" and could be expected to survive for approximately 100 flight hours (Jones et al. 2006: 757). By 2012, early pioneers Koh and Wich successfully demonstrated the ability of unmanned aerial vehicles to gather high quality data in remote areas and declared that the "dawn of drone ecology" had arrived (Koh and Wich 2012). By 2013, informed commentators were predicting that drones "were poised to take off as popular tools for scientific research" (Marris 2013: 156) and would revolutionize spatial ecology (Anderson et al. 2013).

Today, a combination of recent, rapid improvements in technology and a thriving commercial and recreational market result in dramatically lower costs and improved performance. A drone used for the project described in this paper currently costs less than $1,000, and Federal Aviation Administration (FAA) registrations for drones topped one million in January 2018 (Vanian 2018). Similarly, sophisticated phone-based applications now automate data collection by generating and flying optimal flight paths, and the GIS based software required to process drone-captured still imagery has improved dramatically. The combined result is a rapid increase in the use of drones for research: there was a doubling in the number of journal articles focused on drones and conservation between 2013 and 2016 (Baena et al. 2017).

This paper explores the advantages (and challenges) of collecting and analyzing drone captured still images to generate useful conservation management insights. It explains how to plan flights, capture still images, generate georeferenced data layers from drone-captured still imagery, and analyze relationships between drone-derived data layers. The next section focuses on the logistics of using drones for fieldwork. It is followed by a case study analyzing the relationship between fire behavior and landscape features at the Weaver Dunes Preserve in Minnesota.

2 PRE-FLIGHT CONSIDERATIONS, FLIGHT PLANNING, IMAGE CAPTURE AND PROCESSING

In the United States, legislation covering the use of drones is still evolving. As of January 2018, the FAA requires that small unmanned aircraft used for research **be registered** for $5 and that they display a registration number on their drone. The registration is valid for three years. Information and links to the FAA registration page are available here.

Commercial drone pilots must also **earn a Remote Pilot Certificate** from the FAA. This requires that pilots be at least 16 years old, pass a FAA approved aeronautical knowledge test and pass a Transportation Safety Administration security screening. Information about becoming a certified pilot is accessible at this FAA webpage.

Pilots are also **required to follow all FAA operating rules**, including flying at or below 400 feet, flying in proper airspace, flying no faster than 100 mph, flying within line of sight and not flying directly over people in public places. A more complete summary of rules containing information on operational limitations, pilot certification and responsibilities and aircraft requirements can be accessed here. Detailed information appears in the FAA Advisory Circular on Small Unmanned Aircraft Systems is accessible here. Additionally, a wide range of questions about legal uses of drones is addressed at this FAA webpage.

Drone flights are prohibited in some areas. Before conducting flights, pilots should **determine whether they are in restricted airspace** (for example, within five miles of an airport) or if there are any temporary restrictions or requirements in effect.

We find the free FAA smartphone app, B4UFLY useful. It displays frequently updated interactive maps that help pilots determine whether they are in a flight-restricted area. There is a lengthy process for requesting FAA waivers if your study area is within restricted airspace.

After registering the drone, acquiring FAA pilot certification and ensuring that your study area is not in restricted airspace, four steps are necessary for acquiring and processing drone captured still images (Figure 1). The following sections outline these steps.

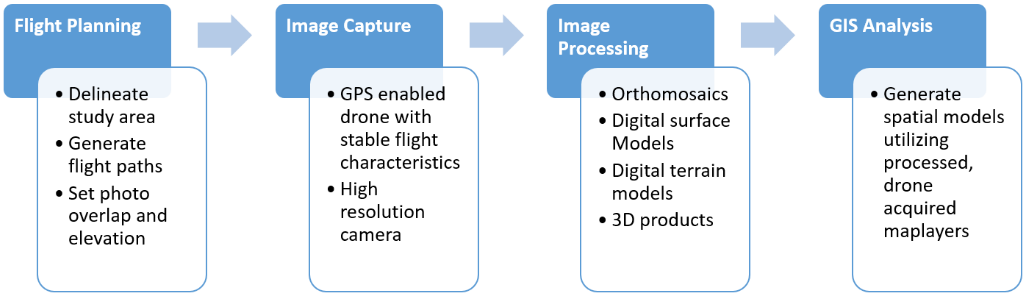

Figure 1. Workflow for acquiring and processing drone captured still images.

2.1 Planning Flights, Delineating Study Areas and Automating Photo Acquisition

Accurate and efficient mapping with drones requires flight control software used to delineate study areas, control flight and automate image acquisition. A wide range of flight planning software for drones is available, including DroneDeploy, Kerspy, Identified Technologies Drone Solution, Pix4D, FPV Camera, Altizure and Commander Skycatch.

For this project, we used the $9.99 Map Pilot app for iPhones (Figure 2). Map Pilot allows users to design flight plans by identifying a survey area, generating flight paths and controlling photo overlap. While increasing photo overlap may improve the quality of resulting map products, this can lead to increased flight times and digital storage requirements (Maps Made Easy 2018). The default setting for photo overlap in Map Pilot is 70% - a reasonable compromise.

Altitude is another key flight plan consideration. Because cameras on most drones have a fixed focal length (they are prime lenses, not zoom lenses), altitude directly affects image resolution. The result is a trade-off between image resolution and flight time. Low elevation flights generate detailed images of relatively small survey areas. Simply flying longer at lower elevations is not always feasible, as current technology limits commercially available drones to roughly 20 minutes of flight per battery. Unless the survey area is perfectly level, image resolution will vary. This is because flight elevation set directly above the takeoff point and does not change throughout the flight. Software updates may make it possible for future flights to follow topography and maintain a constant elevation relative to the ground.

The Map Pilot app estimates flight time, distance flown, area to mapped, speed and flight duration. It also displays the number of batteries required, number of photos to be collected and amount of memory required to store images (Maps Made Easy 2018).

Area: 11.36 hect
Distance: 7.67 km
Max Speed: 6.8 m/s
Duration: 20m 13s
Batteries: 2
Images: 299
Points: 717
Storage: 1.49 GB
Altitude: 45 m
Resolution: 1.9 cm/px

Figure 2. A screenshot of the Map Pilot app, used to generate study areas, design flight paths and control photo acquisition. This app runs on a smart phone and controls the drone during flight. The study area is generated by tapping the screen (orange dots). Users control elevation (and, consequently, image resolution). Users also control image overlap (dropdown menu not shown).

2.2 Image Capture

At the field site, flight plans are uploaded to the drone from the Map Pilot application, which automates survey flight(s). As costs fall and technology improves, many drones are capable of acquiring high-resolution geotagged still images. We use a DJI Inspire 1, a quadcopter with internal GPS and stable flight characteristics. It can be purchased for less than $3,000 (Figure 3). It has a 12-megapixel camera with a 1/2.3” sensor, and flight times of approximately 18 minutes per battery. Newer drones with greater flight times and superior cameras are available for approximately $1,000 as of 2018.

A typical flight at an elevation of 40 meters surveys 10 hectares in a lawnmower pattern and produces 150 geotagged .jpg images with 1cm resolution. Flights at higher elevations map a larger area at lower resolution: images used in the following case study were acquired during a 60-meter flight with approximately 2.5 cm resolution. Flight times for most models rarely exceed 30 minutes, and larger surveys require a wait during charging or multiple batteries that can cost $200 each. Additionally, flight times vary with light conditions. To prevent ground smear (image blurring due to camera movement) flight control software may slow the drone during low light conditions to compensate for slower shutter speeds.

Figure 3. The DJI Inspire 1 quadcopter, used for this project. On the right: a close-up of the standard Zenmuse X3 camera.

2.3 Processing Imagery

Drone collected still images are typically geotagged .jpg files. Because flight control software ensures these images overlap, they can be processed to generate 2D and 3D mapping products. Many image processing programs and on-line services exist, including DroneDeploy map engine, Pix4D and Maps Made Easy. We use ESRI's highly functional (and relatively expensive) Drone2Map software.

Drone2Map software processes .jpg images and can generate both 2D map layers (digital terrain models, digital surface models and orthomosaics) and 3D products (colorized point clouds, textured meshes, and 3D PDFs). Figure 4 displays a sample of drone acquired .jpg images, along with the resulting orthomosaic and digital surface model generated in the Drone2Map environment.

3 CASE STUDY: EXPLORING THE RELATIONSHIP BETWEEN TOPOGRAPHY AND PRESCRIBED BURNS

The orthomosaic and digital surface model depicted in Figure 4 were analyzed to better understand the relationship between prescribed burns and topography at the Nature Conservancy's Weaver Dunes Preserve. The preserve (Figure 5) is a rare sand prairie with rolling topography and dunes that occasionally reach 30-feet. It covers over 320 hectares in Minnesota's Wabasha county. The preserve protects the habitat of several rare species, including the Blanding's turtle, and is a mix of unplowed prairie, patches of oak savanna and former cropland. Since acquiring the land in 1980, the Nature Conservancy has conducted a series of prescribed burns to maintain and restore high quality prairie habitat (Nature Conservancy 2018). We mapped the location and extent of one prescribed burn on May 23, 2017 (this flight took place 3 weeks after the fire had been set). We acquired 105 georeferenced .jpg images of an approximately 2.6-hectare portion of the Weaver Dunes Preserve.

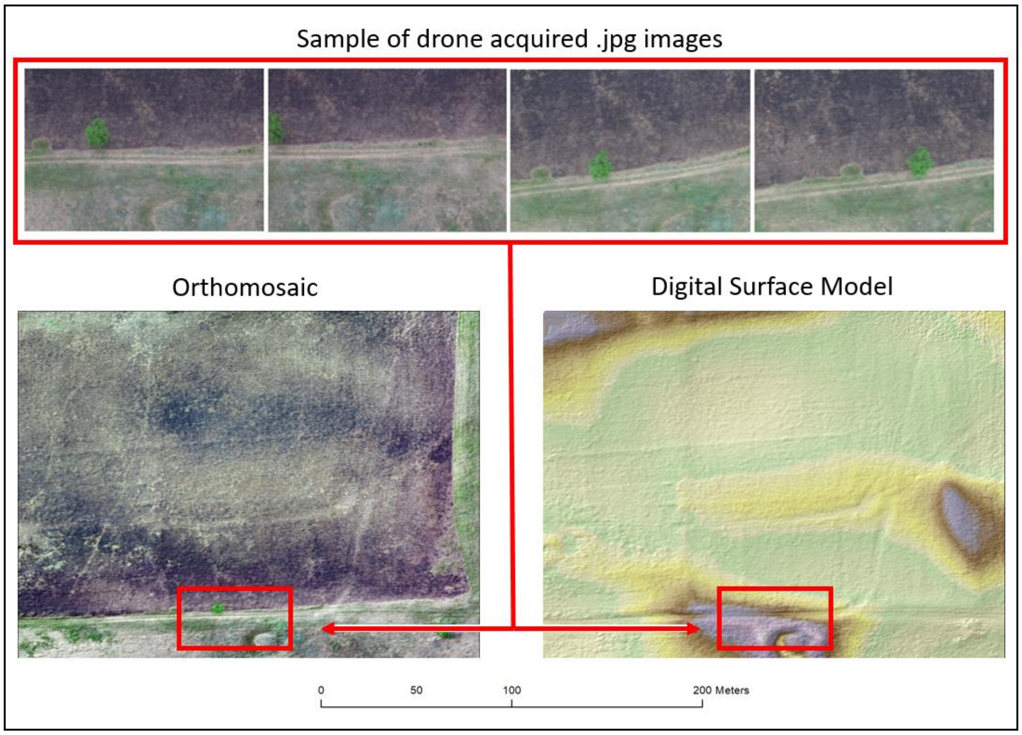

Figure 4. Top: five of 105 drone-acquired, overlapping, geotagged .jpg images of the Weaver Dunes Preserve. The road visible in these pictures served as a firebreak for a prescribed burn, which was set to restore prairie. Bottom: the .jpg images were processed in the Drone2Map environment to generate an orthomosaic and digital surface model.

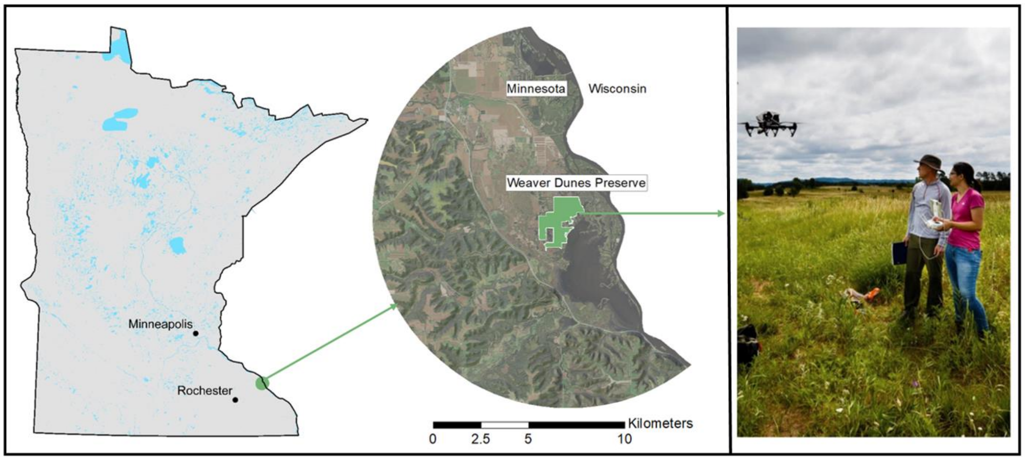

Figure 5. The Nature Conservancy's Weaver Dunes Preserve is located along the Mississippi River in southeast Minnesota. The Preserve is a mix of sand prairie, oak savannah and fields being restored to prairie (top right photo by Mike Ekern).

3.1 Prairies, Prescribed Burns and Topography

Many prairie species benefit from fires that stimulate soil microbes, promote seed germination and sprouting, promote ecological succession, and maintain landscape structure and composition (Lentile et al. 2006). Prescribed burns preserve and restore prairies by removing encroaching trees and shrubs, controlling invasive species, and creating microhabitats for specialist forbs (Valk et al. 2014). After evaluating post-fire vegetation responses in large and small burned patches, scientists found that the size and severity of these patch burns have significant effects on post-fire recovery (Turner et al. 1997). Fire improves species richness, diversity, competitive interactions, and patch structure (Collins and Gibson 1990). Patchy fires are especially effective (instead of completely burning an entire reserve), as leaving unburnt patches promotes plant diversity and does not threaten the majority of insects (Valkó 2016). Fortunately, the prescribed burn at Weaver Dunes resulted in a patchy fire and we were able to map the resulting pattern of ash.

3.2 Analyzing the Impact of Topography on Fire Behavior

While wind speed, persistence and direction can be important factors in shaping fire behavior, prescribed burns at Weaver Dunes are conducted during days with little or no wind. As a result, the patchy distribution of ash at the site is more likely to be influenced by landscape features.

In order to improve our understanding of how prescribed burns result in desirable, “patchy” fires, the orthomosaic and digital surface model depicted in Figure 4 were analyzed in ArcGIS 10.4 to map patterns of ash, as well as slope, elevation and aspect at the Weaver Dunes Preserve. The goal was to inform conservation management practices by helping fire crews understand factors in the landscape that are associated with areas that are relatively likely to burn.

First, the orthomosaic of our study area was processed using the image analysis NDVI tool to generate a raster displaying the location and extent of ash resulting from the prescribed burn. Second, the digital terrain model was processed to generate raster layers displaying slope, elevation and aspect. Slope and elevation were selected as variables because fires move uphill; aspect was selected because south facing slopes at Weaver Dunes are warmer and drier than the relatively shaded north facing slopes.

Third, the fishnet tool was used to create a feature class containing a net of rectangular cells that was clipped to the study area. The resolution of each fishnet cell was 5 x 5 meters. Fourth, four fields (ash, slope, elevation and aspect) were created for the fishnet feature class. These fields were populated using the zonal statistics as table tool, which calculated the mean elevation, slope, aspect and percent ash cover for each fishnet cell. The orthomosaic, digital surface model and the fishnet layers derived from them appear in Figure 6.

The attribute tables from the four fishnet layers were exported to SPSS, and a Pearson product-moment correlation coefficient was computed to assess the relationship between the presence of ash and the three landscape variables (elevation, slope and aspect).

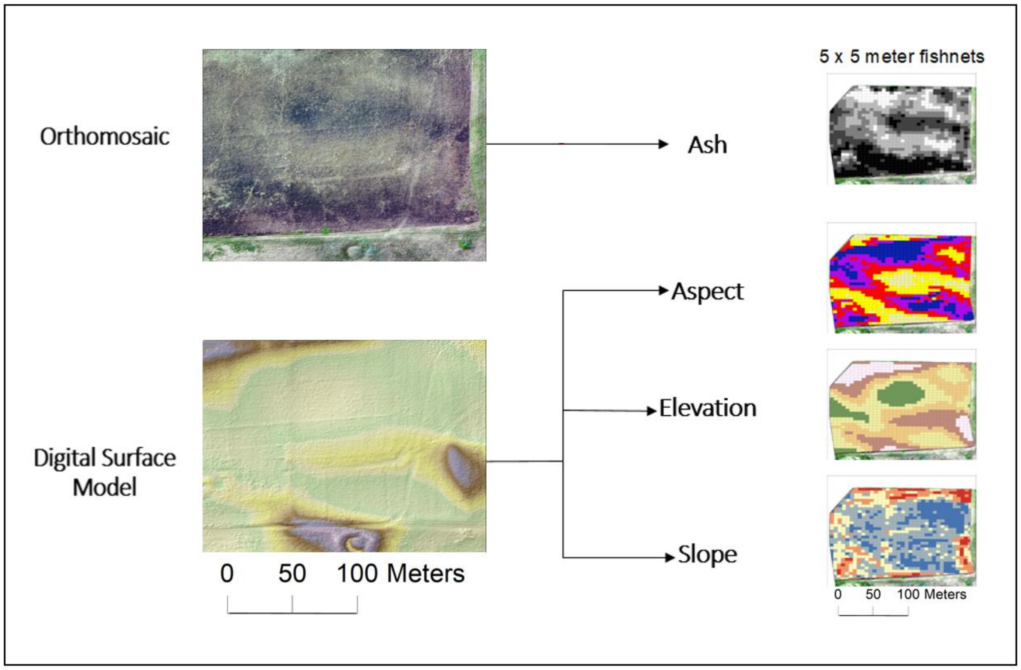

Figure 6. The orthomosaic and the digital surface model depict ash and landscape features of the recently burned portion of the Weaver Dunes Preserve. These layers were processed to generate 5x5 meter resolution fishnets displaying the presence of ash, as well as aspect, elevation and slope.

4 RESULTS AND DISCUSSION

At Weaver Dunes, the presence of ash is correlated with all three of the landscape variables. There is a relatively strong, negative correlation between ash and elevation, which was statistically significant ($r = -0.318$, $n = 1{,}133$, $p = 0.01$). There is a positive, statistically significant correlation between north facing aspect and the presence of ash ($r = 0.244$, $n = 1{,}133$, $p = 0.01$). There is a weak, negative correlation between slope and the presence of ash which was also statistically significant ($r = -0.027$, $n = 1{,}133$, $p = 0.01$). These results indicate that, at the Weaver Dunes site, low-lying areas and north facing slopes were associated with the presence of ash. Relatively steep slopes, however, were slightly less likely to be associated with the presence of ash.

These results were unexpected, as land managers hypothesized that the presence of ash would be associated with steep, south facing slopes and relatively high areas, as fire generally travels uphill, and south facing slopes at Weaver Dunes are relatively sunny, warm and dry.

The actual relationships between landscape and fire at Weaver Dunes suggest several preliminary explanations for factors influencing the location and extent of ash at the Weaver Dunes site. While topography influences fire behavior, we suspect the impact is indirect: elevation, aspect and slope influence the distribution of soil moisture, which, in turn, influences patterns of vegetation growth and the consequent distribution of fuel (see Figure 7).

Our study area consists of sand prairie, with highly permeable soils that drains quickly after rainfall. As a result, low-lying areas are likely to have relatively high levels of soil moisture. Plants here may also benefit from soil nutrients that wash downhill and collect at the base of slopes. Additionally, relatively cool, shaded north facing slopes are likely to retain relatively high levels of soil moisture because of relatively low evaporation rates.

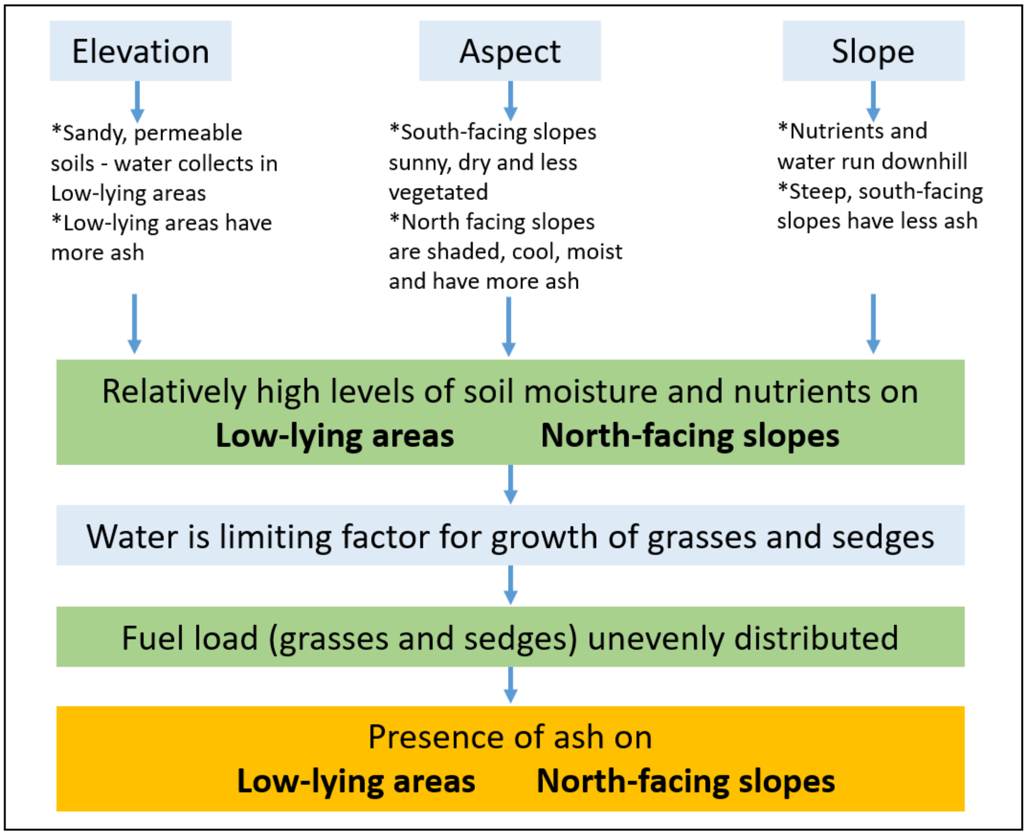

Figure 7. Possible explanations for the relationships between topography and fire intensity as measured by the presence of post-burn ash. We hypothesize the presence of fuel is the proximate driver of fire intensity. Increased biomass is found in low-lying, north facing areas that may benefit from relatively high levels of soil moisture.

Upcoming flights at the Weaver dunes site are scheduled before the next round of prescribed burns and will map patterns of pre-burn vegetation and post burn ash to explore the relationship between biomass and fire behavior. Because managed prairie is typically burned every 3 to 5 years, we plan multiple flights over a period of at least five years. We also plan to map patterns of post-fire regrowth find whether patterns of fuel load remain relatively constant from one year to the next, or if patterns of vegetation shift after patchy fires consume fuel in some areas, while allowing dead grasses and sedges to build up in unburned areas. If the latter is true, it is likely that areas of burn intensity (and patterns of associated ash) shift from one prescribed burn to the next.

5 CONCLUSIONS

Continued habitat degradation poses a threat to both biodiversity and ecosystem services. As a result, effective management of protected areas is increasingly important. This paper demonstrates that drone acquired images can be processed to generate useful data layers that can provide insights into conservation landscapes and inform restoration and management efforts. The performance of readily available drones is improving and costs are declining. With adequate planning, high resolution images of 20+ hectare sites can be generated in less than an hour. Similarly, a wide range of software is now capable of delineating study areas, managing photo acquisition and converting drone acquired images into useful mapping products.

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