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Assessing the impacts of canopy openness and flight parameters on detecting a sub-canopy tropical invasive plant using a small unmanned aerial system

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ABSTRACT

Small unmanned aerial systems (sUAS) have great potential to facilitate the early detection and management of invasive plants. Here we show how very high-resolution optical imagery, collected from small consumer-grade multirotor UAS platform at altitudes of 30–120 m above ground level (agl), can be used to detect individual miconia (*Miconia calvescens*) plants in a highly invaded tropical rainforest environment on the island of Hawai'i. The central aim of this research was to determine how overstory vegetation cover, imagery resolution, and camera look-angle impact the aerial detection of known individual miconia plants. For our finest resolution imagery (1.37 cm ground sampling distance collected at 30 m agl), we obtained a 100% detection rate for sub-canopy plants with above-crown openness values >40% and a 69% detection rate for those with >20% openness. We were unable to detect any plants with <10% above crown openness. Detection rates progressively declined with coarser spatial resolution imagery, ending in a 0% detection rate for the 120 m agl flights (ground sampling distance of 5.31 cm). The addition of forward-looking oblique imagery improved detection rates for plants below overstory vegetation, though this effect decreased with increasing flight altitude. While dense overstory canopy cover, limited flight times, and visual line of sight regulations present formidable obstacles for detecting miconia and other invasive plant species, we show that sUAS platforms carrying optical sensors can be an effective component of an integrated management plan within challenging subcanopy forest environments.

1. Introduction

A key strategy in the fight against invasive weeds, early detection of nascent alien plant populations has long been a focus of applied remote sensing research (see Bradley, 2014; Huang and Asner, 2009; Lass et al., 2005 for reviews of this topic). One aspect that has proven particularly challenging is the detection of subcanopy species of concern within forest environments. When areas with dense canopy cover are observed from above, subcanopy species are often partially or fully obscured by the overstory vegetation layer, making their detection difficult (Anderson et al., 1996; Bradley, 2014). Researchers have attempted a variety of solutions for detecting understory species, including phenological (Tuanmu et al., 2010; Wilfong et al., 2009) and imaging spectroscopy (Asner et al., 2008; Barbosa et al., 2016; Peerbhay et al., 2016) approaches, as well as using microwave and lidar to penetrate forest canopies and detect understory exotic plant species (Ghulam et al., 2014; Singh et al., 2015). While these efforts have shown great promise, phenological approaches developed for deciduous temperate species are of limited value in the tropics, and most researchers and land managers working in this part of the world do not have access to expensive and specialized instrumentation. A different solution may lie in the use of very fine spatial resolution visible imagery collected from inexpensive small unmanned aerial systems (sUAS). sUAS, defined as low altitude, short-endurance systems weighing <5 kg (Watts et al., 2012), can be used to capture very high resolution spatial data on-demand from low flight altitudes (Crommelinck et al., 2016; Puliti et al., 2015; Salamí et al.,

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2014). Though limited in flight time and payload capacity in comparison to manned airplanes and helicopters, sUAS platforms have lower operational costs, carry much lower risks of loss of life and property, and can fly within previously inaccessible areas such as sheer ravines or forest interiors (Chisholm et al., 2013; Ogden, 2013). As a result, many of the constraints previously associated with generating high resolution aerial imagery over an area of interest (e.g., scheduling conflicts, fuel costs, platform availability, accessibility) have been removed or simplified, making it easier to quickly collect imagery with a very fine ground sampling interval (<0.05 m). Specific regulations concerning sUAS flight operations, which may include maintaining visible line-of-sight and other airspace and licensing requirements, provide a new set of constraints and vary by country (ICAO, 2015).sUAS are beginning to be used as a new means of surveying for invasive species, often incorporating image segmentation and machine learning algorithms (Dvorák et al., 2015; Michez et al., 2016; Müllerová et al., 2016; Peña et al., 2015). Most of these efforts have been limited to non-forested and agricultural landscapes. In Hawai'i and other locations with native forests under threat from invasive species, work is needed to determine how well these new sUAS platforms can detect subcanopy invasive species in forest settings with multiple vegetation canopy layers. The purpose of this study was to quantify the impacts of flight altitude, camera look angle, and overstory vegetation canopy cover on the ability of a sUAS platform to detect known individual miconia (*Miconia calvescens* DC.) plants within a highly invaded tropical rainforest on eastern Hawai'i Island. Our original hypotheses were that miconia plants <1 m would be undetectable from the air in this forested setting and that there would be a clearly defined maximum degree of overstory canopy cover beyond which miconia plants would be undetectable. We hypothesized that the addition of oblique photos, in combination with images taken in the traditional nadir orientation, would improve detection results as the angled look direction would better allow us to detect plants beneath the overstory vegetation canopy layer. We were also interested in determining an optimal flight altitude for detecting miconia plants, balancing the need to survey large areas against the minimum resolution required to identify individual plants. The results of this study are broadly applicable to detecting other understory species of interest via sUAS or other platforms.

2. Materials and methods

2.1. Miconia calvescens

Miconia, a highly invasive understory alien tree species from Central and South America, presents a well-documented threat to native tropical ecosystems across the globe due to its fecundity, long-lived seeds, and ability to grow in extreme low light conditions and shade out native species (Meyer, 1994, 1998). Miconia trees can grow up to 15 m tall, with large characteristic leaves up to 1 m in length that have deep purple undersides (inset photo, Fig. 1), and can produce dense monotypic stands in both disturbed and intact rainforest habitat (Csurhes, 1998; Meyer, 2010). The crown size of an individual Miconia plant can vary from <1 m^2 for seedlings to >5 m^2 for mature plants. Currently infested areas include rainforests in Australia, French Polynesia, Hawai'i, New Caledonia, and Sri Lanka (Brooks and Jeffery, 2010; Lowe et al., 2000; Medeiros and Loope, 1997; Meyer, 1996, 2010) with the potential to spread well beyond these areas (González-Muñoz et al., 2015). Decades of intensive miconia eradication efforts across the Pacific have largely been unsuccessful, in part because of difficulties with detection (Leary et al., 2014; Meyer, 2014; Meyer et al., 2011).

2.2. Study site

The study site for this work is located at 19.4719°, −154.9554°, approximately one mile south by southwest of the town of Pāhoa on the Island of Hawai'i (Fig. 1). The 0.8 ha site is oriented as a ∼160 × 50 m rectangle, flanked by a service road on the southern edge. Situated at an elevation of 237 m on an early successional lava flow ranging between 400 and 750 years old (Sherrod et al., 2007), the area has a 3% slope to the northeast and receives an annual rainfall of 3261 ± 104 mm (Giambelluca et al., 2013). Formerly cleared of native forest and used to grow sugarcane between 1897 and 1984, the land has been fallow and colonized by fast growing invasive grasses and tree species since the closure of Puna Sugar LTD in the mid-1980s (HSPAPA, 1992).

The vegetation canopy is now comprised of invasive tree species including Albizia (*Falcataria moluccana*), Common and Strawberry Guava (*Psidium cattleyanum* and *guajava*), Strangling Banyan (*Ficus* sp.), Trumpet Tree (*Cecropia obtusifolia*), Octopus Tree (*Schefflera actinophylla*), Bingabing (*Macaranga mappa*), and Princess Flower (*Tibouchina heteromalla*). Invasive liana species are also present, including Stink Vine (*Paederia foetida*) and Passion Flower (*Passiflora* spp.). Understory vegetation species are dominated by two fern species, Uluhe (Dicranopteris linearis) and Hāpu'u (*Cibotium glaucum*). Miconia was first identified in the area in 2006 and a four-year control effort immediately followed (Big Island Invasive Species Committee, unpublished data). During this period, 566 miconia plants were removed within the study area (172 mature, 394 immature) through mechanical and chemical means. Organized control efforts ended in 2010.

2.3. Data collection

2.3.1. sUAS flights

A consumer-grade Inspire-1 multirotor sUAS platform (DJI Inc., Shenzhen, China) was used to carry a DJI FC350 camera (20 mm lens with a f/2.8 focus, 94 degree FOV, Sony EXMOR 1/2.3-inch CMOS), mounted on a Zenmuse X3 gimbal during a series of flights over the study area on July 28 and August 5, 2016. sUAS flights were conducted between 11 a.m. and 3 p.m. under environmental lighting conditions ranging from full sun to partly cloudy. Flight operations were conducted manually at a forward velocity of 3 m/s and between 30 and 120 m above ground level (agl) to produce imagery datasets with varying ground sampling distance (GSD) (Table 1). It was impossible to safely fly lower than 30 m due to the tree canopy, which reached heights of 25 m within the study area and >30 m outside. Each flight took two to seven minutes and consisted of multiple flight paths (re-flown in opposite directions), parallel to the road bounding the study area (Fig. 1) and spaced between 12 and 30 m apart, depending on altitude, to achieve the desired overlap. For each flight, photos were automatically triggered in transit from a nadir position every 10 m along the flight path, resulting in image sets with an average overlap of 85% or greater, as suggested by Dandois et al. (2015). The exception to this was a portion of the 30 m agl flight which, out of prudence given the proximity of the surrounding tree canopy, followed a slightly modified flight path that produced 15% fewer photos than recommended for 85% overlap, while still covering the study area. For the 60 m agl flight, uncertainty regarding the operation of the camera during the initial flight (which was indeed operating properly) caused us to re-fly the mission, resulting in more than twice as many photos for that flight altitude. For each flight, following the collection of the nadir photos the platform returned to the starting position and the area was re-flown with the camera in a forward oblique (∼45 degree) position. This resulted in two sets of photos that were processed and analyzed for each flight altitude - nadir alone and nadir plus oblique