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RESEARCH ARTICLE

QUALITATIVE EFFECTIVENESS OF UNMANNED AERIAL VEHICLES FOR MONITORING FOREST RESTORATION IN BRAZIL: A BRIEF REVIEW

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ABSTRACT

Images obtained by sensors installed on unmanned aerial vehicles (UAVs), commonly called drones, can be used for several environmental applications such as monitoring the use of soil, estimating biomass, and determining the carbon volume of vegetation and forest restoration projects. The increased use of this technology is due to the easy operation, high spatial resolution of the orthorectified and georeferenced mosaics, precision of the cartographic products, and generation of topography information on the study targets. The present study assesses the effectiveness of UAV in generating images of forest restoration areas in two Brazilian biomes: Cerrado and Amazon. The operational aspects and data quality were analyzed using four different aircraft models. Among the tested aircrafts, the rotary wing category (quadcopter) showed the highest effectiveness for monitoring forest restoration projects. Compared with the fixed-wing models, this equipment was characterized by easier field operation and logistics, better resistance to strong winds, versatility in takeoff and landing, with well stabilized images with little or no drag.

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INTRODUCTION

Human activities cause the suppression of native vegetation,which often exceeds the legal and natural resilience limits of the landscape, thus, making forest restoration (FR) necessary (ARONSON, 2011). In the 2015 Paris Agreement (COSTA, 2015), Brazil set the target of restoring approximately 12 million ha of forest, an area equivalent to that of England. Interestingly, 86% of the rural estates in Brazil are smaller than 100 ha (DIEESE, 2011), and considering that these are the properties where most of the restoration will be performed, the maximum restoration area per property will be less than 20 ha. Therefore, restoration projects in small areas scattered over large territories are required and the monitoring will become even more challenging. The UAVs have acquired a good reputation in various scientific fields. This technology allows high spatial resolution products (often less than 10 cm-pixel), measuring biomass (ZAHAWI *et al*., 2015) and generating the digital surface model (DSM) and digital terrain model (DTM).This technology is thusan alternative and complement to traditional satellite images (AASEN *et al*., 2015; D'OLEIRE-OLTMANNS *et al*., 2012), which usually present restrictions sometimes caused by the climatic season (clouds), or by the low spatial resolution when available for free.Furthermore, the UAV images are not contaminated with clouds nor by the lack of recovery by satellites(BERNI *et al*., 2009). Due to such a potential, many UAVs with different characteristics were developed, each one being more suitable for a given situation. The goal of this study was therefore to assess the effectiveness of different UAV categories in generating images of FRareas,taking into account the small Brazilian areas subjected to restoration. The qualitative effectiveness of the UAV models and sensors were analyzed, as wellas the qualitative operational elements, quality of the obtained data, and the output of cartographic products.

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MATERIALS AND METHODS

Study area

This work includesthe assessment of FR projects on rural properties located in two Brazilian biomes, Cerrado (brazilian savanna environment) and Amazonia (Fig.1). In the Cerrado biome, the experiments were carried out on Pipiripau watershed in Brasília (Federal District), and in Lençóis Paulistacounty (São Paulo state). Both FR projects are supportedby the Brazil Water Program (Programa Água Brasil; www.bbaguabrasil.com.br). In the Amazon biome, the experiments were carried outin Apuí county (Amazonas state), where FR projects are implemented with the support of the Institute for Amazon Conservation and Sustainable Development (Instituto de Conservação e Desenvolvimento Sustentável da Amazônia, IDESAM).

Equipment

FourUAV models were used in this study (Fig. 2), representing three different micro-UAVcategories (less than 25 kg) (ANAC, 2015): quadcopter (rotary-wing with four propellers), short fixed-wing (span <1.4 m), and medium fixed-wing (span >1.5 m). The quadcopter categorywas represented by the Phantom 3 Professionalmodel, while the short-size fixed-wing was represented by the Swinglet CamandIsis models.Echar 20Bmodel was usedas the medium-size fixed-wing model.Optical RGB and NIR activated band filtersensors (HUNT JR., 2010) were installedonthese four platforms.

Preparation of flights and field experiments

According to standard protocol, the flight plans design required the careful evaluation of several parameters:

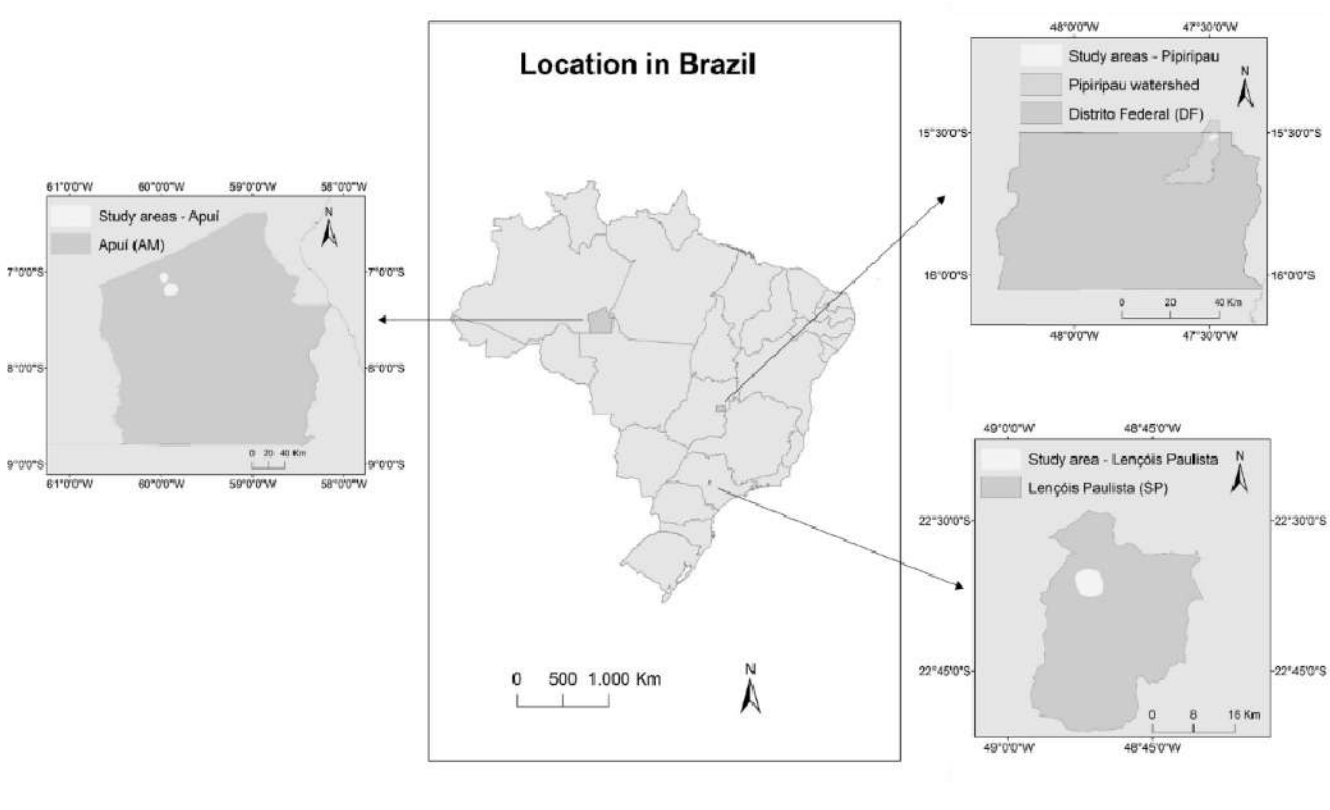


Fig.1. Study areas in Brazil. The counties with assessed forest restoration projects are highlighted

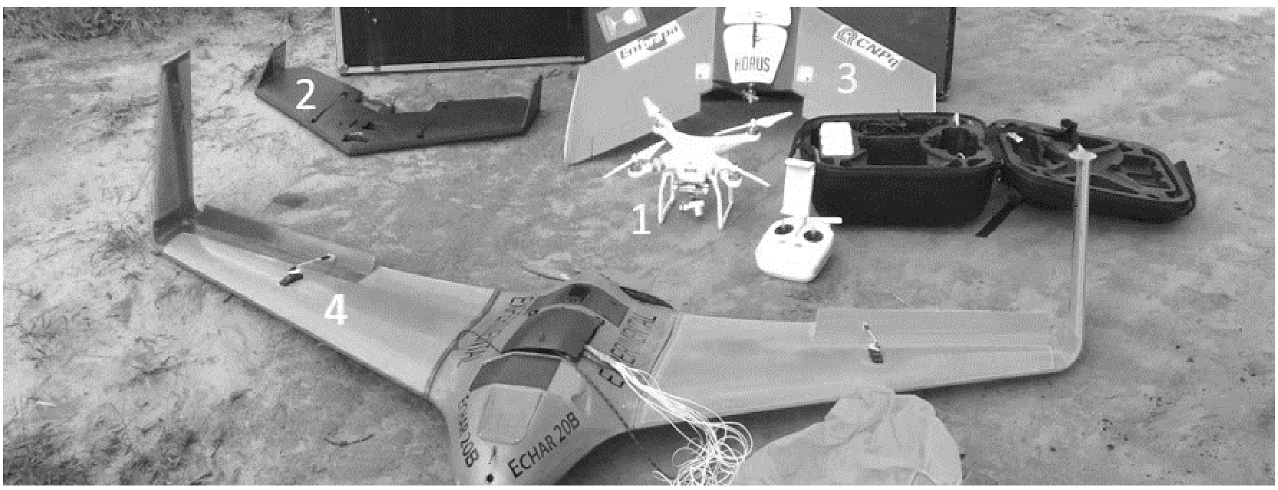


Fig.2. UAVs used in this study: Phantom 3 Professional (1); Swinglet Cam (2), Isis (3); and Echar 20B (4)

definition of the ground sample distance (GSD, or the pixel-size in the surface), considering the influence of the height and lens focal length on the image spatial resolution (ALVES *et al*., 2015); definition of the lateral and longitudinal overlays, considering the influence of the height on the mosaic and DSM/DTM process (D'OLEIRE-OLTMANNS *et al*., 2012; TURNER *et al*., 2012). To compare and validate the vegetation qualitative visualfeatures of the aerial images, field photos were taken and field reports were checked to be used as reference. This allowed the characterization of mosaics in the aerial images collected by sensors installed on the UAVs. We analyzed the effectiveness of each model based on feasibilities of investment, logistics, field operation, wind resistance and area coverage. These attributes evaluation results were summarized in a table for a better comparison.

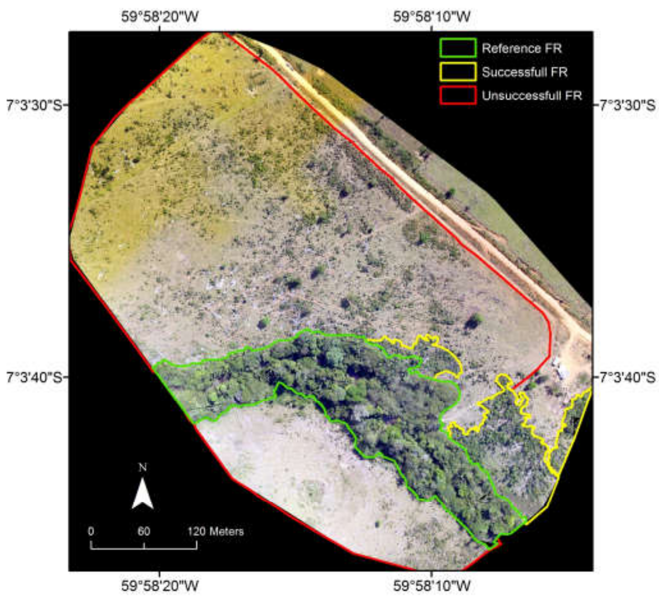
RESULTS AND DISCUSSION

Among the assessed categories of UAVs, the quadcopter class showed the best effectiveness for monitoring of FR projects. The cost of acquisition is low and its lower weight and reduced dimensionsmade thetransportation easier. Thefield operation was alsoeasier because of simplified and intuitive flight programming, which requires the basic knowledge. The quadcopter presented good resistance to strong winds, asit was able to carry out missions even when facing winds over 7 m/s (approximately 36 km/h). Its only restriction is related to the mapping area, because the covering capacity per flight is approximately 20 ha. Nevertheless, considering the Brazilian context ofsmall areas that are being restored, this is of little concern. The operation of the short-size fixed-wing equipment

Table 1. Effectiveness of the UAV categories according to specific characteristics

Attribute	Phantom 3	Swinglet	Isis	Echar 20B
Investment feasibility	High	Low	Low	Low
Logistics feasibility	High	Medium	Medium	Low
Field operation	High	Medium	Medium	Low
Resistance to winds	High	Low	High	Medium
Sizecoverage	< 100 ha	150 to 400ha	150 to 800 ha	> 800 ha
(More than one flight)	(5 flights)	(3 flights)	(5 flights)	(more than 2 flights)

(a)



(b)

Fig.3. Aerial images obtained with a quadcopter. The structural vegetation differences showed stretches with preserved vegetation that serve as FR references, stretches with relative successful restoration and stretches with relative unsuccessful restoration on Lençóis Paulista (a) and Apuí (b)

is more complex, although this type of aircraft has greater flight autonomy and can cover larger areas.It requires trained operators, and launching and landing areas with specific features such as wide spaces (minimum radius of 40 meters), with no shrubs, trees, or other obstacles. Furthermore, the acquisition cost is high and the transportation logistics are more demanding.It is important to know that the Swinglet CAM, for instance, was not able to complete missions in Lencóis Paulista site, due the atmospheric conditions in that moment, with wind speed higher than 7m/s. This is an important factor in defining the aircraft model, considering thatdifferent regions in the country have specific wind conditions. The medium-size fixed-wing equipment requireseven more preparation between the initial set up and the take-off stages. The degree of operational difficulty of this equipment israther high and specific operator training is required for the setup, flight program, take off, and landing.Resistance to winds were medium becausethe parachute opened suddenly in one of the flights due to strong wind. This medium-size fixed-wing equipment was used only in one study areain Lençóis Paulista, mostly because of the great load volume that needs to be transported. This is an important factor limiting the choice of this equipment for monitoring restoration areas that are distant from each other.

Quality of the information

Both image mosaic and DSM of all UAV presented similar quality, except on radiometric content, when NIRsensor-band was evolved. Nevertheless, all UAV data enabled qualitative assessment about the study areas. For example, the mosaics generated during the flights over the rural property atLençóis Paulistaand Apuí display areas with different tree densitiesin FR (Fig.3), including stretches with a relatively successful restoration process, stretches with relatively unsuccessful restoration process, and preserved stretches that serve as a reference to the FR process. At Lençóis Paulista, these findings are in agreement with the information recorded in the field, and documented in specific monitoring reports that assessed the efficiency of the different seeding density implantation, where 3x2 meters densification generally presented better results for FR (Fig. 3a). In the rural propertyat Apuí, the aerial photomosaic alsoindicates areas with different tree densities (Fig. 3b). In this case different FR situations indicated different land use intensity of cattle, firewood and burning, as the FR was less successful where land use was more intense.

Conclusion

The use of UAVs for FR project monitoring is an effective alternative to traditional monitoring methods. The quadcopter has proven to be very versatile and efficient for monitoring areas up to 100 ha and thus is the better option for FR projects in the Brazilian context. The short and medium fixed-wing are more expensive and complex, and their results have same quality on FR projects. Werecommend future studiestargeting the development of automated quantitative assessment indexes for the classification offorest restoration processes, as well the evaluation ofplant biomass, biodiversity, and carbon stock using UAVs technology. Other ecological aspects, such as ecosystem services in the areas that are being restored or that have already been restored or recovered, should also be explored through the use of this technology.

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