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Management in Practice

Development of drone-based methodology for inventory and monitoring invasive plants along river banks in Croatia

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Citation: Sladonja B, Damijanić D, Krapac M, Uzelac M, Linić I, Poljuha D (2022) Development of drone-based methodology for inventory and monitoring invasive plants along river banks in Croatia. *Management of Biological Invasions* 13 (in press)

Received: 24 December 2021

Accepted: 5 May 2022

Published: 14 July 2022

Handling editor: Amy Davis

Thematic editor: Catherine Jarnevich

Abstract

Monitoring invasive species is required, but ground field-based assessment is often impractical, time-consuming and expensive. In the present paper, we compare standard ground and drone mapping methods to estimate the distribution and abundances of *Helianthus tuberosus* and *Solidago canadensis* across a 1.9 km long river bank area in Croatia. We describe beneficial factors and limitations researchers should consider for planning aerial drone surveys. The criteria used include time, precision, cost, and other indicators of the value of each method based on its long term potential. We utilised the Mavic 2 Enterprise Dual model of a drone equipped with an M2ED Visual Camera. Among tested drone modes, the best was the video recording mode at a height of 15 m and speed of 1.2 m/sec, for which we developed a protocol. Obtained data can be useful in adding information on vegetation distribution but also contribute to an effective management plan for invasive species.

Key words: mapping, invasive plant, remote sensing methods, protocol, management plan

Introduction

Monitoring is essential in managing invasive plants because it provides information to make appropriate management decisions (Buckley 2008). Elzinga et al. (1998) defined monitoring as the collection and analysis of repeated observations or measurements to evaluate environmental changes. While monitoring is carried out multiple times for several consecutive years, inventory is implemented at the present moment. Nevertheless, data collected during inventory and monitoring usually overlap and complement each other (Elzinga et al. 1998). Invasive species monitoring can provide data on the abundance and prevalence of their populations over time. It can also determine how invasive species alter local ecosystem processes. Moreover, monitoring invasive species can measure the effectiveness of control methods (Haber 1997).

Standard inventory and monitoring of invasive species can be performed using a series of permanent plots to document the percentage of indigenous coverage in relation to invasive vegetation (Thomas et al. 2007). The second most used method is by using transects. Linear transect surveys are done along roads, rivers, power lines, seashores etc., within a specified geographical area. Specific start and end points are selected to include a reasonable monitoring distance. Ten to fifty km routes, or even longer, may be manageable, depending on the type of transportation used (Buckland et al. 2007). Monitoring methodology should be chosen based on landscape features, target species habitat and management options, depending on human and financial resources. Presence detection and canopy cover estimation are often done by live attendance and visualisation.

An appropriate monitoring approach significantly reduces the costs of invasive species management. Consequently, developing new, efficient and cost-effective inventory and monitoring methods is required.

Remote sensing (RS) has become a notable tool for detecting, mapping, and monitoring invaders in the past few decades. It is also a practical tool for studying inaccessible ecosystems and complex areas on the Earth's surface (Joshi et al. 2004). Underwood et al. (2003) concluded that remote sensing could be used for faster detection and less resource-intensive monitoring of invasive species compared to traditional field methods. Different RS methods have different advantages and limitations. For example, some satellite data providers have problems with insufficient spectral, temporal or spatial resolutions and are dependent on the cloud cover at the time of the acquisition (Müllerová et al. 2017). One of the advantages of using satellite imagery is that the satellite data is mostly freely available to the user. However, none of the freely available satellites reaches the high spatial resolution of images (Nowak et al. 2018). Alvarez-Taboada et al. (2017) suggested using satellite imagery when moderate spatial and temporal resolution is needed and UAV data for high spatial and temporal resolution outputs. Nowak et al. (2018) compared the number of papers using general RS methods (satellites) and those using Unmanned Aerial Vehicles (UAVs), known as drones. They concluded that the use of satellites in environmental biology had been stabilised since 2013, while the use of drones has been steadily increasing over the past 20 years. Sladonja and Damijanić (2021) reported that drones provide an exceptional opportunity to detect invasive alien plant species (IAPS) due to their operational flexibility. This makes drones the prefered next-generation method for monitoring IAPS. Drones were already successfully used to estimate some IAPS abundance and distribution of biological populations (Dvořák et al. 2015). It has proven particularly practical in large or inaccessible study areas (Quang and Lanctot 1991). Furthermore, drones provide data to re-examine the site at later times (Barnas et al. 2019). That is very important in terms of species identification and monitoring effects. However, the possibilities of this tool are numerous and depend on the drone sensors (Nowak et al. 2018). In our case, sensors on the visual camera captured species with easily recognisable morphological

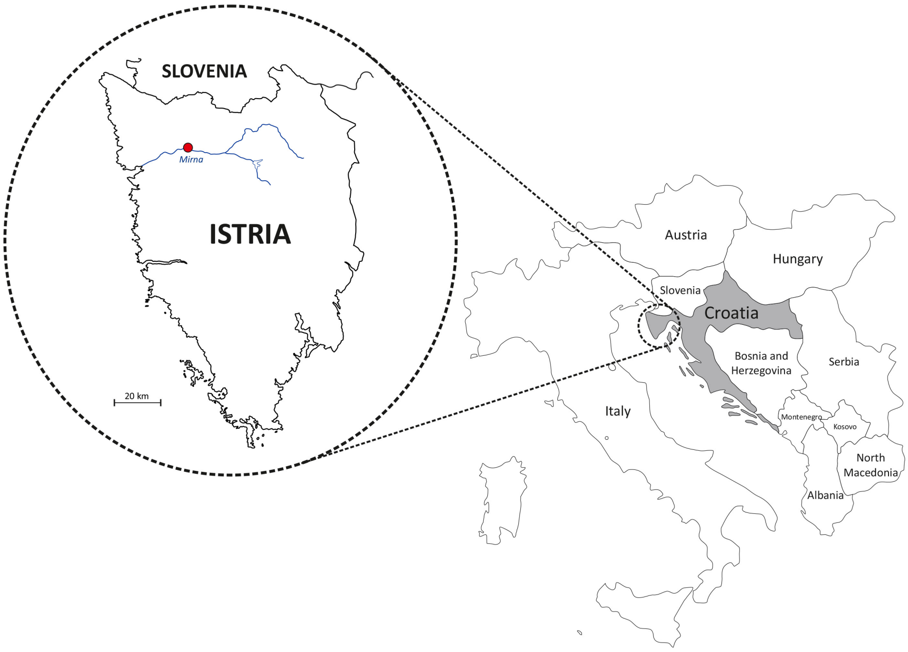

Figure 1. Mapping location (red dot represents mapping area).

characters in the period when these characters were present on the plant. We stipulate that drones can be the most practical and cost-effective method to map individual populations of selected invasive plants.

Our targeted IAPS, *Helianthus tuberosus* L. and *Solidago canadensis* L., are the most spread invasive plant species along the river bank of Mirna River in Istria (Croatia). This area was mapped systematically for the first time by a standard plot ground methodology in 2020, in the framework of the national IAPS survey, and part of this area by drone in 2021. Some partial monitoring activities are done by the *Istarski vodovod* d.o.o., a company for water management in this area.

The present study aimed to: a) determine whether IAPS monitoring via drone can differentiate between similar IAPS; b) compare standard ground and drone mapping by identifying advantages and address problems of drone monitoring; c) develop a protocol for identification and monitoring two specific IAPS by drone.

Materials and methods

Mapping area

The Mirna River is the longest river in the Istrian peninsula (53 km), located in the West of Croatia (Figure 1). Its hydrographic catchment covers approximately 400 km^2, while the hydrogeological catchment of the Mirna River covers around 580 km^2. It results from underground water circulation created by karst processes (Božičević 2005). The upstream part of the Mirna basin is located at slopes formed in marl and flysch. Downstream, the river Mirna flows through a canyon carved into carbonate rocks (Benac et al. 2017). The river Mirna valley is surrounded

Figure 2. *Helianthus tuberosus.* Photo by Danijela Poljuha.

by forests of *Fraxinus angustifolia* Vahl (periodically flooded habitats), mixed forests of *Quercus robur* L., *Fraxinus angustifolia*, *Ulmus minor* Mill. and *Carpinus betulus* L. (higher and drier localities, with a high level of groundwaters) (Vukelić et al. 2018). Part of the Mirna basin is a valuable natural-scientific, economic, cultural-historical, and tourist-recreational locality and is protected as a special reserve of forest vegetation.

The target species

Helianthus tuberosus, also called Jerusalem artichoke, topinambur, sunchoke, sunroot, or earth apple, is a plant of Asteraceae family (Alla et al. 2014) (Figure 2). *Helianthus tuberosus* is an erect, rhizomatous perennial tuber-producing herb, up to 3–4 m high, scarcely to moderately branched in the upper half of the stem, with bright yellow flowers (Pacanoski and Mehmeti 2020). It is native to North America, from where cultivated forms of this species have spread to Western Europe and other parts of the Northern Hemisphere. Today it is present and often invasive in many temperate areas in Europe, Asia, Australia, New Zealand, and tropical South America (Weber 2003). *Helianthus tuberosus* grows aggressively and out-competes local vegetation. It is also known that its roots can have allelopathic effects on nearby plants. It is difficult to eradicate once established at a site (Tesio et al. 2011). *Helianthus tuberosus* is best adapted to rich, moist soil and can be found along roadways, in wasteland, wetlands, and gardens. It reproduces by tubers and occasionally by seed (Wyse et al. 1986). In Croatia, *Helianthus tuberosus* flowering period usually peaks during autumn (mainly in October).

Solidago canadensis, also known as Canadian goldenrod, is a plant of the Asteraceae family (Figure 3). It is native to North America and has spread

Figure 3. *Solidago canadensis.* Photo by Danijela Poljuha.

as an ornamental plant throughout Europe, Asia, Australia, and New Zealand. *Solidago canadensis* is a rhizomatous perennial plant, height from 25 to 250 cm. The tall and leafy stem has tiny yellow flower heads that form broad pyramidal panicles with curved branches and a central axis (Weber 2003). It reproduces by rhizomes and seeds. *Solidago canadensis* is considered a successful invasive plant because of its allelopathic effects on other plant species. It can also limit the access of other plants to light and water due to the high population density (Dudek et al. 2016). *Solidago canadensis* tolerates high concentrations of heavy metals in soil and colonises agricultural land habitats and industrial and municipal waste landfills (Bielecka et al. 2017). *Solidago canadensis* flowering period peaks between mid-August and the end of September, but flowering can continue through October.

Both species are considered invasive alien plant species of major concern in Croatia (Nikolić et al. 2004) and were included in the national survey of most important invasive plants in 2019/20.

Mapping methodology

<u>Standard ground-based methodology</u>

Standard ground mapping of 84 selected invasive alien plant species in priority areas in the Republic of Croatia was performed during the summer of 2019 and 2020 in the framework of the EU Operational Program Competitiveness and Cohesion 2014–2020. The research area (Croatia) was divided into 356 quadrants of size 10 × 10 km. Each quadrant had a minimum number of georeferenced points ranging from 10 to 18. The georeferenced point was determined using a GPS device on a mobile phone with an accuracy of ± 50 m. Mapping was conducted by car and on foot by 19 experts during two vegetation seasons. Our area of interest was covered by one such quadrant. The species determination in the area was assessed visually by sampling the plant and using determination keys and literature. For some morphological traits of the assessed plants (such as hairy stems), a hand magnifier was used. For the assessment of the species cover-abundance, we used the Braun-Blanquet scale (Braun-Blanquet 1964). All the collected

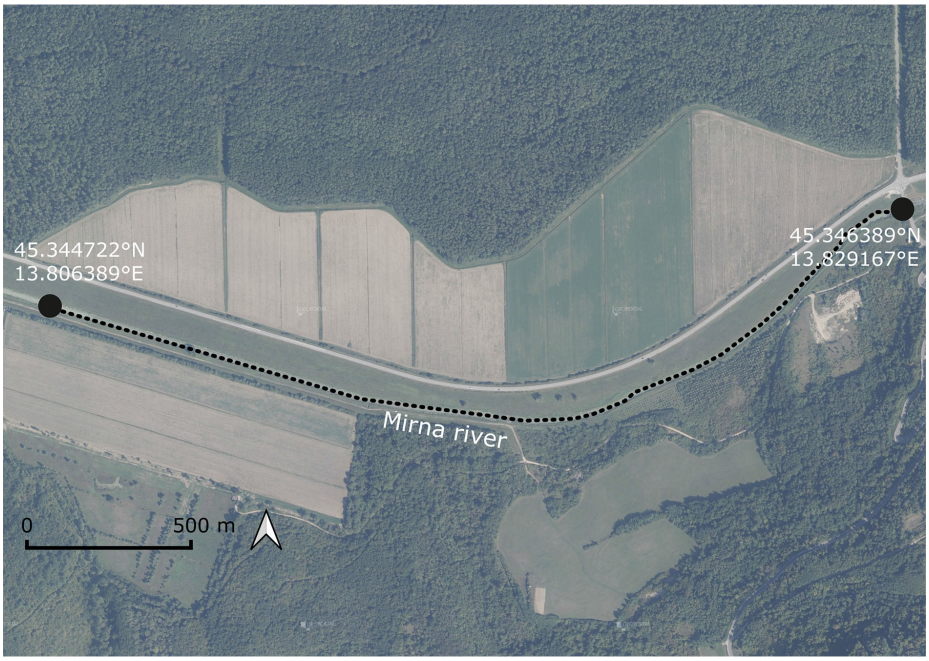

Figure 4. Map of our study area (Source: QGis).

data (time and date, species density, habitat description, photo documentation) was entered into the mobile phone application and the paper version. The IOS and android application for data insertion *in situ* was created during the EU program's preparatory phase.

Drone methodology

All flights were done on October 15, 2021 (from 1 PM to 3 PM) inside the quadrant previously surveyed in traditional field mapping. Weather conditions were suitable for the drone survey (sunny day, no wind, no clouds). Our mapping included 1.9 km from crossroad Livade-Motovun (45.346389°N; 13.829167°E) to the end of the quadrant (45.344722°N; 13.806389°E) inside the protected area (Motovun forest – a special reserve of forest vegetation) (Figure 4). The flights were performed using a Mavic 2 Enterprise Dual model of drone. Images and video were taken with an M2ED Visual Camera (1/2.3-inch CMOS sensor; 12 MP) and were saved in JPEG (photo) and MP4 (video) format. Transect mapping was performed considering the highest abundance of *H. tuberosus* along the river banks. Before mapping, the drone camera angle was set to −90°. We have tested two drone flight modes (Linear flight mission and Manual flight) to take photos at different heights above ground level. Furthermore, we have tried manual video recording at different heights and different speeds. Linear flight mission mode was performed with the following parameters: 25 photos, 1.16 minutes, the total length of 651 m (start–final point–start), and 50 m above ground level. With the Manual flight mode, we have recorded several photos at 20 m above ground level. Video recording was performed in one minute at three different heights: 15 m (73 m length, 1.2 m/sec speed), 10 m (44 m length, 0.6 m/sec speed), 6 m (42 m length, 0.6 m/sec).

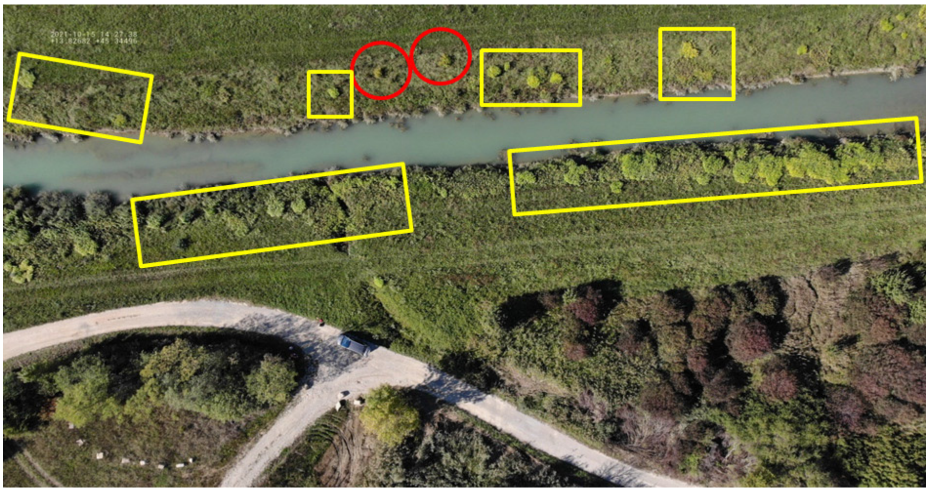

Figure 5. Photo taken by a drone from 50 m during a Linear flight mission. *S. canadensis* rounded in red, *H. tuberosus* framed in yellow.

Results and discussion

Mapping H. tuberosus *and* S. canadensis

During the standard ground survey, only *H. tuberosus* was found along the Mirna river in the quadrant of our interest. The quadrant in question had 13 georeferenced points. *H. tuberosus* was found at one of them and scored as 3 (taxa represented by many shoots, 25–50% cover) according to the Braun-Blanquet cover-abundance scale. *S. canadensis* was not found during the ground survey, most likely because of its smaller clusters and high surrounding wetland vegetation.

Remote sensing mapping revealed the presence of both IAPS. Visual inspection of the registered images by drone was performed in the office and showed that it is possible to distinguish the two surveyed species visually. Within the Linear flight mission mode on the photo taken from a height of 50 meters, a skilled eye can detect single *S. canadensis* bushes and easily distinguish the areas covered by *H. tuberosus. H. tuberosus* bushes are mainly grouped, light yellow and larger than *S. canadensis* bushes (Figure 5). Photos taken with the Manual flight mode from a height of 20 m had better resolution, but the difference between 20 and 50 m was insignificant. Video recording had higher speed monitoring and equal efficiency.

Although all tested drone methodologies were acceptable, we concluded that the best protocol for tested IAPS monitoring is mapping by video recording at the height of 15 m which offers the best balance between monitoring parameters (Figure 6). In particular, we achieved sufficient clarity of distinction between two IAPS, acceptable recording speeds, moderate drone battery consumption and simplicity of setting technical parameters.

Comparison of two mapping methods

A standard and drone mapping comparison was done using the defined criteria and presented in Table 1.

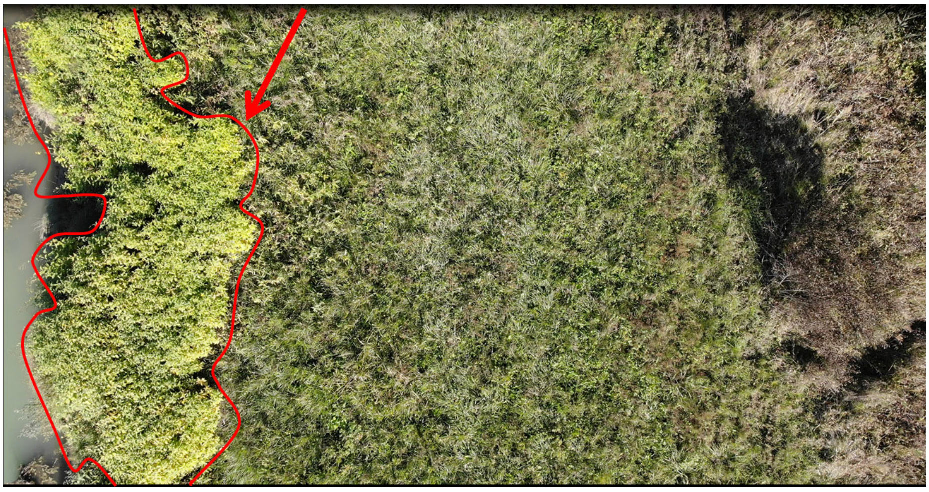

Figure 6. Picture from a video recording at a height of 15 m; recommended as the best drone option. Bushes of *Helianthus tuberosus* are clearly recognisable and circled in red.

Table 1. Comparison of ground field-based and drone-based mapping using quantitative and qualitative criteria. The calculation is referred to as the mapping of a transect along the river bank, long 1.9 km, wide 15 m (Figure 4).

Criteria	Standard point mapping	Drone mapping (video recording at 15 m)
Time (mapping) (refers to the work of 2 experts)	5 h and 13 min	26 min
Time (data elaboration) (refers to the office work of 1 expert)	6 h and 20 min (19 observation points=19 photos × 20 min visual inspection of each)	Basic 120 min, detailed review endless
Precision (low, medium or high)	Medium	High
Costs of mapping for 2 experts (transportation, human labour, drone use…) (eur)*	300 (50 transport+200 work remuneration + 50 paper and photo equipment)	450 (50 transport + 200 work remuneration + 200 drone rental)
Personnel (number)	2 mapping, 1 data elaboration	2 mapping (1 invasive species expert and 1 dron user), 1 data elaboration
Possibility of data re-use	Limited (written records and photo material)	Very high
Species identification reliability	Highly reliable – the possibility of taking samples	Mostly reliable
Interchangeability**	Low	High

*costs are calculated based on personal authors' experience and expert's standard travel and remuneration fees in Croatia.
**different drone parts (controllers, cameras, sensors) are interchangeable and can collect different types of data.

The comparison of the two methods showed that the most remarkable difference is in the time needed for mapping. Furthermore, the possibilities of re-using data after mapping are much more significant in drone mapping, which is also confirmed by Barnas et al. (2019). The biggest shortcomings of standard ground mapping are reflected in the fact that it did not achieve 100% coverage but allowed for obtaining samples, which makes species identification more reliable. The weaknesses of drone mapping are higher initial costs and the need for specialised experts for drone manipulation.

Kattenborn et al. (2019) found that UAV-based remote sensing allows acquiring spatially continuous information on species cover with a very high spatial resolution. Our study confirms this finding. Barnas et al. (2019) found that drones in ecological surveys were much faster than ground-based methods, but these savings came at the cost of increased times used

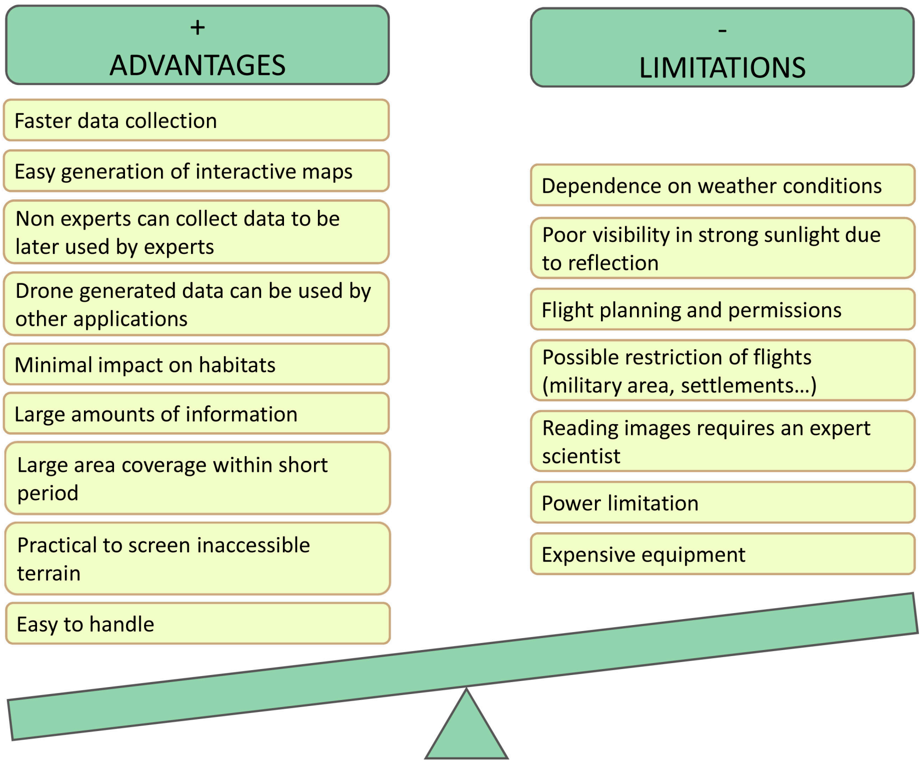

Figure 7. Advantages and addressed problems of drone mapping.

for image processing and classification. Dvořák et al. (2015) and Nowak et al. (2018) discuss more advantages and limitations of drone mapping.

Identified advantages and addressed problems of drone mapping in our study are given in Figure 7.

Conclusion

Our research proved that drones could be a good tool for transect mapping. The two tested IAPS were successfully identified using a drone. Compared to standard ground mapping, drone mapping has proven to be faster and has provided a large amount of data that can be seen and used by many experts indefinitely. Furthermore, we concluded that drones could be more useful for inaccessible mapping areas. On the other side, standard ground mapping is more reliable when accurate species identification is needed. The suggested best protocol for transect drone mapping of *H. tuberosus* and *S. canadensis* is video recording at the height of 15 m and a speed of 1.2 m/sec. This protocol may be integrated into larger planning documents essential for a good long term management plan.

Acknowledgements

The authors would like to thank the reviewers, whose valuable comments contributed to the final appearance of the manuscript.

Funding declaration

This research was supported by the Croatian Science Foundation under the project "NATURe as an ALLY: Alien Invasive Plants as Phytopharmaceuticals – NATURALLY" (IP-2020-02-6899) and Monitoring the occurrence and prevalence of pests in beekeeping in the Republic of Croatia – *Vespa velutina* and *Vespa orientalis* (UP/I-320-09/21-06/0002). The work of doctoral student Mirela Uzelac has been supported by the "Young researchers' career development project – training of doctoral students" of the Croatian Science Foundation (DOK-2021-02-6899).

Authors' contribution

B.S. research conceptualisation, sample design and methodology, investigation and data collection, writing; D.D. research conceptualisation, data analyses, writing; M.K. research conceptualisation, data collection, analyses and interpretation; D.P. Data interpretation, writing, editing, funding provision; M.U. data analyses and interpretation, writing, editing; I.L. data interpretation, writing, editing.

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