Needle in a haystack – detecting hawkweeds using drones

Mark Hamilton[1], Robert Matthews[2] and Jo Caldwell[3]
[1] Pest and Weeds Unit, NSW National Parks and Wildlife Service (NPWS), Hurstville, New South Wales 1481, Australia
[2] Helisurveys Pty Ltd, Jindabyne Airport, Jindabyne, New South Wales 2627, Australia
[3] Southern Ranges Branch, NSW National Parks and Wildlife Service, Tumut, New South Wales 2720, Australia
(mark.hamilton@environment.nsw.gov.au)

Summary Orange hawkweed (*Hieracium aurantiacum* L.) and mouse-ear hawkweed (*H. pilosella* L.) are perennial daisies native to Eurasia and have proven highly invasive in several countries outside their native range. Small incursions are present in New South Wales in Kosciuszko National Park and proximate to the reserve (only orange hawkweed). They pose a significant threat to south eastern Australia and are the subject of a New South Wales (NSW) and Victorian joint eradication program, coordinated in NSW by NPWS and partners.

A key challenge in the NSW Hawkweed Eradication Program is delimiting the infestation, particularly across the remote and rugged area where the infestation occurs. To supplement existing ground surveillance, NPWS sought to utilise drone surveying in the orange hawkweed operation as large and remote areas can be surveyed at low cost. Drones capture colour imagery and a specifically designed algorithm automates the detection process. In the 2017/2018 season, during peak flowering, 608 ha was surveyed by drone over 17 survey days. Eight confirmed infestations were detected, including a new location on Happy Jacks Plain.

Drone surveys have been incorporated into the program as an ongoing component, and are proving to be a highly cost-effective surveillance method. It is expected drone survey during flowering times will contribute significantly to delimitation of the orange hawkweed infestation and be pivotal in reaching eradication rapidly.

Keywords Delimitation, UAV, eradication, *Hieracium aurantiacum*, orange hawkweed.

INTRODUCTION

Orange hawkweed (*Hieracium aurantiacum* L.) and mouse-ear hawkweed (*H. pilosella* L.) are stoloniferous perennial herbs of the Asteraceae family. Native to Eurasia, they are highly invasive in many countries outside their native range, including New Zealand, United States of America, Canada and Japan. Orange hawkweed has naturalised in Australia in New South Wales (NSW), Victoria and Tasmania. In NSW, small infestations of orange hawkweed are found across eleven locations in the Jagungal Wilderness Area of Kosciuszko National Park (KNP) and at two locations on private land east of the reserve. One known NSW incursion of mouse-ear hawkweed is found in a separate part of KNP on the Main Range, proximate to Blue Lake.

In Australia, hawkweeds are at the early stages of establishment but have the potential to occupy large tracts of south-east Australia. Beaumont *et al.* (2009) estimate 27 million ha are susceptible to orange hawkweed invasion and economic modelling indicates potential losses to the grazing sector in excess of $68 million AUD per annum (CPI adjusted to present) (Brinkley and Bomford 2002). Due to the small infestation area and significant potential impacts, the objective is to eradicate both hawkweed species from NSW; similar efforts are occurring in Victoria.

The NSW Hawkweed Eradication Program is one of the largest weed eradication programs in Australia. Eradicating an organism from an invaded range is a deceptively difficult task: the infestation must be delimited; reproduction halted; above ground biomass controlled; and the seedbank exhausted. Owing to this difficulty, there have been no documented cases of state-wide eradications in NSW and very few examples exist in Australia (Panetta 2009).

Since detection in 2003, NPWS has coordinated an orange hawkweed control program, with the objective of eradication since 2009/2010. To be successful, any eradication must quickly and reliably detect the target organism, preferably before reproduction occurs, to ensure timely eradication. A key obstacle to successful eradication is the ability to detect all plants such that control can occur. Delimitation efforts often represent the single largest investment in a weed eradication.

The Jagungal Wilderness Area is remote and rugged, and thus an extremely difficult area to survey. It has very few roads or vehicle trails (Figure 1); the area is steep, being dissected by the Tumut River and its tributaries; and dense heath and Alpine ash forest are common. Within KNP, orange hawkweed infestations are found across an extent of 7080 ha, and including the two off-park locations the full extent of potential area is 31,721 ha (minimum convex polygon method). It is important to note that though this is a large extent, hawkweed is not expected to occur with equal probability across this area. Like other plants, hawkweed is limited by environmental factors that determine where it can disperse and establish. Most high-likelihood areas have been searched multiple times and it is not expected or necessary for all areas to be searched for hawkweed, at least not in one season, or even over several seasons.

Detection of orange hawkweed, a small herb with rosettes 5–20 cm diameter and flowers to 20 mm diameter and up to 40 cm high, is difficult, especially when not in flower. Until recently, the eradication program relied solely on humans undertaking ground surveillance, which has achieved impressive results (Hamilton *et al.* 2015). However, the large areas to be searched and the increasing difficulty reaching and surveying areas, combined with the declining detection certainty of human-assisted surveillance as weed populations become sparser (Chandler 2014), necessitated a method to survey large areas at low cost. Remotely piloted aerial systems (RPAS) or drones have the potential to do this. The benefits of RPAS for weed surveillance are well documented (Clements *et al.* 2014, Dehaan *et al.* 2014, Merz *et al.* 2016). Due to their light weight and small size, and the ability to automate the detection process through algorithms, drones can collect data at high resolution, and can do so at low cost, particularly when compared to manned aircraft. For these reasons, the use of this technology for hawkweed eradication was explored.

In 2014/2015 and 2015/2016 detection of orange hawkweed using drones was trialled by the Australian Centre for Field Robotics with NPWS (Hung and Sukkarieh 2015). The deep orange-red flowers are distinctive, and were considered sufficiently unique to explore the use of colour (RGB) imagery captured aerially by drones. Following this initial work, with assistance from Helisurveys Pty Ltd, drone surveillance and detection mechanisms have been improved and are now operational and integrated into the eradication program. This paper outlines the progress made to date, the process of orange hawkweed drone survey and detection, and the successes achieved in the 2017/2018 season. This paper largely deals with orange hawkweed drone detection, but mouse-ear hawkweed drone and remote sensing options are briefly discussed.

MATERIALS AND METHODS

The challenge at hand was to detect a small herb across a large and remote area with a limited budget.

Automating detection of orange hawkweed Due to the large survey areas and small target size, approximately 400 photos are generated per hectare surveyed. Manual photo processing would reduce any benefit gained from the rapid and low-cost survey. As such, an algorithm was developed by Helisurveys to identify pixels that corresponded to the colour of orange hawkweed flowers. Using the unique colour of the flower as the main predictor, from a small sample of images containing known hawkweed flowers, the upper and lower values of the red, green and blue colour channels were determined. A test version of the software provided an RGB colour detection algorithm that was improved upon once more data was collected, but was robust enough for initial drone survey. When more training data was collected and the algorithm improved, previous images and data sets were re-analysed to confirm no orange hawkweed flowers were missed using the test version of the algorithm.

The RGB values and ranges of orange hawkweed flowers were determined by manually viewing and logging the pixel values. Following this, a period of trial and error testing was performed to narrow pixel values down to an acceptable range. A program was developed to help log pixel values of orange hawkweed flowers, but no machine learning was used.

As more images were collected and true detections were found, the algorithm was refined to make it more likely to detect genuine orange hawkweed flowers. At the same time, the false positives were reduced by adding in shape, graduation of hues away from the centre of the flower, and size. Several filters that are run after the detection is logged were also developed. These filters help to reduce the false positives created by certain types of vegetation and flowers with similar colours.

Sensor and aircraft The camera used was a Canon 70D with an 18–55 mm lens, which was fixed at 48 mm during survey. When over the survey area, the camera was triggered via remote control to take photos at a rate of 3 each second with a shutter speed of 1/1250th of a second.

The RPAS used for the 2017/2018 season was a DJI M600 with a Ronin MX Gimbal. The M600 comes as standard with a LightBridge 2 system that provides the flight control link, telemetry and a realtime HD video downlink. The gimbal can be controlled via the LightBridge 2, and it was configured to point directly down and follow the direction of travel of the M600. The ground control software used for flight planning and execution of the flight plan was UGCS (Universal Ground Control System). This was chosen for its ability to create flight paths that follow an imported

Digital Elevation Model that maintains the drone at a constant 30 m above terrain level.

Image capture Using information from previous trials (Hung and Sukkarieh 2015), it was determined that the ideal Ground Sample Distance (GSD) was 2.6 mm. This was increased from 3.0 mm in 2016/2017 to help confirm detections during the human image analysis phase. Extra initial processing was done in the software to help account for variations in the image brightness. This allowed flights to not be restricted to only sunny, cloudless days. Orange hawkweed flowers were successfully detected on both full overcast and full sun days and between the hours of 8:30 and 17:00.

To attain the required GSD of 2.6 mm, the drone was flown at 30 m elevation with the camera lens set to 48 mm focal length. The speed was set at 8 m per second. This was determined to be the optimum compromise between being able to cover more area per flight and minimising pixel blur.

Field algorithm Initially, the image analysis software was run after the surveys were completed. This could take 6–8 hours to process 2 hectares worth of imagery. With further development, the time was reduced by a factor of 20. Because some of the survey sites are only accessible by helicopter, the inability to run the algorithm in the field was cost prohibitive and meant that ground truthing – and critically, herbicide treatment of hawkweed plants – could be delayed. A 'field' version of the software was developed to quickly process images, but at the possible expense of rigour. To date, the field version has not missed any detections the full version has detected, but the risk exists. It is used *in addition* to the full version to be able to rapidly verify detections on the day of survey.

False positives and manual culling Different survey sites and vegetation types provide different challenges for the algorithm: Some flights produce 10–20 false positives (out of 2500–3000 images), while others could produce up to 600–800 false positives. Filters were developed to reduce the number of false positives, but at the cost of potentially missing genuine detections. To date, the filters have not filtered out any genuine detections. Once the algorithm and filters are run, the remaining images must be viewed by a human to determine if ground truthing is required. The detection is highlighted by a red square overlayed on the image to help the viewer quickly identify the area for close inspection. These images are geotagged using information from the onboard GPS. Together with the images, a KML and CSV file are created with the coordinates of the image to aid with ground truthing.

Survey area selection As per other hawkweed surveys, priority drone survey sites were selected based on a simple surveillance prioritisation model. The model considers: 1) proximity to known infestations; 2) dispersal modelling from wind speed and direction data collected at hawkweed locations; 3) areas of past surveillance; and 4) vegetation type (M. Hamilton unpubl. data). Additional factors to consider are specific site requirements for drone surveying, such as large areas with no sudden changes in topography, and with a vegetation height lower than approximately 20 metres.

RESULTS

Since 2015/2016 the area surveyed by drones has dramatically increased, from 17 ha in 2015/2016, to 85 ha in 2016/2017, and currently to 608 ha in 2017/2018 (Figure 1). Drones now survey almost double the area of humans on the ground do. 2017/2018 saw the first detection of previously unknown patches of orange hawkweed. Prior to this, imagery was captured over known hawkweed infestations and hawkweed was successfully detected (to test the process) but no hawkweed was detected in survey areas, only absences were recorded.

In the 2017/2018 season, 608 ha was surveyed using drones, 515 ha in KNP and 93 ha off park. Surveys occurred during peak flowering period over 17 days from 18 December 2017 to 26 January 2018. A total of 290,277 images were captured and eight detections were confirmed as orange hawkweed. Detections included one infestation detected through broken canopy (Figure 2), a sole orange hawkweed flower amongst 4 small rosettes, and a small infestation in the western part of Happy Jacks Plain. The latter was particularly significant given that parts of this large plain have been surveyed for many years as it is ideal habitat for the weed, and it is a priority for survey as it is closest to the reserve boundary.

Area surveyed varied from 25–50 ha day^{-1}, averaging 35 ha. This was influenced by suitable drone survey areas, inclement weather, and transit time between sites, if multiple sites were surveyed in a day. Later in the survey program, a new drone with longer flying time extended surveying ability to 50 ha day^{-1} in suitable areas. For comparison, a survey of 40 ha using human surveyors would require a team of 5 staff for 16–20 days. This is over one order of magnitude more expensive when compared to drones. Including salaries, vehicle, equipment and accommodation expenses, on-ground survey using staff costs \$556–695 ha^{-1}, compared to the drone rate of approximately \$50 ha^{-1}. Future work will include assessments of drone versus human detection accuracy per unit cost.

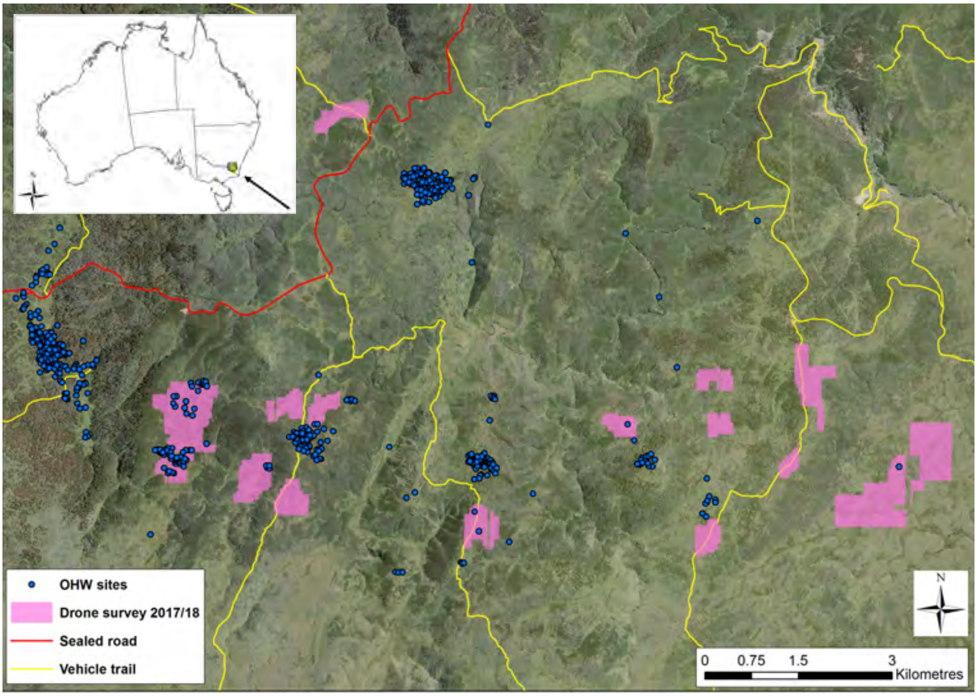

Figure 1. Orange hawkweed (*Hieracium aurantiacum*) infestations (blue dots) in Kosciuszko National Park and location of drone detection surveys (pink areas) in 2017/2018.

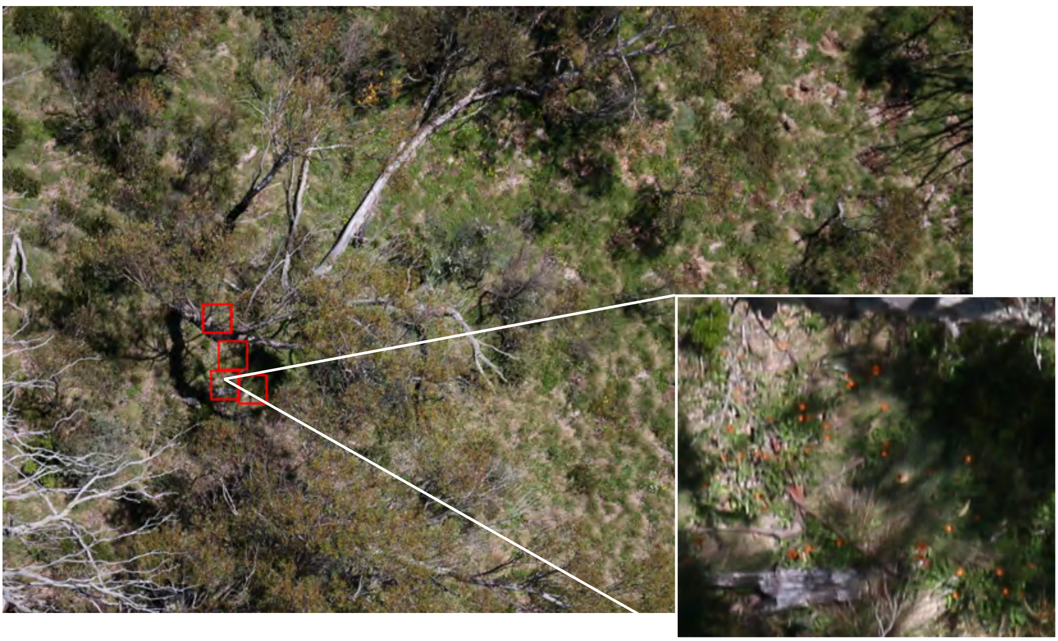

Figure 2. Example of a drone detection (through broken canopy) of orange hawkweed (*Hieracium aurantiacum*), Farm Ridge, Kosciuszko National Park. The four red boxes represent an area with one or more orange hawkweed flowers present. Total image area is approximately 17 × 11 m. Image taken from 30 m above ground.

DISCUSSION

This study outlines an example of where drone survey with automated detection (algorithm) can reliably detect a sparse weed across a large, remote landscape, and significantly contribute to delimitation in a large weed eradication program. Drones have commonly been used for detection or mapping of more abundant weeds or agricultural weeds in more controlled settings such as agriculture. In our work, drones are used to detect a rare weed in a remote and rugged landscape in a cost-effective manner.

Notwithstanding the benefits of drone survey and automated detection based on flower colour, the technology as it is applied here, is clearly limited to being useful only when flowers are present (~6–8 weeks each season). Cost comparisons made with human ground surveillance illustrate the much greater value for money from drone surveys, but mask the higher detection ability of humans (i.e. non-flowering plants are detected). Orange hawkweed flowers from mid-December to February, with a peak around late December. Optimal survey time is a period of 6 weeks and 100% detection certainty cannot be achieved via drone, as plants may not be in flower during survey. In addition, the small flower size requires high-resolution imagery for detection. This requires low altitude flights, thus compromising flight efficiency as smaller areas are covered in each flight.

To increase detection certainty and survey efficiency, NPWS is working with Macquarie University to explore use of hyper- or multi-spectral imagery, sourced from satellite or drone, to detect orange and mouse-ear hawkweed *plants*. The whole plant or plant clusters will be targeted. Being larger than the small flowers, this will allow the use of lower resolution imagery and higher elevation drone survey or satellite imagery. Analysis is under way to determine the reflectance of both hawkweed species in the non-visible spectrum relative to surrounding vegetation, and then test the effectiveness of this detection method.

Into the future, NPWS and partners will utilise drones to increase the area of surveillance to delimit the orange hawkweed infestation. A program for 2018/2019 is already being developed. Greater efficiencies including larger survey areas, more rapid detection verification and synchronisation with control programs will be explored. Drone survey using colour imagery and possibly hyperspectral imagery can contribute significantly to delimitation of hawkweed infestations and may be pivotal in more rapid delimitation, and ultimately successful eradication.

ACKNOWLEDGMENTS

The authors would like to thank Hillary Cherry for comments on the manuscript and the many staff and volunteers that dedicate their time to the NSW Hawkweed Eradication Program. The program in NSW is funded in part by the NSW Weeds Action Program, the Office of Environment and Heritage and NSW Local Land Services.

REFERENCES

Beaumont, L., Gallagher, R., Downey, P., Thuiller, W., Leishman, M. and Hughes, L. (2009). Modelling the impact of *Hieracium* spp. on protected areas in Australia under future climates. *Ecography* 32, 757-64.

Brinkley, T.R. and Bomford, M. (2002). Agricultural sleeper weeds in Australia: What is the potential threat? (Bureau of Rural Sciences, Canberra). 33 pp.

Chandler, B. (2014). Innovation vs. invasion: innovative techniques to assist the eradication of weed populations. Proceedings of the 19th Australasian Weeds Conference, ed. M. Baker, pp. 259-62. (Tasmanian Weed Society, Hobart).

Clements, D., Dugdale, T., Hunt, T., Fitch, R., Hung, C., Sukkarieh, S. and Xu, Z. (2014). Detection of alligator weed using an unmanned aerial vehicle. *Plant Protection Quarterly* 29, 84-9.

Dehaan, R.L., Weston, L.A. and Rumbachs, R. (2012). The design and the development of a hyperspectral unmanned aircraft mapping system for the detection of invasive plants. Proceedings of the 18th Australasian Weeds Conference, ed. V. Eldershaw, pp. 103-7. (Weed Society of Victoria, Melbourne).

Hamilton, M.A., Cherry, H. and Turner, P.J. (2015). Hawkweed eradication from NSW: Could this be 'the first'? *Plant Protection Quarterly* 30, 110-5.

Hung, C. and Sukkarieh, S. (2015). Using robotic aircraft and intelligent surveillance system for orange hawkweed detection. *Plant Protection Quarterly* 30, 100-Merz, T., Hrabar, S., Kendoul, F. and Jeffery, M. (2016). Unmanned helicopter system for miconia weed surveys. Proceedings of the 20th Australasian Weeds Conference, eds R. Randall, S. Lloyd and C. Borger, pp. 191-4. (Weeds Society of Western Australia, Perth).

Panetta, F.D. (2009). Weed eradication – an economic perspective. *Invasive Plant Science and Management* 2, 360-8.