Designing detection experiments: three more case studies

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Summary Detection experiments are designed to reveal which kinds of targets are likely to be detected and left undetected during environmental surveys. These experiments can help plan surveys and reliably interpret survey data. In this paper we outline the designs of three detection experiments. The first evaluates UAVs and human inspectors for detecting a simulated disease in a vineyard. The second and third experiments are two phases in the evaluation of dogs trained to detect the scent of hawkweeds. The experiments illustrate a variety of approaches, each selected to serve the management objectives, priorities, knowledge and resources available in that program at the time.

Keywords Surveys, experimental design, plant disease, weed management, detection dog, unmanned aerial vehicle (UAV), *Hieracium* species.

INTRODUCTION

Imperfect detection of invasive individuals and populations underpins all surveillance. It has implications for early detection of new incursions (Mehta *et al.* 2007), and monitoring established populations (Epanchin-Neill *et al.* 2012), through to finding every last infestation before declaring eradication (Regan *et al.* 2006).

It follows that survey designs and analyses of survey data should account for detection rate. A detection rate describes the expected frequency of detection events for a species, population or individual under a given set of survey conditions (Hauser *et al.* 2015).

Scientific experiments can be designed specifically to estimate detection rate (Bulman *et al.* 1999, Bulman 2008, Christy *et al.* 2010, Britton *et al.* 2011, Moore *et al.* 2011, Stringer *et al.* 2011). We have previously discussed the tricks and trade-offs involved in designing such a detection experiment (Hauser *et al.* 2012). In this paper we show how we have applied these principles in three more field experiments.

1. HUMANS INSPECT VINEYARDS TO DETECT SIMULATED DISEASE

The Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR), in conjunction with the Plant BioSecurity Cooperative Research Centre, are exploring the feasibility of using unmanned aerial vehicles (UAVs) to detect plant diseases. We compared the performance of UAVs and human inspectors when detecting a simulated disease in a Victorian vineyard.

Influencing variables We expected that the severity and prevalence of disease would affect detection rate.

The main environmental factor with potential to affect detection was the vineyard style: *French-style* plots contain small vines at high density, while *Australian-style* plots contain taller vines planted at lower density.

All inspectors had similar levels of experience participating in a range of biosecurity-related searches. We did not seek quantitative measures of their experience level.

UAV model (fixed wing or multi-rotor) and flight height were also expected to influence detection rate.

Site selection The experiment was conducted on a private vineyard with permission. Vineyard rows were selected across three different aspects, capturing the two different vineyard styles (French and Australian). Thirteen rows (totalling 2228 vines) were selected and marked for search.

Targets We sprayed Surround®, a compound approved for sun protection in vineyards, on individual vine leaves to simulate the appearance of a fungal disease similar to downy mildew. We wore protective clothing during the application process and used a plastic paint tray behind the selected leaves to control the number of leaves affected, by reducing splash onto other vine leaves.

Placing targets in plots Rows within the French/Australian strata were randomly assigned a prevalence of 5 or 10% vines affected. Within each 200-vine row, individual vines were selected at random for simulated disease at the assigned prevalence.

An equal number of individuals within each row were assigned a disease severity of 1, 2 or 4 leaves. These leaves were selected haphazardly across the outer and upper leaves of the vine, which would be apparent to the UAVs.

Plastic markers numbering the vines in multiples of 15 or 20 were used to help orient searchers and supervisors.

Searchers Four DEDJTR staff members with experience in biosecurity searches were recruited to individually inspect the vines.

Both fixed wing and multi-rotor UAVs with the same multispectral camera were deployed over the plots at 100 m and 50 m altitude, respectively. Unsupervised and supervised classification of the images was undertaken without prior knowledge of the location of all the 'infected' plants.

Implementing searches All participants searched all of the vine rows in the same order throughout the day. A sufficient delay was set between inspections to ensure that participants could not observe finds made by others in rows they had not yet searched.

Each participant was paired with a supervisor (sometimes another participant who had already searched that row; Figure 1). The participating searcher walked the length of each vine row at their own pace, inspecting vines for the simulated disease. When a diseased vine was detected, the searcher alerted the supervisor and reported the number of leaves that appeared diseased. The supervisor used a stopwatch to record periods of general inspection and resting/counting diseased leaves. They also recorded the vine ID number and number of diseased leaves of each vine where disease was detected.

2. DETECTION DOG SEEKING PLANTED HAWKWEEDS

Studies by Moore *et al.* (2011) and Hauser *et al.* (2012) show that human searchers have a variable capacity to detect invasive hawkweeds (*Hieracium* species) on the Bogong High Plains of Victoria. Hawkweeds can be rapidly detected while in flower, but detection can be severely hampered in the presence of other yellow-flowering species or dense vegetation, and when the hawkweed is not flowering.

The Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) have consequently investigated the capacity for a trained dog to detect the scent of hawkweeds. Initial training exercises were successful, and the agency sought to evaluate one trained dog's detection rate in typical

Figure 1. A DEDJTR staff member inspects vines for a simulated plant disease, while a supervisor times their search and records disease detections.

survey conditions. We designed a series of search trials that would allow us to build a statistical model linking time taken to detect a target hawkweed with influencing factors, such that the model could be compared with the human search models built by Moore *et al.* (2011) and Hauser *et al.* (2012).

Influencing variables We aimed to measure the effects of three target species (*Hieracium aurantiacum*, *H. praealtum* and *H. pilosella*, all of which occur on the Bogong High Plains) and abundance on detection rate.

We also anticipated that environmental factors might influence detection via the diffusion of scent from targets. We measured vegetation type around each target, wind speed and direction, temperature and humidity.

Only one handler-dog pair was recruited for the evaluation, so we were not able to test for differences or variation in detection among handlers or dogs. We anticipated that the time of day and week could influence their energy levels and detection success.

Site selection Our study used four 2 ha plots, in the same area that Hauser *et al.* (2012) tested the detectability of human searchers in 20 × 20 m plots. We decided on this markedly larger plot size to capture the full potential detection distance of a dog and allow for rapid, wide-ranging work where it was preferred by the handler.

The plot locations were selected to align with the hectare grid used by managers to plan their operations. We sought to capture variation in vegetation (classified and mapped as grass, open heath, and closed heath) within each plot, and some variation in difficulty of terrain among plots.

Targets The three hawkweed species were cultivated in pots by DEDJTR staff under permit. We aimed to test whether it was truly the hawkweed scent and not the scent of the soil or pot that might alert the dog to our targets. Therefore DEDJTR additionally cultivated other alpine plants to act as control targets in the experiment.

All targets were re-potted with the same fresh soil and clean, identical black plastic pots two days prior to trial commencement. This both controlled variation among targets, and ensured that hawkweed seeds and other plant material did not contaminate the soil. The non-hawkweed control plants were handled and potted before the hawkweeds were touched to prevent scent transfer. Numbered metal tags were pinned into the soil of each pot to uniquely identify each individual.

Placing targets in plots The study area was not known to contain hawkweeds, and so we expected to have full control over the density and distribution of hawkweed targets.

In placing the targets, we were mindful that the dog would primarily respond to the scent and not the sight of targets. Nevertheless, the dog's handler might be informed by visual cues during the search. We used two different methods of securing targets to the ground. First, we dug pot-sized holes and positioned the target plants at ground level; this produced a visually accurate result but disturbed the soil, potentially affecting the scent cue. Second, we secured outer pots above the ground using weed mat pins and nestled the potted plants inside; this approach produced more visually obvious targets above the ground but minimally disturbed the soil.

In order to obscure the visual cues provided to the handler, we placed 25 targets in each plot trial and altered their location, and the ratio of hawkweeds to control targets, in each trial. Each trial had 3, 12 or 21 hawkweeds (an equal number of *H. aurantiacum, H. praealtum* and *H. pilosella*) with the remainder of targets being randomly selected control target species. We stratified plots by their mapped vegetation, allocating an equal number of controls and hawkweeds (and, where possible, an equal number of each hawkweed species) to each vegetation type. Within a vegetation type, targets were randomly assigned GPS co-ordinate locations.

Maintaining biosecurity while handling State prohibited weeds and preventing scent contamination were high priorities throughout the trial. Potted plants were encased in Ziploc bags at all times (storage, transport, placement) to prevent soil and plant fragments escaping. All control targets were placed before the hawkweeds were retrieved from lidded boxes and directly handled to prevent hawkweed scent transfer.

Target-placing teams walked long and disparate paths around plots and between targets to avoid creating human scent trails to targets. A minimum of a half-day between target placement and search was scheduled, to allow the targets to diffuse their scent into the surrounding environment.

In the human search trial, Hauser *et al.* (2012) achieved replication by rotating a large number of searchers through a large number of plots. By contrast, this trial relied on a single dog-handler pair and only four large plots. We achieved statistical replication by reusing the same plots on multiple occasions throughout the experiment and arranging a different set of target species for each trial. Across a total of 15 trials, the dog-handler pair was exposed to 185 control targets and 190 hawkweed targets.

Searchers We evaluated one single search team, consisting of a trained dog and its handler. We secured an ethics permit in order to perform our trials and minimise the dog's exposure to harm. We relied on the dog's handler-trainer to evaluate the safety of the terrain for the dog, to allow the dog rest at any time, and to perform regular checks for bruises, cuts and ticks. As a biosecurity measure, the dog was brushed twice daily during trials to control the risk of spreading hawkweed material via dog fur.

Implementing searches Hawkweed densities were assigned to plots and plot trials were scheduled throughout the experiment so that the dog-handler pair was exposed to different hawkweed densities in different plots at different times of the day.

At the beginning of each trial, we assembled a weather station in one corner of the plot to collect temperature, humidity and wind data at 5 min intervals throughout the trial.

The speed and style of search by the dog-handler team in the alpine terrain was relatively unknown prior to the trials. We invited the dog-handler pair to search each plot using their preferred path and pace, taking rest breaks whenever they chose (Figure 2).

Two researchers followed the dog-handler pair, using a stopwatch to record time intervals of active search, non-search activities, and the tag numbers of found targets. GPS units were secured to the handler and to the dog in order to record their search paths.

3. DETECTION DOGS AND HUMAN SEARCHERS SEARCHING FOR *IN SITU* HAWKWEED INFESTATIONS

Following the detection dog trials conducted on the Bogong High Plains (see section 2), the NSW Office of Environment and Heritage (OEH) secured funding to train two different dogs to detect hawkweed (specifically *H. aurantiacum*, the most prevalent species in NSW; Cherry *et al.* 2016).

The evaluation team used the findings of the Victorian study to inform their experimental design. First, the two dogs did not have any prior training to detect other kinds of targets. By contrast, the dog trained for the Victorian evaluation had prior training to detect cats, foxes, hares and rabbits, and this was thought to

Figure 2. Hawkweed search trials: the dog and handler seek planted targets in Victoria.

have caused occasional distraction during the searches.

Second, analyses revealed some uncertainty around the dog's ability to distinguish between potted hawkweeds and potted control targets in the Victorian evaluation. To eliminate this possibility, the NSW evaluation used only naturally occurring hawkweed infestations as targets.

Third, a human search team was recruited to survey the same evaluation plots as the dog-handler teams. This maximized our capacity to directly compare the two search styles and detection rates.

Influencing variables Although many characteristics of the target could affect detection rate, we did not have control over these. We focused solely on target size in this experiment.

We anticipated that the same environmental factors could influence detection rate as in the Victorian evaluation: we noted vegetation type around each target, wind speed and direction, temperature and humidity.

With two dog-handler pairs and one human search team, we had some capacity to test for differences between teams. Again we anticipated that the time of day and week could influence the teams' energy levels and detection success.

Site selection OEH staff selected an area where *H. aurantiacum* had been found earlier in the season. These infestations were left untreated so that they could be used in this experiment.

OEH manage infestations using a 50 m × 50 m grid, and seven grids containing hawkweeds were selected as experimental plots. These plots were notably smaller than the 2 ha plots selected in Victoria. The Victorian evaluation indicated that the dog-handler team worked quickly and did not always cover the plot thoroughly, thus overlooking a number of hawkweed targets. In NSW, smaller plots provided consistency with the management scale and an opportunity for finer-scale search.

There was some variation in difficulty of terrain among the plots, due to slope as well as vegetation type. Neither was thoroughly mapped due to time constraints, although GIS vegetation and elevation layers are available for future analyses.

Targets Targets were infestations already occurring in the plots after discovery earlier in the season. Besides withholding herbicide treatment, we did not have control over target characteristics. On detection during the experiment, we estimated each infestation's length and width in cm, and counted the number of rosettes. Target size may influence detection rate, and it was also useful for matching which infestations were detected by more than one team.

Since targets were naturally occurring, we did not have control over their locations beyond strategic selection of plot boundaries. During the design phase, 12 hawkweed infestations were known to occur across the eight plots. Additional infestations were detected during the experiment, leading to a total of 27 different targets.

Searchers The dogs evaluated in NSW were trained exclusively to detect the one target species in this experiment, *H. aurantiacum*, as plant material without pots. One handler was the same handler-trainer who participated in the Victorian evaluation. The other handler had a background in weed management. We relied on the handlers to ensure the health and safety of the dogs throughout the trials.

The human search team comprised eight people; some were weed management staff and others were volunteers with prior experience in the program. They performed line searches typical of the NSW surveillance program (Figure 3).

Implementing searches We assigned teams to search plots so that different plots were visited first by different teams, in case the search path of one team interfered with the detection rate of subsequent teams. We assigned teams to plots to maintain distance between teams wherever possible, such that handlers and human searchers would have difficulty observing the finds made by other teams.

At the beginning of each day, we set up the same weather station used in the Victorian evaluation, in the vicinity of the dog's search plots. The station was within 100 m of the dog's search path at all times, and collected temperature, humidity and wind data at 5 min intervals.

As before, the handler was permitted to direct their dog through the plots using their preferred speed and path, taking rest breaks whenever they deemed appropriate (Figure 4).

One supervisor followed the human search team and two supervisors followed the dog-handler teams. They used a stopwatch to record time intervals of active search, non-search activities, and waypoints for any infestations found. GPS collars were attached to each dog to record their search path and provide live feedback via a handset; this assisted the handlers in covering each plot thoroughly. Similarly, a GPS was held by a human search team member to record the group's path.

Figure 3. Hawkweed search trials: a human team seek *in situ* infestations in New South Wales.

Figure 4. Hawkweed search trials: a dog and handler seek *in situ* infestations in New South Wales.

DISCUSSION

The three case studies here, in addition to the ones published by Moore *et al.* (2011) and Hauser *et al.* (2012), demonstrate a variety of detection experiment designs. Differences among the designs are driven by the survey structure, the influential factors being tested, and the logistics and constraints of the experiment. The vineyard disease study relied entirely on an imitation target, while various hawkweed studies have used different combinations of real rosettes in pots, naturally occurring rosettes in the ground and (in Hauser *et al.* 2012) imitation flowers. The target type has affected the relative control over hawkweed placement and the plant forms tested. They also affect the biosecurity protocols needed to ensure the experiment does not spread the target population further.

The variables expected to influence detection rate can vary markedly among search and searcher types. Vineyards provide a comfortable, linear environment to conduct human inspections. Alpine plots can be more difficult and variable to traverse due to slope and thick vegetation. In all cases, bad weather may increase the difficulty of search. A dog is also expected to be affected by terrain, and its detection rate is more likely to be affected by subtle changes in temperature, humidity and wind.

Searchers are likely to differ in their detection ability, and many searchers must be tested in order to quantify and understand this variation. Hauser *et al.* (2012) achieved this most effectively by recruiting 29 participants and having them search small plots individually. While it does not include any replication, the eight person team tested in this paper's NSW evaluation was a more accurate reflection of training and behaviour during hawkweed searches. Logistical and financial constraints have prevented more than two dogs or two UAVs from being tested at any one time.

Trade-offs must also be made in the layout of each experiment. Only Hauser *et al.* (2012) and the Victorian evaluation in this paper were able to stratify and randomise target placement across vegetation types to thoroughly test the effects of target type and background vegetation on detection rate. A common challenge across most of these studies is the abundance and placement of targets. To place many targets increases the replication in the study and therefore the strength of statistical inference. However, the populations considered typically occur at low densities and increasing their abundance in experimental conditions could falsely boost searchers' morale and detection rate. Locations without targets can seem a waste of testing time but are necessary for moderating a searcher's expectations.

Once detection data are collected, we have used them to build time-to-detection models (Moore *et al.* 2011, Hauser *et al.* 2012, Hauser *et al.* 2015). These have been an effective tool in the hawkweed program for providing feedback on and adjusting search intensity and comparing scenarios among target types, background vegetation types, and between human searchers and dogs. In the latter case we also seek additional information on the number of hours that human and dog-handler teams are fit to work each day, the costs of having them in the field and the costs of maintaining access to the searchers. We are investigating alternative methods for assessing the detection capabilities of dogs and UAVs such as distance sampling (Buckland *et al.* 2001) and cluster and classification techniques (Fielding 2007).

Novel search technologies such as trained dogs and UAVs are exciting avenues of inquiry. We must be mindful that their capacity is likely to change over time as technologies improve and methodologies are refined. Indeed, we observed marked differences in performance between the Victorian and NSW evaluations of hawkweed detection dogs.

We must also acknowledge that conducting detection experiments can be costly, and assess this against the potential benefits of this pursuit at any time. The relative costs and benefits will vary from study to study. Experiments by Hauser *et al.* (2012) and the Victorian detection dog evaluation in this paper drew on substantial financial resources and personnel, yielding large data sets and informative statistical models. The subsequent NSW evaluation was conducted on a smaller scale but made crucial adjustments that simultaneously improved the realism of the data and dramatically reduced its quantity (from 200–1000 observations in Victoria down to less than 50 in NSW). Further research is needed to understand the value of lower-cost small-scale detection experiments to environmental management.

Detection experiments are a sound, scientific tool that can assist us in planning environmental surveys and reliably interpreting survey data. The case studies discussed in this paper demonstrate that a variety of designs are possible for addressing the broad range of survey scenarios that occur in environmental management. Furthermore, different designs might be applied to different stages of a single management program, depending on the knowledge, priorities and resources available at the time.

ACKNOWLEDGMENTS

CEH was supported by the National Environmental Research Program Environmental Decisions Hub. Vineyard disease detection research is funded by the Plant Biosecurity CRC (project #2135), and we thank Michael Dhillon for permission to use his vineyard for the field trial. The detection dog research has been funded by the Victorian Department of Economic Development, Jobs, Transport and Resources and the NSW Office of Environment and Heritage. We thank Hillary Cherry and Angela Constantine for comments and discussion that improved this manuscript.

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