Predicting the dispersal of hawkweeds (*Hieracium aurantiacum* and *H. praealtum*) in the Australian Alps

Roger Cousens[1], Felix Heydel[2], Katherine Giljohann[1], Oliver Tackenberg[2], Mohsen Mesgaran[1] and Nicholas Williams[1]
[1] Department of Resource Management & Geography, The University of Melbourne, Victoria 3010, Australia
[2] Institut für Ökologie, Evolution & Diversität, Universität Frankfurt, Haus B Siesmayerstrasse 70, D-60323 Frankfurt am Main, Germany
(rcousens@unimelb.edu.au)

Summary The hawkweeds *Hieracium aurantiacum* and *H. praealtum* are the targets of an eradication campaign in Victoria and New South Wales. In previous research, a model was developed in which search efforts could be directed according to the distance and direction from previous known infestations, based on a simple empirical dispersal model, summary meteorological station data, and a map of habitat suitability. However, comparison of predictions with the most recent occurrences of *H. praealtum* at Falls Creek suggests as much as a 20–40 degree directional error, which could lead to inefficient or incorrect allocation of searching effort. We collected high-frequency three-dimensional wind data throughout the potential seeding season in 2010/11 at the assumed site of introduction of *H. praealtum*. Together with measured values of the falling velocity of achenes, plant height, a digital elevation map and a vegetation map, this was used as input into a mechanistic model to predict the trajectories of 1 744 500 individual seeds of each species. We conclude that wind strength and directions, at least during this one year, would be sufficient on several days to take seeds into the newly infested areas south-east of the presumed origin, but not those to the north. Future versions of the search allocation model based on meteorological summary data should consider incorporation of dispersal kernels with parameters dependent on wind direction.

Keywords Hawkweed, *Hieracium aurantiacum, Hieracium praealtum*, alpine, grassland, dispersal model, invasive species, terminal velocity.

INTRODUCTION

Detection of new plants is crucial to the success of any eradication campaign for an invasive species. However, the potential area in which these may occur is often extensive, leading to considerable logistical difficulties for on-ground searchers. Added to this, there is no guarantee that plants will be found, even if an area in which they occur is searched thoroughly. Where in the landscape should search teams target their efforts, and how much time should be spent in different areas within it, to maximise the success of an eradication campaign (Hauser and McCarthy 2009)?

Five species of hawkweed have been recorded in Australia, all being aliens from Eurasia. *Hieracium aurantiacum* and *H. praealtum* have been targets for eradication in Victoria since 2000. *H. pilosella* was discovered in Victoria in January 2012 (it has been recorded twice before in Australia and eradicated from a site in Tasmania – Williams and Holland 2007) and is now also the subject of intensive local searches. Every year, employees of land managers, contractors and volunteers spend hundreds of person-hours searching for hawkweed plants, revisiting all known sites and re-treating with herbicides where necessary. They also scout for new infestations or those that may previously have been missed. Since 2007, researchers have been helping to guide the efforts of searchers by making predictions based on potential dispersal and vegetation type. Williams *et al.* (2008) derived recommended search areas for *H. aurantiacum* from maps of suitable vegetation (using expert opinion), proportions of days in which wind blows from each compass direction (based on long term data from the nearest Bureau of Meteorology station), a simple exponential relationship between seed deposition density and distance from source, and rules governing whether seeds were likely to be released (based on time of day and rainfall). The model has now been applied to *H. praealtum* and *H. aurantiacum* at sites in Victoria and to *H. aurantiacum* in New South Wales (Cousens and Williams 2010) and is used by state government agencies in Victoria as part of their operational planning. Hauser and McCarthy (2009) have extended this model to include detection probability in determining optimal surveillance allocation.

Comparison of model predictions with the most recently discovered occurrences of *H. praealtum* at Falls Creek, however, suggests as much as a 20–40 degree directional error, which could lead to inefficient or incorrect allocation of searching effort. Possible reasons for this error are that: wind was not the primary dispersal vector to these locations; dispersal was not (directly) from the assumed source site; long-distance dispersal is often attributed to rare events (e.g. Bullock and Clarke 2000) and thus would not necessarily be correlated with long-term average weather data (especially if based on daily averages), that seed release is biased against specific wind directions or that the topography significantly affects the wind flow and long distance dispersal (Horn *et al*. 2012). A further source of error is that the dispersal distance frequency distribution in the model may not be appropriate. In this study, we used a mechanistic dispersal model, combined with high-frequency local air flow measurements in 2010/11, to predict where *H. praealtum* seeds would travel if released from the putative original infestation in the year of data collection.

MATERIALS AND METHODS

A three-dimensional ultrasonic anemometer (Young model 81000) was placed at 0.8 m height amongst open heathland at the assumed site of origin near Falls Creek in the Bogong High Plains, Victoria (Fig. 1). Horizontal (two directions at 90 degrees) and vertical wind velocities were collected at a frequency of 10 Hz from 17 November 2010 to 14 March 2011 (to include the likely flowering periods of the species). Data were processed to derive compass direction and wind speed in that direction. We obtained a 10 m digital elevation model and vegetation maps with a cell size of 10 m, based on data from the Victorian Department of Sustainability and Environment.

Wind dispersal was simulated using PAPPUS, a mechanistic wind dispersal model which simulates flight trajectories of individual seeds (Tackenberg 2003). PAPPUS uses measured wind data and two plant traits: seed release height and terminal velocity of the seeds. In the simulations, the flight of a seed is partitioned into time periods of 0.1 s, and its movement is calculated separately for each period as the sum of the observed wind vector (horizontal wind speed, direction and vertical wind speed) and terminal velocity. PAPPUS thus incorporates turbulence and convective up-drafts from high-frequency measurements of the wind vector during the period the simulations refer to. Terminal velocity of 30 replicate achene/pappus units was measured using the method of Askew (1997). Values of the terminal velocity used in the simulation runs were randomly adjusted in order to exhibit a variation of 30% around the respective mean value; release height was assumed to be a constant 16 cm for *H. aurantiacum* and 37 cm for *H. praealtum*.

For both species, seed dispersal by wind was modeled using the ultrasonic data. Five hundred starting times were randomly selected within each hour, generating a total of 1.7 million simulated dispersal distances.

Final primary dispersal coordinates were plotted on a map of the site using ArcGIS 10 (ESRI). Frequency distributions of dispersal distance were compiled for each day; Weibull, inverse normal and several other models were fitted to these using SAS *proc severity*.

RESULTS

Measured terminal velocities were 0.47 (sd ± 0.22) ms^{-1} for *H. praealtum* and 0.77 (± 0.41) ms^{-1} for *H. aurantiacum*. Predicted *H. praealtum* dispersal 'plumes' using the 2010/11 site-specific ultrasonic wind data were more easterly than predicted by the Williams *et al*. (2008) model based on long term weather data. Mean predicted dispersal distance was 2.57 m, with a maximum of over one km. All long-distance dispersal events except one were between 126 and 149 degrees, broadly in the direction of most of the discovered 'satellite' outbreaks of the species. Only 58 of the 1.75 million propagules were predicted to travel completely across the lake – a local dispersal barrier – before reaching the ground. These events were spread over 20 days characterised by strong horizontal wind speeds. The best fit to the frequency distributions was the Burr; the inverse normal distribute was one of the poorest.

A few *H. praealtum* plants have been discovered to the north-west of the original infestation. However, using this mechanistic model and the one year of weather data, no seeds would have dispersed to those locations as a result of wind.

DISCUSSION

Although based on high frequency weather data, a mechanistic dispersal model and an impressive number of simulations, our results are merely predictions. They are best guesses based on a single year of data. However, they strongly suggest that the satellite populations 1–2 km south-east from Falls Creek village could have been established as a result of wind dispersal from the original infestation. They also suggest that the populations to the north-west are less likely to have resulted from wind dispersal and may well have been initiated by machinery (the site area is a ski resort) or on human footwear (it is also popular for summer hiking).

It is tempting to suggest that the Williams *et al.* (2008) model should be modified somehow to ensure a more realistic (south-easterly) dispersal of propagules, as predicted by the mechanistic model. But any such change would need to allow the model

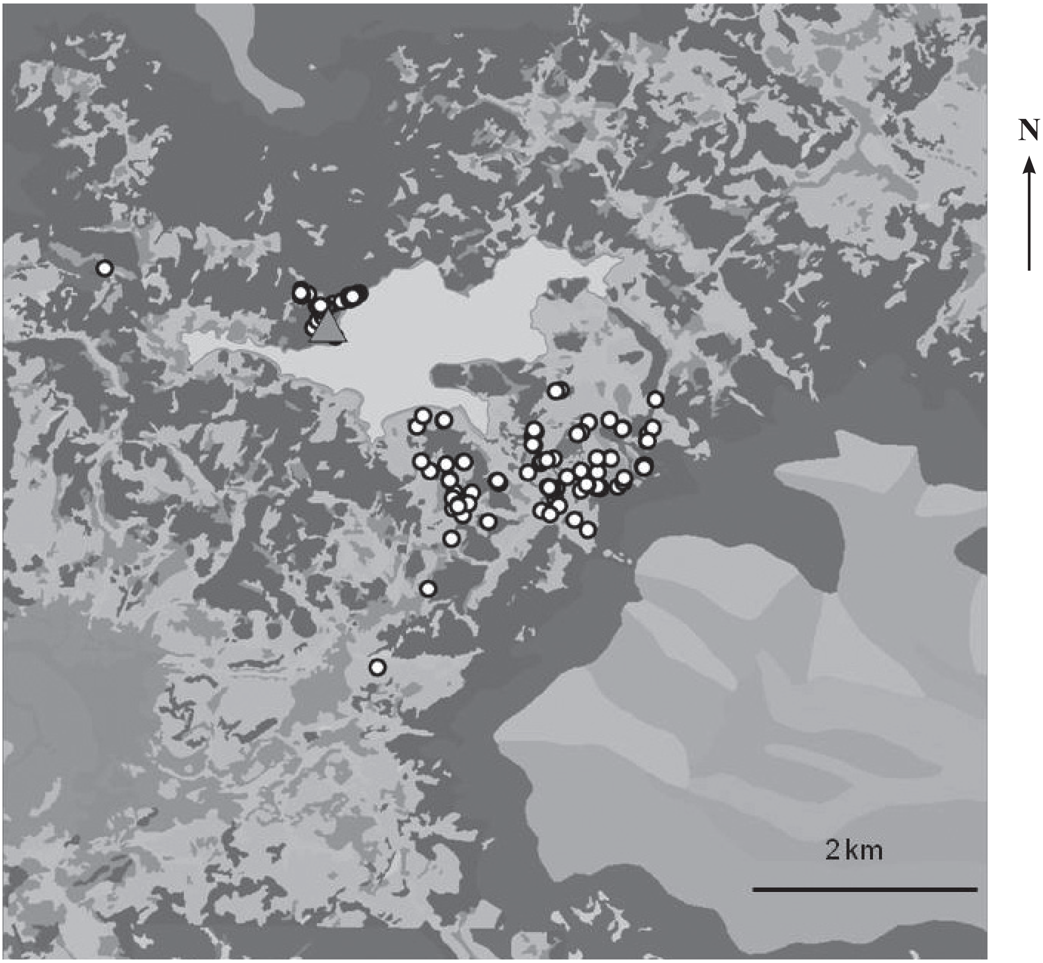

Figure 1. Map of part of the Bogong High Plains showing all known occurrences of *Hieracium aurantiacum* (circles) and the location of the sonic anemometer (triangle). Vegetation types are indicated by grayscale shading; light grey area to the south and east of the anemometer is a lake.

to be transferable to other sites. We cannot use the 2010/11 ultrasonic data from this one microsite in a more generic model; that could lead to considerable prediction errors at other sites. Horn *et al.* (2012) recently presented a mechanistic wind dispersal model that can be parameterised with publically available meteorological data. Long-term dispersal events, in any case, may occur in particular directions only in particular years. Our better prediction using ultrasonic data may have been purely fortuitous; we chanced upon a year in which there were strong wind events in that direction. In order to decide how to improve the Williams *et al*. model, we need to better understand the causes of the difference in correspondence between the predicted dispersal plume and the prevailing wind direction. Is this due to local topography, requiring a detailed topological-meteorological model? There is actually quite a good correspondence between average one-year ultrasonic (at our microsite) and long-term (at the Bureau of Meteorology Falls Creek village site) wind directions. The Williams *et al.* model assumes that dispersal occurs most often in the most frequent wind directions and that dispersal distance is the same in all directions; no account is made of wind strength. The predicted long-distance events in our study are not in the same direction as the most frequent winds. A possible development of the Williams *et al.* model is therefore to weight the parameters of the dispersal frequency distribution according to wind strength (mean or maximum in each cardinal direction) using long term weather data.

Our analysis of the frequency distributions of predicted dispersal distance suggest that the exponential model used by Williams *et al*. (2008) for seed rain density vs distance from source may not be appropriate. Further analyses are required to determine a more appropriate distribution and its parameter values.

ACKNOWLEDGMENTS

This project was funded by an Australian Research Council Linkage grant, Parks Victoria, Department of Primary Industries (Victoria) and Department of Environment and Climate Change NSW. The research project 'Streamlining search and destroy', led by Cindy Hauser, has been an outstanding partnership with many of the staff in the hawkweed eradication program and we thank all those involved. OT was supported by the DFG (Ta 311/3) and acknowledges support through the LOEWE funding program of Hesse's Ministry of Higher Education, Research, and the Arts.

REFERENCES

Askew, A., Corker, D., Hodkinson, D. and Thompson, K. (1997). A new apparatus to measure the rate of fall of seeds. *Functional Ecology* 11, 121-5.

Bullock, J.M. and Clarke, R.T. (2000). Long distance seed dispersal by wind: Measuring and modelling the tail of the curve. *Oecologia* 124, 506-21.

Cousens, R. and Williams, N. (2010). Improved detection and eradication of *Hieracium*: experiments and second generation dispersal models. Report to the Australian Weeds Research Centre.

Cousens, R., Dytham, C. and Law, R. (2008). Dispersal in Plants: A Population Perspective. (Oxford University Press, Oxford, UK).

Hauser, C.E. and McCarthy, M.A. (2009). Streamlining 'search and destroy': cost-effective surveillance for invasive species management. *Ecology Letters* 12, 683-92.

Horn, S., Raabe, A., Will, H. and Tackenberg O. (2012). TurbSeed – A model for wind dispersal of seeds in turbulent currents based on publicly available climate data. *Ecological Modelling* (in press).

Nathan, R., Katul, G.G., Horn, H.S., Thomas, S.M., Oren, R., Avissar, R., Pacala, S.W. and Levin, S.A. (2002). Mechanisms of long-distance dispersal of seeds by wind. *Nature* 418, 409-13.

Tackenberg, O. (2003). Modeling long-distance dispersal of plant diaspores by wind. *Ecological Monographs* 73, 173-89.

Williams, N.S.G. and Holland, K.D. (2007).The ecology and invasion history of hawkweeds (Hieracium species) in Australia. *Plant Protection Quarterly* 22, 76-80.

Williams, N.S.G., Hahs, A.K. and Morgan, J.W. (2008). A dispersal-constrained habitat suitability model for predicting invasion of alpine vegetation. *Ecological Applications* 18, 347-59.