Management of invasive *Poa annua* in the sub-Antarctic wilderness of Macquarie Island

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Summary *Poa annua* L. is the most widespread weed in the sub-Antarctic, present on all major island groups and on the Antarctic Peninsula. Its ability to withstand heavy grazing has enabled it to spread significantly on islands with introduced herbivores. On Australia's World Heritage Macquarie Island it is common and widespread. With the recent eradication of rabbits and associated change to vegetation dynamics it is critical to understand the distribution and abundance of *P. annua* in this rapidly changing environment.

Our study aimed to investigate management techniques for *P. annua* to assist in the development of non-native plant management in the sub-Antarctic and Antarctic. Experiments were designed to study the response of *P. annua* and native species to physical disturbance and herbicide application. Our preliminary studies indicated that physical disturbance promotes the growth of *P. annua* over native species, and glyphosate, rimsulfuron and trifloxysulfuron selectively control *P. annua* under simulated sub-Antarctic temperatures while amitrole, clethodim, dithiopyr, ethofumesate, flupropanate-sodium, imazamox, simazine and methabenzthiazuron are less effective. These results provide promising avenues for further research that will contribute to the development of control programs in the sub-Antarctic and Antarctic region.

Keywords Alien, herbicide, weed management.

INTRODUCTION

***Poa annua* in the sub-Antarctic** The sub-Antarctic islands are of considerable biological and conservation value, yet are threatened by non-native species (Chown *et al.* 1998). At least 108 non-native vascular plant species are established in the sub-Antarctic region (Shaw *et al.* 2010). *Poa annua* (wintergrass) is the most widespread, found on all major islands and the Antarctic Peninsula (Convey *et al.* 2006, Chwedorzewska and Bednarek 2012).

Throughout the sub-Antarctic, *P. annua* is the most common primary coloniser, establishing in the disturbed ground around seals (Haussmann *et al.* 2013a), penguin rookeries, glacial moraines (Walton 1975) and areas of human activity (Scott and Kirkpatrick 1994). It is tolerant of heavy grazing, allowing it to spread significantly on islands with introduced herbivores (Walton 1975).

Poa annua is present on both of Australia's World Heritage sub-Antarctic islands, Macquarie and Heard (Du Puy *et al.* 1993). It is a relatively recent arrival to Heard Island, having a restricted distribution is the only non-native vascular plant (Scott 1989) so the feasibility of its removal is under assessment. Macquarie Island is a Nature Reserve managed by Tasmanian Parks and Wildlife, a Biosphere Reserve and listed as World Heritage for its unique geology and outstanding natural values. Three non-native vascular plant species have established on the island: *P. annua*, *Cerastium fontanum* and *Stellaria media* (Copson and Whinam 2001). *P. annua* is the most common and widespread, particularly around the coast where it is maintained by seasonal wildlife disturbance (Copson 1984, Scott and Kirkpatrick 2008). The plant's high tolerance of grazing has enabled it to increase its distribution on Macquarie Island in response to rabbit grazing and the associated reduction in native vegetation (Bergstrom *et al.* 2009, Scott and Kirkpatrick 2013, Whinam *et al.* 2014). However the recent eradication of rabbits on the island has resulted in another change to vegetation dynamics (Shaw *et al.* 2011) and now more than ever it is critical to understand the distribution and abundance of *P. annua* in this rapidly changing environment.

Control of *Poa annua* *Poa annua* is found in many habitats, however it is considered a serious problem in temperate turfgrass (Warwick *et al.* 1980). This is where most of the research into its control has been undertaken, with very little in cold climates and none in the sub-Antarctic. Prior to the use of herbicides, physical control methods such as the application of boiling water, salt and surface tillage were considered effective in controlling *P. annua*, however these are no longer used as more effective control methods are available (Beard *et al.* 1978). Solar sterilization, biological controls and cultural practices such as varying nitrogen levels, soil moisture, aeration and mowing practices have all shown some level of control (Beard *et al.* 1978, Johnson 1994, Peachey *et al.* 2001). Numerous herbicides have been trialled in turf situations, with some successfully controlling *P. annua*, but many show a lack of selectivity (Beard *et al.* 1978). Furthermore, these tests have not occurred in cold climate soils where herbicide degradation, efficacy and leaching may differ (Benoit *et al.* 2007).

Given the threats that non-native vascular plants pose in the sub-Antarctic and Antarctic regions, it is essential that we understand the optimum methods for their control under cold climate conditions and how these control methods impact on these environments. Physical management methods may present fewer off-target environmental risks while herbicides can provide low-impact, cost-effective control. Little, however, is understood about the effectiveness of different management methods on the Macquarie Island ecotype of *P. annua* (a number of annual and perennial biotypes exist). Our study aims to investigate *P. annua* management techniques to broaden understanding of invasion biology and assist in development of non-native plant management in the sub-Antarctic and Antarctic.

MATERIALS AND METHODS

Study site Macquarie Island is located in the Southern Ocean at 54°30' S, 158°57' E, approximately 1500 km southeast of Tasmania (Copson and Whinam 2001). The climate is cool, wet and windy. The mean annual temperature ranges between 4°C and 6°C (Scott and Kirkpatrick 2013) and mean annual precipitation is around 960 mm (Pendlebury and Barnes-Kleoghan 2007). The island is 35 km long, 5.5 km wide and comprised of an elongated, undulating plateau reaching a maximum elevation of 433 m. It is relatively recent in origin, forming from an emergent portion of the Macquarie Ridge Complex 600–700,000 years ago (Selkirk *et al.* 1990). The flora of Macquarie Island is relatively species poor, with only 42 indigenous vascular plant species comprising small grasses, herbs, cushion plants, ferns, mega herbs and tussock grasses (Selkirk *et al*. 1990). Three non-indigenous vascular plants are present, *Cerastium fontanum* Baumg., *P. annua* and *Stellaria media* (L.) Hill. (Copson and Whinam 2001). Small populations of *Anthroxanthum odoratum* and *Rumex crispus* had established on Macquarie Island but have been eradicated (Copson and Leaman 1981, Copson and Whinam 2001)

Physical disturbance trials Field trials were initiated in the summers of 2012/13 and 2013/14 with repeat survey in 2013/14 to investigate mechanisms for *P. annua* control. Physical disturbance trials were implemented at three low (<50 m asl), three mid (50–150 m asl) and three high altitude (>150 m asl) sites. *P. annua* cover differed at each altitude. Low altitude sites had >90% cover, mid altitude sites had 20–40% cover and at high altitude sites cover was <5%. Over the two seasons, physical disturbance trials were conducted at each of these sites. Prior to treatments being imposed a vegetation survey was carried out in each plot recording the species present, percentage cover of each species and three maximum heights of each species. The four sites established in the summer of 2012/13 consisted of four replicates of four treatments: control (no disturbance), trim (removing all biomass >2 cm tall), scalping (removing all biomass, roots and soil to a depth of 5 cm) and chopping/mulching (hoeing leaving biomass in situ). An additional five sites established in 2013/14 included a hand pulling treatment (removing shoots and roots of *P. annua* plants). All treatments were applied to a 1 m × 1 m plot. Plots established in the summer of 2012/13 were re-surveyed at the beginning and end of the 2013/14 summer (12 and 15 months after treatment) and those established in the summer of 2013/14 surveyed again at the end of the season (3 months after treatment). It is planned that all plots will again be surveyed in the summer of 2014/15 (12 and 24 months after treatment).

Herbicide efficacy Herbicide efficacy was trialled on *P. annua* and three native grass species (*Poa foliosa* (Hook.f.) Hook.f., *Festuca contracta* Kirk, *Agrsotis magellanica* Lam.). Plants were collected from Macquarie Island during summer 2012/13 and potted into 90 mm diameter pots with Macquarie Island peat/sand and grown at 5°C in a cold room in Armidale, New South Wales during winter 2013. Once plants were established measurements of each plant were taken: number of tillers, maximum tiller length, plant reproductive stage and plant health. Eleven herbicides were selected with known low-moderate soil adsorption and acute mammal toxicity and were considered more suitable than other herbicides for use in the sensitive sub-Antarctic environment. The treatments (11 herbicides and 1 control) were applied to each species, with four replicates per species. Treatments were applied at the recommended rate listed on the label using a handheld spray bottle fitted with a nozzle of known application rate. Once treated, plants were left to grow at 5°C and 12 sunlight hours per day. The injury rating of plants was scored regularly following the rating system used by the European Weed Research Council (Sandral *et al.* 1997). Ten weeks after application, when no further plant deaths were occurring, final measurements were recorded, plants harvested and live shoots, dead/unhealthy shoots, roots and reproductive material dried separately and weighed. Further experiments will be carried out during winter 2014 to investigate the effects of herbicide rate and application method on *P. annua* and native grasses.

RESULTS

Physical disturbance trials This work is ongoing however preliminary observations in the summer of 2013/14 indicated that physical disturbance treatments promoted the growth of *P. annua* over native species at each altitude. The scalping treatment appeared to be the most effective management treatment as *P. annua* is much slower to recover, enabling some small herbs and bryophytes to establish in gaps, despite *P. annua* dominating the plot.

Herbicide efficacy Of the 11 herbicides trialled, glyphosate, rimsulfuron and trifloxysulfuron were effective herbicides for *P. annua* with the percentage of dry weight of shoots dead/unhealthy (yellow shoots) significantly higher than the controls. They were also selective with the percentage of dry weight of *P. annua* shoots dead/unhealthy significantly higher than those of the three native grass species (Table 1). These three herbicides all achieved total kill of *P. annua* shoots and less damage to the shoots of the three native grass species. The other herbicides: amitrole, clethodim, dithiopyr, ethofumesate, flupropONATE-sodium, imazamox, methabenzthiazuron and simazine were either ineffective or non-selective.

DISCUSSION

Our preliminary observations suggest that physical disturbance mechanisms will be insufficient to reduce *P. annua* under sub-Antarctic conditions. Rather than suppressing the growth of *P. annua*, they appear to promote its growth and spread. This is consistent with the finding that *P. annua* is promoted by physical disturbance (Walton 1975, Copson 1984, Haussmann *et al.* 2013b, Scott and Kirkpatrick 2013). *P. annua*, however, is reported to require disturbance to be maintained (Scott and Kirkpatrick 2008) and so further monitoring will determine if *P. annua* declines in the absence of disturbance over time and if the native species increase in abundance and density as a consequence.

Initial herbicide trials indicate that three herbicides, glyphosate, rimsulfuron and trifloxysulfuron selectively kill *P. annua* under sub-Antarctic temperatures, without effecting native grass species. The other herbicides trialled: amitrole, clethodim, dithiopyr, ethofumesate, flupropionate-sodium, imazamox, methabenzthiazuron and simazine were less effective for the control of *P. annua*. Ongoing work will investigate the role of different application rates (quarter, half and double recommended rate) and application methods (spray on, brush on) of glyphosate, rimsulfuron and trifloxusulfuron on *P. annua* and three native grass species. This work will contribute to improving management of non-native grasses in the sub-Antarctic and Antarctic by investigating invasive species biology, effective management techniques, and the impact of management on the sub-Antarctic environment.

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Table 1. Final dead/unhealthy shoot dry weight as % of total shoot weight ± SE following the application of herbicide treatments. PA (*Poa annua*); AM (*Agrostis magellanica*); FC (*Festuca contracta*); PF (*Poa foliosa*); Ctrl (control); Ami (amitrole); Cle (clethodim); Dit (dithiopyr); Eth (ethofumesate); Flu (flupropionate-sodium); Gly (glyphosate); Ima (imazamox); Met (methabenzthiazuron); Rim (rimsulfuron); Sim (simazine); Tri (trifloxysulfuron).

Shoot weight (%)	Herbicides											
	Ctrl	Ami	Cle	Dit	Eth	Flu	Gly	Ima	Met	Rim	Sim	Tri
PA	15.4 ± 9.77	82.3 ± 3.13	56.7 ± 20.24	2.9 ± 1.65	5.0 ± 5.55	36.5 ± 20.11	100 ± 0	12.9 ± 7.43	8.1 ± 5.63	100 ± 0	3.0 ± 0.88	100 ± 0
AM	29.3 ± 12.44	85.3 ± 7.2	75.3 ± 8.87	25.1 ± 8.04	21.6 ± 7.09	44.2 ± 16.26	70.3 ± 11.59	52.8 ± 15.30	22.9 ± 7.70	9.1 ± 15.27	48.1 ± 10.06	51.1 ± 19.5
FC	59.2 ± 8.93	80.9 ± 9.57	65.8 ± 15.35	57.3 ± 8.38	63.5 ± 7.91	52.2 ± 12.30	60.8 ± 5.30	51.7 ± 14.55	73.4 ± 8.18	58.5 ± 6.77	64.6 ± 8.28	59.6 ± 13.51
PF	31.6 ± 7.79	46.7 ± 17.03	38.6 ± 6.48	28.9 ± 9.38	25.1 ± 9.21	17.5 ± 4.19	54.3 ± 21.09	11.9 ± 2.99	31.6 ± 19.35	52.9 ± 21.68	34.1 ± 14.72	21.7 ± 6.33

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