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Abstract: In January 2010 a random survey was conducted to determine the frequency of herbicide resistance in populations of Lolium spp. (ryegrass), Avena spp. (wild oat), Bromus diandrus Roth. (brome grass) and Hordeum lepinorum Link (barley grass) across the cropping region of Tasmania, Australia. A total of 84 paddocks were surveyed with 80 containing the aforementioned weed species, resulting in the collection of 76 ryegrass, 16 wild oat, seven brome grass and five barley grass samples. These samples were then screened against the most commonly utilised herbicide groups for annual grass control in Australia. Ryegrass resistance frequencies were highest to aryloxyphenoxypropionate (18%) and sulfonylurea (24%) herbicides with lower incidences of resistance to cyclohexanedione (1%), imidazolinone (7%) and dinitroaniline (1%) herbicides. Sixty four percent of ryegrass samples tested against five herbicide groups (aryloxyphenoxypropionate, cyclohexanedione, sulfonylurea, triazine and dinitroaniline) were susceptible to all herbicides, 27% were resistant to one herbicide only, 7% to two herbicide groups and one sample was resistant to three herbicide groups. In the other species collected, resistance was found only to aryloxyphenoxypropionate herbicides with two wild oat and one barley grass sample exhibiting resistance to herbicides in this group. The frequency of resistance observed in screened populations in this survey is much lower than that found in recent surveys of southern Australian cropping regions. A lower frequency of observed herbicide resistance in Tasmania, combined with our ability to use the knowledge gained from 20 years of herbicide resistance management, should result in a predictably slower spread of herbicide resistant grass weeds than experienced in many other regions of Australia.

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Herbicide resistance frequencies in ryegrass (*Lolium* spp.) and other grass species in Tasmania

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Summary

In January 2010 a random survey was conducted to determine the frequency of herbicide resistance in populations of *Lolium* spp. (ryegrass), *Avena* spp. (wild oat), *Bromus diandrus* Roth. (brome grass) and *Hordeum lepinorum* Link (barley grass) across the cropping region of Tasmania, Australia. A total of 84 paddocks were surveyed with 80 containing the aforementioned weed species, resulting in the collection of 76 ryegrass, 16 wild oat, seven brome grass and five barley grass samples. These samples were then screened against the most commonly utilised herbicide groups for annual grass control in Australia. Ryegrass resistance frequencies were highest to aryloxyphenoxypropionate (18%) and sulfonylurea (24%) herbicides with lower incidences of resistance to cyclohexanedione (1%), imidazolinone (7%) and dinitroaniline (1%) herbicides. Sixty four percent of ryegrass samples tested against five herbicide groups (aryloxyphenoxypropionate, cyclohexanedione, sulfonylurea, triazine and dinitroaniline) were susceptible to all herbicides, 27% were resistant to one herbicide only, 7% to two herbicide groups and one sample was resistant to three herbicide groups. In the other species collected, resistance was found only to

aryloxyphenoxypropionate herbicides with two wild oat and one barley grass sample exhibiting resistance to herbicides in this group. The frequency of resistance observed in screened populations in this survey is much lower than that found in recent surveys of southern Australian cropping regions. A lower frequency of observed herbicide resistance in Tasmania, combined with our ability to use the knowledge gained from 20 years of herbicide resistance management, should result in a predictably slower spread of herbicide resistant grass weeds than experienced in many other regions of Australia.

Introduction

Herbicide resistance is a major problem in the southern Australian cropping region, with annual ryegrass (*Lolium rigidum* Gaud.) the most common herbicide resistant weed species. Across this region annual ryegrass is present in high numbers as a result of its adaptability to the southern climate, extensive use as a pasture species and high seed production (Gill 1996). Other ryegrass species such as perennial (*Lolium perenne* L.) and Italian (*Lolium multiflorum* Lam.) ryegrass are also observed across this region (Wheeler *et al.* 2002). They are all highly genetically variable cross-pollinating species that can potentially develop herbicide resistant biotypes (Heap 2011). While less prevalent, resistance has also been recorded in other grass species including wild oats (*Avena fatua* L. and *A. ludoviciana* Durieu), brome grasses (*Bromus diandrus* Roth. and *B. rigidus* Roth.) and barley grass (*Hordeum lepinorum* Link) (Heap 2011).

Ryegrass and other grass species are commonly controlled by a number of different herbicides, many of which are used in both the cropping and pasture phases of a rotation. Since the release of the first aryloxyphenoxypropionate acetyl coA carboxylase-inhibiting (ACCase) herbicide (diclofop-methyl) in 1978 and sulfonylurea acetolactate synthase-inhibiting (ALS) herbicide (chlorsulfuron) in 1982, these and other herbicides within the same herbicide families have been extensively used for grass weed control. As a result of the extensive and repeated use of these herbicide groups for grass control, resistance to these families has been quick to develop in Australia, especially in ryegrass (Broster and Pratley 2006).

Since 2008 15 ryegrass samples have been received from Tasmania for resistance testing at Charles Sturt University's herbicide resistance testing service. Of these samples all were resistant to both aryloxyphenoxypropionate and sulfonylurea herbicides, 33% were resistant to cyclohexanedione herbicides and 7% to triazine and dinitroaniline herbicides (J. Broster unpub. data). These results are similar to those observed in samples from other states in Australia (New South Wales, Victoria, South Australia and Western Australia) despite the sample numbers from Tasmania being significantly less than those from the other states (Broster and Pratley 2006).

Random surveys are an important tool for identifying the frequency of herbicide resistant weed populations across a cropping region. Information gained from random surveys can aid in the planning of herbicide resistance research and extension for specific regions, as the information needs for growers experiencing resistance are different than those who do not yet have resistance (Llewellyn and Powles 2001).

While many surveys have been undertaken across mainland Australia over the past 20 years (Pratley *et al.* 1993, Llewellyn and Powles 2001, Owen *et al.* 2007, Broster *et al.* 2011b), the cropping area of Tasmania has not yet been surveyed for resistance in associated weeds. Compared to the rest of Australia, Tasmania has only a small area of land used for cropping, specifically 100 000 hectares of Australia's 33.4 million hectares. In 2009-2010, approximately 20 000 hectares of cereals were grown in Tasmania compared to more than 6 million hectares in both New South Wales and Western Australia (Australian Bureau of Statistics 2011a).

Interestingly, Tasmania differs from mainland Australia in the range of crops grown in rotation with cereals. Alkaloid poppies (*Papaver somniferum* L.) (approx. 20 000 ha) and pyrethrum (*Tanacetum cinerariifolium* (Trev.) Schultz Bip.) (approx. 2 000 ha) are grown only in Tasmania, while approximately 15 000 hectares of vegetables are also produced (Department of Primary Industries Water and Environment 2003, Australian Bureau of Statistics 2011a).

Selection pressure for the development of herbicide resistance is related to several events, including the number of repeated applications of a specific herbicide group. With greater variation in crops grown in Tasmania as compared to mainland Australia, there are notable differences in both the herbicides used and the frequency with which the different herbicides are applied. For these reasons it was important to survey Tasmanian cropping regions to determine the frequency of resistance to the commonly used herbicide groups, and to compare resistance frequencies to that found in surveys on mainland Australia.

This paper reports the findings of a random survey conducted in Tasmania in 2010 to determine the extent and distribution of resistance in grass weed populations to commonly used herbicides.

Materials and methods

Sample collection

Cropping paddocks in Tasmania were surveyed in January 2010, prior to the commencement of harvest. Paddocks were randomly selected at ten kilometre intervals, alternating left and right hand side of the road where possible. The location of all sites was recorded using a global positioning system unit (Figure 1).

The paddocks were surveyed by two people walking in an inverted 'V', approximately 150 metres into the paddock for a ten to fifteen minute period. Mature seed heads were collected from plants along the sampling path. After collection the samples obtained by the two people were bulked to obtain a single sample for each species in each paddock. In total, 84 paddocks were surveyed of which 76 contained ryegrass (annual, perennial or Italian), 16 wild oat, seven brome grass and five barley grass plants in sufficient quantities to allow for resistance screening. Comprehensive taxonomic studies for species identification were not undertaken for the ryegrass samples in this survey as the three species expected hybridise easily showing a continuum of variation (Wheeler *et al.* 2002) and all have developed herbicide resistance (Heap 2011). Immediately after collection the seed samples were stored in a glasshouse until March 2010 when they were threshed and cleaned.

Resistance screening

The resistance screening took place between June 2010 and September 2011. For each of the 76 ryegrass samples 0.2 g of seed was planted in plastic punnet trays (330 mm x 280 mm x 60 mm). Each tray contained 14 different samples sown in rows 25 mm apart and 5 mm deep and then covered. The trays were filled with either a 50:50 peat:sand mix or a soil mix (50:50 loam:river wash sand) depending upon the herbicide to be applied. Two weeks after sowing all samples screened to post-emergent herbicides were counted and thinned to a maximum of 20 plants per sample.

The wild oats, brome grass and barley grass samples were sown in May to June 2011. Approximately 20-30 caryopses from each of the samples were planted in plastic trays (150 mm x 100 mm x 60 mm). The trays were filled with either a 50:50 peat:sand mix or a soil mix (50:50 loam:river wash sand) depending upon the herbicide to be applied.

Trays were maintained in a temperature controlled glasshouse (10^{o}C minimum, 25^{o}C maximum) without supplementary lighting and were watered and fertilised as required. Three replicates were sown for all samples except where seed numbers were limited. Two weeks after sowing samples screened to the post-emergent herbicides were counted and thinned to a maximum of 10 per tray.

Pre-emergent herbicides

Herbicides were selected as per current Australian registrations. Ryegrass samples were screened with three herbicides, chlorsulfuron (sulfonylurea), simazine (triazine) and trifluralin (dinitroaniline), the wild oats with triallate (thiocarbamate), and brome grass and barley grass with simazine. For all pre-emergent herbicide treatments, seeds were sown in the soil mix for ease of herbicide incorporation. In ryegrass with the chlorsulfuron and simazine treatments, the seeds were sown in the rows, covered with 5 mm of the soil mix, sprayed with the herbicide and the herbicide watered in. For the trifluralin treatment, the trays were sprayed, raked lightly to incorporate the herbicide, and seed was sown in rows on top of the herbicide and covered with 5 mm of soil. For the wild oats, brome grass, and barley grass samples, the triallate and simazine treatments were sprayed then lightly raked to incorporate the herbicide, and seeds sown and the trays raked again for final incorporation.

Post-emergent herbicides

Herbicides were selected as per current Australian registrations. Ryegrass samples were screened with diclofop-methyl (aryloxyphenoxypropionate), clethodim (cyclohexanedione), imazamox/imazapyr (imidazolinone), and glyphosate (glycine). Wild oat samples were screened with diclofop-methyl, clethodim, mesosulfuron (sulfonylurea), glyphosate and flamprop (arylaminopropionic acid) while the brome grass and barley grass samples were screened with haloxyfop (aryloxyphenoxypropionate), clethodim, mesosulfuron, paraquat+diquat (bipyridyl) and glyphosate (Table 1).

All herbicides were applied when the plants were at growth stage Z12-13 except for the flamprop which was applied at Z13-22 (Zadoks *et al.* 1974). Samples were sown in the peat:sand mix for all herbicides except for imazamox/imazapyr and mesosulfuron, as many ALS herbicides have soil activity. All herbicides in this group were sown in the soil mix whether applied post-emergent or pre-emergent.

Ryegrass seedlings which survived the diclofop-methyl application were sprayed with sethoxydim one week after the surviving plants were trimmed to two centimetres in height. Plants cannot generally metabolise sethoxydim (Tardif and Powles 1994), therefore observed resistance to sethoxydim is assumed at the target site. Seedlings which survived the glyphosate application were then sprayed at twice the rate of the first screening to confirm observed resistance.

The herbicide resistance testing protocol utilised was adopted from Broster and Pratley (2006), although for this experiment herbicides were only applied at the label recommended rate (Table 1). All herbicides were applied using an automated laboratory-sized cabinet sprayer with a moving boom applying a water volume of 77 L ha^{-1} equivalent from a flat fan nozzle at 300 kPa pressure. Adjuvants were added to herbicides as per label requirements (Table 1).

(Insert Table 1 here)

A standard susceptible biotype and a known resistant biotype, where available, were included with each cohort of samples. Due to limited seed availability for some samples not all of the samples were screened with all herbicides.

Herbicide evaluation

All samples were assessed between 21 and 28 days after treatment. Seedlings in post-emergent treatments were counted before and after treatment to enable survival percentages to be calculated. Samples sprayed pre-emergent were rated visually from 0 (no germination) to 10 (no visual difference from susceptible control). Results were analysed by ANOVA using GenStat version 11.1 (GenStat 2008) and the standard error for each herbicide determined.

Samples were classified as resistant if the mean survival percentage for all replicates was greater than 20% for post-emergent herbicides or if a visual score of greater than 2.5 was observed for pre-emergent herbicides or a visual score higher than that of the susceptible control by twice the standard error (S.E.) (whichever was the greater) (Broster and Pratley 2006). Samples with survival percentages of between 10 and 19% for post-emergent herbicides or a visual score of between 1.5 and 2.5 for pre-emergent herbicides or a visual score higher than that of the susceptible control by the standard error (whichever was the greater) were classed as developing resistance. Samples were classed as susceptible if survival was less than 10% or a visual score of below 1.5 or a visual score less than the standard error higher than that of the susceptible control (whichever was greater).

The samples were categorised into respective regions of origin using the Natural Resource Management (NRM) regions (Australian Government Land and Coasts 2011) and the Australian Bureau of Statistics Local Government Areas (LGA) (Australian Bureau of Statistics 2011b). Results were compared both with other regions of Australia and between regions in the surveyed area.

Results

Ryegrass

Illustrating the diversity of crops grown in Tasmania, the 76 samples were collected from 11 different crop types. The vast majority came from wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.) or oats (*Avena sativa* L.) crops, with 32, 19 and 12 paddocks surveyed respectively. Four samples were collected from alkaloid poppy (*Papaver somniferum* L.) crops, two from triticale (x *Triticsecale*) and forage rape (*Brassica napus* L.) crops and one each from paddocks containing potatoes (*Solanum tuberosum* L.) , onions (*Allium cepa* L.) , pyrethrum (*Tanacetum cinerariifolium* (Trev.) Schultz Bip.), forest trees (*Pinus* spp.) and a hay (*Lolium* spp.) crop.

Of the ryegrass samples evaluated for resistance to diclofop-methyl, 18% (14 samples) were classed as resistant or developing resistance. When tested with sethoxydim, all of the diclofop-methyl resistant populations were resistant, indicating that all of these populations had target site resistance (Table 2).

Twenty four percent of samples were classed as resistant or developing resistance to the herbicide chlorsulfuron and seven percent to the herbicide imazamox/imazapyr (Table 2). For both clethodim and trifluralin, one sample was classed as developing resistance, while no samples resistant to simazine or glyphosate were detected (Table 2).

(Insert Table 2 here)

The Northern Midlands LGA had a higher proportion of ryegrass samples resistant to diclofop (35%) than the Southern Midland LGA (13%) and the north-west region of the survey (Burnie, Central Coast, Kentish, Latrobe and Waratah/Wynyard LGA) (9%) (Figure 1). While ryegrass resistance to chlorsulfuron was present in the Northern Midlands (15% of samples) it was more commonly recorded in the Southern Midlands LGA (38%) and the north-west region (36%) (Figure 1). The five samples that were evaluated as resistant or developing resistance to imazamox/imazapyr were located in five different local government areas (Break O'Day, Devonport, Kentish, Northern Midlands and Southern Midlands), one of which was susceptible to chlorsulfuron. The single sample developing resistance to clethodim was located near Devonport while the sample developing resistance to trifluralin was located in the Southern Midlands LGA near Oatlands.

Multiple resistance

Of the 76 samples, 73 were screened to all five groups of selective herbicides screened (aryloxyphenoxypropionate, cyclohexanedione, sulfonylurea, triazine and dinitroaniline). Of the 73 samples, 64% (47 samples) were susceptible to all five herbicide groups. Although no population was identified as having developed multiple resistance to all the four or five groups, one sample was resistant to three groups, five samples (7%) to two and the remaining 20 samples (27%) to only one herbicide group (Figure 2). All samples resistant to two herbicide groups were resistant to aryloxyphenoxypropionate and sulfonylurea herbicides with the sample resistant to three groups also resistant to cyclohexanedione herbicides. Of the three samples not tested with the five herbicide groups, one was tested over four groups (excepting dinitroaniline) and was susceptible to all, another with four groups (excepting sulfonylurea) and was susceptible to all, while the other was tested only with aryloxyphenoxypropionate and cyclohexanedione herbicides and was resistant to diclofop (aryloxyphenoxypropionate). For the ALS inhibiting herbicides, three samples were tested to imazamox/imazapyr but not chlorsulfuron, and all three were evaluated as susceptible to imazamox/imazapyr.

(Insert Figure 1 here)

(Insert Figure 2 here)

Herbicide resistance was found in samples obtained from four of the eleven crop types sampled. Barley paddocks had the highest incidence of resistance with half of these paddocks having ryegrass resistant to one or more groups compared to wheat with 42% of paddocks and oats with 25%. While barley and wheat were the only crops containing ryegrass with resistance to two herbicide groups, the single sample from a pyrethrum crop was the only sample resistant to three herbicide groups (Table 3).

(Insert Table 3 here)

Wild oats, brome grass and barley grass

While these species were collected from across the surveyed area (Figure 3) they were found in only three of the crops sampled. Wild oats were collected from wheat (10), barley (5) and oat (1) crops while the brome grass samples came from wheat (2) and barley (5) crops and the barley grass samples from wheat (3) and oat (2) crops.

All sixteen wild oat samples were susceptible to the herbicides clethodim, flamprop, glyphosate, mesosulfuron and triallate. Fifteen samples were screened to diclofop, with one classed as resistant and one as developing resistance. These samples were both collected in barley crops near Campbell Town in the Midlands region. Ryegrass collected from the same paddock as the resistant sample was also resistant to diclofop and developing resistance to chlorsulfuron; ryegrass from the same paddock as the wild oat sample developing resistance to diclofop was susceptible to diclofop but developing resistance to chlorsulfuron. The barley grass samples were also susceptible to all herbicides except for one sample that was classed as developing resistance to haloxyfop, with a survival percentage of 10%. Brome grass samples did not exhibit resistance to any of the herbicides screened.

(Insert Figure 3 here)

Discussion

Ryegrass

The frequency of herbicide resistance present in ryegrass in this survey was much lower than that found in any recent surveys conducted in the mainland cropping regions of southern Australia. This Tasmanian survey found 18% of ryegrass samples resistant to diclofop-methyl, compared to 81% in southern New South Wales in 2007 (Broster *et al.* 2011b), 68% in Western Australia in 2003 (Owen *et al.* 2007) and greater than 50% in several regions of South Australia and Victoria (C. Preston pers. comm.). The only cropping region of southern Australia recently surveyed with a lower frequency of resistance to diclofop-methyl is the South Australian Mallee where only six percent of populations were resistant (C. Preston pers. comm.).

The major reason for the lower incidence of herbicide resistance in Tasmania is likely due to lower cropping intensity in this state. While some localised areas of Tasmania have a history of more intense wheat and barley cropping, pastures and forage crops traditionally predominate in the majority of regions (Scott 1957, Australian Bureau of Statistics 2011a, Australian Bureau of Statistics 2012), thereby reducing the selection pressure on herbicides. In 2009-2010 only 14% of arable land (crop and improved pasture) was sown to crops in Tasmania, compared to over 59% in South Australia and 68% in Western Australia (Australian Bureau of Statistics 2011a). While the three NRM regions in Tasmania (North, North West and South) had similar levels of crop as a percentage of arable land (range 10.4 -

16.9%), five regions in other states had levels of greater than 70% (Victorian Mallee, Eyre Peninsula and Northern & Yorke Peninsula in South Australia and Northern Agricultural and Avon in Western Australia) (Australian Bureau of Statistics 2011a).

It is not surprising that the three regions in which the majority of the resistant populations were found (Northern Midlands LGA, Southern Midlands LGA and the group of north-west LGAs) had different resistance profiles (Figure 1). The ratio of cereal crops to vegetables grown in the Northern Midlands LGA is 3.5:1 compared to 20:1 in the Southern Midlands and 0.16:1 in the north-west (Australian Bureau of Statistics 2011a). Likewise the ratio of cereal crops to non-cereal broadacre crops (e.g. alkaloid poppies and pyrethrum) grown varies between the three areas, with the ratio 2.75:1 in the Northern Midlands, 1.4:1 in the Southern Midlands and 0.13:1 in the north-west (Australian Bureau of Statistics 2011b). These differences would suggest strong differences in crop rotations and herbicide usage patterns resulting in differences in selection pressure from each herbicide group in these three areas.

Although comprehensive taxonomic studies for species identification was not undertaken for each sample in this survey, it is most likely that the ryegrass present in Tasmania were different genetically to those collected in surveys on mainland Australia. Both perennial and Italian ryegrass have also been reported to exhibit herbicide resistance to Group aryloxyphenoxypropionate, sulfonylurea and glycine herbicides, and in many countries (Heap 2011). It is also possible that some of the samples in mainland surveys (Owen *et al.* 2007, Broster *et al.* 2011b) are not annual ryegrass but rather perennial or Italian, particularly in higher rainfall mixed farming regions. In addition, these *Lolium* species hybridise freely (Wheeler *et al.* 2002), so it is difficult to determine the genetic identity of ryegrass screened in this survey.

Many of the improved pastures in Tasmania contain ryegrass; perennial ryegrass (*L. perenne*) being the most widespread pasture species in the temperate region with Italian ryegrass (*L. multiflorum*) also widespread (Lane *et al.* 1999). This means that there is potential for farmers to be treating massive populations of ryegrass with herbicides at the start of the cropping phase. With higher ryegrass numbers the potential for individually resistant plants to occur within a population is greater, and resistance may develop more quickly with larger numbers existing in current cropping scenarios.

As described, there is also a greater diversity of crops grown in Tasmania compared to the mainland, with significant areas undertaking production of alkaloid poppies, pyrethrum and vegetables in rotation with cereal and pulse crops. While this variety of crops may allow for a wider range of herbicide groups to be used to control ryegrass, some of these crops may limit the use of certain herbicides as a result of long plant back requirements due to herbicide persistence. Poppy crops, for example, are susceptible to potential injury for up to five years after trifluralin application and for two years after the application of many sulfonylurea herbicides (P. Cotterill pers. comm.).

Interestingly, all ryegrass populations resistant to diclofop-methyl in this survey were also resistant to sethoxydim. As ryegrass cannot metabolise sethoxydim all populations resistant to this herbicide must have target site resistance (Tardif and Powles 1994). The finding that all diclofop-methyl resistant populations were target site resistant is in contrast to our findings in the mainland surveys where a significant proportion of the resistant populations were due to non-target site resistances. Only 43% of diclofop-methyl resistant populations were target site resistant in a recent survey of southern New South Wales (Broster *et al.* 2011b) and 61% in Western Australian (Owen *et al.* 2007).

Additionally, this survey found the frequency of resistance to the sulfonylurea herbicide, chlorsulfuron, to be higher than that found to the imidazolinone, imazamox/imazapyr (24% vs. 7%). This differed from the most recent survey in southern New South Wales (Broster *et al.* 2011b) which found that, although higher, the frequency of populations resistant to the sulfonylurea and imidazolinone herbicides tested was similar (70% vs. 65%). Although both of these herbicide families inhibit acetolactate synthase it has been suggested that these two groups bind to different areas of the target site. Therefore different mutations at this site will provide different patterns of resistance within the ALS inhibiting herbicides (Preston and Mallory-Smith 2001).

There are two possible reasons for these differences. Firstly, the different species present (*L. perenne* and *L. multiflorum*) combined with the separation from mainland ryegrass genotypes may have led to a different range of resistance mechanisms, both target site and non-target site, being present in Tasmanian ryegrass compared to populations on the mainland. Alternatively, it is entirely possible that with the reduced frequency of resistant populations found in this survey some forms of resistance (e.g. metabolic resistance to aryloxyphenoxypropionate herbicides), although potentially present, were just not observed in the samples collected.

In addition, the lack of non-target site resistance to the aryloxyphenoxypropionate herbicides could be related to the herbicide rates used by Tasmanian farmers. The use of reduced herbicide rates has been shown to select for resistance mechanisms other than target site for the aryloxyphenoxypropionate herbicides (Neve and Powles 2005). The higher value of some of the crops grown in Tasmania (poppies and pyrethrum) and the higher yields experienced for wheat and barley compared to many other areas of Australia (Australian Bureau of Statistics 2011a, Australian Bureau of Statistics 2012) may reduce the likelihood of farmers using herbicide rates well below the label recommendation. The use of higher or labelled rates would therefore encourage the development of target site resistance rather than non-target site (Renton *et al.* 2011).

Wild oats, brome grass and barley grass

Thirteen percent of wild oat samples were resistant or developing resistance to diclofop. The frequency of resistance is lower than found in recent surveys of wild oats in southern New South Wales in 2007 (Broster *et al.* 2011a) and Western Australia in 2005 (Owen and Powles 2009) that found significant levels of resistance to diclofop-methyl (38% and 71% respectively).

None of the brome grass samples were resistant to any herbicide groups evaluated. A recent survey of southern New South Wales also found no resistance in populations of brome grass (Broster *et al.* 2010), although both of these surveys screened a relatively small number of samples. However resistant brome grass populations have been reported in Australia; of the 33 brome grass populations received by the herbicide resistance testing service at Charles Sturt University over 30% were resistant to aryloxyphenoxypropionate and/or cyclohexanedione herbicides (J. Broster unpub. data)

One barley grass sample was classed as developing resistance to haloxyfop. While a survey of southern New South Wales in 2007 found none of the 13 barley grass samples to be resistant to this or other tested herbicides (Broster *et al.* 2010), it was not unexpected that a population exhibited resistance to haloxyfop. The herbicide resistance testing service at Charles Sturt University received a barley grass population in 2001 exhibiting resistance to both haloxyfop and clethodim (J. Broster unpub. data) and populations resistant to paraquat+diquat have been found in both New South Wales (J. Broster unpub. data) and Victoria (Powles 1986).

Differences in weed species were also observed between the regions. All of the brome grass and barley grass samples were collected from the Midlands (Southern and Northern) and none were observed in the north-west (Figure 3). While collecting samples, the most common non-collected species in the Midlands was wireweed (*Polygonum aviculare* L.) while in the north-west it was wild radish (*Raphanus raphanistrum* L.) (J. Broster pers. obs.). The differences in the existing weed spectrum can also result in variation in herbicide use and therefore selection pressure.

Conclusion

This survey has shown that for ryegrass the incidence of resistance in Tasmania for both aryloxyphenoxypropionate and sulfonylurea herbicides is only marginally higher than that found in a survey of southern New South Wales in 1991 (Pratley *et al.* 1993). At 13% the incidence of resistance to aryloxyphenoxypropionate herbicides for wild oats is also only slightly higher than the 1991 southern New South Wales survey (3%) (Broster *et al.* 1998) and a 1993 survey in South Australia (4%) (Nietschke *et al.* 1996), particularly when taking into account the limited number of wild oat samples collected. The most recent survey of ryegrass in southern New South Wales found 81% and 70% of populations to be resistant to aryloxyphenoxypropionate and sulfonylurea herbicides respectively (Broster *et al.* 2011b) and for wild oats aryloxyphenoxypropionate resistance to be 38% (Broster *et al.* 2011a).

Therefore, significant increases in the frequency of resistance of both ryegrass and wild oats could be expected over the next 10 to 15 years in Tasmania, if trends similar to those occurring in New South Wales and Western Australia populations occur. However, the rate of predicted increase in herbicide resistance in Tasmania may not be as rapid as seen in both southern New South Wales (Broster *et al.* 2011b, Broster *et al.* 2011a) and Western Australia (Owen *et al.* 2007, Owen and Powles 2009) for two reasons. Firstly, as previously stated, the cropping intensity is not as great in Tasmania, allowing for a wider range of non-herbicidal control options. Secondly, and possibly most importantly, the knowledge gained from the previous 20 years of research into herbicide resistance management will potentially be able to be utilised by Tasmanian farmers and advisors, hopefully limiting the development of herbicide resistance over time in grass weeds.

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Table 1. Herbicides and rates used for resistance screening.

Herbicide	Herbicide group	Pre- or post-treatment	Rate (g ha^{-1} a.e.)	Adjuvant (rate % v/v)
Ryegrass				
diclofop-methyl	aryloxyphenoxypropionate	Post	375	Chemwet 1000 (0.25)
sethoxydim	cyclohexanedione	Post	186	DC Trate (1.0)
chlorsulfuron	sulfonylurea	Pre	15	-
imazamox/imazapyr	imidazolinone	Post	48	Hasten (0.5)
simazine	triazine	Pre	1260	-
trifluralin	dinitroaniline	Pre	816	-
Wild oat				
diclofop-methyl	aryloxyphenoxypropionate	Post	563	Chemwet 1000 (0.25)
mesosulfuron	sulfonylurea	Post	10	Chemwet 1000 (0.25)
triallate	thiocarbamate	Pre	800	-
flamprop	arylaminopropionic acid	Post	225	-
Brome grass and barley grass				
haloxyfop-R methyl	aryloxyphenoxypropionate	Post	26	Uptake (0.5)
mesosulfuron	sulfonylurea	Post	10	Chemwet 1000 (0.25)
simazine	triazine	Pre	1260	-
paraquat+diquat	bipyridyl	Post	400	-
All four species				
clethodim	cyclohexanedione	Post	60	Hasten (0.5)
glyphosate	glycine	Post	576	-

Table 2. Ryegrass (*Lolium* spp.) classification for resistance to the screened herbicides (R - Resistant; DR - Developing Resistance; S – Susceptible, TR – Total Resistant, including the Resistant and Developing Resistant combined). Numbers presented in each category refer to number of samples rated for each category.

	diclofop	sethoxydim*	clethodim	chlorsulfuron	imazamox/ imazapyr	simazine	trifluralin	glyphosate
R	11	13	0	10	3	0	0	0
DR	3	1	1	7	2	0	1	0
S	62	0	75	54	69	75	73	73
Tested	76	14	76	71	74	75	74	73
% TR	18	100	1	24	7	0	1	0

* sethoxydim was only screened to the diclofop resistant populations

R: diclofop, sethoxydim, clethodim, imazamox/imazapyr, glyphosate survival >20%, chlorsulfuron, simazine, trifluralin score >2.5

DR: diclofop, sethoxydim, clethodim, imazamox-imazapyr, glyphosate survival 10-19%, simazine, trifluralin score 1.5-2.5, chlorsulfuron score 1.7 – 2.5 (1 x S.E. > susceptible control)

S: diclofop, sethoxydim, clethodim, imazamox-imazapyr, glyphosate survival <10%, simazine, trifluralin score <1.5, chlorsulfuron score <1.7 (<1 x S.E. > susceptible control)

Table 3. Multiple resistance status for ryegrass for five of the sampled crops. Numbers represent number of samples screened positively for resistance ranging from 0-3 herbicide groups.

	Resistant groups				
Crop	0	1	2	3	Total
Wheat	18	10	3	0	31
Barley	9	7	2	0	18
Oats	9	3	0	0	12
Poppies	4	0	0	0	4
Pyrethrum	0	0	0	1	1
Total	40	20	5	1	68

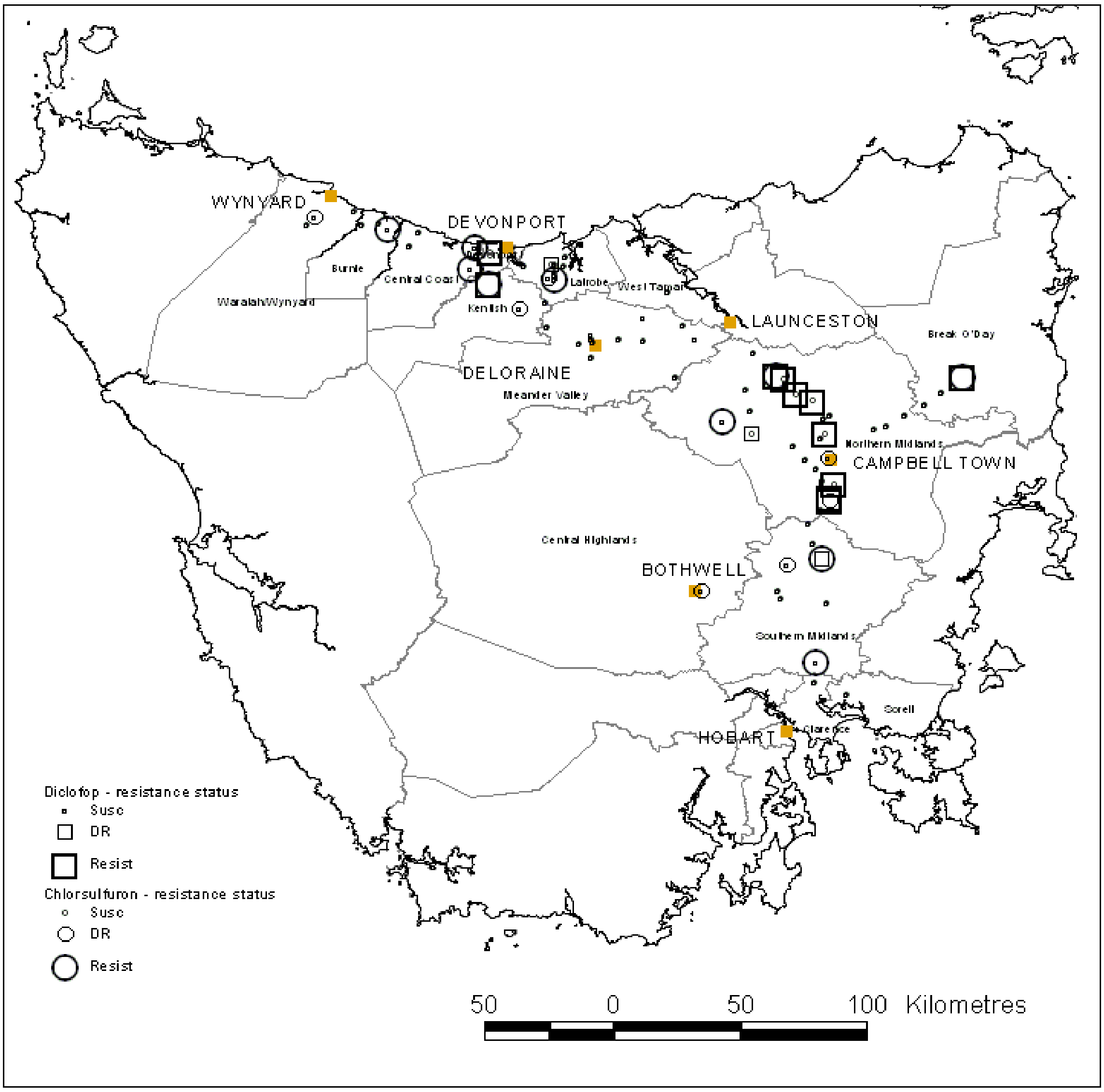

Figure 1. Location of sites showing resistance status of ryegrass populations to diclofop-methyl and chlorsulfuron in Tasmania, Australia

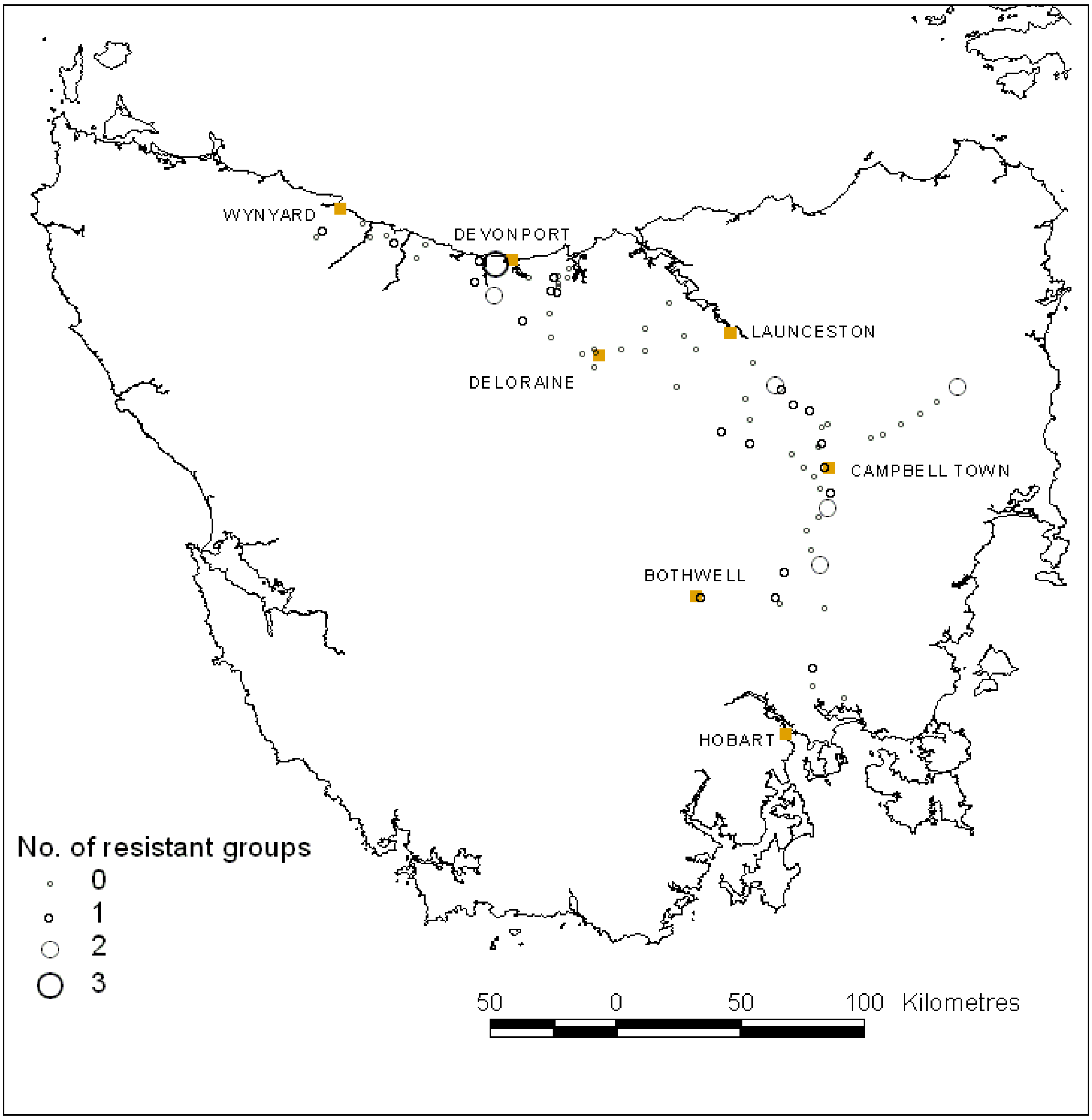

Figure 2. Location of sites showing number of resistant herbicide groups for each ryegrass population collected in Tasmania, Australia

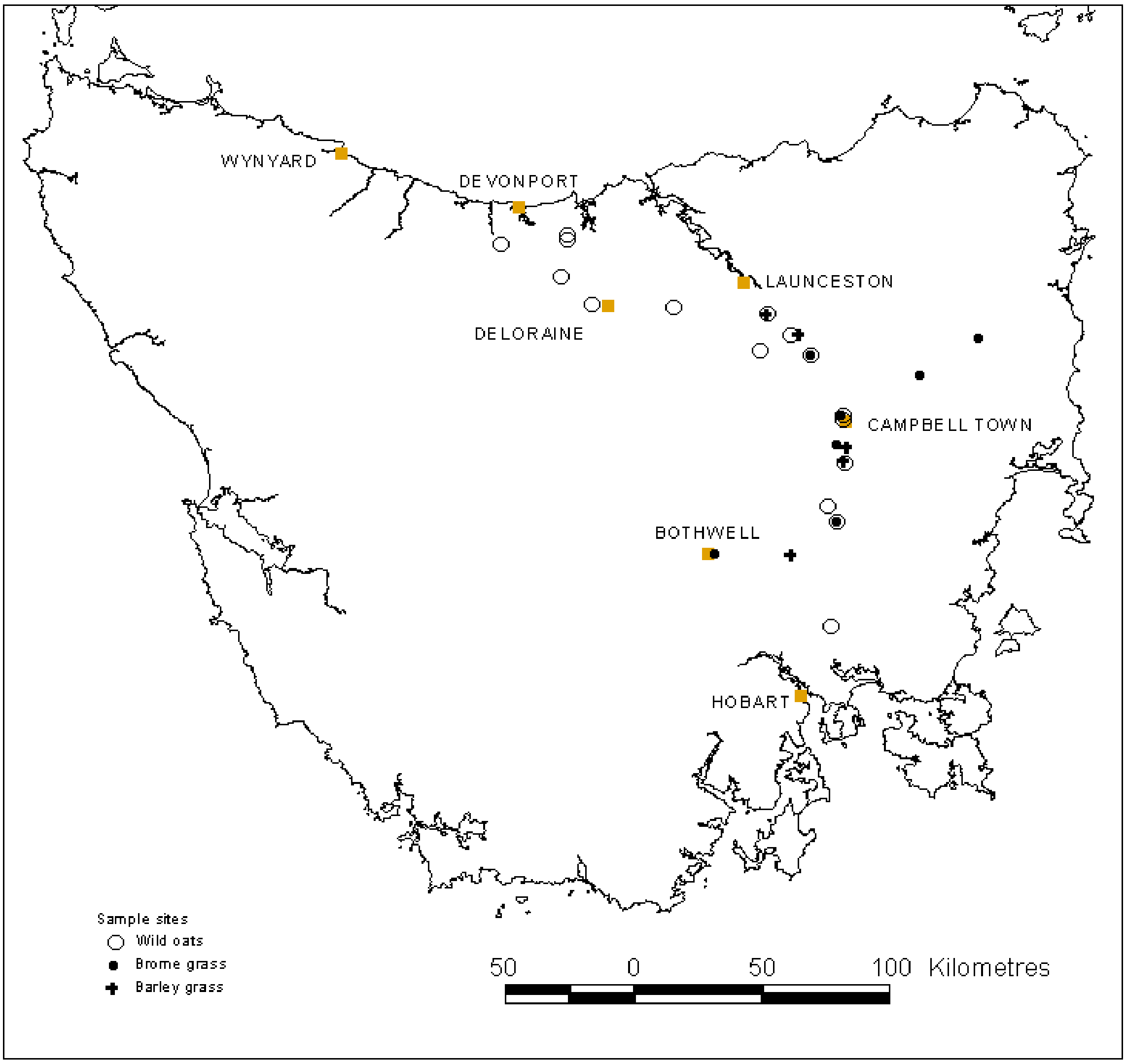

Figure 3. Location of sites from which wild oats, brome grass and barley grass were collected in Tasmania, Australia