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Frequency of herbicide resistance in wild oats (*Avena* spp.), brome grass (*Bromus* spp.) and barley grass (*Hordeum* spp.) as determined by random surveys across south-eastern Australia

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ABSTRACT

Context. Wild oats (*Avena* spp.), brome grass (*Bromus* spp.) and barley grass (*Hordeum* spp.) are significant grass weeds of crop production in south-eastern Australia. The presence of herbicide resistance in these weed species is a major limiting factor on both productivity and profitability. **Aims.** We aimed to determine the distribution of herbicide resistance in these weed species across south-eastern Australia. **Methods.** Several surveys were conducted in randomly selected fields across four states in south-eastern Australia over a 5-year period, collecting 663 wild oats, 366 brome grass and 262 barley grass samples that were screened for resistance with up to five different herbicide groups or subgroups. **Key results.** In wild oats, resistance was most common to clodinafop-propargyl ('fop' ACCase inhibitor), with 22% of samples resistant and resistance detected in all regions except Tasmania. Resistance to sulfonylurea herbicides (ALS inhibitors) was less common with 7% of samples resistant, but regionally more variable. For both brome grass and barley grass, a greater proportion of samples was resistant to the sulfonylurea mesosulfuron-methyl, at 24% and 19%, respectively, than to quizalofop-ethyl ('fop' ACCase inhibitor). **Conclusions.** Resistance was recorded in all three species, with differences in the extent of resistance among herbicide groups and regions. Overall, a higher than average frequency of wild oats resistance to clodinafop-propargyl was found in regions of New South Wales and of brome grass and barley grass resistance to mesosulfuron-methyl in regions of South Australia. However, for all species some herbicides were still effective on all samples. **Implications.** The presence of significant herbicide resistance in these weed species indicates that management decisions need to include consideration of resistance to enable successful control measures.

Keywords: ACCase-inhibiting herbicide, ALS-inhibiting herbicide, barley grass, brome grass, clodinafop-propargyl, glyphosate, pre-emergent herbicide, wild oats.

Introduction

Grass weeds are a major problem in grain cropping systems across south-eastern Australia. Annual ryegrass (*Lolium rigidum* Gaud.) is the major species of concern; however, other species such as wild oats (*Avena* spp.), brome grass (*Bromus* spp.) and barley grass (*Hordeum* spp.) are of high importance (Llewellyn *et al.* 2016). Changes in management practices for crop production combined with the development of non-herbicidal control systems used to control herbicide-resistant annual ryegrass (Walsh and Powles 2007; Llewellyn *et al.* 2016) may increase the importance these other grass weed species, if they are either more suited to the cropping systems or less suited for control under new weed management systems.

A survey of weed species remaining in fields ranked wild oats, brome grass and barley grass the third-, fifth- and ninth-most important weeds, respectively, across south-eastern Australia with regard to crop yield and revenue losses (Llewellyn *et al.* 2016). In parts of this area they are considered even more important; for example, in the Mallee region of South

Australia (SA) and Victoria, brome grass is considered the most important weed of cereal crops and second-most important in canola and pulses (Llewellyn *et al.* 2016).

In 1993, a survey of southern New South Wales (NSW) found wild oats to be the second-most common weed of cereal crops, present in 72% of fields, behind only capeweed (*Arctotheca calendula*) and ahead of annual ryegrass (Lemerle *et al.* 1996). A subsequent survey of a portion of this area in 2010 recorded wild oats in 63% of fields, behind only annual ryegrass in prevalence (Broster *et al.* 2012*a*). Barley grass was recorded in 25% of the fields in 1993 and 17% in 2010, whereas in both surveys, brome grass was recorded in ~10% of the fields (Lemerle *et al.* 1996; Broster *et al.* 2012*a*).

Although annual ryegrass is the main herbicide-resistant weed in Australia, herbicide resistance has also been reported in other species of grass weeds. Resistance was first reported in wild oats (*Avena fatua* L.) in 1985 (Piper 1990) and *Avena sterilis* subsp. *ludoviciana* in 1989 (Mansooji *et al.* 1992); in two species of barley grass (*Hordeum glaucum* Steud. and *H. leporinum* Link) in 1982 and 1987, respectively (Powles 1986; Tucker and Powles 1991); and in two species of brome grass (*Bromus diandrus* Roth and *B. rigidus* Roth) in 1998 (Boutsalis and Preston 2006).

Many of the herbicides used for annual ryegrass control are also effective on these other grass species; therefore, these weed species have been subject to selection for resistance to these herbicides even if they were not the major targeted species in the fields. Previous surveys looking at herbicide resistance in wild oats have found resistance to several herbicides, albeit at lower levels than for annual ryegrass collected from the same regions (Owen and Powles 2009; Broster *et al.* 2011*a*, 2012*b*, 2013; Owen and Powles 2016). Similarly, the results for brome grass and barley grass samples collected in surveys show either very low levels of resistance (Owen *et al.* 2015) or no resistance (Broster *et al.* 2010).

The aim of this study was to test for herbicide resistance in wild oats, brome grass and barley grass samples and where present determine its distribution across south-eastern Australia. The samples collected were tested with a range of herbicides used for the control of these species in winter cropping in south-eastern Australia.

Materials and methods

Sample collection

From 2013 to 2017, surveys were conducted in the cropping regions of SA, Victoria, Tasmania and southern NSW (for survey sites and year of sampling, see Broster *et al.* 2022). Fields were selected by travelling for a predetermined distance (5 or 10 km depending upon the size of surveyed area). At each stop, a single field was surveyed with the aim to visit a minimum of 120 crop fields in each region and collect wild oats, brome grass and barley grass. Seeds were collected by either stripping the seed from the plant or removing the entire seed head. After collection, the samples were stored for after-ripening with all other seed samples collected in the survey. Full descriptions of the sampling methodology are provided in Boutsalis *et al.* (2012).

Plant growth and treatment

Samples collected from SA and Victoria were tested at the Waite Campus, University of Adelaide (UA), and those collected from Tasmania and NSW were tested at Charles Sturt University (CSU), Wagga Wagga. A standard susceptible sample was included in every test. At CSU, susceptible samples were wild oats BASF190143w, and for barley grass and brome grass a mix of samples previously found to be susceptible to each herbicide. At UA, susceptible populations of each species were collected from a field at Pallamana. A standard resistant sample was also included where one was available for that herbicide. Owing to limited seed availability for some samples, not all herbicides were applied to all samples.

Seeds were sown, grown and treated with a range of pre-emergent and post-emergent herbicides as described by Broster *et al.* (2011*a*). The wild oats seeds were pre-germinated on either agar (0.6%) (at CSU) or moistened filter paper (at UA) and kept in a cold room at 10°C until emergence. They were then transplanted into plastic trays (CSU, 36 plants; UA, 24 plants). For the brome grass and barley grass samples, ~50 seeds were sown directly into pots or plastic trays and thinned to 25 seedlings per tray before treatment.

At CSU, plastic trays (150 mm by 100 mm by 60 mm) were used, containing either a 50:50 peat:sand mix (for testing clodinafop, quizalofop, clethodim, paraquat + diquat and glyphosate) or garden loam (for all other herbicides). At UA, 0.9-L pots containing a coco peat mix were used. Seeds treated with pre-emergent herbicides were sown on the soil surface, sprayed, and then covered with a 5-mm layer of either garden loam (CSU) or coco peat mix (UA). For post-emergent herbicides, seedlings were treated at the 1- or 2-leaf stage. At CSU the trials were conducted in a temperature-controlled glasshouse (10–25°C), whereas at UA they were conducted outdoors under natural autumn and winter growing conditions. At both locations the trials were watered daily and fertilised as required. After this, the plants were maintained as described by Broster *et al.* (2012*b*). The herbicides and rates used for the different species are listed in Table 1.

Plants were counted as survivors of the herbicide if they had emerged and developed to the 2-leaf stage at 28 days after treatment with pre-emergent herbicides or if they had new shoot growth at 21 days after treatment with post-emergent herbicides. Following Boutsalis *et al.* (2012), samples from each field were considered resistant if ≥20% of the individuals in that sample survived the herbicide application. In these self-pollinated species, samples with 1–19% survival were uncommon, so a category of developing resistance as used in some surveys for annual ryegrass (Owen *et al.* 2014) was not included.

Table 1. Herbicides, modes of action and rates used for resistance screening.

Herbicide	Herbicide mode of action	Pre- or post-emergent treatment	Rate (g a.i. or a.e. ha^{-1})	Species treated
Clodinafop	ACCase inhibitor ('fop')	Post	20.4	Wild oats
Quizalofop	ACCase inhibitor ('fop')	Post	30	Brome grass, barley grass
Clethodim	ACCase inhibitor ('dim')	Post	96	Wild oats (NSW, Tas., SA Mid North only), brome grass (NSW and Tas. only), barley grass (NSW, Tas., SA Mid North only)
Iodosulfuron	ALS inhibitor (sulfonylurea)	Post	20	Wild oats (NSW, Tas. only)
Mesosulfuron	ALS inhibitor (sulfonylurea)	Post	10	Wild oats (Vic., SA only), brome grass, barley grass
Imazapyr + imazamox	ALS inhibitor (imidazolinones)	Post	28.8	Brome grass, barley grass
Tri-allate	Fat synthesis inhibitor	Pre	500	Wild oats
Paraquat + diquat	PSII inhibitor	Post	300	Barley grass
Glyphosate	EPSPS inhibitor	Post	540	Wild oats (Southern NSW only), brome grass, barley grass

ACCase, acetyl-CoA carboxylase; fop, aryloxyphenoxypropionate; dim, cyclohexanedione; ALS, acetolactate synthase; PSII, Photosystem II; EPSPS, 5-enolpyruvylshikimate-3-phospate; a.i., active ingredient; a.e., acid equivalent.

Statistical analyses

In cases where (1) two different herbicide modes of action were used on a species, (2) two herbicides were used within a mode of action, or (3) the same mode of action was used on different weed species, a multinomial goodness of fit test (*G*-statistic) was used to test whether the frequency of resistance was similar (McDonald 2014). The null hypothesis was that resistance occurred equally between the two parameters.

The frequency of resistance to each herbicide in each region was compared with the average frequency across all regions, using an exact binomial test (McDonald 2014) with the null hypothesis being no difference between the regions. The same test was used to compare the presence of the three species across all regions with the null hypothesis that they were equally distributed across the regions.

Results

Samples collected and crop distribution

Over the period 2013–17, 996 of the 1760 fields visited contained one or more of wild oats, brome grass and barley grass. In total, 663 wild oats, 366 brome grass and 262 barley grass samples were collected from these fields (Table 2). Of these 996 fields, 741 contained only one of these species (458 wild oats, 169 brome grass, 114 barley grass), 215 contained two species (107 wild oats and brome grass, 58 wild oats and barley grass, 50 brome grass and barley grass), and 40 contained all three species (Fig. 1).

Table 2. Number of wild oats, brome grass and barley grass samples collected by region and year.

State/region	Year surveyed	No. of fields visited	No. of samples collected		
			Wild oats	Brome grass	Barley grass
New South Wales					
Slopes	2013	199	100	39	43
Eastern	2014	75	35	11	13
Western	2015	164	96	30	50
Plains	2016	152	71	9	7
Southern	2017	162	108	23	10
Tasmania	2014	75	17	12	6
South Australia					
Mid North	2013	150	47	45	19
Eyre Peninsula	2014	167	31	52	56
Mallee	2017	164	11	56	39
South East	2017	74	20	0	0
Victoria					
Southern	2014	116	26	22	0
Wimmera–Mallee	2015	140	42	50	14
North East	2016	122	59	17	5
Total		1760	663	366	262

Extent of herbicide resistance

Wild oats samples were screened to three herbicide modes of action, except for samples from Southern Victoria on which tri-allate was not used. No resistance to clethodim (ACCase inhibitor ('fop')), glyphosate (EPSPS inhibitor) or tri-allate

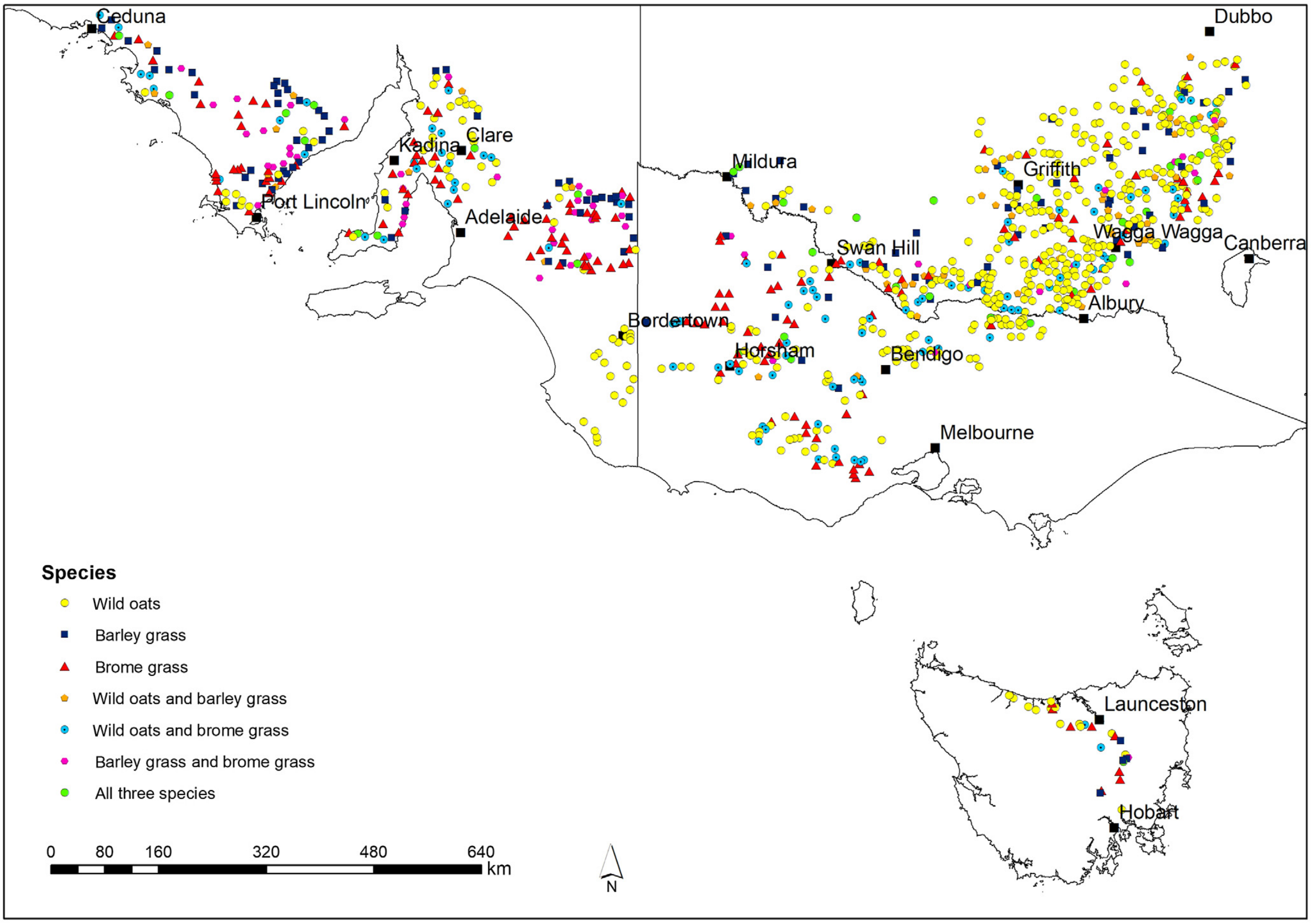

Fig. 1. Sites at which wild oats, brome grass and barley grass samples were collected.

(fat synthesis inhibitor) was identified. Resistance to the ACCase-inhibitor clodinafop-propargyl was highest in NSW, with four of the five regions having more resistance than the average (Slopes, Eastern, Plains and Southern regions) (Table 3). Resistance in SA and Victoria ranged from 2% to 10% of samples, whereas none of the samples from Tasmania were resistant (Table 3).

Resistance to the ALS-inhibiting sulfonylurea herbicides screened (iodosulfuron-methyl-Na in NSW and Tasmania, and mesosulfuron-methyl in SA and Victoria) was more localised (Table 3). In each of NSW, SA and Victoria, there was one region with a high frequency of resistance (>25%), but no other regions in those states had >3% resistant samples, whereas 6% of the Tasmanian samples were resistant (Table 3). There was more resistance to ACCase-inhibiting herbicides in wild oats than to ALS-inhibiting herbicides (G-statistic 98.7; $P < 0.0001$) (Table 4).

Unlike wild oats where resistance to the ACCase-inhibitor was more common than to the ALS-inhibiting sulfonylurea herbicides, brome grass had higher resistance to the sulfonylurea herbicide than the ACCase-inhibiting herbicide (Tables 4 and 5). Less than 1% of samples showed resistance to the ACCase inhibitor quizalofop-ethyl, and all of these were from the Wimmera–Mallee region in Victoria, compared with 24% of samples resistant to a sulfonylurea herbicide, mesosulfuron-methyl (Table 5). Resistance to sulfonylurea herbicide was most common in SA, with three regions in that state having 40–45% of samples resistant, all higher than the mean (Mallee region, $P = 0.0011$; Eyre Peninsula region $P = 0.0027$; Mid North region $P = 0.013$). Sulfonylurea herbicide resistance was next most common in Tasmania (21% of samples). Only a single region in both NSW (Western region) and Victoria (Wimmera–Mallee region) had samples resistant to the sulfonylurea herbicide, but in both of these regions >10% of samples showed resistance (Table 5). Resistance was less common to the ALS-inhibiting imidazolinone herbicide mix (Table 4), recorded only in NSW Western region and the SA Eyre Peninsula, and no samples tested were resistant to clethodim or glyphosate (Table 5).

For barley grass, resistance was more common to the sulfonylurea herbicide than to the ACCase inhibitor (Table 4), with only 2% of samples resistant to quizalofop-ethyl compared with 19% resistant to mesosulfuron-methyl (Table 6). All samples resistant to quizalofop-ethyl were from SA. The SA Mid North and SA Mallee regions had higher than the mean

Table 3. Extent of herbicide resistance in wild oats to two herbicides tested across all states.

State/region	Clodinafop-propargyl		Iodosulfuron-methyl-Na or mesosulfuron-methyl	
	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value
New South Wales				
Slopes	49	<0.0001	1	0.014
Eastern	43	0.0034	47	<0.0001
Western	12	0.017	2	0.066
Plains	31	0.058	0	0.014
Southern	30	0.056	0	0.0063
Tasmania	0	0.033	6	1
South Australia				
Mid North	2	0.0004	28	<0.0001
Eyre Peninsula	3	0.0079	3	0.727
Mallee	9	0.475	0	1
South East	5	0.099	0	0.396
Victoria				
Southern	4	0.029	0	0.258
Wimmera–Mallee	10	0.06	29	<0.0001
North East	9	0.015	0	0.021
Mean	22		7	

The exact binomial test compared the extent of resistance for each region with the average distribution across south-eastern Australia.
Number of samples collected from each region provided in Table 2; not all samples were tested to all herbicides when seed supplies were limited.

frequency of barley grass resistant to mesosulfuron-methyl (Table 6).

In addition, barley grass samples from NSW, Tasmania and SA Mid North were tested to the dim ACCase inhibitor clethodim, with one sample from SA Mid North resistant (142 tested). Samples from NSW (Slopes, Eastern and Southern) and Tasmania were tested for resistance to paraquat, with 6% of these resistant (64 tested) including two of the six Tasmanian samples, resulting in a higher frequency of resistance to paraquat in this region than the mean (Table 6).

Discussion

For each of the grass species, resistance to at least one herbicide was identified in each of the states where samples were collected. The extent of resistance in these three grass species is lower than observed for annual ryegrass in Australia not only for the equivalent surveying period and region (Broster *et al.* 2022), but also in previous annual ryegrass surveys (Broster *et al.* 2011*b*, 2012*b*, 2013; Boutsalis *et al.* 2012; Owen *et al.* 2014). However, more than 20% of samples of wild oats collected were resistant to the ACCase-inhibiting herbicide clodinafop-propargyl and brome grass to the ALS-inhibiting herbicide mesosulfuron-methyl.

Table 4. Results of statistical tests of comparisons of the frequency of resistant samples between herbicides within species and between species for herbicide modes of action.

Comparison		G-statistic	*P*-value
ACCase inhibitors vs ALS inhibitors	*Avena* spp.	98.7	<0.0001
	Bromus spp.	395	<0.0001
	Hordeum spp.	132	<0.0001
Sulfonylurea vs imidazolinones	*Bromus* spp.	154	<0.0001
Avena spp. vs *Bromus* spp.	ACCase inhibitors	157	<0.0001
	ALS inhibitors	86.8	<0.0001
Avena spp. vs *Hordeum* spp.	ACCase inhibitors	92.7	<0.001
	ALS-inhibitors	33.8	<0.0001
Bromus spp. vs *Hordeum* spp.	ACCase inhibitors	2.87	0.091
	ALS inhibitors	3.49	0.06

In the case of wild oats, there was considerable variation among regions sampled, with 32% of samples resistant to clodinafop-propargyl in NSW, but only 8% in Victoria and 4% in SA (Table 3). This higher frequency of resistance in NSW is also higher than reported by Owen and Powles (2016), who found only 7% of samples from Western Australia (WA) resistant to diclofop-methyl, another ACCase-inhibiting herbicide. These frequencies are lower than those reported from Canada, where Beckie *et al.* (2013) found 44% of wild oats samples from the Canadian Prairies to be resistant to one or more fop herbicides. However, Travlos *et al.* (2011) found that 28% of wild oats samples from wheat fields in Greece were resistant to clodinafop-propargyl. By contrast, a low level of resistance to fop herbicides (9%) was identified in the Canterbury region of New Zealand (Buddenhagen *et al.* 2021).

Previous surveys have shown differences in the extent of resistance between the fop herbicides. Owen and Powles (2009) reported that the number of samples resistant to diclofop-methyl (16%) was higher than to clodinafop-propargyl (3%) in WA fields. Travlos *et al.* (2011) reported similar findings, with resistance to clodinafop-propargyl lower than to either fenoxaprop-P-ethyl (41%) or diclofop-methyl (64%). Beckie *et al.* (2013) screened wild oats to three fop herbicides (fenoxaprop-P-ethyl, clodinafop-propargyl and quizalofop-ethyl) but did not report results for the different herbicides.

The frequency of resistance to the fop herbicides in NSW Slopes and Plains has increased over the 6-year period since previously surveyed. Previously, 30% of samples from NSW

Slopes (2007) (Broster *et al.* 2011*a*) and 19% from the NSW Plains (2010) (Broster *et al.* 2013) were resistant to diclofop-methyl compared with 49% of samples from the NSW Slopes resistant to clodinafop-propargyl in 2013 ($P < 0.0001$) and 31% from the NSW Plains in 2016 ($P = 0.009$) (Table 3).

Resistance to the ALS-inhibiting herbicides was lower than to ACCase-inhibiting herbicides in wild oats (Table 5). However, resistance was more common in SA (12% of samples) and Victoria (10% of samples) than in NSW (5% of samples; Table 3). These differences between states likely reflect different crop rotations and herbicides used. Owen and Powles (2016) identified one sample with resistance to sulfonylurea herbicides in 118 samples of wild oats tested from WA. Beckie *et al.* (2013), on the other hand, identified resistance to ALS-inhibiting herbicides in 12% of samples collected from the Canadian Prairies.

In contrast to wild oats, resistance to ACCase-inhibiting herbicides was less common in barley grass and brome grass (Table 4). Only three samples of brome grass were resistant to quizalofop-ethyl, all from Victoria Wimmera–Mallee (Table 5), and five samples of barley grass, all from SA (Table 6). There was no difference in the frequency of ACCase-inhibitor resistance between brome grass and barley grass (Table 4). Previous surveys in NSW and Tasmania identified no resistance to the ACCase-inhibiting herbicides in these two weed species (Broster *et al.* 2010, 2012*b*; Owen *et al.* 2015). Boutsalis *et al.* (2014) reported resistance to ACCase-inhibiting herbicides in brome grass from the Wimmera–Mallee at a similar frequency to the present survey and in 14% of samples from South East SA. A smaller survey of barley grass in the Eyre Peninsula and Mid North of SA identified resistance (>20% survival) to quizalofop-ethyl in 6 of the 90 barley grass samples screened (Shergill *et al.* 2015), similar to the frequency of resistance identified in this survey (Table 6). In a survey of brome grass and barley grass in WA, 1% of brome grass samples had survivors when treated with fluazifop-butyl and clethodim; however, all of the barley grass samples were completely controlled by ACCase-inhibiting herbicides (Owen *et al.* 2015).

Over 40% of samples from all three regions in SA where brome grass was collected showed resistance to sulfonylurea herbicides (Table 5) with resistance also occurring in >10% of the samples from Western NSW, Tasmania and the Wimmera–Mallee in Victoria. For barley grass, all regions except for the Victorian North East had samples resistant to mesosulfuron-methyl (Table 6), with two of the three regions in which it was collected in SA having >40% of samples resistant (Table 6). In both brome grass and barley grass, there was more resistance to sulfonylurea herbicides than to ACCase inhibitors, and there was more resistance to sulfonylurea herbicides than occurred in wild oats (Table 4). Previous surveys of brome grass (2008–12) in SA and Victoria

Table 5. Extent of herbicide resistance in brome grass to four herbicides tested across all states.

Region	Quizalofop-ethyl		Mesosulfuron-methyl		Imazapyr + imazamox		Glyphosate	
	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value
New South Wales								
Slopes	0	1	0	<0.0001	0	1	0	1
Eastern	0	1	0	0.082	0	1	0	1
Western	0	1	17	0.781	7	0.0078	0	1
Plains	0	1	0	0.347	0	1	0	1
Southern	0	1	–		0	1	0	1
Tasmania	0	1	21	0.777	0	1	0	1
South Australia								
Mid North	0	1	40	0.013	0	1	0	1
Eyre Peninsula	0	1	44	0.0027	2	0.013	0	1
Mallee	0	1	44	0.0011	0	1	0	1
South East	n.d.		n.d.		n.d.		n.d.	
Victoria								
Southern	0	1	0	0.0044	0	1	0	1
Wimmera–Mallee	6	0.0082	12	0.065	0	1	0	1
North East	0	1	0	0.019	0	1	0	1
Mean	1		24		1		0	

–, not tested; n.d., species not detected in surveyed fields for that region.
The exact binomial test compared the extent of resistance for each region with the average distribution across south-eastern Australia.
Number of samples collected from each region provided in Table 2; not all samples were tested to all herbicides when seed numbers were limited.

Table 6. Extent of herbicide resistance in barley grass to two herbicides tested across all states.

Region	Quizalofop-ethyl		Mesosulfuron-methyl		Clethodim		Paraquat + diquat	
	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value	Samples resistant (%)	*P*-value
New South Wales								
Slopes	0	1	7	0.05	0	1	3	0.517
Eastern	0	1	8	0.49	0	1	0	1
Western	0	1	9	0.09	0	1	–	
Plains	0	1	20	1	0	1	–	
Southern	0	1	–		0	1	11	0.42
Tasmania	0	1	17	1	0	1	33	0.044
South Australia								
Mid North	11	0.05	53	0.0009	5	0.122	–	
Eyre Peninsula	4	0.274	16	0.862	–		–	
Mallee	3	0.536	42	0.0066	–		–	
South East	n.d.		n.d.		n.d.		n.d.	
Victoria								
Southern	n.d.		n.d.		n.d.		n.d.	
Wimmera–Mallee	0	1	7	0.49	–		–	
North East	0	1	0	0.592	–		–	
Mean	2		19		0.7		6	

–, not tested; n.d., species not detected in surveyed fields for that region.
The exact binomial test compared the extent of resistance for each region with the average distribution across south-eastern Australia.
Number of samples collected from each region provided in Table 2; not all samples were tested to all herbicides when seed numbers were limited.

reported that 2–45% of samples collected were resistant to mesosulfuron-methyl (Boutsalis *et al.* 2014). There was less resistance found to mesosulfuron-methyl in Victoria and more in SA in this survey. Previous surveys in Tasmania (Broster *et al.* 2012*b*) and SA (Shergill *et al.* 2015) identified no resistance to ALS-inhibiting herbicides in barley grass. However, Owen *et al.* (2015) reported 8% of barley grass samples collected in WA were resistant to sulfonylurea herbicides. There has been a rapid increase in resistance to ALS-inhibiting herbicides in barley grass in south-eastern Australia in recent years.

Across the surveyed regions, annual ryegrass was the most commonly collected grass weed species, collected from 81% of fields, and in no region was it collected from <60% of fields (Broster *et al.* 2022). By comparison, wild oats was collected from 38% of fields, brome grass 21% and barley grass 15%. There were differences among regions in the incidence of the different weed species, likely resulting from different environments and soil types present. Wild oats was most common in NSW, collected from 55% of fields, and less common in SA and Victoria, collected from 20% and 34% of fields, respectively (Table 2). On the other hand, brome grass was most common in SA, collected from 28% of fields, compared with only 15% of fields in NSW (Table 2).

Resistance in wild oats was more common in NSW than in the other states (Table 3), and likewise, resistance in brome grass was more common in SA than in NSW (Table 5). This suggests that resistance is being selected more often where there are higher populations of these grass weeds. This agrees with studies from Canada and Greece. In Canada, wild oats was the most common weed species, found in 67% of paddocks, with 44% of these resistant to a fop herbicide, whereas in Greece, wild oats was collected from ~20% of fields and the resistance level was lower at 28% of samples (Travlos *et al.* 2011; Beckie *et al.* 2013). If the initial frequency of resistance to herbicides is similar among the weed species, then lower populations make it less likely that resistance will evolve (Preston and Powles 2002; Kreiner *et al.* 2018).

This group of surveys of three major grass weed species across south-eastern Australia shows that these species are found across this region and that resistance occurs in all species. The extent of resistance differs among species, herbicides and regions, reflecting the importance of the weed in a region and/or the herbicides used for weed control in that region as has been shown in annual ryegrass (Broster *et al.* 2019). Despite the high levels of resistance in some regions, there are still herbicides that control all populations, allowing alternatives for control.

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Data availability. The data that support this study are available in the article and upon request to the corresponding author.

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