Adaptive changes of farmers to the continued invasion of Senecio madagascariensis Poir. (fireweed) in pasture-based systems

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Abstract

Senecio madagascariensis Poir. (fireweed) is a rapidly invading poisonous weed of temperate and subtropical pastures across several continents and islands worldwide. While the geographic spread of pasture weeds, such as fireweed, can be relatively readily monitored, it is often farmer perceptions of weed impact that form the imperative for their management. In order to assess the types of adaptive changes that farmers may consider to the continued invasion of weeds in pasture-based systems, in 2011, we repeated a published 1985 farmer survey in fireweed-impacted regions in Australia to investigate: its continued spread; changes in the perceptions of its importance; and resulting changes in management. Fireweed had spread to new regions and was better established in previously lightly infested regions. It was less likely to be considered troubling by respondents when it was new on their farms, or had been present for an extended period. The effectiveness of a control method was only one of several factors driving adaptive changes in pasture weed management amongst survey respondents. Use of some approaches had declined alongside a perception that they were relatively ineffective, while the level of use of other reportedly successful techniques remained static, indicating major impediments to adoption. Weed invasions are by definition dynamic, and landholder perceptions of pasture weeds appear equally dynamic. As poisonous *Senecio* species spread around the world, the findings of this Australian research emphasise the need to understand how farmers adapt to weed invasion. Policymakers and landholders can benefit from such research for *Senecio* and other important weed species, by exploring the perceptions that may drive successful adaptive management of these species on-farm.

Introduction

Both from ecological and management perspectives, it is important to understand how pasture and rangeland weeds spread through time and across geographic areas, the impacts these weeds have on grazing systems, and how farmers adapt their management in response to changes in weed spread and infestation level (DiTomaso et al. 2010). Weed invasion is a dynamic process that varies enormously between species, leading to a variety of actual and perceived impacts to which policymakers and land managers (private and public) must respond. Responses may range from inaction to localised eradication efforts (sometimes mandated by legislation) to management aimed at reduction of weed impact to tolerable levels (Panetta & Scanlan 1995, Reeve et al. 2015, van Kleunen et al. 2018). Therefore the most appropriate management techniques are likely to change over time.

Toxic *Senecio* species are highly invasive in European pastures, for example, *S. inaequidens* (African ragwort) in France, Belgium and the Netherlands (Monty & Mahy 2009). Originating in southern Africa, *Senecio madagascariensis* Poir. (fireweed) is an annual, winter-growing (Radford 1997, Wijayabandara et al. 2022), wind-dispersed herbaceous species (Radford 1997) that has invaded a range of grazed systems in parts of Argentina (Verona et al. 1982, Villalba & Fernández 2007), Uruguay (Villalba & Fernández 2007) and Brazil (Bandarra et al. 2012, Panziera et al. 2018). It has invaded and spread from southern Tohoku to southern Kyushu in Japan since initial detection in 1976, with further spread predicted (Tsutsumi 2011). It has rapidly invaded pasture systems in Hawaii since the early 1980s (Le Roux et al. 2010), and it was recently found established in New Zealand (Schmidt-Lebuhn & Gooden 2022). In Australia, fireweed was first recorded in the Hexham region of the Hunter Valley, New South Wales (NSW) in 1918 (Nelson 1980), spreading through temperate and subtropical pastures along the south east coast of Australia and beginning to establish in higher altitude locations in NSW and in northern Queensland (Qld) (Sindel et al. 2008, Wijayabandara et al. 2022).

Fireweed invades a range of soil and pasture types across its global range (Verona et al. 1982, Wijayabandara et al. 2022), competing strongly with existing pasture plants for resources (Sindel & Michael 1992a), particularly those overgrazed, for example, following drought (Sindel 1989), or improved under sub-optimal conditions (Radford 1997). It is of particular concern to farmers grazing livestock (especially cattle and horses) as it contains pyrrolizidine alkaloids (PAs) that when ingested by livestock can damage the liver, reduce growth and, in severe cases, cause death (Walker & Kirkland 1981, Gardner et al. 2006, Bandarra et al. 2012, Panziera et al. 2018). Due to its potential impacts, farmers can be highly motivated to remove fireweed plants from a pasture, often resorting to labour-intensive hand weeding (Sindel and Michael 1988).

The importance of any pasture weed can be gauged by its realised or potential impact on livestock production. However, because direct and indirect impacts are rarely measured by farmers, perceptions of impact are often the substitute imperative for on-ground management (Dowling et al. 2000). Given that recent climate suitability modelling indicates the potential for fireweed to establish across large parts of Asia, Australasia and the Pacific, Africa and the Middle East, Europe, South and Central America, and the southern United States (Wijayabandara et al. 2022), it is critical to understand farmer perceptions and management of this weed to limit such spread. In a 1985 survey of dairy farmers and beef producers in coastal NSW, Australia, Sindel and Michael (1988) assessed the occurrence and spread of fireweed, farmer perceptions of the weed and its impact, the cost of control, and adoption and effectiveness of various control options. Very rarely have such surveys been repeated at two or more points in time to determine what changes may have occurred over the intervening period, though research has assessed the effect of plant invasions on the dynamics of pasture plant communities over time (e.g. Dostál et al. 2013). Here we report the findings and implications of a repeat survey conducted in 2011, 26 years after the initial survey, focusing on the known area of fireweed distribution in Australia at that time. Subsequent research (Wijayabandara et al. 2022) explores more recent distribution of and management approaches used for fireweed in Australia.

Our objectives were to assess the changes that may have occurred in the period from 1985 to 2011 in the spread of fireweed in Australia, farmer perceptions of its impact on their grazing enterprises, and the methods they found to be most successful in managing the weed. Specifically, survey repetition allowed us to test the hypotheses that: 1) fireweed had continued to spread rapidly; 2) the perceptions of importance of fireweed had changed at a regional scale; and 3) there had been adaptive changes in management techniques for fireweed amongst farmers over this period of time.

Materials and Methods

Study area

The south east area of Australia in which the survey was conducted (Fig. 1) has a climate ranging from temperate in the south to sub-tropical in the north. Annual mean (5–95 percentile) precipitation ranges from approximately 600 to 1,700 mm and temperature from 12 to 20°C (Sindel & Michael 1992b). The area is characterised by low-lying flood plains along the coast and more undulating hills and plateaus of the Great Dividing Range in the west. Elevation ranges from sea level to about 1000 m. The soils in the study region range from clay-rich Ferrosols and Dermosols on the slopes of the Great Dividing Range to texture contrast Chromosols and Kurosols on the coastal plains and some areas on the plateau regions (Isbell 2021). The dominant pasture species vary between coastal and inland regions, and between sub-tropical and temperate locations. The sub-tropical grass *Pennisetum clandestinum* (Kikuyu) is the most common grass across the area. Other prominent species in improved pastures include *Lolium perenne* (perennial ryegrass), *Paspalum dilatatum* (paspalum), *Trifolium repens* (white clover) and *T. subterraneum* (subterranean clover) (Sindel and Michael 1988). Various native grasses are also present, particularly in the more undulating, less improved country.

Survey design

In 1985 (Sindel & Michael 1988), the survey covered eight regions from the study area corresponding with the regions served at the time by eight dairy cooperatives. For the 2011 survey, responses were divided into 12 regions on the basis of postal (zip) code (Fig. 1), allowing for direct comparative analysis of eight of these regions with 1985 data. Four new regions were delimited based on the continued spread of fireweed since 1985: South-East Qld; and Mid-North Coast, Northern Tablelands, and Southern Tablelands (NSW).

In 1985, 60 dairy farmers were randomly selected from mailing lists supplied by each of the eight dairy cooperatives. Sixty beef cattle producers from each of the five northern regions were also surveyed for comparison between farmer types. They were chosen randomly from telephone directory listings, and lists supplied by NSW district agronomists. For the results in which all eight regions were compared, only the dairy farm data were presented. However, in other cases, the results of the two farm types were combined to provide a larger data set and because there were minimal differences in the results between the two types of grazing enterprises. In total, 780 farmers were surveyed and a 74% response rate was obtained.

A revised sampling approach was necessary in 2011, due to closure of the NSW dairy cooperatives and reduction in the number of dairy farms in many regions. We identified postal codes representing the known distribution of fireweed, sourced at the time from the Atlas of Living Australia (ALA 2022). Three organisations assisted with the 2011 mail survey distribution: South-East Qld Catchments, the Queensland Dairyfarmers' Organisation, and the NSW Farmers' Association. Their membership lists were filtered by postal code, and to include only dairy farmers and beef cattle farmers where identifiable. Dairy and beef farmers were also identified in these regions using telephone directories for inclusion in the sample. The final sample size was 1,764, and the survey distributed in spring 2011 when fireweed was likely to be flowering and more evident to those responding, as occurred in 1985. Nearly all questions from the original 1985 questionnaire were included in their same format in the 2011 questionnaire. Human research ethics approval was provided by the authors' institution.

Statistical analysis

Statistical analysis was completed using SPSS (IBM Corp 2020). Where possible, we tested for differences in response from 1985 to 2011, or where such testing was not possible, data from the surveys are presented alongside one another for comparison, with the objective of assessing changes in spread, perceptions of impact, and management of fireweed from 1985 to 2011. A chi-squared test was used to test for non-independence of pairs of nominal variables of interest in the 2011 survey data alone, with a p value of < 0.05 indicating a statistically significant relationship in the data (Tables 1 to 6). Standardised residuals were used to identify particular cells in the cross-tabulation of the two variables that contributed to significant chi-square statistics, but are not presented in the results.

The binomial test was used to identify significant changes in proportions of responses to questions with nominal response categories between the 1985 and 2011 surveys (Table 7). The test was used on relevant variables in the 2011 data set by comparing the overall response with that to the 1985 survey. A p value of < 0.05 indicated that the proportion of respondents in favour of a response in 2011 had changed significantly from the overall response in 1985.

The Mann-Whitney U test was used to determine whether the mean of an ordinal variable was significantly different in 2011 to 1985 (Table 2). The test was used to show whether there had been a significant increase or decrease in the ratings given on ordinal variables between the first and second surveys. Since the 1985 survey data were no longer available, but the proportions responding to each ordinal response item were available, a synthetic data set was created for the analyses for which the Mann-Whitney U test was used. The proportion of responses for each response item was based on percentages included in Sindel and Michael (1988), and the number of responses in the synthetic 1985 data set matched to the number of responses to the actual survey. While it was not known whether all respondents had answered each of the questions in the 1985 survey, small departures from the total number of responses were expected to make only a trivial difference to the Mann-Whitney U test statistic. As with the binomial test, a Mann-Whitney U test p value of < 0.05 was taken to represent a significant change in response.

Results

A 30% response rate was obtained for the 2011 survey, giving a similar number of actual responses (528) to 1985 (581), although not all respondents answered every question in the survey.

Occurrence, spread and duration of presence

Some 88% of respondents had at least a small amount of the weed on their farm (Table 1). The overall percentage of respondents across the eight original regions with large or moderate amounts of the weed increased from 51% in 1985 to 63% in 2011.

In 1985, fireweed was most likely to be absent, or present in small amounts, on farms in the Bega and Shoalhaven regions. By 2011, the proportion of respondents with moderate to large amounts of fireweed had increased substantially (especially in the Bega region), indicating that fireweed had become a more serious problem in both regions, and to some extent in Muswellbrook and Lismore (Table 1). In the previously relatively heavily infested regions of Taree, Gloucester and Hexham, near to where fireweed first became established in Australia, there was little apparent change in the weed's occurrence. It had become a less serious problem, and was most likely to be considered under control, in the Cumberland region.

Of the four regions not previously surveyed, fireweed was entrenched in 2011 in the South-East Qld and the Mid-North Coast regions, and less so in the Northern Tablelands region. The pattern of occurrence in the Southern Tablelands region in 2011 was similar to that in its neighbouring region of Bega in 1985, with few small to moderate infestations and most farms free of fireweed (Table 1).

Table 1
Occurrence of fireweed by region, as a percentage of total response, in 2011 (12 regions) and where sampled in 1985 (eight regions; *in brackets*).

	Absent	**Small amounts**	**Moderate amounts**	**Large amounts**	**Under control**	***n* (2011 only)**
South-East Qld	14	37	30	8	10	99
Lismore	2 *(0)*	13 *(29)*	57 *(46)*	25 *(10)*	3 *(15)*	60
Mid-North Coast	0	35	38	11	16	37
Northern Tablelands	35	50	9	6	0	34
Taree	0 *(0)*	17 *(18)*	59 *(48)*	14 *(17)*	10 *(17)*	29
Gloucester	0 *(0)*	25 *(24)*	75 *(59)*	0 *(15)*	0 *(2)*	16
Muswellbrook	5 *(29)*	23 *(56)*	64 *(9)*	9 *(0)*	0 *(6)*	22
Hexham	0 *(0)*	8 *(21)*	72 *(50)*	16 *(19)*	4 *(10)*	25
Cumberland	30 *(4)*	22 *(35)*	22 *(42)*	0 *(13)*	26 *(6)*	23
Shoalhaven	0 *(14)*	46 *(43)*	19 *(20)*	16 *(4)*	19 *(19)*	37
Southern Tablelands	69	13	13	0	6	16
Bega	11 *(65)*	24 *(25)*	18 *(2)*	32 *(0)*	16 *(8)*	38
Total, 2011 regions*, **	12	28	37	13	10	436
Total, 1985 regions*, †	5 *(10)*	22 *(30)*	46 *(40)*	17 *(11)*	10 *(9)*	250
chisq = 216.7, d.f. = 44, p = < 0.001 (2011 data only)						

* Totals include respondents not providing a postal code and whose response is therefore absent from regional results.

** Totals include percentage response and *n* using all 12 regions included in the 2011 survey.

† Totals include percentage response and *n* from the 2011 survey using only the subset of eight regions included in the 1985 survey, with 1985 total percentage response data provided in brackets for comparison.

Of those respondents with fireweed on their farm, 18% observed its arrival within the last five years, while 33% had it on their farm for more than 20 years (Table 2). Amongst the eight regions included in both surveys, the duration of fireweed presence had increased, with a higher proportion having fireweed on their farm for greater than 20 years, and fewer respondents having fireweed on the farm for less than 10 years in 2011 than in 1985. The increase in the duration of fireweed presence was particularly sharp in Shoalhaven and Bega, where it had not been considered present for more than 10 years at the time of the 1985 survey (Table 2). Relatively high proportions of respondents from Southern Tablelands, South-East Qld, and Northern Tablelands had fireweed on their farm for less than 5 years in 2011. In contrast, fireweed had infested all surveyed farms in the Gloucester and Hexham regions (Table 2), with no new farms infested within the 5 years prior to 2011.

Table 2
Duration of fireweed presence by region, as a percentage of respondents with the weed in 2011 (12 regions) and where sampled in 1985 (eight regions; *in brackets*).

	Less than 5 years	**Between 5 and 10 years**	**Between 10 and 20 years**	**Between 20 and 30 years**	**More than 30 years**	***n* (2011 only)**
South-East Qld	43	35	16	4	2	83
Lismore	2 *(29)*	7 *(29)*	38 *(25)*	26 *(7)*	28 *(10)*	61
Mid-North Coast	8	39	22	25	6	36
Northern Tablelands	36	23	18	23	0	22
Taree	4 *(14)*	18 *(50)*	29 *(36)*	21 *(0)*	29 *(0)*	28
Gloucester	0 *(0)*	19 *(27)*	19 *(49)*	19 *(22)*	44 *(2)*	16
Muswellbrook	5 *(63)*	14 *(8)*	29 *(25)*	14 *(0)*	38 *(4)*	21
Hexham	0 *(4)*	0 *(13)*	16 *(28)*	24 *(38)*	60 *(17)*	25
Cumberland	13 *(62)*	25 *(36)*	25 *(2)*	31 *(0)*	6 *(0)*	16
Shoalhaven	8 *(89)*	28 *(11)*	42 *(0)*	17 *(0)*	6 *(0)*	36
Southern Tablelands	83	17	0	0	0	6
Bega	27 *(94)*	35 *(6)*	21 *(0)*	15 *(0)*	3 *(0)*	34
Total, 2011 regions*, **	18	23	25	17	16	384
Total, 1985 regions*, †	7 *(29)*	17 *(29)*	30 *(28)*	21 *(10)*	25 *(4)*	237
chisq = 206.6, d.f. = 44, p < 0.0005 (2011 data only)						

* Mann-Whitney U Test p < 0.0005. Total includes those who did not provide a postal code and whose response is therefore absent from regional results.

** Totals include percentage response and *n* using all 12 regions included in the 2011 survey.

† Totals include percentage response and *n* from the 2011 survey using only the subset of eight regions included in the 1985 survey, with 1985 total percentage response data provided in brackets for comparison.

Of those respondents with fireweed on their farm, slightly fewer overall considered it to be their worst weed in 2011 than in 1985, however, there were large increases in Bega and Muswellbrook (Table 3), both of which in 1985 had many respondent farms free of the weed (Table 1). In contrast, the percentage of farmers rating fireweed as their worst weed had fallen considerably in Taree and Gloucester (Table 3), where the weed was present on all farms included in the 1985 survey (Table 1).

Table 3
Number of respondents considering fireweed to be their worst weed on farm, as a percentage of respondents with the weed in 2011 (12 regions) and where sampled in 1985 (eight regions; *in brackets*).

	Worst weed	**Not worst weed**	***n* (2011 only)**
South-East Qld	33	67	122
Lismore	23 *(36)*	77 *(64)*	79
Mid-North Coast	40	60	79
Northern Tablelands	23	77	25
Taree	28 *(77)*	72 *(23)*	70
Gloucester	14 *(54)*	86 *(46)*	18
Muswellbrook	24 *(8)*	76 *(92)*	36
Hexham	44 *(46)*	56 *(54)*	44
Cumberland	27 *(48)*	73 *(52)*	28
Shoalhaven	58 *(51)*	42 *(49)*	104
Southern Tablelands	40	60	8
Bega	56 *(6)*	44 *(94)*	126
Total, 2011 regions*, **	35	65	383
Total, 1985 regions*, †	36 *(43)*	64 *(57)*	232
chisq = 26.5, d.f. = 11, p = 0.005 (2011 data only)			

* Total includes those who did not provide a postal code and whose response is therefore absent from regional results.

** Totals include percentage response and *n* using all 12 regions included in the 2011 survey.

† Totals include percentage response and *n* from the 2011 survey using only the subset of eight regions included in the 1985 survey, with 1985 total percentage response data provided in brackets for comparison.

Perceptions of problem status

Half of the respondents in 2011 considered fireweed to be either no problem or a minor problem, with the remainder perceiving it to be a moderate to major problem (Table 4). It was particularly notable that 70% of respondents from Bega considered it a moderate or major problem in 2011, up from 19% in 1985. A similar result was recorded in Muswellbrook. Respondents from the ‘core’ fireweed regions of Taree and Gloucester, and the more recently infested areas of the Northern and Southern Tablelands, were amongst the least likely to perceive it a major problem, though many still considered it a moderate problem. Only in Taree, Gloucester and Cumberland, was there an increase in the percentage of respondents between the two surveys considering fireweed not to be a problem. In all other regions, including Lismore and Hexham, there was an increase in the perceived problem status of fireweed (Table 4).

Table 4
Perceived size of the fireweed problem, as a percentage of respondents with the weed in 2011 (12 regions) and where sampled in 1985 (eight regions; *in brackets*).

	No problem	**Minor problem**	**Moderate problem**	**Major problem**	***n* (2011 only)**
South-East Qld	21	36	29	14	84
Lismore	8 *(19)*	34 *(48)*	43 *(19)*	15 *(14)*	61
Mid-North Coast	11	38	41	11	37
Northern Tablelands	27	46	23	5	22
Taree	10 *(8)*	31 *(33)*	52 *(41)*	7 *(18)*	29
Gloucester	6 *(2)*	63 *(46)*	25 *(43)*	6 *(9)*	16
Muswellbrook	5 *(58)*	55 *(28)*	35 *(14)*	5 *(0)*	20
Hexham	4 *(19)*	32 *(27)*	44 *(48)*	20 *(6)*	25
Cumberland	20 *(10)*	40 *(41)*	27 *(37)*	13 *(12)*	15
Shoalhaven	11 *(26)*	44 *(34)*	25 *(19)*	19 *(21)*	36
Southern Tablelands	0	60	40	0	5
Bega	6 *(52)*	24 *(29)*	18 *(5)*	52 *(14)*	33
Total, 2011 regions*, **	12	38	34	16	387
Total, 1985 regions*, †	9 *(19)*	38 *(36)*	35 *(33)*	19 *(12)*	235
chisq = 68.5, d.f. = 33, p < 0.0005 (2011 data only)					

* Total includes those who did not provide a postal code and whose response is therefore absent from regional results.

** Totals include percentage response and *n* using all 12 regions included in the 2011 survey.

† Totals include percentage response and *n* from the 2011 survey using only the subset of eight regions included in the 1985 survey, with 1985 total percentage response data provided in brackets for comparison.

The foregoing data indicated a potential relationship between duration of fireweed presence on farm (Table 2), the likelihood that farmers will consider it to be their most important weed (Table 3), and the extent of the problem (Table 4). Where fireweed had only arrived relatively recently, such as in the Northern and Southern Tablelands, it was less likely to be considered the worst weed on farm or thought of as a moderate or major problem. This result was similar in regions where it had been present for longest, such as in Muswellbrook, Gloucester, and Taree, though a relatively high proportion of those from Hexham still considered it their worst weed (Table 3).

Cross-tabulation analysis did show significant relationships between duration of fireweed presence, its rating as the worst weed, and the severity of the problem. Those respondents who had fireweed on their farm for between 5 and 30 years were more likely to consider it their worst weed (Table 5) and a moderate or major problem (Table 6) than those who had it for less than 5 years, or more than 30 years, with the peak being between 10 and 20 years (Fig. 2). The reverse was true for the assessment of fireweed as a minor problem or no problem at all (Table 6).

Table 5
Duration of fireweed presence by whether it was considered the worst weed on farm in 2011.

	Worst weed	**Not worst weed**	***n***
Less than 5 years	16.4	83.6	67
Between 5 and 10 years	41.9	58.1	86
Between 10 and 20 years	49.0	51.0	96
Between 20 and 30 years	34.8	65.2	66
More than 30 years	27.4	72.6	62
chisq = 21.5, d.f. = 4, p < 0.0005			

Table 6
Duration of fireweed presence by perceived size of the problem in 2011.

	No problem	**Minor problem**	**Moderate problem**	**Major problem**	***n***
Less than 5 years	30.9	50	11.8	7.4	68
Between 5 and 10 years	12.4	34.8	40.4	12.4	89
Between 10 and 20 years	5.3	29.5	48.4	16.8	95
Between 20 and 30 years	6	32.8	31.3	29.9	67
More than 30 years	8.1	50	27.4	14.5	62
chisq = 63.8, d.f. = 12, p < 0.0005					

Management

Of those respondents with fireweed on their farm, 76% attempted to control it using one or more techniques in 2011, and 80% in 1985. Hand weeding remained the most popular of the management techniques available in 2011 and was rated amongst the most successful (Table 7), although considered most relevant to smaller outbreaks, ‘spot control’ of occasional plants, or on smaller farm areas. Herbicide control of fireweed increased significantly from 1985 to 2011, though ratings of its success declined, with a relatively large proportion of 2011 respondents having only low to moderate success (Table 7).

Use of slashing or mowing declined significantly from 1985 to 2011 (Table 7), alongside low ratings for success in both 1985 and 2011. Respondents who had used it successfully noted that regular follow-up slashing was required to minimise flowering and seed-set. Cultivation was considered a relatively unsuccessful control method, and its low use declined further from 1985 to 2011 (Table 7).

Promoting competitive pastures was considered by 86% of respondents to provide moderate to high success and was relatively widely used (Table 7). Nonetheless, its use had not increased significantly since 1985, and the associated technique of reduced stocking rates to increase pasture competition was seldom used. Survey respondents using sheep or goat grazing to control fireweed considered it to be the most successful technique overall (Table 7). However, the proportion of respondents using this method in 2011 remained small.

Table 7
Use and success of fireweed control methods, as a percentage of respondents who attempted control in 2011 and where surveyed in 1985 (*in brackets*).

Control method	**Level of use*** (n 2011 = 298)	**Level of success****			
		Low	Moderate	High	*n* (2011 only)
Hand weeding	75 *(74)*	26 *(37)*	29 *(29)*	45 *(34)*	242
Herbicides†	49 *(12)*	41 *(22)*	47 *(37)*	13 *(41)*	143
Slashing†	36 *(68)*	37 *(41)*	50 *(46)*	13 *(13)*	119
Cultivation†	5 *(19)*	38 *(33)*	41 *(54)*	22 *(13)*	32
Promoting competitive pasture	39 *(35)*	14 *(21)*	54 *(37)*	32 *(42)*	108
Reduced stocking rates	8	28	55	17	29
Grazing with sheep or goats†	7 *(5)*	18 *(11)*	36 *(22)*	46 *(67)*	22

* Percentage of respondents who attempt fireweed control.

** Percentage of respondents who attempt control by that method.

† Binomial test (Level of use) $p < 0.0005$.

Discussion

Repeating a farmer survey on fireweed provided the opportunity to characterise the continuing spread of an invasive pasture weed, assess alterations in farmer perceptions of weed impact and importance between points in time, and detect adaptive changes in weed management practices.

The spread of fireweed

We confirmed our first hypothesis that fireweed had continued to spread into new areas in Australia since 1985 while establishing a more significant presence in regions that had previously been sparsely infested. Fireweed had been present for longest in a ‘core’ area (Nelson 1980) centred on Cumberland, Hexham, Gloucester, Muswellbrook, Taree and Lismore, while continuing to spread further north and south from its previous extremities as well as inland from the coast. Fringe infestation regions in the NSW Northern and Southern Tablelands, at altitudes of up to 1,000 m or more had previously thought to be somewhat unsuitable for fireweed (Sindel 1989), but were shown in the 2011 survey to have a relatively recent and spreading fireweed presence.

Given that fireweed has been present in Australia for over 100 years, and is still spreading rapidly, it is highly likely that it will continue to do the same in more recently invaded livestock systems around the world. The 18% of respondents across the survey who had fireweed on their land for less than 5 years (Table 2), also indicated that the weed had not yet reached the full extent of its potential distribution in Australia. This contention was supported by subsequent research by Wijayabandara (2020) and Wijayabandara et al. (2022) which demonstrated through landholder survey and climate modelling that fireweed had become more widespread in south-east Qld, had established in northern Qld and further inland in NSW, and that it had the potential to establish in much of coastal Australia. Fireweed likewise continues to expand its range in other countries (Le Roux et al. 2010, Tsutsumi 2011, Schmidt-Lebuhn et al. 2022), with further spread having been forecast (Wijayabandara et al. 2022) using global spread data and climate modelling. It is in these newly invaded pasture regions where landholders are likely to be in most need of information and support to manage fireweed most effectively.

Changing perceptions of the impact of fireweed

Our second hypothesis that the perceived importance and associated negative impact of fireweed may have changed in certain regions in the period 1985 to 2011, was also supported by the data. Fireweed was more problematic in Bega and several other areas in 2011 than in 1985, and appeared to have become a somewhat less serious problem in Taree, Gloucester and Cumberland (Table 4). While both Taree and Gloucester are largely rural areas dominated by farming and have had fireweed for a long period of time, Cumberland is dominated by the urban sprawl of the city of Sydney and fireweed was not considered to have been present on many farms on the outskirts of the city for a long period of time (Table 2). These results indicate that a variety of factors may be influencing the perception of fireweed across regions.

The 2011 survey results show that fireweed was considered less problematic by farmers who had either only found the weed on their farm recently, or who had several decades of experience with it (Tables 5 and 6). Whether such a pattern of perceptions (what we term the ‘problem status curve’; Fig. 2) is typical of farmers in pasture systems elsewhere or with other pasture weeds, needs further examination. Similar results were evident in the 1985 survey (Sindel & Michael 1988).

While the intensity of pasture weed infestations can decline over time at different stages of weed invasions due to ecological factors (e.g. Panetta & Scanlan 1995, Dostál et al. 2013, van Kleunen et al. 2018), a decline in the perception of impact and importance may be due to farmers developing more effective weed management strategies, or learning to live with a weed and restrict its most significant negative impacts. Such adaptations need to be understood by policy makers and agricultural advisers. Alternatively, the weed problem status may diminish relative to other species (including more recent incursions) and other farm management concerns.

In the case where a weed has recently invaded an area, and where infestations are presumably small, farmers may have insufficient experience to understand the potential problems that the weed may cause to be concerned about it. The dramatic increase in perceived importance of the fireweed problem in the Bega region in the period 1985–2011 (Tables 3 and 4) supports such an explanation and emphasises the need for early detection and control of invasive weeds like fireweed in new areas (Panetta & Scanlan 1995, DiTomaso et al. 2010). This may include preventive measures at a regional scale in anticipation of a weed’s likely spread into previously un-infested pastures, or eradication measures in the early stages of invasion.

Given the continuing high percentage of respondents overall who attempt to control fireweed (76% of those who had it on their farm in 2011), it evidently remains an important weed of grazed pastures throughout its Australian distribution. This is also reflected in its continued importance to livestock enterprise managers in key areas of fireweed distribution in places such as South America (Villalba & Fernández 2007, Bandarra et al. 2012, Panziera et al. 2018).

Adaptations in management

Our final hypothesis that there may have been adaptive changes in preferred fireweed control methods since 1985, was also supported by the survey data (Table 7). Exploring the changes in preferred fireweed control methods was intended to not necessarily provide landholders and their advisors with a series of recommendations about the best approach to managing this weed, but rather to identify those particular approaches that may have either fallen out of favour or become more popular from one point in time to another, and the potential reasons such as effectiveness, affordability and practicality At the time of writing, recent work suggested that integrated management of fireweed, using several supporting methods, was likely to give landholders the greatest chance of success in minimising its impact (Wijayabandara et al. 2022).

The two methods showing declined use between 1985 and 2011 were slashing (or mowing) and cultivation. Both techniques have several potential drawbacks. If not carried out and timed correctly, slashing can spread fireweed seed and promote plant regrowth into a second year (Verona et al. 1982).

Cultivation also stimulates seed germination, reduces competition, and can lead to increases in fireweed plant density (Sindel 1989, Wijayabandara et al. 2022). In the 1985 survey, both methods were regarded as having only a low to moderate level of success by 87% of respondents, suggesting that experience amongst farmers with these techniques has played an important role in their declining use and that they should not generally be promoted for fireweed control in pasture systems elsewhere.

Despite 79% of respondents in 1985 regarding the promotion of pasture competition as a moderately or highly successful technique for fireweed control, and its use recognised as an important contributor towards integrated management of this species by helping to reduce rates of seedling establishment (Wijayabandara et al. 2022), its use had not increased significantly by 2011. Likewise, implementation of reduced stocking rates, a key component of maintaining a competitive pasture, was used only by a small proportion of respondents. There are several potential reasons for this non-adoption of the promotion of competitive pastures and reduced stocking rates, relevant to fireweed and other pasture weed management globally. One reason may be that these practices are time-consuming and expensive, making them cost prohibitive for many farmers (Hogg & Davis 2009, Moss 2019, Jordon et al. 2023). Some farmers may lack the knowledge and resources necessary to adopt pasture management innovations (Wang et al. 2020), while others may need to maintain a high stocking rate to remain profitable (Jordon et al. 2023). Other factors may include apathy about long-term techniques that have no apparent immediate benefit (versus herbicides, for example) (Moss 2019), changing land ownership and lack of education on the techniques (Hogg & Davis 2009), and a perceived risk that the proposed weed management and other benefits of pasture improvement may not materialise (Moss 2019, Jordon et al. 2023).

Although sheep and goats readily eat fireweed plants and are relatively less susceptible to liver damage associated with PA consumption than cattle and horses (Bandarra et al. 2012, Panziera et al. 2018), the proportion of respondents using sheep or goats to manage fireweed (7%) increased only marginally from 1985 to 2011, despite their success rating remaining high. This result may be attributable to the fact that sheep and goats are likely to require more secure fencing and other modifications to farm infrastructure, more frequent yarding, and management practices with which cattle farmers may be less familiar. It can also be difficult to graze sheep or goats on steep, inaccessible land, such as that found in many regions of eastern Australia where fireweed is present. The wetter coastal environments where fireweed thrives are also not well suited for many breeds of Australian sheep that are more typically found in drier areas on and west of the mountains (Chapman et al. 1973). Nonetheless, sheep or goats have the potential to reduce infestations to minimal levels in a short timeframe (Bandarra et al. 2012, Wijayabandara et al. 2022) if such barriers to adoption can be overcome or are not present elsewhere in fireweed's worldwide range. The incidence of other pasture weeds containing PAs, for example *Echium plantagineum* (Paterson's curse), have been reduced successfully using sheep grazing (Burton et al. 2006).

While hand weeding was found to be effective and popular, it was usually impractical as a farm-wide management technique on larger farms with heavier infestations. It is one of the more time-consuming and expensive weed management techniques in pasture and rangeland systems (DiTomaso et al. 2010).

However, it may be particularly useful for smaller outbreaks, as an alternative to spot spraying for control of mature plants, and on smaller land areas, such as those found in Cumberland, which had the highest percentage of respondents of any region considering fireweed to be under control (26%).

Unlike other control methods, herbicide use increased dramatically from 12 to 49% between surveys despite respondents in 2011 giving herbicides a relatively low effectiveness rating. The reasons for this increase are unknown, but may be due to the rapidly observable effects of herbicides relative to other techniques (Dowling et al. 2000). The low success rate is likely due to the large soil seed bank of fireweed and multiple emergence events that require several applications per season due to the short-term efficacy of many herbicides, and the reduced effectiveness of certain chemicals as fireweed matures (Sindel & Michael 1996, Wijayabandara et al. 2022).

Conclusion

Repeated surveys regarding landholder perceptions of weed impact and management at different points in time are rare. This study highlighted the dynamic nature of weed infestations and how land managers respond to them, particularly as they discover over time what impact they are having on production, and what control methods are more or less effective. Although different sampling methodologies were used in 1985 and 2011, the survey questions were common, respondent types similar, and the differences in results intuitively logical, allowing for a high degree of confidence in comparing the results of the two surveys.

Over the 26 year period between the authors' surveys, fireweed was found to have spread to new areas in Australia, and become well established in previously lightly infested regions, altering its perceived importance at a regional scale. More recent research by other authors has demonstrated continuing spread of fireweed in Australia, and forecast significant potential further spread both in Australia and globally. Respondents to our 2011 survey were least troubled when fireweed was relatively new to their farm (< 5 years) or when it had been present for an extended time (> 30 years) compared with the intervening period. We have termed this phenomenon the 'problem status curve', and the reasons for changing perceptions of the importance of fireweed and other weed species around the world warrant further research as they may be used to inform weed management and extension policy given that farmer perceptions of impact are often the substitute imperative to measured impact for management. For example, weed importance perceptions indicate that education is required on the importance of prevention, early detection and control of highly invasive pasture weeds in new areas of occurrence before they become well established. On the other hand, the experience gained by farmers in the long term seems to enable them to adapt to living with fireweed or keeping it at a manageable level.

The effectiveness of control methods, however, was not the only factor driving adaptive changes in weed management. While low success of cultivation and slashing appeared to contribute to a decline in their use, herbicide use increased between the two surveys possibly due to its rapid visual effects despite its perceived ineffectiveness long-term. In contrast, although improving the competitiveness of pastures and grazing with sheep or goats were both shown in the 2011 survey (as in 1985) to be highly effective in managing fireweed, the lack of increased adoption of these techniques from 1985 to 2011 suggests that there are major impediments to their adoption. Such impediments require investigation in all livestock systems to enable better management of this and other similar invasive pasture weed species. Hand weeding remained both highly popular and effective as a method for controlling smaller infestations of fireweed, which is erect, readily visible and easily pulled from the ground when flowering. The same may not necessarily be true of other pasture weeds such as grass, deep tap-rooted, rhizomatous, prostrate and spiny species.

Weed invasions are by definition dynamic. So it seems are landholder perceptions of such invasions both regionally and individually between points in time. Poisonous *Senecio* species are becoming more problematic in many parts of the world. From this research, the lessons learned about spread, impact and control in earlier infested regions, the perceived importance of these weeds within the range of management problems faced by farmers, and how these perceptions may drive successful adaptive management, may well be instructional for those trying to manage new invasions of such weeds elsewhere. Consulting with land managers about pasture weed spread, impact and control through time may also inform the development of policy to support effective pasture weed management at the landscape level.

Declarations

Statements and Declarations

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The authors have no relevant financial or non-financial interests to disclose.

Human research ethics approval was provided by the University of New England (HE11-209).

The data developed for this research are not publicly available in order to preserve human research ethics and the privacy of farmers participating in the research.

All authors contributed to the study conception and design. Data collection instrument design, data collection and analysis were performed by all named authors. The first draft of the manuscript was written by Michael J Coleman, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

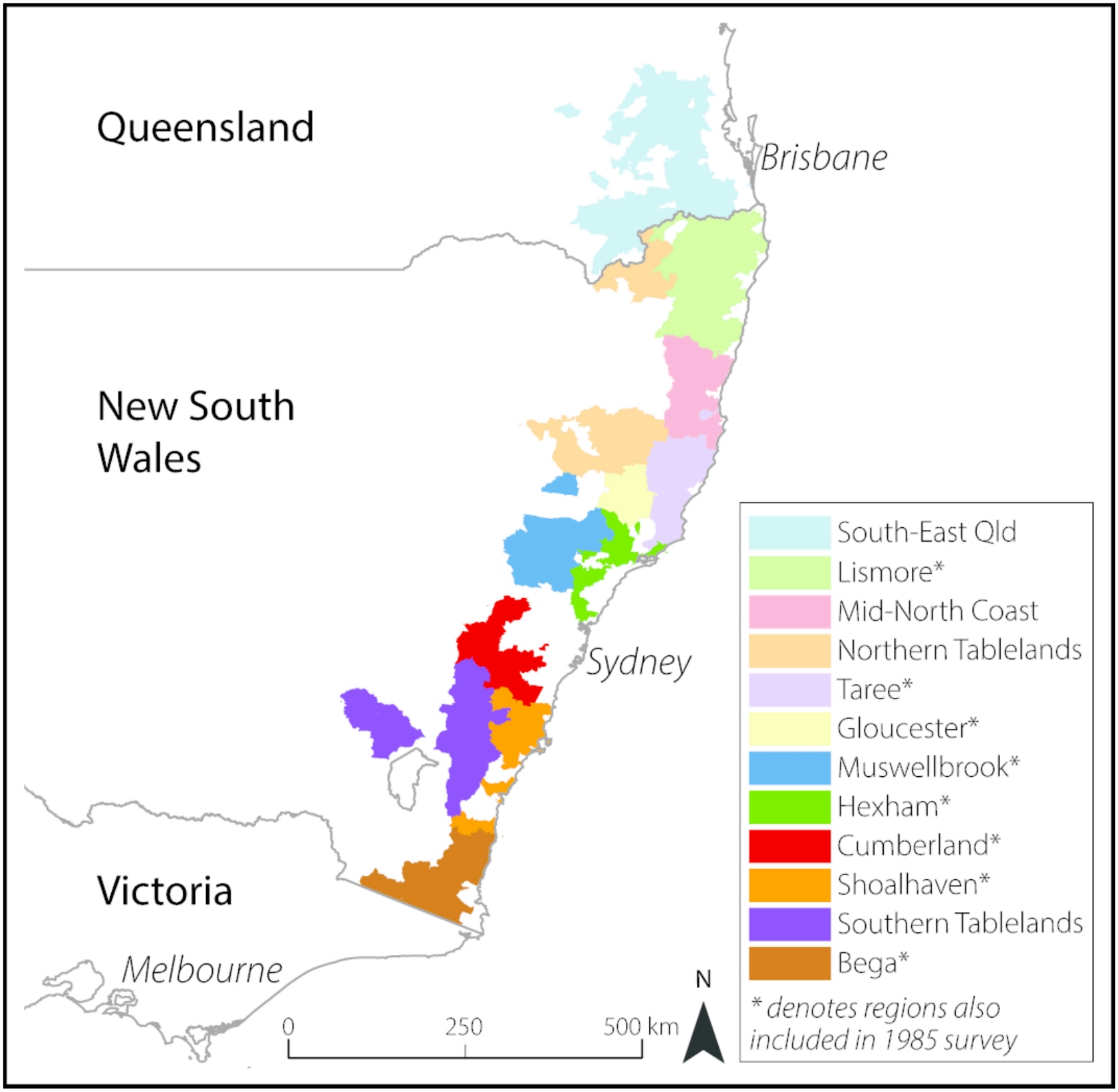

Figure 1

Regions of south-eastern Australia surveyed in relation to fireweed in 2011.

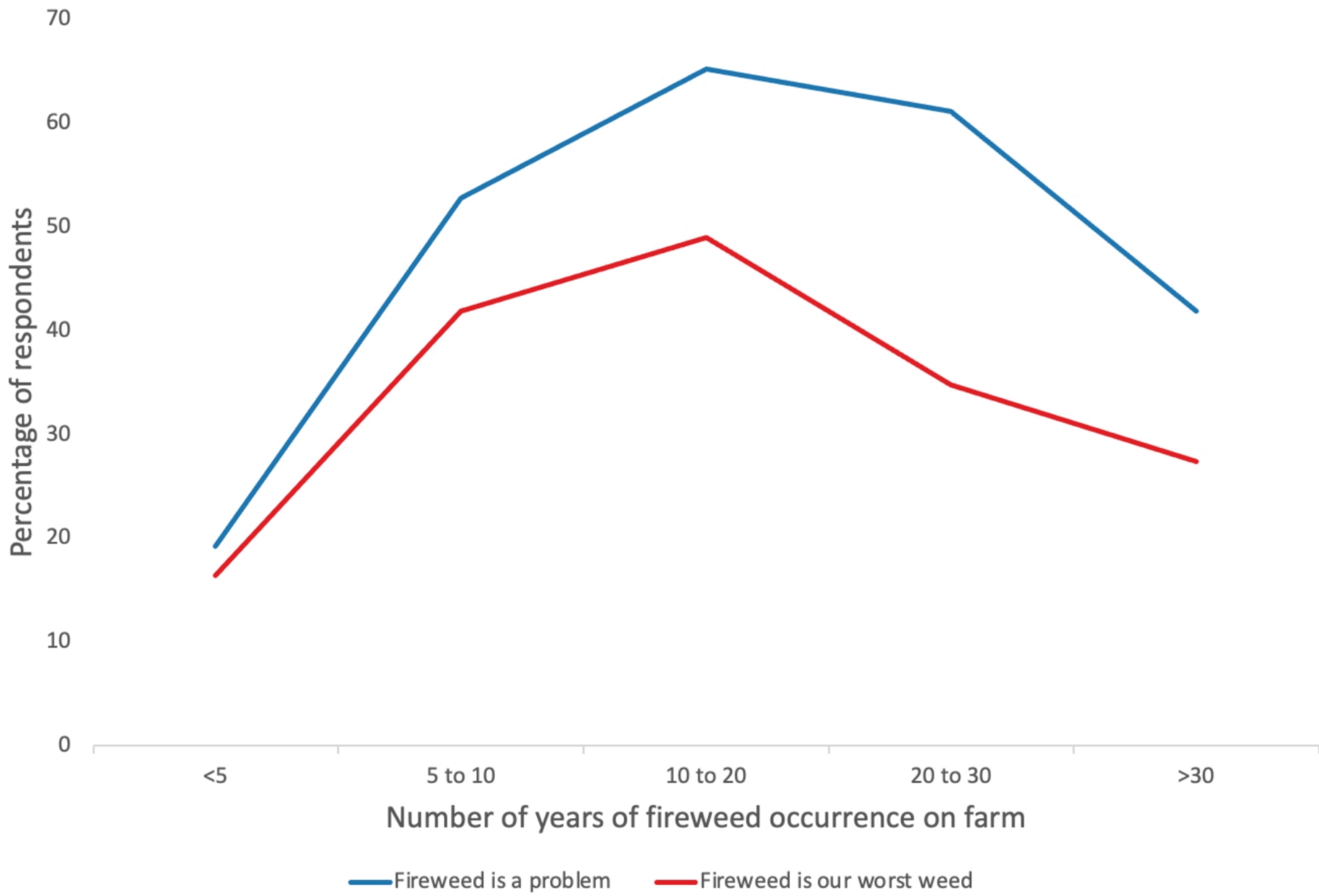

Figure 2

Percentage of respondents who consider fireweed to be either a moderate or major problem on their farm, or to consider it their worst weed problem, related to the years of its occurrence.