Charles Sturt University
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Final Report

Saving our Soils: Groundcover trigger points for pasture resilience during drought

A report prepared for Local Land Services project Saving Our Soils

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Executive Summary

Grazed lands have an increased risk of soil erosion during drought with the loss of soil nutrients impacting on future productivity. Overgrazing may also cause pasture decline and weed invasion, further reducing productivity. A groundcover threshold of 70% is recommended to minimise erosion and maintain pasture persistence in temperate regions, with a 50% threshold for rangelands. This study aimed to compare the delay in recovery of groundcover due to grazing to lower thresholds.

The GrazPlan software GrassGro was used to simulate grazing of annual or perennial pastures at five locations across the southern New South Wales Local Land Services area: Wagga Wagga, Temora, Orange, Yass and Hillston through the 2002, 2006 and 2018 drought periods. Sheep were either grazed throughout the droughts or were removed and fed in a feedlot when groundcover reached 90, 70, 50 and 30%, and were not returned to pasture. Annual pastures were simulated at each location, but a perennial pasture was only tested at Wagga Wagga as the persistence of the perennial pasture was not reduced by overgrazing, so was considered inaccurate.

At all locations, groundcover for annual pasture usually continued to decline after sheep were removed and only increased with pasture growth, which was usually due to autumn rain. Grazing to lower cover thresholds usually caused short delays (< 6 weeks) in the date at which pastures attained >70% groundcover, but prolonged the period when soil was exposed, and increased the level of risk of erosion. The risk was generally increased if thresholds were reached in spring rather than late autumn, due to the continued decline in cover until autumn growth. Annual pastures regenerated from soil seed reserves, so while delaying the removal of sheep often reduced seed reserves, adequate hard seed reserves minimised any impact of overgrazing on pasture recovery. Successive years of drought with overgrazing and poor seed set could reduce seed reserves to quantities which would compromise the recovery of pastures after drought.

The removal of sheep from pastures at 70% groundcover is recommended to minimise the duration of time when soil is exposed to an increased risk of soil erosion while reducing the time sheep need to be removed from pastures. Grazing annual pastures to lower groundcover levels may not cause large delays in the recovery of pasture after drought, but due to groundcover often continuing to fall after the removal of sheep, may result in a high risk of soil erosion. Graziers have a large capacity to sustainably manage their soils and pastures through managing stocking rates and destocking when appropriate.

Table of Contents

Project objectives

Overgrazing of pastures during drought leads to excessive removal of plant material, exposing the soil to an increased risk of erosion. Overgrazing can also lead to reduced seed-set and/or reduced persistence of the pasture, resulting in poor recovery to productive levels after the drought ends. The lack of adequate density of pasture plants may lead to prolonged periods of lower groundcover, with associated increased risk of soil erosion, invasion of weed species (Dear *et al.* 2007; Robertson *et al.* 2020) and may necessitate costly re-sowing of the pasture. Pasture decline is increased when low rainfall is combined with suboptimal soil and grazing management (Kemp and Dowling 1991; Reeve *et al.* 2000; Nie and Norton 2009; Norton *et al.* 2020). The resilience of pastures to drought and protection of the soil resource is dependent on adoption of regionally appropriate pasture species and management practices which maintain adequate groundcover.

Field studies in medium to high rainfall regions have enabled a target threshold of 70% groundcover to be recommended to minimise the risk of soil erosion and reduce water runoff, allowing rainfall to infiltrate the soil and be available for pasture production (Lang 1998). While soil loss was minimal at 70% groundcover, losses increased to approximately 15 T/ha per year at 50% groundcover, and 80 T/ha per year at 20% groundcover, highlighting the importance of critical thresholds for removal of stock from pasture. The risk also varied with pasture species due to the pasture structure (erect versus prostrate), such that a single critical quantity of herbage threshold at which to cease grazing would not be appropriate for all conditions. The risk of erosion increased with higher degrees of soil slope and on soil types which eroded more easily. In rangelands, a minimum groundcover of 54% has been recommended as the lower level to minimise soil erosion of sandplains (Leys 1992).

The ability of pastures to regain productivity quickly after drought is important to enable a return to more normal levels of livestock grazing. While the adverse impact of overgrazing is clear, there is a lack of information describing the increase in time to return to normal pasture production post-drought resulting from removal of stock before overgrazed. The aim of this simulation study was therefore to assess the delay in pasture recovery post-drought when stock were removed from pastures at decreasing levels of groundcover (overgrazing) across the low to high-rainfall regions of the Local Land Services Riverina region of southern NSW.

Methodology

A simulation study was conducted using GrassGro 3.4.3 (Donnelly *et al.* 1997). This is a biophysical model which simulates pasture growth using a defined soil type and daily historical weather records. Grazing of the pasture is simulated using a user-defined type of livestock with all key management activities considered.

Southern NSW is diverse with a range of different landscapes and farming systems including rangelands, wheat-sheep and high rainfall. Modelled locations were selected to represent this range of environments, and included Wagga, Orange, Temora, Yass and Hillston. The models used pasture species relevant to each location with sheep removed at 90, 70, 50, and 30% groundcover in order to show a progressive reduction in the groundcover target. The 30% target was not modelled for some droughts in some locations as this was not achieved with the stocking rates used.

Pasture-only systems were modelled because GrassGro does not model crops. Simulations (Table 1) were run using a mixed perennial/annual pasture and/or an annual pasture to allow the impact on different types of pastures to be defined. The soil parameters used for each location are shown in Appendix 1, and average monthly pasture growth rates provided in Appendix 2. Each simulation used a stocking rate typical for each location, with the stocking rate then increased where necessary to allow lower levels of groundcover to be achieved. This also recognises that when not continuously stocked the stocking rates used on an individual paddock at some times will be higher than the annual average, and in any case stocking rates vary widely between farms. The pastures were continuously grazed. While continuous grazing is not the recommended strategy for some pasture species, it overcame the difficulty in setting time of removal of stock from a pasture dependant on groundcover whilst grazing more than one paddock. The simulation of perennial species also does not allow overgrazing to kill plants, limiting the impact of continuous grazing on persistence. For this reason, a perennial pasture was only modelled at Wagga Wagga. The seed set of annual species is accurately simulated allowing the impact of drought and overgrazing to be assessed, and annual-only pastures are also common at some of the locations.

Simulations were conducted for the period 1969 to 2019 to establish long-term production, and 1999 to 2019 or 2021 (dependant on the duration of weather records) to evaluate groundcover trigger points in recent droughts, with the first year of data deleted to allow the model to initialise. The pasture reset option was turned on to allow resowing of failed pastures in the period before each drought. Sheep were fed in the paddock to maintain condition score if condition score of the thinnest sheep fell to 1, in order to maximise grazing pressure. Drought years were identified using both rainfall data and the simulated pasture availability.

Table 1. Description of key simulation parameters for each location.

	Wagga Wagga	Temora	Orange	Yass	Hillston
Weather station	Wagga 35° 10'S 147° 27'E	Temora 34°24'S 147°32'E	Blayney 33° 32'S 149° 15'E	34° 50'S 148° 55'E	Hillston 33° 30'S 145° 31'E
Average long-term rainfall (mm)	587	536	875	701	393
Stocking rate	10 breeding ewes/ha	6 breeding ewes/ha	4.7 breeding ewes/ha (6 sheep/ha)	7.8 breeding ewes/ha (10 sheep/ha)	2 breeding ewes/ha
Pastures	Perennial: Phalaris, subclover (Seaton Park), annual ryegrass Annual: annual grass early (e.g., barley grass); annual ryegrass; subclover (Seaton Park)	Annual: subclover (Seaton Park), annual grass	Annual: subclover (Leura); annual ryegrass	Annual: annual ryegrass; subclover (Seaton Park)	Annual: annual grass, annual medic (Paraggio)
Soil type	Red duplex (undulating hills) Dr 2.32	Red earth Gn 2.11	Massive and structured earth Gn 2.15	Standard GrassGro file "Kia-Ora" Bookham	Red duplex Dr2.33
Soil fertility scalar	0.80	0.90	0.79	0.76	0.55

For each drought period the simulation was started in the first year of the drought period at a time when groundcover was above 90%. The pasture reset option was turned off and the simulation run using an estimated common stocking rate for each location, without stock being removed from pasture in order to establish the base level of groundcover and pasture recovery over the drought. The simulation was then re-run with sheep removed using the drought feeding option with all sheep fed in a feedlot. The sheep were not returned to the pasture and ungrazed pasture performance was simulated to 2006, 2010 or 2019, respectively for the 2002, 2006 and 2018 drought periods. Groundcover, green herbage mass and seed mass were used to compare the recovery of pastures after drought for the different groundcover thresholds.

Results

Wagga Wagga

Mixed phalaris/annual pasture

Drought years occurred at Wagga Wagga in 2001/2002, 2006 to 2009, and 2018/2019 (Table 2). These were reflected in the large reductions in simulated available green phalaris/annual pasture (Figure 1) compared with longer term trends. Annual ryegrass was the dominant species although phalaris and subclover persisted throughout the simulation.

Groundcover did not decline to the lower thresholds if a common district stocking rate (5 ewes/ha) was used, so a higher stocking rate (10 ewes/ha) was applied from the start of each drought period. The quantity of dead pasture was also reduced at the start of the 2002 drought to allow the cover thresholds to be reached. For all droughts, the 90% threshold was reached in late spring/early summer, with the lowest thresholds not reached for up to 5 months (Table 3a). The lowest threshold of 30% was not reached in the 2006 and 2018 droughts at the stocking rate used.

The removal of sheep from pasture at each groundcover threshold clearly maintained groundcover at higher proportions than if pasture continued to be grazed, as shown in Figure 2. Removal of sheep did not prevent groundcover declining by a further 20% when removal occurred during late spring or summer when annual pasture was mature (dead) and phalaris dormant (Table 3a). When removal of sheep occurred in autumn, further reductions in groundcover were minimal because recovery of groundcover was rapid with growth of pasture in autumn. For all thresholds, groundcover had returned to at least 70% by August 2003, May 2007 or April 2018 for the 2001, 2006 and 2018 droughts, respectively. While there was a minimal difference in the time at which 70% cover was regained, the duration of time at which soil was exposed and the level of exposure did increase with later thresholds for removal.

The time at which the groundcover thresholds were reached varied with stocking rate. If stocked at 10 rather than 5 ewes/ha, critical thresholds were reached up to several months earlier for the summer/autumn 2008/09 period, while during the winter periods groundcover was often similar between stocking rates, shown in Figure 3. However, the high stocking rate resulted in groundcover below 70% for most of the year even when not in drought, demonstrating the need to set stocking rates appropriate to pasture production.

The removal of sheep from grazing at lower groundcover thresholds tended to delay and reduce herbage production at the next autumn/winter by 200 to 400 kg DM/ha in 2003, 2007 and 2019 Figure

4. The reduction was reduced when the times of removal were close. There was no or a limited impact in later years.

Table 2. Annual rainfall (mm) January to December 2000 – 2021 for Wagga Wagga, Temora, Orange, Yass and Hillston, showing drought years simulated, and long-term average annual rainfall 1970-2021.

Year	Wagga Wagga	Temora	Orange	Yass	Hillston	Drought year
2000	653	564	1034	730	500	
2001	488	374	754	554	395	drought
2002	384	290	621	549	185	drought
2003	443	438	805	746	416	
2004	494	379	842	626	277	
2005	513	582	905	718	370	
2006	267	197	502	330	217	drought
2007	466	500	851	636	395	drought
2008	477	447	856	626	288	drought
2009	362	411	641	603	281	drought
2010	1019	750	1526	1042	820	
2011	721	832	849	728	481	
2012	628	593	784	909	599	
2013	398	444	672	584	n/a	
2014	478	535	834	782	300	
2015	648	579	839	652	448	
2016	779	911	1261	967	698	
2017	503	475	593	666	268	
2018	410	340	589	532	198	drought
2019	492	332	480	526	197	drought
2020	874	n/a	n/a	1039	n/a	
2021	873	n/a	n/a	1083	n/a	
Average	587	536	875	701	393	

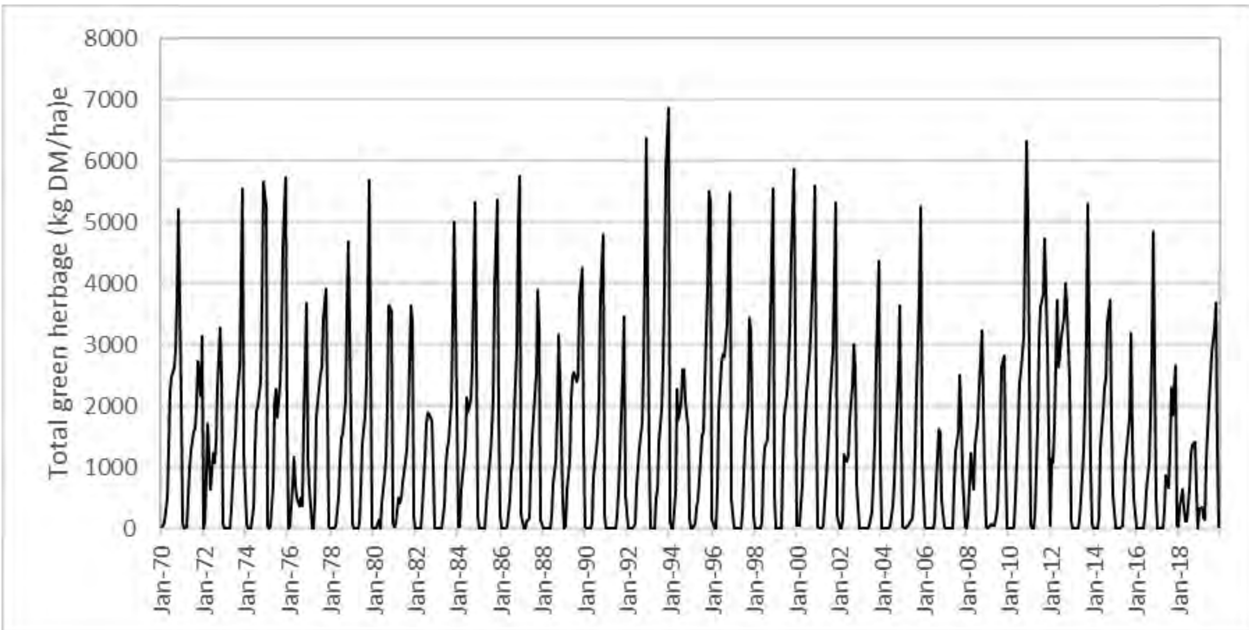

Figure 1. Simulated total green herbage (kg DM/ha) for a mixed phalaris, subclover and annual ryegrass pasture at Wagga Wagga 1970-2021 when continuously grazed by 5 ewes/ha.

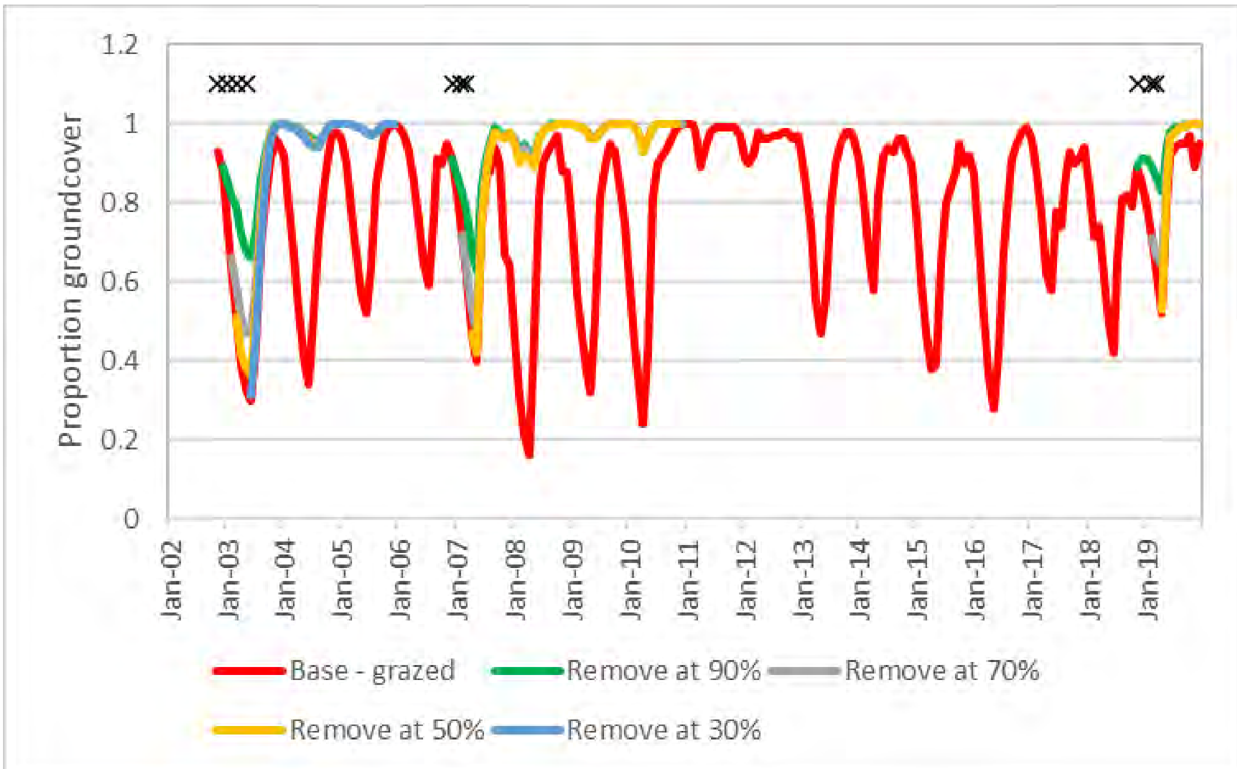

Figure 2. Proportion groundcover for a mixed phalaris/annual pasture at Wagga Wagga when continuously grazed by 10 ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

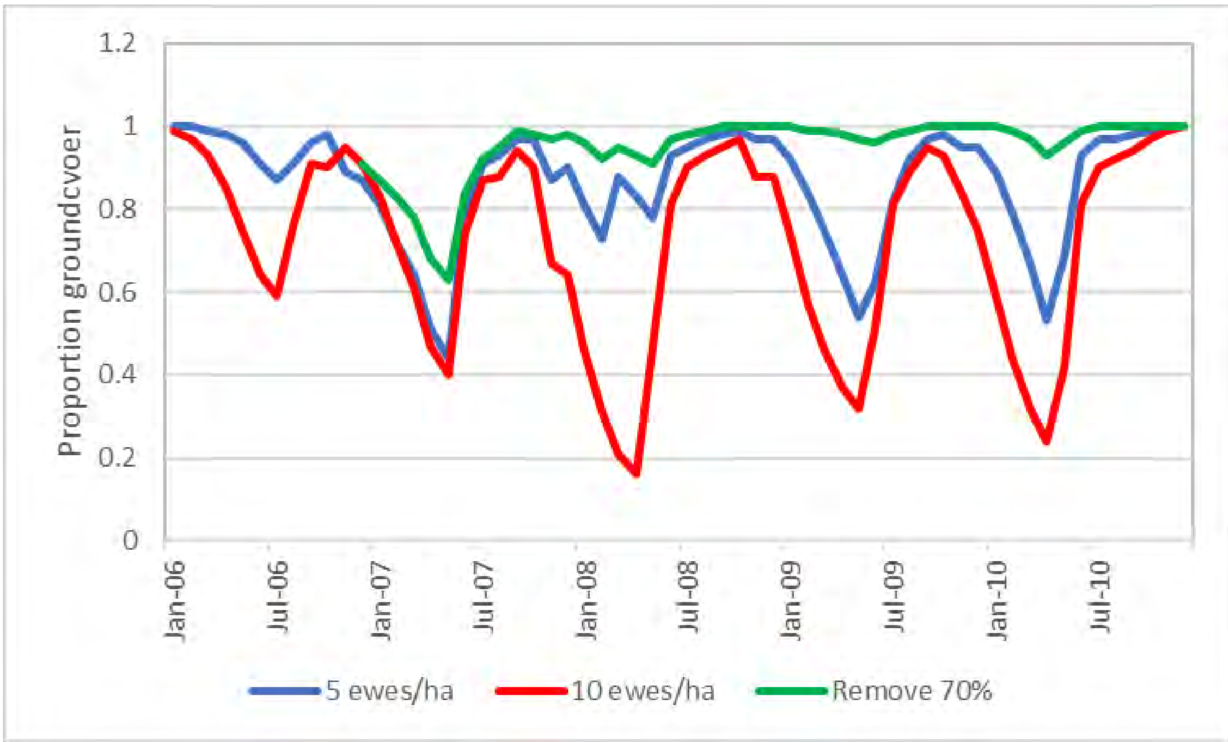

Figure 3. Proportion groundcover for a mixed Phalaris/annual pasture at Wagga Wagga when continuously grazed at either 5 or 10 ewes/ha, or if sheep were removed at 0.70 groundcover threshold on 5 February 2007 in the 2006 drought.

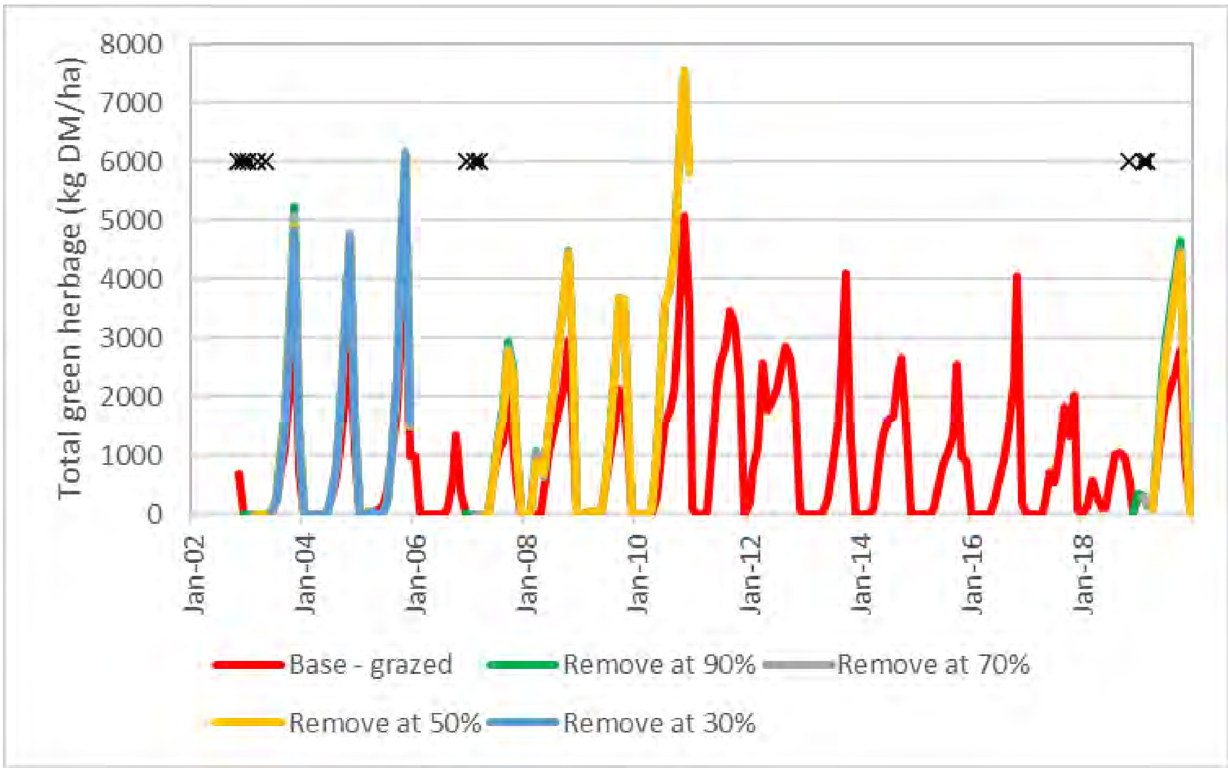

Figure 4. Total green herbage mass (kg DM/ha) for a mixed phalaris/annual pasture at Wagga Wagga when continuously grazed by 10 ewes/ha or where sheep were removed when groundcover fell to 0.90, 0.70, 0.50 or 0.30 proportion groundcover in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

Table 3a. Date of removal of sheep from pastures at 90, 70, 50 and 30% groundcover at Wagga Wagga and Temora in simulated drought periods of 2002, 2006 and 2018 and the date when groundcover regained 70%.

		Wagga Wagga (Phalaris)				**Wagga Wagga (annual)**				**Temora**			
Drought	**Threshold**	Date Removed	Date regain 70%	Minimum cover	Days < 70%[A]	Date removed	Date regain 70%	Minimum cover	Days < 70%[A]	Date removed	Date regain 70%	Minimum cover	Days < 70%[A]
2002	Base	No	4 Aug 2003	28	196	No	11 Jul 2003	39	144	No	4 Jun 2003	47	177
	90%	22 Nov 2002	14 Jun 2003	66	53	19 Dec 2002	26 May 2003	66	28	18 Jan 2002	Not below	76	0
	70%	20 Jan 2003	15 Jul 2003	45	175	16 Feb 2003	23 Jun 2003	50	125	18 Mar 2002	31 Mar 2002	68	19
	50%	4 Mar 2003	22 Jul 2003	35	183	10 Apr 2003	4 Jul 2003	42	137	11 Mar 2003	29 May 2003	49	171
	30%	15 May 2003	1 Aug 2003	29	193	-			-	-			-
2006	Base	No	28 May 2007	40	178	No	2 Jun 2007	32	222	No	30 Jun 2007	29	234
	90%	7 Dec 2006	14 May 2007	63	46	21 Oct 2006	15 May 2007	59	55	29 Apr 2006	Not below	79	0
	70%	5 Feb 2007	24 May 2007	48	106	27 Dec 2006	15 May 2007	42	148	6 Nov 2006	4 Jun 2007	47	208
	50%	25 Mar 2007	28 May 2007	42	110	25 Feb 2007	27 May 2007	37	150	30 Jan 2007	18 Jun 2007	35	222
	30%	-	-	-	-	25 Apr 2007	31 May 2007	32	154	30 Apr 2007	28 Jun 2007	29	232
2018	Base	No	21 Apr 2019	52	74	No	2 Jun 2019	14	314	No	8 May 2019	48	368
	90%	1 Nov 2018	Not below 70%	82	0	9 Mar 2018	Not below 70%	73	0	19 Feb 2018	Not below	74	0
	70%	4 Feb 2019	10 Apr 2019	63	52	25 Apr 2018	30 Jun 2018	59	65	21 Apr 2018	27 Jun 2018	62	65
	50%	25 Mar 2019	19 Apr 2019	52	72	28 Dec 2018	17 May2019	30	294	30 Dec 2018	5 Apr 2019	50	251
	30%	-	-	-	-	4 Feb 2019	22 May 2019	20	299	-	-	-	-

[A] Days<70% cover from the period: Wagga Wagga perennial: 1 Nov 2002 to 31 Dec 2003; 1 Nov 2006 to 31 Dec 2007; 1 Nov 2018 to 31 Dec 2019; Wagga Wagga annual: 1 Nov 2002 to 31 Dec 2003; 1 Oct 2006 to 31 Dec 2007; 1 Dec 2017 to 31 Dec 2019; Temora: 1 Jan 2002 to 31 Dec 2003; 1 Jan 2006 to 31 Dec 2007; 1 Jan 2018 to 31 Dec 2019.

Table 3b. Date of removal of sheep from pastures at 90, 70, 50 and 30% groundcover at Orange, Yass and Hillston in simulated drought periods of 2002, 2006 and 2018 and the date when groundcover regained 70%.

		Orange				Yass				Hillston			
Drought	**Threshold**	Date removed	Date regain 70%	Minimum cover	Days < 70%[A]	Date removed	Date regain 70%	Minimum cover	Days < 70%[A]	Date removed	Date regain 70%	Minimum cover	Days < 70%[A]
2002	Base	No	7 Apr 2003	20	174	No	3 Apr 2003	45	111	No	29 Jun 2003	34	255
	90%	3 Aug 2001	Not below	87	0	24 Oct 2002	Not below	81	0	14 Mar 2002	3 Jun 2003	55	129
	70%	2 Nov 2002	1 Mar 2003	51	119	13 Dec 2002	19 Mar 2003	61	96	14 Oct 2002	12 Jun 2003	45	236
	50%	27 Nov 2002	5 Mar 2003	43	123	9 Feb 2003	31 Mar 2003	48	108	23 Jan 2003	23 Jun 2003	37	249
	30%	5 Jan 2003	20 Mar 2003	27	138	-	-	-	-	29 Apr 2003	28 Jun 2003	34	254
2006	Base	No	19 Mar 2007	27	176	No	4 May 2007	33	148	No	15 Jun 2008	26	774
	90%	3 Jul 2006	Not below	84	0	17 May 2006	Not below	87	0	26 Nov 2006	4 May 2007	69	74
	70%	21 Oct 2006	21 Feb 2007	59	123	6 Dec 2006	5 Apr 2007	53	133	3 Mar 2007	25 May 2007	61	169
	50%	9 Dec 2006	7 Mar 2007	43	137	14 Jan 2007	30 Apr 2007	39	144	14 Apr 2008	12 Jun 2008 and 2 Jul 2010	46	374
	30%	12 Jan 2007	15 Mar 2007	29	145	1 Mar 2007	2 May 2007	33	146	9 Jun 2009	13 Jun 2010	27	755
2018	Base	-	-	-	-	No	12 Apr 2019 and 12 May 2020	26	317	No	24 May 2019	24	559
	90%	-	-	-	-	4 May 2018	Not below	82	0	4 Nov 2017	9 Jul 2018	61	221
	70%	-	-	-	-	4 Oct 2018	15 Nov 2018	61	42	25 Feb 2018	13 May 2019	47	465
	50%	-	-	-	-	12 Feb 2019	6 Apr 2019	46	151	10 May 2018	16 May 2019	42	481
	30%	--	-	-	-	26 Feb 2020	4 May 2020	26	309	18 Mar 2019	23 May 2019	29	498

[A] Days<70% cover from the period: Orange 1 Jul 2001 to 31 Dec 2003; 1 Jan 2006 to 31 Dec 2007; Yass: 1 Apr 2002 to 31 Dec 2003; 1 Dec 2005 to 31 Dec 2010; 1 Jan 2017 to 31 Dec 2019; Hillston: 1 Jan 2001 to 31 Dec 2003; 1 Dec 2005 to 31 Dec 2010; 1 Jan 2017 to 31 Dec 2019.

Annual grass pasture

The total green herbage of annual pasture varied widely over the years simulated at Wagga Wagga (Figure 5). Annual grass dominated the mixed subclover/grass pasture. The lowest threshold of 30% was not reached in the 2002 drought at the stocking rate of 10 ewes/ha. As for the phalaris pasture, removal of sheep during the summer/early autumn period did not prevent further decline in groundcover by up to 28% with a lesser decline with removal of sheep closer to the autumn break (Figure 6; Table 3a). However, removal of sheep at higher thresholds reduced the extent of decline in comparison to continued grazing, with removal at 90% cover in December 2006 and March 2018 preventing cover falling below 90%. Groundcover increased when the annual pasture germinated in autumn, so when removal of sheep was delayed to the 30% threshold, this tended to occur closer to autumn rains, minimising the continued decline in cover for this strategy. The increase in groundcover with autumn rains meant that the time from removal of sheep to 70% groundcover being regained was only increased by up to 6 weeks by delaying the removal of sheep. However, delaying removal resulted in prolonged periods of time when cover was below the 70% threshold. The duration of time when sheep were removed from paddocks was much longer in the 2018 drought for those removed at higher thresholds (90 or 70%) due to the pattern of pasture growth in that year.

Green herbage mass was minimally reduced (< 200 kg DM/ha) by the later removal of sheep during the 2002 and 2006 droughts, and production did not vary in post-drought years. However, herbage production in autumn/winter 2019 was at least doubled by the removal of sheep in autumn 2018 compared with delaying removal to a threshold of 50% cover in December 2018, shown in Figure 7.

The reserves of annual grass and subclover seed were halved by continuing to graze pasture from December to April 2003. However, a large quantity of seed (> 400 kg/ha) was produced by both grazed and ungrazed paddocks in spring 2003, such that ample seed was available to regenerate pastures in 2004 (Figure 8). Similarly, large reductions in seed reserves resulted from later removal of sheep between October 2006 and April 2007. Only 2 kg/ha of seed remained in August 2007 in paddocks where sheep were not removed, compared with 32 kg/ha if sheep were removed at 90% cover in December 2006. Adequate regeneration of pasture was enabled by adequate seed production (> 150 kg/ha) in 2007. The winter reserves of seed remained < 20 kg/ha in the winters of 2007 to 2010 where sheep were continuously grazed and annual seed production was relatively low. Reductions in seed due to delayed removal of sheep also occurred in 2018/19. Successive drought years increased the risk of seed reserves being depleted to levels which would prevent re-establishment.

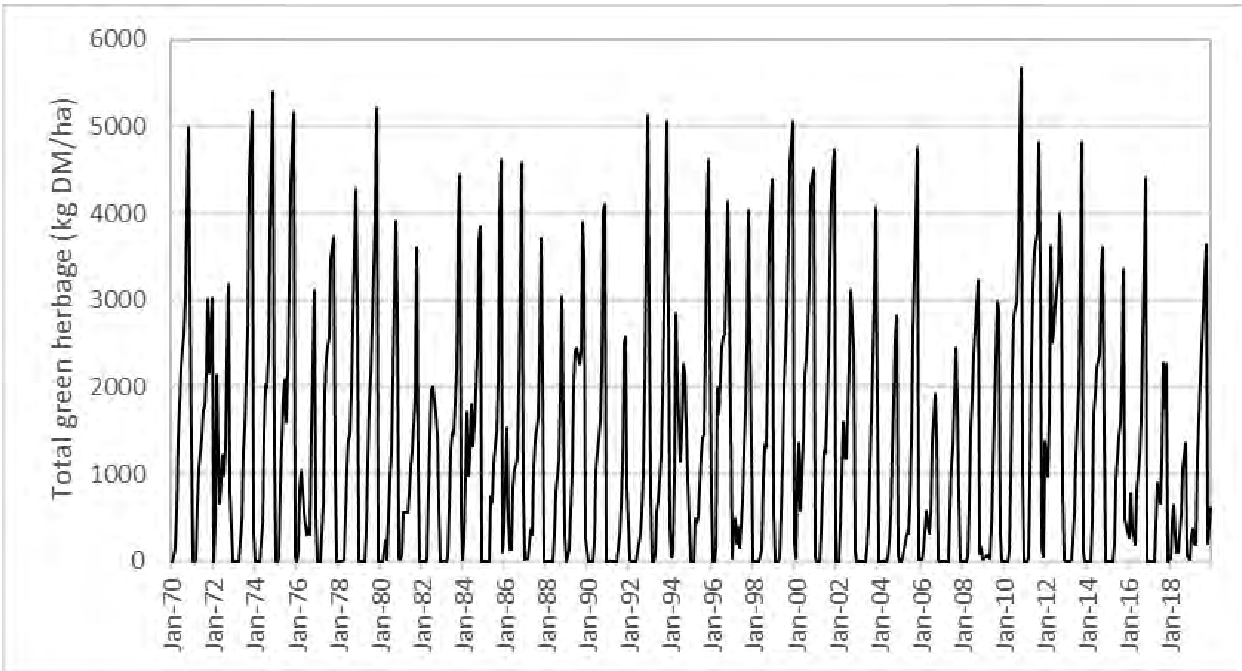

Figure 5. Simulated total green herbage (kg DM/ha) for an annual pasture at Wagga Wagga 1970-2019 when continuously grazed by 5 ewes/ha.

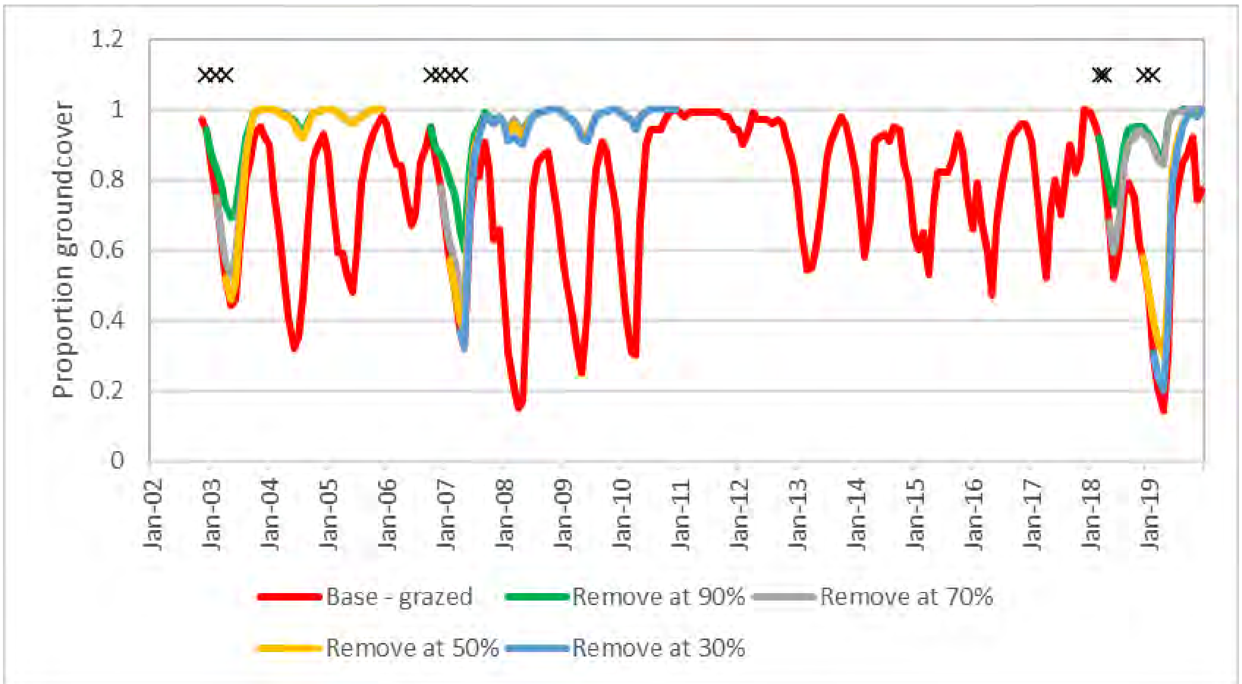

Figure 6. Proportion groundcover for an annual pasture at Wagga Wagga when continuously grazed by 10 ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

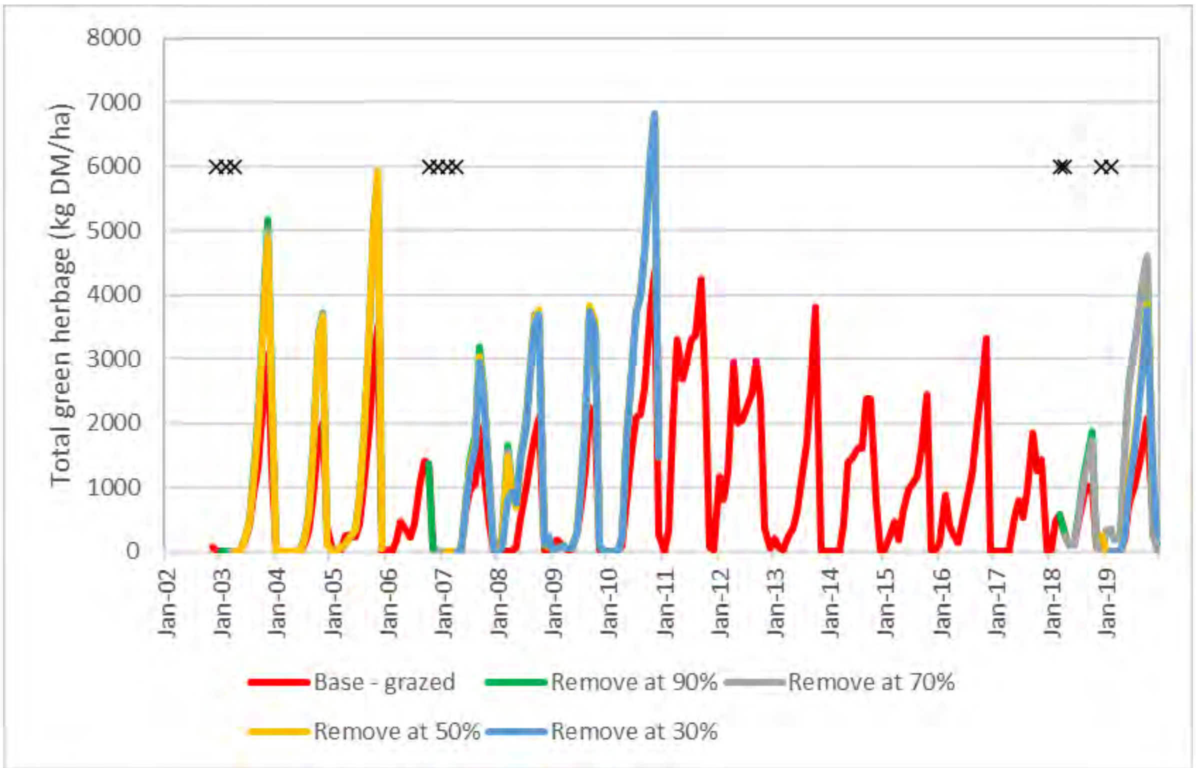

Figure 7. Total green herbage mass (kg DM/ha) for an annual pasture at Wagga Wagga when continuously grazed by 10 ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 and 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

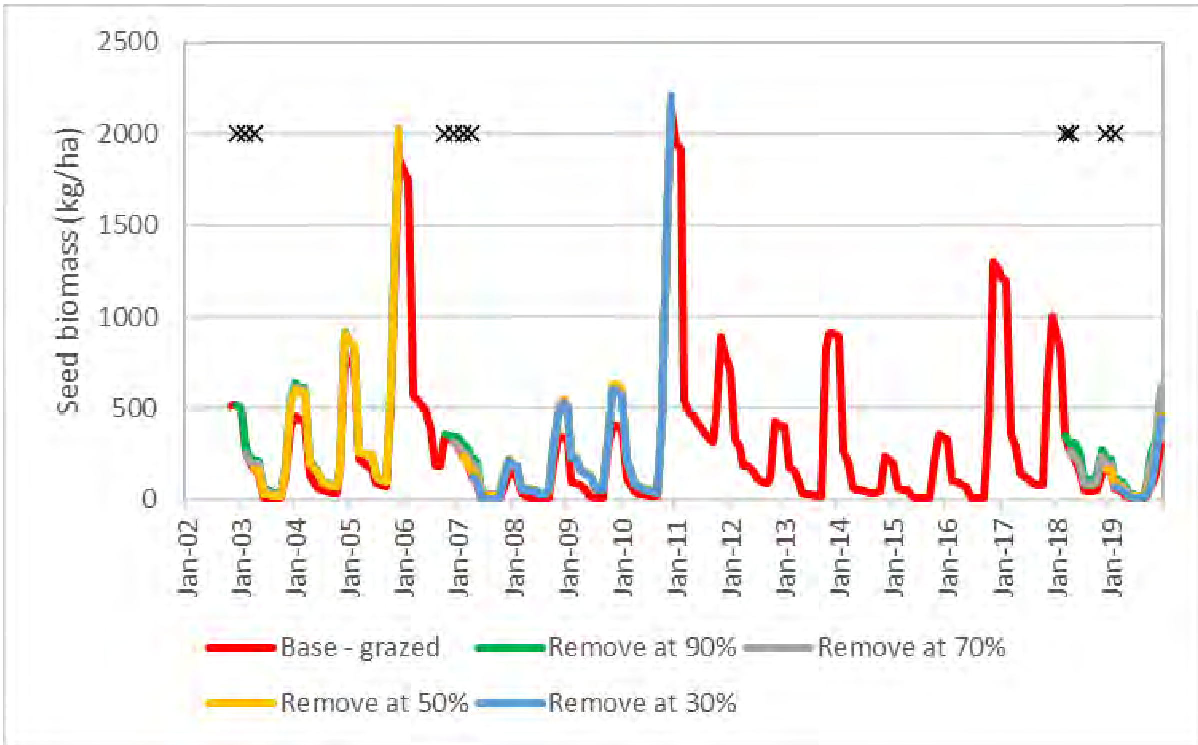

Figure 8. Total seed mass (kg/ha) for an annual pasture at Wagga Wagga when continuously grazed by 10 ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 and 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

Orange

Annual ryegrass/subclover pasture

The simulated annual pasture at Orange had some growth in summer, which differed from published estimates. Pasture growth during winter was slow due to cold temperatures, resulting in low productivity (Figure 9).

Annual pasture was not modelled for the 2018 drought at Orange because groundcover did not fall to 50% until 2019, which did not allow the recovery period to be assessed. While groundcover did not fall below 70% if sheep were removed at the 90% threshold, cover continued to decline by up to 19% after removal of sheep at all thresholds in both the 2002 and 2006 droughts (Figure 10). The further decline was reduced at removals in January rather than November due to growth of pasture. Groundcover recovered to above 70% in late February to March 2003 and 2007 for the 30 to 70% thresholds (Table 3b). Delaying removal of sheep from the annual pasture therefore increased the time to recovery of groundcover by a maximum of 4 weeks. Delaying the removal of sheep meant cover was below the 70% threshold for a longer period of time, and the level of exposure was increased.

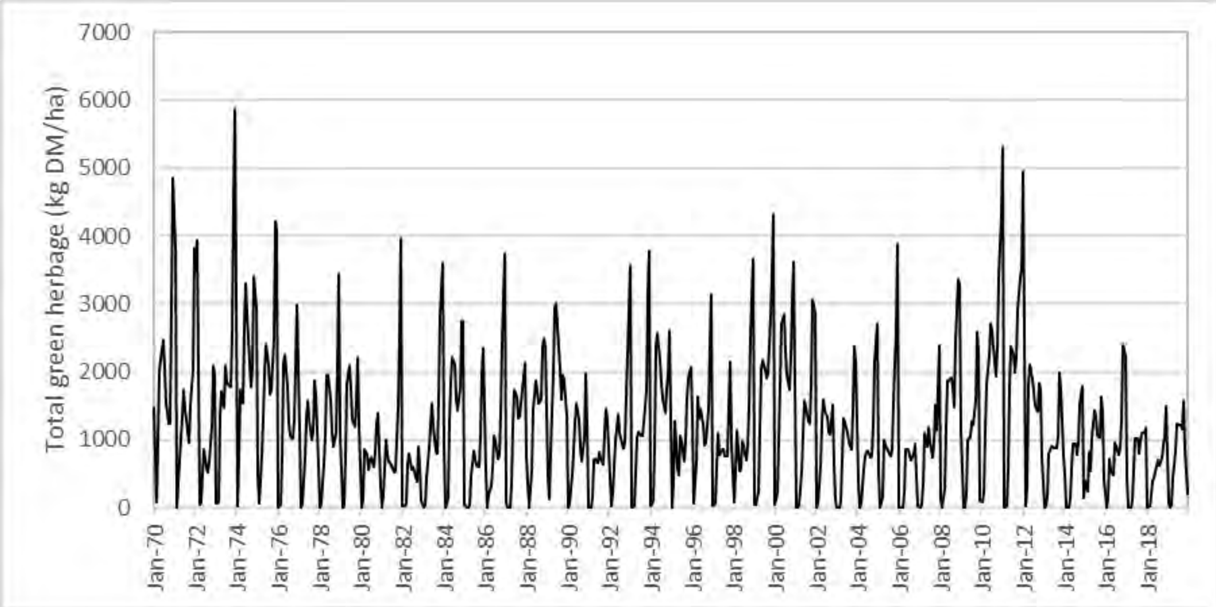

Figure 9. Simulated total green herbage (kg DM/ha) for an annual pasture at Orange 1970-2019 when continuously grazed by 6 sheep/ha.

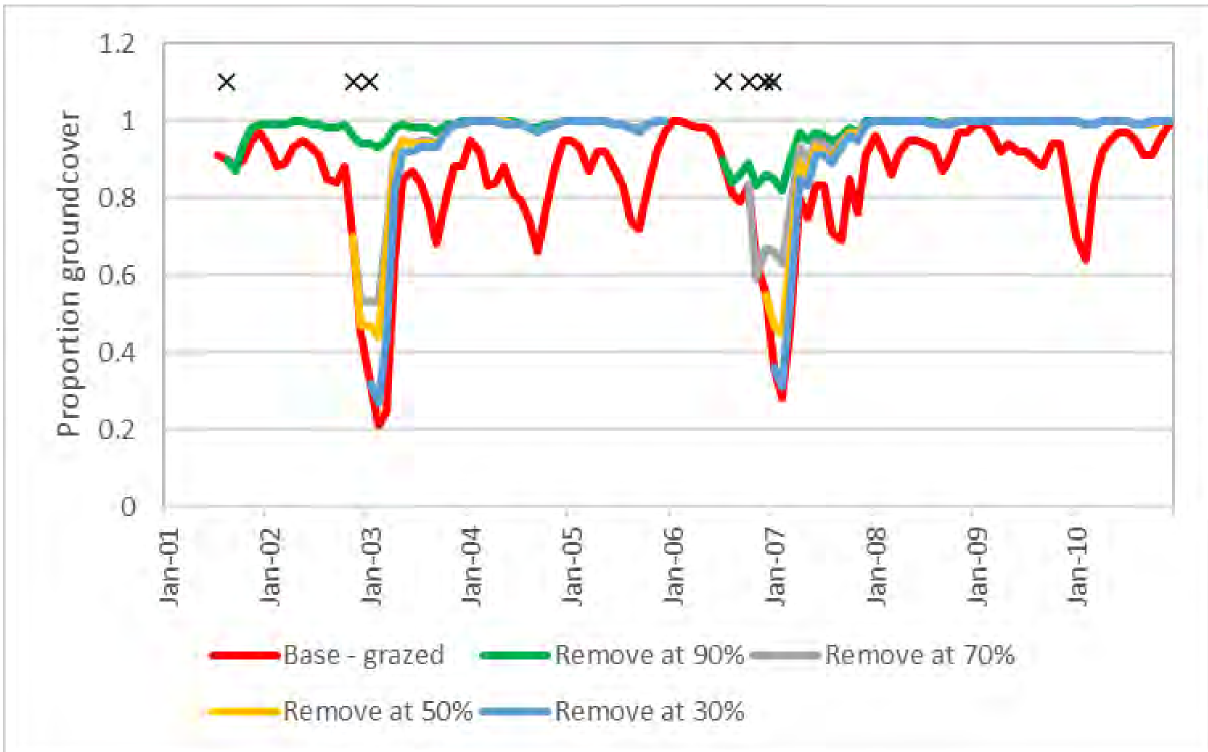

Figure 10. Proportion groundcover for an annual grass pasture at Orange when continuously grazed by 6 sheep/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002 and 2006 droughts. X = times at which sheep were removed for each groundcover threshold.

The quantity of green herbage in winter/spring 2003 was increased by approximately 500 kg DM/ha through removal of sheep at 90% cover in August 2001 rather than 30% cover in January 2003 (Figure 11). There was a gradual reduction in the quantity of winter herbage with progressively later removal of sheep, but during 2004 the difference was minimal (< 100 kg DM/ha). A similar pattern occurred with sheep removal between July 2006 and January 2007.

Seed reserves in autumn 2003 were halved if sheep were removed from pastures in January 2003 rather than August 2001 (Figure 12). However, the quantity of seed in January 2003 was reduced from 256 to 149 kg/ha by removing sheep at 30% cover in January 2003, rather than 70% cover in November 2003. A large quantity of seed set (> 1400 kg/ha) for all thresholds meant the 11% difference between thresholds would have little effect on pasture regeneration in 2004. Seed production was similarly reduced by 50% in the 2006 drought through continuing to graze pastures below the 90% threshold (August 2006) until 30% cover was reached (January 2007). High seed production (> 550 kg/ha) in 2007 again resulted in minor differences in seed reserves for 2008.

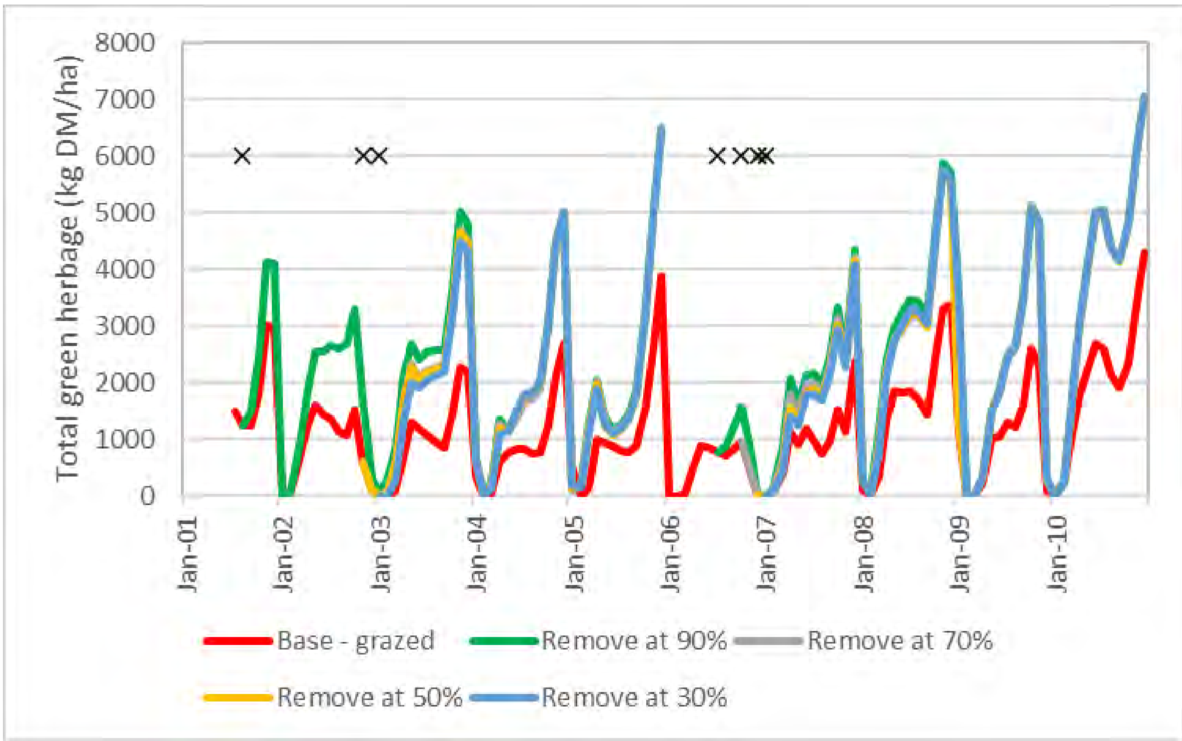

Figure 11. Total green herbage mass (kg DM/ha) for an annual pasture at Orange when continuously grazed by 6 sheep/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002 and 2006 droughts. X = times at which sheep were removed for each groundcover threshold.

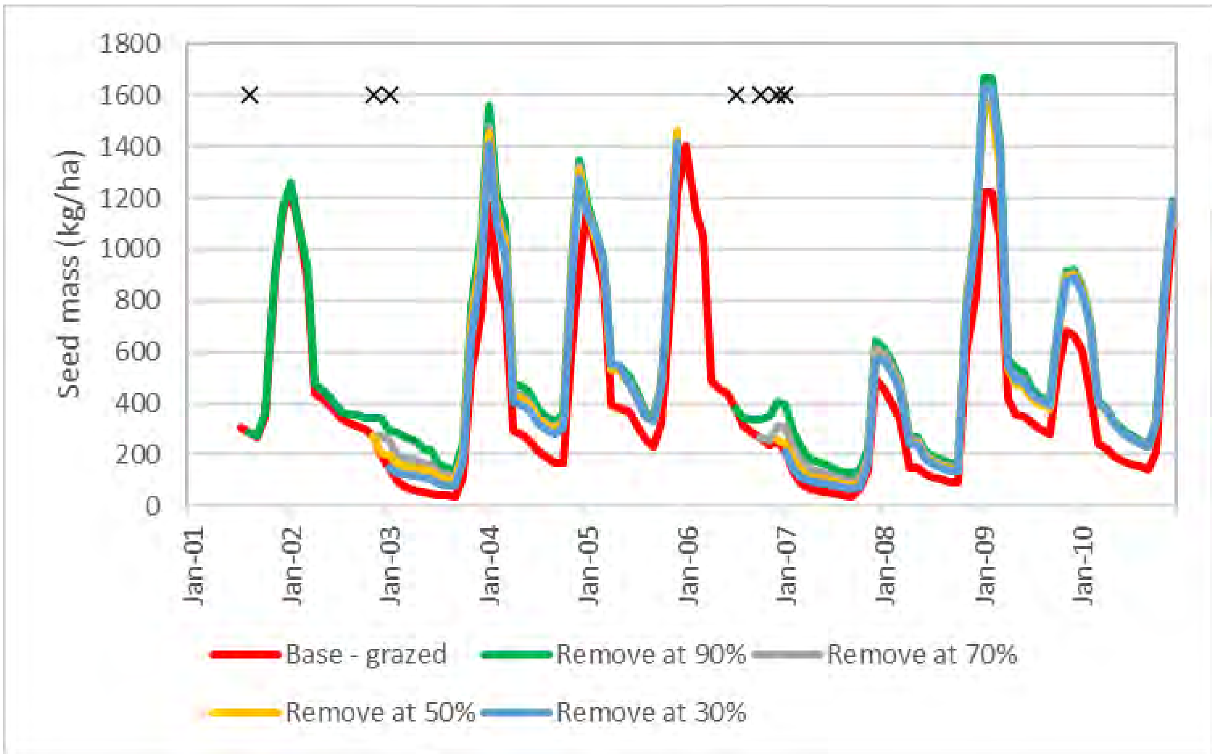

Figure 12. Total seed mass (kg/ha) for an annual pasture at Orange when continuously grazed by 6 sheep/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 and 0.30 in the 2002 and 2006 droughts. X = times at which sheep were removed for each groundcover threshold.

Temora

Despite being a widely grown perennial in the region, a lucerne pasture was not modelled for Temora because sensible growth rates were not obtained and grazing at excessive stocking rates did not prevent pasture growth. The literature indicates that continuous grazing at high stocking rates in dry periods will quickly reduce the density of lucerne plants. Therefore, the model was unable to adequately test the impact of overgrazing of lucerne on groundcover and recovery post-grazing.

Annual grass/subclover pasture

Drought years occurred at Temora in 2001/2002, 2006 to 2009, and 2018/2019 (Table 2; Figure 13). The regional stocking rate of 3.5 breeding ewes per pasture ha did not reduce groundcover sufficiently to analyse the impacts of thresholds below 70% due to a high quantity of herbage produced in years preceding the droughts. A higher stocking rate of 6 ewes/ha was therefore used, with the quantity of dead herbage at the start of 2002 also reduced by 50% to allow lower groundcover thresholds to be reached. The lowest threshold of 30% was still not reached in the 2002 and 2018 droughts at the stocking rate used.

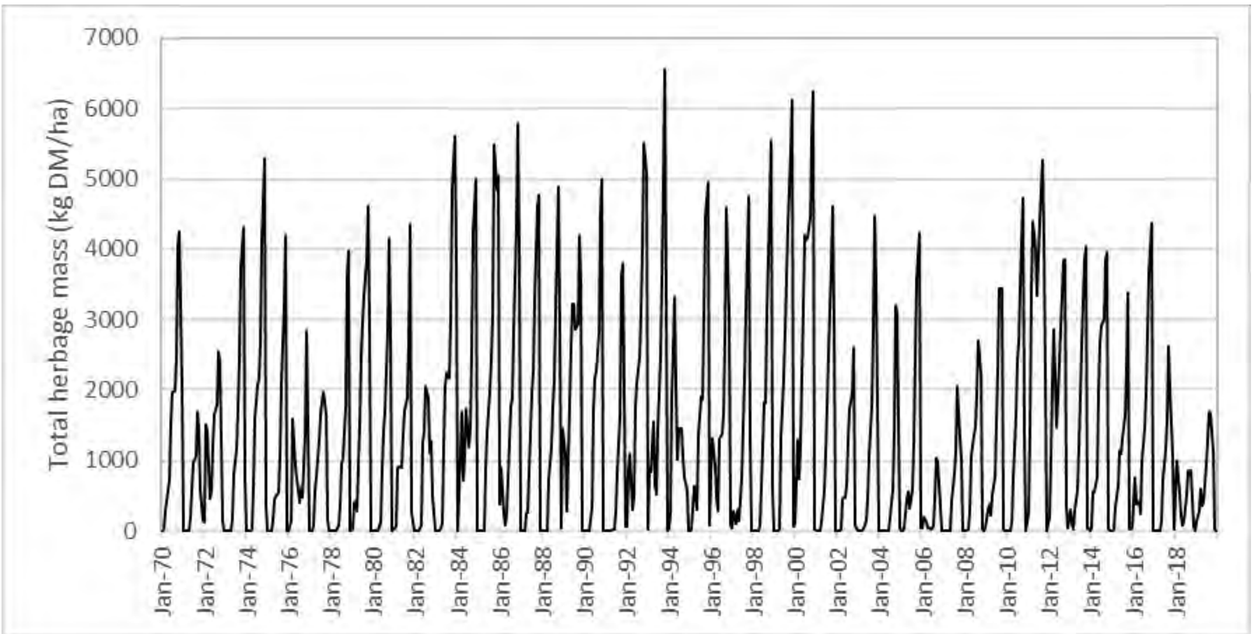

Figure 13. Simulated total green herbage (kg DM/ha) for an annual grass/subclover pasture at Temora 1970-2019 when continuously grazed by 3.5 breeding ewes/ha.

The removal of sheep from annual pastures at Temora did not prevent further declines in cover of up to 23% except where the removal occurred close to a period of pasture growth (Figure 14). Cover returned to above 70% in all scenarios with autumn pasture growth (Table 3a). The rate of recovery in autumn was similar for the different removal thresholds, but pastures regained at least 70% cover earlier with removal at higher thresholds because less cover had to be regained. Delay in the removal of sheep therefore extended the period of time at which cover was reduced. The time between removal of sheep at 70% rather than 50% was more than 1 year in both the 2002 and 2018 droughts but cover increased rapidly after autumn rain despite prolonged heavy grazing.

The quantity of green herbage was not reduced by removal of sheep at 70% cover rather than 90% early in 2002 (Figure 15). Delaying removal to the 50% threshold in autumn 2003 increased winter/spring herbage by generally < 200 kg DM/ha. A similar pattern was observed in 2007, with removal of sheep at lower thresholds reducing green herbage by ≤500 kg DM/ha. However, removal at higher thresholds in 2018 resulted in minimal (generally < 100 kg DM/ha) differences in green herbage.

Seed reserves were reduced by grazing to lower thresholds, but the difference was generally small with spring seed set removing most differences (Figure 16). However, seed reserves were very low in July 2007, and were 2.5 kg/ha where sheep had continued to graze pastures over the summer to the 50 and 30% cover thresholds, compared with 7.2 to 8.1 kg/ha if removed at 70 or 90% cover. If adequate seed set had not occurred in spring 2007 the regeneration of the more heavily grazed pastures would have been poor.

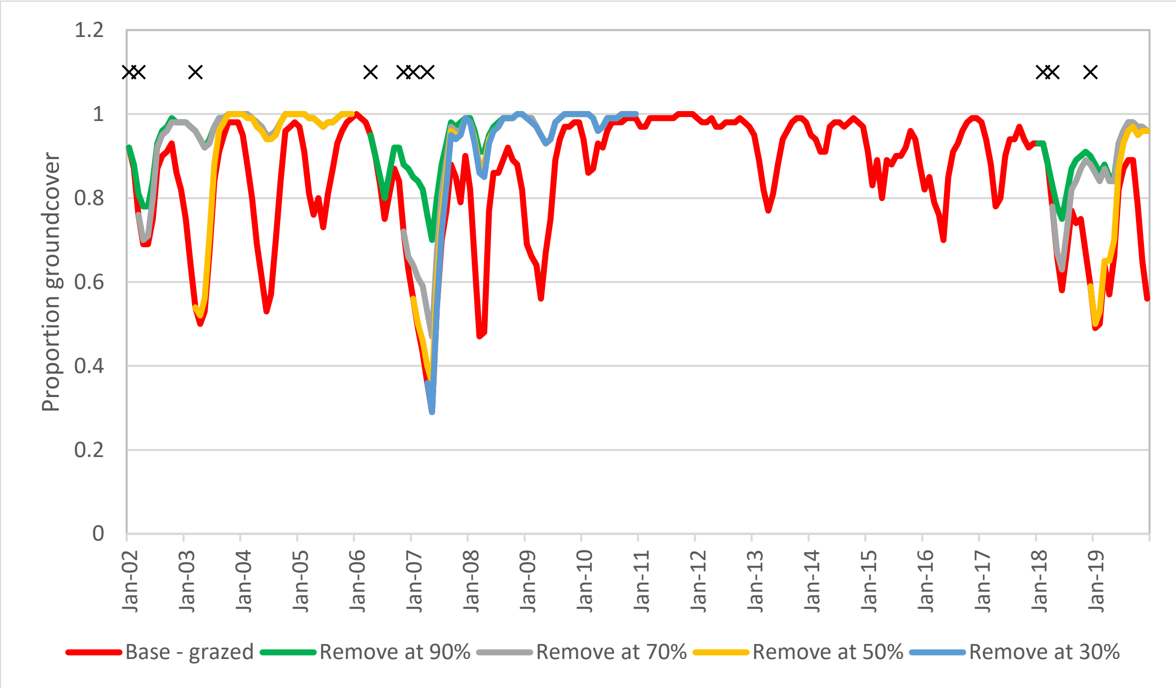

Figure 14. Simulated proportion groundcover for an annual grass/subclover pasture at Temora when continuously grazed by 6 breeding ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

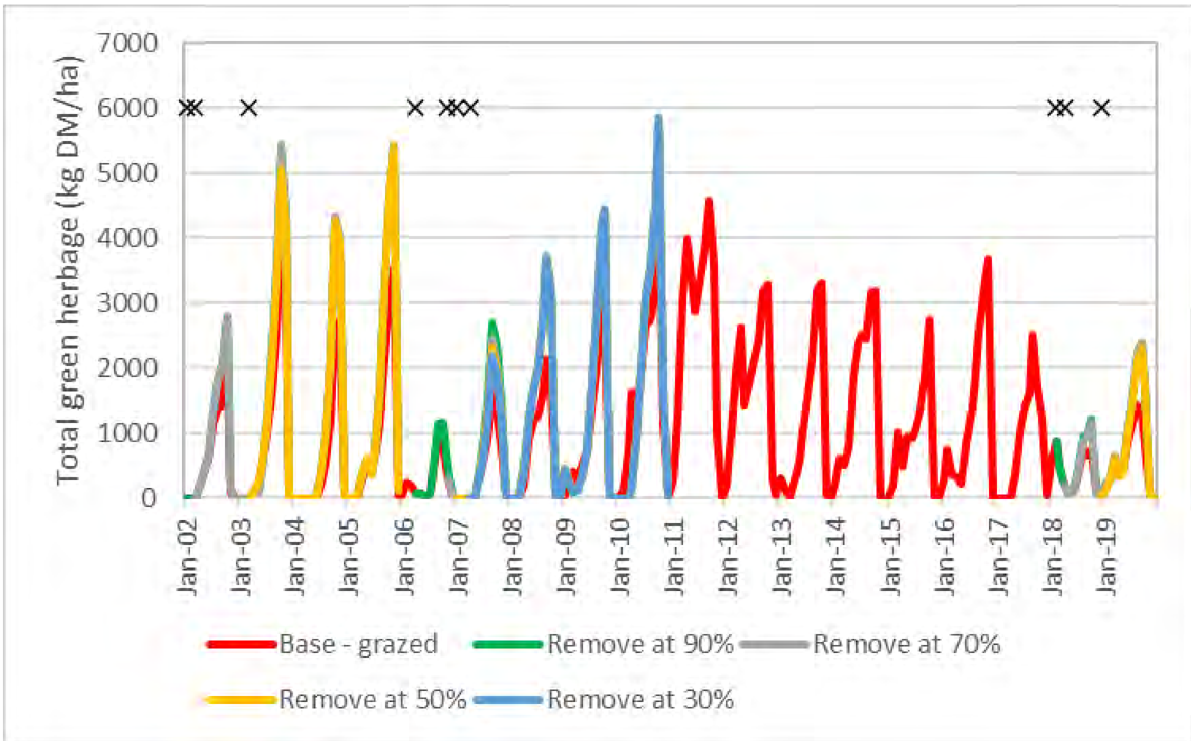

Figure 15. Simulated total green herbage (kg DM/ha) for an annual grass/subclover pasture at Temora when continuously grazed by 6 breeding ewes/ha. or where sheep were removed when the proportion groundcover fell to 0.90, 0.70 or 0.50 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

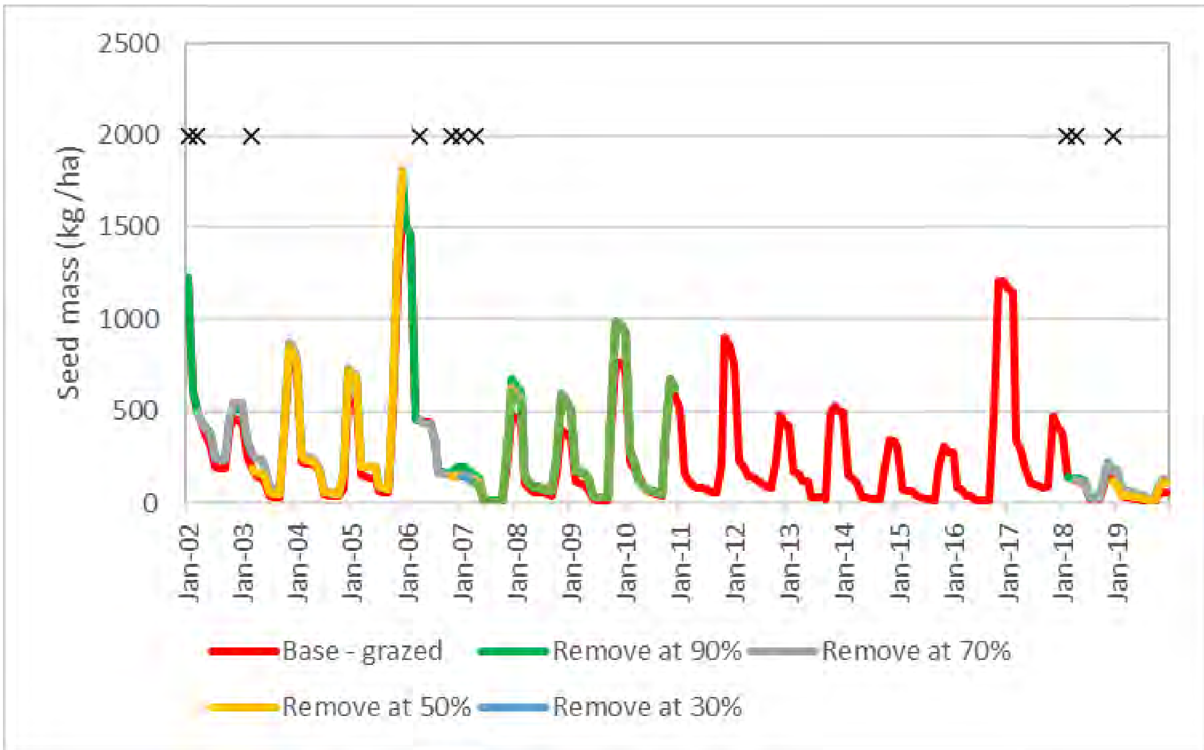

Figure 16. Simulated total seed mass (kg/ha) for an annual grass/subclover pasture at Temora when continuously grazed by 6 breeding ewes/ha. or where sheep were removed when the proportion groundcover fell to 0.90, 0.70 or 0.50 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

Yass

<u>Annual grass/subclover pasture</u>

At Yass droughts occurred in 2001/02, 2006 and 2017 (Table 2; Figure 17). The stocking rate was increased above the district level to 10 sheep/ha (7.8 breeding ewes) to allow the lowest groundcover thresholds to be simulated. The lowest threshold of 30% was still not reached in the 2002 and 2006 droughts and a threshold of 33% was used to remove sheep for the 2006 drought.

Groundcover at Yass declined rapidly from October 2002 with continued grazing with the 50% threshold reached in February 2003. However, all threshold levels regained at least 70% cover by April 2003 (Figure 18; Table 3b). In the 2006 drought the 90% threshold was reached in autumn 6 months earlier than the lower thresholds, which were reached from December. A minimum 70% cover had been regained by 2 May 2007 after autumn growth of pasture. The range in time at which thresholds were reached was extended for the 2018 drought, with 90% cover reached in May 2018, 50% in February 2019 and the 30% level not reached until February 2020. Groundcover continued to decline after the removal of sheep in summer/autumn, but even where grazing continued, rapid growth of pasture in autumn 2019 allowed groundcover to return to > 70% by May. Removal of sheep at 26% cover in February 2020 did not prevent rapid recovery of pastures after autumn rains.

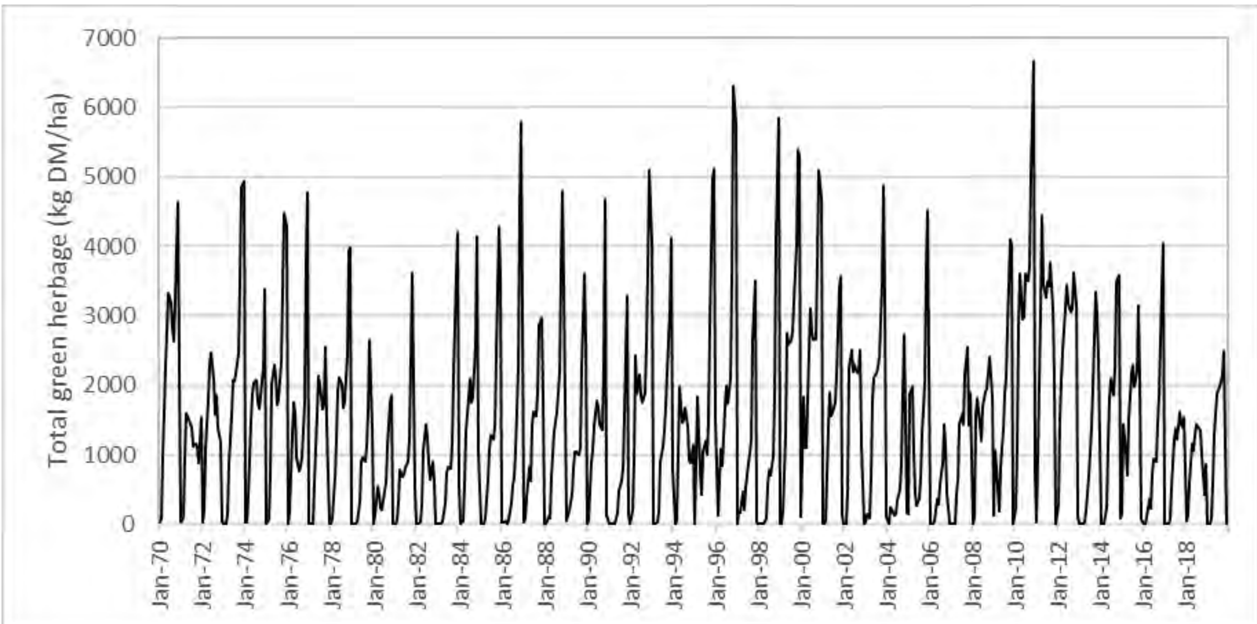

Figure 17. Simulated total green herbage (kg DM/ha) for a mixed subclover and annual ryegrass pasture at Yass 1970-2019 when continuously grazed by 6.0 breeding ewes/ha.

The quantity of green herbage in autumn 2003 was progressively reduced by removal of sheep at lower cover from October 2002 (Figure 19). However, the difference was usually only a maximum of 200 kg DM/ha, and production was similar in 2004. The quantity of green herbage in 2007 was increased by < 200kg DM/ha by removing sheep in May 2006 at 90% cover, rather than in December at 70% cover. Continuing to graze pasture over summer reduced 2007 green herbage by usually < 200 kg DM/ha). In contrast, green herbage in 2019 was increased by approximately 400 kg DM/ha by removal of sheep at 90% cover in May 2019 rather than at 50% cover in February 2019. However, in 2020 production was similar for the 90 to 50% cover thresholds. Grazing pastures throughout the 2018/19 drought and only removing sheep at 30% cover in March 2020 reduced autumn/winter green herbage by up to 800 kg DM/ha although production in 2021 was not reduced.

Pasture seed reserves and production in 2003 and 2007 were similar for the varying 90 to 50% cover thresholds with sheep removed over the previous late spring to autumn. Seed reserves in July 2019 were reduced by 22% (23 kg/ha) if sheep were removed in early October 2018 at 90% cover, but differences were small in 2020, and all pastures produced > 1400 kg/ha seed (Figure 20).

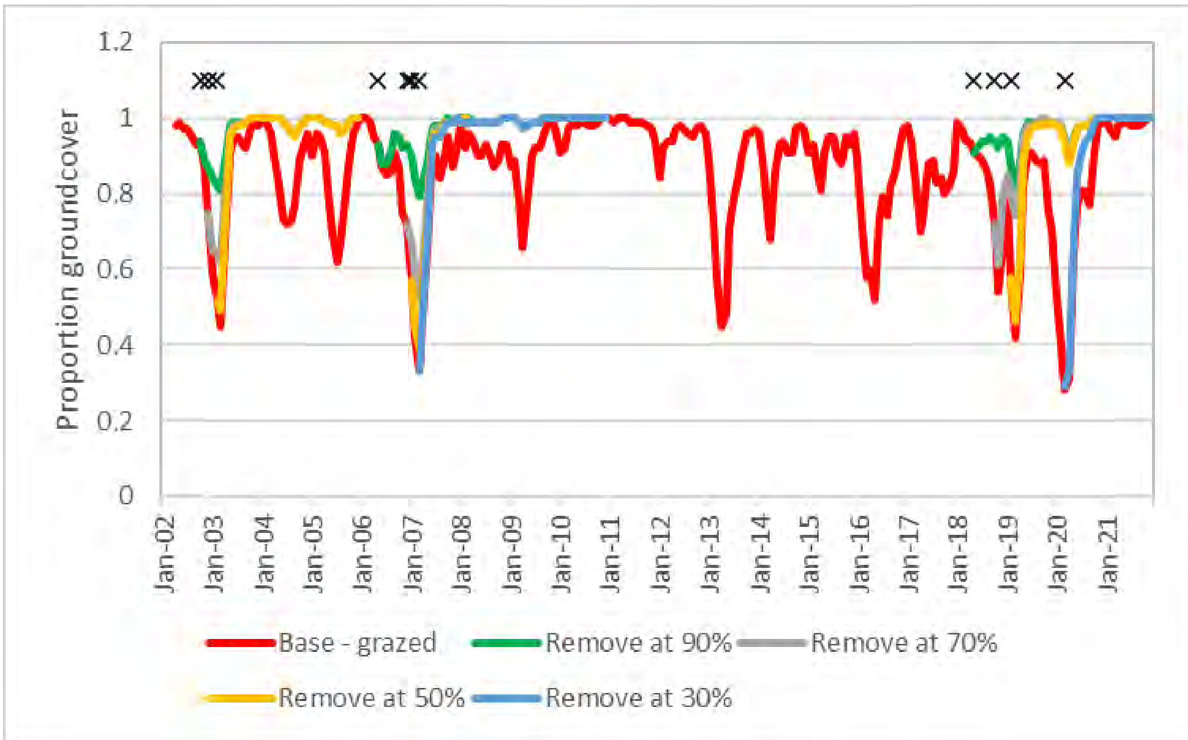

Figure 18. Simulated proportion groundcover for an annual grass/subclover pasture at Yass when continuously grazed by 7.8 breeding ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 30% in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

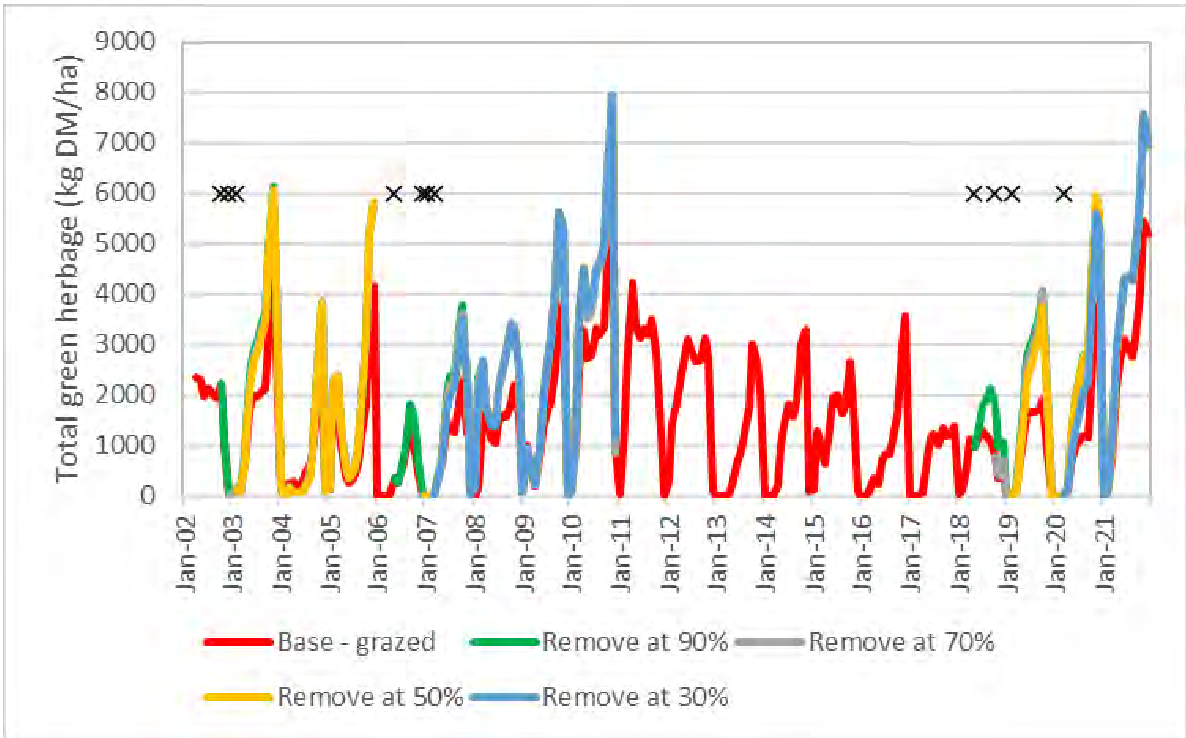

Figure 19. Simulated total green herbage (kg DM/ha) for an annual grass/subclover pasture at Yass when continuously grazed by 7.8 breeding ewes/ha. or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 30% in the 2002,2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

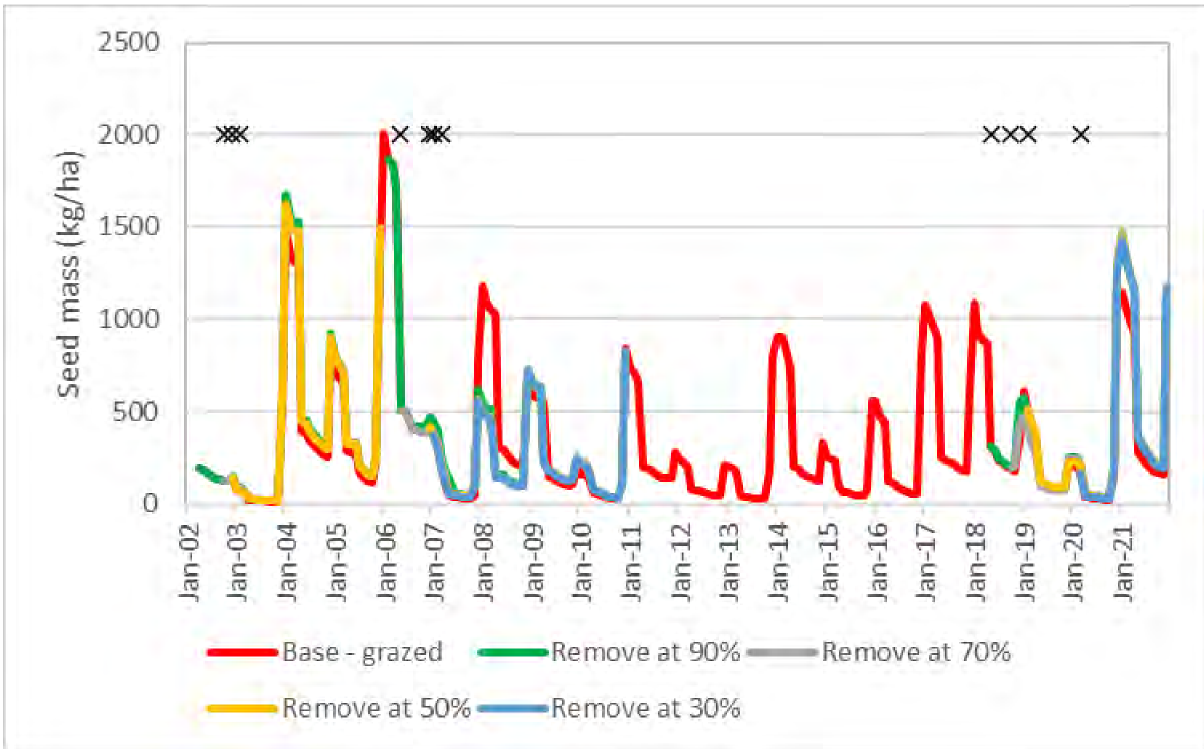

Figure 20. Simulated quantity of seed (kg DM/ha) for an annual grass/subclover pasture at Yass when continuously grazed by 7.8 breeding ewes/ha. or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 30% in the 2002,2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

Hillston

Annual medic/grass pasture

Droughts occurred at Hillston in 2002, 2006 and 2018 (Table 2; Figure 21). An estimated district stocking rate of 0.9 ewes/ha did not allow the 50% groundcover threshold to be reached in all droughts, so a stocking rate of 2 sheep/ha was used from 2001. The lowest cover achieved in the 2002 drought was 34%, so sheep were removed at this level rather than 30% used for the other periods.

The removal of sheep at higher groundcovers did not prevent further decline in cover but reduced the duration of time at which groundcover was reduced to lower levels (Figure 22). Although the removal of sheep at 90% cover in autumn 2002 prevented cover falling to the 50% threshold during 2003, cover declined by 35% after the removal of sheep although at a slower rate than if grazing continued. Similar although smaller declines also occurred in the other drought years when ungrazed and were associated with low quantities of herbage production in those years. Later time of removal usually caused delays of < 5 weeks in the month in which groundcover had returned to above 70%, which occurred with autumn or winter pasture growth. However, in the prolonged droughts of 2006 and

2018 where cover failed to return to high levels with spring growth, removal at lower levels delayed the return to 70% cover until the following year.

The quantity of green herbage in winter/spring 2003 was reduced by 200 – 300 kg DM/ha by delaying removal of sheep. Removing sheep at 70% cover in October 2002 rather than at 90% in March 2002 approximately halved the reduction. Grazing to the 90, 70 and 50% thresholds resulted in similar quantities of herbage in 2007 to 2009 (Figure 23). However, grazing to the 30% threshold which occurred in June 2009 reduced the quantity of green herbage in September 2009 by at least 900 kg DM/ha, with a smaller difference persisting into 2010. Green herbage was similar for the different cover thresholds in the 2018/19 drought.

Seed reserves in July 2003 were halved (6 versus 12 kg/ha) by continuing to graze pastures over summer/autumn from the 70% to the 30% cover threshold, although all pastures produced > 400 kg/ha of seed in spring 2003 to allow adequate regeneration in subsequent years (Figure 24). Seed reserves were also reduced by delayed removal of sheep in the 2006 and 2018 droughts. Minimal quantities of seed remained at the end of 2019 due to largely failed seed set in that year, and this occurred for all grazing thresholds.

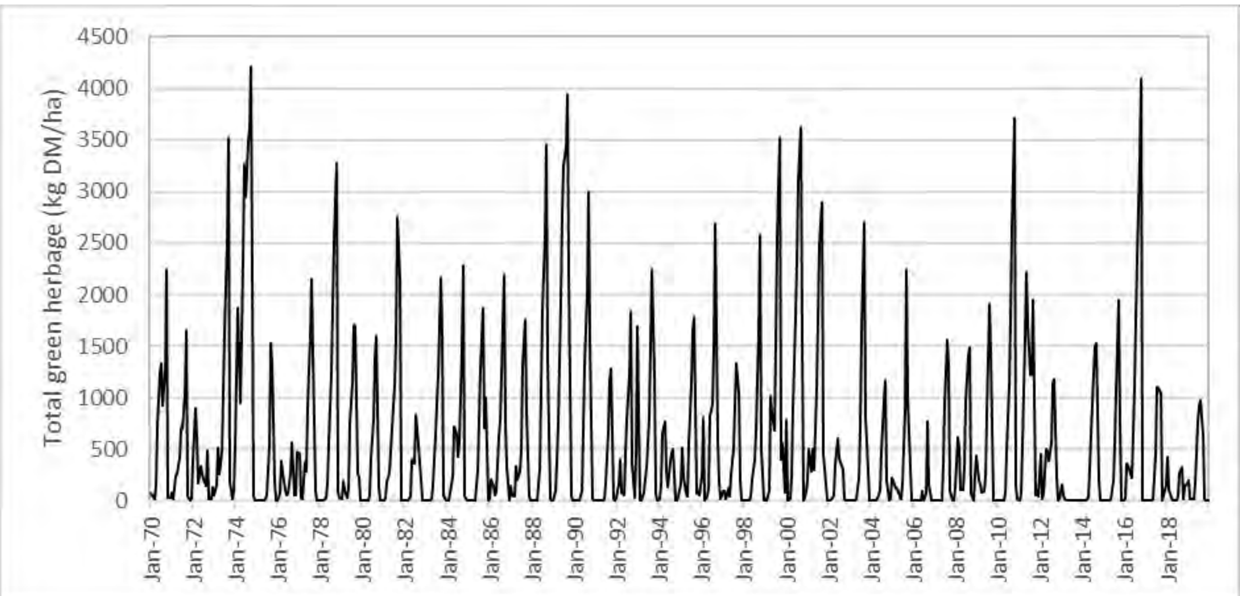

Figure 21. Simulated total green herbage (kg DM/ha) for a mixed annual medic and annual grass pasture at Hillston 1970-2019 when continuously grazed by 0.9 breeding ewes/ha.

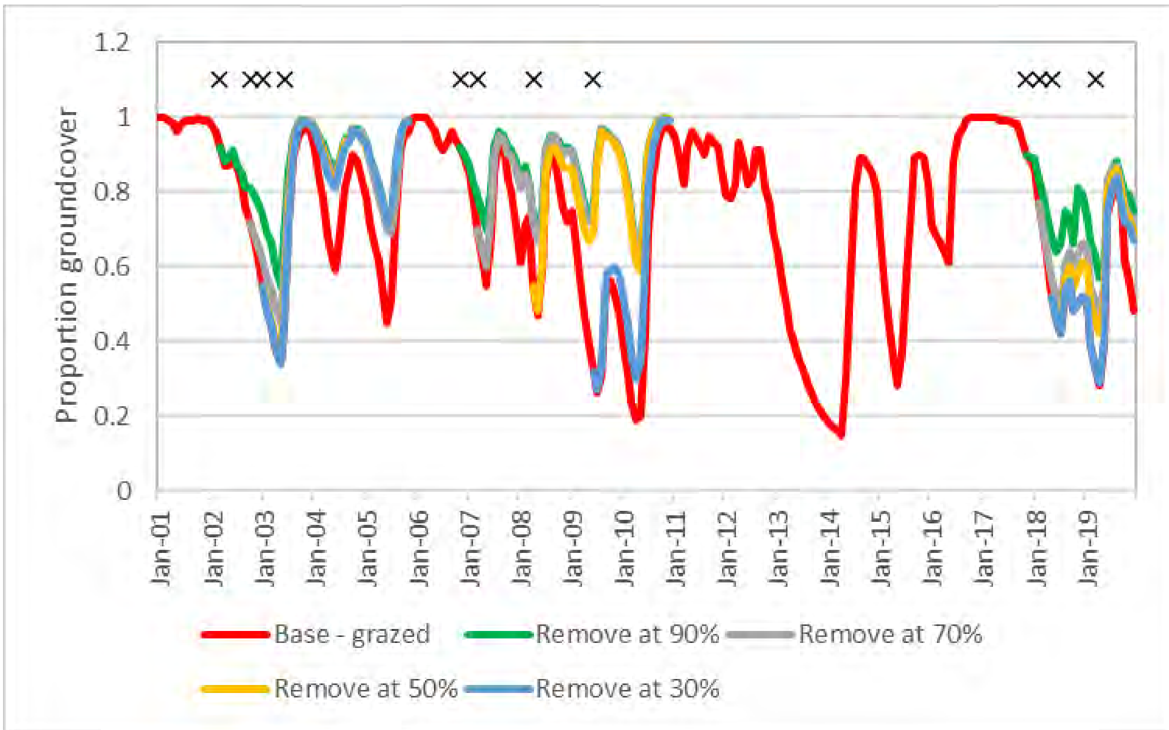

Figure 22. Simulated proportion groundcover for an annual grass/medic pasture at Hillston when grazed by 2 breeding ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

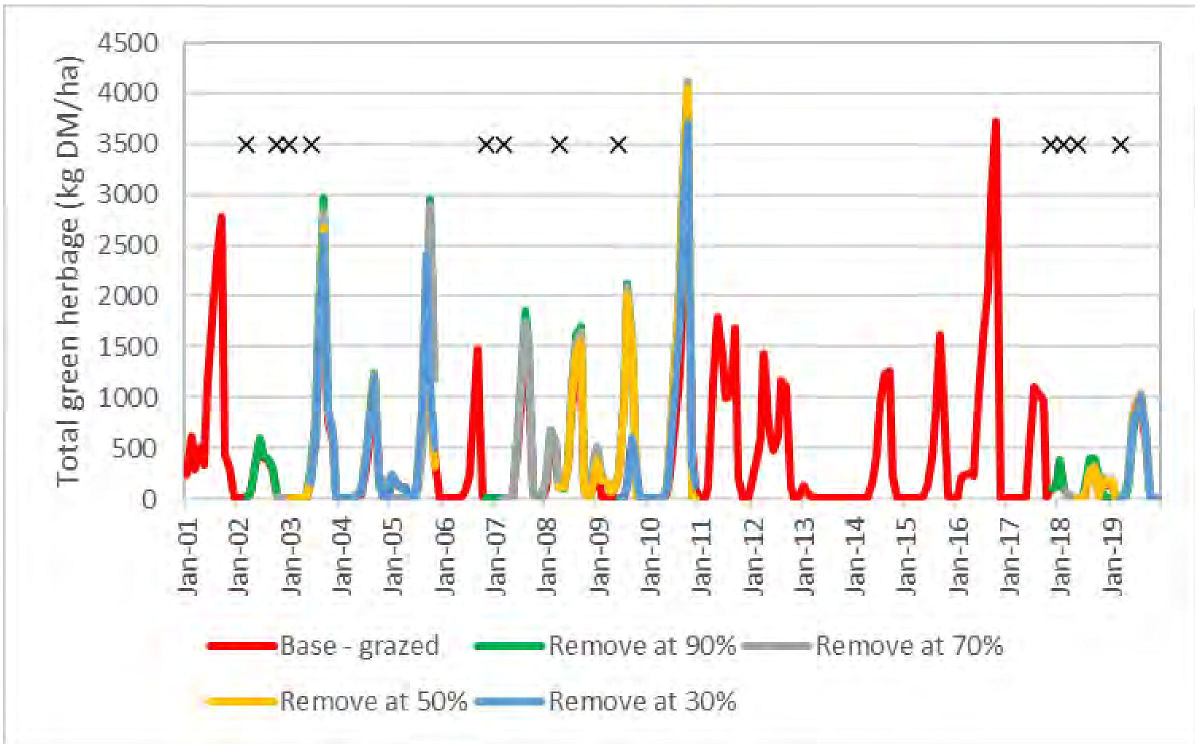

Figure 23. Simulated total green herbage (kg DM/ha) for an annual grass/medic pasture at Hillston when grazed by 2 breeding ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

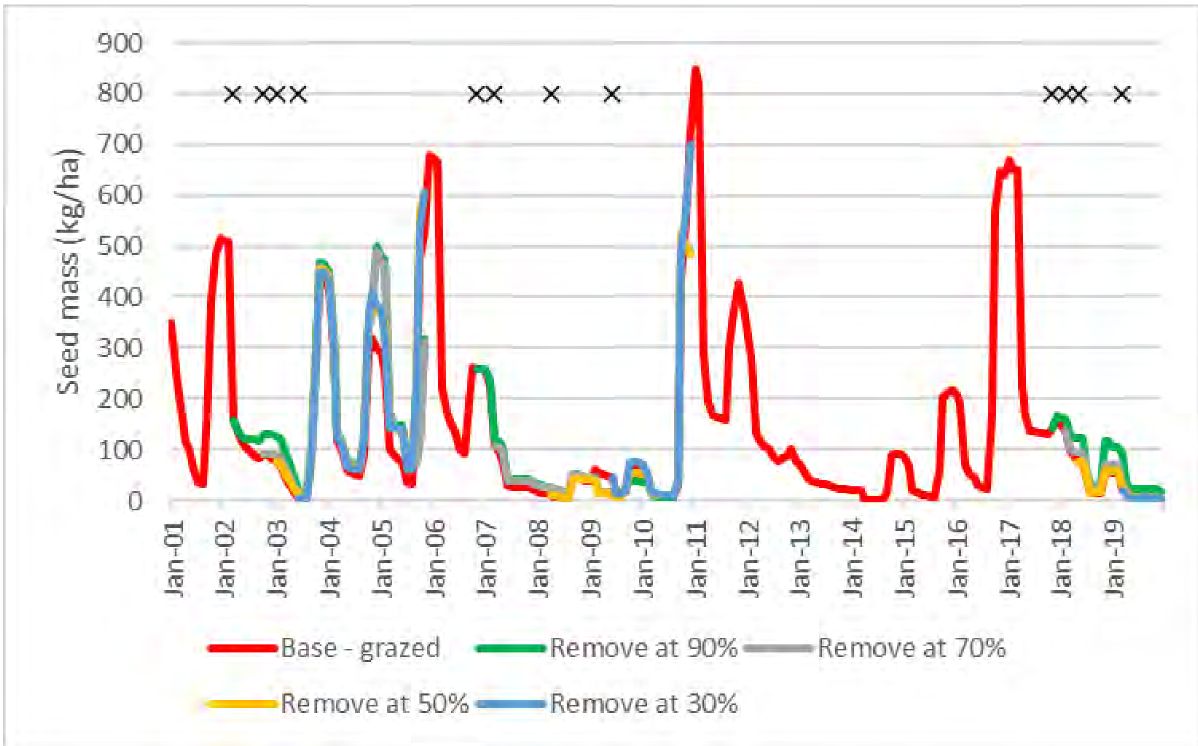

Figure 24. Simulated seed mass (kg/ha) for an annual grass/medic pasture at Hillston when grazed by 2 breeding ewes/ha or where sheep were removed when the proportion groundcover fell to 0.90, 0.70, 0.50 or 0.30 in the 2002, 2006 and 2018 droughts. X = times at which sheep were removed for each groundcover threshold.

Discussion

The removal of sheep at lower pasture groundcover thresholds generally resulted in short delays in the recovery of annual pastures after drought as cover generally only increased after autumn pasture growth, and this occurred across all locations. In most simulations there was a continued decline in groundcover after the removal of sheep, unless removal occurred just prior to or during a period of pasture growth. While the recovery was not generally delayed, allowing cover to decline to lower thresholds substantially increased the period of time at which soil was exposed, as well as the level of risk to soil erosion. This confirms the recommendation that sheep should be removed from pastures before very low groundcover is reached in order to protect soils.

The simulation results for perennial pastures should be interpreted cautiously. The persistence of perennial species was not reduced with extreme stocking rates. Field studies have established that continuous grazing of both lucerne (Lodge 1991) and phalaris (Virgona *et al.* 2000) will reduce plant persistence, particularly under conditions of inadequate rainfall and high stocking rates (Southwood and Robards 1975; Hutchinson 1992). Large reductions in the density of the perennial species due to prolonged grazing to very low groundcover would be expected to delay the recovery of plant growth and groundcover after adequate rainfall, unless large seed reserves of annual species were present. The seed and herbage production of annual medics simulated by GrassGro has previously been validated against numerous field trials in the low-rainfall regions of far north-west Victoria and was considered adequate (Robertson 2006). Therefore, the simulated results for annual pastures are expected to be more accurate than those for perennials.

Prostrate annual species such as subclover may be more resilient to high stocking rates during drought than perennials such as phalaris because they regenerate from a seedbank, rather than relying on the survival of plants long-term (Norton *et al.* 2020). However, this also depends on the use of varieties with a maturity and level of hard-seededness suitable for the location. The seedbank for annual species was often but not always reduced by delaying removal of sheep to lower groundcover thresholds. The timing of sheep removal varied throughout the year, and the difference in time also varied from one month to up to a year at a single location. Heavier grazing to promote flowering can increase seed set in subclover, while excessive grazing may reduce seed set. Grazing after seed set can result in variable consumption of seeds, with those that are palatable and easily accessible on the soil surface such as barrel medic at greater risk in comparison with subclover where seed is buried, or barley grass where seedheads are less palatable. It is not surprising therefore that a reduction in seedbank did not occur consistently. While there were some reductions in seed with lower groundcover thresholds, the quantity of hard seed reserves was sufficient to allow recovery of pastures with autumn germination. The quantity of herbage in autumn was reduced on some occasions where sheep had been removed later but seed production in the spring was generally similar and replenished the seedbank for the following year. This meant that in annual species there were generally not large impacts on pasture productivity from removal of sheep at lower groundcovers.

The typical district stocking rates were not always sufficient to reduce groundcover to the lower target thresholds (50%; 30%). This may be due in part to simulated pasture growth rates being higher than expected for the location on some occasions. It may also be due to district stocking rates often being lower than possible to reduce the risk of overgrazing. The results should not be considered as defining actual timepoints when groundcover targets would be met due to the use of high stocking rates. Higher stocking rates increase the risk of overgrazing and hasten the month in which thresholds will be reached. This meant an increased chance of thresholds being met in spring or early summer, prolonging the period when soil would be at increased risk of erosion prior to annual pasture growth in autumn. Producers using higher stocking rates have a greater need for stock management plans in drought to optimise profitability whilst maintaining the soil resource.

The effect on soil fertility from removal of sheep at different thresholds was not considered in this study. The GrassGro model does not simulate the loss of nutrients which would occur if soil erosion occurred. The removal of sheep at groundcover below 70% would increase soil erosion (Lang 1998) and therefore loss of nutrients, which may reduce the productivity of subsequent pastures and require increased fertiliser application to correct.

The cost to maintain stock in containment areas for longer periods of time or to sell and replace stock post-drought was also not considered in this study. The 90% groundcover threshold was reached up to 15 months earlier than the 70% level, and the removal of stock at the earlier time was not justified through improved resilience of annual pasture to drought. The removal of sheep at 50% cover reduced the time sheep were removed from pasture but usually resulted in a < 5-week delay in the date 70% cover was regained. The risk of soil erosion from prolonged periods below 50% cover needs to be considered for the soil type, risk of water erosion after rain, and time of year relative to expected pasture growth.

Recommendations

1. Removal of sheep at 90% groundcover rarely allowed groundcover to fall below 70% but, in some droughts, would result in a prolonged duration of feeding sheep or destocking.
2. Groundcover often continues to fall after the removal of stock and does not increase in annual pastures until pasture growth occurs. Removing stock promptly when thresholds are reached in spring/early summer will reduce the risk of soil erosion to a greater extent than if thresholds occur close to autumn rains.
3. Removing sheep from annual pastures at 70% groundcover will reduce the period of time soil is exposed to a high risk of erosion. Grazing to lower thresholds may not cause large delays in pasture recovery if they occur close to the autumn break but increases the risk of soil erosion.
4. Use of pasture species and varieties with suitable levels of maturity and hard-seededness for the region will allow soil reserves of seed to regenerate annual pastures following years of low seed-set. Overgrazing and excessive removal of seedpods by sheep over summer/autumn may delay the recovery of pastures after drought.
5. Perennial pasture persistence through drought will be reduced by overgrazing and inadequate rest periods appropriate for the species.
6. Graziers have a large capacity to sustainably manage their soils and pastures through managing stocking rates and destocking when appropriate.

Acknowledgements

Phil Graham generously provided GrassGro models for Hay and Orange, which were adapted to simulate the Hillston and Orange locations.

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Appendices

Appendix 1. Soil parameters used in models

Location	Layers (mm)	Bulk density (Mg/m3)	LL15 (mm/mm)	DUL (mm/mm)	SHC (mm/d)	Soil evaporation parameter (mm/d ½)	Soil albedo
Wagga	130	1.49	0.08	0.28	2400	3.8	0.17
	590	1.55	0.08	0.25	240		
Temora	130	0.9	0.21	0.36	7200	3.6	0.17
	720	1.2	0.21	0.34	2400		
Orange	300	1.40	0.13	0.27	2400	3.3	0.17
	700	1.50	0.17	0.29	2400		
Yass	460	1.36	0.06	0.24	62.31	3.5	0.17
	740	1.70	0.28	0.33	0.01		
Hillston	200	1.5	0.14	0.26	720	3.3	0.17
	700	1.6	0.23	0.34	240		

LL15: soil moisture content at wilting point

DUL: soil moisture content at the drained upper limit

SHC: saturated hydraulic conductivity

Appendix 2. Pasture growth rates

Simulated and estimated[A] average monthly pasture growth rates (kg DM/ha/day) 1970-2019 compared with published estimates for each location.

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wagga Wagga	Phalaris/subclover/annual ryegrass	Simulated	0	0	1	9	21	19	17	31	58	69	31	1
	Phalaris/subclover	Estimated	5	7	16	25	24	17	16	26	47	64	43	12
	Annual grass	Simulated	0	0	2	11	21	18	14	35	67	58	25	0
	Annual grass/subclover	Estimated	3	4	10	23	24	14	10	25	45	64	35	7
Temora	Annual grass/subclover	Simulated	0	0	2	10	22	21	19	35	67	58	16	0
	Annual grass/subclover	Estimated	1	4	8	10	12	10	11	18	35	38	25	6
Orange	Subclover/annual ryegrass	Simulated	2	9	19	24	19	7	3	8	31	54	53	24
	Subclover/annual grass	Estimated	0	0	2	6	12	11	9	17	45	74	10	0
Yass	Subclover/annual ryegrass	Simulated	1	5	16	15	20	13	7	18	43	64	57	12
	Perennial/annual grass/clover	Estimated	10	80	20	26	20	12	10	15	45	75	55	20
Hillston	Annual grass/annual ryegrass/medic	Simulated	1	0	0	2	10	12	19	26	28	5	1	0
		Estimated	-	-	-	-	-	-	-	-	-	-	-	-

[A]Estimates sourced from: https://mbfp.mla.com.au/pasture-utilisation/tool-33-pasture-growth-estimates/tool-33-nsw-feed-year-growth-rate-patterns/ and https://www.evergraze.com.au/library-content/regional-pasture-growth-rates/index.html. Published estimates were not found for Hillston.

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SUSTAINABLE AGRICULTURE, LANDSCAPES AND COMMUNITIES
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Local Land Services

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