

## Supplementary Material

### **Mapping pasture dieback impact and recovery using an aerial imagery time series: a central Queensland case study**

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Supplementary Material  
Supplementary Figures

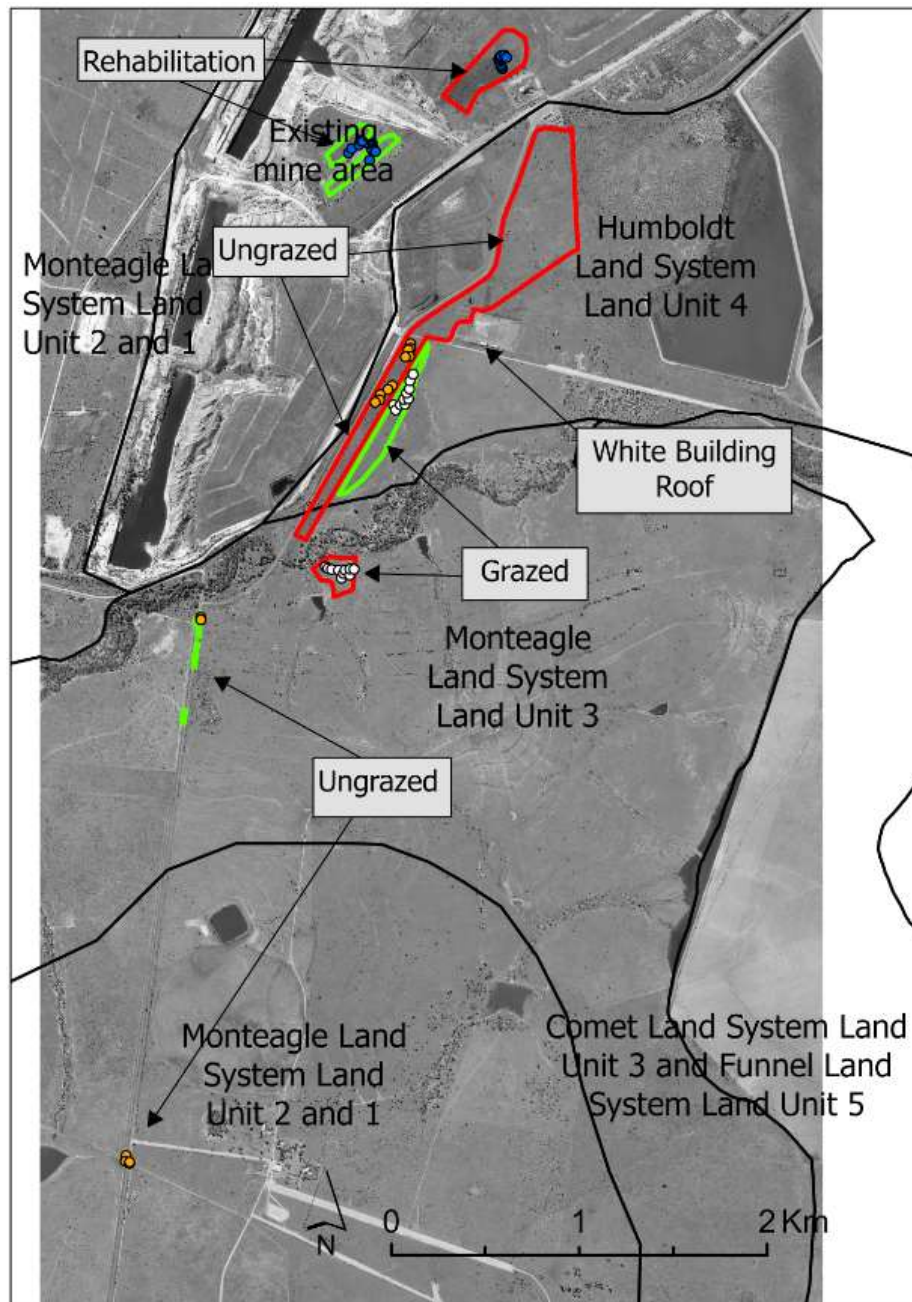


Fig. S1 Soil descriptions in the study area.



Fig. S2 Rehabilitation age class boundaries. White text indicates year of establishment and seeding. Rehabilitation impact aoi covers 2004, 2006 and 2007 age classes, while the control aoi covers 2006. Note that quadrats for both treatments were located in 2006 with the exception of some quadrats from the impact area that also included 2007 rehabilitation. Aerial Image in May 2019. The disturbance histories for both sites are described in the Methods (Study site) section.

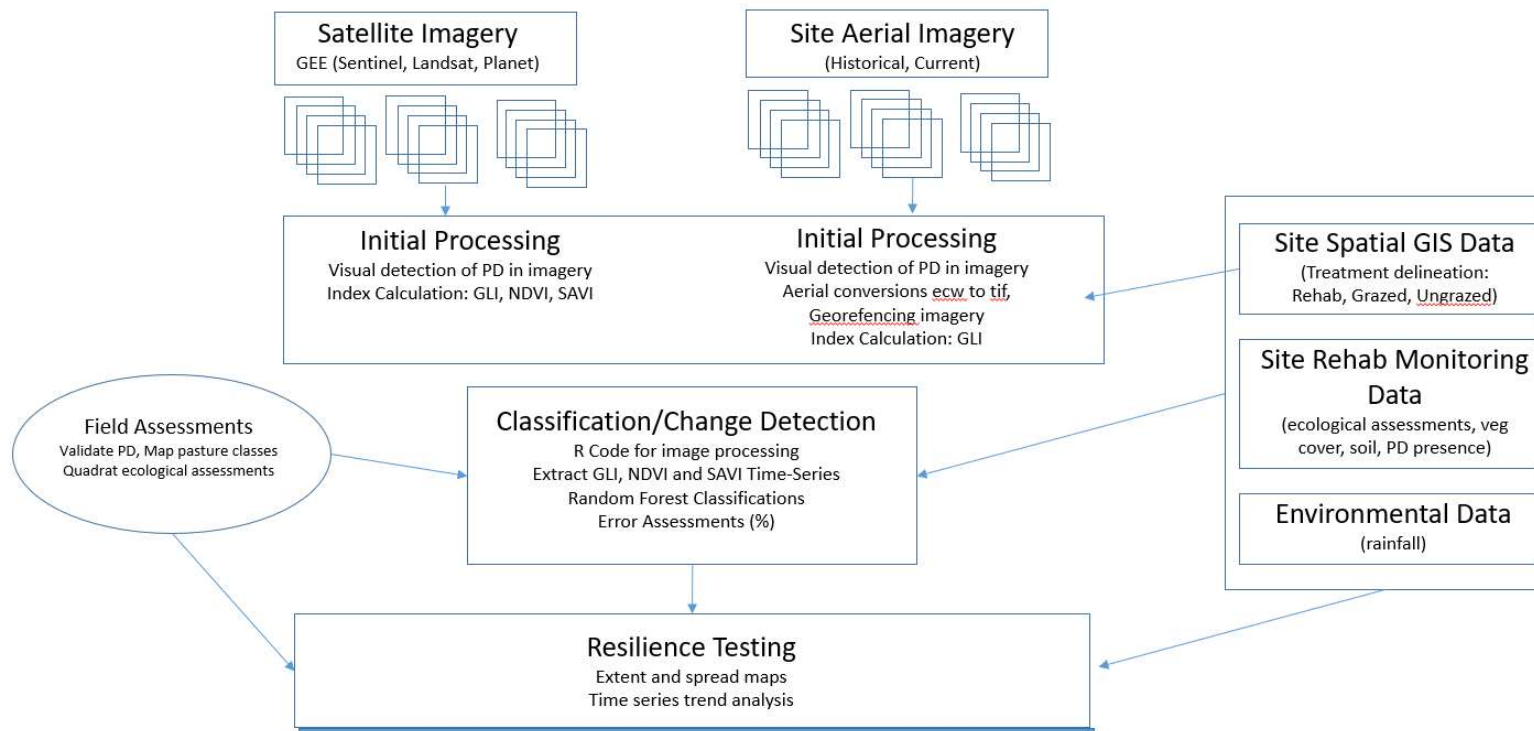


Fig. S3 Workflow for the project.

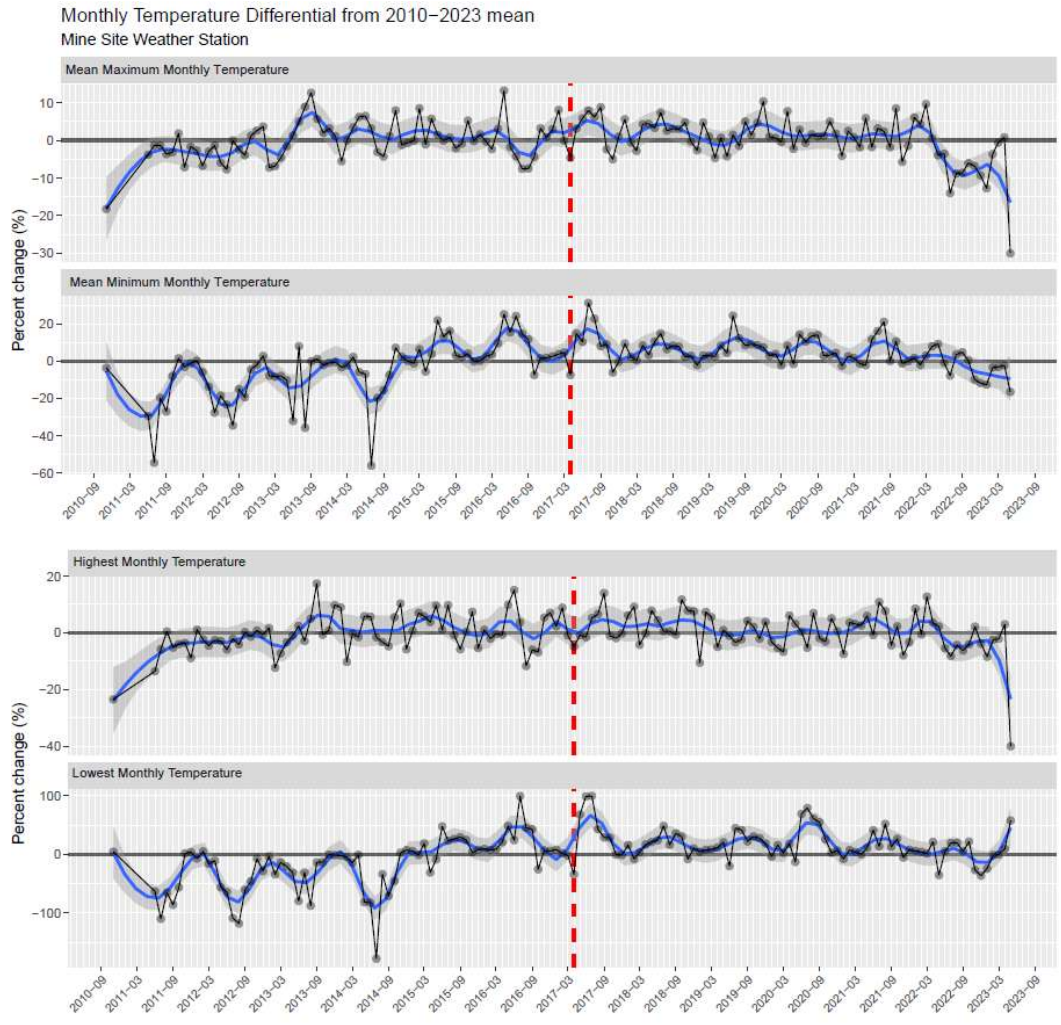
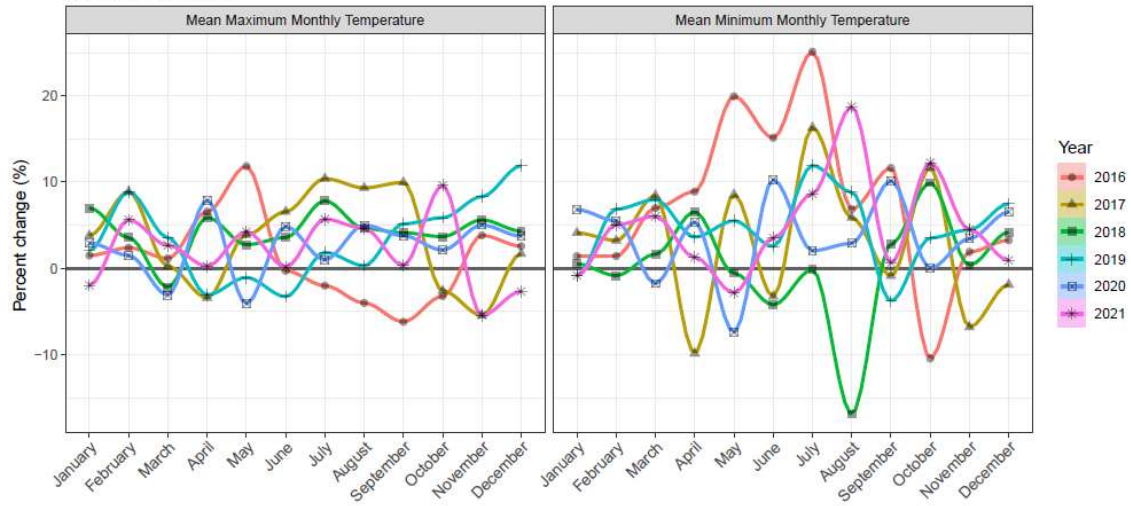


Fig. S4 Percent change in monthly temperatures recorded by the Mine Site weather station between 2010 and 2023. Red vertical line represents timing of PD first observed in aerial imagery.

Temperature Differential from 1992–2022 mean  
Emerald BOM Station



Temperature Differential from 1992–2022 mean  
Emerald BOM Station

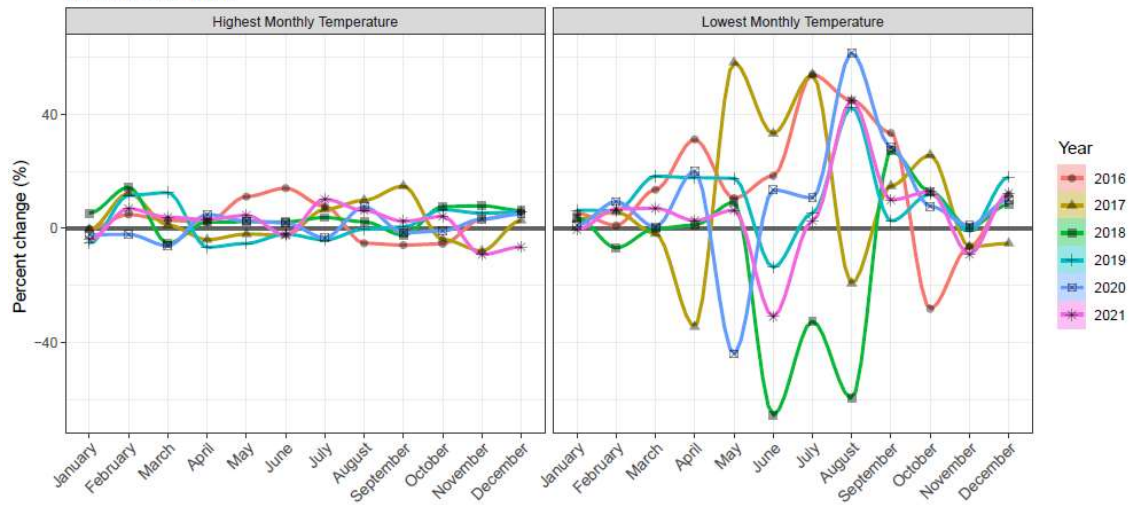
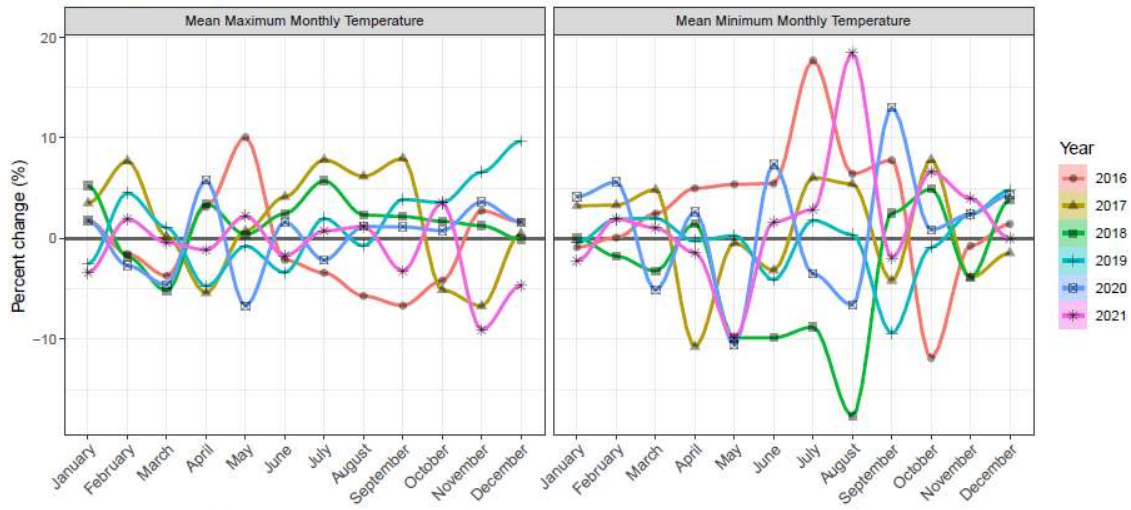


Fig. S5 Percent change between the dataset mean (1993-2022) and the years when PD occurrence was first observed in the imagery and spread throughout the sites.

Temperature Differential from 2013–2023 mean  
Blackwater BOM Station



Temperature Differential from 2013–2023 mean  
Blackwater BOM Station

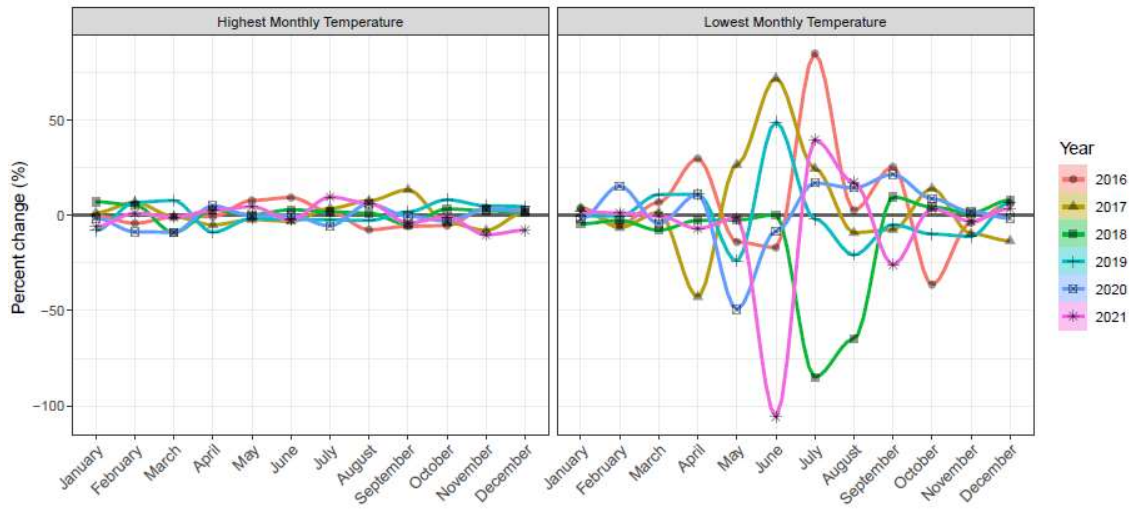


Fig. S6 Blackwater BOM percent change in monthly values compared to long-term monthly averages for mean maximum and mean minimum (top) and highest and lowest monthly temperature (bottom).

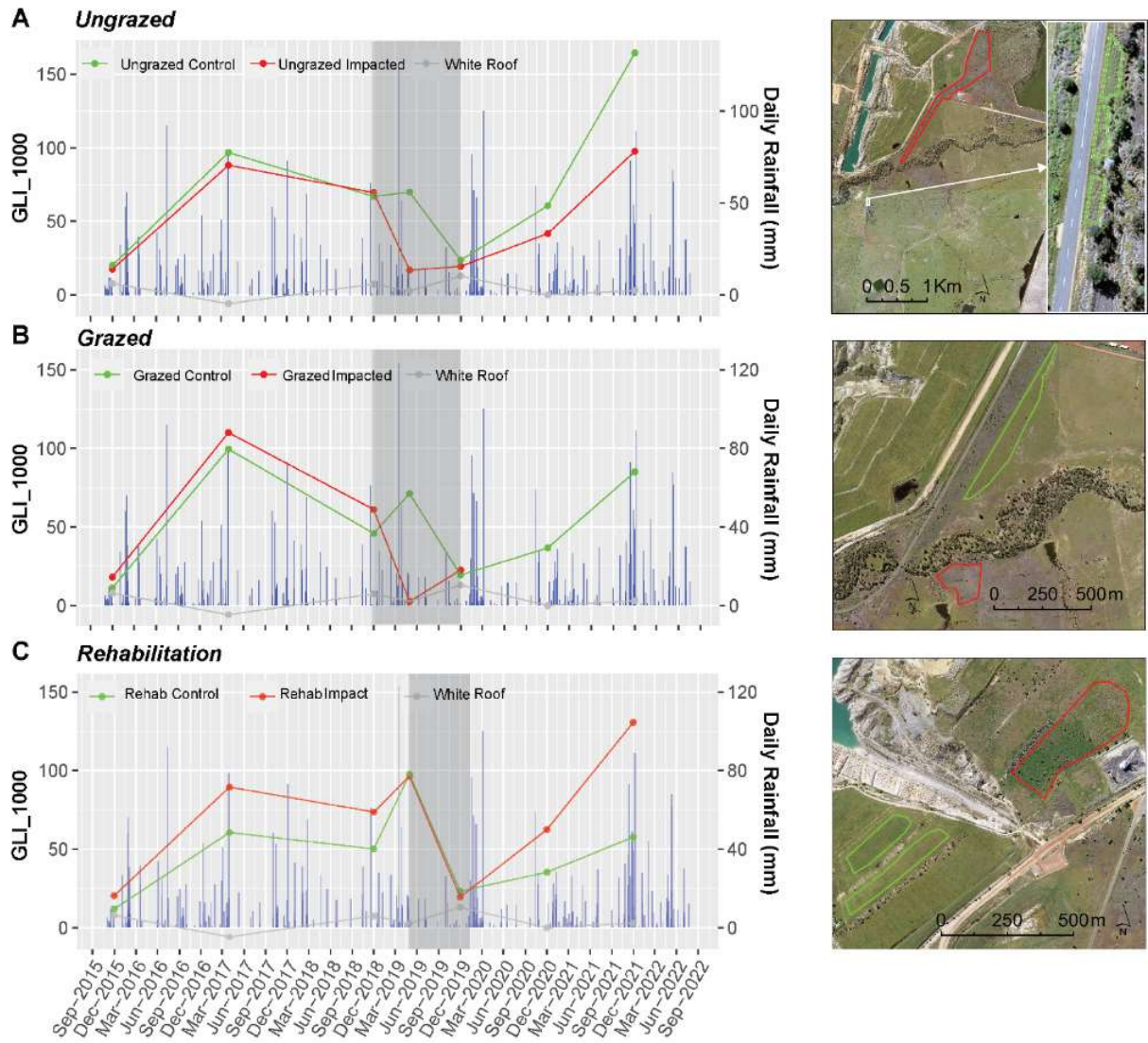


Fig. S7 Aerial imagery derived green leaf index (GLI) mean values for A) Ungrazed treatment, B) Grazed treatment and C) Rehabilitation treatment area as a time-series. Grey rectangles represent the detection of PD by the changes in index trajectory. Maps show location where pixel averages were derived. Red polygons = impact areas, green polygons = unimpacted controls. Background aerial is taken from May 2019.



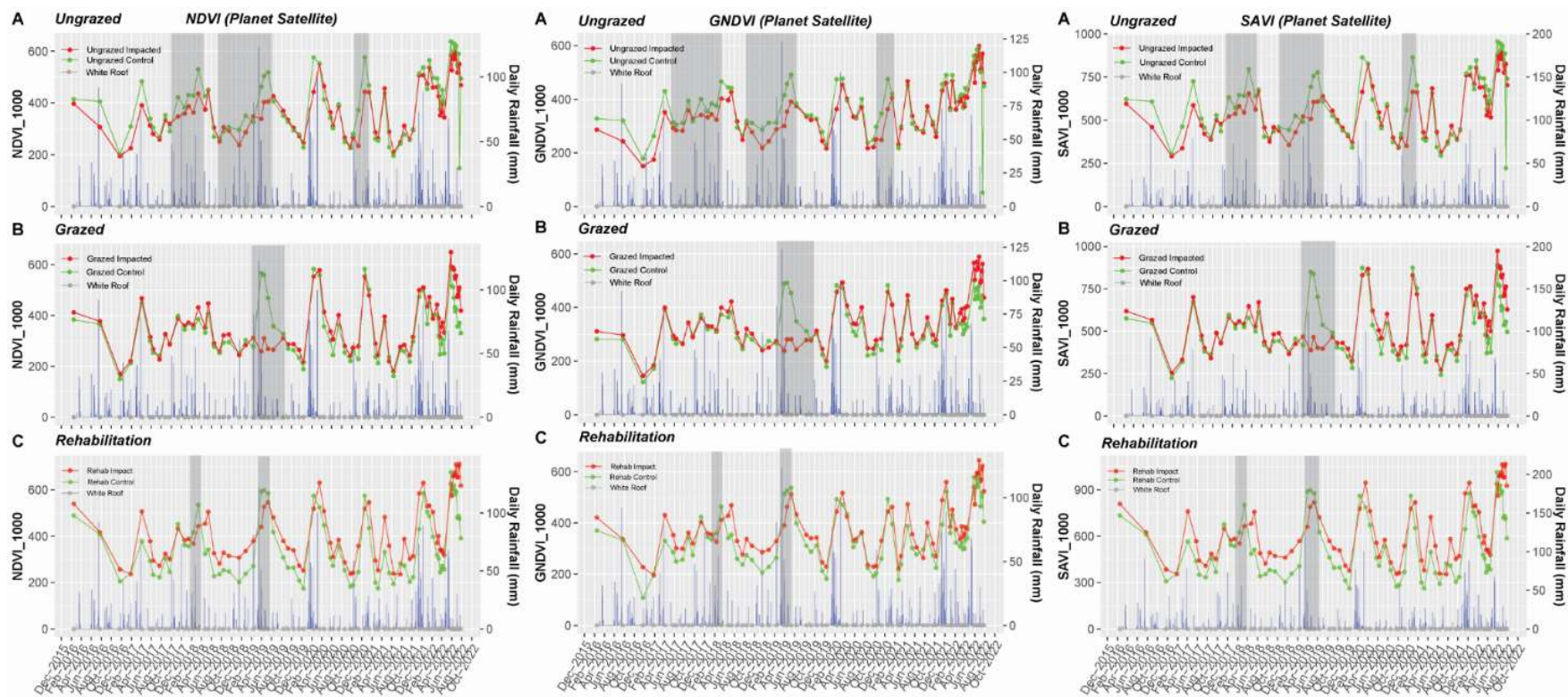
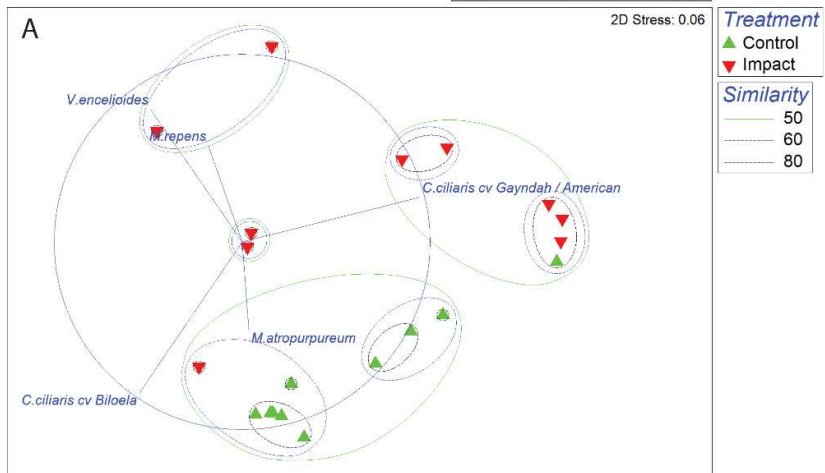


Fig. S8 Planet Satellite time series for NDVI (left column), GNDVI (middle column) and SAVI (right column) for ungrazed (A), grazed (B) and rehabilitation (C) polygons. Grey areas represent times when the impacted areas divert from the control trajectories. This data has been corrected for the reflectance values recorded by the white roof.

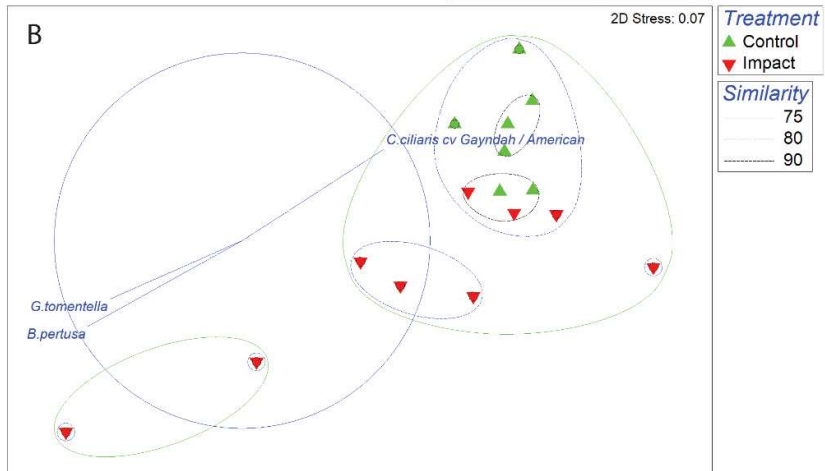
### Ungrazed

Transform: Square root  
Resemblance: S17 Bray Curtis similarity



### Grazed

Transform: Square root  
Resemblance: S17 Bray Curtis similarity



### Rehabilitation

Transform: Square root  
Resemblance: S17 Bray Curtis similarity

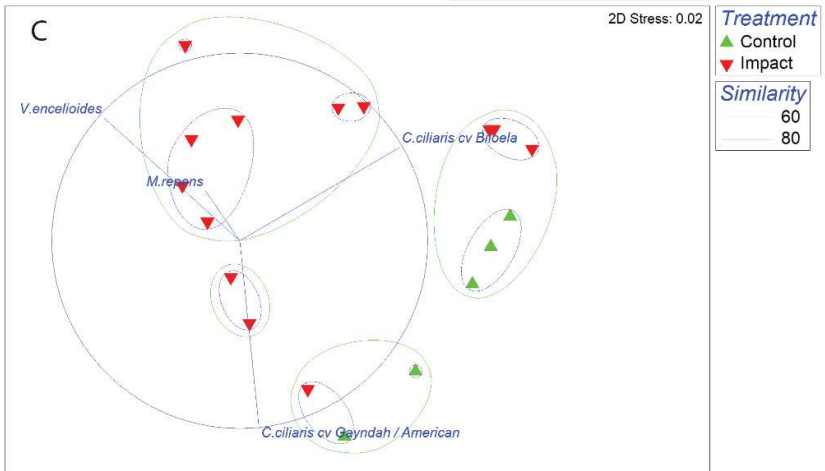


Fig. S9 nMDS ordination based on species contribution to cover for ungrazed quadrats (A), grazed quadrats (B) and rehabilitation quadrats (C). Indicator species were plotted where  $p < 0.05$ . Treatment was significant for all plots ( $p < 0.001$ ).

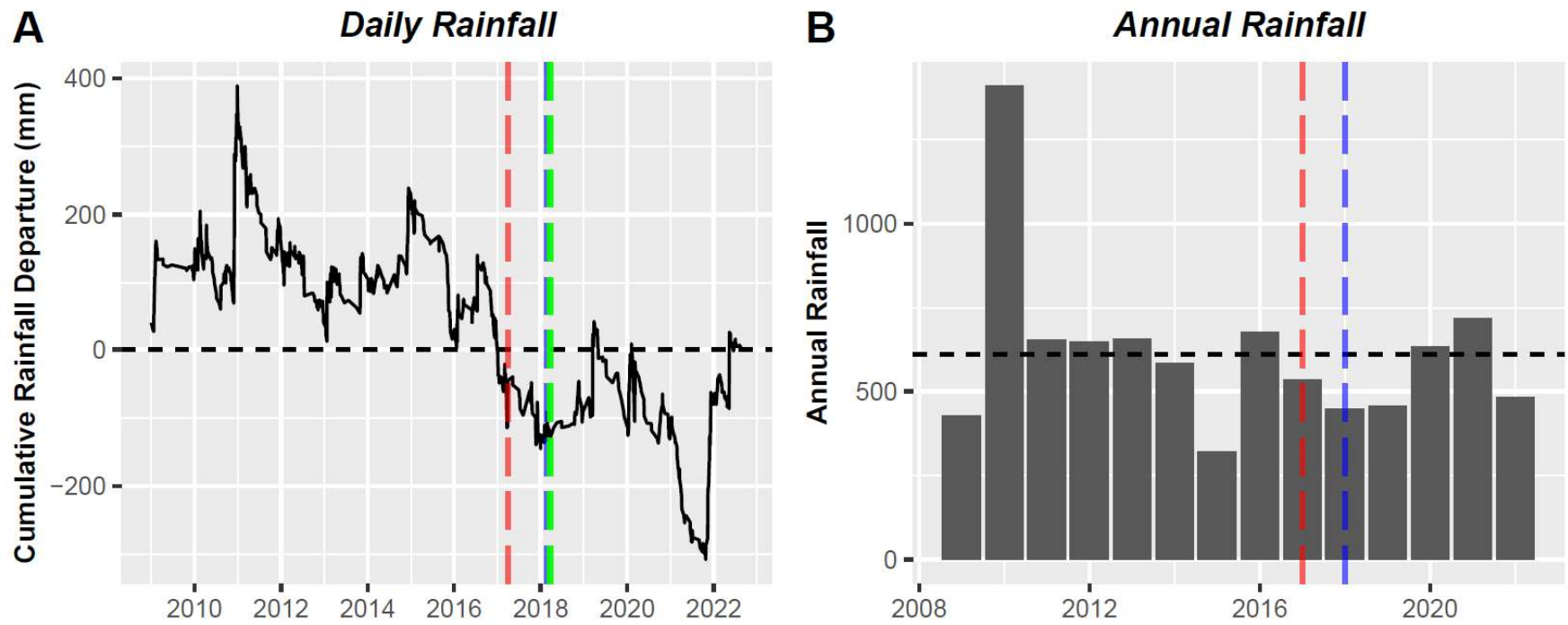


Fig. S10 Cumulative rainfall departure (A) and annual rainfall (B) totals from 2009-2022. Rainfall data is taken from weather station on site. Red vertical dashed line indicates timing of the first appearance of PD in ungrazed, the blue horizontal line indicates the first detection of PD in grazed and the green vertical line indicates the first detection of PD in rehabilitation. Black horizontal line in (B) shows the mean of the data set.

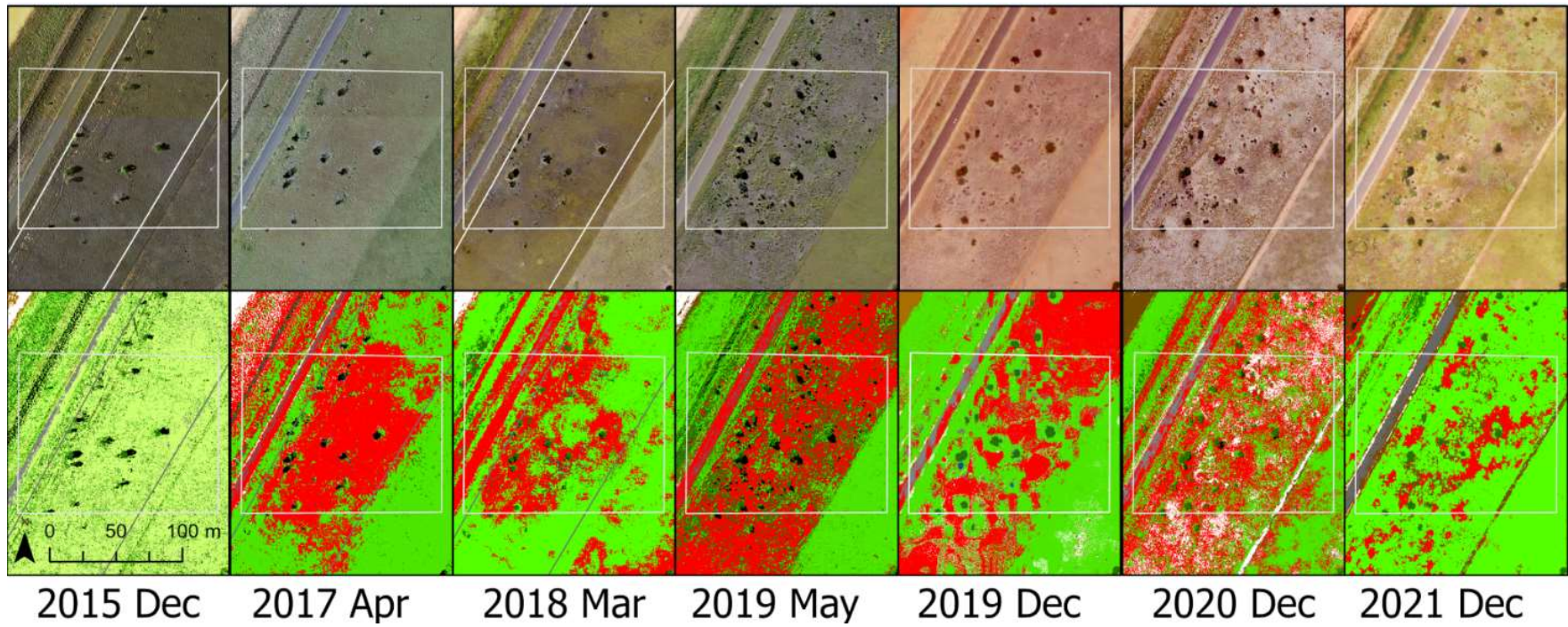


Fig. S11      *Ungrazed roadside showing the location of the first detected PD (red) in April 2017 and subsequent spread of the infected area.*



Fig. S12 A selection of representative quadrats from each of the three treatments.

## Random Forest Error Matrices

Table S1 2015 image classification Error matrix. Note that the class 'Cured Veg' was not PD, but was kept separate from the healthy veg class which represented less cured grasses.

Prediction	Bare White	Bare Brown	Bare Asphalt	Cured Veg	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	50	0	0	0	3	0	0	0	53	0.94
Bare Brown	0	29	0	2	1	0	0	0	32	0.91
Bare Asphalt	0	0	21	4	1	2	0	0	28	0.75
Cured Veg	0	0	7	25	1	3	0	0	36	0.69
Healthy Veg	0	0	0	1	27	12	0	0	40	0.68
Trees & Shrubs	0	0	0	0	21	44	0	0	65	0.68
Shadow	0	0	0	0	0	1	29	0	30	0.97
Water	0	0	0	0	0	1	0	12	13	0.92
<b>Total</b>	50	29	28	32	54	63	29	12	297	
<b>Prod. Accuracy</b>	1.00	1.00	0.75	0.78	0.50	0.70	1.00	1.00		
<b>Kappa:</b>					<b>0.76</b>		<b>Overall Map Accuracy</b>			<b>0.80</b>

Table S2

2017 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	23	1	0	0	0	0	0	1	25	0.92
Bare Brown	0	51	0	3	0	0	0	0	54	0.94
Bare Asphalt	0	0	2	0	0	0	0	0	2	1.00
Pasture Dieback	0	3	6	70	0	2	0	1	82	0.85
Healthy Veg	0	0	0	0	267	34	0	0	301	0.89
Trees & Shrubs	0	0	0	0	11	30	0	1	42	0.71
Shadow	0	0	0	0	0	3	21	0	24	0.88
Water	0	0	0	0	0	1	0	17	18	0.94
<b>Total</b>	23	55	8	73	278	70	21	20	548	
<b>Prod. Accuracy</b>	1.00	0.93	0.25	0.96	0.96	0.43	1.00	0.85		
					<b>Kappa</b>	0.82		<b>Overall Map Accuracy</b>		0.88

Table S3

2018 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	93	4	0	3	2	0	0	0	102	0.91
Bare Brown	0	64	0	1	0	0	1	0	66	0.97
Bare Asphalt	0	0	22	3	0	0	0	0	25	0.88
Pasture Dieback	2	2	13	192	3	0	0	1	213	0.90
Healthy Veg	0	0	0	5	270	5	0	1	281	0.96
Trees & Shrubs	0	0	0	0	8	87	2	0	97	0.90
Shadow	0	0	0	0	0	5	20	0	25	0.80
Water	0	0	0	1	0	1	0	27	29	0.93
<b>Total</b>	95	70	35	205	283	98	23	29	838	
<b>Prod. Accuracy</b>	0.98	0.91	0.63	0.94	0.95	0.89	0.87	0.93		
<b>Kappa</b>						<b>90.05</b>	<b>Overall Map Accuracy</b>			<b>0.92</b>



Table S4

2019 05 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	74	2	0	3	0	1	0	0	80	0.93
Bare Brown	0	37	0	0	0	0	0	0	37	1.00
Bare Asphalt	0	0	20	20	0	0	0	0	40	0.50
Pasture Dieback	1	12	21	251	0	0	0	0	285	0.88
Healthy Veg	0	0	0	0	311	76	0	1	388	0.80
Trees & Shrubs	0	0	0	1	44	101	0	8	154	0.66
Shadow	0	0	0	0	1	2	83	5	91	0.91
Water	0	0	0	0	1	1	0	18	20	0.90
<b>Total</b>	75	51	41	275	357	181	83	32	1095	
<b>Prod. Accuracy</b>	0.99	0.73	0.49	0.91	0.87	0.56	1.00	0.56		
<b>Kappa</b>						<b>76.60</b>	<b>Overall Map Accuracy</b>			<b>0.82</b>

Table S5

2019 12 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	69	4	0	7	9	0	0	2	91	0.76
Bare Brown	4	66	0	1	2	0	1	0	74	0.89
Bare Asphalt	0	0	21	4	0	0	0	2	27	0.78
Pasture Dieback	1	2	7	204	8	0	0	0	222	0.92
Healthy Veg	8	12	1	11	182	0	0	1	215	0.85
Trees & Shrubs	0	0	0	0	0	76	0	0	76	1.00
Shadow	0	0	0	0	0	0	22	1	23	0.96
Water	1	0	0	0	0	1	0	25	27	0.93
<b>Total</b>	83	84	29	227	201	77	23	31	755	
<b>Prod. Accuracy</b>	0.83	0.79	0.72	0.90	0.91	0.99	0.96	0.81		
<b>Kappa</b>						<b>85.10</b>	<b>Overall Map Accuracy</b>			<b>0.88</b>

Table S6

2020 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	160	4	0	1	0	0	0	1	166	0.96
Bare Brown	2	68	0	0	0	0	0	0	70	0.97
Bare Asphalt	0	0	30	3	0	0	0	0	33	0.91
Pasture Dieback	2	2	18	145	2	0	0	0	169	0.86
Healthy Veg	0	2	0	1	317	10	0	1	331	0.96
Trees & Shrubs	0	0	0	0	19	135	3	0	157	0.86
Shadow	0	2	0	1	0	4	34	0	41	0.83
Water	0	0	0	0	0	0	0	22	22	1.00
<b>Total</b>	164	78	48	151	338	149	37	24	989	
<b>Prod. Accuracy</b>	0.98	0.87	0.63	0.96	0.94	0.91	0.92	0.92		
				<b>Kappa</b>		90.12		<b>Overall Map Accuracy</b>		0.92

Table S7

2021 image classification error matrix.

Prediction	Bare White	Bare Brown	Bare Asphalt	Pasture Dieback	Healthy Veg	Trees & Shrubs	Shadow	Water	Total	Users Accuracy
Bare White	31	3	0	0	0	0	0	0	34	0.91
Bare Brown	2	43	0	0	0	0	0	0	45	0.96
Bare Asphalt	0	0	36	1	0	0	0	1	38	0.95
Pasture Dieback	0	0	0	35	0	0	0	1	36	0.97
Healthy Veg	0	1	0	1	110	4	0	1	117	0.94
Trees & Shrubs	0	0	0	0	1	52	9	0	62	0.84
Shadow	0	0	0	1	0	15	36	0	52	0.69
Water	0	0	0	0	0	1	0	48	49	0.98
Total	33	47	36	38	111	72	45	51	433	
Prod. Accuracy	0.94	0.91	1.00	0.92	0.99	0.72	0.80	0.94		
<b>Kappa</b>						88.60	<b>Overall Map Accuracy</b>			0.90

Table S8

2015-2021 random forest modelling error matrix.

	BareWhite	BareBrown	Bare Asphalt	PastureDieback	HealthyVeg	TreesShrubs	Shadow	Water	Total	Users accuracy
BareWhite	1205	30	13	112	66	1	0	14	1441	0.84
BareBrown	64	1050	0	39	69	1	8	0	1231	0.85
BareAsphalt	15	1	336	256	17	3	1	2	631	0.53
PastureDieback	77	36	155	2155	108	27	19	4	2581	0.83
HealthyVeg	31	35	23	108	3865	492	15	14	4583	0.84
TreesShrubs	1	1	3	16	636	1268	53	24	2002	0.63
Shadow	0	17	1	31	16	60	627	4	756	0.83
Water	29	1	7	7	15	22	17	451	549	0.82
Total	1422	1171	538	2724	4792	1874	740	513	13774	
producers accuracy	0.85	0.90	0.62	0.79	0.81	0.68	0.85	0.88		

OMA	0.795
Kappa	0.75

Table S9

Variable importance from 2015-2021 random forest modelling.

Band	BareWhite	BareBrown	BareAsphalt	PastureDieback	HealthyVeg	TreesShrubs	Shadow	Water	MeanDecreaseAccuracy	MeanDecreaseGini
red	117.55	519.27	78.92	317.85	141.95	83.44	122.08	414.44	426.40	2963.96
green	36.00	42.01	37.49	76.25	78.98	12.11	97.29	36.07	144.87	1149.76
blue	917.67	114.33	220.44	382.87	311.39	224.59	190.39	162.99	735.82	3352.81
gli	375.48	321.50	248.17	505.22	356.97	202.77	62.44	264.63	819.51	3526.35

## Statistical Tables

*Table S10 Summary statistics for species richness*

Treatment	Site	variable	n	mean	sd
Control	Grazed	Richness	10	2.7	1.337
Impact	Grazed	Richness	10	2.6	0.699
Control	Rehab	Richness	20	1.2	0.41
Impact	Rehab	Richness	20	1.75	0.716
Control	Ungrazed	Richness	10	2.6	0.966
Impact	Ungrazed	Richness	10	3.5	1.509

*Table S11 Summary statistics for biomass*

Site	Treatment	variable	n	mean	sd
Grazed	Control	biomass_tha	10	3.845	1.02
Grazed	Impact	biomass_tha	10	6.087	1.639
Rehab	Control	biomass_tha	20	6.461	1.569
Rehab	Impact	biomass_tha	20	2.97	2.324
Ungrazed	Control	biomass_tha	10	10.104	2.918
Ungrazed	Impact	biomass_tha	10	4.618	2.351

*Table S12 Summary statistics for cover estimates*

Site	Treatment	Cover	variable	n	mean	sd
Grazed	Control	Bare	Percent	10	21.4	13.858
Grazed	Control	Detached_litters	Percent	10	5.7	5.355
Grazed	Control	Rock	Percent	10	0.5	1.581
Grazed	Control	Standing_dead	Percent	10	0.16	0.334
Grazed	Control	Standing_live	Percent	10	72.2	16.91
Grazed	Impact	Bare	Percent	10	2.2	1.814
Grazed	Impact	Detached_litters	Percent	10	2	1.491
Grazed	Impact	Rock	Percent	10	0	0
Grazed	Impact	Standing_dead	Percent	10	0.3	0.675
Grazed	Impact	Standing_live	Percent	10	95.5	3.136
Rehab	Control	Bare	Percent	20	3.85	10.505

Rehab	Control	Detached_litters	Percent	20	1.605	2.323
Rehab	Control	Rock	Percent	20	0.4	0.598
Rehab	Control	Standing_dead	Percent	20	1.065	1.305
Rehab	Control	Standing_live	Percent	20	93.1	13.01
Rehab	Impact	Bare	Percent	20	0.8	1.361
Rehab	Impact	Detached_litters	Percent	20	4.45	5.643
Rehab	Impact	Rock	Percent	20	0.075	0.245
Rehab	Impact	Standing_dead	Percent	20	4.8	4.83
Rehab	Impact	Standing_live	Percent	20	89.85	10.698
Ungrazed	Control	Bare	Percent	10	0.3	0.483
Ungrazed	Control	Detached_litters	Percent	10	1.7	1.16
Ungrazed	Control	Rock	Percent	10	0	0
Ungrazed	Control	Standing_dead	Percent	10	0.3	0.483
Ungrazed	Control	Standing_live	Percent	10	97.7	1.337
Ungrazed	Impact	Bare	Percent	10	5.8	7.584
Ungrazed	Impact	Detached_litters	Percent	10	7.3	7.088
Ungrazed	Impact	Rock	Percent	10	0.1	0.316
Ungrazed	Impact	Standing_dead	Percent	10	2.25	1.55
Ungrazed	Impact	Standing_live	Percent	10	84.5	14.585

Table S13 Statistical test results for species richness comparison of means

Site	.y.	group1	group2	n1	n2	statistic	p	p.signif
Ungrazed	Richness	Control	Impact	10	10	29	0.105	ns
Grazed	Richness	Control	Impact	10	10	50.5	1	ns
Rehab	Richness	Control	Impact	20	20	114	0.00756	**

Table S14 Statistical test results for biomass comparison of means

Site	.y.	group1	group2	n1	n2	statistic	df	p	p.signif
Ungrazed	biomass_tha	Control	Impact	10	10	4.630406	17.22008	0.000232	***
Grazed	biomass_tha	Control	Impact	10	10	-3.67432	15.0604	0.00224	**
Rehab	biomass_tha	Control	Impact	20	20	5.566852	33.34013	3.35E-06	***

Table S15 Statistical test results for % cover comparison of means

Site	Cover	.y.	group1	group2	n1	n2	statistic	p	p.signif
Ungrazed	Bare	Percent	Control	Impact	10	10	11	0.00229	**
Ungrazed	Detached_litters	Percent	Control	Impact	10	10	27.5	0.0927	ns
Ungrazed	Rock	Percent	Control	Impact	10	10	45	0.368	ns
Ungrazed	Standing_dead	Percent	Control	Impact	10	10	11	0.00249	**
Ungrazed	Standing_live	Percent	Control	Impact	10	10	85.5	0.00709	**
Grazed	Bare	Percent	Control	Impact	10	10	93.5	0.00108	**
Grazed	Detached_litters	Percent	Control	Impact	10	10	74	0.0691	ns
Grazed	Rock	Percent	Control	Impact	10	10	55	0.368	ns
Grazed	Standing_dead	Percent	Control	Impact	10	10	52.5	0.842	ns
Grazed	Standing_live	Percent	Control	Impact	10	10	6	0.000977	***
Rehab	Bare	Percent	Control	Impact	20	20	239.5	0.254	ns
Rehab	Detached_litters	Percent	Control	Impact	20	20	105	0.00913	**
Rehab	Rock	Percent	Control	Impact	20	20	254	0.0467	*
Rehab	Standing_dead	Percent	Control	Impact	20	20	60.5	0.000139	***
Rehab	Standing_live	Percent	Control	Impact	20	20	285	0.0216	*



## Species List

Table S16 Species found in quadrats for each treatment (1= present).

Lifeform	Common Name	Species	Grazed		Ungrazed		2006 Rehabilitation	
			Control	Impact	Control	Impact	Control	Impact
Forb	Common Joyweed	<i>Alternanthera nodiflora</i>	1			1		
Grass	Indian Bluegrass	<i>Bothriochloa pertusa</i>		1				
Forb	Burr Daisy	<i>Calotis cuneata</i>	1	1				
Grass	Buffel	<i>Cenchrus ciliaris cv Biloela</i>			1	1	1	1
Grass	Buffel	<i>Cenchrus ciliaris cv Gayndah/American</i>	1	1	1	1	1	1
Fern	Mulga Fern	<i>Cheilanthes sieberi subsp. sieberi</i>				1		
Vine	Butterfly Pea	<i>Clitoria ternatea</i>						1
Vine	Creeping Tick Trefoil	<i>Desmodium campylocaulon</i>				1		
Forb	baby blue eyes	<i>Evolvulus alsinoides</i>				1		
Vine	woolly glycine	<i>Glycine tomentella</i>		1		1		
Vine	Bellvine	<i>Ipomoea plebeia</i>			1			
Forb	Milk Thistle	<i>Lactuca serriola forma serriola</i>				1		
Vine	Siratro	<i>Macroptilium atropurpureum</i>			1			
Grass	Red Natal Grass	<i>Melinis repens</i>		1		1		1
Forb	Minnie Daisy	<i>Minuria leptophylla</i>				1		
Forb	creeping oxalis	<i>Oxalis corniculata</i>				1		
Vine	Rough Silkpod	<i>Parsonsia lanceolata</i>			1	1		
Forb	Pigweed	<i>Portulaca oleracea</i>	1					
Forb	Hairy Portulaca	<i>Portulaca pilosa</i>	1					
Forb	Fruit-salad Plant	<i>Pterocaulon sphacelatum</i>		1				
Forb	Rhyncho	<i>Rhynchosia minima</i>				1		
Forb	Rolypoly	<i>Salsola australis</i>						1
Forb	Yellow burr	<i>Sclerolaena anisacanthoides</i>	1					
Forb	Spiny sida	<i>Sida spinosa</i>	1	1	1			
Grass	Unk1	<i>Sporobolus sp.</i>		1				
Forb	Caribbean stylo	<i>Stylosanthes hamata</i>		1				
Forb	Crownbeard	<i>Verbesina encelioides</i>		1		1		1
Forb	Unk2	<i>Asteraceae seedling</i>	1					