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Supplementary material

Lack of reliable post-fire recovery mechanisms makes the iconic Tasmanian conifer *Athrotaxis cupressoides* susceptible to population decline

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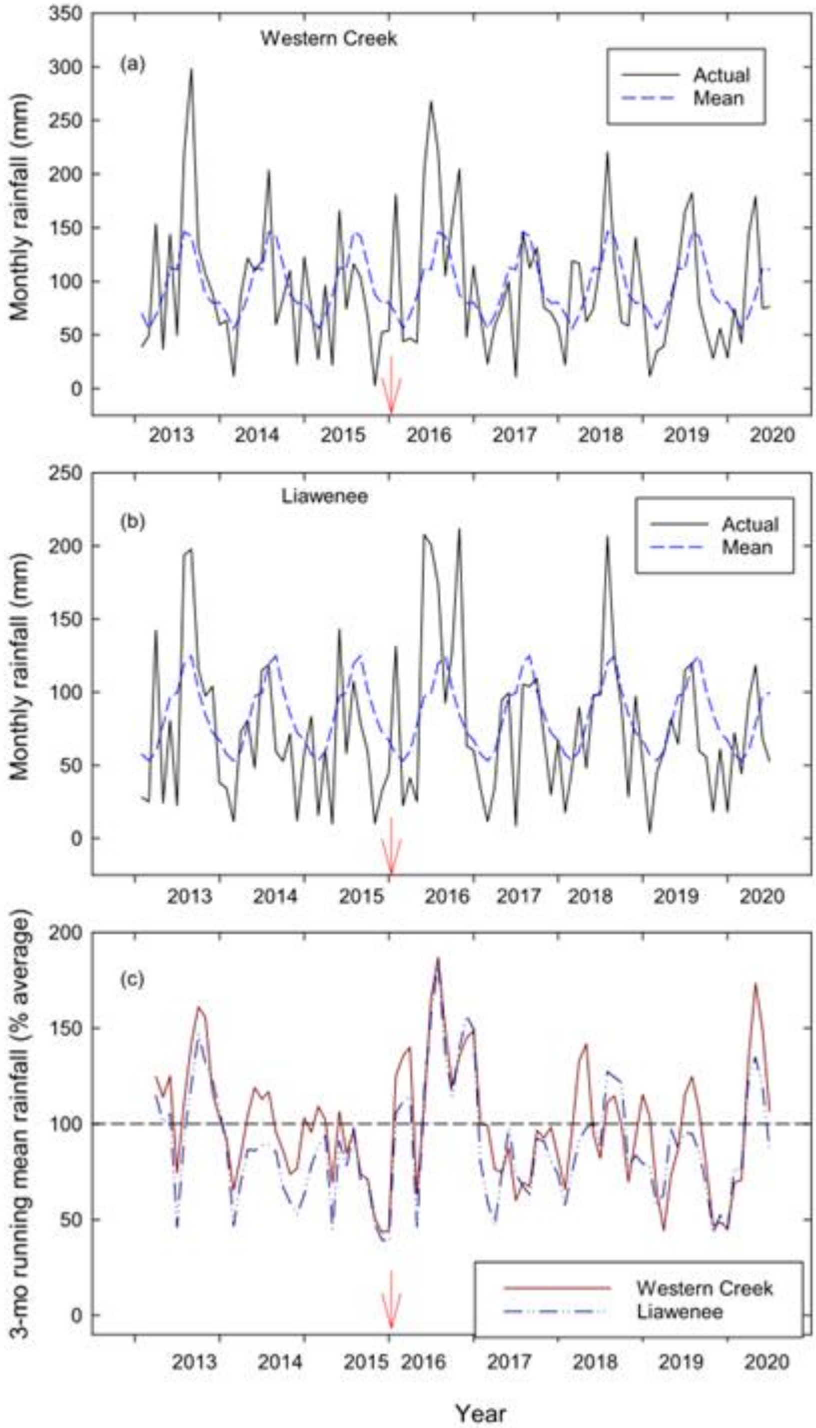

Fig. S1. Monthly rainfall totals in relation to long-term averages between January 2013 and June 2020 at (a) Western Creek and (b) Liawenee rainfall stations. (c) 3-month running average monthly rainfall at Western Creek and Liawenee as a percentage of their respective long-term running 3-month averages. Note the rainfall deficiencies immediately before the fire (red arrow) and again in late 2019. The correlations between monthly rainfall at Lake Mackenzie and (d) Liawenee, and (e) Western Creek, between January 1974 and December 1992, when the rainfall station at Lake Mackenzie was open, are also shown. Western Creek is the rainfall station closest to Lake Mackenzie (12 km away), but is only at 417 m ASL, and Liawenee is the closest, high-altitude station (1057 m ASL, 31 km away). Based on data from Bureau of Meteorology (2020).

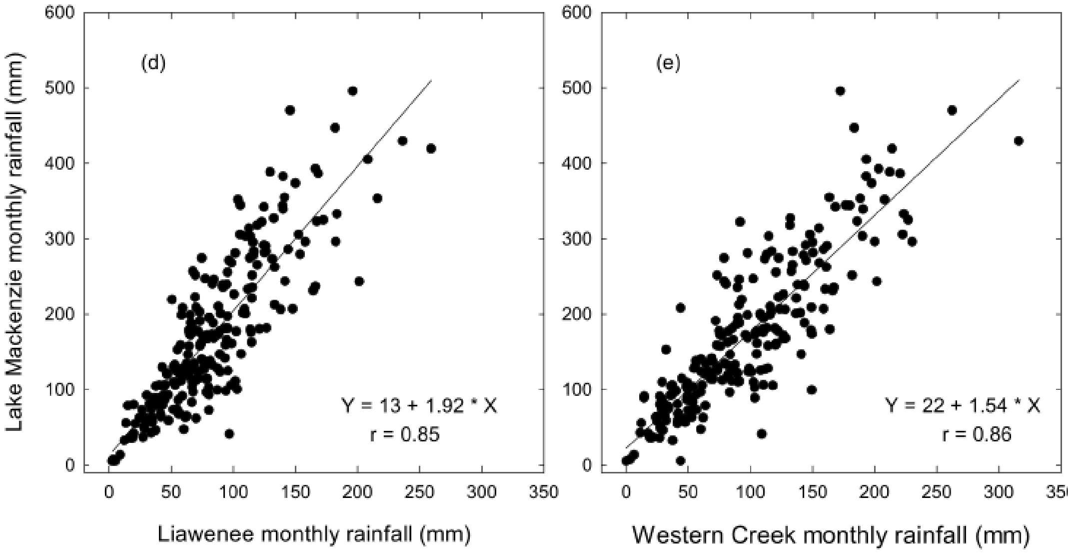
(d)
Y = 13 + 1.92 * X
r = 0.85
Lake Mackenzie monthly rainfall (mm)
Liawenee monthly rainfall (mm)
(e)
Y = 22 + 1.54 * X
r = 0.86
Western Creek monthly rainfall (mm)

Fig. S1. *(Cont.)*

Table S1. Summary of sample counts and results, for the three sites and overall, in (a) the burnt and (b) the unburnt plots

Only survival is shown for the unburnt plots, but for the burnt plots, *Athrotaxis* population and fire severity characteristics are also shown. Measurements were made at the plot, tree and stem levels, but the means, s.e.m. and analyses shown here are based on plot means (enabling analysis of variability among sites; note that overall means based on these values will differ slightly from means based on pooled data). All measurements, except those labelled 2020, were made in 2017. Stand BA (basal area) and stem density apply to all *Athrotaxis* stems that were alive at the time of the 2016 fires. The statistical support for differences among sites is shown by Akaike weights (w_i) of the site model relative to the intercept only model, and the percentage deviance explained by the site model. Values of $w_i > 0.73$, which correspond to AIC_c being at least 2 less than that of the null model, are indicative of support for the model and are shown in bold

Site		'Scree East'		'Scree West'		'South Bog'		Site differences	
	Unit	average	s.e.m.	average	s.e.m.	average	s.e.m.	w_i	Deviance explained (%)
(a) Burnt plots									
Plot level	Count:	110		111		73			
Stand BA	$m^2\ ha^{-1}$	5.5	0.8	16.8	1.9	12.8	1.4	**1**	10.5
Stem density	ha^{-1}	307	36	415	33	229	27	**1**	4.6
Tree level	Count:	369		563		232			
Canopy scorched	%	75.8	3.5	75	2.9	69.1	4.4	0.24	0.62
Canopy consumed	%	33.3	3.4	22.2	3.1	24	3.9	**0.8**	2.19
Canopy Dead-2020	%	74.6	3.7	73.9	3	67.5	4.6	0.26	0.65
Burnt twig diameter	mm	2.69	0.16	2.6	0.15	3.31	0.27	**0.8**	2.4
Juveniles – 2017	%[A]	2.7	1.3	11.3	2.6	13.7	3.6	**1**	3.7
Juveniles – 2020	%[A]	0	0	1	0.6	6.6	2.7	**1**	4.7
Stem level	Count:	1050		1427		520			
Live stems – 2017	%[B]	29	4	32.9	3.5	40.1	5.1	0.41	1.13
Live stems – 2020	%[B]	28.3	3.9	29.5	3.3	38	5.1	0.36	1.01
DBH	cm	14.7	0.9	19.9	1.2	26.5	1.4	**1**	13.6
Resprouting	%[B]	6.8	2.2	1.6	1	1.3	0.8	**0.9**	2.6
(b) Unburnt plots									
Plot level	Count:	6		8		6			
Tree level	Count:	23		28		24			
Stem level	Count:	49		55		50			
Live stems – 2017	%[B]	100	0	100	0	100	0	n.a.	n.a.
Live stems – 2020	%[B]	100	0	100	0	100	0	n.a.	n.a.

[A]Percentage of trees with juveniles within a 2-m radius of the base.

[B]As a percentage of all stems that were alive at the time of the fire.

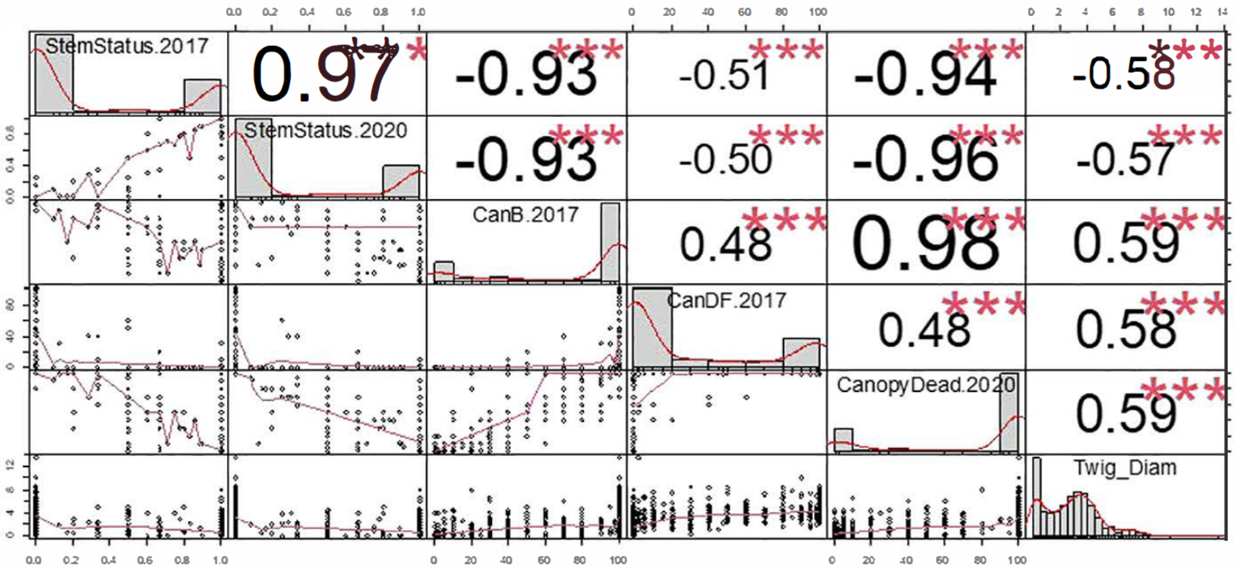

Fig. S2. Correlations matrices for survival of *A. cupressoides* stems and fire severity attributes (tree level data) in burnt plots only. The variables (from top left) are the proportion of stems alive in 2017 and 2020 in each tree, percentage canopy scorched and percentage canopy consumed in 2017, percentage canopy dead in 2020, and minimum burnt twig diameter of shrubs around the tree in 2017. The top of each matrix shows the Pearson correlation coefficient and the significance of the correlation ('.', $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$). The bottom of the matrix shows bivariate scatterplots, with a fitted line. The R package PerformanceAnalytics (ver. 1.4.354, B. G. Peterson and P. Carl, see http://CRAN.R-project.org/package=PerformanceAnalytics) was used to generate the matrices.

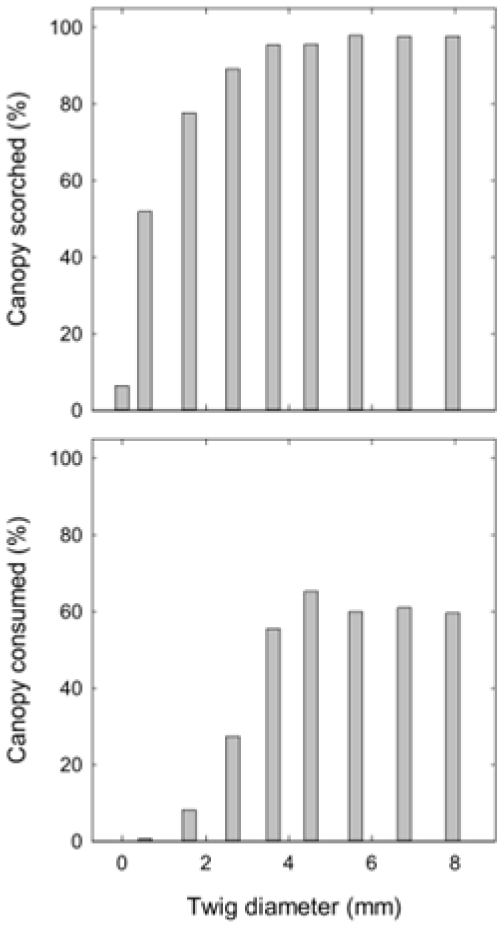

Fig. S3. (a) Canopy scorched, and (b) canopy consumed, in relation to minimum burnt twig diameter of shrubs around each tree, in burnt plots only. All variables were measured in 2017, at tree level. Twigs were binned into 1-mm classes for presentation, but actual values were used in analyses.

Table S2. Comparison of models describing canopy scorched and canopy consumed in relation to minimum burnt twig diameter and DBH

Fire severity variables were recorded in 2017, at tree level, in burnt plots only. DBH was recorded at stem level in 2017, and in this analysis, was averaged for each tree

	Canopy scorched		Canopy consumed	
Model	w_i	Explained deviance (%)	w_i	Explained deviance (%)
Twig diameter	1.000	34.8	1.000	21.1
Intercept only	<0.001	n.a.	<0.001	n.a.

Table S3. Comparison of models to evaluate (a) stem survival in 2020 and (b) the probability of survivors in 2017 surviving to 2020, in relation to three 2017 fire severity measures (percentage canopy scorched, percentage canopy consumed and minimum burnt twig diameter)

Summaries of the stem-level analyses demonstrating support for a peaked relationship with stem diameter (DBH) for (c) stem survival in 2020, but (d) not for stem survival between 2017 and 2020, are also shown. Burnt plots only were used in these analyses. Models are listed in order of decreasing statistical support

	log(l)	K	AICc	Delta.AICc	wi	expdev
(*a*) Survival in 2020						
Canopy scorched + DBH	–378	3	764	0	1	77.5
Canopy scorched	–399	2	805	41	0	76.2
Canopy consumed + DBH	–1038	3	2084	1319	0	38.2
Twig_Diam + DBH	–1038	3	2084	1320	0	38.1
Canopy consumed	–1066	2	2137	1373	0	36.5
Twig_Diam	–1112	2	2231	1466	0	33.7
DBH	–1626	2	3259	2495	0	3.1
intercept only	–1678	1	3360	2596	0	NA
(*b*) Survival between 2017 and 2020						
Canopy scorched + DBH	–149	3	306	0	0.881	25.7
Canopy scorched	–152	2	310	4	0.119	24.2
Canopy consumed	–195	2	397	91	0	2.4
Twig_Diam + DBH	–195	3	397	92	0	2.8
Canopy consumed + DBH	–195	3	398	92	0	2.7
Twig_Diam	–196	2	398	92	0	2.1
intercept only	–200	1	405	99	0	NA
DBH	–200	2	406	100	0	0.2
Adding a $(DBH)^2$ term to the top models						
(*c*) Survival in 2020						
Canopy scorched + DBH + $(DBH)^2$	–371	4	751	0	0.999	79.5
Canopy scorched + DBH	–378	3	764	13	0.001	77.5
(*d*) Survival between 2017 and 2020						
Canopy scorched + DBH	–148.8	3	305.6	0	0.706	25.7
Canopy scorched + DBH + $(DBH)^2$	–148.7	4	307.4	1.8	0.294	25.8

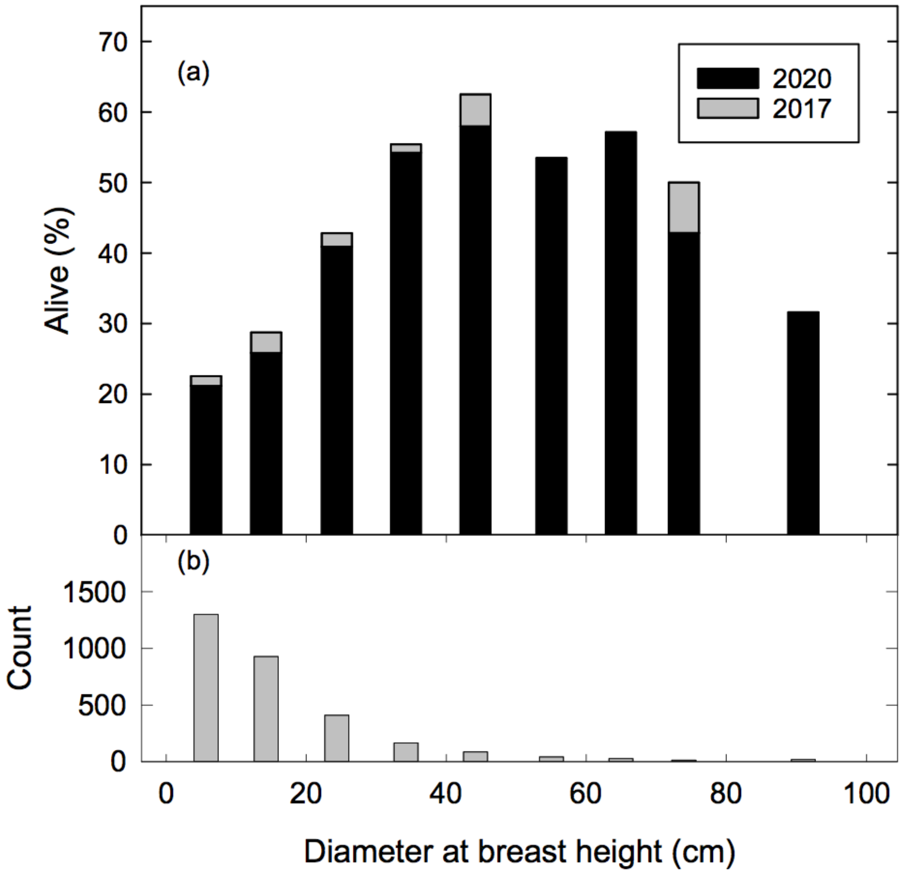

Fig. S4. (a) The percentage of stems alive in 2017 and 2020, in burnt plots only, in relation to diameter at breast height, and (b) the frequency distribution of stems according to diameter. For presentation, observations were binned into arbitrary classes, but actual values were used in the analysis. The support for a peaked relationship in 2020 is shown in Table S3*c*.

Table S4. Comparison of models describing resprouting in relation to the fire severity measures canopy scorched, canopy consumed and minimum burnt twig diameter, in combination with DBH, in burnt plots only

We anticipated there could be a peaked relationship, with little resprouting in undamaged and severely damaged stems, so included a severity^2 term to test for this. (Indeed, this was the case for canopy scorched). The w_i for the best supported model in each set is indicated in bold

Severity measure	Canopy scorched		Canopy consumed		Twig diameter	
Model	w_i	Exp dev (%)	w_i	Exp dev (%)	w_i	Exp dev (%)
severity^2 + severity + DBH	0.342	22.2	0.092	12.2	0.186	12.3
severity^2 + severity	**0.658**	22.1	0.178	12.1	0.160	11.9
severity + DBH	<0.001	8.3	0.250	12.2	**0.347**	12.2
severity	<0.001	8.2	**0.480**	12.1	0.307	11.7
DBH	<0.001	0.5	<0.001	0.5	<0.001	0.5
intercept only	<0.001	NA	<0.001	NA	<0.001	NA

Table S5. Comparison of binomial GLMs describing juvenile presence in relation to three fire severity measures (canopy scorched, canopy consumed and minimum burnt twig diameter), in combination with tree basal area (summed for all stems of the 'tree' that were alive at the time of the fire in 2016)

Burnt plots only were used in this analysis. The w_i for the best supported model in each set is indicated in bold

Severity measure	Canopy scorched		Canopy consumed		Twig diameter	
Model	w_i	Exp dev (%)	w_i	Exp dev (%)	w_i	Exp dev (%)
In 2017						
Severity + Tree.BA	**0.806**	19.49	**0.846**	14.72	**0.992**	20.4
Severity	0.194	18.84	0.154	14	0.008	18.64
Tree.BA	0.000	1.34	0.000	1.34	0.000	1.44
intercept only	0.000	NA	0.000	NA	0.000	NA
In 2020						
Severity + Tree.BA	0.473	18.58	0.491	13.49	**0.428**	3.457
Severity	**0.527**	17.72	**0.509**	12.57	0.356	2.267
Tree.BA	0.000	1.38	0.000	1.382	0.116	1.15
intercept only	0.000	NA	0.000	NA	0.100	NA

Table S6. Data used as the basis for Fig. 6 in main text (in bold)

The Kane *et al*. (2017) study was based on a large dataset documenting effects of planned fires on canopy damage and tree survival in mixed conifer forests in the western USA. Conifers and broadleaf trees are grouped together. Weighted average crown volume scorched damage was calculated for live and dead trees combined, as an indication of fire severity. These planned fires were less severe overall than the wildfire in our study

	Count			Crown volume scorched (%)			Mean DBH (%)	
Species	Live	Dead	Percentage survival	Live	Dead	Weighted average	Live	Dead
Athrotaxis cupressoides	875	2122	**29**	20	97	**75**	20	14
Kane *et al*. (2017) Table 3								
Abies concolor	371	2075	**15**	33	66	**61**	25	19
Abies magnifica	21	99	**18**	21	77	**67**	61	31
Calocedrus decurrens	112	581	**16**	21	77	**68**	33	20
Juniperus osteosperma	48	87	**36**	25	75	**57**	25	27
Pinus contorta	60	227	**21**	13	48	**41**	19	24
Pinus lambertiana	19	252	**7**	13	60	**57**	56	23
Pinus ponderosa	1890	1325	**59**	20	65	**39**	32	28
Pseudotsuga menziesii	494	290	**63**	38	71	**50**	19	28
Mean-conifers			29			55	34	25
Populus tremuloides	67	50	57	3	21	**11**	20	19
Quercus gambelii	31	91	25	20	54	**45**	16	13
Quercus kelloggii	33	150	18	37	40	**39**	25	23
Mean- broadleafs			34			**32**	20	18

References

Bureau of Meteorology (2020) Climate Data Online. Available at http://www.bom.gov.au/climate/data/ [Verified 10 August 2020]

Kane JM, van Mantgem PJ, Lalemand LB, Keifer M (2017) Higher sensitivity and lower specificity in post-fire mortality model validation of 11 western US tree species. *International Journal of Wildland Fire* **26**, 444–454. doi:10.1071/WF16081