Ecography

ECOG-02228
De Palma, A., Dennis, R. L. H., Brereton, T., Leather, S. and Oliver, T. H. 2016. Large reorganizations in butterfly communities during an extreme weather event. – Ecography doi: 10.1111/ecog.02228

Supplementary material

Appendix 1: Triangular representation of UK butterfly species used in this study in CSR-space.

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Appendix 3: Species included in the analysis and their CSR-scores

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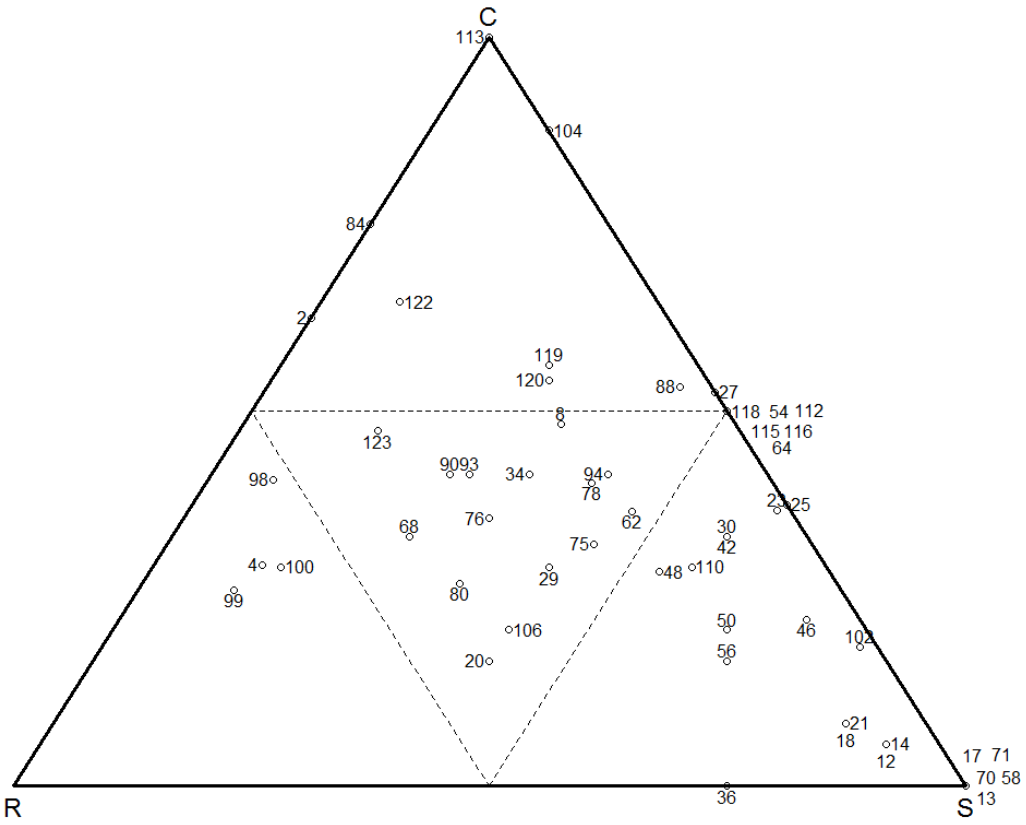
Appendix 9: Results of analysis assessing how change in abundance (Δ abundance from 1994 to 1995) varies with landscape heterogeneity, for dietary specialists and generalists separately.

Appendix 1: Triangular representation of UK butterfly species used in this study in *CSR*-space. Numbers correspond to the species UKBMS code:

2: *Aglais urticae;* 4: *Anthocharis cardamines;* 8: *Aphantopus hyperantus;* 12: *Argynnis aglaja;* 13: *Argynnis adippe;* 14: *Boloria euphrosyne;* 17: *Argynnis paphia;* 18*: Boloria selene;* 20: *Aricia agestis;* 21: *Aricia artaxerxes;* 23: *Callophrys rubi;* 25: *Carterocephalus palaemon*; 27: *Celastrina argiolus;* 29: *Coenonympha pamphilus;* 30: *Coenonympha tullia;* 34: *Colias croceus;* 36: *Cupido minimus;* 42: *Erebia aethiops;* 46: *Erynnnis tages*; 48: *Hipparchia semele;* 50: *Euphydryas aurinia;* 54: *Gonepteryx rhamni;* 56: *Hamearis lucina;* 58: *Hesperia comma;* 62: *Leptidea sinapis;* 64: *Limenitis Camilla;* 68: *Lycaena phlaeas;* 70: *Polyommatus bellargus;* 71: *Polyommatus coridon;* 75: *Maniola jurtina;* 76: *Pyronia tithonus*; 78*: Melanargia galathea;* 80: *Melitaea athalia;* 84: *Aglais io;* 88: *Ochlodes sylvanus;* 90: *Papilio machaon britannicus;* 93: *Pararge aegeria;* 94: *Lasiommata megera;* 98: *Pieris brassicae;* 99: *Pieris napi;* 100: *Pieris rapae;* 102: *Plebejus argus;* 104: *Polygonia c-album;* 106: *Polyommatus icarus;* 110: *Pyrgus malvae;* 112: *Satyrium pruni;* 113: *Satyrium w-album;* 115: *Thecla betulae;* 116: *Favonius quercus;* 118: *Thymelicus action;* 119: *Thymelicus lineola;* 120: *Thymelicus sylvestris;* 122: *Vanessa atalanta;* 123: *Vanessa cardui* (Adapted from Dennis, 2010).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Appendix 2: Correlations between the *C*-*S*-*R* score of butterfly host plants and biological traits of the butterfly. Bold indicates that there were consistently significant correlations for all and main host plants; normal print indicates that these correlations were significant for one or other of all and main host plants; *italics* indicate that there was no significant correlation. Reproduced from Dennis *et al.* (2004).

	Correlation with:		
Biological Trait	***C*-score**	***S*-score**	***R*-score**
Wing expanse	Larger	**Smaller**	*Larger*
Proboscis length	Longer	**Shorter**	*Longer*
Oviposition behaviours	*Relatively precise*	Relatively careless	*Relatively precise*
Pre-oviposition periods	*Relatively longer*	*Various*	**Shorter**
Egg load	*Various, generally higher*	**Lower**	**Higher**
Egg size	*Relatively larger*	*Relatively smaller*	*Relatively smaller*
Egg batch size	*Relatively larger*	*Relatively smaller*	*Relatively larger*
Larval growth rate	*Relatively faster*	**Slower**	*Relatively faster*
Larval duration	**Shorter**	**Longer**	Relatively shorter
Duration of early stages	*Relatively shorter*	**Longer**	Relatively shorter
Adult life span	**Longer**	Relatively shorter	Relatively shorter
Hibernation stage (egg)	*Several*	*Relatively more*	**Fewer**
Hibernation stage (larva)	Generally less	**Prominent**	*Various*

Hibernation stage (pupa)	*Various*	*Various*	**Increasing**
Hibernation stage (adult)	**Increasing**	**Decreasing**	*Generally decreasing*
Adult hardiness, tolerance of ambient conditions	Decreasing (except overwintering adults)	Increasing	Increasing
Symbiotic relationship with ants	Decrease	**Prominent (Lycaenidae)**	**Decrease**
Voltinism	*Various*	**Increasingly univoltine**	**Increasingly multivoltine**
Number of host plants	*Various*	**Fewer**	**More**
Mean phagy score	*Various*	Relatively monophagous	**Relatively polyphagous**
Number of biotopes	*Various*	**Fewer**	**More**
Annual host plants	*Lacking*	**Fewer**	**Increasing**
Biennial host plants	*Lacking*	**Fewer**	**Increasing**
Short-lived perennial host plants	**Generally fewer (exceptions Nymphalidae)**	Generally increasing	**Increasing**
Long-lived perennial host plants	*Usual but various*	*Various*	**Fewer**
Host plant phenology: range	*Generally narrowing*	Narrower	**Increasing**
Nectar sources	*Increasing*	**Fewer**	**Increasing**

Utility resources for pupae and adults	Generally increasing	Fewer	*Various*
Host plant phenology	*Longer-lived plants*	*Longer-lived plants*	**Short-lived plants**
Host plant growth form	Relatively taller and more prominent plants	*Short herbs and shrubs*	**Short plants**
Plant life form association (immature stages)	**Typically tall herbs, shrubs and trees**	**Typically shorter turf to ground substrates**	*Typically tall herbs or below*
Plant life form association (adult stage)	**Taller vegetation, typically trees**	**Shorter vegetation to ground substrates**	**Relatively shorter vegetation**
Minimum habitat space occupied	Relatively larger minimum habitat size	Tendency for minimum habitat size to be smaller	*Various sizes*
Minimum population density	Tendency for typical minimum density to be lower	*Tendency for typical minimum density to be higher*	*Typical minimum densities vary*
Population structure	**Increasingly open structure**	Increasingly closed structure	*Open structure expected*
Mobility	**Higher**	**Lower**	**Higher**
Geographical range	*Various, including large*	**Increasingly restricted**	**Increasingly larger**
Metapopulation type	**Decreasing (none to patchy populations)**	**Increasing (distinctive and typically Levins)**	*Decreasing (none to patchy populations)*

Distribution cover	Relatively dense cover	**Sparse cover**	**Dense cover**
Incidence on offshore islands	Variable incidence	**Lower incidence**	**Higher incidence**
Change in population status over past 200 years	**Slower losses, persisting and expanding**	**Declining towards extinction**	SLOWER LOSSES, persisting and expanding
Recent losses to distribution cover	**Relatively fewer**	**Increasing losses**	Relatively few
Conservation status	**Low priority**	**High priority**	**Low priority**

Appendix 3: Species included in the analysis and their *CSR*-scores. Data reproduced from Dennis (2010).

Latin name	Common name	*C*-score	*S*-score	*R*-score
Aglais urticae	Small tortoiseshell	0.625	0	0.375
Anthocharis cardamines	Orange tip	0.2955	0.1136	0.5909
Aphantopus hyperantus	Ringlet	0.4833	0.3333	0.1833
Argynnis aglaja	Dark green fritillary	0.0556	0.8889	0.0556
Argynnis adippe	High brown fritillary	0	1	0
Boloria euphrosyne	Pearl-bordered fritillary	0.0556	0.8889	0.0556
Argynnis paphia	Silver-washed fritillary	0	1	0
Boloria selene	Small pearl-bordered fritillary	0.0834	0.8334	0.0834
Aricia agestis	Brown argus	0.1667	0.4167	0.4167
Aricia artaxerxes	Northern brown argus	0.0834	0.8334	0.0834
Callophrys rubi	Green hairstreak	0.3681	0.6181	0.0139
Carterocephalus palaemon	Chequered skipper	0.375	0.625	0
Celastrina argiolus	Holly blue	0.525	0.475	0
Coenonympha pamphilus	Small heath	0.2917	0.4167	0.2917
Coenonympha tullia	Large heath	0.3333	0.5833	0.0833
Colias croceus	Clouded yellow	0.4167	0.3334	0.25
Cupido minimus	Small blue	0	0.75	0.25
Erebia aethiops	Scotch argus	0.3334	0.5834	0.0834
Erynnnis tages	Dingy skipper	0.2222	0.7222	0.0556
Hipparchia semele	Grayling	0.2857	0.5357	0.1786
Euphydryas aurinia	Marsh fritillary	0.2083	0.6458	0.1458
Gonepteryx rhamni	Brimstone	0.5	0.5	0

Hamearis lucina	Duke of Burg. Frit.	0.1667	0.6667	0.1667
Hesperia comma	Silver-spotted skipper	0	1	0
Leptidea sinapis	Wood white	0.3667	0.4667	0.1667
Limenitis camilla	White admiral	0.5	0.5	0
Lycaena phlaeas	Small copper	0.3333	0.25	0.4167
Polyommatus bellargus	Adonis blue	0	1	0
Polyommatus coridon	Chalk-hill blue	0	1	0
Maniola jurtina	Meadow brown	0.3229	0.4479	0.2292
Pyronia tithonus	Gatekeeper	0.3571	0.3214	0.3214
Melanargia galathea	Marbled white	0.4048	0.4048	0.1905
Melitaea athalia	Heath fritillary	0.2708	0.3333	0.3958
Aglais io	Peacock	0.75	0	0.25
Ochlodes sylvanus	Large skipper	0.5333	0.4333	0.0333
Papilio machaon britannicus	Swallowtail	0.4167	0.25	0.3333
Pararge aegeria	Speckled wood	0.4167	0.2708	0.3125
Lasiommata megera	Wall brown	0.4167	0.4167	0.1667
Pieris brassicae	Large white	0.4091	0.0682	0.5227
Pieris napi	Green-veined white	0.2619	0.1012	0.6369
Pieris rapae	Small white	0.2917	0.1354	0.5729
Plebejus argus	Silver-studded blue	0.1852	0.7963	0.0185
Polygonia c-album	Comma	0.875	0.125	0
Polyommatus icarus	Common blue	0.2084	0.4167	0.375
Pyrgus malvae	Grizzled skipper	0.2917	0.5667	0.1417
Satyrium pruni	Black hairstreak	0.5	0.5	0
Satyrium w-album	White-letter hairstreak	1	0	0
Thecla betulae	Brown hairstreak	0.5	0.5	0
Favonius quercus	Purple hairstreak	0.5	0.5	0

Thymelicus acteon	Lulworth skipper	0.5	0.5	0
Thymelicus lineola	Essex skipper	0.5625	0.2813	0.1563
Thymelicus sylvestris	Small skipper	0.5417	0.2917	0.1667
Vanessa atalanta	Red admiral	0.6458	0.0833	0.2708
Vanessa cardui	Painted lady	0.474	0.1458	0.3802

Appendix 4

4.1: To confirm the assumption that 1995 was a drought year and 1994 could be taken as a pre-drought reference year, linear mixed effects models were constructed for each of the climatic variables and pre-defined orthogonal contrasts carried out (1995 vs all other years, expected to be significant; and 1994 vs all other years except 1995, expected to be non-significant) (packages nlme, lme4 and gmodels: Bates & Maechler, 2010; Pinheiro *et al.*, 2010; Warnes, 2011). For soil deficit data (at 2km scale), a first order autoregressive model was constructed with year as a fixed effect and site as a random effect. For rainfall data, a similar model was constructed but no autocorrelation structure was required. For APET, a generalized linear mixed effects model was constructed as above, with a binomial error term.

4.2: Results of models assessing climatic variables as a function of year (categorical factor) and orthogonal contrasts (n = 122). For rainfall data, the assumptions described above were not met: 1994 was significantly different from all other years. However, soil moisture deficit and APET data did meet these assumptions: 1995 was different from other years but 1994 was not.

Climate Variable	**Treatment significance**	**1995 vs all other years contrast**	**1994 vs all other years except 1995 contrast**
Soil moisture deficit	F-value = 82.765, p <0.0001	t = 17.0125, p = 0	t = -1.224672, p = 0.2210
Rainfall	F-value = 398.277, p<0.0001	t-value = -37.8971, p = 0	t-value = -18.8652, p = 0
APET	χ^2= 78.136, p < 0.001	z-value = -8.043, p <0.001	z-value = -1.859, p = 0.0631

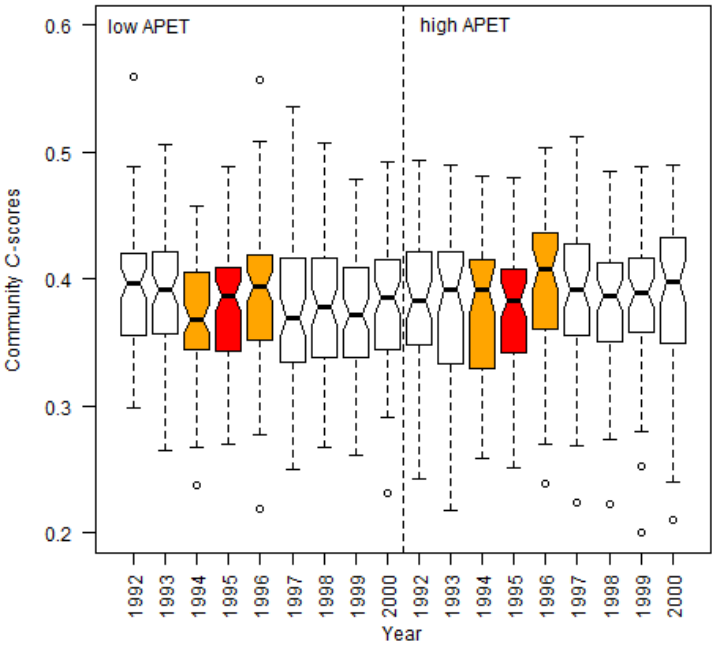
Appendix 5:

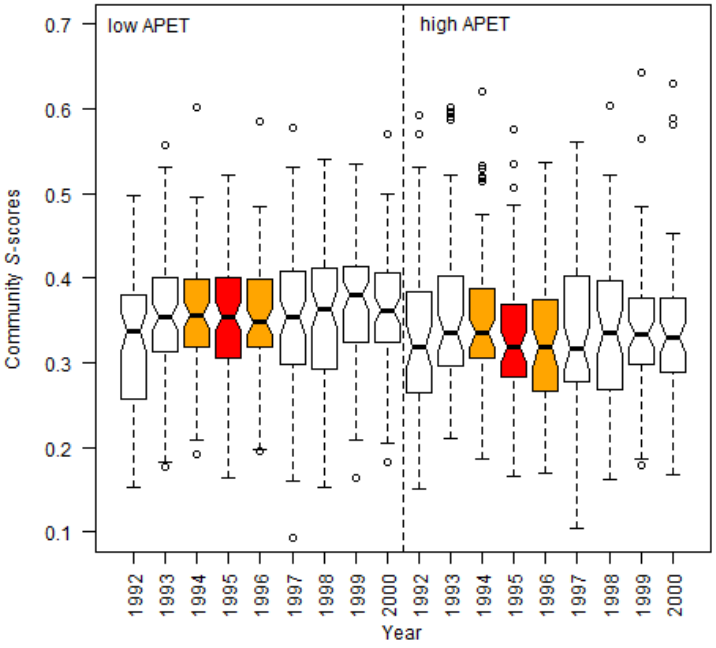
5.1: Linear univariate models were constructed of each change score as a function of APET in 1995 or soil moisture deficit (SMD) in 1995 (Rainfall was not included as it did not meet previous assumptions, see Appendix 4). Models were compared using Akaike's Information Criterion and ranked, with a rank of one being the model with the lowest AIC score.

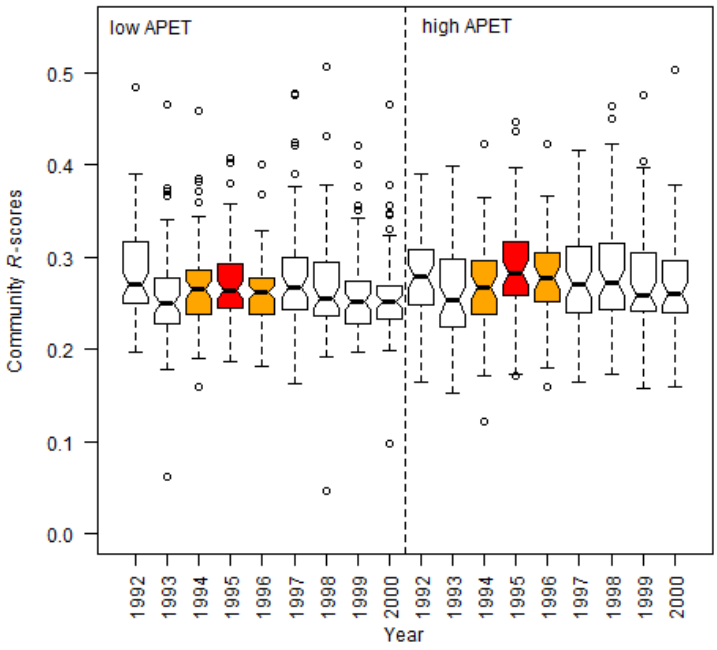
5.2: Results of linear univariate models were constructed of each change score as a function of APET and SMD. For brevity, only the models using the smallest spatial extent (0.5km) of soil moisture deficit (SMD) are shown. Asterisks indicate significance ($p < 0.01$**, $p < 0.001$***). Note that for SMD, estimates of the slope were often negligible.

Response	**Metric**	**AICc**	**AICc Rank**	**Estimate (± standard error)**	**T-value**
Δ *C*-score	APET	-563.21	1	-0.02 (± 0.02)	-1.01
change	SMD	-562.23	2	-0.00 (± 0.00)	0.24
Δ *S*-score	APET	-494.32	1	-0.09 (± 0.03)	**-2.72****
	SMD	-487.09	2	0.00 (± 0.00)	0.21
Δ *R*-score	APET	-556.11	1	0.11 (± 0.03)	**4.50*****
	SMD	-537.38	2	-0.00 (± 0.00)	-0.48
Δ	APET	1899.71	2	96.48 (± 704.57)	0.14
abundance	SMD	1898.85	1	-1.32 (± 1.42)	-0.93
Δ species	APET	20.44	1	-0.44 (± 0.28)	-1.57
number	SMD	22.97	2	-0.00 (± 0.00)	0.16

Appendix 6: Boxplots of Community *C-, S-,* and *R*-scores from 1992 to 2000. The sites have been split by the median APET score. The drought year (1995 is highlighted in red), pre- and post-drought years (1994 and 1996) are highlighted in orange. Strong differences are indicated by non-overlapping notches. While community metrics in 1995 and 1996 are often different to the pre-drought year, by 1997-1998, metrics appear to return to similar levels as in 1994.







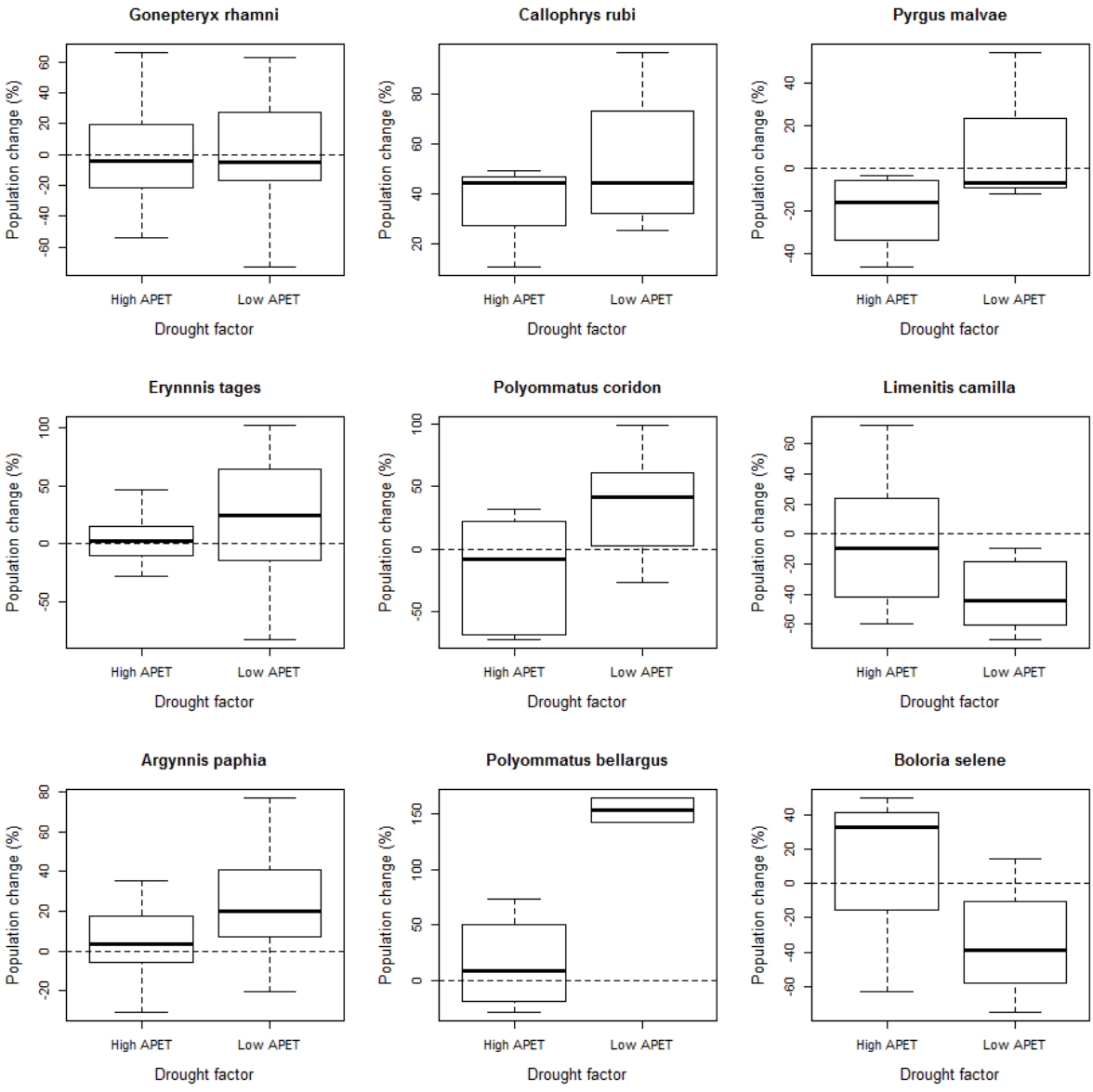
Appendix 7: Full results of derived variable analysis. Asterisks indicate statistical significance of the coefficient estimate (p<0.05*, p<0.01**, p<0.001***); statistics are emboldened when significance was supported following adjustment for multiple comparisons (False Discovery Rate method). Std Aspect = Standard deviation of Northness.

Response	Scale	Intercept	APET	H'	Std Aspect	Std Slope	AICc	Rank
Δ C	0.5km	-0.0023	-	-	-	**0.088****	-575.82	1
	2km	0.0018	-	-	-	-	-570.55	4
	5km	0.0028	-	-0.0052*	-	0.0040	-572.69	3
	10km	0.0032	-	**-0.0060****	-	0.0041*	-574.65	2
Δ *S*	0.5km	**-0.036*****	**-0.011*****	-	-	-	-510.05	3.5
	2km	**-0.036*****	**-0.011*****	-	-	-	-510.05	3.5
	5km	**-0.034*****	**-0.0089****	0.0063*	-	**-0.0063***	-512.93	2
	10km	**-0.033*****	**-0.008***	**0.0077****	-	**-0.0065***	-514.81	1
Δ R	0.5km	**0.035*****	**0.011*****	-	-	-	-567.87	3
	2km	**0.035*****	**0.011*****	-	-	-	-567.87	3
	5km	**0.035*****	**0.011*****	-	-	-	-567.87	1
	10km	**0.035*****	**0.011*****	-	-	-	-567.87	3
Δ abundance	0.5km	**239.21*****	-	-	-	-	1930.57	3.5
	2km	**239.21*****	-	-	-	-	1930.57	3.5
	5km	**227.65*****	-	-	-	-86.26	1930.39	2
	10km	**220.41*****	-	-	-	**-129.24***	1927.2	1
Δ species number	0.5km	**0.0659***	-	-	-	**-0.89***	15.32	1
	2km	-0.06	-0.0409	-	-	-	18.86	4
	5km	-0.0685	-0.0454	-	-0.0446	-	18.41	3
	10km	-0.0962	-0.0559*	-	-0.0587	-	17.65	2

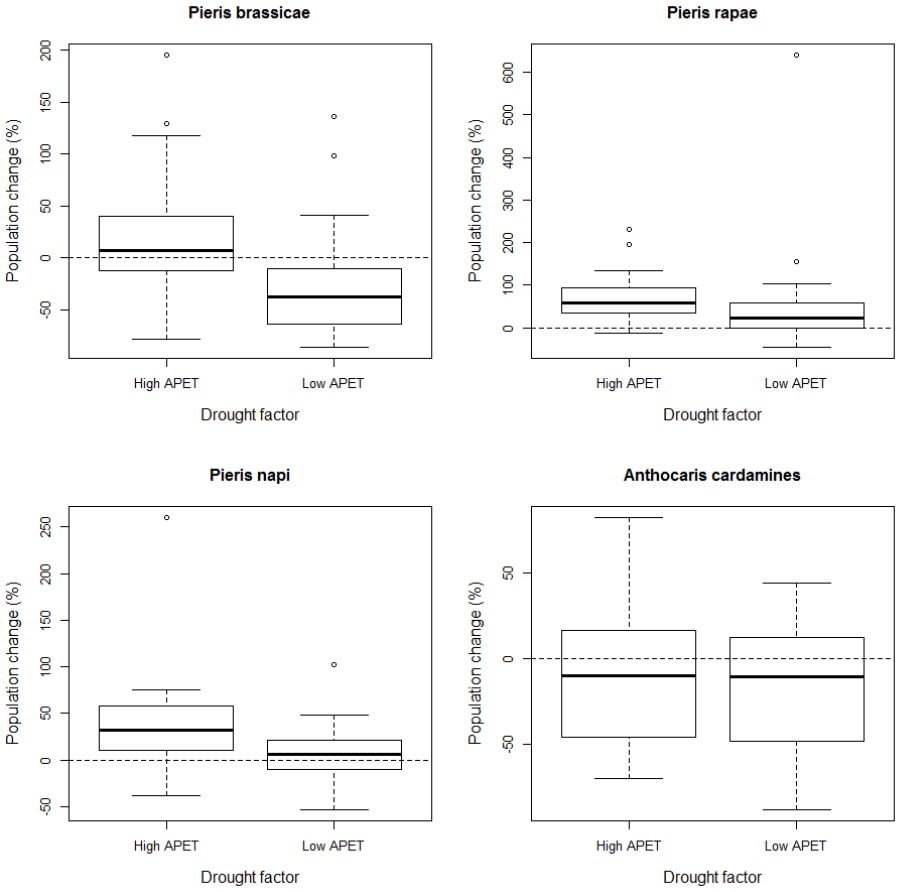
Appendix 8: Analysis of population change relative to expected population change for species with high *S*-scores and high *R*-scores.

(8.1) For species with high *R*-scores and *S*-scores (i.e., their score was greater than 0.5), we calculated the population change relative to that expected had there been no drought following the method of Oliver et al. (2013) and Oliver et al. (2015). This involves the expected population count had no drought occurred being predicted using a linear population trend fitted to the annual site indices for each species for the six years previous to 1995. Differences in population size (population changes) are then expressed as the difference between the expected population count in 1995 and the observed. A positive population change therefore indicates that a species population is larger in 1995 than expected and vice versa. Analysis was carried out separately for sites with high and low moisture index (split by the median value of APET in all sites combined). The box plots represent the drought impacts (population change) across all sites occupied by a species for both high APET (wetter) and low APET (drier) sites."

a)



b)



(8.2) Most species with high *S*-scores (panel a) tended to fare better than expected in sites of low APET (drier sites), whilst species with high *R*-scores (panel b) tended to fare better than expected in sites of high APET (wetter sites).

Appendix 9: Results of analysis assessing how change in abundance (Δ abundance from 1994 to 1995) varies with landscape heterogeneity, for dietary specialists and generalists separately. Asterisks indicate statistical significance of the coefficient estimate ($p<0.05$*, $p<0.01$**, $p<0.001$***); however, significance was not supported following adjustment for multiple comparisons (False Discovery Rate method). Std Aspect = Standard deviation of Northness.

	Scale	**Intercept**	**APET**	**H'**	**Std Aspect**	**Std Slope**	**AICc**	**Rank**
Generalists	0.5km	212.19	-	-	-	-	1866.65	2.5
	2km	212.19	-	-	-	-	1866.65	2.5
	5km	212.19	-	-	-	-	1866.65	2.5
	10km	212.19	-	-	-	-	1866.65	2.5
Specialists	0.5km	54.70	-	-	-	-599.69	1707.04	4
	2km	41.23	-	-	-	-478.94	1706.25	3
	5km	20.60	-	-	-	-47.93*	1705.23	2
	10km	25.31	-	-44.73	-	-53.17*	1698.51	1

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