Supplementary Information

Supplementary Methods
Supplementary References

Supplementary Methods

Range shift records

In Last *et al.* (2011), present-day species ranges were compared to those in the 1980s based on extensive presence-only records from fishing competitions and scientific surveys. From this study, we extracted only species for which historical and present-day poleward range edges could be assigned to an approximate landmark from Appendix S2 of Last *et al.* (2011). This way, a distance of range boundary shift could be estimated (Dataset 1). Because the published dataset only included species with apparent range shifts, the primary author of that study (Last, *personal communication*) provided us with a list of species (n=8, see Dataset 1) for which the same sources showed no range change.

We expected the climate signal to be greater in studies where observations spanned a longer number of years, relative to the noise associated with natural variability and observation error. Most of the records had a time span greater than 20 years (threshold used in Parmesan & Yohe 2003; Poloczanska *et al.* 2013), except for the RLS and LTRMP data, in which multiple systematic observations were made across 10-14 years via more intensive sampling (4 or 5 sampling times across time; RLS and LTRMP data). We included these data if species weren't already included in the dataset based on longer-duration studies, and ran a linear regression through each time series to estimate the most poleward limit as a function of time (Fig. S3). For species sampled twice in the remaining dataset (n=1), we used the most poleward observations. We identified one invertebrate species as an outlier, with an apparent range shift >500 times the expected rate (the benthic snail, *Phasianella ventricosa*, Fig. S4).

Supplementary References:

S1.
Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V., Rowell, D.P., *et al.* (2003). Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late Nineteenth Century. *J. Geophys. Res.*, 4407.
S2.
Froese, R. & Pauly, D. (2014). FishBase [WWW Document]. *World Wide Web Electron. Publ. www.fishbase.org*.
S3.
Hobday, A.J., Smith, A., Webb, H., Daley, R., Wayte, S., Bulman, C., *et al.* (2007). *Ecological risk assessment for effects of fishing: methodology*. *Methodology*.
S4.
Dooley, E. (2002). Global Biodiversity Information Facility. *Environ. Health Perspect.*, 110, A669.
S5.
Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & R, D.C.T. (2013). nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-111.
S6.
Bartoń, K. 2013. MuMIn: Multi-model inference. R package version 1.9.13. http://CRAN.R-project.org/package=MuMIn
S7.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2014d). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-5.
S8.
Skaug H, Fournier D, Bolker B, Magnusson A and Nielsen A (2014-05-23). Generalized Linear Mixed Models using AD Model Builder.

Supplementary Tables and Figures

Table S1. Summary of survey methods across time periods for each study.

Data Source	Methods for first time period survey	Methods for resurvey
Pitt *et al.* 2010	Original surveyors did 20 cm transects parallel to the shore, followed by a more detailed search of the wider shore for additional species occurring at that site.	Revisited 8 out of 10 survey sites on the Tasmanian outer coast. Survey consisted of 10 m transects parallel to shore. In resurvey, 2 sites were surveyed 3 times throughout season and species lists did not change. Study was reduced to 29 most common and visible species, so error due to variability in detection of less-common species was reduced.
Poloczanska *et al.* 2011	Original surveyors did detailed transect survey plus extensive visual survey of shore.	Contemporary surveyors did intensive shoreline search for presence/absence of 80 key macrofaunal species. Chitons, macroalgae, and species with confusing name changes between the time periods were excluded due to challenges with their accurate and consistent identification. 37 species had information from both time periods, and of these, only 13 species were species with southern range edges in the surveyed region.
Last *et al.* 2011, and P. Last, *personal communication*	First time period range limits were based on high-intensity sampling of fish, through checklists and books, spearfishing competition results, field surveys, commercial fishing records, underwater observations, photographic records, and other unpublished anecdotal information.	The second time period range limits were based on the combination of commercial and recreational fishery catches, diver observations and information provided by scientists, scuba divers and recreational and commercial fishers about species found repeatedly outside their previous range.
LTRMP & RLS data	All surveys done with same protocol and high personnel training (Edgar & Barrett 2012; Edgar & Stuart-Smith 2014).	All resurveys done with same protocol and high personnel training (Edgar & Barrett 2012; Edgar & Stuart-Smith 2014).

Table S2. Variable inflation factors (VIFs) for variables included in global models. Removing log body size in the all-species model reduced the high VIFs attributable to multicollinearity between body size and adult mobility (swimming species had larger bodies). With log body size removed from the all-species model, and in all other global models, VIFs were 2.5 or less.

Variables	All species models			Fish-only models		
	all variables	excluding body size	excluding body size and abundance change	all variables	excluding life-history mode	excluding life-history and abundance change
	n=41	n=41	n=89	n=31	n=37	n=50
climate expectation	1.68	1.58	1.79	1.17	1.21	1.45
log range size	1.35	1.24	1.87	1.56	1.50	1.29
log body size	2.74	-	-	2.74	1.92	2.06
mobility	2.50	1.98	2.31	NA	NA	NA
trophic position/level	1.87	1.86	2.50	2.18	1.65	2.12
life-history mode	3.15	2.21	1.53	2.08	-	-
specialization	1.80	1.58	1.20	1.89	1.74	1.63
change in abundance	2.09	1.62	-	1.81	1.47	-

Table S3. Comparisons of global models including 'study' as a random effect or including 'study duration' as a factor influencing variance structure. Table shows *Akaike Information Criterion* for each model, specifically for pairwise comparisons between models with and without each structural element, and bold values indicate the model used (more parameterized model used only if AIC was lower by ~2). The all-species models excluded body size due to multicolinearity, and all models included taxonomy as an independent random effect. In all cases, including study as an independent random effect did not improve model fit and so was removed. In several cases, including study duration as a factor influencing residual variance improved model fit, and so was included in subsequent models. Models including study as a random effect were compared using the lme4 package in *R* to allow fitting multiple independent random effects (study and taxonomy), and models with and without variance structures were fit using the nlme package in *R*. In the all-species model that included abundance change as a variable (and therefore a much smaller sample size), there was insufficient data coverage to include taxonomy or study as random effects, so comparisons were not made.

		'study' included as a random effect		'study duration' included as a factor influencing variance		Table with model results
		yes	no	yes	no	
All-species global models						
All variables except body size	n=41	NA	NA	NA	NA	Table S6
Excluding abundance-change and body size	n=89	226.1	**224.2**	227.7	**226.2**	Table 2
Excluding abundance-change and including mobility instead of body size	n=89	239.3	**240.9**	248.5	**242.9**	Table S9
Excluding abundance-change and body size, and excluding 2 high-leverage barnacle species	n=87	210.3	**208.3**	241.9	**222.5**	Table S10
Fish-only global models						
All variables	n=31	81.1	**79.3**	78.8	**77.4**	Table S6
Excluding life-history mode	n=37	110.6	**109.1**	**105.1**	107.3	Table S7
Excluding abundance-change	n=43	122.3	**120.7**	120.1	**118.7**	Table S8
Excluding abundance-change and life-history mode	n=50	152.1	**150.1**	**148.2**	150.1	Table 2

Table S4. Multimodel averaging results from linear mixed effects models using a greater number of observations per variable (n=15) than main models reported in Table 2. As in Table 2, change-in-abundance was excluded from both global models and life-history was excluded from the fish-only model. The relative variable importance (w_i), variable coefficients, and their 95% confidence limits (*coef.* and *CL*) are shown for each variable from the multimodel average, showing contrasts from base levels (climate expectation = 0, latitudinal range size = 0, trophic position = herbivores, trophic level = 1, specialization = not specialized, life history mode = benthic, adult mobility=low).

	mulitimodel average				best model	climate only model
Explanatory variable	w_i	*coef.*	*Lower CL*	*Upper CL*	*coef.*	*coef.*
All taxa (n=89, max. variables per model = 6)						
Climate expectation	1	0.63	-0.22	1.48	+	+
Adult mobility (high)	1	0.78	0.26	1.30	+	
Trophic position (omnivore)	1	-0.32	-0.88	0.24	+	
Trophic position (carnivore)	1	0.06	-0.22	0.33	+	
Adult mobility (high) x climate expectation	1	2.08	0.97	3.19	+	
Trophic position (omni.) x climate expectation	1	1.08	0.67	1.48	+	
Trophic position (carn.) x climate expectation	1	-0.65	-1.75	0.45	+	
Log lat. range size	0.45	0.25	0.03	0.48	+	
Specialization	0.17	0.47	-0.36	1.30		
pseudo-R-squared					0.578	0.231
AICc					226	250.1
Akaike weight					0.401	<0.001
Fishes (n=50, max. variables per model = 3)						
climate expectation	1	0.24	-0.17	0.66	+	+
Log lat. range size	1	0.37	0.08	0.67	+	
Log lat. range size x climate expectation	0.66	0.42	0.09	0.75	+	
pseudo-R-squared					0.462	0.173
AICc					142.1	152.4
Akaike weight					0.571	0.003

Table S5: Multimodel averaging results including study as a random effect. Models were fit using the using the *lme4* package in R to allow fitting multiple independent random effects (study and taxonomy). As in Table 2, abundance change was excluded from both global models, and life-history was excluded from the fish-only model. Abbreviations are as in Table S4.

	mulitimodel average				best model	climate only model
Explanatory variable	w_i	*coef.*	*Lower CL*	*Upper CL*	*coef.*	*coef.*
All taxa (n=89, 'study' included as random effect)						
Climate expectation	1	0.10	-0.33	0.54	+	+
Trophic position (omnivore)	1	0.82	0.37	1.27	+	
Trophic position (carnivore)	1	-0.20	-0.79	0.40	+	
Trophic position (omni.) x climate expectation	1	1.09	0.73	1.46	+	
Trophic position (carn.) x climate expectation	1	-0.41	-1.63	0.80	+	
Adult mobility (high)	0.82	0.54	-0.48	1.56	+	
Adult mobility (high) x climate expectation	0.72	2.08	1.04	3.13	+	
Log lat. range size	0.51	0.25	0.05	0.45	+	
Specialization	0.43	0.56	-0.36	1.48		
Life history mode (pelagic)	0.22	0.24	-0.36	0.84		
Specialization x climate expectation	0.19	0.93	-1.42	3.29		
Life history mode (pel) x climate expectation	0.04	-0.42	-1.49	0.66		
Life history mode (pel) x adult mobility (high)	0.03	-0.11	-1.30	1.09		
Log lat. range size x climate expectation	0.01	-0.04	-0.23	0.14		
pseudo-R-squared					0.587	0.234
AICc					223.4	245.9
Akaike weight					0.149	<0.001
Fishes (n=50, 'study' included as random effect)						
climate expectation	1	0.31	-0.10	0.73	+	+
Log lat. range size	1	0.15	-0.19	0.50	+	
Log lat. range size x climate expectation	0.87	0.45	0.16	0.75	+	
Specialization	0.33	0.57	-0.39	1.52		
Trophic level	0.19	-0.22	-0.48	0.04		
Log body size	0.05	-0.05	-0.36	0.26		
Trophic level x climate expectation	0.02	-0.16	-0.45	0.13		
pseudo-R-squared					0.4076	0.1315
AICc					144.7	152.9
Akaike weight					0.368	0.006

Table S6. Multimodel averaging results of linear models on observed range shifts including abundance change and life-history mode in the global models and therefore using a smaller subset of species for which all complete data were available. In the all-species model, there was insufficient data coverage to include taxonomy or 'study' as random effects, so linear models only were explored, and results are to demonstrate the low variable importance of abundance change. In both the all-species and the fish-only models, abundance change and reproductive mode had uncertain effects on range extensions (confidence intervals crossing zero). Taxonomy was included as a random effect, and abbreviations are as in Table S4.

	mulitimodel average				best model	climate only model
Explanatory variable	w_i	*coef.*	*Lower CL*	*Upper CL*	*coef.*	*coef.*
All taxa, abundance change included (n=41)						
Climate expectation	1	-0.31	-2.68	2.06	+	+
Adult mobility (high)	0.96	0.80	-0.65	2.24	+	
Adult mobility (high) x climate expectation	0.88	2.76	0.89	4.63	+	
Specialization	0.26	0.48	-0.18	1.15		
Log range size	0.26	0.26	-0.12	0.64		
Abundance change	0.1	0.07	-0.17	0.32		
Life history mode (pelagic)	0.09	0.03	-0.55	0.62		
Log range size x climate expectation	0.07	1.24	0.19	2.28		
Trophic position (omnivore)	0.02	0.39	-0.95	1.72		
Trophic position (carnivore)	0.02	0.00	-0.43	0.42		
Life history mode (pel.) x climate expectation	0.01	-1.56	-3.28	0.15		
pseudo-R-squared					0.598	0.443
AICc					82.9	91.2
Akaike weight					0.264	0.004
Fishes, abundance change and life-history mode included (n=31)						
climate expectation	1	0.84	0.59	1.09	+	+
Log lat. range size	0.69	0.49	0.20	0.79	+	
Abundance change	0.44	1.50	-5.02	8.02	+	
Log body size	0.14	0.33	-0.02	0.67		
Specialization	0.1	0.47	-0.32	1.26		
Log lat. range size x climate expectation	0.08	0.25	-0.03	0.53		
Life history mode (pel)	0.07	-0.39	-1.25	0.46		
Trophic level	0.01	-0.10	-0.36	0.16		
pseudo-R-squared					0.709	0.613
AICc					73.1	76.4
Akaike weight					0.244	0.049

Table S7. Multimodel averaging results from linear mixed effects model of observed range shifts in fish, including abundance-change but excluding life-history mode in the global model, and thus using a slightly larger data subset (n=37) than in Table S6. Abundance change had uncertain effects on range shifts and other variables had similar affects without its inclusion, therefore it was dropped to allow a larger complete dataset. Taxonomy was included as a random effect (see Table S3). Abbreviations are as in Table S4.

	mulitimodel average				best model	climate expectation only model
Explanatory variable	w_i	*coef.*	*Lower CI*	*Upper CI*	*coef.*	*coef.*
Fishes, abundance change included but not life-history mode (n=37)						
Climate expectation	1	0.53	0.20	0.87	+	+
Log lat. range size	0.7	0.30	-0.19	0.78	+	
Log lat. range size x climate expectation	0.44	0.68	0.21	1.14	+	
Abundance change	0.35	2.16	-6.52	10.85		
Specialization	0.11	0.56	-0.39	1.50		
Log body size	0.03	0.29	-0.09	0.67		
pseudo-R-squared					0.543	0.331
AICc					106.6	110.7
Akaike weight					0.417	0.055

Table S8. Multimodel averaging results from linear mixed effects model of observed range shifts in fish, including life-history mode in the global model but excluding abundance-change, and thus using a slightly larger data subset (n=43) than in Table S5. Life-history mode had low variable importance and other variables had similar affects without its inclusion, therefore it was dropped to allow a larger complete dataset. Taxonomy was included as a random effect and study duration was included as a factor affecting residual variance (see Table S3). Abbreviations are as in Table S4.

	mulitimodel average				best model	climate expectation only model
Explanatory variable	*w_i*	*coef.*	*Lower CI*	*Upper CI*	*coef.*	*coef.*
Fishes, life-history mode included but not abundance change (n=43)						
climate expectation	1	0.57	0.34	0.80	+	+
Log lat. range size	1	0.41	0.12	0.69	+	
Specialization	0.34	0.58	-0.30	1.46		
Log lat. range size x climate expectation	0.27	0.26	-0.02	0.55		
Trophic level	0.1	-0.17	-0.44	0.10		
Life-history mode (pel)	0.09	0.00	-0.59	0.58		
Log body size	0.07	-0.01	-0.34	0.31		
Log body size x climate expectation	0.03	-0.31	-0.58	-0.03		
Trophic level x climate expectation	0.01	-0.22	-0.50	0.05		
pseudo-R-squared					0.542	0.344
AICc					112.5	121.8
Akaike weight					0.30	0.003

Table S9. Multimodel averaging results of linear mixed effects models on observed range shifts in all species, including body size instead of adult mobility. As in Table 2, abundance change was not included to allow a larger complete dataset.

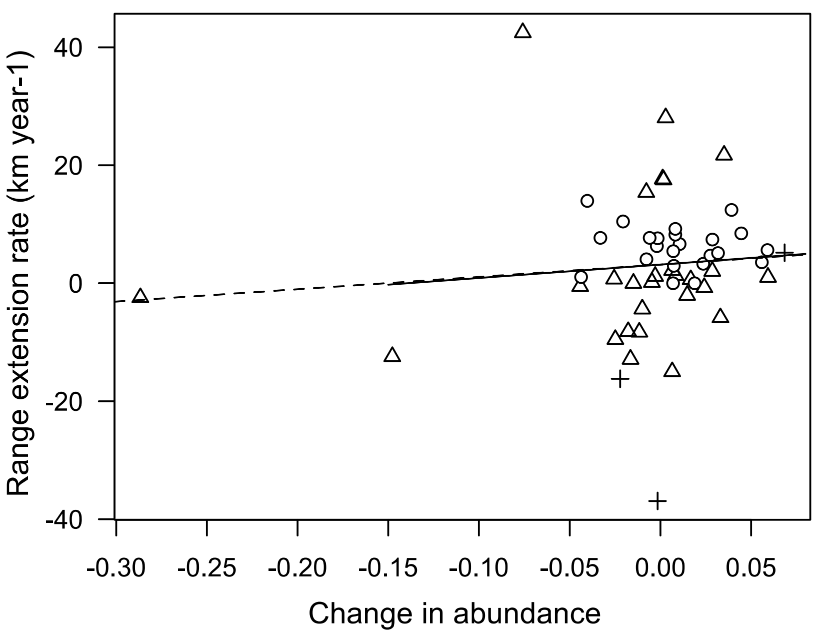
	mulitimodel average				best model	climate expectation only model
Explanatory variable	w_i	*coef.*	*Lower CI*	*Upper CI*	*coef.*	*coef.*
All taxa including body size instead of adult mobility (n=89)						
Climate expectation	1	0.15	-0.28	0.57	+	+
Trophic position (omnivore)	1	0.75	0.22	1.28	+	
Trophic position (carnivore)	1	0.36	-0.10	0.82	+	
Trophic position (omni.) x climate expectation	1	1.08	0.65	1.52	+	
Trophic position (carn.) x climate expectation	1	0.96	0.21	1.72	+	
Specialization	0.78	1.03	-0.05	2.11	+	
Specialization x climate expectation	0.67	2.31	-0.03	4.65	+	
Log lat. range size	0.25	0.21	-0.02	0.44		
Life history mode (pelagic)	0.2	0.21	-0.33	0.74		
Log body size	0.13	0.15	-0.15	0.45		
Life history mode (pel) x climate expectation	0.04	-0.22	-1.51	1.06		
Log body size x climate expectation	0.04	0.39	-0.11	0.89		
Log lat. range size x climate expectation	0.02	-0.12	-0.33	0.10		
Climate expectation	1	0.15	-0.28	0.57		
Trophic position (omnivore)	1	0.75	0.22	1.28		
pseudo-R-squared					0.5035	0.2314
AICc					233	250.1
Akaike weight					0.319	<0.001

Table S10. Multimodel averaging results of linear mixed effects models on observed range shifts in all species, excluding the 2 high-leverage barnacle species. As in Table 2, abundance change was not included to allow a larger complete dataset.

	mulitimodel average				best model	climate expectation only model
Explanatory variable	*w_i*	*coef.*	*Lower CI*	*Upper CI*	*coef.*	*coef.*
All taxa minus high-leverage barnacles (n=87)						
Climate expectation	1	0.09	-0.34	0.51	+	+
Adult mobility (high)	1	0.17	-0.70	1.04	+	
Adult mobility (high) x climate expectation	1	1.48	0.74	2.21	+	
Specialization	0.61	0.69	-0.20	1.58		
Log lat. range size	0.48	0.24	0.02	0.46		
Specialization x climate expectation	0.29	0.90	-1.38	3.17		
Life history mode (pel.)	0.22	0.04	-0.81	0.90		
Life history mode (pel.) x adult mobility (high)	0.06	0.41	-0.93	1.76		
Life history mode (pel.) x climate expectation	0.05	-0.14	-1.64	1.36		
Log lat. range size x climate expectation	0.04	-0.11	-0.31	0.10		
Trophic position (omnivore)	0.03	0.64	-0.45	1.72		
Trophic position (carnivore)	0.03	-0.26	-0.83	0.30		
Trophic position (omni.) x climate expectation	0.02	1.17	-0.08	2.41		
Trophic position (carn.) x climate expectation	0.02	-0.63	-1.76	0.50		
Life history mode (pel.) x adult mobility (high) x climate expectation	0.01	0.82	-2.41	4.05		
pseudo-R-squared					0.307	0.105
AICc					215.1	229.6
Akaike weight					0.135	<0.001

Fig S1. Poleward range extension rate as a function of abundance change in southern Australia. (A) In 53 species from our dataset, range extension rate was not related to changes in species' abundance (see also multivariate model results in Table S6). Change in southern range limits from the periods 1980-2009 (23 species; circles), 1996-2010 (27 species; triangles) and 2000-2010 (3 species; crosses) as shown. Abundance change shown for the same species across all sites in the LTRMP database (encompassing southern Australia) between 1992 and 2013 (Edgar & Barrett, 2012). "Change in abundance" is the linear coefficient of year on abundance within sites, estimated by fitting a generalized linear mixed effects model with an AD model builder (R package, glmmADMB; ref. S8) to abundance for each species, with year, latitude and the Southern Oscillation Index as fixed effects, and survey location as a random effect. Lines in (A) show best-fit relationship between change in abundance and range extension rate from simple linear regressions, including (dotted line) and not including (solid line) the left-most high-leverage datapoint; both slopes are non-significant from zero (p=0.499 and p= 0.629, respectively). (B) Sampled sites for abundance data in LTRMP dataset.

(A)



(B)

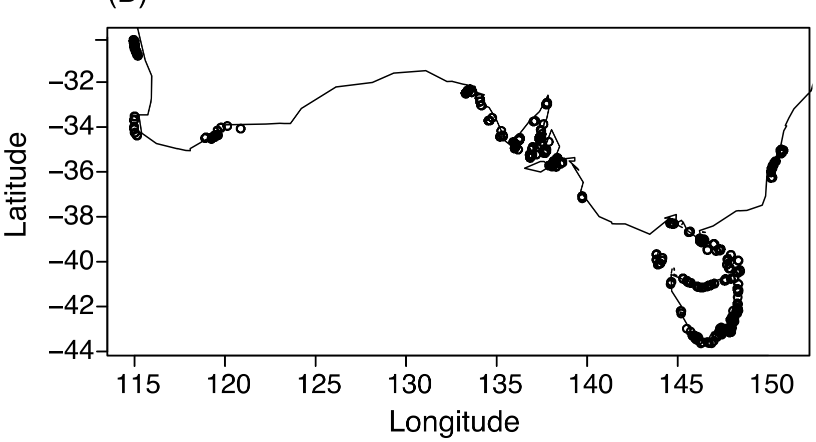


Fig. S2. Rate of range shift relative to climate expectation for different reproductive modes of fishes (a) and invertebrates (b), showing high variability within groups and no strong pattern across groups. Dotted line shows grand mean, large horizontal lines for each life history mode shows mean for that group, polygons show density function of observations.

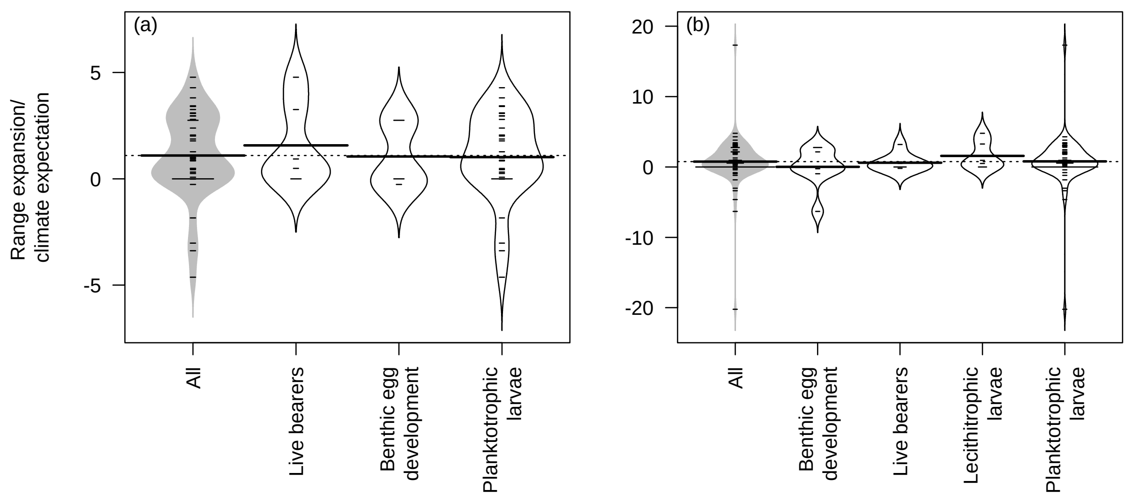


Fig. S3. Linear regressions through the most southern record of each species' range in combined RLS and LTRMP data. Regression coefficients were used to estimate each species' poleward limit through time. Species excluded as they were sampled elsewhere in longer-term studies using different methods shown in grey (n=15).

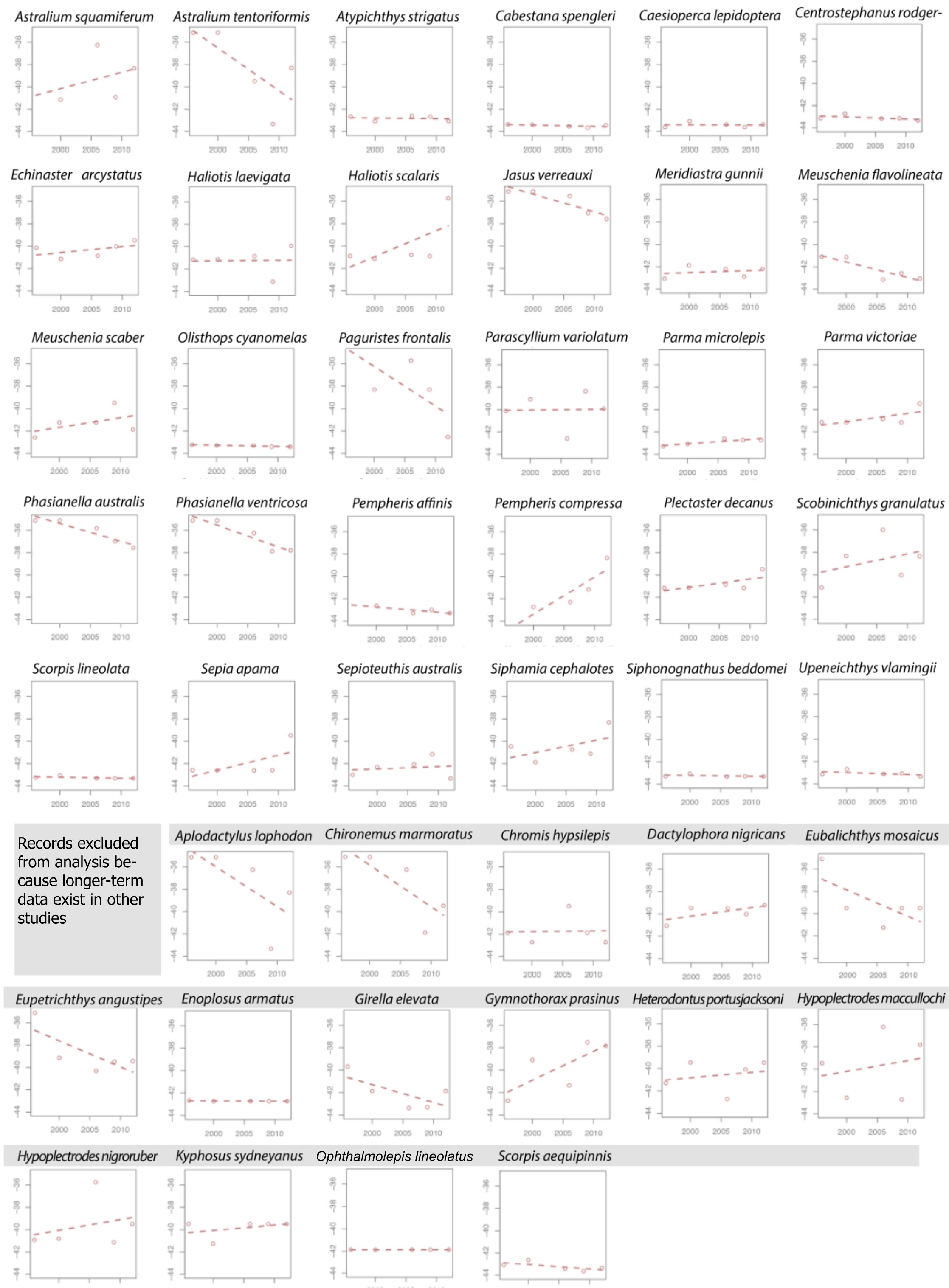


Fig. S4. Distribution of range shifts relative to climate expectation for all species, indicating putative outlier with range extensions far outpacing (>500x) the expectation based on climate velocity.