Section 3:
Species range shifts

Patterns within the Patterns

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In the species-by-species study, the overwhelming majority of species showed the poleward and upslope shifts expected with warming. In 1700 species studied, poleward range shifts averaged 6 km per decade. A total of 279 of the species showed responses that tracked climate change—poleward shift during warming periods and shift away from the poles in cooling periods—but a net poleward shift. This gives strong indication of climate causality.

(Hannah p 72-73)
Hannah, Lee. *Climate Change Biology, 2nd Edition*. Academic Press, 11/2014. VitalBook file.

A globally coherent fingerprint of climate change impacts across natural systems

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Causal attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse species and geographic regions; however, debates within the Intergovernmental Panel on Climate Change (IPCC) reveal several definitions of a 'systematic trend'. Here, we explore these differences, apply diverse analyses to more than 1,700 species, and show that recent biological trends match climate change predictions. Global meta-analyses documented significant range shifts averaging 6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. We define a diagnostic fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems.

Nature, 2003

Table 1 **Summary of data studying phenological and distributional changes of wild species**

Taxon	Ref. number	Total no. of species (or species groups)	Spatial scale L	Spatial scale R	Spatial scale C	Time scale (range years)	Change in direction predicted (*n*)	Change opposite to prediction (*n*)	Stable (*n*)	No prediction (*n*)
Phenological changes										
Woody plants	20,23,24*,25*	*n* = 38 sp		2	1	35–132	30	1	7	–
Herbaceous plants	20,21*	*n* = 38 sp	1	1		63–132	12	–	26	–
Mixed plants	22*	*n* = 385 sp	1			46	279	46	60	–
Birds	20,21*,30,31,32,33	*n* = 168 sp	2	3	1	21–132	78	14	76	–
Insects	26	*n* = 35 sp		1		23	13	–	22	–
Amphibians	27,28	*n* = 12 sp	2			16–99	9	–	3	–
Fish	20	*n* = 2 sp		1		132	2	–	–	–
Distribution/abundance changes										
Tree lines	54,55,56*	*n* = 4 sp + 5 grps	2	1		70–1,000	3 sp + 5 grps	–	1	–
Herbs and shrubs	18,19,41*,42*	*n* > 66 sp, 15 detailed		3		28–80	13	2	–	–
Lichens	36	4 biogeographic grps (*n* = 329 sp)	1			22	43	9	113	164
Birds	8*	*n* = 3 sp		1		50	3	–	–	–
	16,57*	N sp (*n* = 46 sp)		2		20–36	13	15	18	
		S sp (*n* = 73 sp)		2		20–36	36	16	21	6
	43*	Low elevation (>91 sp)	1			20	71	11	9	–
		High elevation (>96 sp)	1			20	37	27	32	–
Mammals	37	*n* = 2 sp		1		52	2	–	–	–
Insects	17,49*	*n* = 36 sp		1	1	98–137	23	2	10	1
	17	N boundaries (*n* = 52 sp)		1		98	34	1	17	–
		S boundaries (*n* = 40 sp)		1		98	10	2	28	–
Reptiles and amphibians	43*	*n* = 7 sp	1			17	6	–	1	–
Fish	39	4 biogeographic grps (*n* = 83 sp)	1			–	2 grps	–	1 grp	1 grp
	40*	N sp (*n* > 1 sp)		1		70	>1	–	–	–
		S sp (*n* > 1 sp)		1		70	>1	–	–	–
Marine invertebrates	34*,40*	N sp (*n* > 21)	1	1		66–70	>19	2	–	>1 sp not classified
		S sp (*n* > 21)	1	1		66–70	>20	1	–	
		Cosmopolitan sp (*n* = 28 sp)	1			66	–	–	–	28
Marine zooplankton	40*	Cold water (*n* > 10 sp)		1		70	>10	–	–	>8 sp not classified
		Warm water (*n* > 14 sp)		1		70	>14	–	–	
	35	6 biogeographic grps (*n* ≥ 36 sp)			1	39	6 grps	–	–	–

N, species with generally northerly distributions (boreal/arctic); S, species with generally southerly distributions (temperate); L, local; R, regional (a substantial part of a species distribution; usually along a single range edge); C, continental (most or the whole of a species distribution). No prediction indicates that a change may have been detected, but the change was orthogonal to global warming predictions, was confounded by non-climatic factors, or there is insufficient theoretical basis for predicting how species or system would change with climate change.
*Study partially controlled for non-climatic human influences (for example, land-use change). Studies that were highly confounded with non-climatic factors were excluded. (See Supplementary Information for details of species classification.)

Table 2 **Summary statistics and synthetic analyses derived from Table 1**

Type of change	Changed as predicted	Changed opposite to prediction	*P*-value
Phenological ($N = 484/(678)$)	87% ($n = 423$)	13% ($n = 61$)	$<0.1 \times 10^{-12}$
Distributional changes			
At poleward/upper range boundaries	81%	19%	–
At equatorial/lower range boundaries	75%	25%	–
Community (abundance) changes			
Cold-adapted species	74%	26%	–
Warm-adapted species	91%	9%	–
$N = 460/(920)$	81% ($n = 372$)	19% ($n = 88$)	$<0.1 \times 10^{-12}$
Meta-analyses			
Range-boundaries ($N = 99$)	6.1 km m^{-1} per decade northward/upward shift*		0.013
Phenologies ($N = 172$)	2.3 days per decade advancement*		<0.05

Data points represent species, functional groups or biogeographic groups. *N*, number of statistically or biologically significant changes/(total number species with data reported for boundary, timing, or abundance processes). The no prediction category is not included here.

*Bootstrap 95% confidence limits for mean range boundary change are 1.26, 10.87; for mean phenological shift the limits are −1.74, −3.23.

Table 3 **Biological fingerprint of climate change impacts**

Sign-switching pattern	Percentage of species showing diagnostic pattern
Community	
Abundance changes have gone in opposite directions for cold-adapted compared with warm-adapted species. Usually local, but many species in each category. Diverse taxa, $n = 282$*.	80%
Temporal	
Advancement of timing of northward expansion in warm decades (1930s/40s and 1980s/90s); delay of timing or southward contraction in cool decades (1950s/60s), 30–132 years per species. Diverse taxa, $n = 44$*.	100%
Spatial	
Species exhibit different responses at extremes of range boundary during a particular climate phase. Data are from substantial parts of both northern and southern range boundaries for each species. All species are northern hemisphere butterflies, $n = 8$*.	100%

Differential sign-switching patterns diagnostic of climate change as the underlying driver.
*Numbers of species represent minimum estimates, as not all species were described in sufficient detail in each study to classify. A few species showed two types of sign switching, and so are included in more than one cell. Data are from references in text and from raw data provided by L. Kaila, J. Kullberg, J. J. Lennon, N. Ryrholm, C. D. Thomas, J. A. Thomas and M. Warren.

[in locations of overlapping ranges, polar (cold-adapted) species have responded negatively to warming whereas temperate (warm-adapted) species have responded positively]

Parmesan and Yohe, Nature, 2003