Global-scale species distributions predict temperature-related changes in species composition of rocky shore communities in Britain

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Supporting Information

This supporting information contains.

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Fig. S3 Changes in average abundance of predominant species in MarClim surveys across frequently sampled sites in southwest Britain from 2002 to 2018.
Fig. S4 Changes in average abundance of predominant species in SOTEAG surveys at sites around Sullom Voe in Shetland from 1976 to 2018.

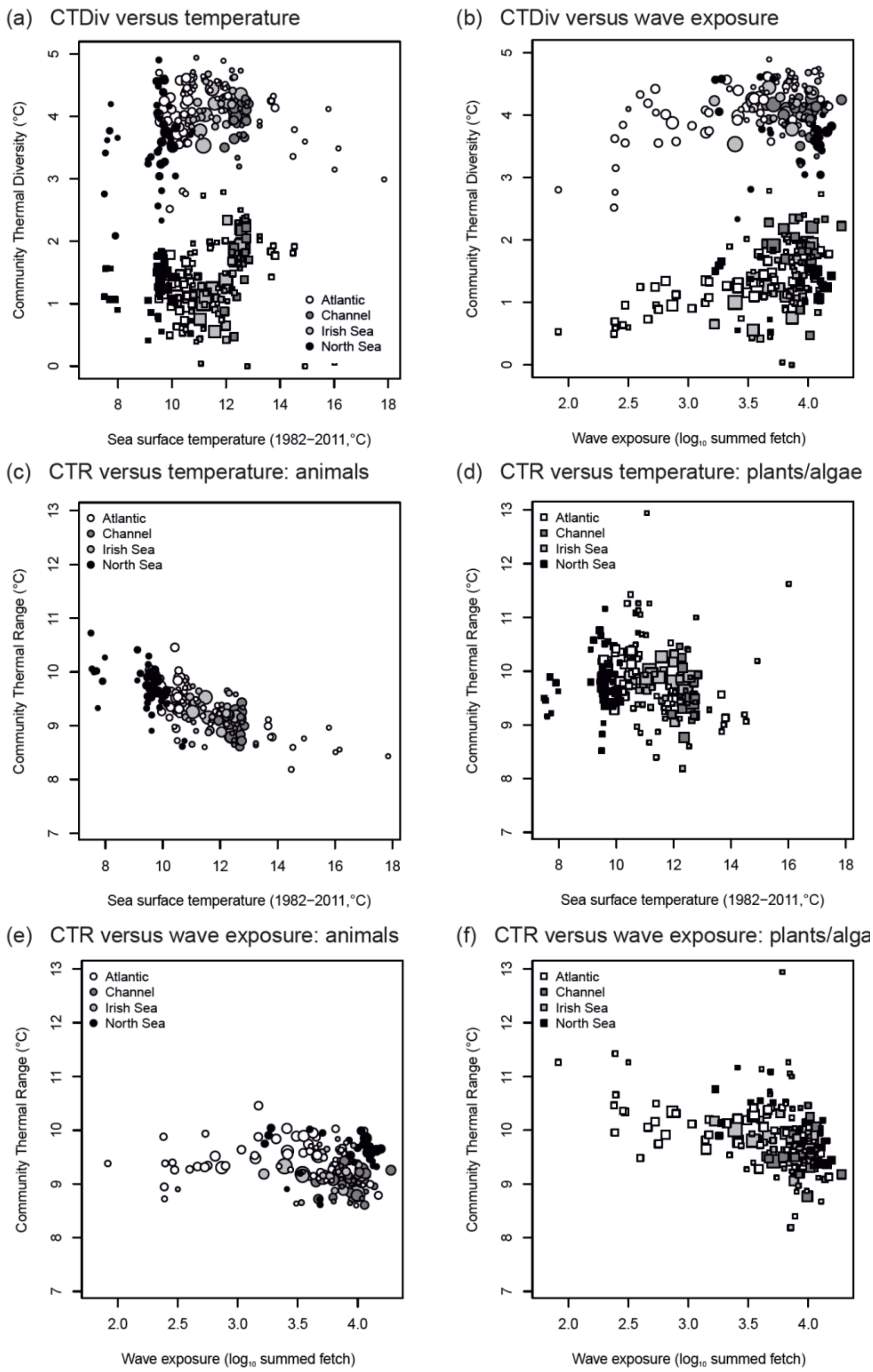

Fig. S1 Patterns in community thermal metrics across temperature and wave exposure gradients, averaged in 0.5° latitude-longitude areas. (a) Diversity of species thermal affinities (Community Thermal Diversity, CTDiv) for animal communities (circles) and (b) plant-algae communities (squares, size indicating number of sites in each area) versus sea surface temperature (SST). (c) Average species thermal range width (CTR) for animals and (d) plant-algae communities versus SST and (e, f) wave exposure.

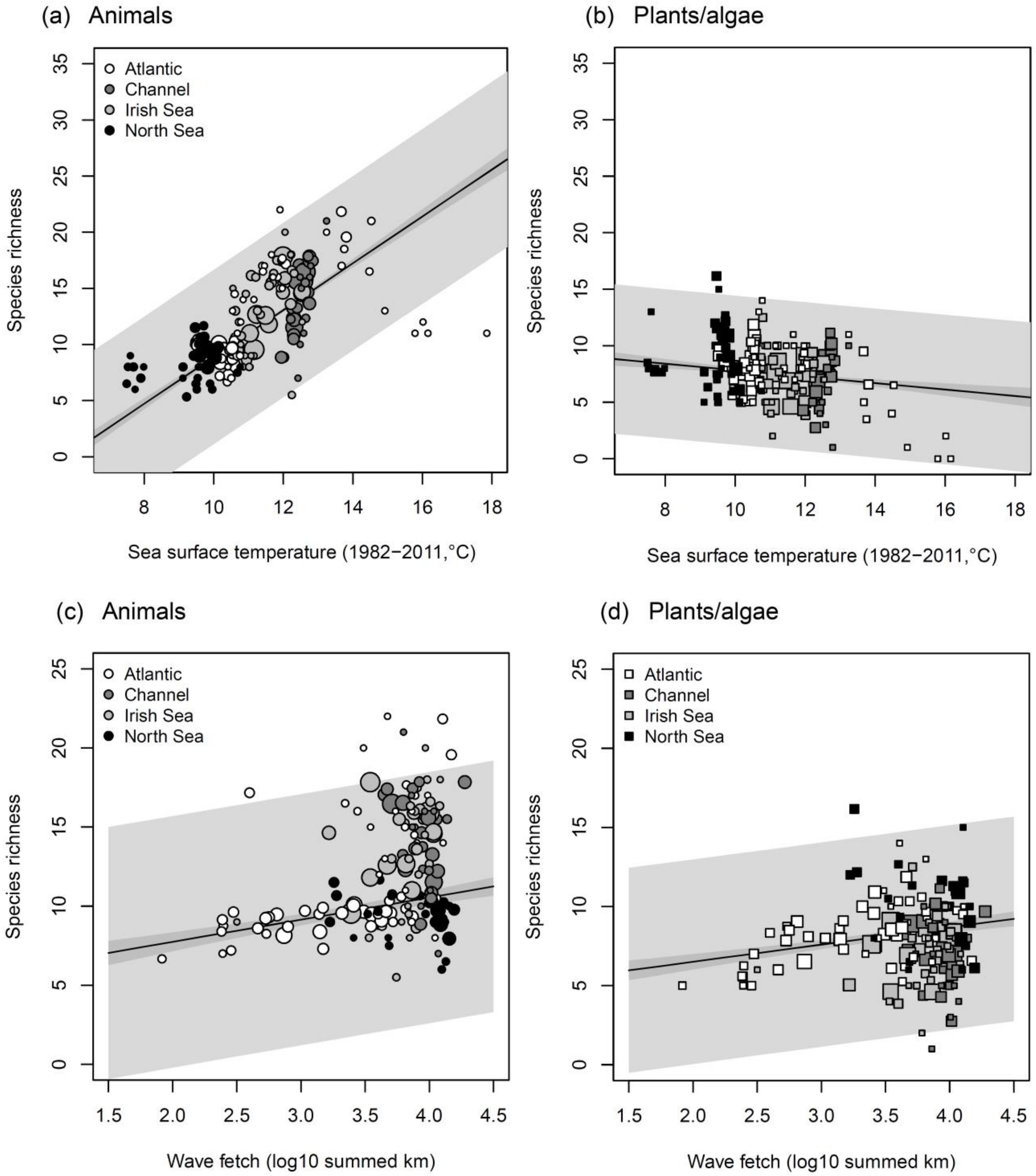

Fig. S2 Patterns in species richness for rocky-shore animal communities (a,c) and plant-algal communities across temperature (a,b) and wave exposure (c,d) gradients, averaged in 0.5° latitude-longitude areas. Symbol sizes reflect numbers of sites surveyed per 0.5° area, and symbol shading showing coastline locations. Lines show regression models: (a, c) R^2 = 0.22, (b, d) R^2 = 0.08.

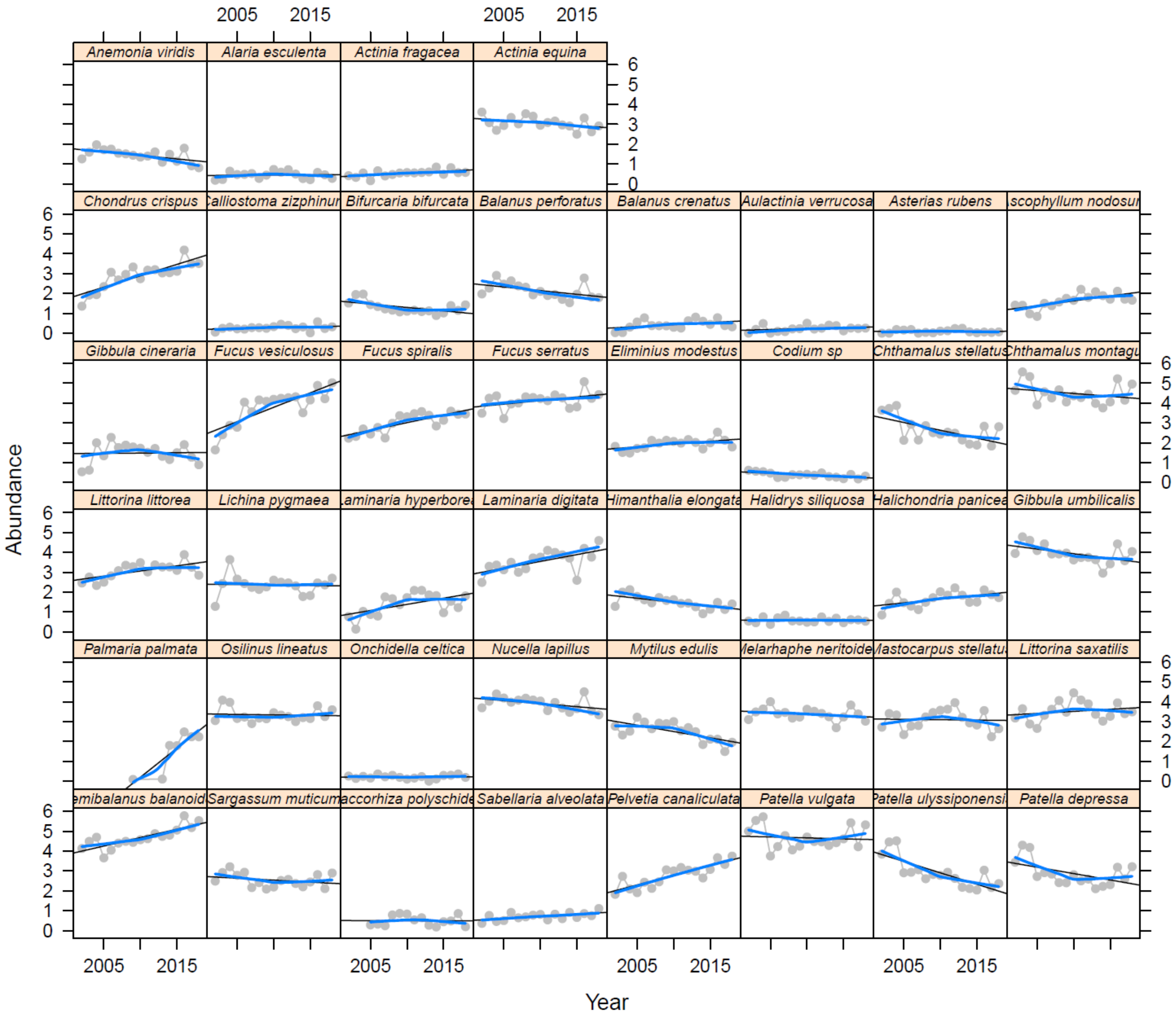

Fig. S3 Changes in average abundance of predominant species in MarClim surveys across frequently sampled (n visits ≥10) sites in southwest Britain from 2002 to 2018, as average values of SACFORN categories expressed as integers (S:6 to N:0). In each panel the black line shows the simple linear regression fit and the blue line shows a loess-smoothed regression (span=1).

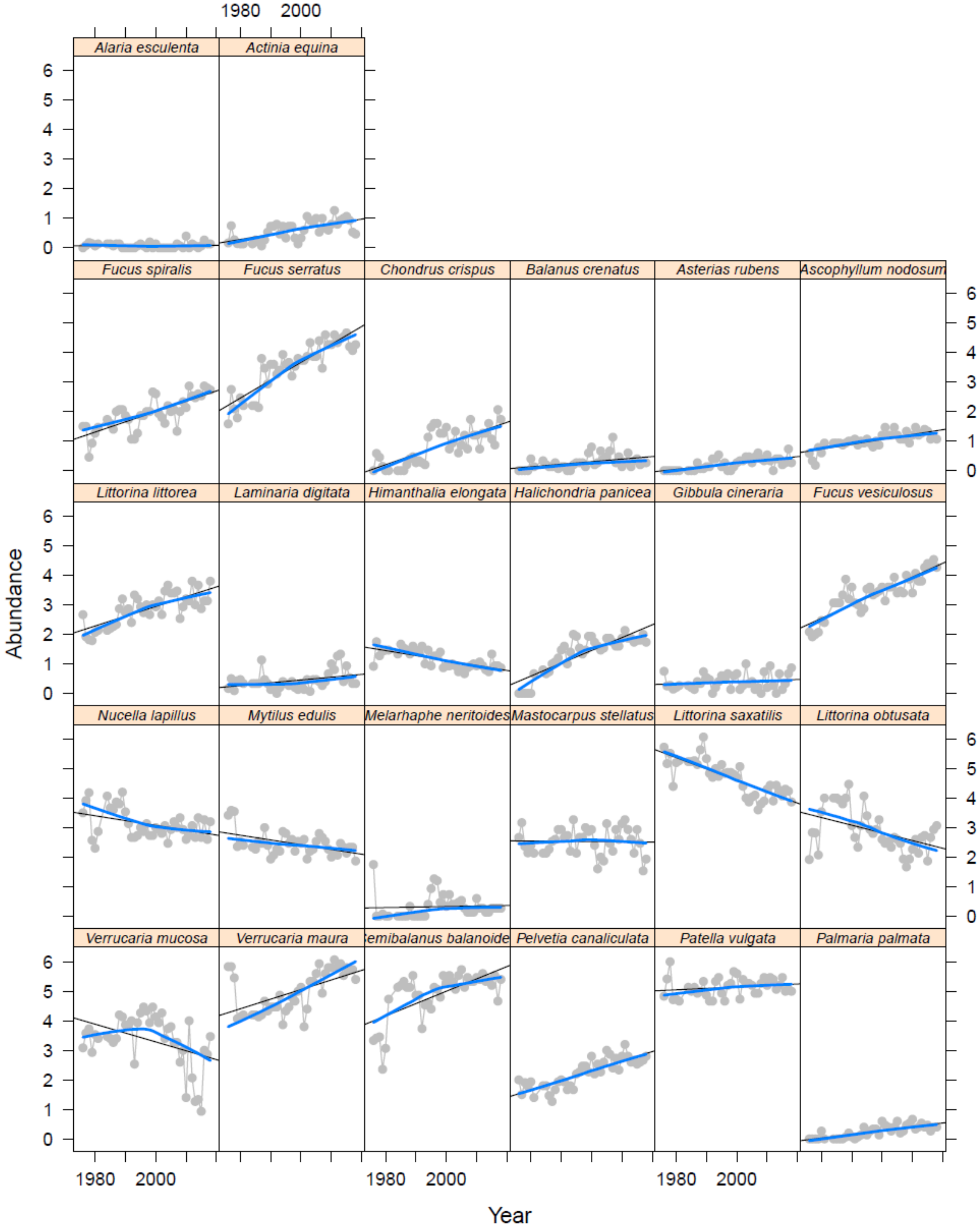

Fig. S4 Changes in average abundance of predominant species in SOTEAG surveys at sites around Sullom Voe in Shetland from 1976 to 2018, as average values of SACFORN categories expressed as integers (S:6 to N:0). In each panel the black line shows the simple linear regression fit and the blue line shows a loess-smoothed regression (span=1).

Table S1 Species Temperature Index (STI) values for the subset of UK rocky shore species used in CTI estimation, arranged by taxonomy. Geographical range polygons derived from literature reports and personal observations were used to extract sea surface temperatures for coastal cells from the NOAA OISST HR 0.25° dataset (Reynolds et al., 2007) using average annual values for 1982 to 2011 inclusive. Thermal ranges were expressed as percentiles of the within-range set of coastal temperatures, with the STI taken as the median temperature T50 and the Species Thermal Range (STR) as the difference between the 10th and 90th percentiles (T90-T10). Numbered reference and information sources for range extents are listed in Table S2. Range polygons are available as ESRI shapefiles at doi:10.6084/m9.figshare.8284016 .

Abbr	**Species1**	**Class**	**Phylum**	**Kingdom**	**T0**	**T10**	**T25**	**T50**	**T75**	**T90**	**T100**	**STR**	**Reference**				
Saalv	*Sabellaria alveolata*	Polychaeta	Annelida	Animalia	10.54	11.07	11.79	12.80	15.93	17.77	19.04	6.70	58				
Bacre	*Balanus crenatus*	Hexanauplia	Arthropoda	Animalia	-1.68	-1.15	-0.71	1.82	6.39	9.96	14.56	11.10	25				
Baper	*Perforatus perforatus*	Hexanauplia	Arthropoda	Animalia	11.55	12.48	14.67	18.39	19.43	22.27	26.41	9.78	25				
Chmon	*Chthamalus montagui*	Hexanauplia	Arthropoda	Animalia	9.42	11.66	16.28	18.62	19.58	21.30	22.34	9.64	1	12	13		
Chspp	*Chthamalus species*	Hexanauplia	Arthropoda	Animalia	9.43	12.08	16.16	18.65	19.72	21.34	22.46	9.26					
Chste	*Chthamalus stellatus*	Hexanauplia	Arthropoda	Animalia	9.44	12.49	16.03	18.67	19.85	21.38	22.58	8.88	1	15	16	12	13
Elmod	*Eliminius modestus*	Hexanauplia	Arthropoda	Animalia	9.43	10.38	11.67	14.02	15.79	17.44	22.48	7.06	67	68	70		
Sebal	*Semibalanus balanoides*	Hexanauplia	Arthropoda	Animalia	-0.07	1.20	4.20	7.51	10.50	12.41	22.65	11.22	2	3	4	19	
Acequ	*Actinia equina*	Anthozoa	Cnidaria	Animalia	2.48	9.57	12.32	18.16	19.48	21.24	25.14	11.67	54	55	56	57	
Acfra	*Actinia fragacea*	Anthozoa	Cnidaria	Animalia	11.00	11.93	12.38	15.08	16.45	18.81	19.67	6.88	80	81	82	83	84
Anvir	*Anemonia viridis*	Anthozoa	Cnidaria	Animalia	9.49	11.51	15.37	18.23	19.12	19.93	21.76	8.43	64				
Auver	*Aulactinia verrucosa*	Anthozoa	Cnidaria	Animalia	9.49	10.73	12.20	14.94	18.35	20.35	21.21	9.62	82	83			
Asrub	*Asterias rubens*	Asteroidea	Echinodermata	Animalia	2.48	4.26	6.31	8.50	10.58	12.18	14.30	7.92	66				
Lemue	*Leptasterias muelleri*	Asteroidea	Echinodermata	Animalia	0.20	1.75	4.64	6.33	7.95	9.72	10.85	7.98	89				
Paliv	*Paracentrotus lividus*	Echinoidea	Echinodermata	Animalia	10.52	15.67	18.11	19.04	20.30	21.49	22.58	5.82	82	86	87		
Stdro	*Strongylocentrotus droebachiensis*	Echinoidea	Echinodermata	Animalia	-1.09	0.26	2.90	5.02	7.21	9.42	12.00	9.16	47				
Myspp	*Mytilus edulis*	Bivalvia	Mollusca	Animalia	2.84	5.00	6.40	9.17	11.31	12.74	22.65	7.73	27	28	29		
Caziz	*Calliostoma zizphinum*	Gastropoda	Mollusca	Animalia	6.77	10.30	12.83	18.56	19.65	21.39	22.58	11.09	41	63			
Gicin	*Steromphala cineraria*	Gastropoda	Mollusca	Animalia	2.88	6.99	9.51	10.73	12.48	15.76	18.81	8.78	41	40	42	43	44
Gipen	*Steromphala pennanti*	Gastropoda	Mollusca	Animalia	12.53	12.80	14.54	15.69	16.95	18.59	19.26	5.79	44	46			
Giumb	*Steromphala umbilicalis*	Gastropoda	Mollusca	Animalia	9.72	10.54	11.90	13.72	16.97	18.75	19.67	8.21	9	45			
Hatub	*Haliotis tuberculata*	Gastropoda	Mollusca	Animalia	12.68	15.40	17.41	18.98	20.31	23.65	25.14	8.24	88				
Lilit	*Littorina littorea*	Gastropoda	Mollusca	Animalia	2.48	5.59	7.12	9.70	11.90	13.74	16.96	8.15	33	35			

Abbr	Species1	Class	Phylum	Kingdom	T0	T10	T25	T50	T75	T90	T100	STR	Reference			
Limar	*Littorina mariae*	Gastropoda	Mollusca	Animalia	4.20	6.67	8.91	10.34	12.12	13.78	16.29	7.11	33			
Liobt	*Littorina obtusata*	Gastropoda	Mollusca	Animalia	-1.46	0.14	1.50	6.31	9.83	12.27	16.66	12.14	33	36	37	
Lisax	*Littorina saxatilis*	Gastropoda	Mollusca	Animalia	-0.68	0.76	1.63	6.58	10.47	13.12	19.67	12.36	33	36	37	38
Mener	*Melarhaphe neritoides*	Gastropoda	Mollusca	Animalia	8.03	11.52	15.87	18.76	19.91	21.52	25.14	10.00	32	34		
Nulap	*Nucella lapillus*	Gastropoda	Mollusca	Animalia	3.65	6.39	7.67	9.98	12.10	15.37	18.81	8.98	14			
Oncel	*Onchidella celtica*	Gastropoda	Mollusca	Animalia	9.96	10.55	11.26	12.36	15.18	16.29	18.59	5.74	78	79		
Oslin	*Phorcus lineatus*	Gastropoda	Mollusca	Animalia	11.13	11.91	12.67	15.47	18.36	19.03	19.67	7.11	6	7		
Padep	*Patella depressa*	Gastropoda	Mollusca	Animalia	11.55	12.53	13.55	15.76	18.28	19.17	19.67	6.64	8	9		
Pauly	*Patella ulyssiponensis*	Gastropoda	Mollusca	Animalia	8.75	9.57	10.50	12.07	15.22	17.54	19.67	7.97	60	61	62	
Pavul	*Patella vulgata*	Gastropoda	Mollusca	Animalia	6.01	8.37	9.74	11.11	12.66	16.00	18.81	7.63	9	10	11	
Tetes	*Testudinalia testudinalis*	Gastropoda	Mollusca	Animalia	-0.30	0.88	1.55	5.52	9.07	11.07	13.31	10.19	38	39	14	
Hapan	*Halichondria panicea*	Demospongiae	Porifera	Animalia	1.01	2.79	5.27	8.21	11.87	16.24	19.14	13.44	49			
Alesc	*Alaria esculenta*	Phaeophyceae	Ochrophyta	Chromista	-1.13	-0.21	1.59	5.72	8.23	11.01	12.81	11.22	26			
Asnod	*Ascophyllum nodosum*	Phaeophyceae	Ochrophyta	Chromista	0.20	2.75	6.05	9.39	11.73	14.56	21.21	11.81	22	23		
Bibif	*Bifurcaria bifurcata*	Phaeophyceae	Ochrophyta	Chromista	10.68	11.95	12.48	15.13	18.16	19.16	19.67	7.21	26			
Chfil	*Chorda filum*	Phaeophyceae	Ochrophyta	Chromista	-1.00	2.73	5.63	7.98	12.20	18.77	24.22	16.03	26			
Fudis	*Fucus distichus*	Phaeophyceae	Ochrophyta	Chromista	-1.18	4.75	6.43	8.08	9.51	10.53	12.30	5.78	19			
Fuser	*Fucus serratus*	Phaeophyceae	Ochrophyta	Chromista	-0.51	5.29	7.14	9.72	11.64	12.77	17.08	7.48	21	24		
Fuspi	*Fucus spiralis*	Phaeophyceae	Ochrophyta	Chromista	2.88	5.54	7.15	10.18	12.83	19.01	21.36	13.47	26			
Fuves	*Fucus vesiculosus*	Phaeophyceae	Ochrophyta	Chromista	1.21	5.03	6.98	9.18	11.64	15.22	21.36	10.19	17	18		
Hasil	*Halidrys siliquosa*	Phaeophyceae	Ochrophyta	Chromista	6.48	8.24	9.50	10.45	12.04	12.67	16.08	4.43	26			
Hielo	*Himanthalia elongata*	Phaeophyceae	Ochrophyta	Chromista	6.29	7.91	9.54	10.73	12.40	15.09	16.93	7.18	26			
Ladig	*Laminaria digitata*	Phaeophyceae	Ochrophyta	Chromista	-0.58	1.11	3.59	7.17	9.61	11.27	12.81	10.17	26			
Lahyp	*Laminaria hyperborea*	Phaeophyceae	Ochrophyta	Chromista	4.20	6.04	8.08	10.04	11.94	12.74	15.57	6.71	26			
Laoch	*Laminaria ochroleuca*	Phaeophyceae	Ochrophyta	Chromista	12.30	12.70	14.61	16.02	18.14	18.77	19.59	6.07	77			
Lasac	*Saccharina latissima*	Phaeophyceae	Ochrophyta	Chromista	-1.53	0.11	3.67	6.98	9.61	11.66	15.73	11.55	26			
Pecan	*Pelvetia canaliculata*	Phaeophyceae	Ochrophyta	Chromista	2.48	5.28	8.09	10.29	12.17	15.06	17.04	9.78	20			
Sapol	*Saccorhiza polyschides*	Phaeophyceae	Ochrophyta	Chromista	8.03	9.51	10.53	12.49	16.85	19.02	20.05	9.51	26			
Samut	*Sargassum muticum*	Phaeophyceae	Ochrophyta	Chromista	6.70	9.58	11.03	13.65	17.65	20.58	24.22	11.00	71	72	73	
Vemau	*Verrucaria maura*	Eurotiomycetes	Ascomycota	Fungi	1.41	6.92	8.07	9.72	11.54	12.82	16.68	5.90	82	91	92	93
Vemuc	*Verrucaria mucosa*	Eurotiomycetes	Ascomycota	Fungi	1.74	6.41	8.08	9.92	11.71	12.70	15.39	6.29	31	90		

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Lipyg	*Lichina pygmaea*	Lichinomycetes	Ascomycota	Fungi	9.42	9.83	10.60	12.04	13.74	16.05	18.54	6.22	30			
Chcri	*Chondrus crispus*	Florideophyceae	Rhodophyta	Plantae	2.84	5.57	7.03	9.42	11.33	12.66	17.87	7.09	26			
Cooff	*Corallina officinalis*	Florideophyceae	Rhodophyta	Plantae	1.21	4.50	6.63	10.10	14.74	19.14	22.31	14.64	26	74	75	76
Maste	*Mastocarpus stellatus*	Florideophyceae	Rhodophyta	Plantae	4.20	7.11	9.15	11.00	15.09	19.08	21.36	11.97	50	51	52	53
Papal	*Palmaria palmata*	Florideophyceae	Rhodophyta	Plantae	-0.58	3.01	5.47	7.47	10.01	12.01	15.57	8.99	26			

Table S2 Literature sources for global distributions of selected UK rocky shore species used for Species Temperature Index estimation. ID numbers show sources referenced in Table S1

ID	Reference
1	Crisp, D. J., A. J. Southward, and E. C. Southward. 1981. On the distribution of the intertidal barnacles *Chthamalus stellatus*, *Chthamalus montagui* and *Euraphia depressa*. Journal of the Marine Biological Association of the United Kingdom 61:359–380.
2	Barnes, H. 1957. The northern limits of *Balanus balanoides* (L). Oikos 8:1–15.
3	Wethey, D. S., and S. A. Woodin. 2008. Ecological hindcasting of biogeographic responses to climate change in the European intertidal zone. Hydrobiologia 606:139–151.
4	Wethey, D. S., S. A. Woodin, T. J. Hilbish, S. J. Jones, F. P. Lima, and P. M. Brannock. 2011. Response of intertidal populations to climate: effects of extreme events versus long term change. Journal of Experimental Marine Biology and Ecology 400:132–144.
5	Jones, S. J., A. J. Southward, and D. S. Wethey. 2012. Climate change and historical biogeography of the barnacle *Semibalanus balanoides*. Global ecology and biogeography 21:716–724.
6	Mieszkowska, N., S. J. Hawkins, M. T. Burrows, and M. A. Kendall. 2007. Long-term changes in the geographic distribution and population structures of *Osilinus lineatus* (Gastropoda : Trochidae) in Britain and Ireland. Journal of the Marine Biological Association of the United Kingdom 87:537–545.
7	Lewis, J. R. 1964. The Ecology of Rocky Shores. English Universities Press London.
8	Burrows, M. T., Moore, P., and Hawkins, S.J. 2006. Recommendations for intertidal biodiversity surveillance. Report to the Joint Nature Conservation Committee from the Marine Biological Association. Plymouth: Marine Biological Association. JNCC Contract F90-01-893.
9	http://www.mba.ac.uk/marclim/pdf/european_distribution_of_species.pdf
10	http://www.marlin.ac.uk/specieshabitats.php?speciesID=4050
11	Lewis, J. R., R. S. Bowman, M. A. Kendall, and P. Williamson. 1982. Some geographical components in population dynamics: Possibilities and realities in some littoral species. Netherlands Journal of Sea Research 16:18–28.
12	Hawkins, S. J., H. Corte-Real, F. G. Pannacciulli, L. C. Weber, and J. D. D. Bishop. 2000. Thoughts on the ecology and evolution of the intertidal biota of the Azores and other Atlantic islands. Hydrobiologia 440:3–17.
13	Pannacciulli, F. G., J. D. D. Bishop, and S. J. Hawkins. 1997. Genetic structure of populations of two species of *Chthamalus* (Crustacea: Cirripedia) in the north-east Atlantic and Mediterranean. Marine Biology 128:73–82.
14	http://iobis.org/mapper/
15	La Gomera (MTB, 11/2013)
16	Madeira (MTB, 1/2013)
17	http://www.algaebase.org/search/species/detail/?species_id=T76489787afdd60df

ID	Reference
18	Coyer, J. A., G. Hoarau, J. F. Costa, B. Hogerdijk, E. A. Serrão, E. Billard, M. Valero, G. A. Pearson, and J. L. Olsen. 2011. Evolution and diversification within the intertidal brown macroalgae *Fucus spiralis / F. vesiculosus* species complex in the North Atlantic. Molecular Phylogenetics and Evolution 58:283–296.
19	Węsławski, J. M., M. Zajaczkowski, J. Wiktor, and M. Szymelfenig. 1997. Intertidal zone of Svalbard. Polar Biology 18:45–52.
20	http://www.algaebase.org/search/bibliography/detail/?biblio_id=c9e9a5f3e4c752b1f
21	http://www.algaebase.org/search/species/detail/?species_id=f877b167bd42f68b0&sk=0&from=results
22	http://www.algaebase.org/search/species/detail/?species_id=T29dae1de89957165&sk=0&from=results
23	Pedersen, P. M. 2011. Grønlands havalger. Epsilon. dk.
24	Hoarau, G., J. A. Coyer, M. C. W. G. Giesbers, A. Jueterbock, and J. L. Olsen. 2015. Pre-zygotic isolation in the macroalgal genus *Fucus* from four contact zones spanning 100–10 000 years: a tale of reinforcement? Royal Society Open Science 2:140538.
25	Southward, A. J. 2008. Barnacles. Field Studies Council for The Linnean Society of London and The Estaurine and Coastal Sciences Association.
26	Lüning, K. 1990. Seaweeds: their environment, biogeography, and ecophysiology. John Wiley & Sons.
27	Jones, S. J., N. Mieszkowska, and D. S. Wethey. 2009. Linking Thermal Tolerances and Biogeography: *Mytilus edulis* (L.) at its Southern Limit on the East Coast of the United States. The Biological Bulletin 217:73–85.
28	Riginos, C., and C. W. Cunningham. 2005. Invited review: local adaptation and species segregation in two mussel (*Mytilus edulis* x *Mytilus trossulus*) hybrid zones. Molecular ecology 14:381–400.
29	Hilbish, T. J., A. Mullinax, S. I. Dolven, A. Meyer, R. K. Koehn, and P. D. Rawson. 2000. Origin of the antitropical distribution pattern in marine mussels (Mytilus spp.): routes and timing of transequatorial migration. Marine Biology 136:69–77.
30	http://doris.ffessm.fr/fiche2.asp?fiche_numero=2030
31	Øvstedal, D. O., and R. I. L. Smith. 2001. Lichens of Antarctica and South Georgia: A Guide to Their Identification and Ecology. Cambridge University Press.
32	Gibson, R., B. Hextall, and A. Rogers. 2001. Photographic Guide to the Sea and Shore Life of Britain and North-west Europe. Oxford University Press, Oxford, UK.
33	Reid, D. G. 1990. Trans-Arctic migration and speciation induced by climatic change: the biogeography of *Littorina* (Mollusca: Gastropoda). Bulletin of Marine Science 47:35–49.
34	http://www.marinespecies.org/aphia.php?p=taxdetails&id=140266
35	http://www.marinespecies.org/aphia.php?p=taxdetails&id=140262
36	Weslawski, J. M., J. Wiktor, M. Zajaczkowski, and S. Swerpel. 1993. Intertidal zone of Svalbard. 1. Macroorganism distribution and biomass. Polar Biology 13:73–79.

ID	Reference
37	Węsławski, J. M., M. Zajaczkowski, J. Wiktor, and M. Szymelfenig. 1997. Intertidal zone of Svalbard. 3. Littoral of a subarctic, oceanic island: Bjornoya. Polar Biology 18:45–52.
38	Ingólfsson, A. 1996. The distribution of intertidal macrofauna on the coasts of Iceland in relation to temperature. Sarsia 81:29–44.
39	http://www.malacolog.org/search.php?nameid=47
40	Høsaeter, T. 1986. An annotated check-list of marine molluscs of the Norwegian coast and adjacent waters. Sarsia 71:73–145.
41	Graham, A. 1988. Molluscs: Prosobranchs and Pyramidellid Gastropods: Keys and Notes for the Identification of the Species. Synposes of the British Fauna (New Series). No. 2 (Second Edition). (D. M. Kermack, and R. S. K. Barnes, Eds.). Brill Archive.
42	Fretter, V., and A. Graham. 1962. British prosobranch molluscs. Their functional anatomy and ecology. Ray Society.
43	Nekhaev, I. O. 2013. Distributional notes on *Gibbula cineraria* (Linnaeus, 1758), *Pseudosetia turgida* (Jeffreys, 1870) and *Haliella stenostoma* (Jeffreys, 1858) in Russian part of the Barents Sea (Gastropoda). Ruthenica 23.
44	Smith, D. A. S. 1969. Some aspects of the biology of *Gibbula cineraria* (L.) with observations on *Gibbula umbilicalis* (Da Costa) and *Gibbula pennanti* (PHIL.).(Mollusca: Prosobranchia). Durham University.
45	Crisp, D. J., and A. J. Southward. 1958. The Distribution of Intertidal Organisms Along the Coasts of the English Channel. Journal of the Marine Biological Association of the United Kingdom 37:157–203.
46	Bazaïri, H., A. Bayed, M. Glémarec, and C. Hily. 2003. Spatial organisation of macrozoobenthic communities in response to environmental factors in a coastal lagoon of the NW African coast (Merja Zerga, Morocco). Oceanologica Acta 26:457–471.
47	Scheibling, R. E., and B. G. Hatcher. 2001. The ecology of *Strongylocentrotus droebachiensis*. Pages 271–306 *in* J. M. Lawrence, editor. Developments in Aquaculture and Fisheries Science. Elsevier.
48	http://www.algaebase.org/search/species/detail/?species_id=E73ec774871e7ea72&-session=abv4:C223DB630a5af2C318XrB06821D5
49	Vethaak, A. D., R. J. A. Cronie, and R. W. M. Van Soest. 1982. Ecology and distribution of two sympatric, closely related sponge species, *Halichondria panicea* (Pallas, 1766) and *H. bowerbanki* Burton, 1930 (Porifera, Demospongiae), with remarks on their speciation. Bijdragen tot de Dierkunde 52:82–102.
50	http://www.algaebase.org/search/species/detail/?species_id=j7fdb9763a20082eb&-session=abv4:5868C3200a6771DE57IG4F828795
51	Espinosa, F., and J. M. Guerra-García. 2005. Algae, macrofaunal assemblages and temperature: a quantitative approach to intertidal ecosystems of Iceland. Helgoland Marine Research 59:273–285.
52	Munda, I.-M. 2004. The structure and distribution of Fucacean Associations in the Icelandic Coastal Area. Acta Bot. Islandica 14:103–159.
53	Guiry, M. D., J. A. West, D.-H. Kim, and M. Masuda. 1984. Reinstatement of the genus *Mastocarpus* Kützing (Rhodophyta). Taxon:53–63.

ID	Reference
54	Monteiro, F. A., A. M. Solé-Cava, and J. P. Thorpe. 1997. Extensive genetic divergence between populations of the common intertidal sea anemone *Actinia equina* from Britain, the Mediterranean and the Cape Verde Islands. Marine Biology 129:425–433.
55	Fautin, D. G., M. Daly, and V. A. Cappola. 2005. Sea anemones (Cnidaria: Actiniaria) of the Faroe Islands: a preliminary list and biogeographic context. Pages 77–87 Annales Societatis Scientiarum Faeroensis Supplementum.
56	Chomsky, O., Y. Kamenir, M. Hyams, Z. Dubinsky, and N. E. Chadwick-Furman. 2004. Effects of temperature on growth rate and body size in the Mediterranean Sea anemone *Actinia equina*. Journal of experimental marine biology and ecology 313:63–73.
57	Gashout, S. F., and A. D. Haddoud. 2001. Libyan Lagoon Management Proceeding of Fifth International Conference on the Mediterranean Coastal Environment MEDCOAST. Pages 1033–1042 *in* D. I. Eozkan, editor. Proceeding of Fifth International Conference on the Mediterranean Coastal Environment MEDCOAST.
58	Cunningham, P. N., S. J. Hawkins, H. D. Jones, and M. T. Burrows. 1984. The geographical distribution of *Sabellaria alveolata* (L.) in England, Wales and Scotland, with investigations into the community structure of, and the effects of trampling on *Sabellaria alveolata* colonies. Report to the Nature Conservancy Council from the Department of Zoology, Manchester University, Manchester. HF3/11/22 535.
59	*Chthamalus montagui* and *C. stellatus* distributions combined
60	Firth, L. B., T. P. Crowe, P. Moore, R. C. Thompson, and S. J. Hawkins. 2009. Predicting impacts of climate-induced range expansion: an experimental framework and a test involving key grazers on temperate rocky shores. Global Change Biology 15:1413–1422.
61	Mieszkowska, N., R. Leaper, P. Moore, M. A. Kendall, M. T. Burrows, D. Lear, E. Poloczanska, K. Hiscock, P. S. Moschella, and R. C. Thompson. 2005. Marine Biodiversity and Climate Change (MarClim) Assessing and predicting the influence of climatic change using intertidal rocky shore biota. Marine Biological Association Occasional Publications.
62	Moore, J. J., and C. Howson. 2013. Surveys of the Rocky Shores in Sullom Voe.
63	Ávila, S. P., J. Azevedo, J. M. Gonçalves, J. Fontes, and F. Cardigos. 2000. Checklist of the shallow-affinity marine molluscs of the Azores: 2-São Miguel Island.
64	Kendall, M. A., M. T. Burrows, A. J. Southward, and S. J. Hawkins. 2004. Predicting the effects of marine climate change on the invertebrate prey of the birds of rocky shores. Ibis 146 Suppl 1:40–47.
65	Fransen, C., and P. Wirtz. 1997. Contribution to the knowledge of decapod crustaceans from Madeira and the Canary Islands. Zoologische Mededeelingen 71:215–230.
66	Wares, J. P. 2001. Biogeography of *Asterias*: North Atlantic climate change and speciation. The Biological Bulletin 201:95.
67	Simkanin, C., A. M. Power, A. Myers, D. McGrath, A. Southward, N. Mieszkowska, R. Leaper, and R. O’Riordan. 2005. Using historical data to detect temporal change in the abundances of intertidal species on Irish shores. Journal of the Marine Biological Association of the United Kingdom 85:1329–1340.

ID	Reference
68	O'Riordan, R. M., and N. F. Ramsay. 1999. The current distribution and abundance of the Australasian barnacle *Elminius modestus* in Portugal. Journal of the Marine Biological Association of the UK 79:937–939.
69	Harms, J., and K. Anger. 1989. Settlement of the barnacle Elminius modestus Darwin on test panels at Helgoland(North Sea): A ten year study. SCI. MAR. 53:417–421.
70	Moore, L. B. 1944. Some intertidal sessile barnacles of New Zealand. Pages 315–334 Transactions of the Royal Society of New Zealand.
71	Phillips, N. 1995. Biogeography of *Sargassum* (Phaeophyta) in the Pacific basin. Taxonomy of economic seaweeds 5:107–145.
72	Sanchez, I., C. Fernández, and J. Arrontes. 2005. Long-term changes in the structure of intertidal assemblages after invasion by *Sargassum muticum* (Phaeophyta). Journal of Phycology 41:942–949.
73	Baer, J., and D. B. Stengel. 2010. Variability in growth, development and reproduction of the non-native seaweed *Sargassum muticum* (Phaeophyceae) on the Irish west coast. Estuarine, Coastal and Shelf Science 90:185–194.
74	Brodie, J., R. H. Walker, C. Williamson, and L. M. Irvine. 2013. Epitypification and redescription of *Corallina officinalis* L., the type of the genus, and *C. elongata* Ellis et Solander (Corallinales, Rhodophyta). Cryptogamie, Algologie 34:49–56.
75	South, G. R. 1975. Common Seaweeds of Newfoundland: A Guide for the Layman. Department of Biology, Memorial University of Newfoundland.
76	Garbary, D. J., E. R. Tarakhovskaya, and others. 2013. Marine macroalgae and associated flowering plants from the Keret Archipelago, White Sea, Russia. Algae 28:267–280.
77	Smale, D. A., T. Wernberg, A. L. Yunnie, and T. Vance. 2014. The rise of *Laminaria ochroleuca* in the Western English Channel (UK) and comparisons with its competitor and assemblage dominant *Laminaria hyperborea*. Marine Ecology.
78	http://www.marinespecies.org/aphia.php?p=taxdetails&id=140626
79	Wirtz, P. 1995. One vascular plant and ten invertebrate species new to the marine flora and fauna of Madeira.
80	Carter, M. A., and J. P. Thorpe. 1981. Reproductive, genetic and ecological evidence that *Actinia equina* var. *mesembryanthemum* and var. *fragacea* are not conspecific. Journal of the Marine Biological Association of the United Kingdom 61:79–93.
81	Den Hartog, J. C., and O. Ocaña. 2003. A new endemic *Actinia* species (Actiniaria: Actiniidae) from the central Macaronesian Archipelagos. Zool Meded (Leiden) 77:229–244.
82	MarClim data 2002-2006
83	Bellomio, A., K. Morante, A. Barlič, I. Gutiérrez-Aguirre, A. R. Viguera, and J. M. González-Mañas. 2009. Purification, cloning and characterization of fragaceatoxin C, a novel actinoporin from the sea anemone *Actinia fragacea*. Toxicon 54:869–880.
84	Pereira, A., C. BritoRITO, J. Sanches, C. Sousa-Santos, and J. I. Robalo. 2014. Absence of consistent genetic differentiation among several morphs of *Actinia* (Actiniaria: Actiniidae) occurring in the Portuguese coast. Zootaxa 3893:595–600.

ID	Reference
85	Ocaña, Ó., and J. C. Den Hartog. 2002. A catalogue of actiniaria and corallimorpharia from the Canary Islands and from Madeira.
86	Boudouresque, C. F., and M. Verlaque. 2001. Ecology of *Paracentrotus lividus*. Developments in Aquaculture and Fisheries Science 32:177–216.
87	Penant, G., D. Aurelle, J.-P. Feral, and A. Chenuil. 2013. Planktonic larvae do not ensure gene flow in the edible sea urchin *Paracentrotus lividus*. Mar Ecol Prog Ser 480:155–170.
88	Mgaya, Y. D. 1995. Synopsis of biological data on the European abalone (ormer), *Haliotis tuberculata* Linnaeus, 1758 (Gastropoda: Haliotidae). Food & Agriculture Org.
89	http://www.marinespecies.org/aphia.php?p=taxdetails&id=125158
90	http://www.gbif.org/species/5259482
91	Hansen, J. R., and I. Haugen. 1989. Some observations of intertidal communities on Spitsbergen (79°N), Norwegian Arctic. Polar Research 7:23–27.
92	Engelskjøn, T. 1987. Eco-geographical relations of the Bjornoya vascular flora, Svalbard. Polar Research 5:79–127.
93	Hansen, J. R., and A. Ingólfsson. 1993. Patterns in species composition of rocky shore communities in sub-arctic fjords of eastern Iceland. Marine Biology 117:469–481.

Table S3 Spatial variation in thermal community composition metrics related to site-averaged values with local sea surface temperature and site-specific wave exposure ($\log_{10}$ summed wave fetch). All p-values <0.001 except *.

	Estimate	SE	t		Estimate	SE	t
CTDiv, Community Thermal Diversity				**CTR, Community Thermal Range**			
(Intercept)	*-0.077	0.219	-0.35	(Intercept)	11.791	0.114	103.79
SST	0.205	0.020	10.51	SST	-0.170	0.010	-16.77
Wave fetch	0.327	0.038	8.71	Wave fetch	-0.130	0.019	-6.69
aCTDiv, Animal species				**aCTR, Animal species**			
(Intercept)	2.975	0.231	12.90	(Intercept)	11.873	0.134	88.79
SST	*0.005	0.021	0.25	SST	-0.251	0.012	-21.10
Wave fetch	0.271	0.040	6.86	Wave fetch	0.077	0.023	3.35
mCTDiv, Algae and plant species				**mCTR, Algae and plant species**			
(Intercept)	-1.286	0.186	-6.92	(Intercept)	12.119	0.225	53.79
SST	0.119	0.017	7.18	SST	-0.076	0.020	-3.76
Wave fetch	0.372	0.032	11.64	Wave fetch	-0.396	0.039	-10.22

Table S4 CTI trends in Shetland time series by site, 1984-2018

Site	SiteName	n	Estimate	SE	*p*	Long	Lat	Easting	Northing
ST1-1	West of Mioness	24	0.0207	0.0033	0.0033	-1.24	60.49	441828	1179071
ST2-3	Roe Clett	34	0.0051	0.0743	0.0743	-1.28	60.48	439437	1178127
ST3-3	Noust of Burraland	35	0.0056	0.0561	0.0561	-1.32	60.45	437201	1175186
ST3-4	Gluss Island East	31	0.0083	0.0013	0.0013	-1.31	60.47	437711	1177551
ST3-5	South of Swarta Taing	35	0.0066	0.0035	0.0035	-1.27	60.48	440160	1177901
ST4-1	Grunn Taing	35	0.0023	0.2066	0.2066	-1.31	60.49	437942	1178992
ST4-3	The Kames	35	0.0190	0.0001	0.0001	-1.30	60.47	438437	1176459
ST4-6	Voxter Ness	35	0.0046	0.0299	0.0299	-1.34	60.41	436084	1170089
ST5-1	South of Skaw Taing	35	0.0057	0.0621	0.0621	-1.28	60.48	439621	1178236
ST5-2	Jetty 3	35	0.0090	0.0111	0.0111	-1.30	60.46	438594	1175578
ST5-5	Mavis Grind (Stream 3)	35	0.0149	0.0000	0.0000	-1.38	60.39	434054	1168462
ST6-1	Fugla Ayre	34	0.0144	0.0059	0.0059	-1.32	60.44	437342	1174182
ST6-12	Scatsta Ness (cleared)	35	0.0140	0.0000	0.0000	-1.29	60.44	438874	1173544
ST6-13	Scatsta Ness (uncleared)	35	0.0104	0.0000	0.0000	-1.29	60.44	438976	1173524
ST6-2	South of Jetty 2	35	0.0324	0.0000	0.0000	-1.28	60.45	439163	1175089

Table S5 CTI trends in MarClim time series by site, 2002-2018, as linear regressions over time. n is the number of site surveys since 2002, usually annually.

IDn	Site	n	Estimate	SE	*p*	Longitude	Latitude
28	Lynmouth	14	-0.0948	0.0181	0.0002	51.2356	-3.8378
30	Menai Bridge	13	-0.0859	0.0251	0.0057	53.2207	-4.1643
33	Nefyn	12	-0.0802	0.0248	0.009	52.9430	-4.5702
56	Trevone	20	-0.0745	0.022	0.0033	50.5450	-4.9850
54	Swanage Peverill Point	14	-0.0705	0.0244	0.0135	50.6070	-1.9449
42	Porth Dafarch	12	-0.0661	0.0153	0.0015	53.2856	-4.6522
50	Sennen Cove Exposed	13	-0.0653	0.0289	0.0449	50.0780	-5.7092
35	Newquay Towan Head (Lenards Rock)	17	-0.0639	0.021	0.0082	50.4235	-5.0969
9	Cellar	14	-0.0599	0.0276	0.0506	50.3108	-4.0645
46	Portland (Pulpit Rock)	17	-0.0593	0.0277	0.0489	50.5130	-2.4600
16	Great Orme East	12	-0.0575	0.0392	0.1736	53.3321	-3.8297
31	Moelfre	11	-0.057	0.0189	0.0144	53.3490	-4.2354
25	Looe SJH site	15	-0.0548	0.0179	0.0091	50.3410	-4.4580
39	Point Lynas	11	-0.051	0.0272	0.0931	53.4111	-4.2823
15	Duckpool	17	-0.0501	0.0189	0.0184	50.8712	-4.5625
4	Brixham Shoalstone	19	-0.0494	0.0112	0.0004	50.4010	-3.4970
58	Wembury Church Reef	19	-0.0487	0.016	0.0073	50.3140	-4.0830
51	Sennen Cove Sheltered	10	-0.0487	0.0148	0.0108	50.0787	-5.7060
26	Lyme Regis Broadledge	17	-0.0456	0.0142	0.0058	50.7221	-2.9333
27	Lyme Regis MAK	14	-0.0437	0.0185	0.0357	50.7161	-2.9471
49	Rhosneigr	15	-0.0405	0.0176	0.038	53.2233	-4.5253
47	Prawle Point	18	-0.0402	0.0246	0.1215	50.2032	-3.7165
48	Prawle Point	18	-0.0402	0.0246	0.1215	50.7238	-2.9293
37	Penmaenmawr Natural	11	-0.0373	0.0272	0.2029	53.2683	-3.9440
38	Penmon North	17	-0.0346	0.0176	0.0677	53.3111	-4.0413
18	Hartland Quay	20	-0.0333	0.019	0.0966	50.9950	-4.5370
41	Porth Ceriad	11	-0.0331	0.0556	0.5667	52.7940	-4.5094
2	Aberffraw (Briach-Lwyd)	13	-0.0310	0.0209	0.1670	53.1776	-4.4899
52	South Haven	12	-0.0305	0.0151	0.0708	51.7319	-5.2845
45	Porthleven	19	-0.0305	0.0128	0.0296	50.0810	-5.3210
60	Widemouth	10	-0.0302	0.033	0.3874	50.7802	-4.5673
40	Port Gaverne	14	-0.0277	0.0245	0.2805	50.5952	-4.8259
43	Porth Neigwl	17	-0.0271	0.026	0.3143	52.7908	-4.5404
24	Looe Hannafore Pt (AJS)	13	-0.025	0.0319	0.4503	50.3465	-4.4512
53	St Ives Porthguiddan	19	-0.0238	0.0171	0.1823	50.2179	-5.4751
23	Llanbedrog	10	-0.0234	0.0344	0.5159	52.8516	-4.4742
20	Langerstone Point	14	-0.0209	0.0289	0.4834	50.2051	-3.7069
8	Cape Cornwall	17	-0.0204	0.0154	0.2061	50.1288	-5.7080
6	Bude	16	-0.0176	0.0122	0.1692	50.8362	-4.5592
61	Woolacombe	17	-0.0171	0.0135	0.2244	51.1796	-4.2161
10	Cemlyn	15	-0.0138	0.0155	0.3900	53.4134	-4.5087

IDn	Site	n	Estimate	SE	*p*	Longitude	Latitude
12	Crackington Haven	14	-0.0135	0.0175	0.4541	50.7417	-4.6405
11	Corbyn Head	12	-0.0130	0.0181	0.4865	50.4586	-3.5400
5	Broadhaven	14	-0.0130	0.0258	0.6231	51.7871	-5.1057
17	Great Orme Trwynygogarth	16	-0.0119	0.0276	0.6733	53.3327	-3.8801
22	Lizard	15	-0.0116	0.0218	0.6056	49.9590	-5.2080
3	Brighton Marina East	13	-0.0093	0.0289	0.7529	50.8221	-0.1309
32	Monkstone Point	14	-0.0069	0.0224	0.7626	51.6978	-4.6784
44	Porth Swtan	15	-0.0069	0.0136	0.6213	53.3713	-4.5595
21	Little Orme	15	-0.0015	0.0188	0.9365	53.3260	-3.7852
36	North Haven	13	0.00217	0.0202	0.9166	51.7365	-5.2819
59	West Angle Bay	14	0.00338	0.01	0.7397	51.6916	-5.1151
14	Criccieth Castle	17	0.0100	0.0196	0.6189	52.9146	-4.2412
13	Criccieth (East)	16	0.0170	0.0168	0.3300	52.9171	-4.2302
19	Holyhead	10	0.01911	0.0351	0.6012	53.3108	-4.6461
29	Martin's Haven	13	0.02524	0.0247	0.3295	51.7357	-5.2471
57	Welcombe Mouth	13	0.02871	0.0264	0.3007	50.9328	-4.5489
34	Newquay Little Fistral	11	0.03258	0.031	0.3199	50.4218	-5.1014
1	Aberdaron	14	0.0404	0.0314	0.2223	52.8003	-4.7220
7	Caernarfon (Aber Foreshore Road)	11	0.0474	0.0315	0.1675	53.1374	-4.2897
55	Trefor	11	0.05349	0.0635	0.4216	52.9992	-4.4215

Table S6 Regional average community thermal metrics at time-series sites using average abundance as weighting, expressed in °C. CTI, Community Temperature Index: abundance-weighted average of species thermal midpoints; CTDiv, variability among species' thermal affinities within a community; CTR, average species thermal range; nspp, species richness; Thermal Bias, difference between CTI and local SST.

SW Britain	SST	12.46°C			
	CTI	**CTDiv**	**CTR**	**nspp**	**Thermal bias**
All	12.13	3.90	9.20	53	-0.33
Animals	13.30	4.32	9.14	33	0.84
Macroalgae	10.12	2.01	9.54	18	-2.34
Other	12.04	0.00	6.22	2	-0.42

Shetland	SST	9.58°C			
	CTI	**CTDiv**	**CTR**	**nspp**	**Thermal bias**
All	9.11	1.97	9.42	31	-0.47
Animals	8.70	2.38	10.12	15	-0.88
Macroalgae	9.80	0.93	10.03	13	0.22
Other	9.80	0.12	6.05	3	0.22