Electronic Supplementary Material

Functional shifts in rocky reef communities from an ocean warming hotspot depend on protection from exploitation

Amanda E. Bates, Rick D. Stuart-Smith, Neville S. Barrett, Graham J. Edgar

Figures S1-S9

Tables S1-S9

Table S1. Summary of locations monitored between 1992 and 2012.

Table S2. Summary of full monitoring used to calculate CTI.

Table S3. Species-specific traits.

Table S4. Summary table for statistical tests of the response of CTI specifying the GAMM model.

Table S5. Summary table for the trends in sea surface temperature specifying the model.

Table S6. Summary table for the statistical test of the response of CTI over time with and without increases in urchins.

Table S7. Summary table for statistical tests of response of richness and abundance.

Table S8. Summary table for statistical tests of response of total richness and abundance.

Table S9. Summary table for statistical tests of response of functional group abundance.

Figures S1-S9

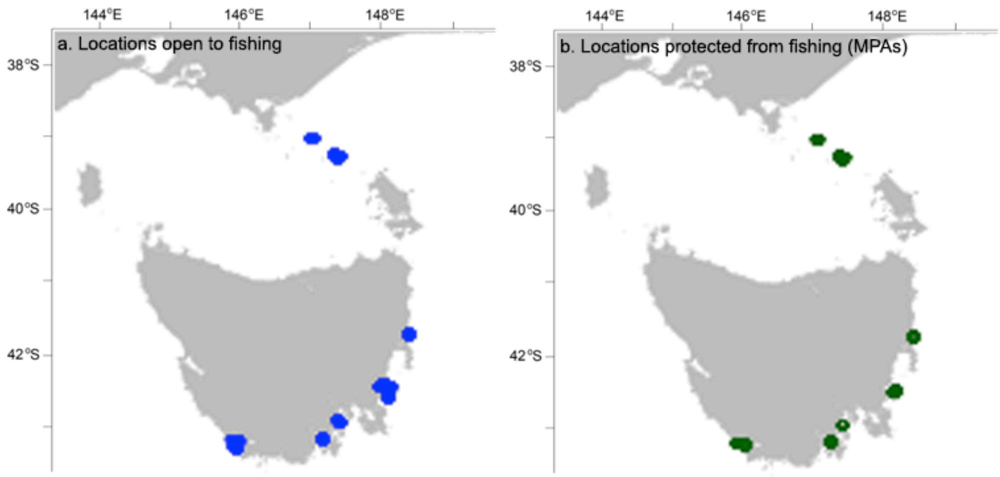

Figure S1. Sampling locations in southeast Australia (a, Open and b, Protected) monitored for eight or more years between 1992 and 2012 (summarized in Table S1).

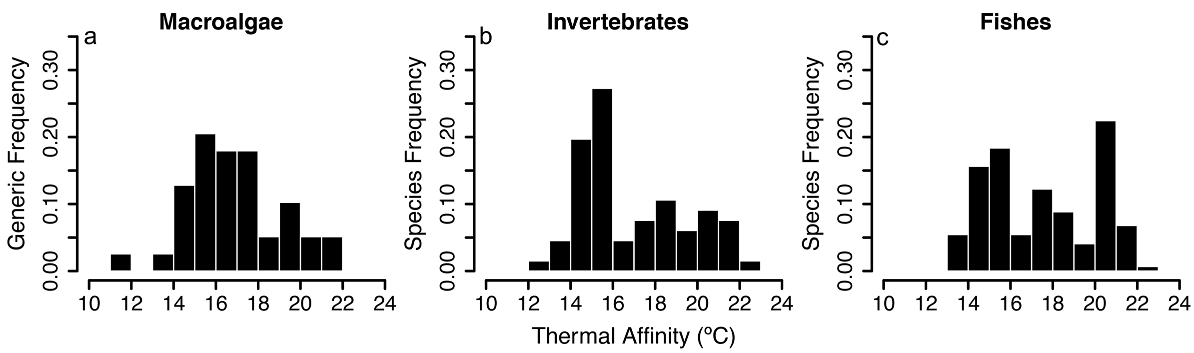

Figure S2. Frequency of genera (macroalgae) and species (invertebrates and fishes) versus thermal affinity (median of the thermal distribution calculated for all occurrence records recorded in the sampling summarized in table S2).

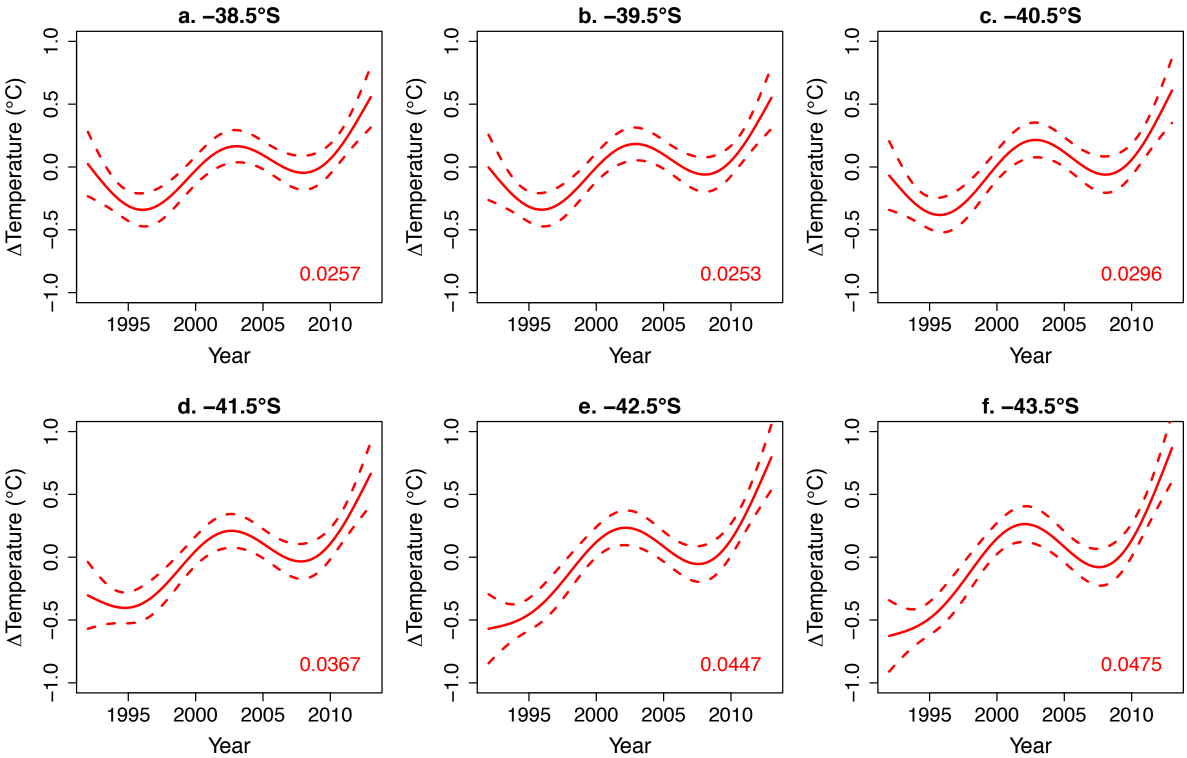

Figure S3. Trends in temperature for the study duration. Sea surface temperature (SST) change averaged across southeast Australia for six bands of latitude. Trends through time were modeled with a general additive model, after accounting for the seasonal patterns (i.e., a "Month" term was included in the model and fit using a bicubic function). Temperature patterns are described in two ways to reflect the influence of climate patterns: (1) fit using a spline function (red line, dotted red lines are the 95% CI) to allow oscillations, and the overall trend (2) fit as a linear relationship (the slope is presented in red text). Temperature data was extracted from http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html, representing monthly mean SST for a 1° latitude x 1° longitude grid. Table S5 provides details on the modeling methods and results.

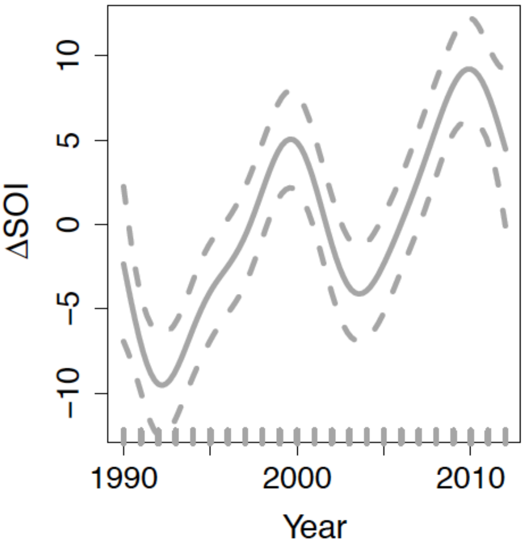

Figure S4. Trends in the Southern Oscillation Index (SOI) for the study duration. Change in the SOI (relative to the mean) over the study duration, driven by the strength of the *El Niño* (low) and *La Niña* (high) phases in the southern hemisphere.

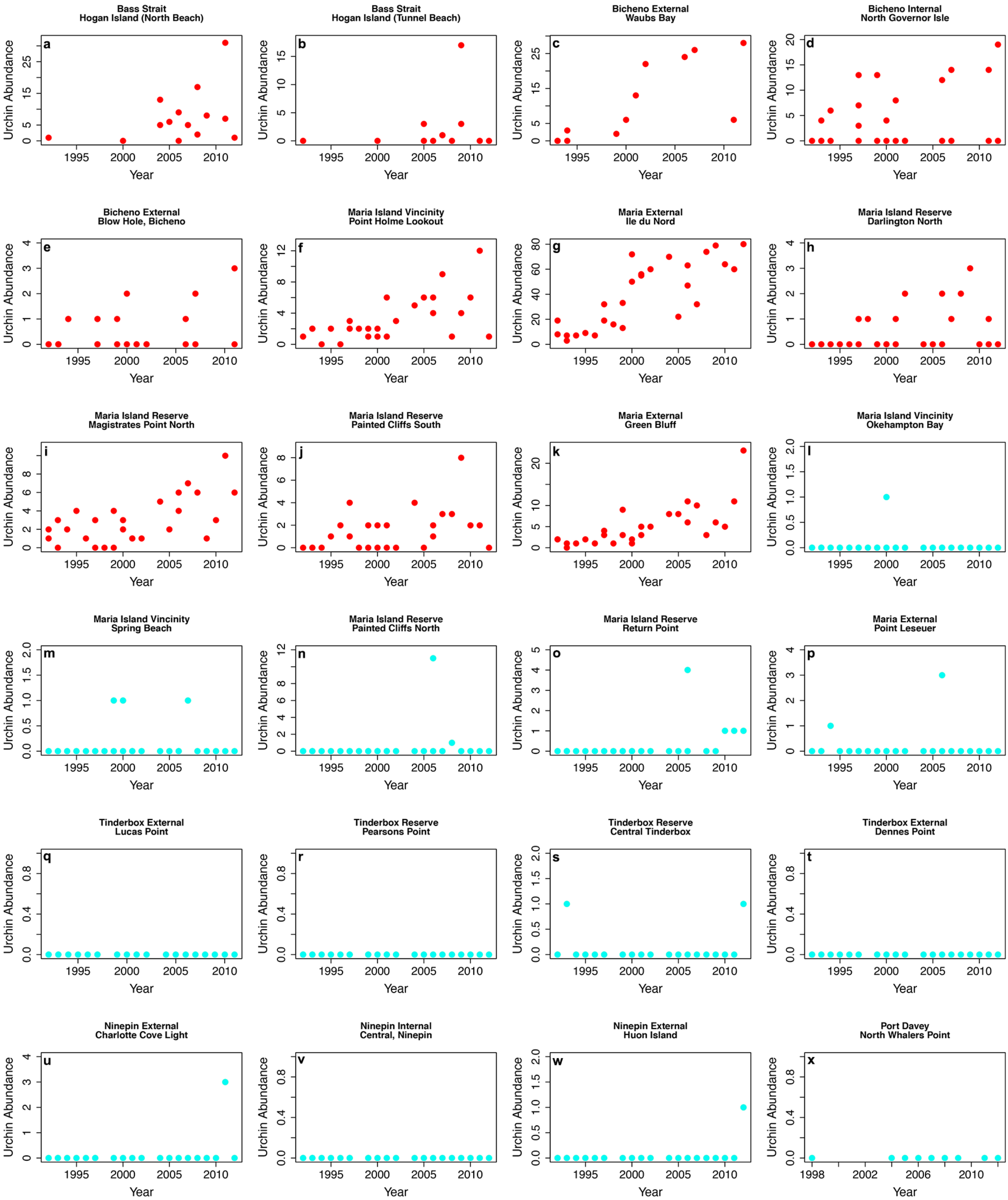

Figure S5. Sites with contrasting trends in abundance of the urchin, *Centrostephanus rodgersii*. Abundance of the urchin (log-transformed) across sites with either increasing abundance trends (a-k, red) or very few urchins (l-x, cyan) and surveyed since the 1990s. Table S6 reports the results of a statistical test of the response of CTI between these sites, grouped according to the observed trend in urchin abundance reported here.

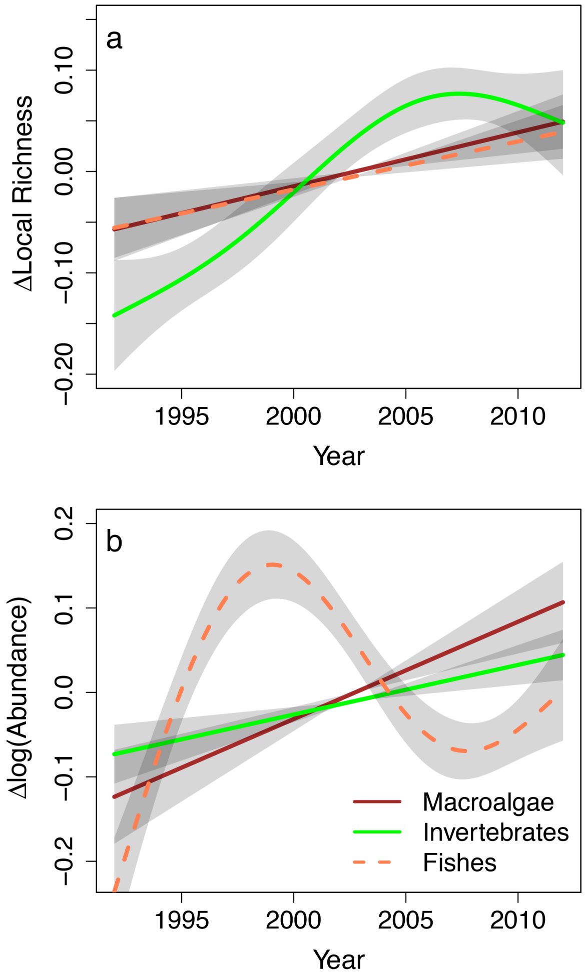

Figure S6. Trends in total taxonomic richness and abundance at the survey scale for the study duration. a, Local richness and b, abundance patterns in the macroalgae, invertebrate and fish communities from 1992 to 2012. Model results are reported in table S8.

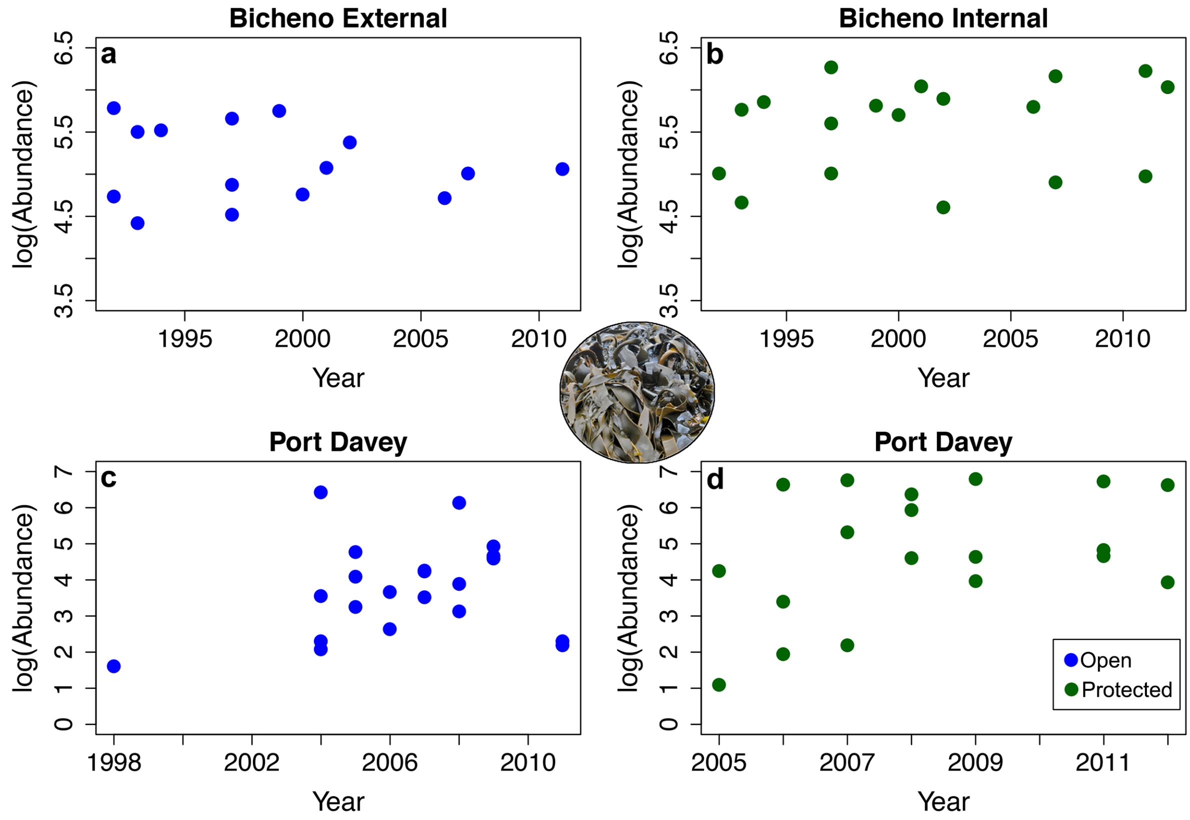

Figure S7. Contrasting patterns in the abundance of a cool affinity macroalgal species with exploitation. Abundance of *Durvillaea* (measured as percent cover (log transformed) in surveys from locations open to fishing and protected from fishing.

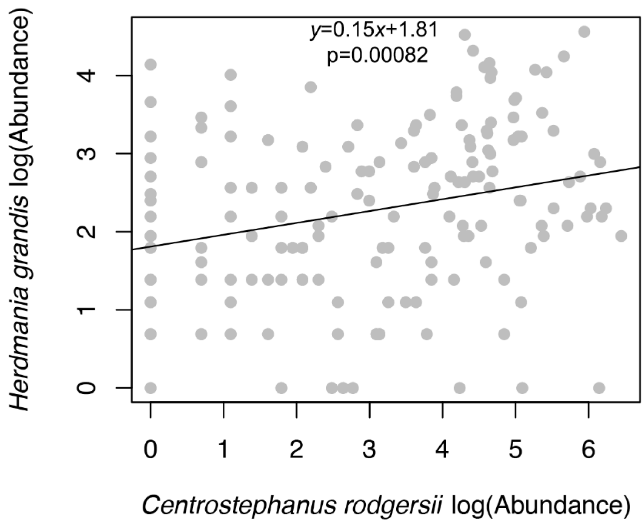

Figure S8. Relationship of abundance between a warm affinity sessile invertebrate and the urchin, *Centrostephanus rodgersii*. Abundance (log-transformed) of the sea squirt, *Herdmania grandis,* versus the urchin across all surveys where the urchin was present.

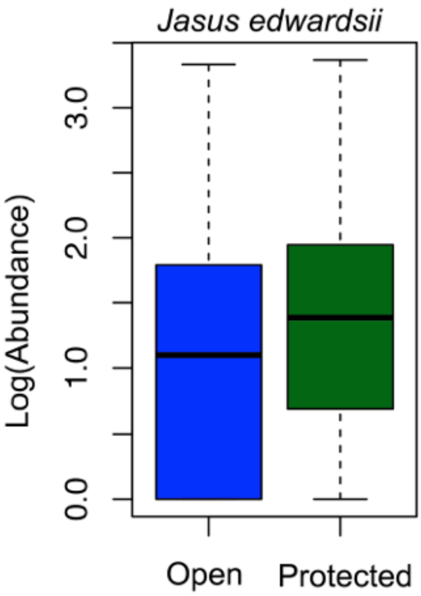

Figure S9. Contrasting abundance distributions of lobsters with exploitation versus protection. Abundance (log-transformed) of lobsters in locations open to fishing and protected from fishing in southeast Australia, pooled across all years and surveys where lobsters (*Jasus edwardsii*) were present.

Tables S1-S9

Table S1. Summary of locations with monitoring that spanned eight or more years between 1992 and 2012 in Tasmania, southeast Australia (also shown in figure S1).

Location	Mean Latitude	Mean Longitude	# Surveys	# Sites	First Year of Survey	Last Year of Survey	Reserve
Bass Strait	-39 2	147 0	44	4	1992	2012	no
Bathurst Harbour	-43 3	146 0	7	1	2005	2012	yes
Bicheno External	-41 9	148 3	52	3	1992	2012	no
Bicheno Internal	-41 9	148 3	54	2	1992	2012	yes
Kent Group	-39 5	147 3	62	11	1992	2012	no
Kent Group	-39 5	147 3	68	8	2005	2012	yes
Maria External	-42 6	148 0	80	3	1992	2012	no
Maria Island Reserve	-42 6	148 0	160	6	1992	2012	yes
Maria Island Vicinity	-42 6	147 9	80	3	1992	2012	no
Ninepin External	-43 3	147 1	43	2	1992	2012	no
Ninepin Internal	-43 3	147 2	23	1	1992	2012	yes
Port Davey	-43 3	145 9	46	9	1994	2012	no
Port Davey	-43 3	145 9	24	3	2005	2012	yes
Tinderbox External	-43 1	147 3	46	2	1992	2012	no
Tinderbox Reserve	-43 1	147 3	48	2	1992	2012	yes

Table S2. Summary of full monitoring used to calculate CTI. Temporal and spatial scope of long-term monitoring in Australia that contributing to the matching of observations of taxa in space and time with sea surface temperature (http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html) for calculation of CTI.

Location	Mean Latitude	Mean Longitude	# Surveys	# Sites	First Year of Survey	Last Year of Survey
Albany/Esperance	-34 4	119 5	25	25	1997	1997
Bass Strait	-39 3	147 0	75	11	1992	2012
Batemans Bay	-35 8	150 3	58	37	2005	2007
Bathurst Harbour	-43 3	146 0	13	6	1993	2012
Bicheno External	-41 9	148 3	63	11	1992	2012
Bicheno Internal	-41 9	148 3	56	2	1992	2012
Bruny Island	-43 2	147 3	18	11	1994	2007
Bunurong	-38 7	145 7	8	8	1999	1999
Central West	-42 2	145 2	14	6	1994	2006
Derwent	-43 0	147 4	5	5	2010	2010
Encounter Bay	-35 6	138 2	113	40	2005	2012
Eyre Peninsula	-34 5	135 8	27	22	2007	2007
Flinders	-40 1	148 0	26	16	1994	2006
Jervis Bay	-35 1	150 8	283	32	1996	2009
Jurien Bay	-30 4	115 0	284	44	1999	2009
Kent Group	-39 5	147 3	160	17	1992	2012
King Island	-39 9	144 0	17	11	1992	2007
Maria External	-42 6	148 1	114	9	1992	2012
Maria Island Reserve	-42 6	148 0	161	6	1992	2012
Maria Island Vincinity	-42 6	147 9	96	7	1992	2012
Ninepin External	-43 3	147 2	55	8	1992	2012
Ninepin Internal	-43 3	147 2	23	1	1992	2012
North Coast	-40 8	147 7	23	9	1992	2006
North East	-41 3	148 3	42	19	1994	2006
North West	-41 0	145 7	45	19	1992	2007
Northern	-41 1	146 7	33	11	1994	2007
Northern West	-40 9	144 6	7	3	1994	2007
Port Davey	-43 3	145 9	174	28	1993	2012
Port Phillip Heads	-38 3	144 7	46	15	1998	1999
Robe	-37 1	139 7	4	4	2012	2012
Schouten Island	-42 3	148 3	22	12	1992	2006
South West	-43 5	146 4	25	13	1994	2007
Tasman Peninsular	-43 0	147 9	31	15	1994	2007
The Capes WA	-33 9	115 0	19	19	2007	2007
Tinderbox External	-43 0	147 4	61	7	1992	2012
Tinderbox Reserve	-43 1	147 3	51	2	1992	2012
Upper Spencer Gulf	-33 2	137 5	8	8	2009	2009
West Coast SA	-32 6	133 7	22	17	2009	2009
Wilsons Promontory	-39 1	146 4	54	28	1999	2000
Yorke Peninsula	-35 0	137 2	46	33	2004	2006

Table S3. Species-specific traits representing habitat structure (a, Macroalgal genera) and trophic level (b, Invertebrate and c, Fish Species) traits for species observed during the monitoring period from 1992 to 2012.

a. Macroalgal Genus-specific Traits

Genus	Trait
Lessonia	canopy blade
Phyllospora	canopy blade
Platythalia	canopy blade
Undaria	canopy blade
Xiphophora	canopy blade
Carpoglossum	canopy blade
Durvillaea	canopy blade
Ecklonia	canopy blade
Acrocarpia	canopy foliose
Caulocystis	canopy foliose
Cystophora	canopy foliose
Hormosira	canopy foliose
Sargassum	canopy foliose
Scaberia	canopy foliose
Seirococcus	canopy foliose
Asperococcus	epiphytic
Chlanidophora	epiphytic
Colpomenia	epiphytic
Ectocarpus	epiphytic
Leathesia	epiphytic
Lobospira	epiphytic
Pachydictyon	epiphytic
Lobophora	small foliose
Perithalia	small foliose
Scytosiphon	small foliose
Sporochnus	small foliose
Taonia	small foliose
Zonaria	small foliose
Bellotia	small foliose
Carpomitra	small foliose
Cladostephus	small foliose
Dictyopteris	small foliose
Dictyota	small foliose
Dictyotaceae	small foliose
Dilophus	small foliose
Distromium	small foliose
Halopteris	small foliose
Homoeostrichus	small foliose
Macrocystis	surface canopy

b. Invertebrate Species-specific Traits

Species Name	Trophic Group
Paguristes brevirostris	benthic invertivore
Petrocheles australiensis	benthic invertivore
Agnewia tritoniformis	benthic invertivore
Amoria undulata	benthic invertivore
Argobuccinum pustulosum	benthic invertivore
Cabestana spengleri	benthic invertivore
Cabestana tabulata	benthic invertivore
Charonia lampas rubicunda	benthic invertivore
Cominella lineolata	benthic invertivore
Conus anemone	benthic invertivore
Cymatium parthenopeum	benthic invertivore
Dicathais orbita	benthic invertivore
Fusinus australis	benthic invertivore
Fusinus noveahollandiae	benthic invertivore
Jasus edwardsii	benthic invertivore
Metacarcinus novaezelandiae	benthic invertivore
Mitra glabra	benthic invertivore
Naxia aurita	benthic invertivore
Notocypraea angustata	benthic invertivore
Notocypraea comptoni	benthic invertivore
Octopus berrima	benthic invertivore
Octopus maorum	benthic invertivore
Octopus tetricus	benthic invertivore
Penion mandarinus	benthic invertivore
Penion maximus	benthic invertivore
Plagusia chabrus	benthic invertivore
Pleuroploca australasia	benthic invertivore
Ranella australasia	benthic invertivore
Sagaminopteron ornatum	benthic invertivore
Sassia parkinsonia	benthic invertivore
Sassia subdistorta	benthic invertivore
Sassia verrucosa	benthic invertivore
Sepia apama	benthic invertivore
Sepioteuthis australis	benthic invertivore
Thalamita admete	benthic invertivore
Tylodina corticalis	benthic invertivore
Umbraculum umbraculum	benthic invertivore
Astralium aureum	herbivore
Astralium tentoriformis	herbivore
Chlorodiloma odontis	herbivore
Clanculus undatus	herbivore
Haliotis laevigata	herbivore
Haliotis rubra	herbivore
Ischnochiton australis	herbivore
Nectocarcinus integrifrons	herbivore
Nectocarcinus tuberculosus	herbivore
Phasianella australis	herbivore
Phasianella ventricosa	herbivore
Phasianotrochus eximius	herbivore
Plaxiphora albida	herbivore

Scutus antipodes	herbivore
Turbo undulatus	herbivore
Paguristes frontalis	omnivore
Pagurixus handrecki	omnivore
Strigopagurus strigimanus	omnivore
Cnemidocarpa pedata	suspension feeders
Equichlamys bifrons	suspension feeders
Herdmania grandis	suspension feeders
Mactra pura	suspension feeders
Maoricolpus roseus	suspension feeders
Mimachlamys asperrima	suspension feeders
Notochlamys hexactes	suspension feeders
Pecten fumatus	suspension feeders
Phlyctenactis tuberculosa	suspension feeders
Pyura australis	suspension feeders

c. Fish Species-specific Traits

Species Name	Trophic Group
Achoerodus viridis	benthic invertivore
Aetapcus maculatus	benthic invertivore
Aploactisoma milesii	benthic invertivore
Aracana aurita	benthic invertivore
Aracana ornata	benthic invertivore
Arothron firmamentum	benthic invertivore
Aspasmogaster tasmaniensis	benthic invertivore
Asymbolus analis	benthic invertivore
Bovichtus angustifrons	benthic invertivore
Cheilodactylus nigripes	benthic invertivore
Cheilodactylus spectabilis	benthic invertivore
Chironemus marmoratus	benthic invertivore
Contusus brevicaudus	benthic invertivore
Cristiceps australis	benthic invertivore
Dactylophora nigricans	benthic invertivore
Dasyatis brevicaudata	benthic invertivore
Dasyatis thetidis	benthic invertivore
Diodon nicthemerus	benthic invertivore
Dipturus whitleyi	benthic invertivore
Dotalabrus aurantiacus	benthic invertivore
Enoplosus armatus	benthic invertivore
Eocallionymus papilio	benthic invertivore
Eupetrichthys angustipes	benthic invertivore
Foetorepus calauropomus	benthic invertivore
Forsterygion varium	benthic invertivore
Gerres subfasciatus	benthic invertivore
Gnathanacanthus goetzeei	benthic invertivore
Gymnothorax prasinus	benthic invertivore
Halaphritis platycephala	benthic invertivore
Heteroclinus johnstoni	benthic invertivore
Heteroclinus perspicillatus	benthic invertivore
Heteroclinus wilsoni	benthic invertivore
Heterodontus portusjacksoni	benthic invertivore

Hippocampus abdominalis	benthic invertivore
Hypoplectrodes maccullochi	benthic invertivore
Hypoplectrodes nigroruber	benthic invertivore
Latridopsis forsteri	benthic invertivore
Lepidotrigla papilio	benthic invertivore
Lepidotrigla vanessa	benthic invertivore
Mendosoma lineatum	benthic invertivore
Meuschenia scaber	benthic invertivore
Myliobatis australis	benthic invertivore
Nemadactylus douglasii	benthic invertivore
Nemadactylus macropterus	benthic invertivore
Neosebastes scorpaenoides	benthic invertivore
Nesogobius hinsbyi	benthic invertivore
Notolabrus fucicola	benthic invertivore
Notolabrus gymnogenis	benthic invertivore
Notolabrus tetricus	benthic invertivore
Omegophora armilla	benthic invertivore
Ophthalmolepis lineolatus	benthic invertivore
Parapriacanthus elongatus	benthic invertivore
Parequula melbournensis	benthic invertivore
Pempheris multiradiata	benthic invertivore
Pentaceropsis recurvirostris	benthic invertivore
Pictilabrus laticlavius	benthic invertivore
Pseudolabrus psittaculus	benthic invertivore
Pseudophycis barbata	benthic invertivore
Scorpaena papillosa	benthic invertivore
Tetractenos glaber	benthic invertivore
Thamnaconus degeni	benthic invertivore
Threpterius maculosus	benthic invertivore
Trianectes bucephalus	benthic invertivore
Trinorfolkia clarkei	benthic invertivore
Upeneichthys lineatus	benthic invertivore
Upeneichthys vlamingii	benthic invertivore
Urolophus cruciatus	benthic invertivore
Urolophus paucimaculatus	benthic invertivore
Vincentia conspersa	benthic invertivore
Acanthaluteres spilomelanurus	herbivore
Acanthaluteres vittiger	herbivore
Aldrichetta forsteri	herbivore
Aplodactylus arctidens	herbivore
Aplodactylus lophodon	herbivore
Atherinason hepsetoides	herbivore
Brachaluteres jacksonianus	herbivore
Eubalichthys gunnii	herbivore
Eubalichthys mosaicus	herbivore
Girella elevata	herbivore
Girella tricuspidata	herbivore
Girella zebra	herbivore
Haletta semifasciata	herbivore
Heteroscarus acroptilus	herbivore
Kyphosus sydneyanus	herbivore

Meuschenia australis	herbivore
Meuschenia flavolineata	herbivore
Meuschenia freycineti	herbivore
Meuschenia galii	herbivore
Meuschenia hippocrepis	herbivore
Meuschenia venusta	herbivore
Mugil cephalus	herbivore
Neoodax balteatus	herbivore
Olisthops cyanomelas	herbivore
Parablennius tasmanianus	herbivore
Parma microlepis	herbivore
Parma victoriae	herbivore
Siphonognathus attenuatus	herbivore
Siphonognathus beddomei	herbivore
Siphonognathus radiatus	herbivore
Arripis trutta	higher carnivore
Aulopus purpurissatus	higher carnivore
Cephaloscyllium laticeps	higher carnivore
Conger verreauxi	higher carnivore
Cyttus australis	higher carnivore
Dentiraja lemprieri	higher carnivore
Dinolestes lewini	higher carnivore
Genypterus tigerinus	higher carnivore
Helicolenus percoides	higher carnivore
Heteroclinus tristis	higher carnivore
Kathetostoma laeve	higher carnivore
Latris lineata	higher carnivore
Lotella rhacina	higher carnivore
Parascyllium ferrugineum	higher carnivore
Parascyllium variolatum	higher carnivore
Platycephalus bassensis	higher carnivore
Pseudocaranx moretonii	higher carnivore
Pseudophycis bachus	higher carnivore
Seriolella brama	higher carnivore
Seriolella punctata	higher carnivore
Sphyraena novaehollandiae	higher carnivore
Squalus acanthias	higher carnivore
Thyrsites atun	higher carnivore
Trachurus declivis	higher carnivore
Trachurus novaezelandiae	higher carnivore
Atypichthys strigatus	planktivore
Caesioperca lepidoptera	planktivore
Caesioperca rasor	planktivore
Chromis hypsilepis	planktivore
Engraulis australis	planktivore
Hippocampus breviceps	planktivore
Hyporhamphus melanochir	planktivore
Paratrachichthys trailli	planktivore
Phyllopteryx taeniolatus	planktivore
Sardinops neopilchardus	planktivore
Scorpis aequipinnis	planktivore

Scorpis lineolata	planktivore
Siphamia cephalotes	planktivore
Siphonognathus tanyourus	planktivore
Stigmatopora nigra	planktivore
Trachinops caudimaculatus	planktivore
Trachinops taeniatus	planktivore

Table S4. Summary table for statistical tests of the response of CTI (figure 1, main text). We fit a generalized additive mixed model (GAMM), implemented with the package *mgcv*[1] and the function "gamm" in R[2]). We included the random effects of site nested in location to account for repeated sampling in space and time. Sea surface temperature (Temperature) during the month of sampling, the southern oscillation index (SOI), abundance of *Centrostephanus* (sqrt(Urchin Abundance)), and age of the reserve at the time of sampling (Duration, note that fished sites were assigned a value of zero) were included as fixed effects and scaled for direct comparisons of the coefficients (LME component). "s" indicates fixed effects (Year) modelled with penalized regression splines (GAM component). Seasonal change in temperature across months was modeled as a cyclic cubic spline but was dropped from all models, as this term did not improve the model fit, based on Akaike information criterion (AIC). Estimated degrees of freedom = edf; Ref df = Reference degree of freedom (prior to deductions); Standard error = Std Error.

a. Macroalgal CTI (figure 1a,d)

Random Effects

~1|Location	0.305
~1|Location/Site	0.207
Residual	0.285

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	16.074	0.0936	171.734	<0.0000
Temperature	0.0689	0.0154	4.473	<0.0000
SOI	-0.0590	0.0130	-4.550	<0.0000
sqrt(Urchin Abund)	0.0662	0.0259	2.551	0.0109
Duration	-0.0402	0.0213	-1.888	0.0594

AIC = 414.412

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	1.914	1.914	28.080	<0.0000

b. Invertebrate CTI (figure 1b,e)

Random Effects

~1|Location	0.163
~1|Location/Site	0.126
Residual	0.537

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	15.922	0.0554	287.330	<0.0000
Temperature	0.0897	0.0412	2.175	0.0300
SOI	-0.0335	0.0291	-1.154	0.249
sqrt(Urchin Abund)	0.0896	0.0343	2.614	0.00912
Duration	-0.0848	0.0339	-2.503	0.0125

AIC = 1606.882

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	2.855	2.855	61.270	<0.0000
s(Month)	1.779	2.000	7.564	0.000242

c. Fish CTI (figure 1c,f)

Random Effects

~1|Location	0.536
~1|Location/Site	0.0675
Residual	0.285

LME	Estimate	Std Error	t-value	p-value
(Intercept)	15.987	0.150	106.442	<0.0000
Temperature	0.110	0.0151	7.303	<0.0000
SOI	-0.0232	0.0151	-1.534	0.125
sqrt(Urchin Abund)	0.0861	0.0189	4.548	<0.0000
Duration	0.0140	0.0202	0.693	0.489

AIC = 424.536

GAM	edf	Ref df	F-value	p-value
s(Year)	3.891	3.891	14.260	<0.0000

Table S5. Summary table for the trends in sea surface temperature across 1° bands of latitude on the eastern coast of Tasmania, southeast Australia (shown in figure S3). We fit a generalized additive model (GAM), implemented with the package *mgcv*[1] and the function "gam" in R[2]) for each band of latitude. This allows the seasonal change in temperature across months to be modeled as a cyclic cubic spline (i.e. the temperature in January is aligned with the temperature in December). Thus, in the first model, trends across years is modeled as a non-linear trend in temperature across years via smooth functions using penalized regression splines (coded as: SST ~ s(Month, bs = "cc") + s(Year)). In the second model, we were interested in describing the linear trend in temperature through time (coded as: SST ~ s(Month, bs = "cc") + Year) for each band of latitude. Estimated degrees of freedom = edf; Ref df = Referecne degree of freedom (prior to deductions); Standard Error = Std Error. "s" indicates fixed effects (Month and Year) modelled with a spline function.

a. -38.5°S

	edf	Ref df	F-value	p-value
s(Month)	6.514	8.000	443.058	<0.0000
s(Year)	3.907	3.995	9.257	<0.0000

R-sq.(adj) = 0.933
Deviance explained = 93.5%

	Estimate	Std Error	t-value	p-value
Year	0.0256	0.00593	4.328	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	6.439	8.000	415.900	<0.0000

R-sq.(adj) = 0.929
Deviance explained = 93.1%

b. -39.5°S

	edf	Ref df	F-value	p-value
s(Month)	6.424	8.000	398.300	<0.0000
s(Year)	3.910	3.995	9.000	<0.0000

R-sq.(adj) = 0.926
Deviance explained = 92.9%

	Estimate	Std Error	t-value	p-value
Year	0.0253	0.00602	4.197	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	6.351	8.000	373.900	<0.0000

R-sq.(adj) = 0.921
Deviance explained = 92.3%

c. -40.5°S

	edf	Ref df	F-value	p-value
s(Month)	6.367	8.000	344.980	<0.0000
s(Year)	3.976	4.000	10.420	<0.0000

R-sq.(adj) = 0.916
Deviance explained = 91.9%

	Estimate	Std Error	t-value	p-value
Year	0.0296	0.00626	4.732	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	6.253	8.000	324.100	<0.0000

R-sq.(adj) = 0.911
Deviance explained = 91.3%

d. -41.5°S

	edf	Ref df	F-value	p-value
s(Month)	6.229	8.000	285.140	<0.0000
s(Year)	3.891	3.993	13.790	<0.0000

R-sq.(adj) = 0.901
Deviance explained = 90.5%

	Estimate	Std Error	t-value	p-value
Year	0.0366	0.00616	5.948	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	6.163	8.000	268.600	<0.0000

R-sq.(adj) = 0.895
Deviance explained = 89.8%

e. -42.5°S

	edf	Ref df	F-value	p-value
s(Month)	5.983	8.000	181.710	<0.0000
s(Year)	3.876	3.990	18.650	<0.0000

R-sq.(adj) = 0.857
Deviance explained = 86.2%

	Estimate	Std Error	t-value	p-value
Year	0.0447	0.00640	6.916	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	5.903	8.000	167.200	<0.0000

R-sq.(adj) = 0.844
Deviance explained = 84.8%

f. -43.5°S

	edf	Ref df	F-value	p-value
s(Month)	5.896	8.000	148.100	<0.0000
s(Year)	3.891	3.995	21.500	<0.0000

R-sq.(adj) = 0.833
Deviance explained = 83.9%

	Estimate	Std Error	t-value	p-value
Year	0.0474	0.00672	7.0690	<0.0000
	edf	**Ref df**	**F-value**	**p-value**
s(Month)	5.803	8.000	133.800	<0.0000

R-sq.(adj) = 0.814
Deviance explained = 81.9%

Table S6. Summary table for the statistical test of the response of CTI over time in sites with and without increases in the abundance of the urchin, *Centrostephanus rodgersii* (figure S5). We fit a linear mixed effects model (LME) using maximum likelihood (ML) using the package *nlme*[3] and the function "lme" to test for a different CTI trend in sites with urchin abundances that increased through time, versus those where *Centrostephanus* abundance was low through time (as shown in figure S5). We included the random effect of site nested in location to account for spatial structuring of the data. Year was scaled prior to analysis. The reference (intercept) represents sites where urchins did not accumulate over the monitoring period. Standard deviation = Std Dev; Standard error = Std Error; Akaike information criterion = AIC.

Random Effects

~1| Location	0.467
~1| Location/Site	0.0349
Residual	0.303

	Estimate	**Std Error**	**t-value**	**p-value**
Intercept	15.839	0.143	110.139	<0.0000
Year	0.0921	0.0175	5.243	<0.0000
Urchin	0.0643	0.0427	1.505	0.158
Year*Urchin	0.0547	0.0266	2.055	0.0403

AIC = 318.037

Table S7. Summary table for statistical tests of response of richness and abundance for species grouped by thermal affinity (figure 2 in the main manuscript). We fit a generalized additive mixed model (GAMM), implemented with the package *mgcv*[1] and the function “gamm” in R[2]). We included the random effects of site nested in location to account for spatial structuring of the data. “s” indicates fixed effects (Year) modelled with penalized regression splines (GAM component) for the warm and cool component of the community, defined as species with a thermal distribution midpoint that was greater (warm) or lesser (cool) than 16.25°C (patterns were robust to this threshold). Estimated degrees of freedom = edf; Ref df = Referecne degree of freedom (prior to deductions); Standard error = Std Error; Akaike information criterion = AIC. Month was included and fitted as a bicubic term only when inclusion reduced the model AIC score. We ran models with different distribution families (poisson and quasipoisson) and transformed response data to ensure patterns were consistent.

a. Trends in Warm and Cool Affinity Macroalgal Genera (figure 2a)

Random Effects

~1|Location	0.0732
~1|Location/Site	0.190
Residual	0.809

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	1.301	0.0381	34.103	<0.0000

AIC = 1740.179

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Cool Genera	1.807	1.807	2.862	0.11877
s(Year):Warm Genera	1.695	1.695	9.951	0.00267

b. Trends in Warm and Cool Affinity Invertebrate Richness (figure 2b)

Random Effects

~1|Location	0.247
~1|Location/Site	0.0611
Residual	0.625

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	1.318	0.0704	18.730	<0.0000

AIC = 879.590

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Cool Genera	1.948	1.948	9.080	0.000191
s(Year):Warm Genera	1	1	12.860	0.000347

c. Trends in Warm and Cool Affinity Fish Richness (figure 2c)

Random Effects

~1|Location	0.209
~1|Location/Site	0.141
Residual	1.457

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	1.974	0.0654	30.190	<0.0000

AIC = 2676.137

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Cool Genera	2.682	2.682	3.572	0.027
s(Year):Warm Genera	2.908	2.908	33.297	<0.0000

d. Trends in Warm and Cool Affinity Macroalgal Abundance (figure 2d)

Random Effects

~1|Location 2.439
~1|Location/Site 1.905
Residual 9.521

LME	Estimate	Std Error	t-value	p-value
(Intercept)	17.823	0.815	21.860	<0.0000

AIC = 11183.210

GAM	edf	Ref df	F-value	p-value
s(Year):Cool Genera	1	1	20.59	<0.0000
s(Year):Warm Genera	2.967	2.967	28.05	<0.0000

*see R-script

e. Trends in Warm and Cool Affinity Invertebrate Abundance (figure 2e)

Random Effects

~1|Location 0.781
~1|Location/Site 1.301
Residual 2.618

LME	Estimate	Std Error	t-value	p-value
(Intercept)	5.717	0.315	18.170	<0.0000

AIC = 6772.384

GAM	edf	Ref df	F-value	p-value
s(Year):Cool Genera	1.621	1.621	3.420	0.0232
s(Year):Warm Genera	1	1	10.990	0.000940

f. Trends in Warm and Cool Affinity Fish Abundance (figure 2f)

Random Effects

~1|Location 6.923
~1|Location/Site 3.420
Residual 10.307

LME	Estimate	Std Error	t-value	p-value
(Intercept)	14.610	2.041	7.157	<0.0000

AIC = 12510.67

GAM	edf	Ref df	F-value	p-value
s(Year):Cool Genera	2.968	2.968	28.400	<0.0000
s(Year):Warm Genera	1	1	21.660	<0.0000

Table S8. Summary table for statistical tests of response of total richness and abundance across the macroalgal, invertebrate and fish communities (figure S6). We fit a generalized additive mixed model (GAMM), implemented with the package *mgcv*[1] and the function “gamm” in R[2]). We included the random effects of site nested in location to account for spatial structuring of the data. “s” indicates fixed effects (Year and Month) modelled with a spline function (GAM component) for the entire community. Seasonal change in temperature across months was modeled as a cyclic cubic spline and is included when significant. Estimated degrees of freedom = edf; Ref df = Referecne degree of freedom (prior to deductions); Standard error = Std Error; Akaike information criterion = AIC.

a. Trends in the Richness of Macroalgal Genera (figure S6a)

Random Effects

~1|Location	0.256
~1|Location/Site	0.352
Residual	0.640

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	1.285	0.0489	26.290	<0.0000

AIC = 80.865

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	1	1	13.529	<0.0000
s(Month)	1.934	8	0.736	0.0299

b. Trends in Invertebrate Richness (figure S6a)

Random Effects

~1|Location	0.232
~1|Location/Site	0.155
Residual	0.650

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	1.539	0.0712	21.610	<0.0000

AIC = 476.603

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	2.5124	2.512	17.485	<0.0000

c. Trends in Fish Richness (figure S6a)

Random Effects

~1|Location	0.285
~1|Location/Site	0.177
Residual	0.864

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	2.626	0.0858	30.610	<0.0000

AIC = 43.978

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	1	1	11.390	<0.0000
s(Month)	4.696	8	25.560	<0.0000

d. Trends in Macroalgal Abundance (figure S6b)

Random Effects

~1|Location	1.052
~1|Location/Site	1.069
Residual	0.808

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	3.729	0.349	10.690	<0.0000

AIC = 1960.551

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	2.919	2.919	16.420	<0.0000

e. Trends in Invertebrate Abundance (figure S6b)

Random Effects

~1|Location	0.333
~1|Location/Site	0.596
Residual	0.631

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	3.365	0.136	24.650	<0.0000

AIC = 1731.863

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year)	1	1	13.180	0.0003

f. Trends in Fish Abundance (figure S6b)

Random Effects

~1|Location	1.050
~1|Location/Site	0.529
Residual	0.756

LME	Estimate	Std Error	t-value	p-value
(Intercept)	5.744	0.308	18.630	<0.0000

AIC = 2105.961

GAM	edf	Ref df	F-value	p-value
s(Year)	2.957	2.957	32.51	<0.0000
s(Month)	4.333	8	19.09	<0.0000

Table S9. Summary table for statistical tests of response of functional group abundance (figure 3). We fit a generalized additive mixed model (GAMM), implemented with the package *mgcv*[1] and the function “gamm” in R[2]). We included the random effects of site nested in location to account for spatial structuring of the data. “s” indicates fixed effects (Year) modelled with penalized regression splines (GAM component) for locations open versus protected from exploitation. Estimated degrees of freedom = edf; Ref df = Reference degree of freedom (prior to deductions); Standard error = Std Error; Akaike information criterion = AIC. We ran models with different distribution families (poisson and quasipoisson) and transformed response data to ensure patterns were consistent; results are for family=quasipoisson with a log link.

a. Trends in the Surface Canopy in Locations Open and Protected from Exploitation (figure 3a)

Random Effects

~1|Location/Site	0.160
~1|Site	0.621
Residual	3.410

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	2.825	0.235	12.027	<0.0000

AIC = 251.794

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Open	3.721	3.721	3.822	0.00817
s(Year):Protected	2.871	2.871	4.867	0.00233

b. Trends in the Blade Canopy in Locations Open and Protected from Exploitation (figure 3b)

Random Effects

~1|Location/Site	0.256
~1|Site	0.642
Residual	6.726

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	6.127	0.125	49.120	<0.0000

AIC = 586.757

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Open	1	1	0.285	0.594
s(Year):Protected	1	1	23.598	<0.0000

c. Trends in the Foliose Canopy in Locations Open and Protected from Exploitation (figure 3c)

Random Effects

~1|Location	0.968
~1|Location/Site	0.655
Residual	6.524

LME	**Estimate**	**Std Error**	**t-value**	**p-value**
(Intercept)	4.408	0.308	14.320	<0.0000

AIC = 1424.005

GAM	**edf**	**Ref df**	**F-value**	**p-value**
s(Year):Open	2.920	2.920	9.659	<0.0000
s(Year):Protected	2.983	2.983	55.358	<0.0000

d. Trends in the Small Foliose Understory in Locations Open and Protected from Exploitation (figure 3d)

Random Effects

~1|Location	0.830
~1|Location/Site	0.648
Residual	4.441

LME	Estimate	Std Error	t-value	p-value
(Intercept)	3.597	0.261	13.770	<0.0000

AIC = 1507.734

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.600	1.600	25.564	<0.0000
s(Year):Protected	1	1	2.764	0.0968

e. Trends in the Herbivorous Invertebrates in Locations Open and Protected from Exploitation (figure 3e)

Random Effects

~1|Site	0.837
Residual	5.371

LME	Estimate	Std Error	t-value	p-value
(Intercept)	3.025	0.133	22.712	<0.0000

AIC = 2509.688

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.594	1.594	2.969	0.0359
s(Year):Protected	1	1	16.829	<0.0000

f. Trends in the Suspension Feeding Invertebrates in Locations Open and Protected from Exploitation (figure 3f)

Random Effects

~1|Location	0.519
~1|Location/Site	0.632
Residual	3.380

LME	Estimate	Std Error	t-value	p-value
(Intercept)	-1.8574	0.464	-4.007	0.00852

AIC = 15938.840

GAM	edf	Ref df	F-value	p-value
s(Year):Open	2.882	2.882	21.950	<0.0000
s(Year):Protected	2.663	2.663	25.300	<0.0000

g. Trends in the Omnivorous Invertebrates in Locations Open and Protected from Exploitation (figure 3g)

Random Effects

~1|Location/Site	0.186
~1|Site	0.343
Residual	1.318

LME	Estimate	Std Error	t-value	p-value
(Intercept)	0.904	0.104	8.663	<0.0000

AIC = 887.432

GAM	edf	Ref df	F-value	p-value

s(Year):Open	1	1	3.059	0.0812
s(Year):Protected	1	1	7.468	0.00659

h. Trends in the Carnivorous Invertebrates (Benthic Invertivores) in Locations Open and Protected from Exploitation (figure 3h)

Random Effects

~1|Location/Site	0.479
~1|Site	0.540
Residual	3.727

LME	Estimate	Std Error	t-value	p-value
(Intercept)	2.353	0.170	13.835	<0.0000

AIC = 2638.242

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.000	1.000	2.061	0.151
s(Year):Protected	1.471	1.471	27.420	<0.0000

i. Trends in the Herbivorous Fishes in Locations Open and Protected from Exploitation (figure 3i)

Random Effects

~1|Site	0.637
~1|Location/Site	0.405
Residual	7.232

LME	Estimate	Std Error	t-value	p-value
(Intercept)	3.496	0.201	17.350	<0.0000

AIC = 2650.958

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.812	1.812	1.758	0.129
s(Year):Protected	1.872	1.872	6.299	0.014

j. Trends in the Planktivorous Fishes in Locations Open and Protected from Exploitation (figure 3j)

Random Effects

~1|Location	1.353
~1|Location/Site	0.596
Residual	22.381

LME	Estimate	Std Error	t-value	p-value
(Intercept)	5.506	0.404	13.620	<0.0000

AIC = 2392.695

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.966	1.966	14.64	<0.0000
s(Year):Protected	1.956	1.956	10.62	<0.0000

k. Trends in the Carnivorous Fishes (Benthic Invertivores) in Locations Open and Protected from Exploitation (figure 3k)

Random Effects

~1|Location	0.486
~1|Location/Site	0.399
Residual	6.482

LME	Estimate	Std Error	t-value	p-value
(Intercept)	4.542	0.155	29.320	<0.0000

AIC = 1781.795

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.898	1.898	22.920	<0.0000
s(Year):Protected	1.000	1.000	16.190	<0.0000

I. Trends in the Higher Carnivorous Fishes in Locations Open and Protected from Exploitation (figure 3I)

Random Effects

~1|Location	0.471
~1|Location/Site	0.949
Residual	15.584

LME	Estimate	Std Error	t-value	p-value
(Intercept)	3.423	0.241	14.220	<0.0000

AIC = 3057.355

GAM	edf	Ref df	F-value	p-value
s(Year):Open	1.867	1.867	2.827	0.0497
s(Year):Protected	1.000	1.000	20.337	<0.0000

References

1. Wood, S.N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *J. Roy. Statist. Soc. (B)* 73, 3-36.
2. R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.
3. Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D. & R Core Team (2015). nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-120. http://CRAN.R-project.org/package=nlme.