

Indications of hysteresis and early warning signals of reduced community resilience during a Bering Sea cold anomaly

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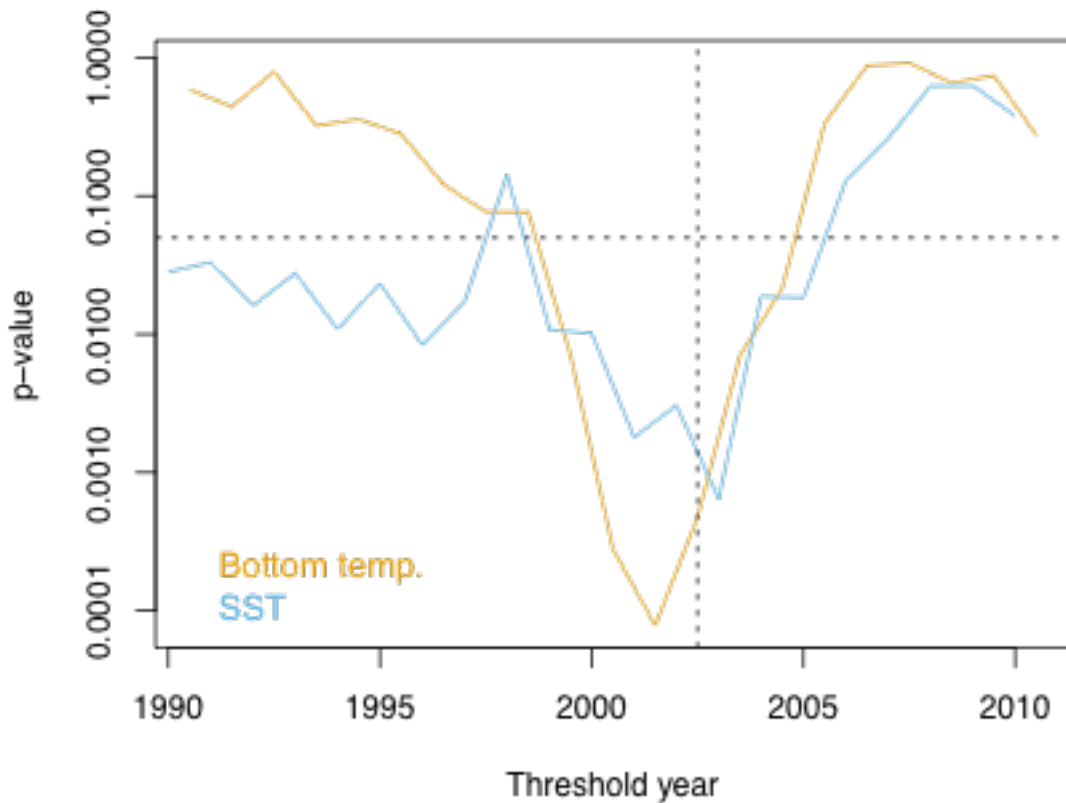


Fig. S1. Possible choices of the threshold between “warming” and “cooling” eras in Bering Sea summer bottom temperature and winter SST. Each line plots the p -value from an interactive model testing for different slopes between possible warming and cooling periods separated at every possible threshold year from 1990/91 to 2010/11. Dashed horizontal line indicates $p = 0.05$, dashed vertical line indicates the threshold year that was selected *a priori* for analysis (2002/03). Note that 2002/03 provides the strongest definition of distinct warming and cooling periods across the two time series.

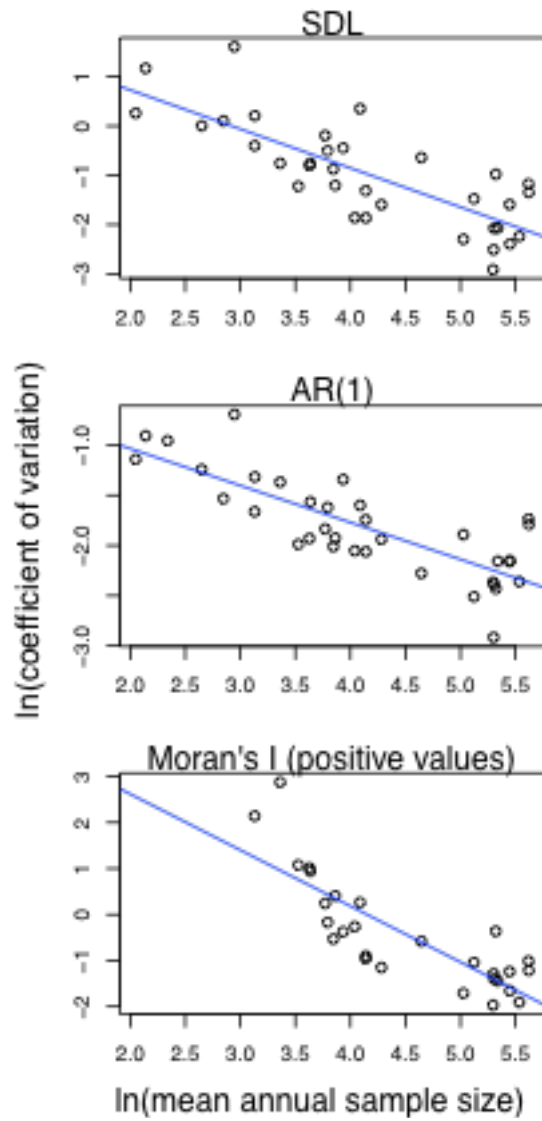


Fig. S2. Relationship between sample size (average number of positive stations per year) and variability (coefficient of variation) in three early warning signals for 35 well-sampled taxa in the Bering Sea trawl survey.

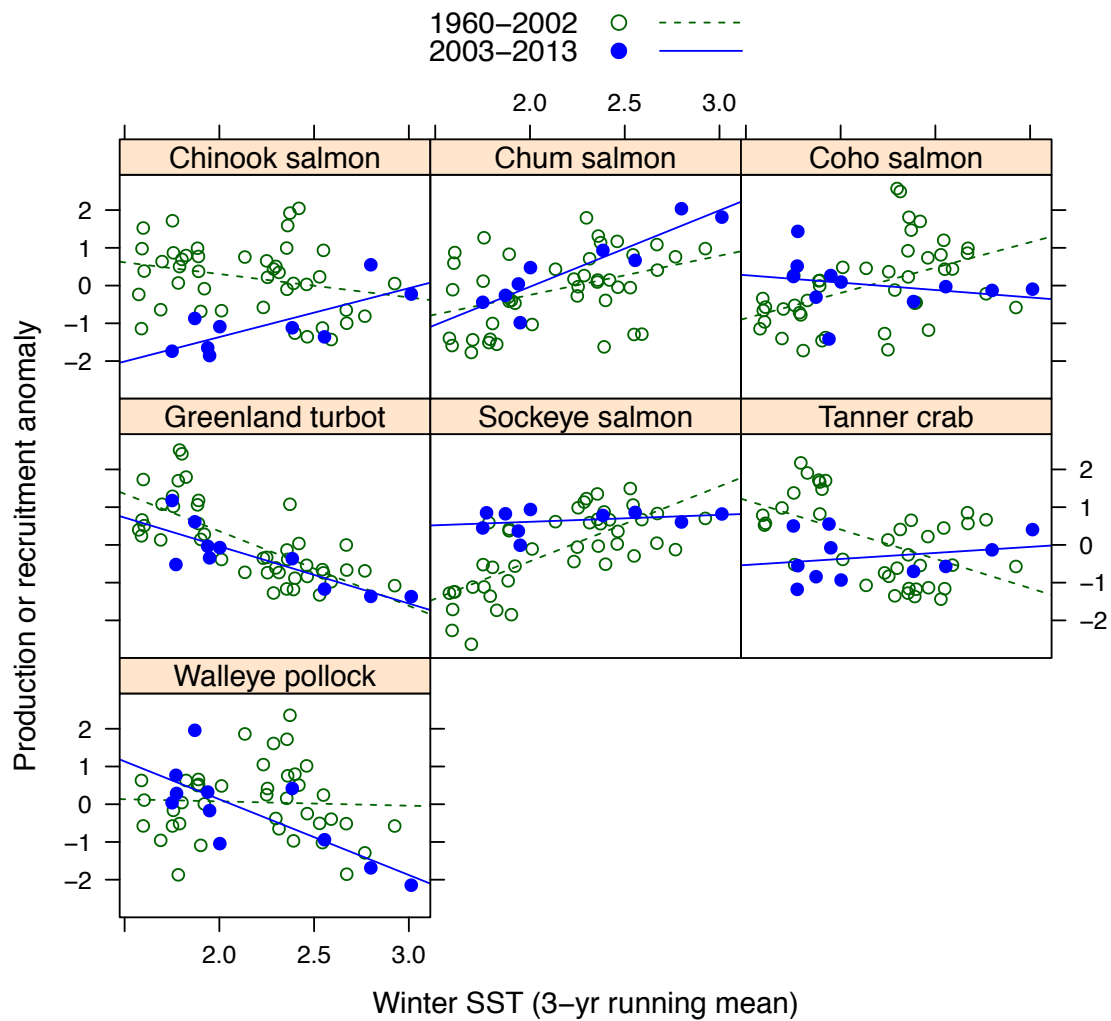


Fig. S3. Changing relationships for recruitment or production anomalies compared with winter SST for individual taxa.

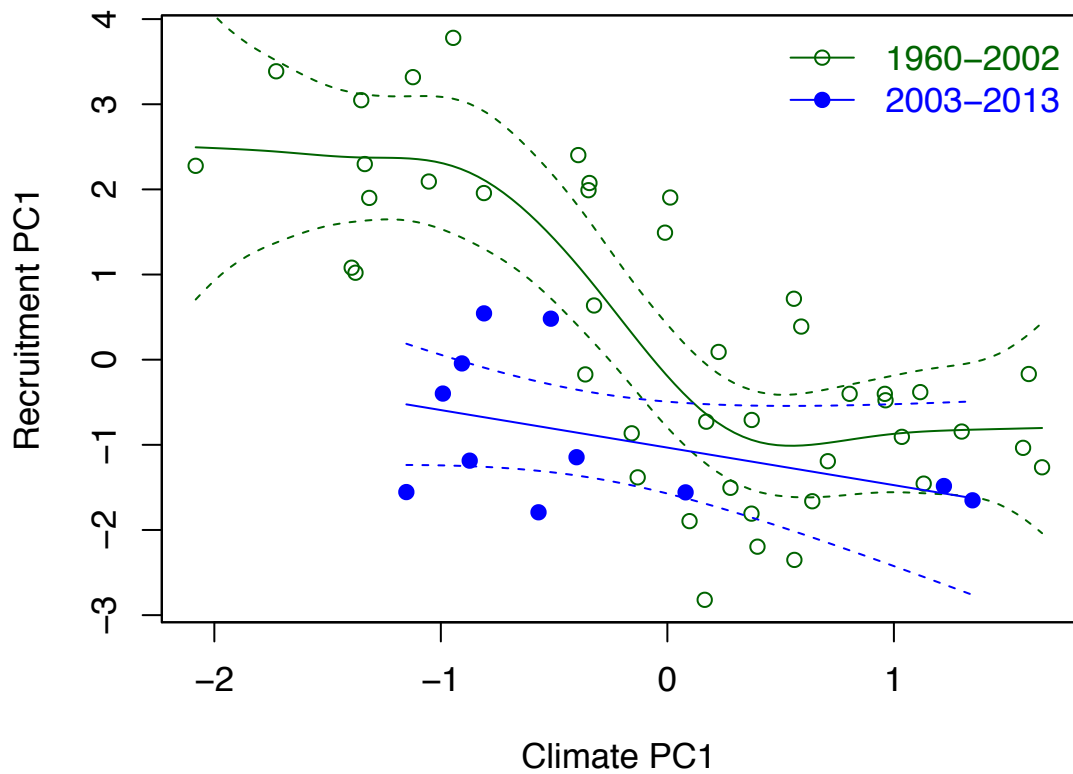


Fig. S4. Indications of hysteresis in response of community recruitment patterns to the first PC of winter SST, winter U- and V-wind speed, and winter and summer Kuskokwim River input. Plot shows change in the leading axis of recruitment/production variability for ten taxa (recruitment PC1 score) during warming period (1960-2002, green) and subsequent cooling period (2003-13, blue). Dashed lines indicate 95% CI around regressions. The plotted TGAM was superior to a non-hysteresis model of recruitment PC1-climate PC1 relationships ($\Delta AIC_c = 18.5$).

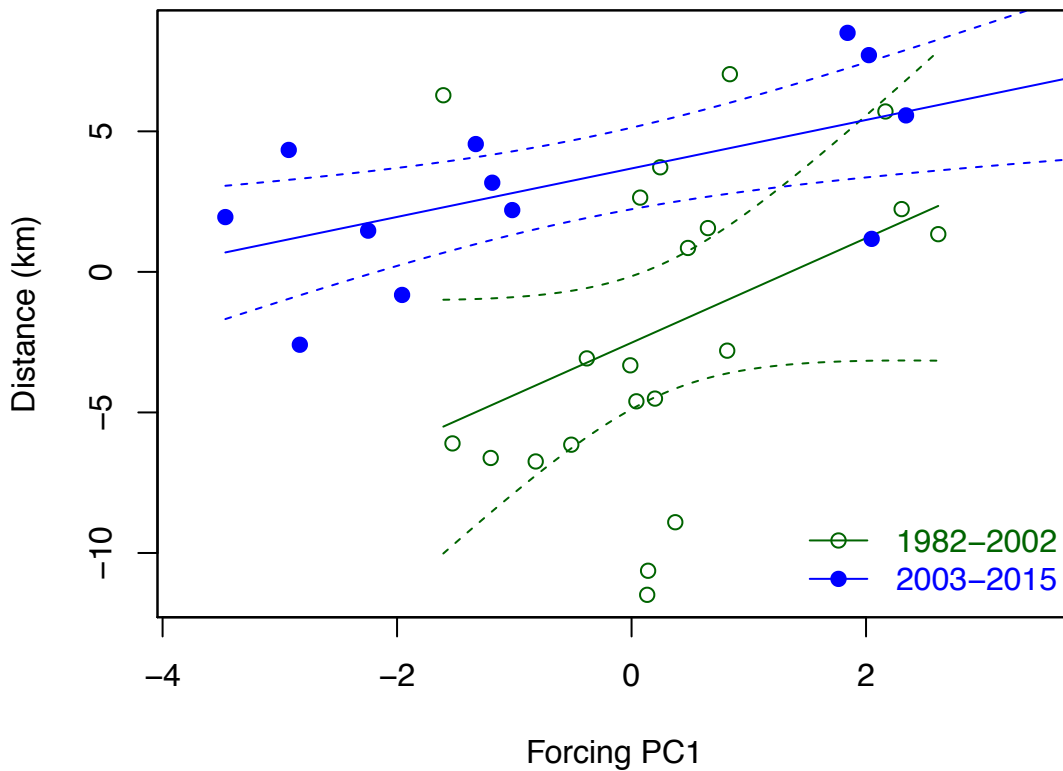


Fig. S5. Test for hysteresis in response of community distribution to PC1 of a broad set of climate and commercial fishing parameters (summer bottom temperature, winter SST, winter ice extent, winter U- and V-wind speed, winter and summer Kuskokwim River discharge, the sum of commercial catch for the species under consideration, and the first PC for distribution of the commercial catch among species). This model was inferior to the simpler model invoking only summer bottom temperature ($\Delta\text{-AIC}_c = 26.9$). Plotted values are the change in the average center of distribution (distance from mean latitude, averaged across twelve taxa) during warming period (1982-2002, green open circles) and subsequent cooling period (2003-15, blue filled circles). Dashed lines indicate 95% CI around regressions.

Table S1. Spatial variability (standard deviation of log-transformed CPUE) by taxon.

Year	<i>Atheresthes</i> spp.	<i>Chionoecetes</i> <i>bairdi</i>	<i>C.</i> <i>opilio</i>	<i>Gadus</i> <i>chalcogrammus</i>	<i>G.</i> <i>macrocephalus</i>	<i>Hippoglossoides</i> <i>elassodon</i>	<i>Hippoglossus</i> <i>stenolepis</i>	<i>Lepidopsetta</i> spp.	<i>Limanda</i> <i>aspera</i>	<i>Pleuronectes</i> <i>quadrituberculatus</i>	<i>Podothecus</i> <i>accipenserinus</i>	Rajidae
1982	1.952	1.891	2.153	2.206	1.346	1.474	1.150	2.325	2.086	1.591	1.731	1.556
1983	1.870	1.870	2.047	2.105	1.280	1.539	1.158	2.147	1.876	1.659	1.614	1.373
1984	1.927	1.943	1.926	2.459	1.516	1.637	1.212	2.236	1.997	1.616	1.647	1.223
1985	1.608	1.826	1.776	2.270	1.133	1.674	1.302	2.117	2.143	1.665	1.287	1.163
1986	2.289	1.592	1.704	2.219	1.511	1.665	1.113	2.092	2.011	1.609	1.225	1.208
1987	1.692	1.751	2.353	1.988	1.062	1.522	1.125	1.806	1.799	1.595	1.386	1.137
1988	1.993	1.785	2.311	2.169	1.454	1.764	1.315	1.865	1.840	1.706	1.564	1.267
1989	1.849	1.962	2.395	2.064	1.495	1.621	1.507	1.718	1.675	1.695	1.524	1.413
1990	1.929	1.862	2.424	2.203	1.976	1.480	1.076	1.876	2.088	1.505	1.585	1.284
1991	2.318	1.719	2.182	1.928	1.813	1.421	1.219	1.984	1.717	1.642	1.708	1.399
1992	1.889	1.689	2.120	1.961	1.656	1.618	1.334	1.978	1.959	1.690	1.644	1.362
1993	1.595	1.557	2.198	1.795	1.341	1.402	1.248	2.076	1.852	1.534	1.768	1.209
1994	1.651	1.723	2.113	2.104	1.679	1.631	1.082	2.350	2.037	1.697	1.507	1.221
1995	1.856	1.700	2.327	2.353	1.652	1.590	1.177	2.279	2.111	1.700	1.395	1.289
1996	1.555	1.658	2.226	2.203	1.171	1.587	1.137	1.841	1.810	1.636	1.399	1.064
1997	2.055	1.611	2.019	2.046	1.404	1.488	1.077	1.922	1.792	1.681	1.412	1.282
1998	1.617	1.479	1.732	1.982	1.210	1.441	1.239	1.864	1.834	1.651	1.334	1.279
1999	2.103	1.769	1.486	2.304	2.142	1.743	1.368	1.977	1.784	1.562	1.684	1.312
2000	1.782	1.741	1.608	2.071	1.321	1.484	1.177	1.877	1.786	1.559	1.466	1.141
2001	1.998	1.774	1.776	1.720	1.198	1.740	1.049	2.033	1.711	1.557	1.531	1.203
2002	1.780	1.656	1.715	2.176	1.422	1.636	1.251	2.013	1.806	1.494	1.530	1.340
2003	1.848	1.870	1.802	2.276	1.227	1.588	1.165	2.021	1.849	1.630	1.593	1.027
2004	2.059	1.711	2.112	1.850	1.394	1.770	1.442	2.028	1.813	1.627	1.670	0.884
2005	1.448	1.713	2.278	2.100	1.262	1.844	1.188	1.941	1.782	1.625	1.516	0.980
2006	2.008	1.617	2.068	2.441	1.614	1.822	1.196	2.108	1.828	1.559	1.572	1.021
2007	2.424	1.516	1.974	2.957	1.509	1.875	1.159	2.253	1.828	1.619	1.604	1.075
2008	2.058	1.613	1.951	2.885	1.640	1.653	1.147	2.136	1.905	1.604	1.486	1.259
2009	0.635	0.649	0.706	0.668	0.537	0.596	0.179	0.799	0.853	0.780	0.664	0.416
2010	0.678	0.677	0.711	0.665	0.263	0.685	0.187	0.789	0.823	0.719	0.679	0.381
2011	0.686	0.656	0.743	0.540	0.275	0.627	0.472	0.775	0.844	0.751	0.569	0.420
2012	0.613	0.710	0.698	0.612	0.388	0.653	0.416	0.815	0.799	0.735	0.587	0.460
2013	0.612	0.796	0.719	0.586	0.507	0.634	0.340	0.838	0.849	0.699	0.612	0.388
2014	0.581	0.732	0.635	0.580	0.281	0.562	0.433	0.829	0.861	0.710	0.522	0.362
2015	0.680	0.591	0.491	0.366	0.432	0.609	0.332	0.836	0.820	0.690	0.469	0.412

Table S2. Year-to-year temporal autocorrelation in CPUE by taxon. See *Methods* for calculation details.

Year	<i>Atheresthes</i> spp.	<i>Chionoecetes</i> <i>bairdi</i>	<i>C.</i> <i>opilio</i>	<i>Gadus</i> <i>chalcogrammus</i>	<i>G.</i> <i>macrocephalus</i>	<i>Hippoglossoides</i> <i>elassodon</i>	<i>Hippoglossus</i> <i>stenolepis</i>	<i>Lepidopsetta</i> spp.	<i>Limanda</i> <i>aspera</i>	<i>Pleuronectes</i> <i>quadrituberculatus</i>	<i>Podothecus</i> <i>accipenserinus</i>	Rajidae
1982	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1983	0.584	0.644	0.381	0.308	0.316	0.551	0.247	0.830	0.752	0.675	0.140	0.287
1984	0.610	0.637	0.714	0.403	0.275	0.704	0.307	0.819	0.795	0.716	0.271	0.405
1985	0.571	0.593	0.680	0.444	0.174	0.748	0.353	0.809	0.798	0.734	0.367	0.381
1986	0.643	0.475	0.574	0.482	0.319	0.739	0.346	0.823	0.778	0.722	0.309	0.380
1987	0.606	0.435	0.646	0.341	0.322	0.798	0.264	0.735	0.772	0.668	0.477	0.306
1988	0.687	0.560	0.681	0.490	0.256	0.693	0.255	0.764	0.785	0.641	0.422	0.376
1989	0.518	0.613	0.717	0.512	0.221	0.677	0.257	0.729	0.764	0.728	0.592	0.467
1990	0.592	0.711	0.752	0.482	0.359	0.696	0.116	0.677	0.678	0.612	0.474	0.316
1991	0.732	0.581	0.722	0.631	0.515	0.690	0.234	0.777	0.812	0.576	0.588	0.475
1992	0.636	0.675	0.683	0.596	0.372	0.660	0.441	0.743	0.759	0.612	0.527	0.379
1993	0.588	0.499	0.702	0.429	0.456	0.684	0.234	0.690	0.764	0.708	0.540	0.129
1994	0.496	0.731	0.624	0.359	0.334	0.776	0.224	0.785	0.845	0.702	0.508	0.257
1995	0.571	0.732	0.654	0.569	0.504	0.758	0.233	0.838	0.843	0.713	0.611	0.381
1996	0.629	0.669	0.764	0.367	0.344	0.685	0.183	0.732	0.815	0.619	0.553	0.354
1997	0.651	0.654	0.753	0.552	0.407	0.765	0.207	0.830	0.845	0.629	0.493	0.365
1998	0.761	0.614	0.649	0.383	0.263	0.737	0.247	0.833	0.808	0.784	0.658	0.391
1999	0.593	0.615	0.680	0.180	0.080	0.676	0.070	0.551	0.790	0.620	0.521	0.236
2000	0.659	0.541	0.526	0.278	0.297	0.597	0.159	0.491	0.765	0.682	0.444	0.330
2001	0.696	0.519	0.546	0.383	0.431	0.627	0.267	0.834	0.862	0.694	0.525	0.370
2002	0.740	0.601	0.616	0.407	0.278	0.694	0.113	0.852	0.810	0.611	0.662	0.391
2003	0.710	0.629	0.588	0.541	0.376	0.642	0.246	0.827	0.768	0.659	0.412	0.282
2004	0.642	0.589	0.711	0.604	0.472	0.706	0.262	0.861	0.841	0.691	0.590	0.358
2005	0.762	0.626	0.657	0.519	0.417	0.762	0.185	0.880	0.841	0.748	0.561	0.394
2006	0.595	0.659	0.604	0.590	0.548	0.645	0.173	0.786	0.817	0.744	0.585	0.361
2007	0.703	0.706	0.713	0.661	0.524	0.762	0.231	0.844	0.897	0.781	0.565	0.537
2008	0.647	0.678	0.712	0.697	0.360	0.712	0.399	0.849	0.868	0.788	0.612	0.375
2009	0.635	0.649	0.706	0.668	0.537	0.596	0.179	0.799	0.853	0.780	0.664	0.416
2010	0.678	0.677	0.711	0.665	0.263	0.685	0.187	0.789	0.823	0.719	0.679	0.381
2011	0.686	0.656	0.743	0.540	0.275	0.627	0.472	0.775	0.844	0.751	0.569	0.420
2012	0.613	0.710	0.698	0.612	0.388	0.653	0.416	0.815	0.799	0.735	0.587	0.460
2013	0.612	0.796	0.719	0.586	0.507	0.634	0.340	0.838	0.849	0.699	0.612	0.388
2014	0.581	0.732	0.635	0.580	0.281	0.562	0.433	0.829	0.861	0.710	0.522	0.362
2015	0.680	0.591	0.491	0.366	0.432	0.609	0.332	0.836	0.820	0.690	0.469	0.412

Table S3. Spatial correlation (Moran's I) of CPUE by taxon.

Year	<i>Atheresthes</i> spp.	<i>Chionoecetes</i> <i>bairdi</i>	<i>C.</i> <i>opilio</i>	<i>Gadus</i> <i>chalcogrammus</i>	<i>G.</i> <i>macrocephalus</i>	<i>Hippoglossoides</i> <i>elassodon</i>	<i>Hippoglossus</i> <i>stenolepis</i>	<i>Lepidopsetta</i> spp.	<i>Limanda</i> <i>aspera</i>	<i>Pleuronectes</i> <i>quadrituberculatus</i>	<i>Podothecus</i> <i>accipenserinus</i>	Rajidae
1982	0.118	0.101	0.112	0.114	0.080	0.146	0.056	0.247	0.226	0.148	0.202	0.038
1983	0.098	0.066	0.144	0.082	0.062	0.127	0.067	0.217	0.184	0.090	0.102	0.039
1984	0.112	0.093	0.149	0.113	0.059	0.139	0.071	0.244	0.193	0.111	0.119	0.057
1985	0.094	0.076	0.186	0.105	0.037	0.162	0.051	0.223	0.207	0.081	0.029	0.053
1986	0.131	0.099	0.111	0.098	0.099	0.143	0.035	0.243	0.243	0.098	0.031	0.069
1987	0.115	0.077	0.221	0.086	0.022	0.139	0.053	0.216	0.211	0.082	0.046	0.055
1988	0.129	0.100	0.176	0.114	0.052	0.116	0.011	0.225	0.245	0.074	0.114	0.067
1989	0.111	0.155	0.164	0.137	0.081	0.116	0.050	0.199	0.184	0.064	0.084	0.049
1990	0.141	0.131	0.166	0.160	0.107	0.095	-0.003	0.190	0.236	0.062	0.082	0.089
1991	0.165	0.084	0.182	0.137	0.056	0.127	0.059	0.212	0.202	0.073	0.092	0.064
1992	0.155	0.099	0.141	0.115	0.068	0.120	0.075	0.210	0.206	0.064	0.086	0.056
1993	0.122	0.144	0.158	0.079	0.024	0.126	0.025	0.214	0.194	0.061	0.083	0.088
1994	0.102	0.131	0.135	0.074	0.086	0.130	0.033	0.224	0.272	0.080	0.133	0.050
1995	0.111	0.112	0.192	0.068	0.059	0.108	0.025	0.174	0.247	0.079	0.057	0.066
1996	0.098	0.120	0.169	0.065	0.061	0.112	0.028	0.171	0.171	0.060	0.087	0.075
1997	0.130	0.140	0.141	0.060	0.066	0.107	0.029	0.172	0.222	0.055	0.096	0.063
1998	0.110	0.123	0.156	0.070	0.035	0.127	0.040	0.170	0.225	0.059	0.094	0.038
1999	0.103	0.123	0.104	0.103	0.099	0.102	0.028	0.133	0.238	0.082	0.155	0.029
2000	0.114	0.157	0.145	0.054	0.044	0.086	0.010	0.188	0.221	0.060	0.120	0.061
2001	0.125	0.171	0.128	0.091	0.027	0.107	0.032	0.184	0.170	0.065	0.104	0.047
2002	0.139	0.159	0.116	0.104	0.066	0.106	0.006	0.184	0.227	0.047	0.089	0.098
2003	0.129	0.163	0.146	0.106	0.072	0.101	0.003	0.209	0.171	0.059	0.072	0.037
2004	0.120	0.121	0.145	0.091	0.079	0.097	0.021	0.228	0.204	0.106	0.105	0.083
2005	0.140	0.116	0.159	0.128	0.077	0.107	0.015	0.205	0.180	0.101	0.083	0.054
2006	0.116	0.152	0.194	0.126	0.130	0.104	0.039	0.211	0.234	0.087	0.102	0.068
2007	0.134	0.135	0.198	0.127	0.075	0.101	0.069	0.203	0.222	0.120	0.088	0.098
2008	0.095	0.176	0.184	0.138	0.097	0.090	0.091	0.241	0.263	0.111	0.106	0.064
2009	0.162	0.159	0.152	0.138	0.089	0.113	0.086	0.262	0.245	0.120	0.083	0.058
2010	0.145	0.148	0.158	0.131	0.048	0.072	0.076	0.235	0.281	0.087	0.080	0.050
2011	0.149	0.149	0.197	0.164	0.049	0.096	0.135	0.277	0.247	0.092	0.129	0.049
2012	0.088	0.181	0.149	0.138	0.057	0.087	0.121	0.279	0.242	0.107	0.126	0.058
2013	0.087	0.175	0.096	0.203	0.068	0.088	0.072	0.212	0.289	0.087	0.045	0.041
2014	0.126	0.160	0.068	0.134	0.068	0.081	0.056	0.224	0.223	0.059	0.102	0.051
2015	0.174	0.176	0.070	0.140	0.093	0.080	0.019	0.246	0.213	0.088	0.115	0.073