Spatial and temporal trends in the abundance and distribution of jellyfish in the eastern Bering Sea during late summer, 2002-2016

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Description of index: Pelagic jellyfish were sampled using a trawl net towed in the upper 20 m of the eastern Bering Sea during the Alaska Fisheries Science Centers' Bering Arctic Subarctic Integrated Surveys (BASIS) during late summer, 2004-2016. Stations were approximately 30 nautical miles apart and a trawl was towed for approximately 30 minutes. Area swept was estimated from horizontal net opening and distance towed.

Jellyfish catch was estimated in kilograms. Surveys were not conducted in the south (<60 °N) during 2013 and 2015 and north (≥60 °N) during 2008 but jellyfish densities in these areas were estimated using geostatistical modeling methods (Thorson et al. 2015). All jellyfish medusae caught in the surface trawl (top 18-20 m of the water column) are sorted by species and subsampled for bell diameter and wet weight. Six species are commonly caught with the surface trawl: *Aequorea sp., Chrysaora melanaster, Cyanea capillata, Aurelia labiata, Phacellocephora camtschatica,* and *Staurophora mertensi*. Biomass is calculated for each species and compared across species, and oceanographic domains on the Bering Sea shelf.

Abundance and distribution (center of gravity and area occupied) were estimated for each jellyfish species using the VAST package for multispecies version 1.1.0 (Thorson 2015; Thorson et al. 2016a, b, c) in RStudio version 0.99.896 and R software version 3.3.0 (R Core Team 2016). The abundance index is a standardized geostatistical index developed by Thorson et al. (2015, 2016a, 2016b, 2016c) to estimate indices of abundance for stock assessments. We specified a gamma distribution and estimated spatial and spatio-temporal variation for both encounter probability and positive catch rate components at a spatial resolution of 50 knots. Parameter estimates were within the upper and lower bounds.

Status and trends: Temporal trends in the estimated abundance of jellyfish indicated an increase in the productivity of smaller sized jellyfish (Aequorea, Aurelia, Cyanea) and a decrease in the larger jellyfish (Chrysaora) in the eastern Bering Sea during 2016 (Figure 1, Table 1). Starting in 2014, notable increased in jellyfish species composition were observed for all taxa except *C. melanaster* and continued through 2016 (Figure 1). The larger jellyfish was typically more abundant during the 2007-2013 cold stanza, while the smaller sized species were more abundant during the 2004-2006 and 2014-2016 warm stanzas (Figure 1), with the except of the 2014 warm year. In 2016, Aurelia exceeded the typically most abundant Chrysaora (Figure 1, Table 1). Several anecdotal reports of large die offs of Aurelia were observed in the southeastern Bering in early August of 2015, no reports had been received in prior years to indicate similar conditions.

Distribution of jellyfish varied among species and years (Figure 2-7). Yearly distributions throughout the sample grid for all species have been patchy and highly variable. Despite uneven distributions throughout oceanographic domains, highest concentrations of all species were found to occur in the Middle Domain. Center of gravity plots indicate no warm and cold year trend in the distribution of jellyfish (Figure 8). Area occupied was higher for all species during 2016 than the long-term average (Figure 9), except for Aurelia. Aequorea and Aurelia were the only species with a trend of an expanded distribution during warm years and contracted distribution during cold years, with the exception of 2016 for Aurelia (Figure 9).

Factors causing trends: Shifts in abundance of single large sized jellyfish in cold years to multiple smaller sized species in warm years indicate that there could possibly be a shift to multiple taxa present in the future during warm stanzas. The cause for the shifts in biomass and distribution do not seem to rely solely on physical ocean factors (temperature and salinity). These shifts could also be a result of environmental forcing earlier in the growing season or during an earlier life history stage (polyp), which may influence large medusae biomasses and abundances (Purcell et al., 2009).

Implications:
Significant increases in jellyfish biomass may redirect energy pathways in the eastern Bering Sea food web through jellyfish predation on zooplankton and larval fish, and could result in limiting carbon transfer to higher trophic levels (Condon et al., 2011).

Citations:
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R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

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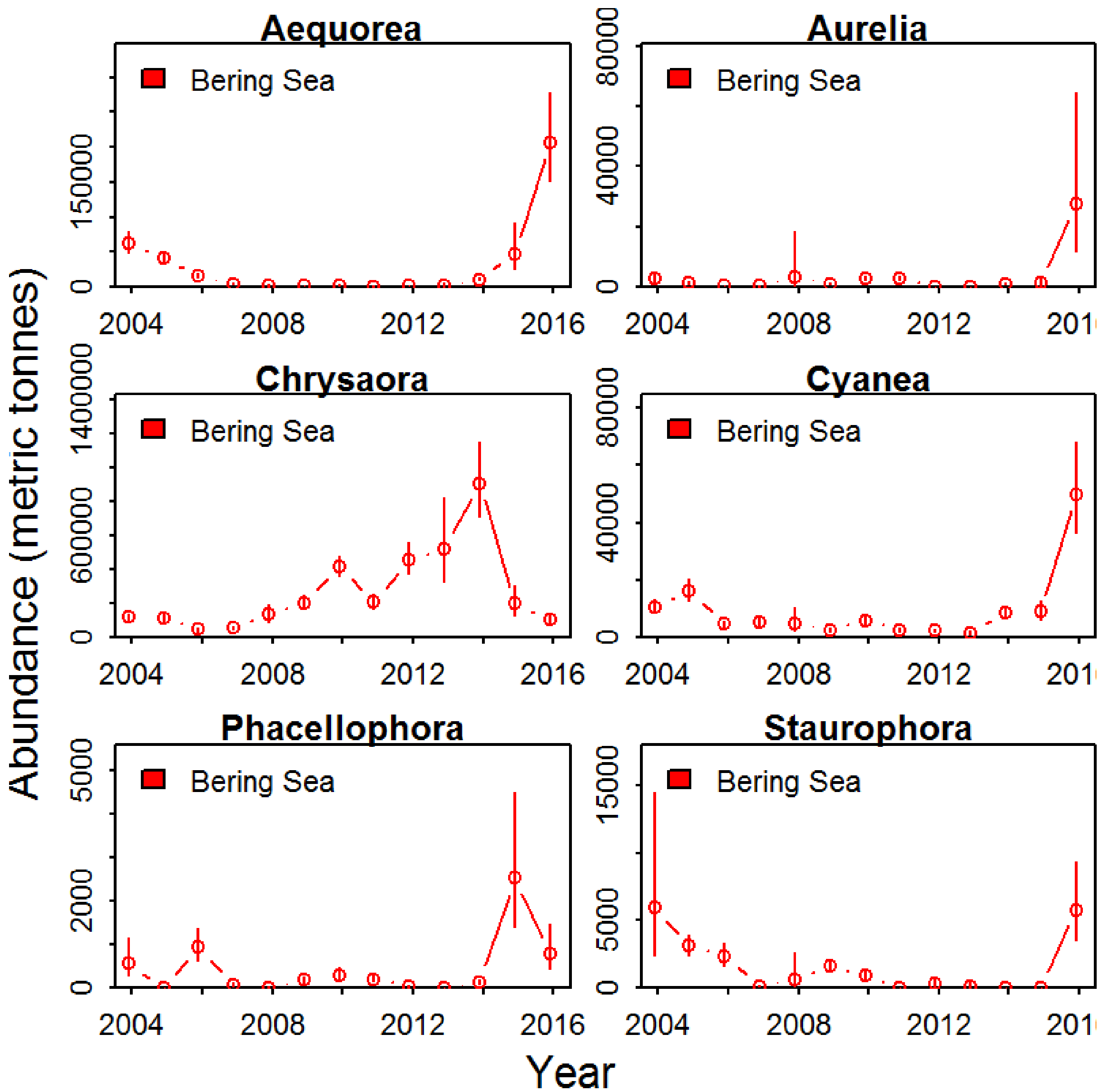

Figure 1. Index of abundance (metric tonnes) plus/minus 1 standard error for jellyfish in the eastern Bering Sea during late summer, 2004-2016.

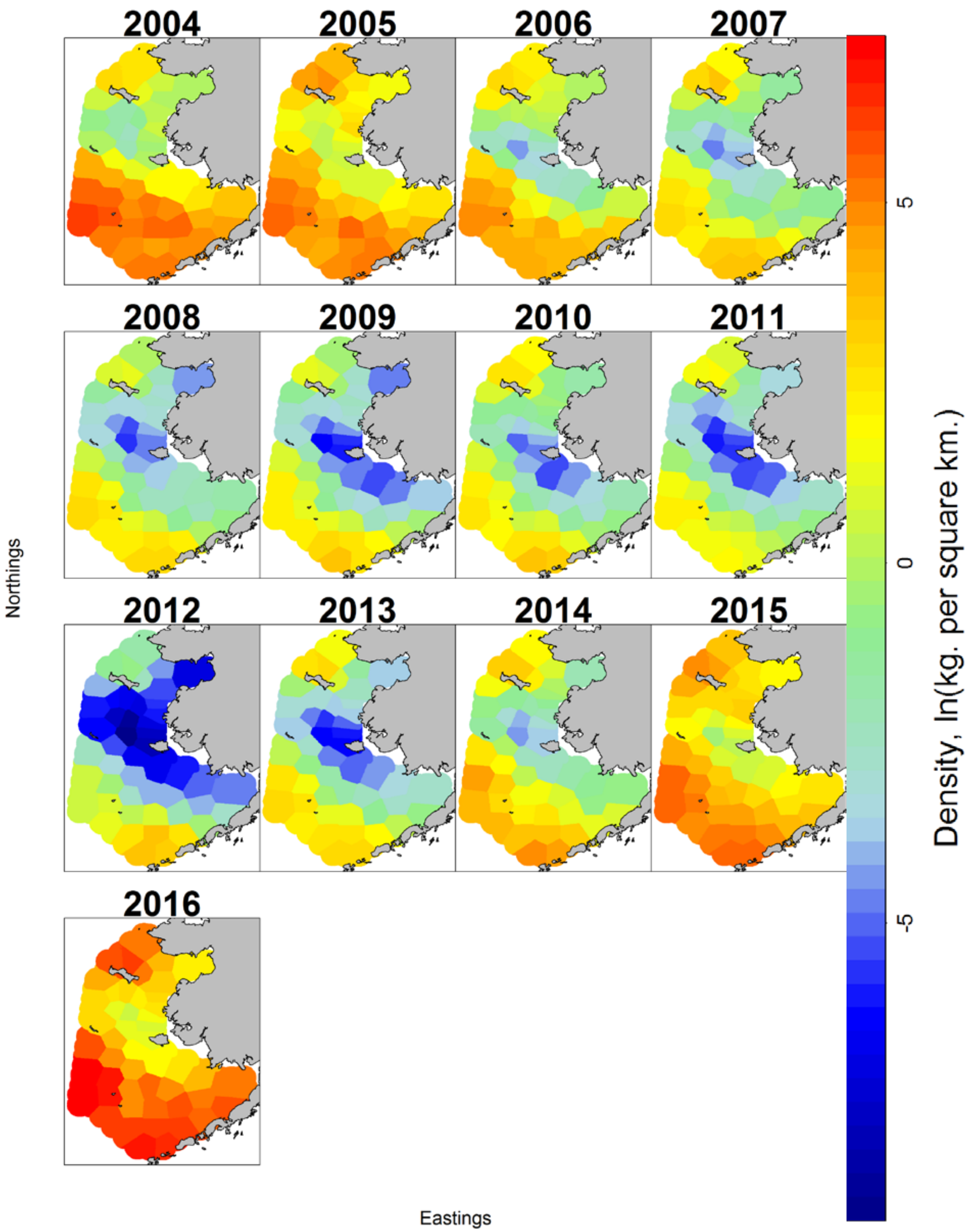

Figure 2. Predicted field densities of Aequorea in the eastern Bering Sea during late summer, 2002-2016.

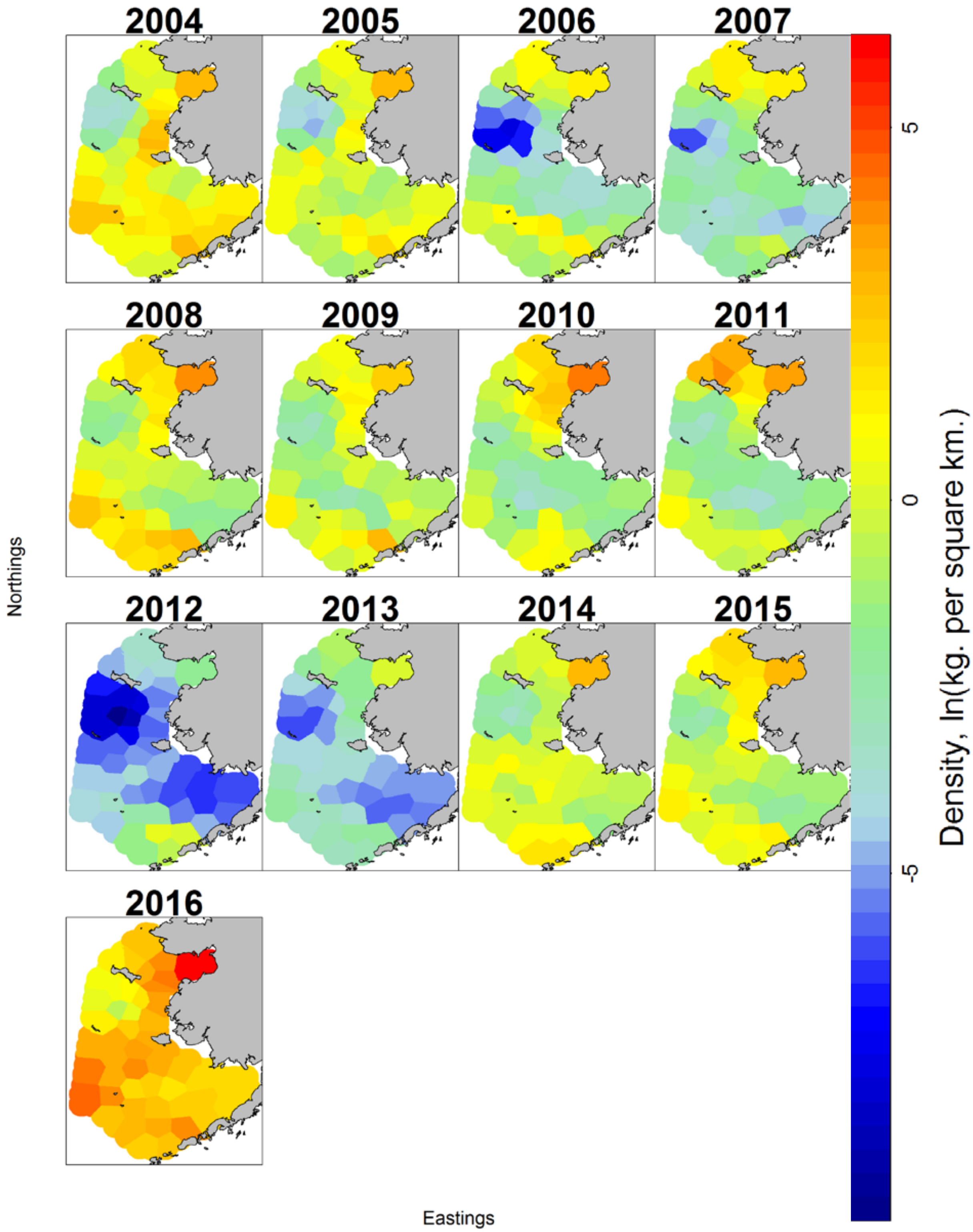

Figure 3. Predicted field densities of Aurelia in the eastern Bering Sea during late summer, 2002-2016.

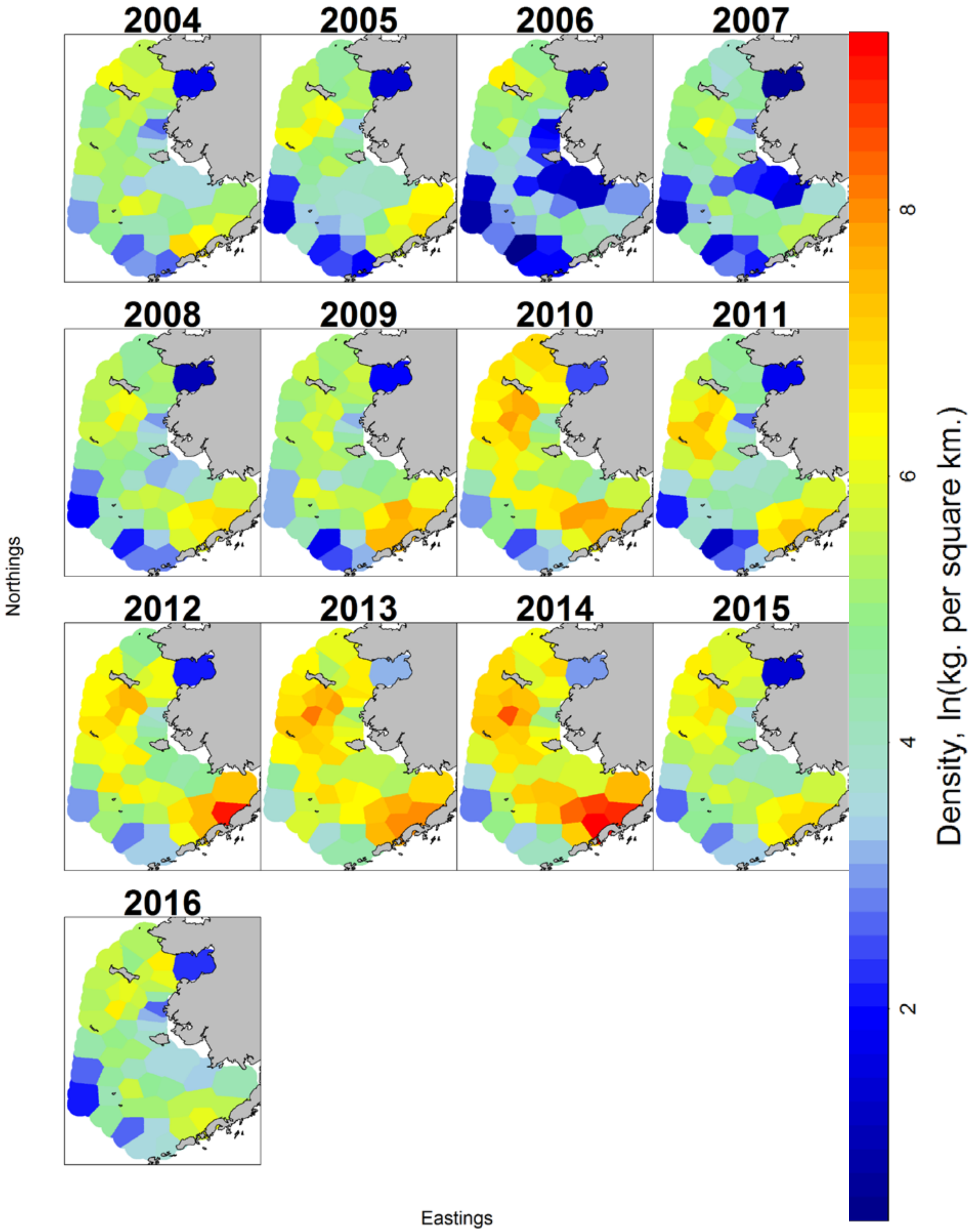

Figure 4. Predicted field densities of Chrysaora in the eastern Bering Sea during late summer, 2002-2016.

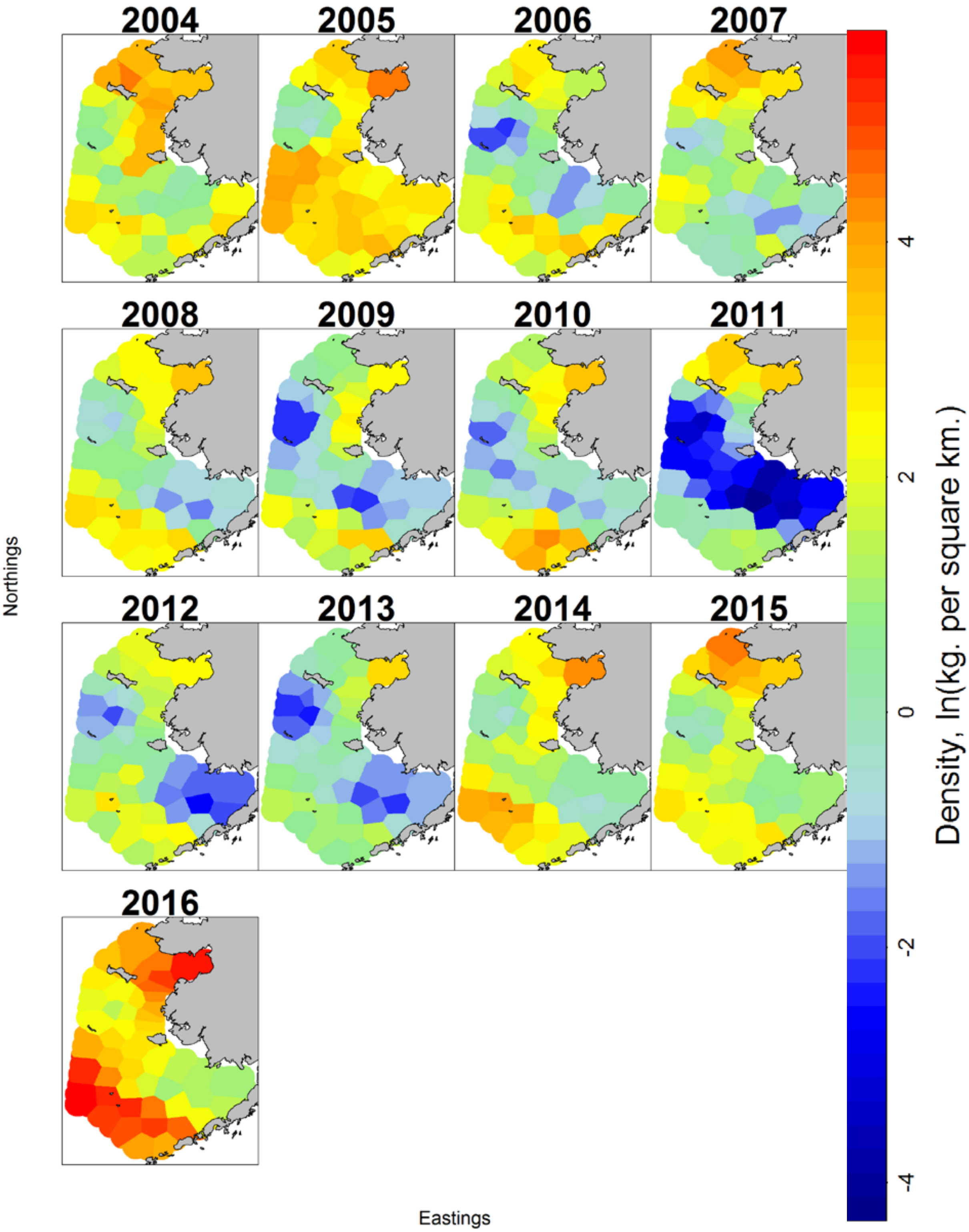

Figure 5. Predicted field densities of Cyanea in the eastern Bering Sea during late summer, 2002-2016.

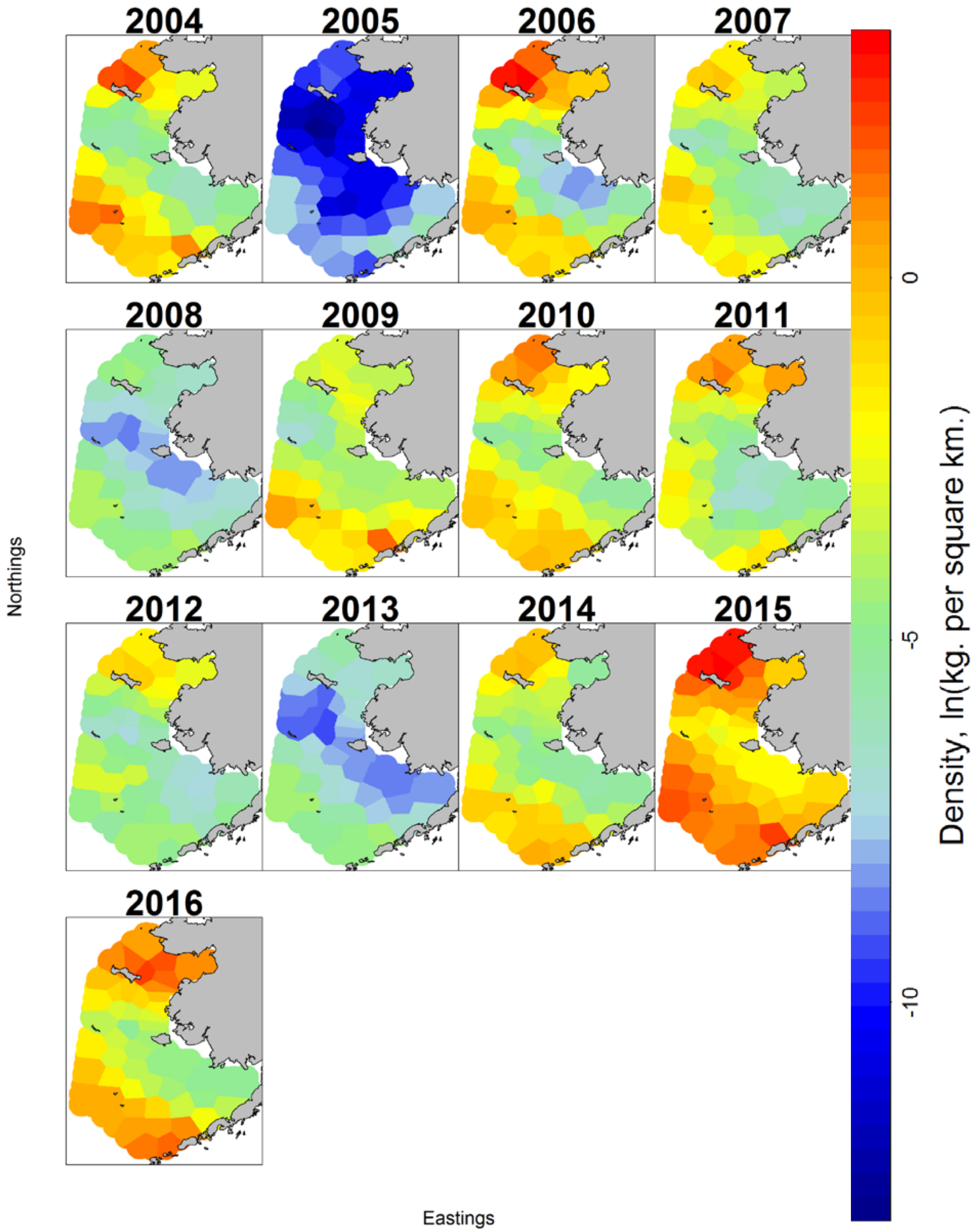

Figure 6. Predicted field densities of Phacellophora in the eastern Bering Sea during late summer, 2002-2016.

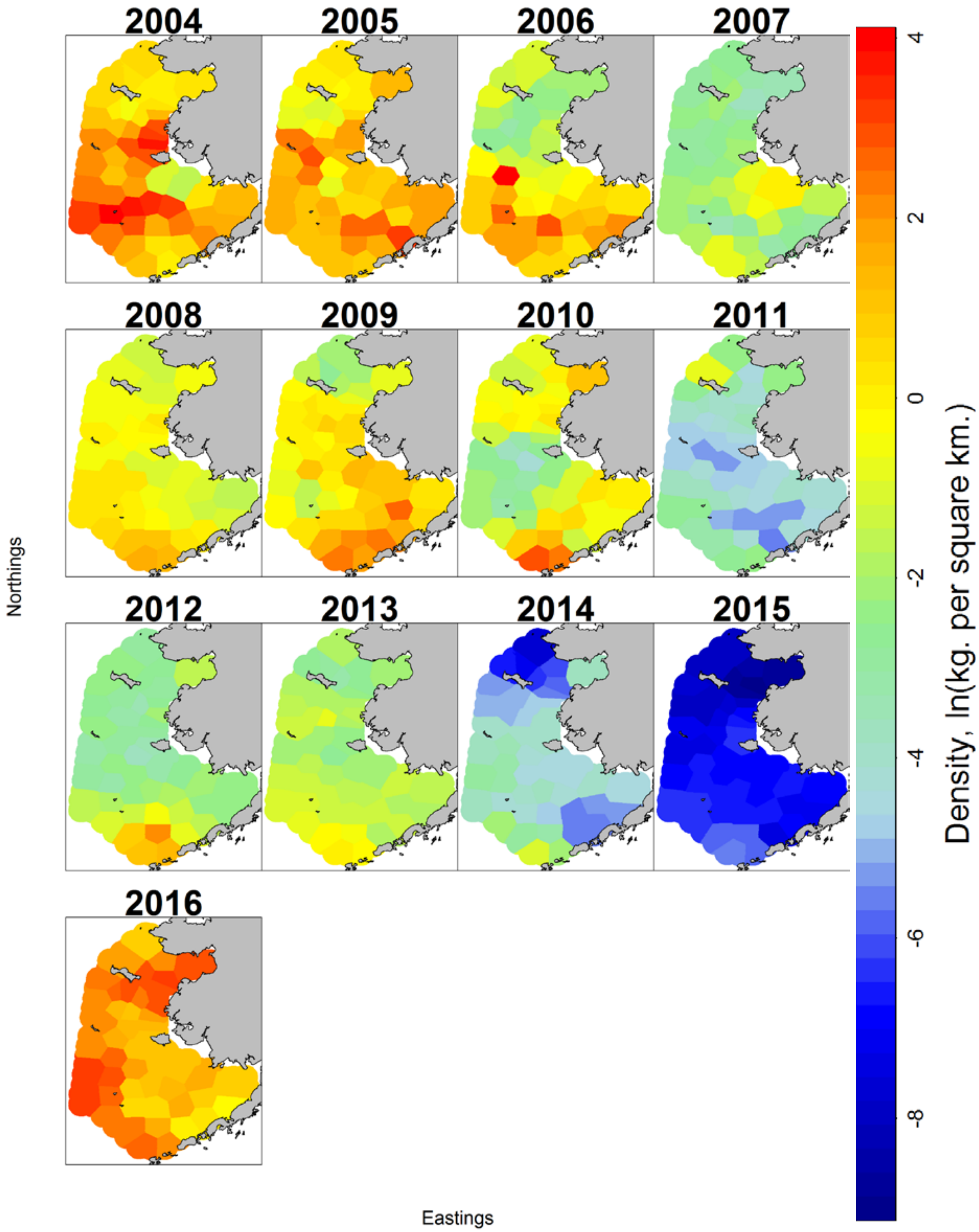

Figure 7. Predicted field densities of Staurophora in the eastern Bering Sea during late summer, 2002-2016.

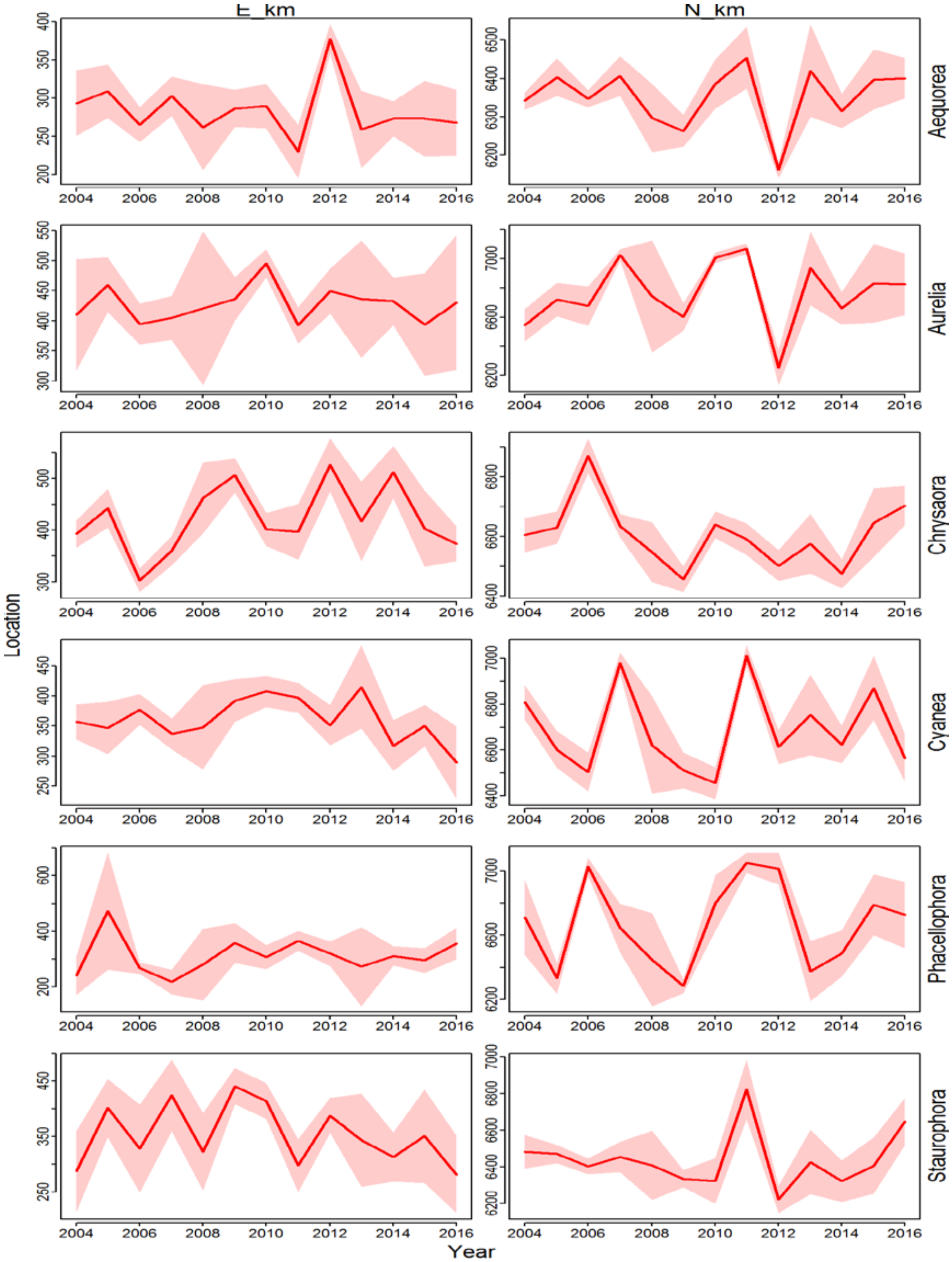

Figure 8. Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard error in UTM (km) for jellyfish on the eastern Bering Sea during late summer, 2002-2016.

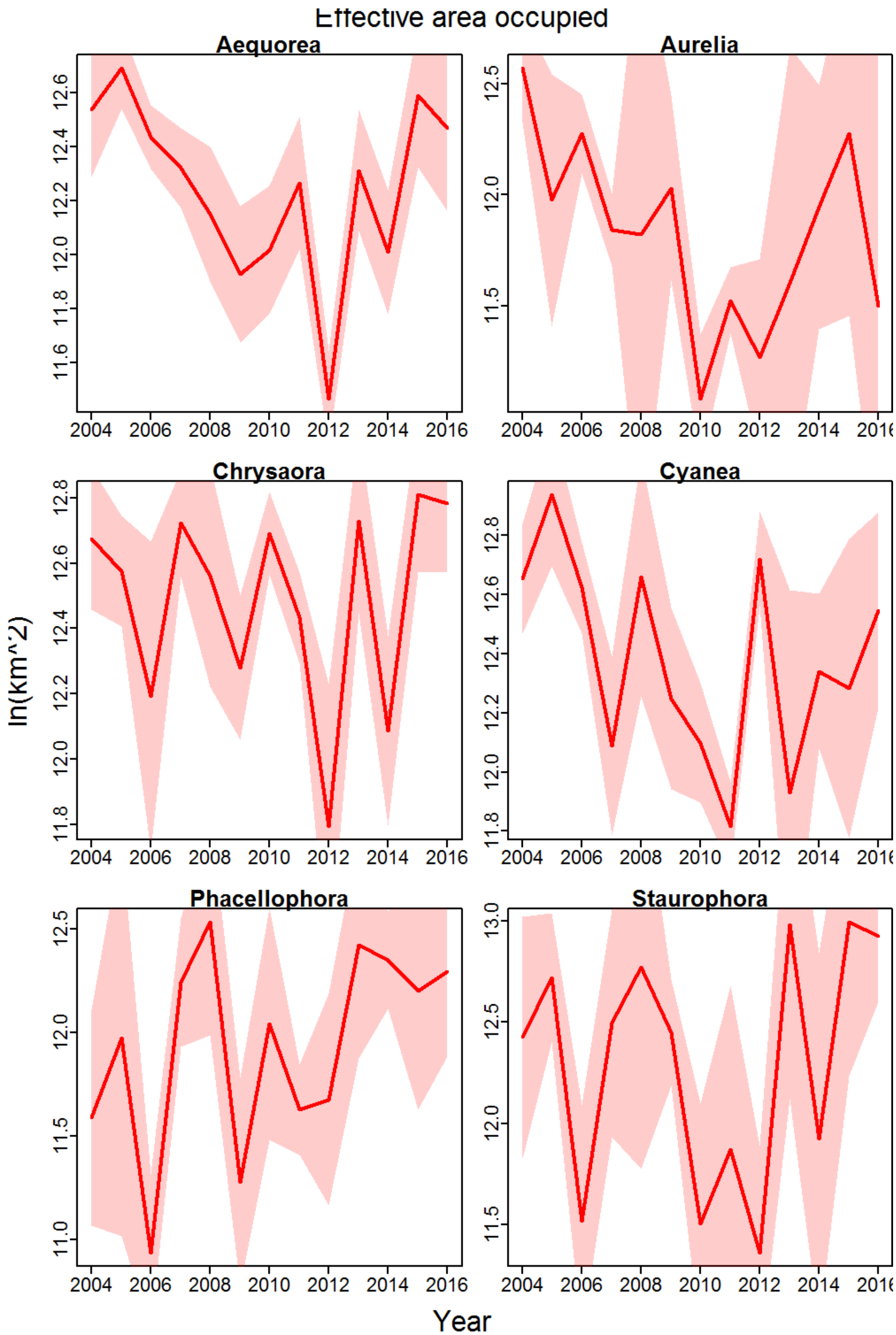

Figure 9. Effective area occupied (ln(km^2)) indicating range expansion/contraction plus/minus 1 standard error for jellyfish in the eastern Bering Sea during late summer, 2002-2016.

Table 1. Index of abundance (metric tonnes) plus/minus 1 standard error (SE), and the coefficient of variation (%) for jellyfish in the eastern Bering Sea during late summer, 2002-2016.

	Aeuqorea			Aurelia			Chrysaora		
	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.
2004	62,684	15,206	24%	2,939	1,147	39%	119,427	17,451	15%
2005	41,561	8,688	21%	1,236	406	33%	114,544	18,979	17%
2006	16,373	2,374	15%	517	171	33%	46,557	11,196	24%
2007	4,387	805	18%	354	117	33%	57,088	7,944	14%
2008	2,241	1,549	69%	3,391	5,782	170%	133,737	50,695	38%
2009	2,206	567	26%	1,084	288	27%	203,984	40,504	20%
2010	2,725	606	22%	2,833	791	28%	418,871	59,378	14%
2011	1,145	340	30%	2,929	666	23%	206,857	41,559	20%
2012	1,874	564	30%	55	40	72%	457,877	93,824	20%
2013	2,633	2,203	84%	60	63	104%	519,766	241,167	46%
2014	11,017	2,057	19%	1,163	345	30%	903,598	214,856	24%
2015	47,656	31,052	65%	1,395	1,058	76%	197,977	86,248	44%
2016	206,354	62,113	30%	27,396	23,571	86%	104,211	22,378	21%
Mean	30,989	9,856	35%	3,489	2,650	58%	268,038	69,706	24%

	Cyanea			Phacellophora			Staurophora		
	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.
2004	10,703	2,363	22%	563	411	73%	5,919	5,272	89%
2005	16,155	3,752	23%	0.2	0.3	165%	3,077	779	25%
2006	4,778	819	17%	928	367	40%	2,334	835	36%
2007	5,310	1,161	22%	71	35	50%	114	59	51%
2008	4,840	3,769	78%	3.1	6.1	194%	641	913	142%
2009	2,627	635	24%	178	69	39%	1,601	430	27%
2010	5,870	1,134	19%	273	148	54%	919	403	44%
2011	2,573	575	22%	201	60	30%	28	18	66%
2012	2,525	521	21%	31	19	62%	308	260	84%
2013	1,488	686	46%	2.0	4.3	222%	155	221	142%
2014	8,663	1,767	20%	139	51	37%	18	16	89%
2015	8,893	3,315	37%	2,524	1,452	58%	0.6	1.3	209%
2016	49,806	15,516	31%	798	494	62%	5,775	2,781	48%
Mean	9,556	2,770	30%	439	240	83%	1,607	922	81%