Spatial and temporal trends in the abundance and distribution of forage fish in pelagic waters of the eastern Bering Sea during late summer, 2002-2016

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Description of index: Pelagic fish and 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, 2002-2016. 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.

Fish 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 fish densities in these areas were estimated using geostatistical modeling methods (Thorson et al. 2015). Four forage fish commonly captured in the trawl: capelin (*Mallotus villosus*), herring (*Clupea pallasii*), sand lance (*Ammodytes hexapterus*), and sandfish (*Trichodon trichodon*).

Abundance and distribution (center of gravity and area occupied) were estimated for using the VAST package for multispecies version 1.1.0 (Thorson 2015; Thorson et al. 2016a, b, c) in RStudio version 1.0.136 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, 2016) 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 100 knots. Parameter estimates were within the upper and lower bounds and final gradients were less than 0.0005.

Status and trends: Temporal trends in the estimated abundance of these forage fish species indicate a decline in productivity in pelagic waters of the eastern Bering Sea during 2016 (Figure 1-5, Table 1). Herring were the most abundant species followed capelin, sandfish, and sand lance (Figure 1, Table 1). Trends in abundance did not track the recent warm (2002-2005, 2014-2016) and cold years (2007-2013).

Distribution of forage fish in pelagic waters varied among species and years (Figure 2-5). Capelin were distributed in the central and northern Bering Sea shelf. Herring were distributed in the northeastern Bering Sea middle and inner domains (0-100 m bottom depth). Sand lance were captured primarily in the inner domain of the eastern Bering Sea shelf, while sandfish distributed in the southeastern Bering Sea shelf.

Center of gravity indicated that sandfish was distributed farther west during warm stanzas (2002-2005 and 2014-2016) and farther east during the cold stanza (2008-2013). No warm and cold year trend in the latitudinal or longitudinal distribution were observed in the distribution of capelin, herring, and sand lance in the survey area (Figure 6). Area occupied indicated that these fish did not expand or contract their ranges during warm years relative to cold years (Figure 7).

Factors causing trends: The forage fish had lower abundances during 2016, the third consecutive warm year indicating poor environmental conditions for the growth and survival for forage fish in the eastern Bering Sea. However, over the 15 year time series trends in the abundances of forage fish did not coincide with warm or cold conditions.

Implications: Recent declines in the abundance of forage fish in pelagic waters during later summer implies poor conditions for growth and survival of pelagic fish species in our survey area during August and September. Lower forage fish abundance may impact the feeding and survival of birds, fish, and marine mammals that rely on them for prey.

Citations:

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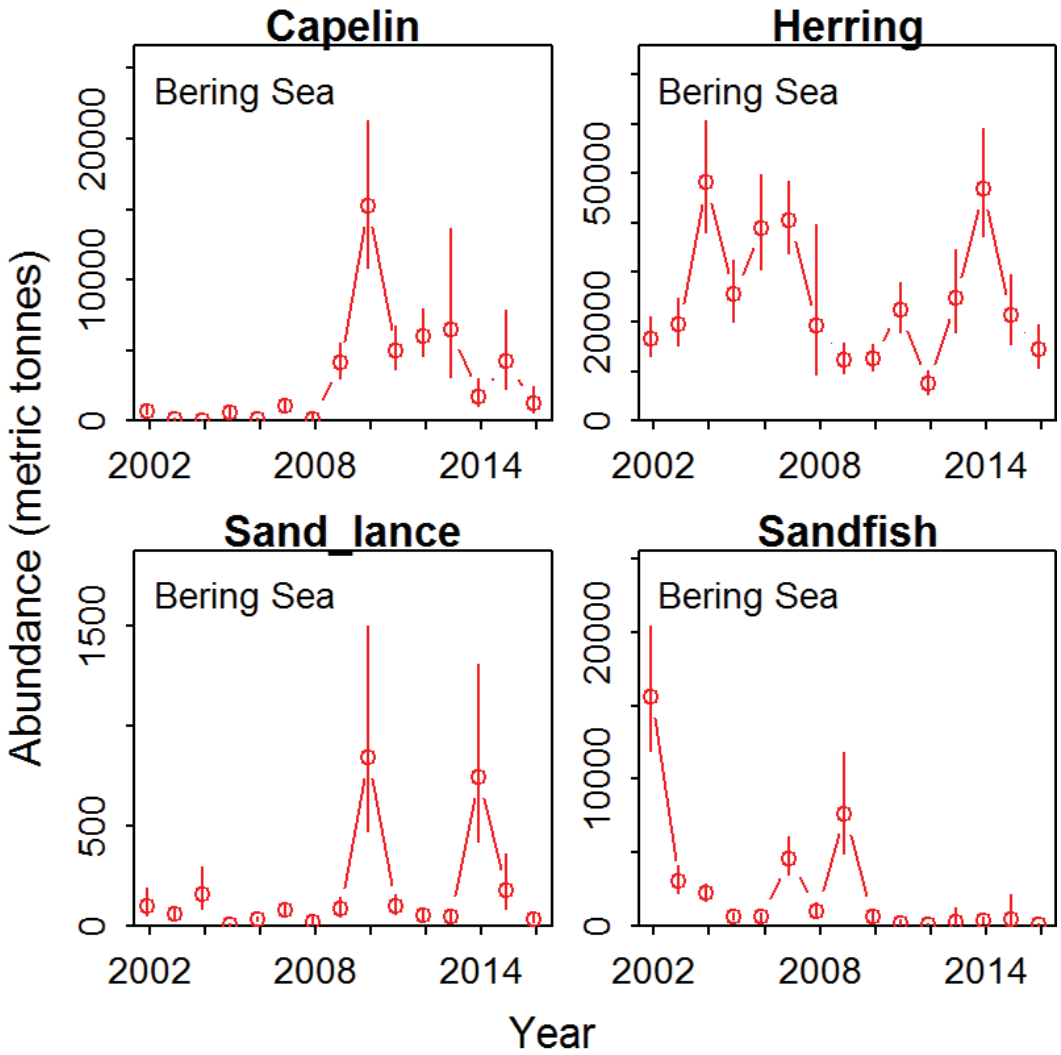

Figure 1. Index of abundance (metric tonnes) plus/minus 1 standard error for forage fish species in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

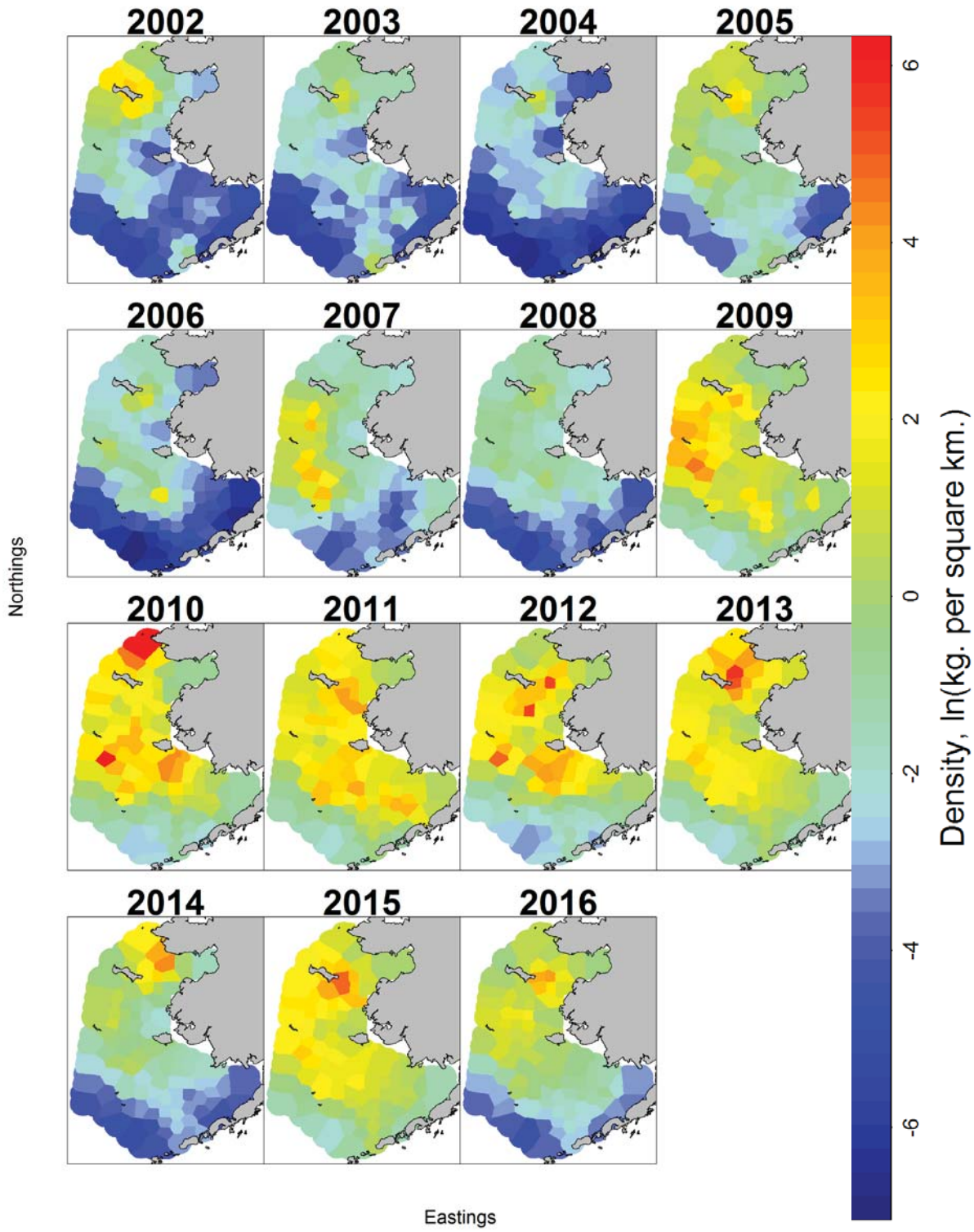

Figure 2. Predicted field densities of capelin in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

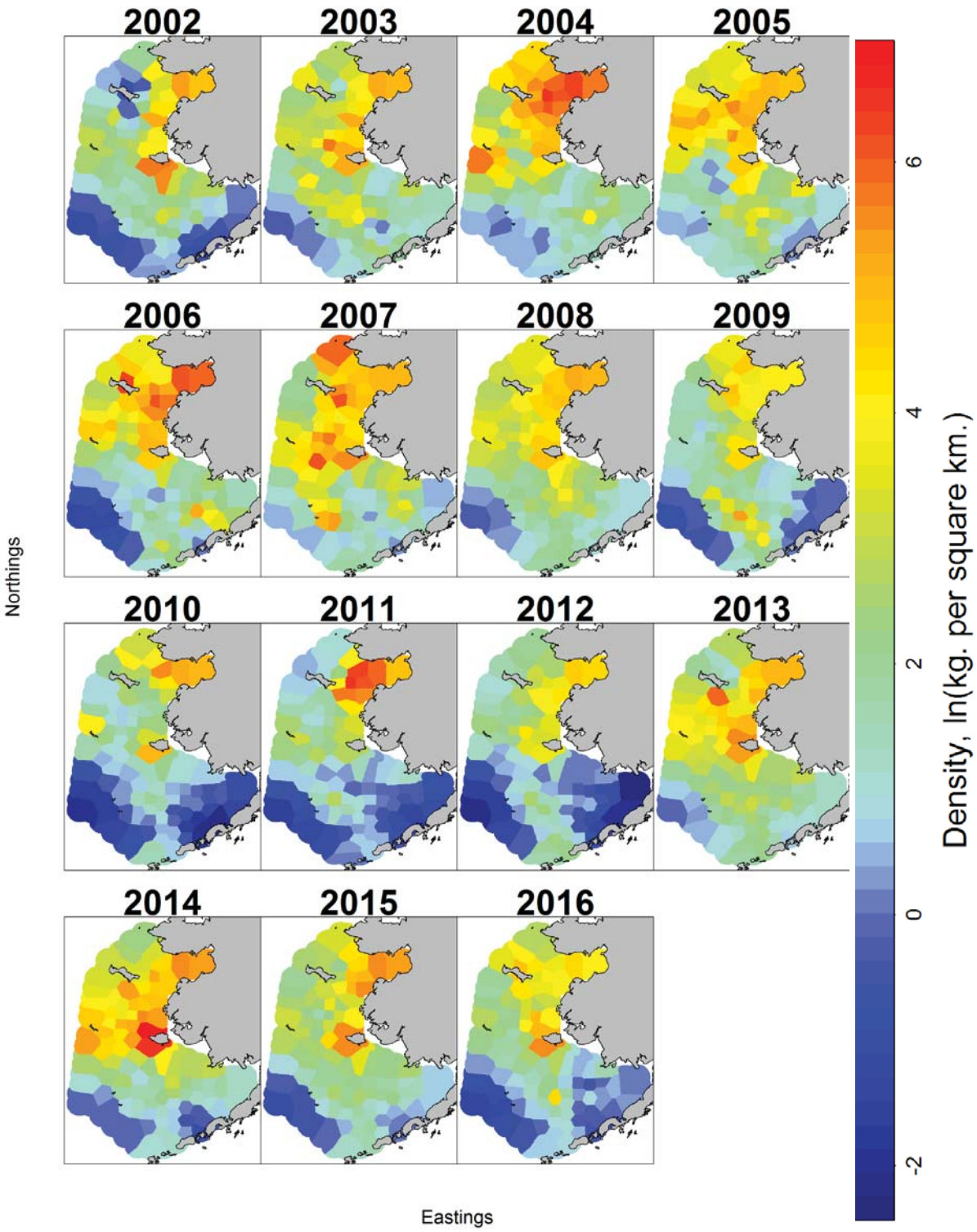

Figure 3. Predicted field densities of herring in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

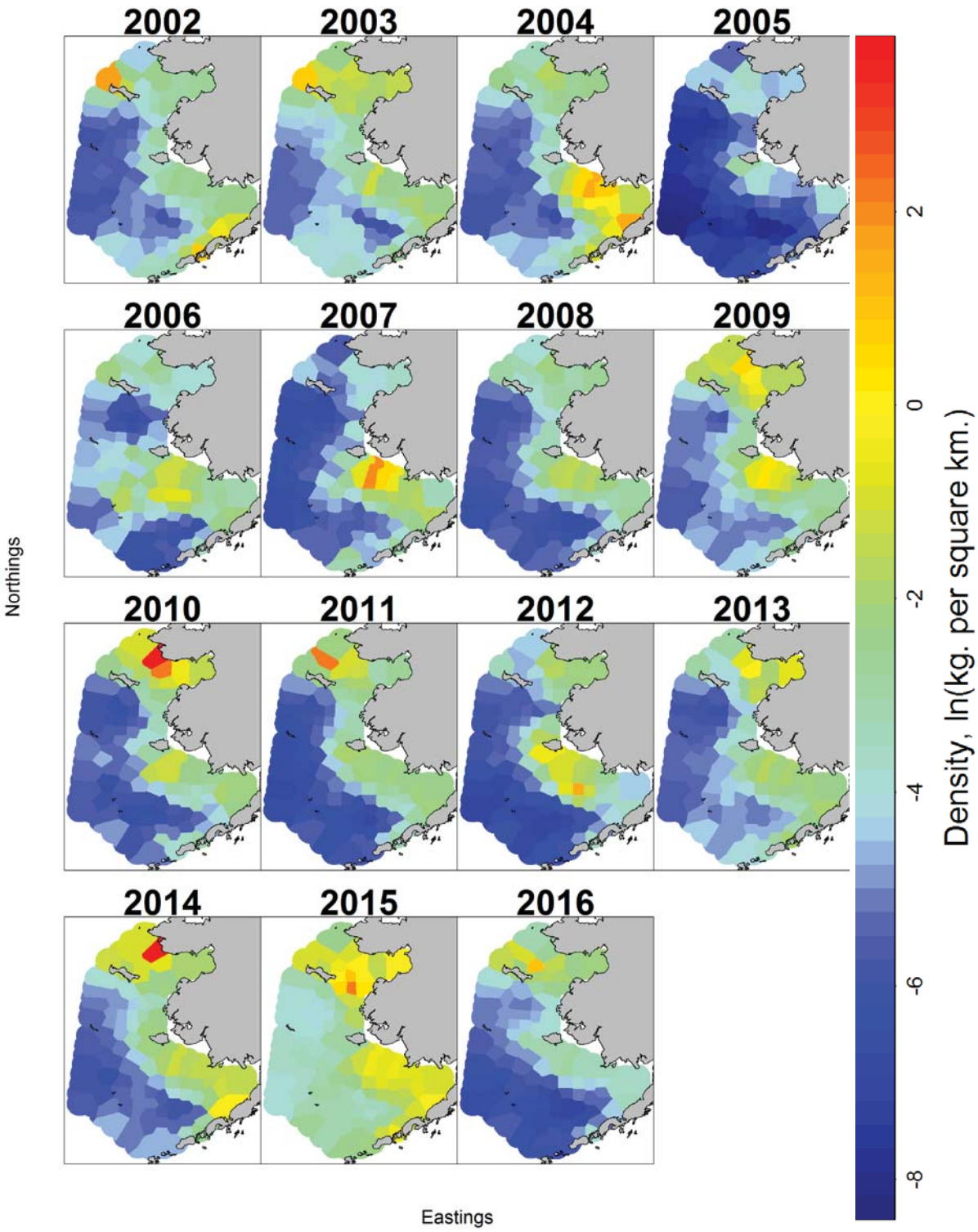

Figure 4. Predicted field densities of sand lance in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

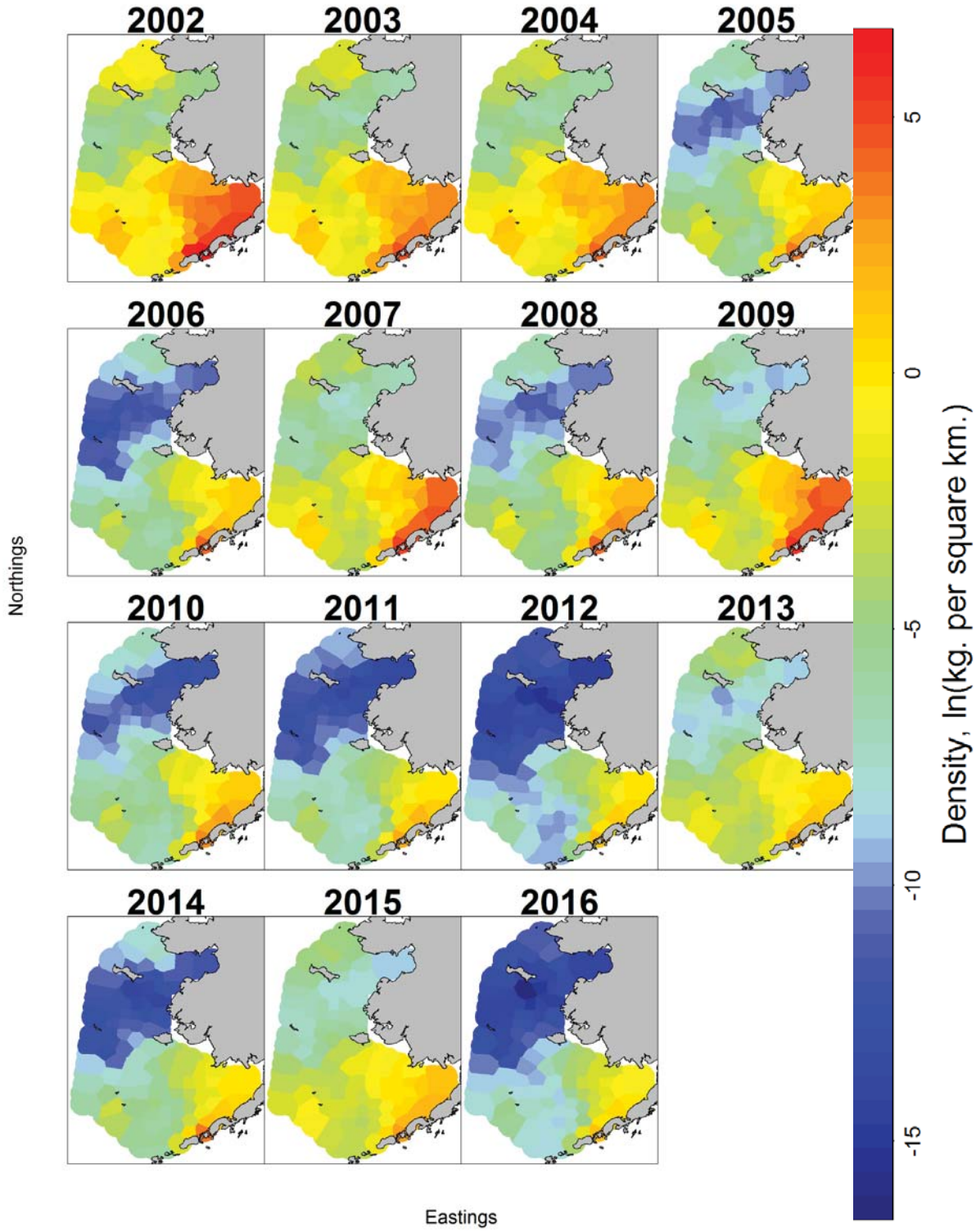

Figure 5. Predicted field densities of sandfish in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

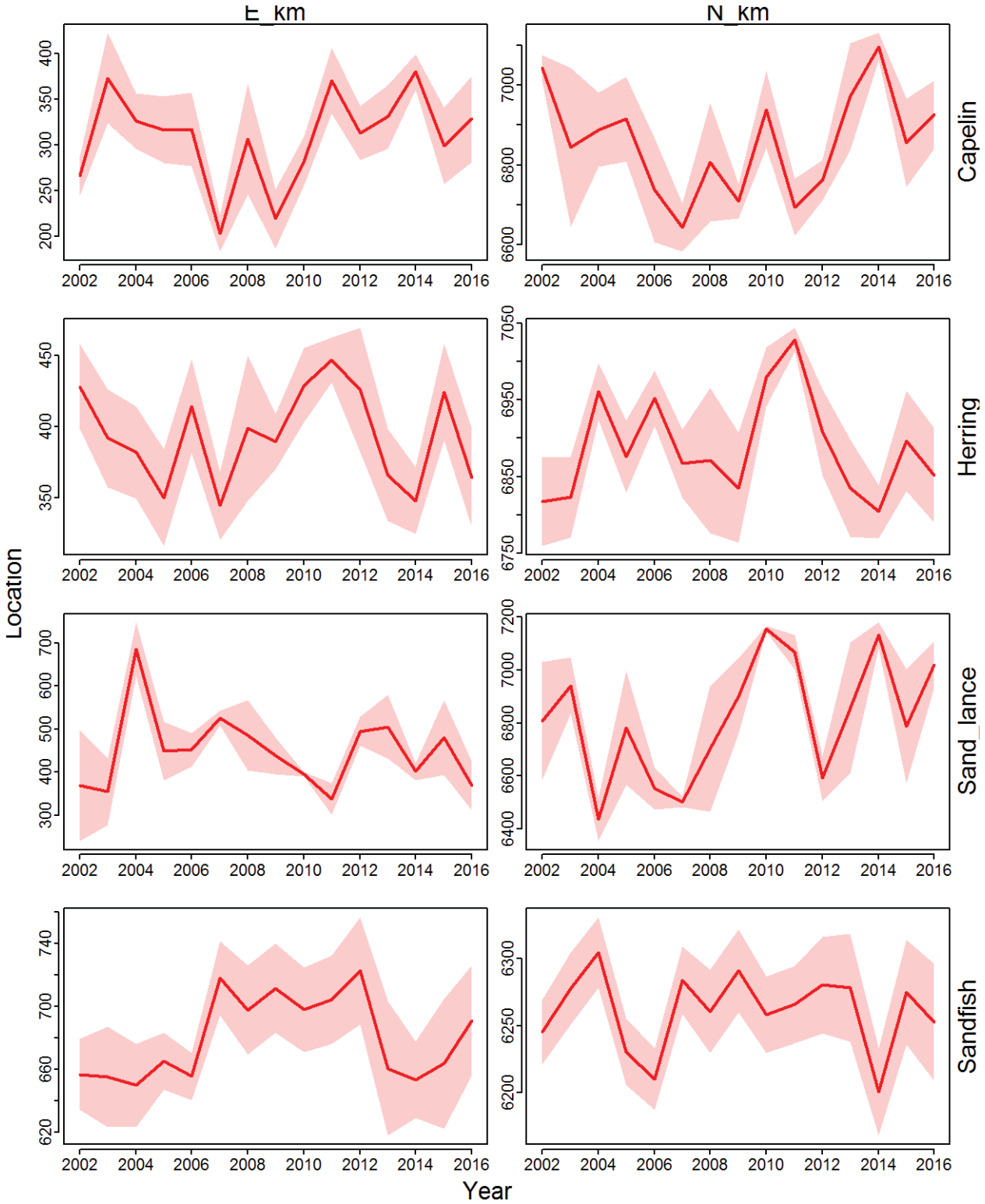

Figure 6. Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard error in UTM (km) for forage fish in pelagic waters of the eastern Bering Sea during late summer, 2002-2016.

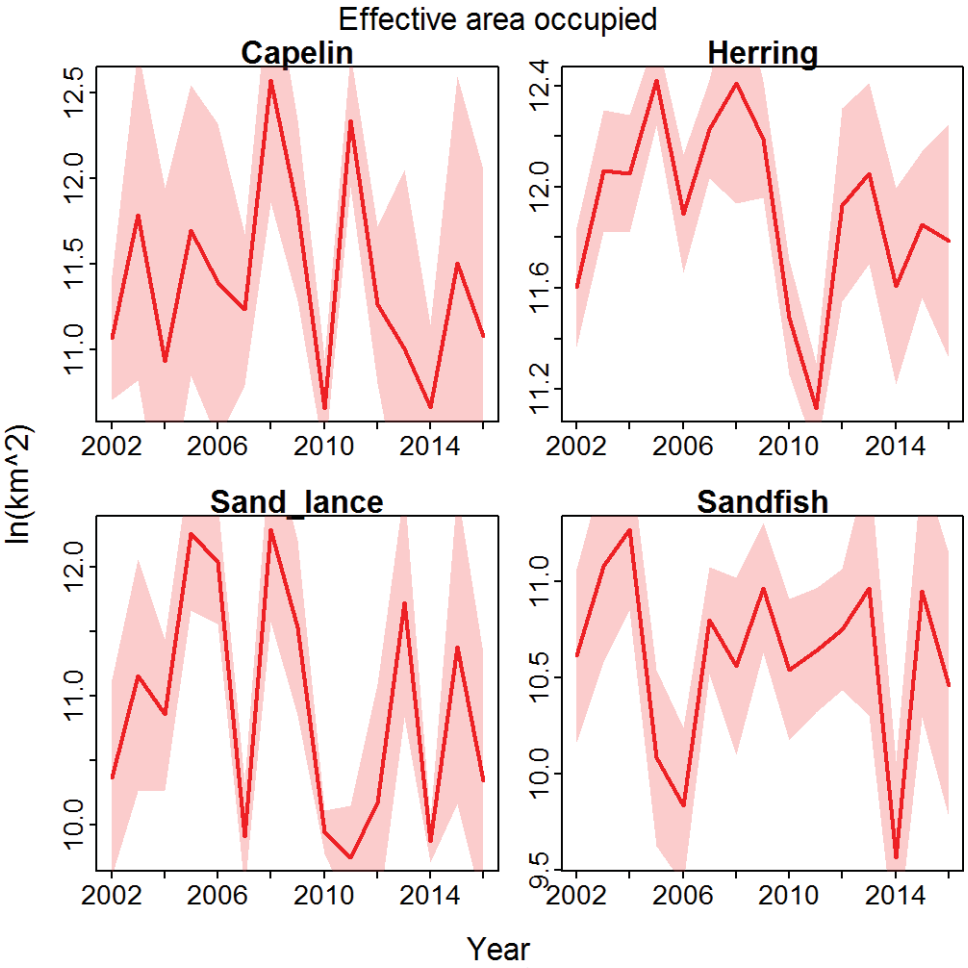

Figure 7. Effective area occupied (ln(km^2)) indicating range expansion/contraction plus/minus 1 standard error for forage fish in pelagic waters of the eastern Bering Sea shelf during late summer, 2002-2016.

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

	Capelin			Herring			Sand lance			Sandfish		
	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.	Estimate	S.E.	C.V.
2002	693	270	39%	16,614	4,029	24%	98	64	66%	15,592	4,221	27%
2003	117	84	72%	19,523	4,753	24%	60	29	48%	3,053	943	31%
2004	54	32	60%	48,091	11,128	23%	155	99	64%	2,233	562	25%
2005	553	344	62%	25,644	6,171	24%	4	4	96%	638	231	36%
2006	135	79	59%	39,032	9,430	24%	31	9	30%	576	260	45%
2007	1,024	393	38%	40,475	7,262	18%	80	31	39%	4,588	1,274	28%
2008	133	166	125%	19,272	13,962	72%	17	19	107%	1,009	494	49%
2009	4,115	1,219	30%	12,378	2,962	24%	83	46	56%	7,640	3,328	44%
2010	15,216	5,092	33%	12,532	2,671	21%	843	486	58%	612	287	47%
2011	4,986	1,480	30%	22,390	5,051	23%	98	46	47%	200	136	68%
2012	6,034	1,683	28%	7,462	2,312	31%	51	25	49%	97	54	56%
2013	6,483	4,844	75%	24,840	8,248	33%	42	29	67%	228	388	171%
2014	1,746	932	53%	46,933	10,782	23%	743	420	57%	346	187	54%
2015	4,200	2,651	63%	21,453	6,944	32%	175	127	72%	442	689	156%
2016	1,238	868	70%	14,407	4,376	30%	34	20	60%	78	63	81%
Mean	3,115	1,343	56%	24,736	6,672	29%	168	97	61%	2,489	874	61%