Spatial and temporal trends in the abundance and distribution of juvenile Pacific salmon in 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). As juveniles during the first year at sea, four of the five salmon species were commonly captured in the trawl: Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), and sockeye salmon (*O. nerka*).

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 juvenile salmon indicated a recent increase in the productivity of Pacific salmon in the eastern Bering Sea (Figure 1, Table 1). Juvenile sockeye were the most abundant species followed pink, chum, and Chinook salmon (Figure 5, Table 1). Both juvenile pink and sockeye salmon had an alternating year pattern with higher abundances in even-numbered years. Juvenile salmon were typically more abundant during warm years (2002-2005 and 2014-2016) than during cold years (2007-2013), with the exception of higher juvenile pink and chum salmon abundances during 2007 and 2009 (Figure 5).

Distribution of juvenile salmon varied among species and years (Figure 2-5). Chinook were concentrated in the inner domains (<50m depths) of the north and south and south eastern Bering Sea domains indicating an origin of Norton Sound (Yukon River) in the north and the Kuskokwim River in the south. Chum salmon were most abundant around Nunivak Island (60 °N) and were likely from the Kuskokwim River. Sockeye salmon were abundant in the south indicating primarily Bristol Bay origin. Center of gravity indicated that juvenile Chinook, chum, and pink salmon were farther south during warm years, while juvenile sockeye salmon were distributed farther north and west in warm years (Figure 6). Area occupied indicated that all juvenile salmon species expanded their distribution in 2016 (Figure 7). Juvenile sockeye were the only species that occupied a smaller area during cold years and a larger area in warm years.

Factors causing trends: Higher abundances of juvenile salmon during recent warm years indicate improved environmental conditions for the survival in the eastern Bering Sea during summer and/or in freshwater rivers and lakes of western Alaska. Juvenile sockeye salmon responded to warming with an expansion in their range and s distribution farther north. The northern origin juveniles distributed farther south in warm years, possibly in search of food such as age-0 pollock during warm years of low abundances of large zooplankton (Coyle et al. 2011).

Implications: Recent increases in the abundance of juvenile salmon in our survey area during later summer implies improved conditions for growth and survival of salmon from western Alaska salmon lakes and rivers and/or a change in the distribution of juvenile salmon into our survey area during August and September. Juvenile indices may be an early indication for the numbers of returning adults to the region of origin.

Citations:

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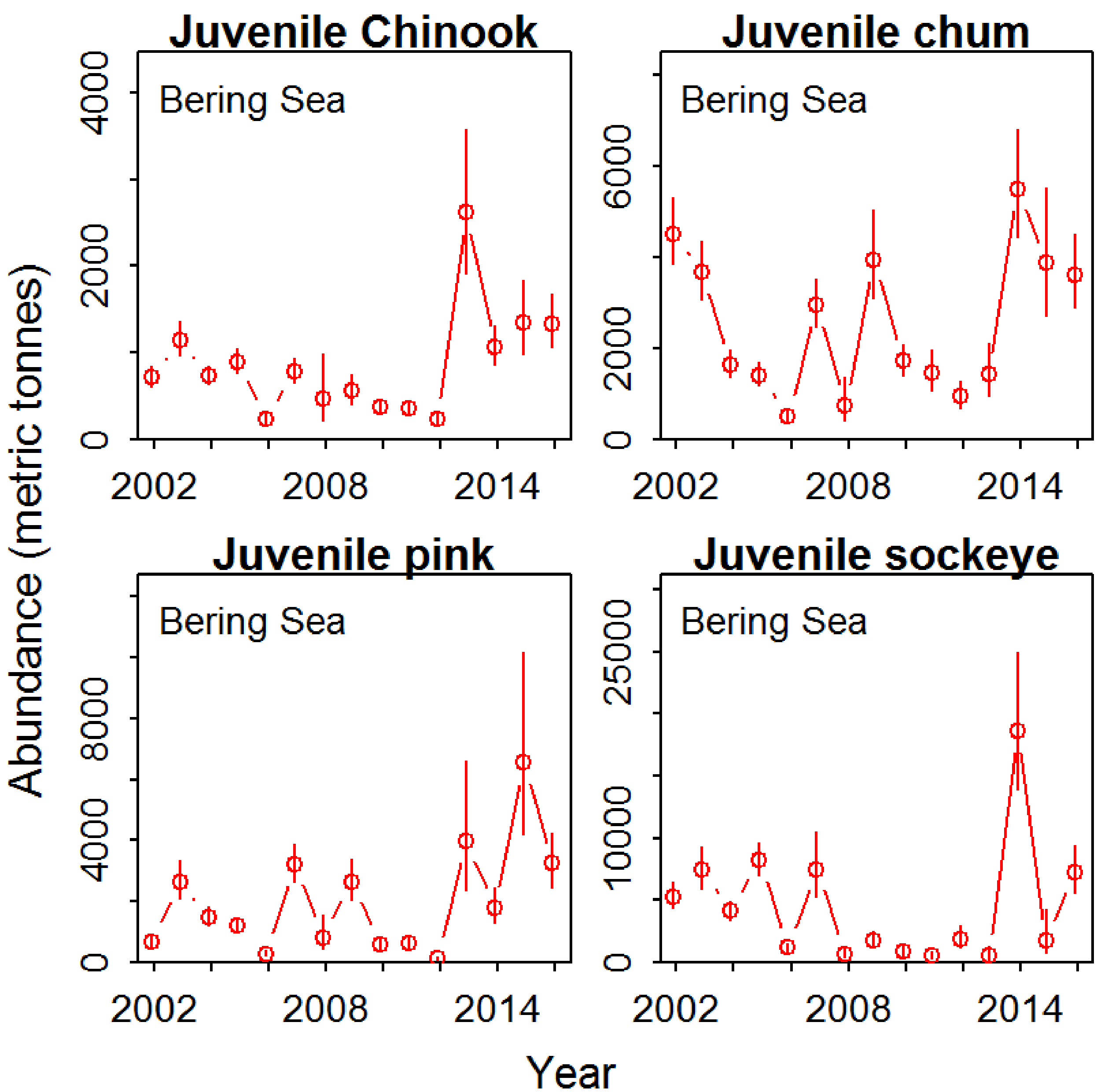

Figure 1. Index of abundance (metric tonnes) plus/minus 1 standard error for Pacific salmon in the eastern Bering Sea during late summer, 2002-2016.

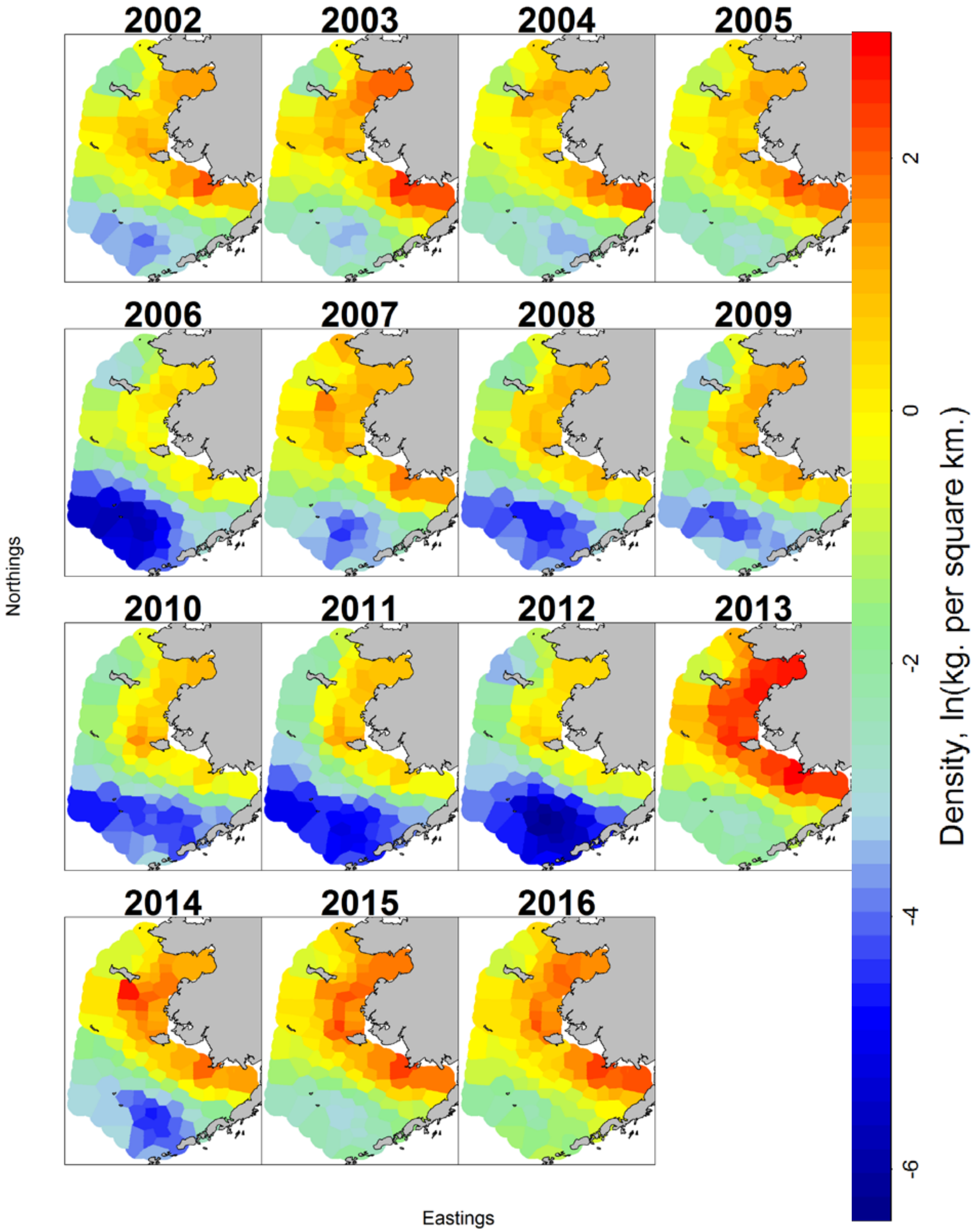

Figure 2. Predicted field densities of juvenile Chinook salmon in the eastern Bering Sea during late summer, 2002-2016.

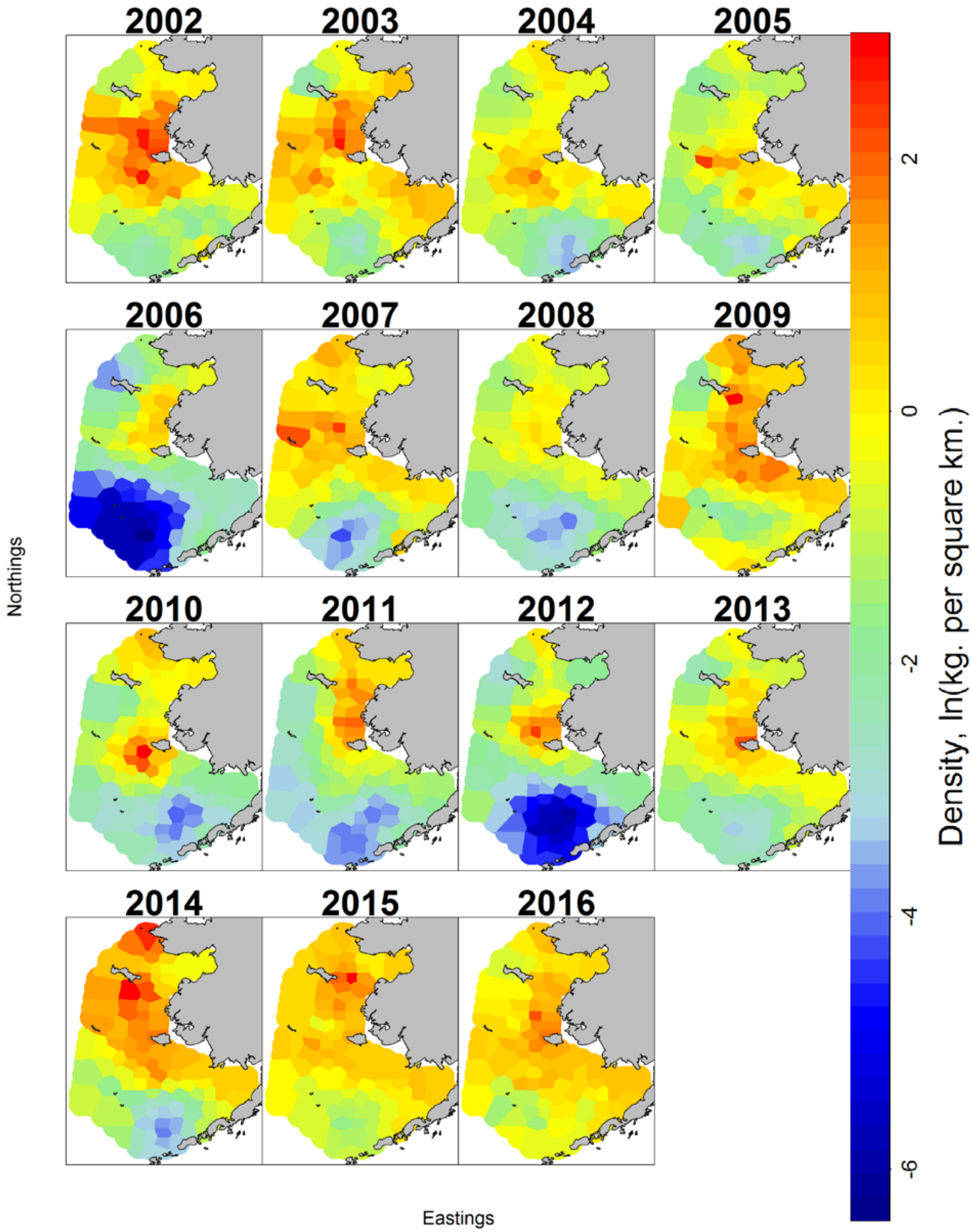

Figure 3. Predicted field densities of juvenile chum salmon in the eastern Bering Sea during late summer, 2002-2016.

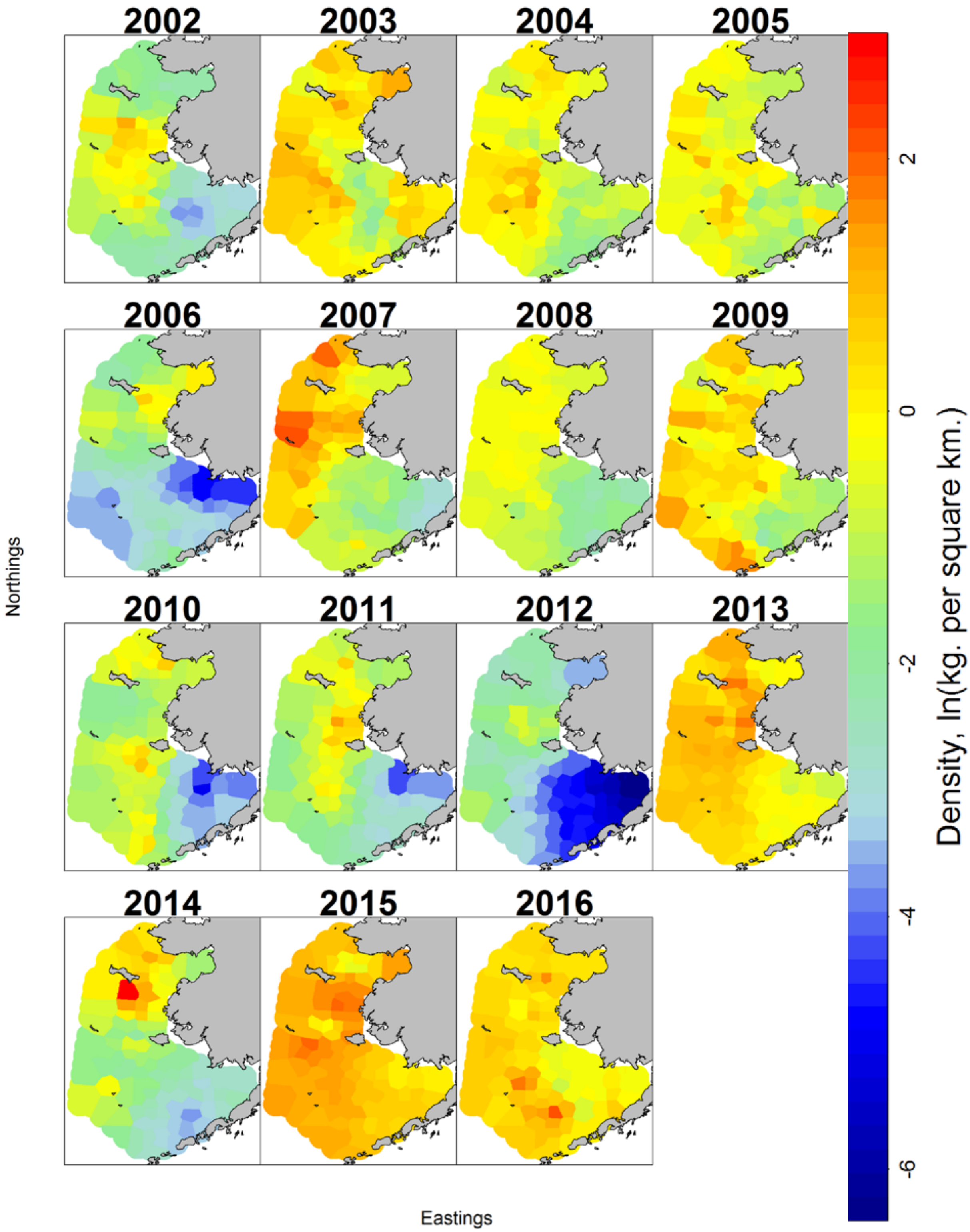

Figure 4. Predicted field densities of juvenile pink salmon in the eastern Bering Sea during late summer, 2002-2016.

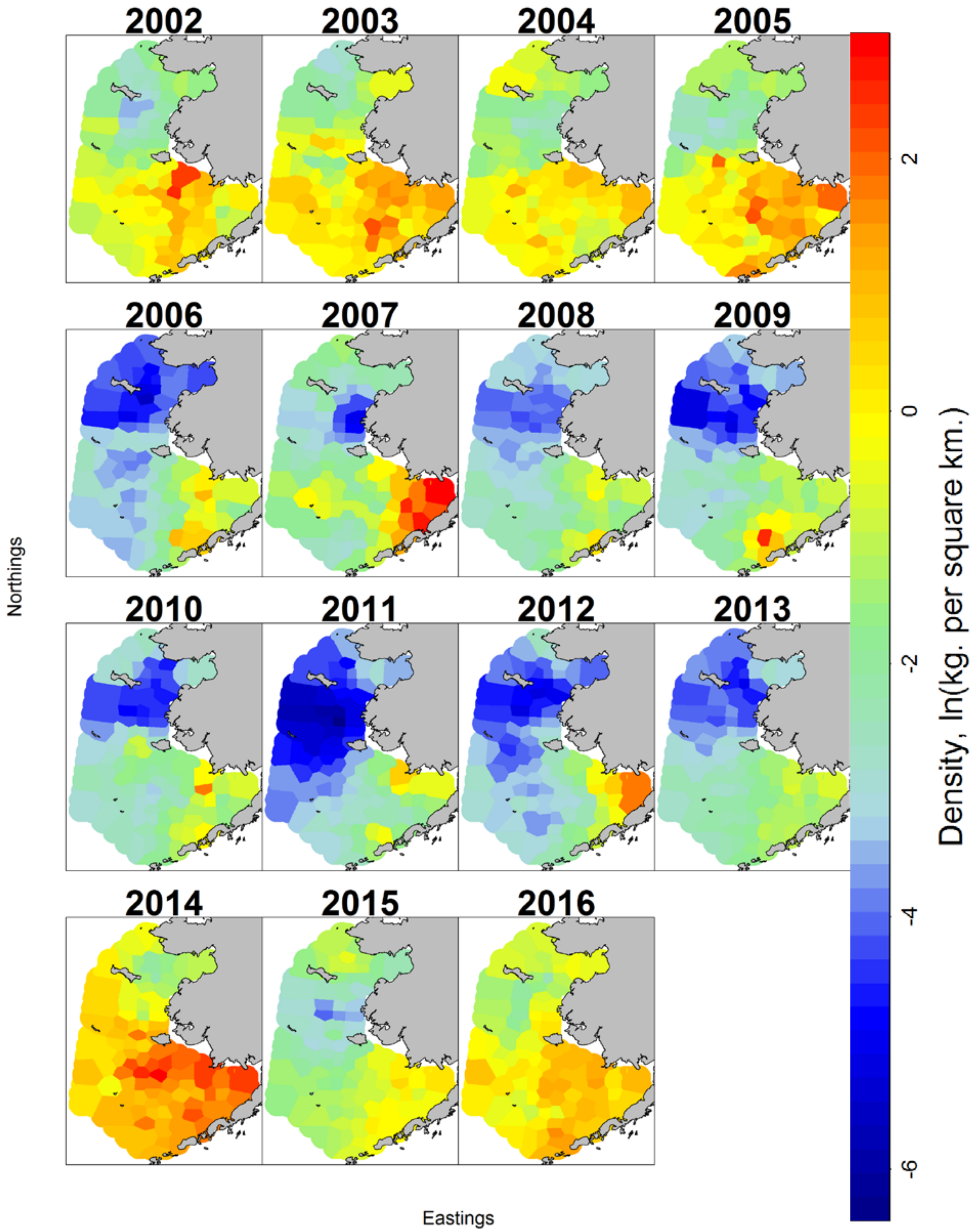

Figure 5. Predicted field densities of juvenile sockeye salmon in the eastern Bering Sea during late summer, 2002-2016.

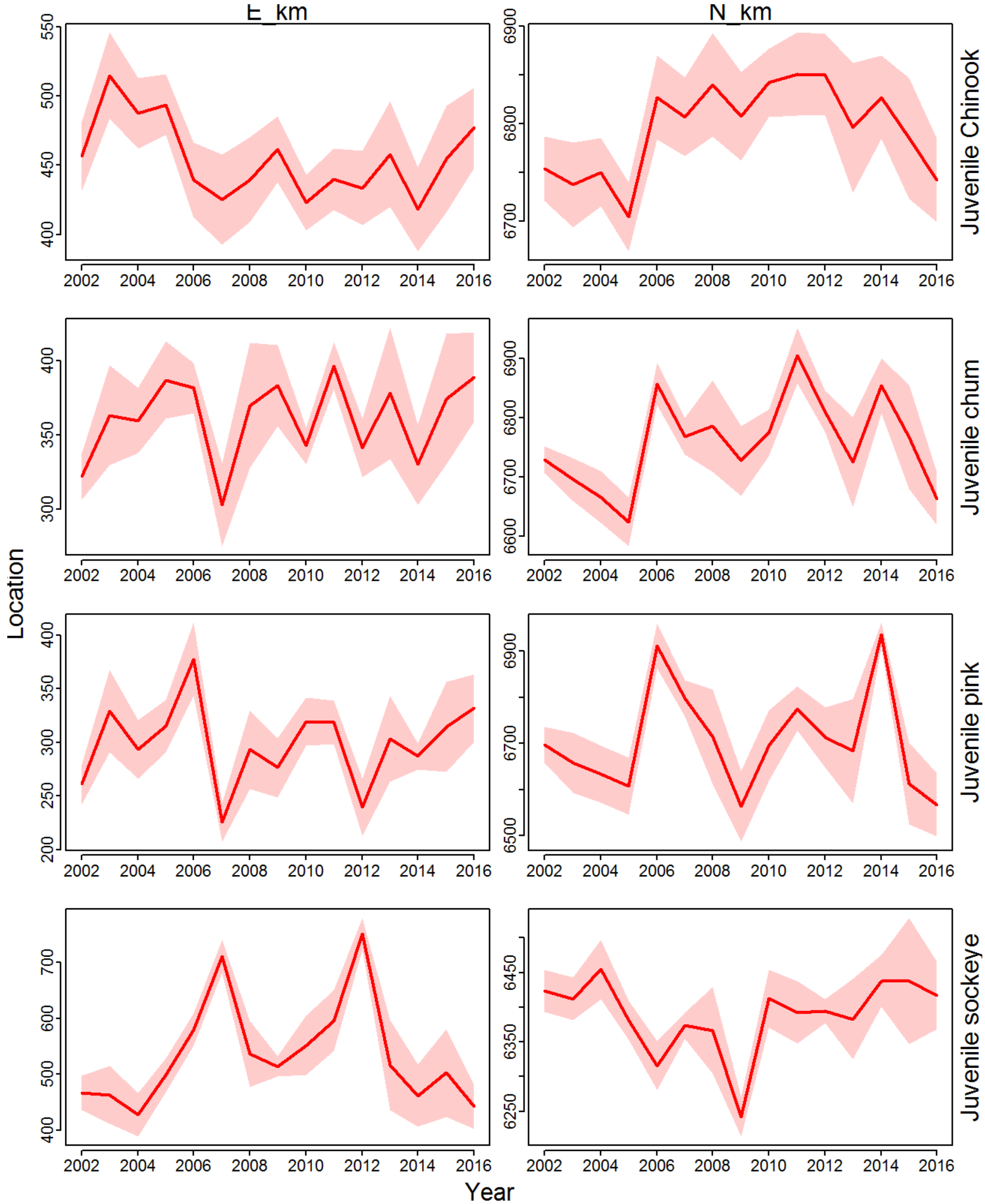

Figure 6. Center of gravity indicating temporal shifts in the mean east-to-west and north-to-south distribution plus/minus 1 standard error in UTM (km) for juvenile Pacific salmon on the eastern Bering Sea during late summer, 2002-2016.

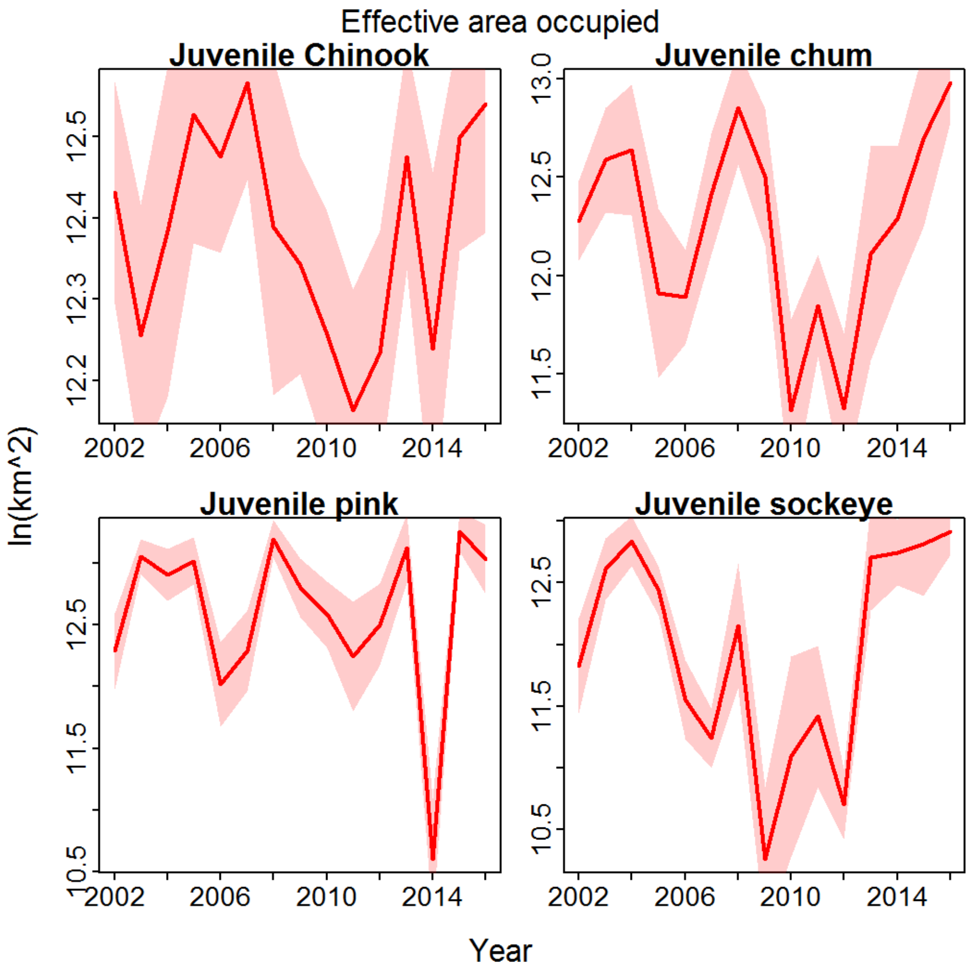

Figure 7. Effective area occupies (ln(km^2)) indicating range expansion/contraction plus/minus 1 standard error for juvenile Pacific salmon on the eastern Bering Sea shelf during late summer, 2002-2016.

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

Year	Chinook	Chum	Pink	Sockeye
2002	723 (115) 16%	4,527 (721) 16%	661 (150) 23%	5,281 (1,043) 20%
2003	1,154 (196) 17%	3,670 (648) 17%	2,643 (614) 23%	7,390 (1,704) 23%
2004	746 (104) 14%	1,656 (293) 18%	1,485 (313) 21%	4,119 (770) 19%
2005	902 (134) 15%	1,425 (252) 18%	1,218 (241) 20%	8,201 (1,360) 17%
2006	239 (51) 21%	525 (123) 24%	279 (90) 32%	1,148 (343) 30%
2007	793 (143) 18%	2,964 (525) 18%	3,205 (626) 20%	7,461 (2,577) 35%
2008	478 (346) 72%	760 (448) 59%	822 (534) 65%	631 (309) 49%
2009	564 (170) 30%	3,963 (962) 24%	636 (659) 25%	1,710 (634) 37%
2010	378 (76) 20%	1,731 (344) 20%	587 (141) 24%	888 (372) 42%
2011	361 (87) 24%	1,468 (427) 29%	624 (169) 27%	509 (260) 51%
2012	233 (65) 28%	952 (296) 31%	120 (44) 37%	1,838 (833) 45%
2013	2,614 (813) 31%	1,445 (569) 39%	3,963 (2,019) 51%	527 (490) 93%
2014	1,073 (226) 21%	5,501 (1,168) 21%	1,773 (574) 32%	18,650 (5,439) 29%
2015	1,348 (419) 31%	3,878 (1,366) 35%	6,544 (2,893) 44%	1,752 (1,539) 88%
2016	1,338 (302) 23%	3,622 (789) 22%	3,238 (887) 27%	7,241 (1,913) 26%