The following supplements accompany the article

Estimating synchronous changes in condition and density in eastern Bering Sea fishes

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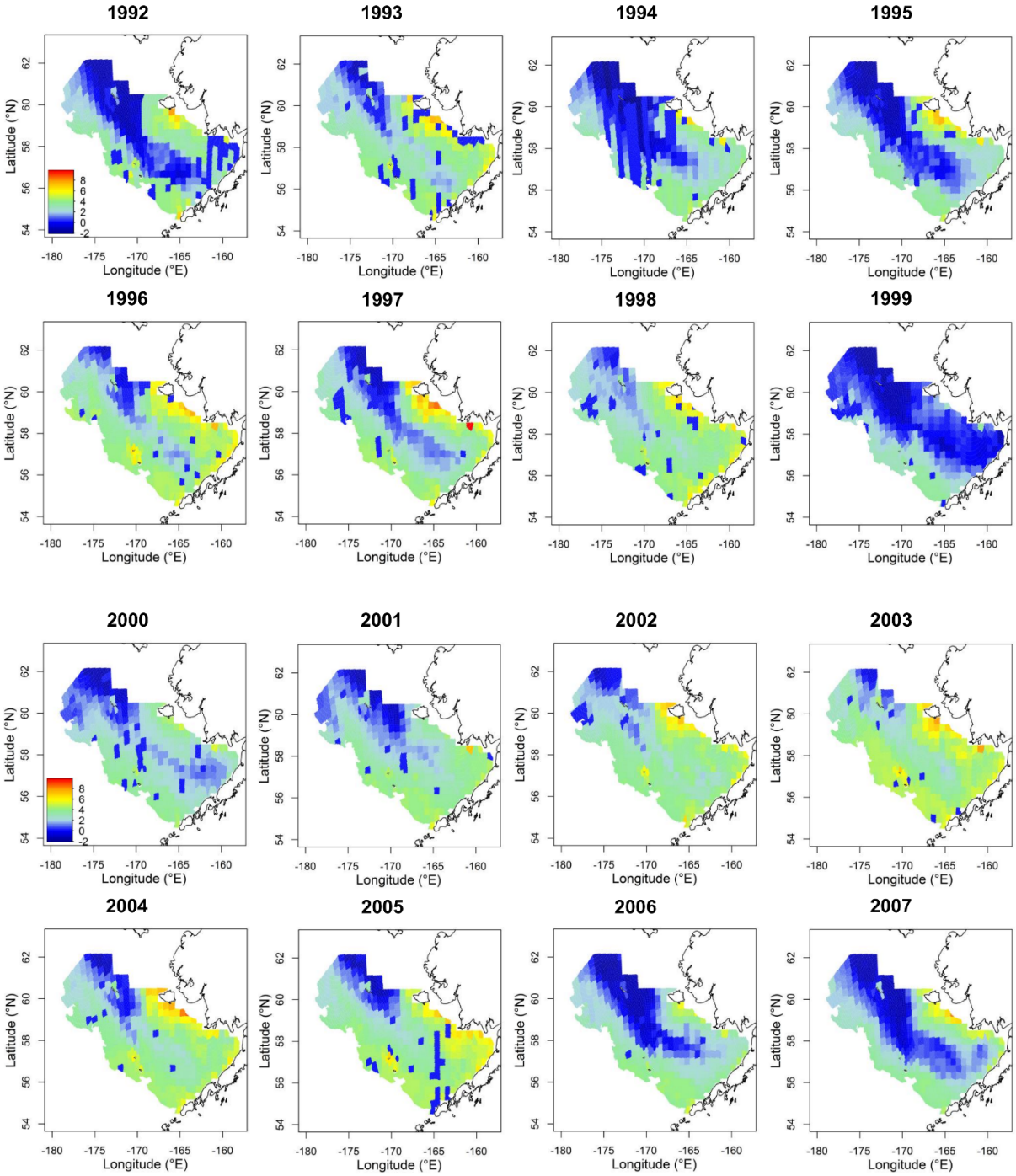
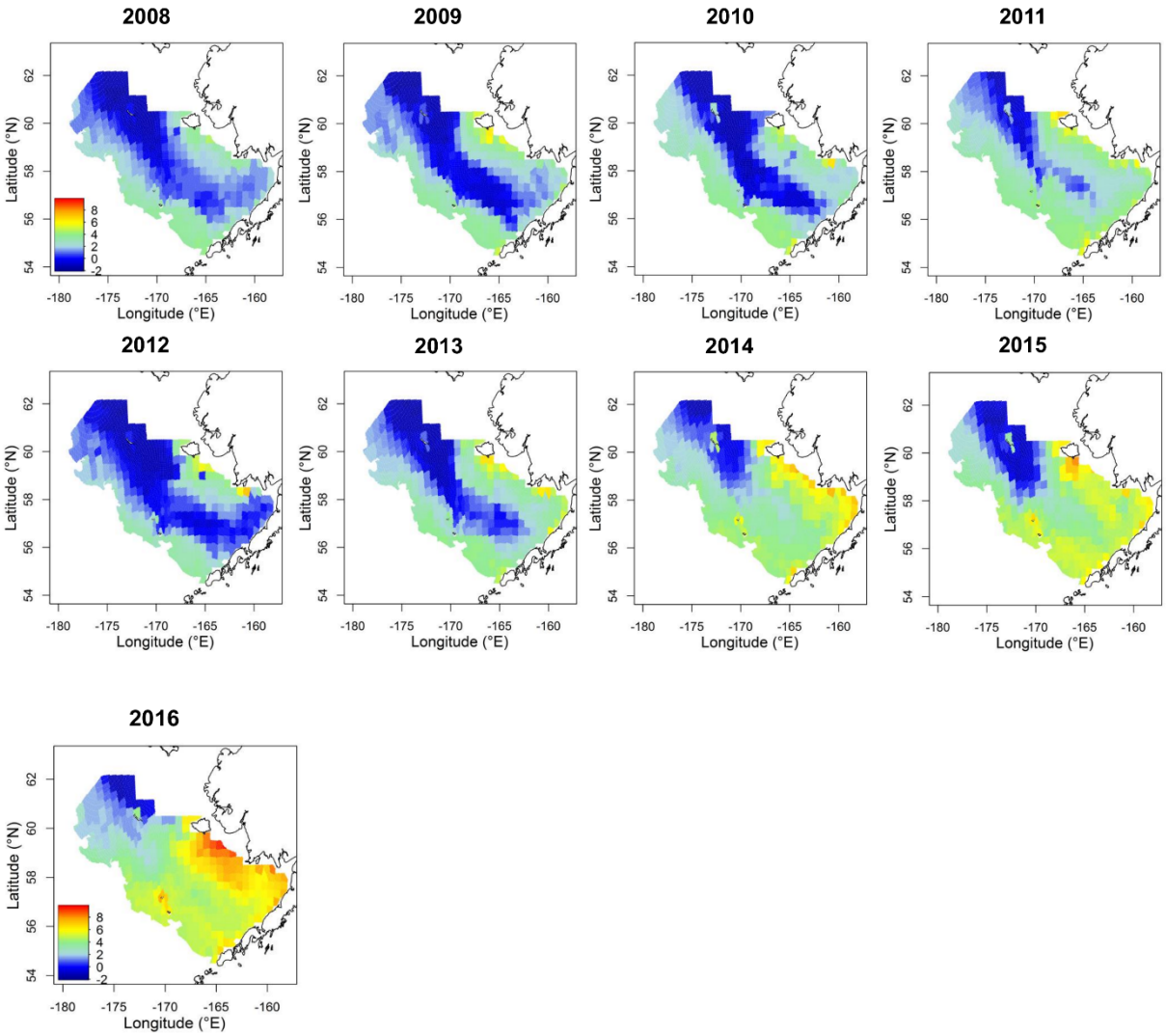
Supplement 1

Fig. S1. Maps showing the bottom temperature estimates (in °C) used within the spatio-temporal models to approximate spatial and spatio-temporal variation in density and condition, for each year of the period 1992-2016.




2008
2009
2010
2011
2012
2013
2014
2015
2016
Latitude (°N)
Longitude (°E)
54
56
58
60
62
-180
-175
-170
-165
-160
8
6
4
2
0
-2

Supplement 2. Details and predictions of the simplified estimator.

Since an abundance-weighted estimate was generated with R package "VAST" for the first time in the present study, we compared the abundance-weighted condition predicted by spatio-temporal models with the abundance-weighted condition predicted by a simplified estimator. The simplified estimator reconstructs trends in abundance-weighted condition directly from data based on dividing the spatial domain into n_l strata, calculating average condition and average density in each stratum, and then calculating the abundance-weighted expansion of condition across strata:

$$\tilde{z}(t) = \frac{1}{n_l}\sum_{l=1}^{n_l} a_l \times \tilde{n}(l,t) \times \tilde{\alpha}(l,t) \tag{S2.1}$$

$$\tilde{n}(l,t) = \frac{1}{n_{s_i}}\sum_{s_i=1}^{n_{s_i}} \frac{n(s_i,t_i)}{a_i}$$

$$\tilde{\alpha}(l,t) = \frac{1}{n_{s_i}}\sum_{s_i=1}^{n_{s_i}} \frac{w(s_i,t_i)}{{l_i}^{\beta}}$$

where $\tilde{z}(t)$ is the abundance-weighted condition at time *t* estimated by the simplified estimator (in units kilograms); n_l is the number of geographic strata considered for calculations with the simplified estimator; a_l is the surface area of strata *l* (in km²); $\tilde{n}(l,t)$ is density in strata *l* at time *t* (in numbers.km^{-2}); $\tilde{\alpha}(l,t)$ is condition in strata *l* at time *t* (in units kilograms); n_{s_i} is the total number of data points collected in strata *l*; t_i and s_i are, respectively, the year and the location associated with sample *i*; $n(s_i,t_i)$ is density at location s_i in year t_i (in numbers.km^{-2}); a_i is the area sampled at location s_i in year t_i (in km²); $w(s_i,t_i)$ is predicted body weight at location s_i in year t_i (in units kilograms); and β is the allometric coefficient estimated by VAST (dimensionless). We specifically applied the simplified estimator when specifying three geographic strata: a north stratum (>59°N), a

central stratum (57-59°N), and a south stratum (<57°N). Our goal was to verify whether the relative trends in abundance-weighted condition predicted by VAST concurred with those calculated using the simplified estimator.

For the six study species, the trends in abundance-weighted condition estimated by the spatio-temporal models usually concurred with the trends produced with the simplified estimator. An exception to this usual pattern was Pacific cod (*Gadus macrocephalus*), for which the simplified estimator suggested a marked peak in abundance-weighted condition in 2004 contrary to the spatio-temporal model (Fig. S2).

Fig. S2. Trends in relative abundance-weighted condition predicted by the Akaike's Information Criterion (AIC)-selected spatio-temporal models (grey line: mean; grey shading: 95% confidence interval) and the simplified estimator (dashed black line) for the six study species. For each species, only predictions for those years where both density and length-weight data were available are shown. Relative abundance-weighted condition is abundance-weighted condition relative to mean abundance-weighted condition over the years for which both density and length-weight data were available.

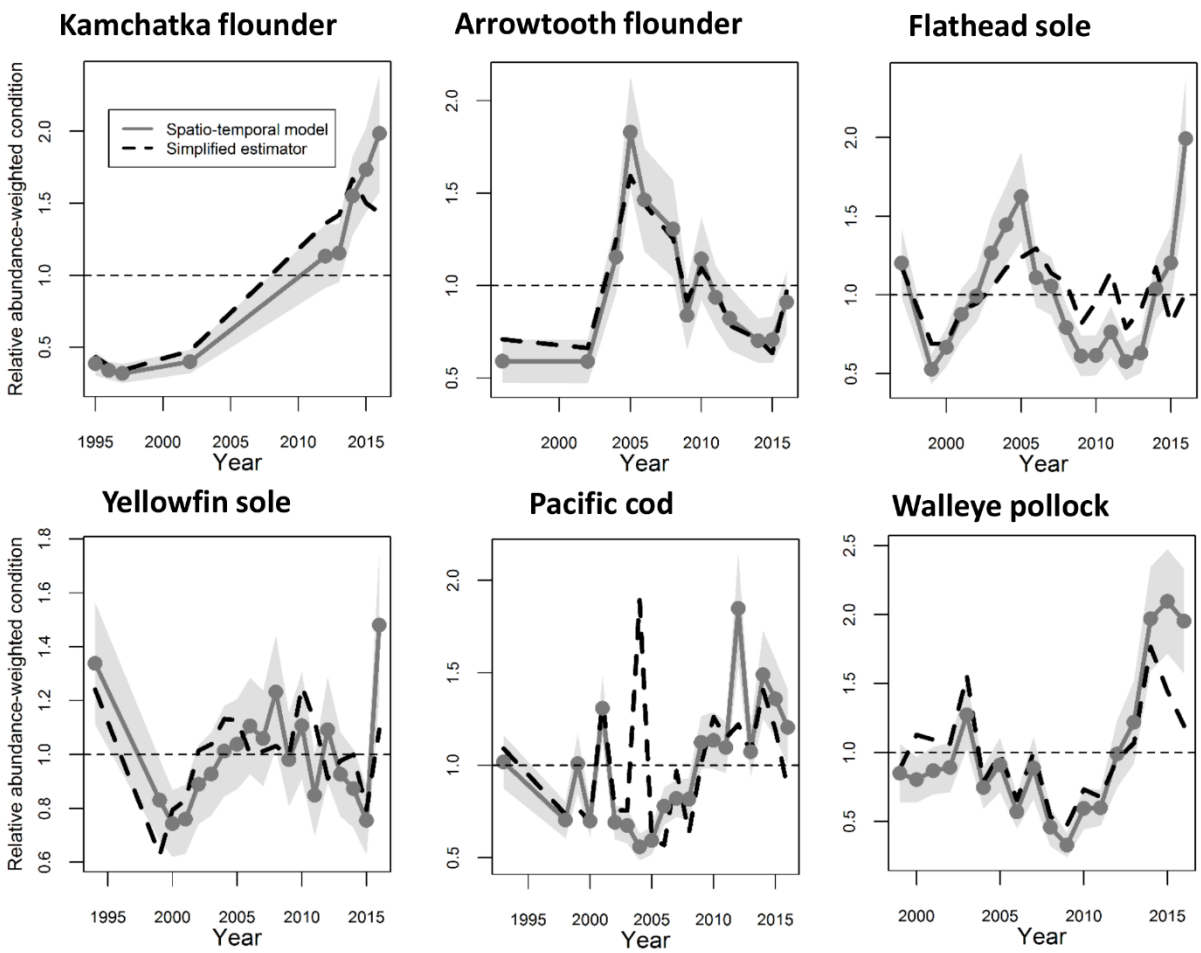


Fig. S3. Residuals of the Akaike's Information Criterion (AIC)-selected models versus fish length (in mm).

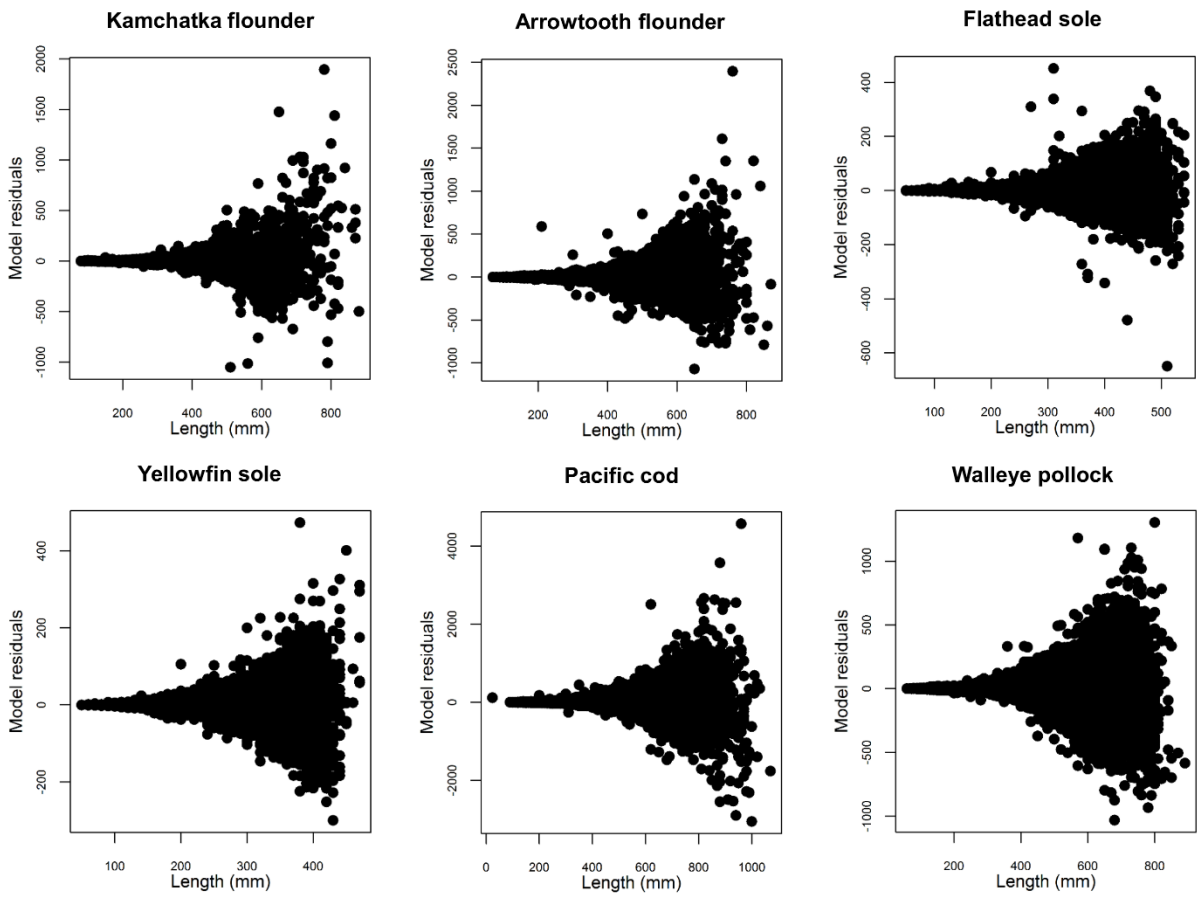
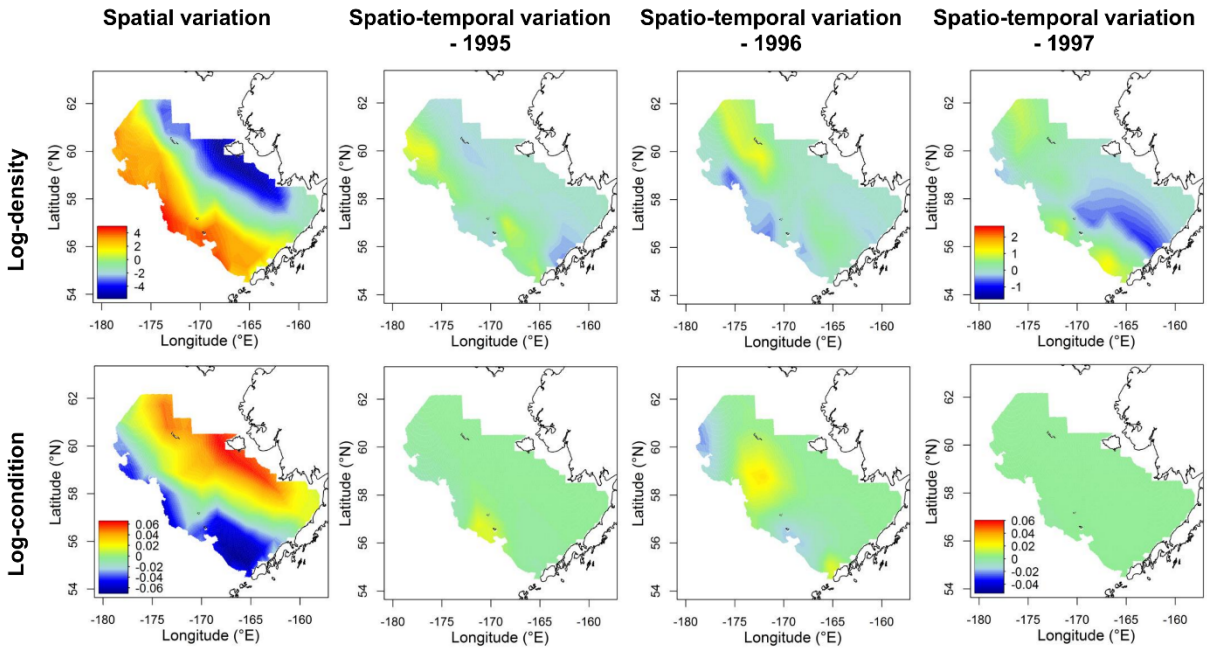
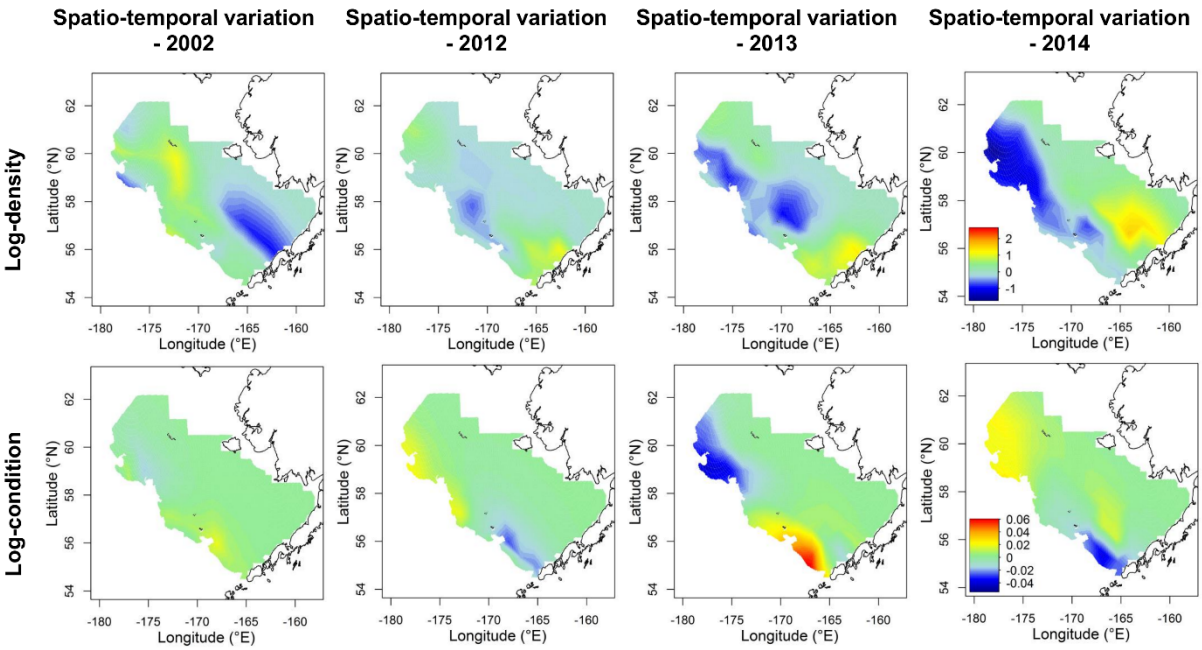
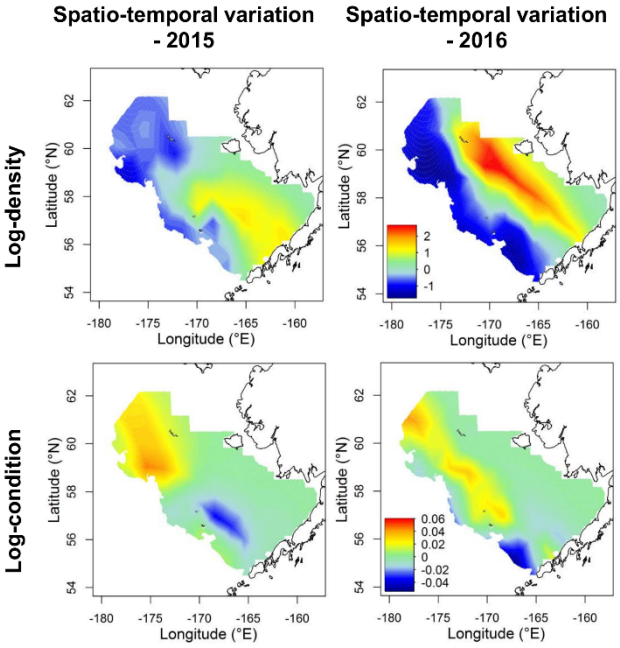


Fig. S4. Spatial variation in log-density and log-condition and spatio-temporal variation in log-density and log-condition for different years of the period 1992-2016, for the Akaike's Information Criterion (AIC)-selected models of the six study species. The color legends for spatio-temporal variation in log-density and log-condition are provided in the rightmost columns and have units ln(abundance.km^{-2}) in the case of log-density and ln(g) in the case of log-condition. For each species, only estimations for those years where both density and length-weight data were available are shown.

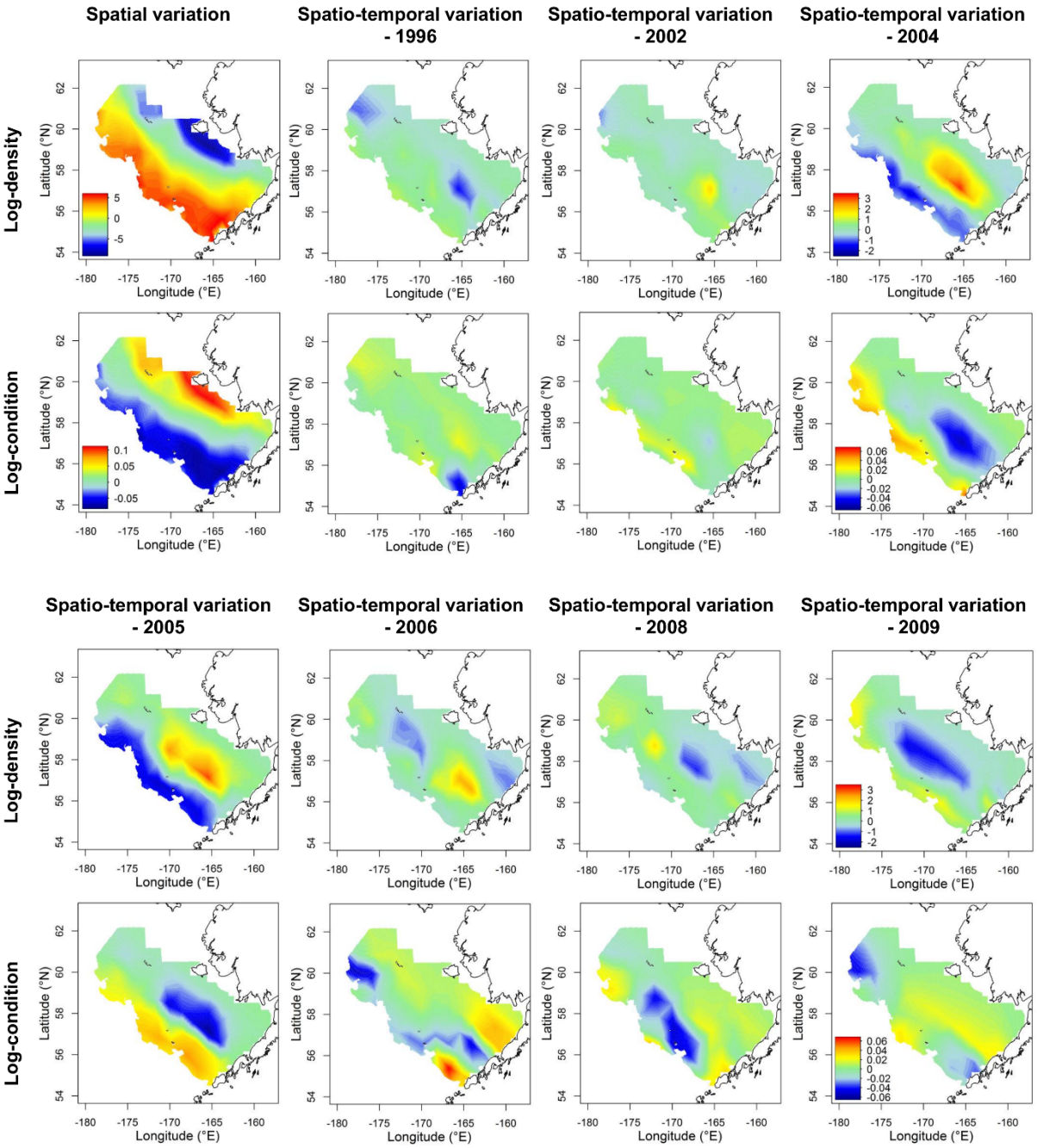
Kamchatka flounder (*Atheresthes evermanni*)

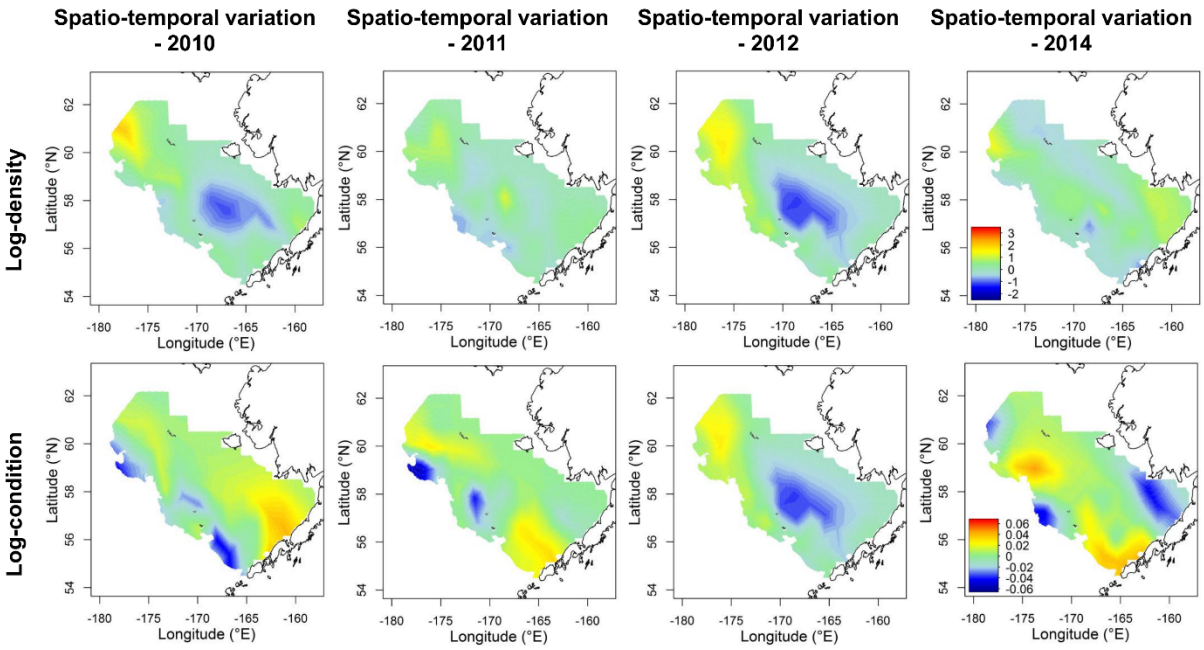


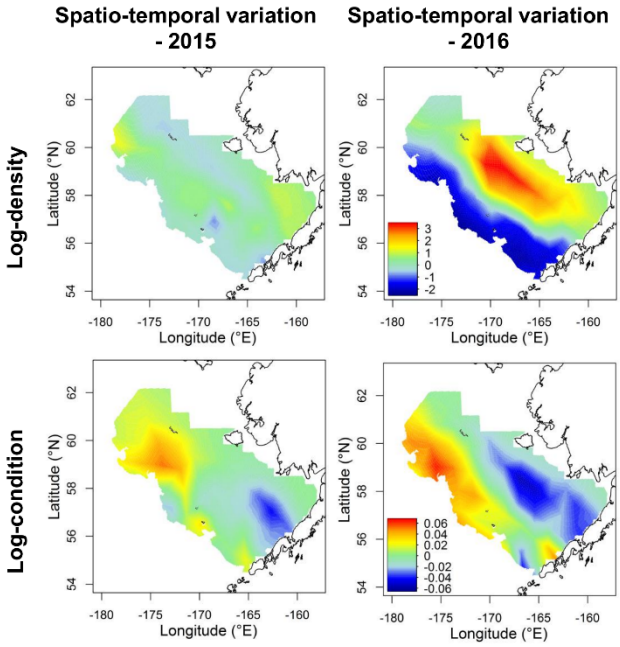

Spatio-temporal variation - 2002
Spatio-temporal variation - 2012
Spatio-temporal variation - 2013
Spatio-temporal variation - 2014
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
0.06
0.04
0.02
0
-0.02
-0.04


Spatio-temporal variation - 2015
Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
0.06
0.04
0.02
0
-0.02
-0.04

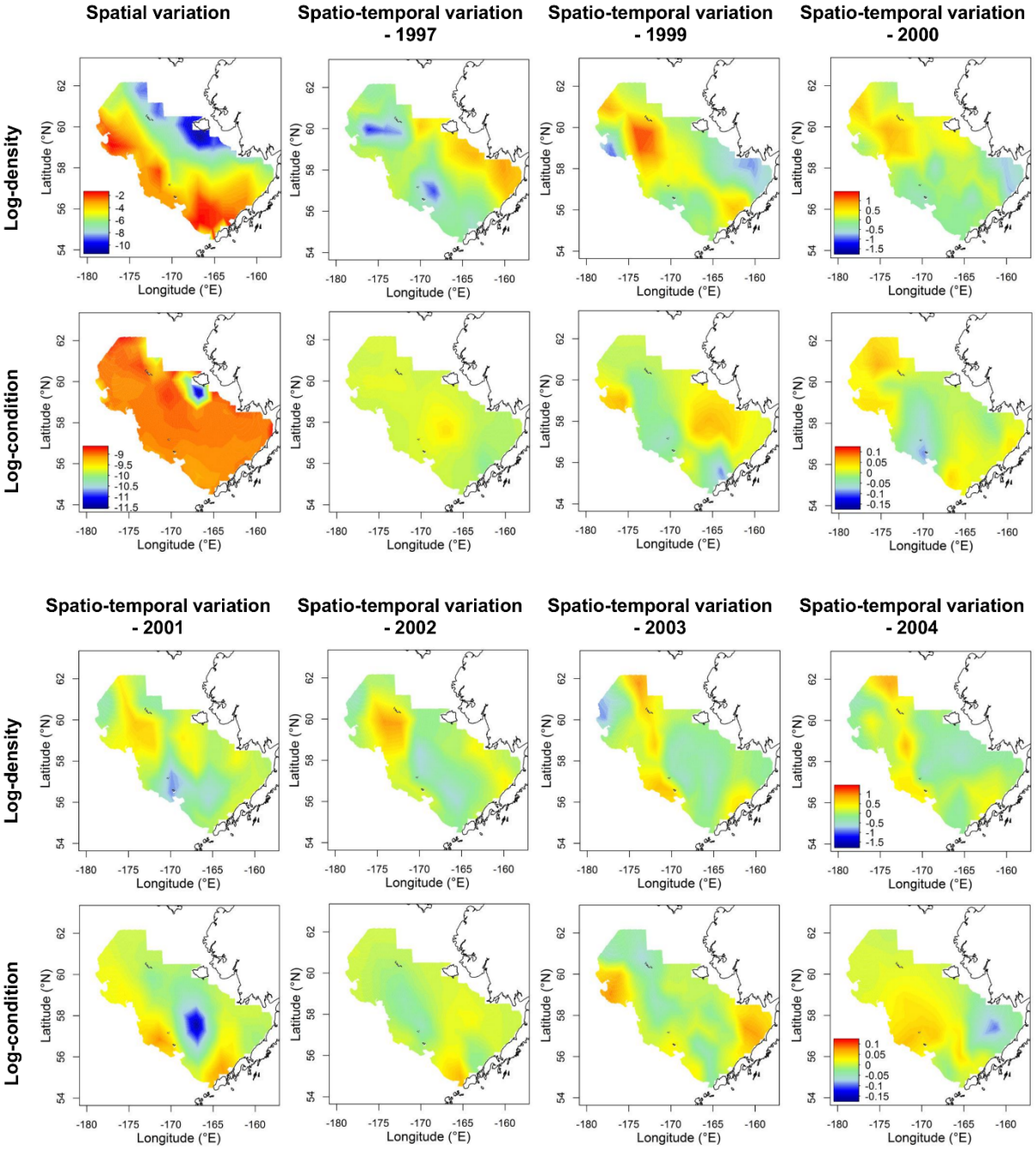
Arrowtooth flounder (*Atheresthes stomias*)

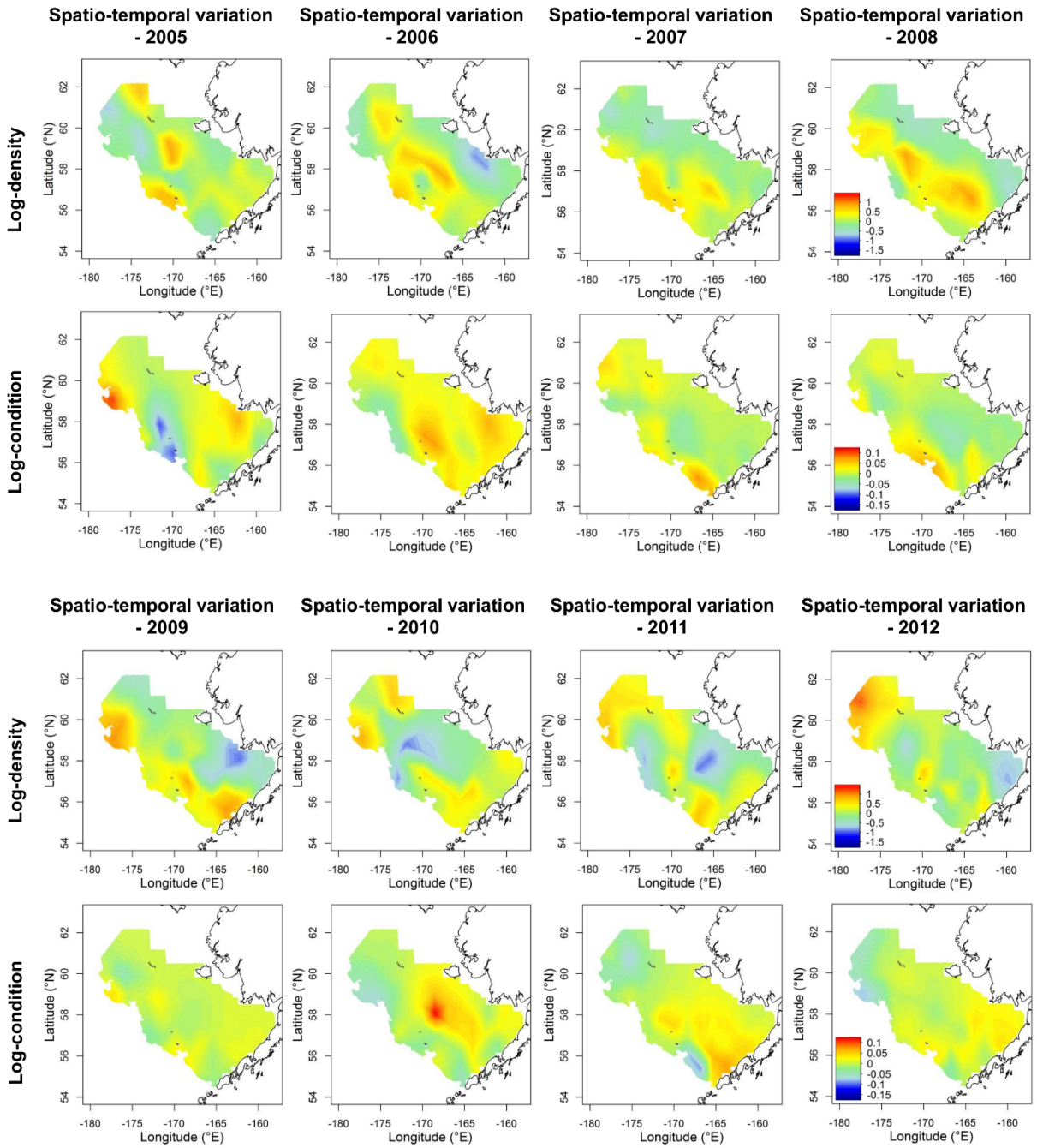


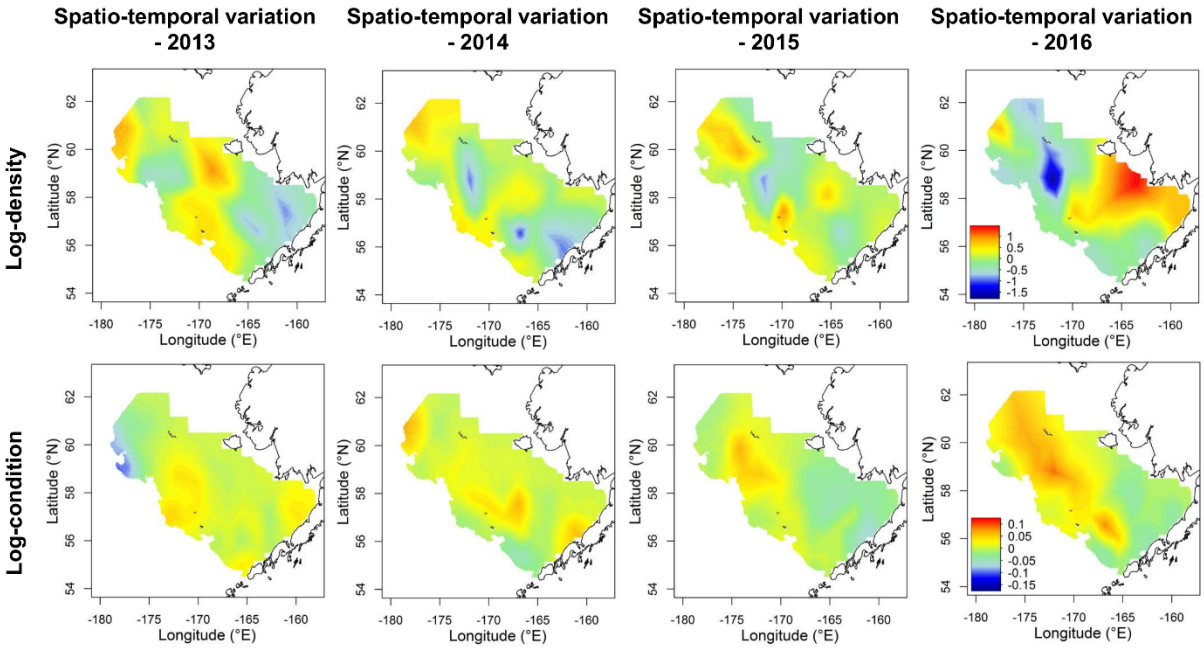

Spatio-temporal variation - 2010
Spatio-temporal variation - 2011
Spatio-temporal variation - 2012
Spatio-temporal variation - 2014
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
3
2
1
0
-1
-2
0.06
0.04
0.02
0
-0.02
-0.04
-0.06


Spatio-temporal variation - 2015
Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
3
2
1
0
-1
-2
0.06
0.04
0.02
0
-0.02
-0.04
-0.06

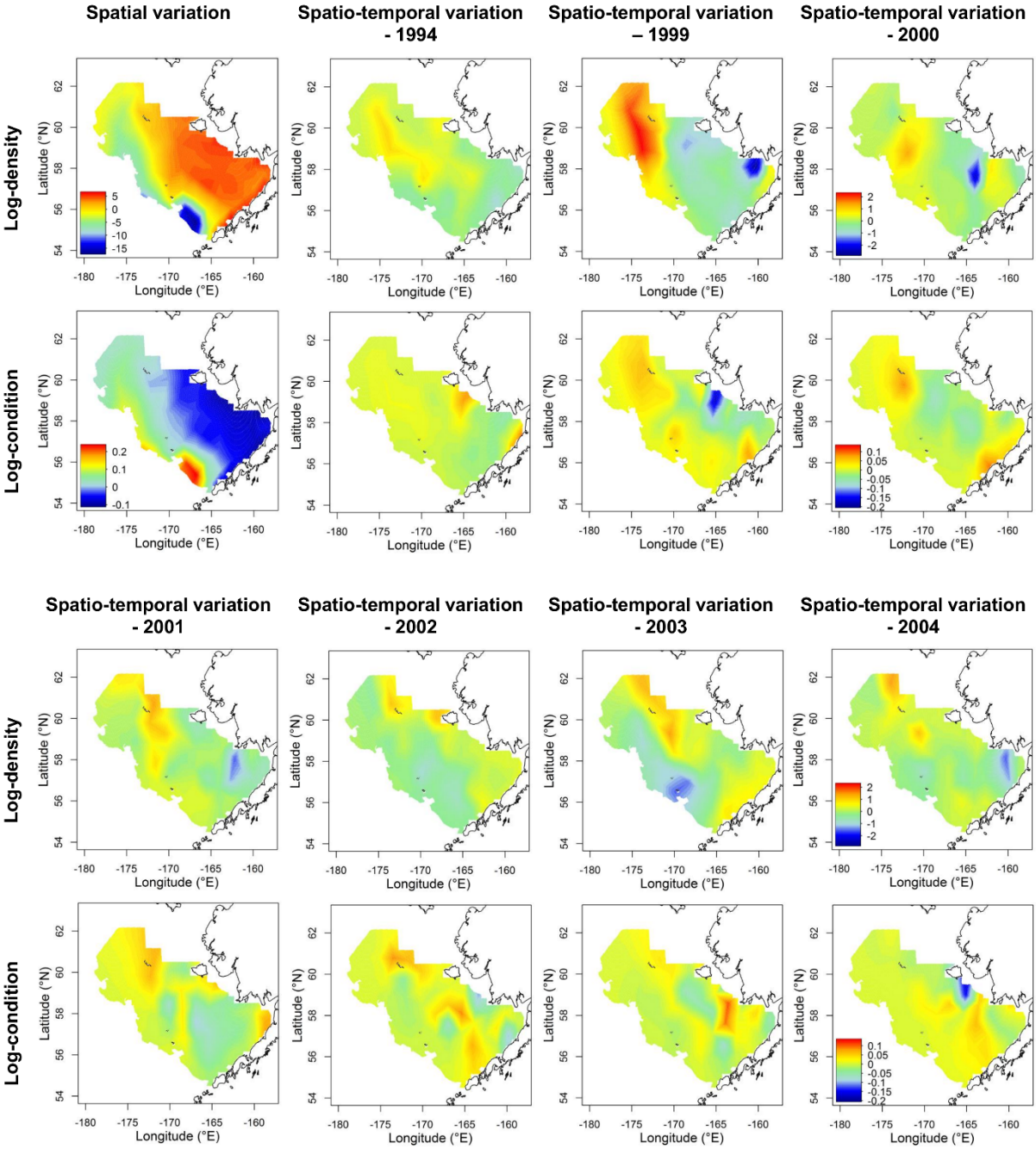
Flathead sole (*Hippoglossoides elassodon*)

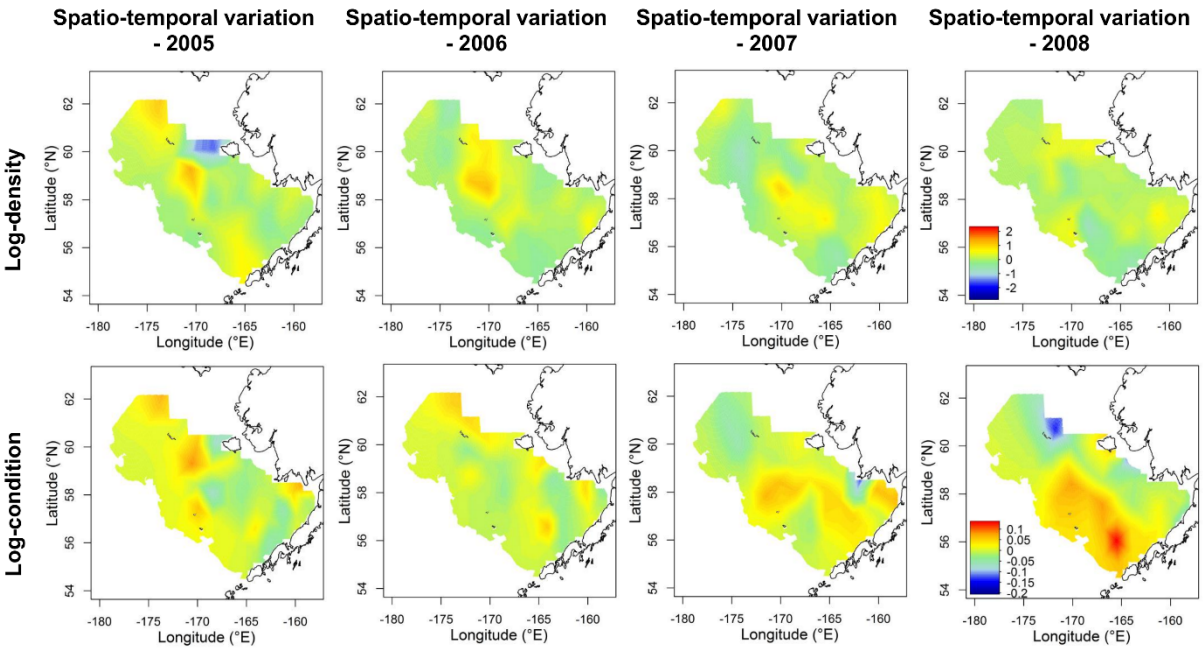


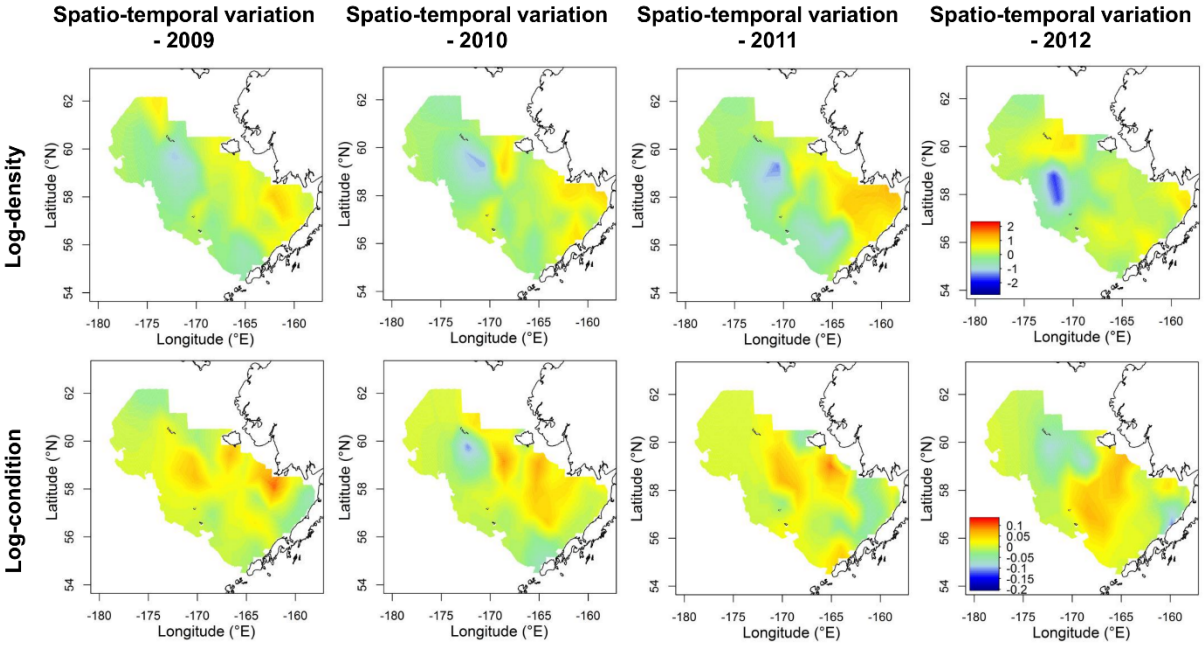

Spatio-temporal variation - 2005
Spatio-temporal variation - 2006
Spatio-temporal variation - 2007
Spatio-temporal variation - 2008
Spatio-temporal variation - 2009
Spatio-temporal variation - 2010
Spatio-temporal variation - 2011
Spatio-temporal variation - 2012
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
1
0.5
0
-0.5
-1
-1.5
0.1
0.05
0
-0.05
-0.1
-0.15

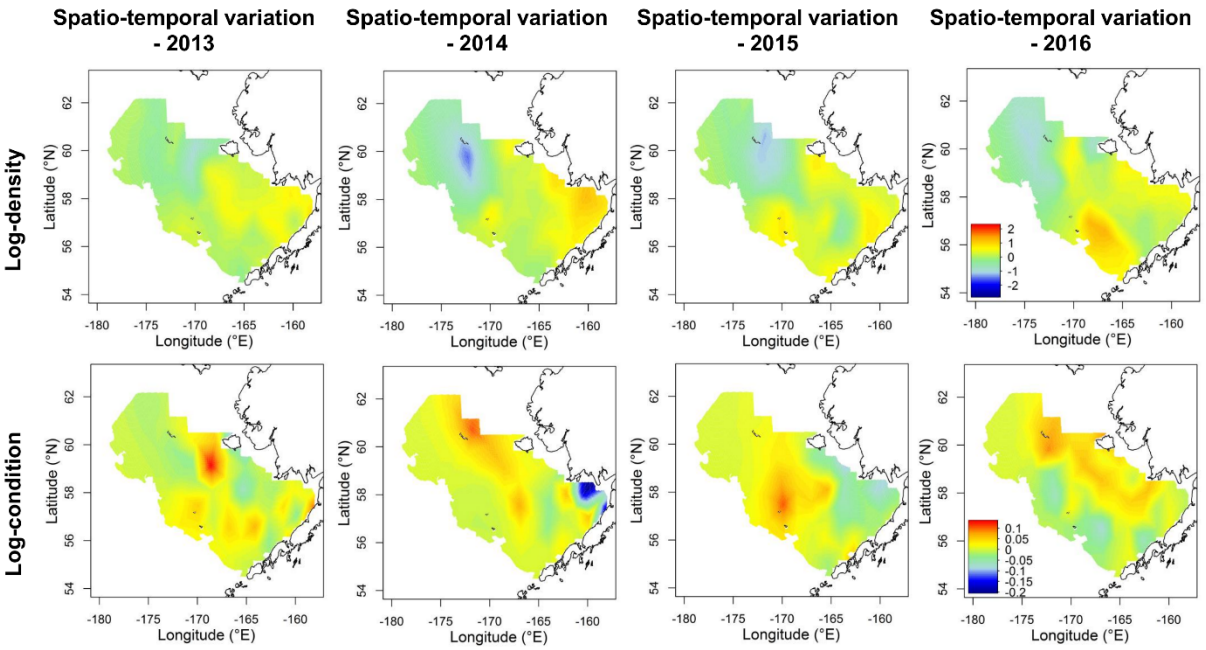

Spatio-temporal variation - 2013
Spatio-temporal variation - 2014
Spatio-temporal variation - 2015
Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
1
0.5
0
-0.5
-1
-1.5
0.1
0.05
0
-0.05
-0.1
-0.15

Yellowfin sole (*Limanda aspera*)

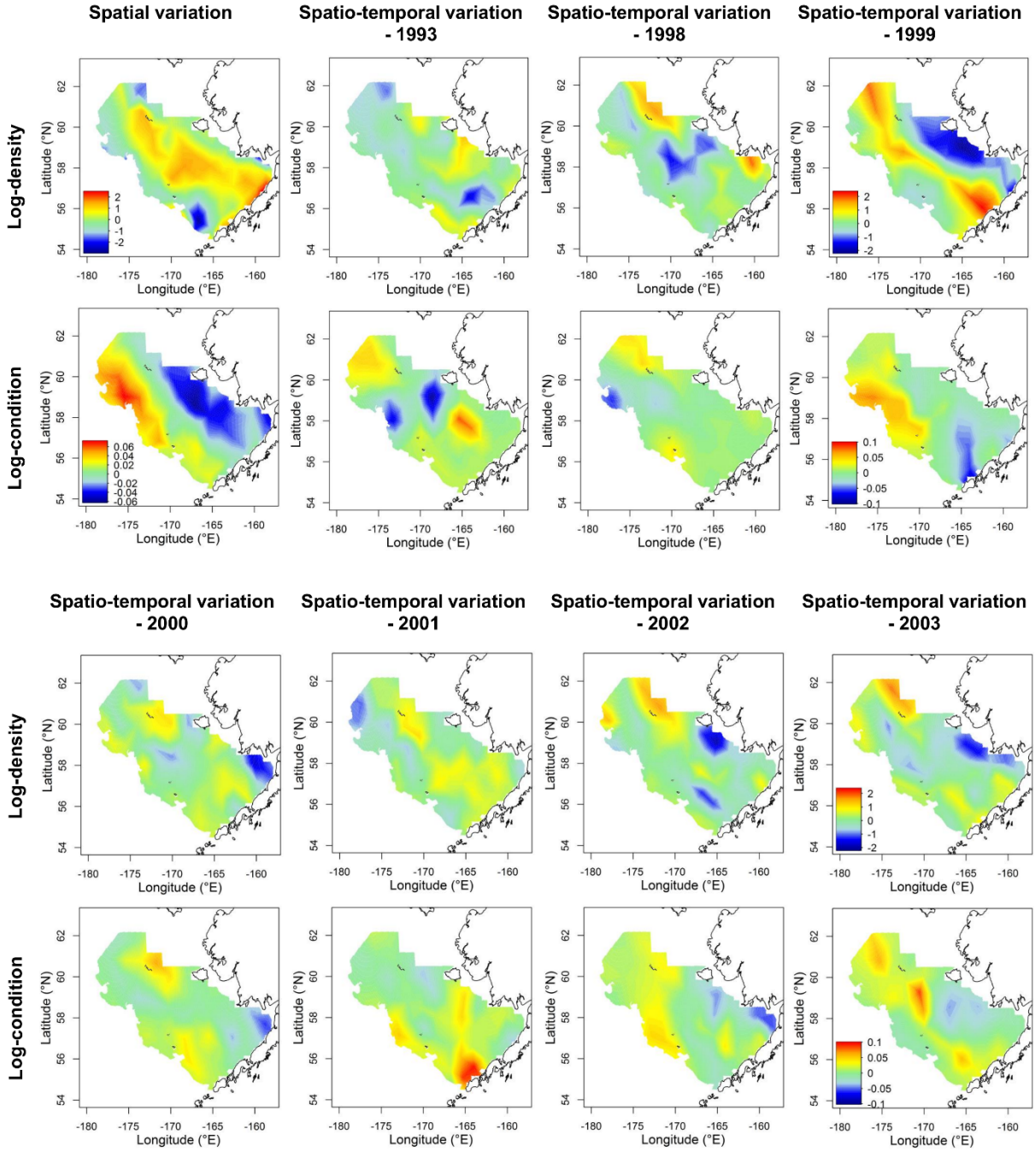


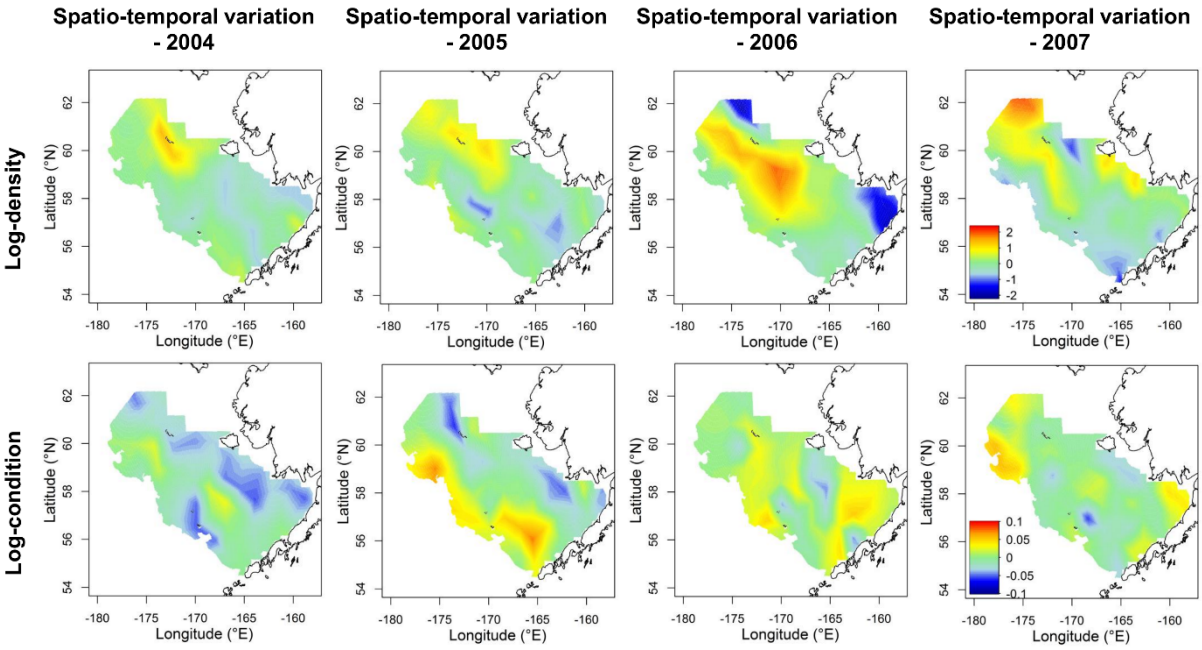

Spatio-temporal variation - 2005
Spatio-temporal variation - 2006
Spatio-temporal variation - 2007
Spatio-temporal variation - 2008
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

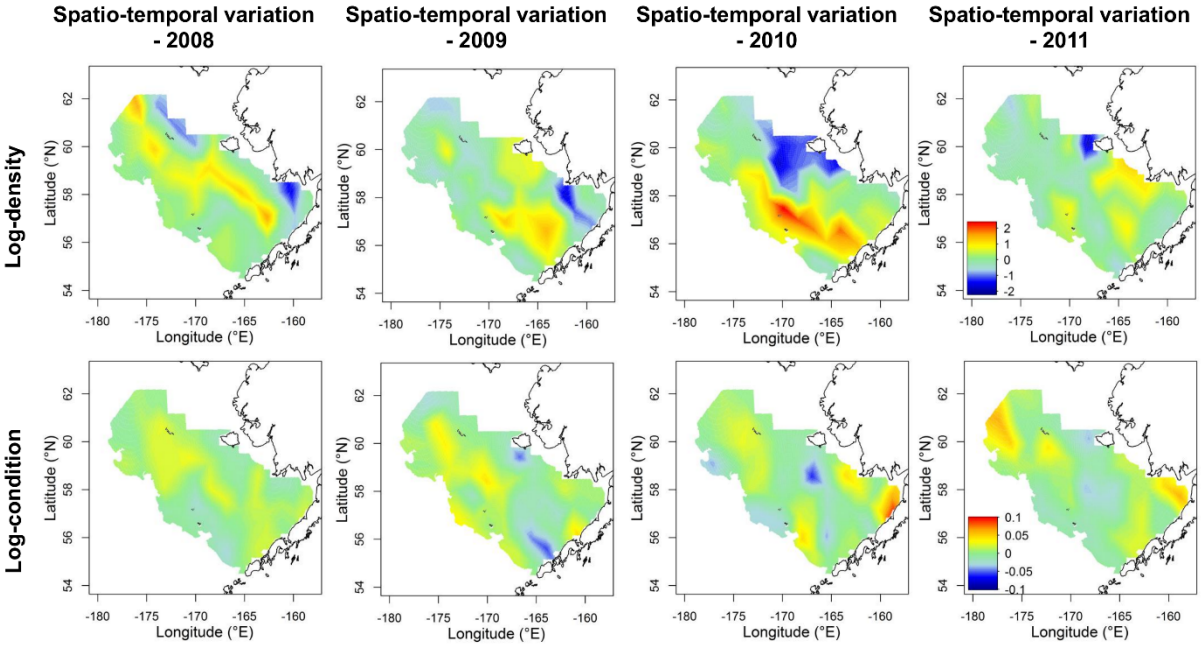

Spatio-temporal variation - 2009
Spatio-temporal variation - 2010
Spatio-temporal variation - 2011
Spatio-temporal variation - 2012
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

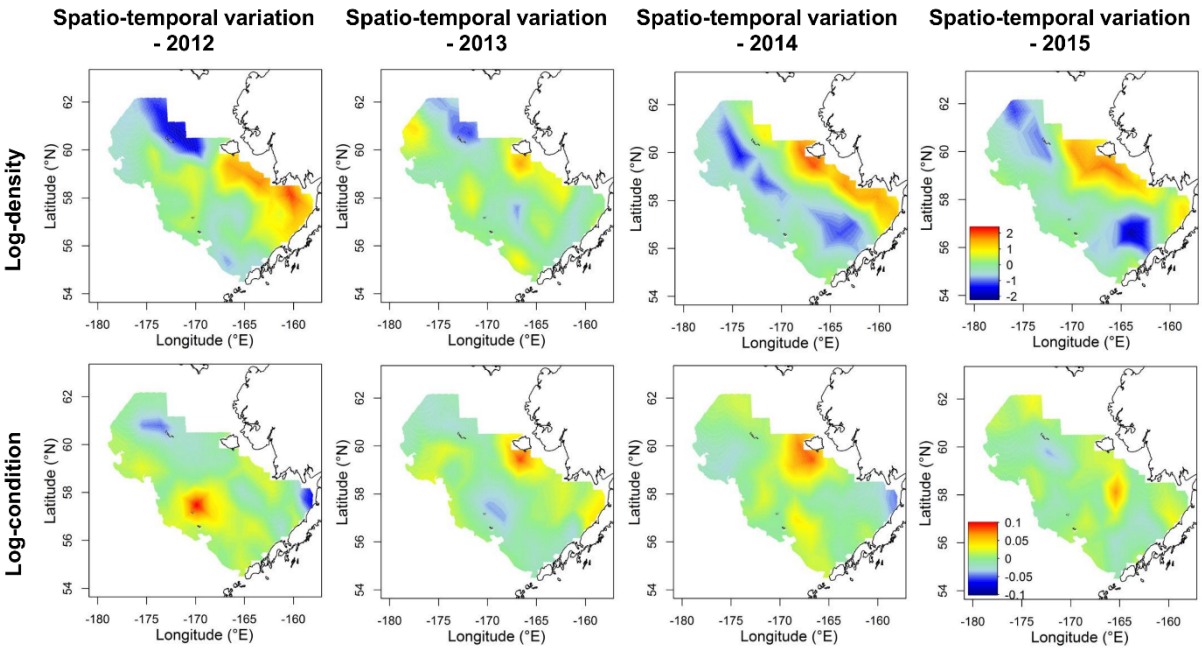

Spatio-temporal variation - 2013
Spatio-temporal variation - 2014
Spatio-temporal variation - 2015
Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2

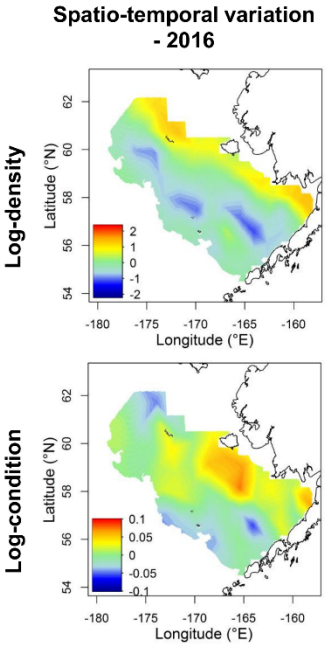
Pacific cod (*Gadus macrocephalus*)



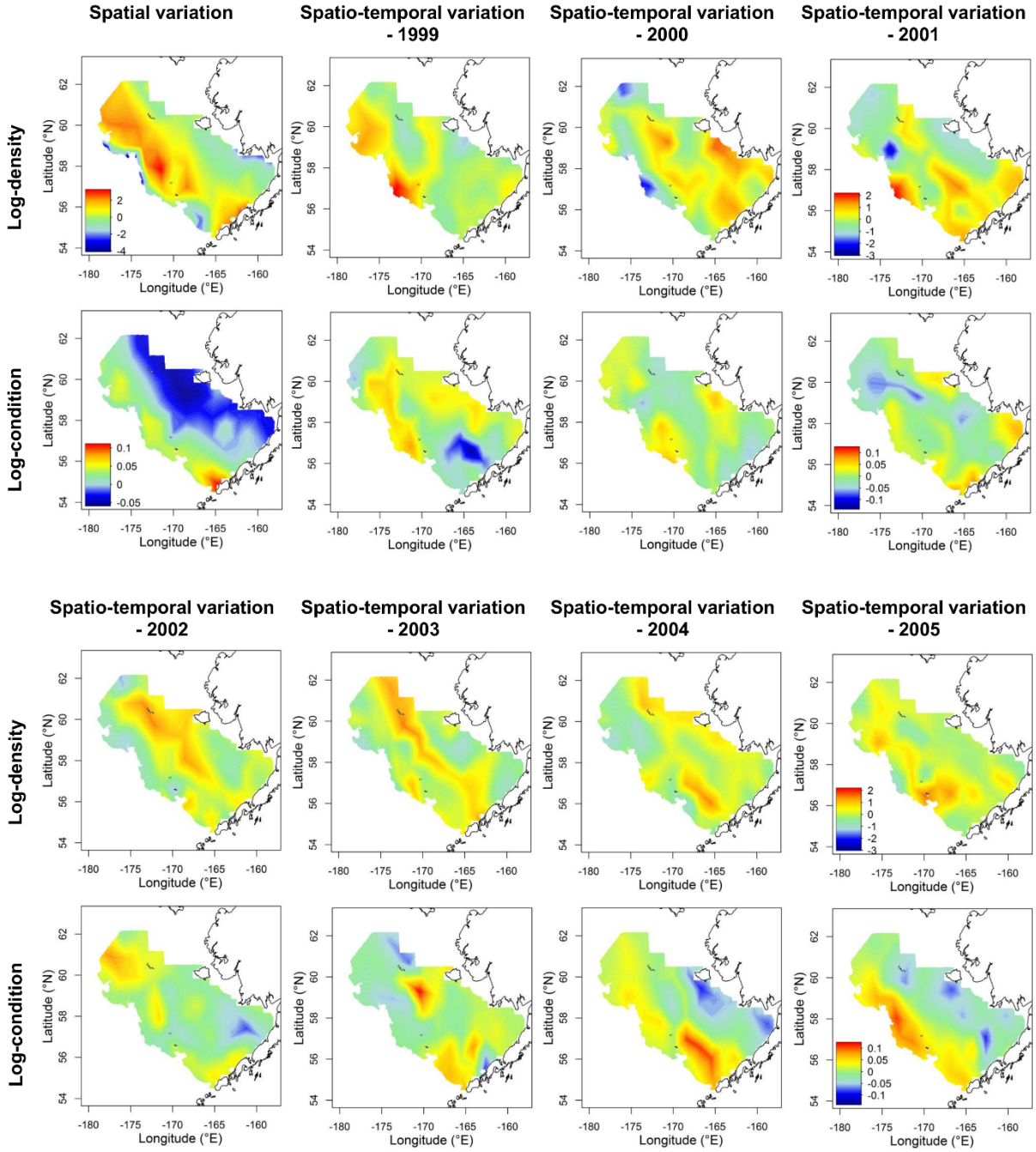

Spatio-temporal variation - 2004
Spatio-temporal variation - 2005
Spatio-temporal variation - 2006
Spatio-temporal variation - 2007
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1

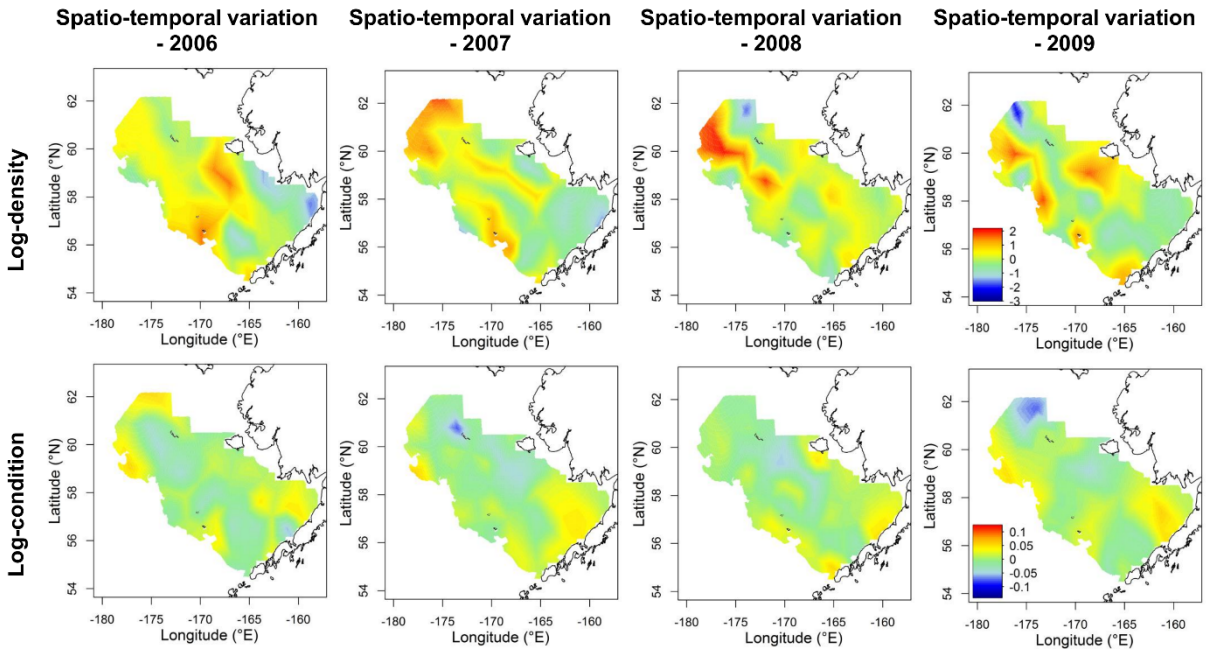

Spatio-temporal variation - 2008
Spatio-temporal variation - 2009
Spatio-temporal variation - 2010
Spatio-temporal variation - 2011
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1

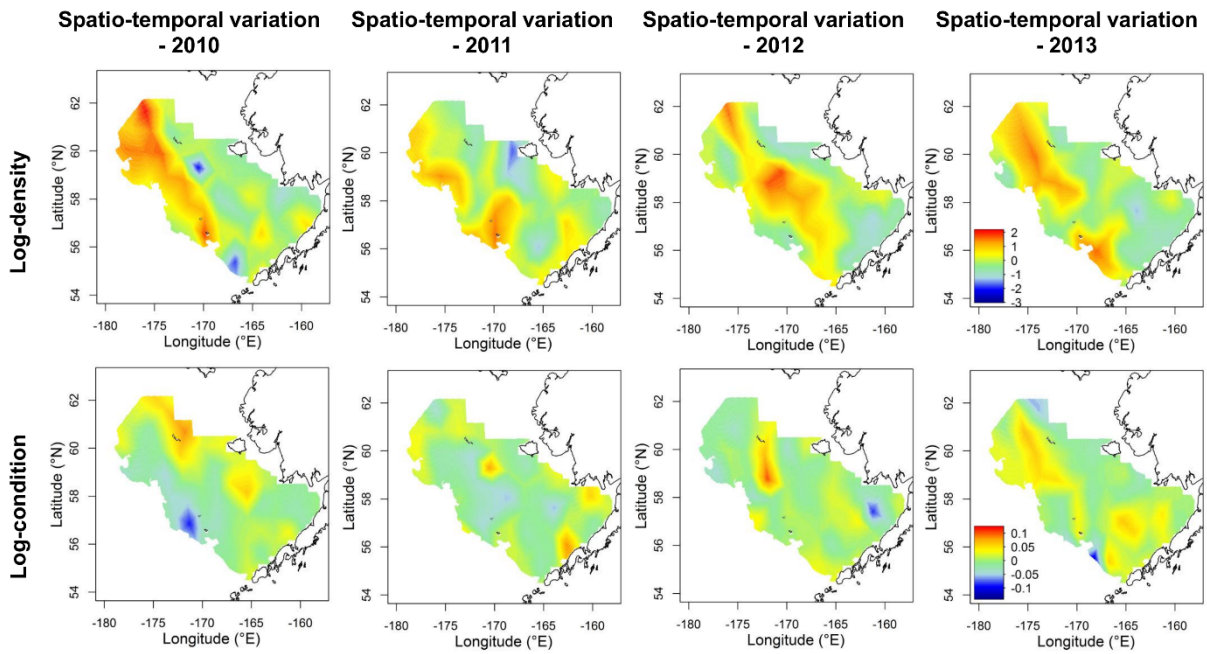

Spatio-temporal variation - 2012
Spatio-temporal variation - 2013
Spatio-temporal variation - 2014
Spatio-temporal variation - 2015
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1


Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
0.1
0.05
0
-0.05
-0.1

Walleye pollock (*Gadus chalcogrammus*)




Spatio-temporal variation - 2006
Spatio-temporal variation - 2007
Spatio-temporal variation - 2008
Spatio-temporal variation - 2009
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
-3
0.1
0.05
0
-0.05
-0.1


Spatio-temporal variation - 2010
Spatio-temporal variation - 2011
Spatio-temporal variation - 2012
Spatio-temporal variation - 2013
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
2
1
0
-1
-2
-3
0.1
0.05
0
-0.05
-0.1

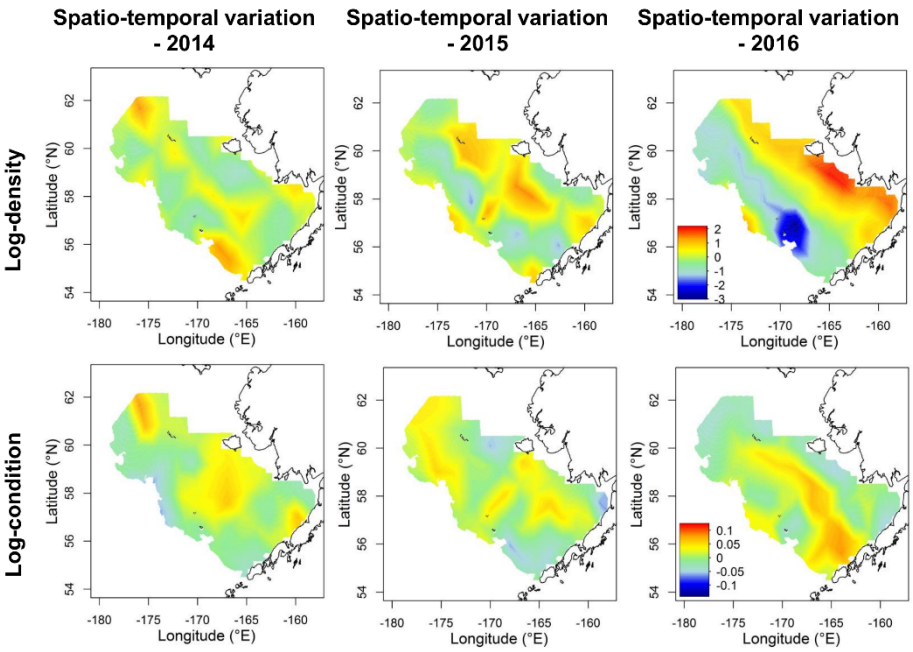
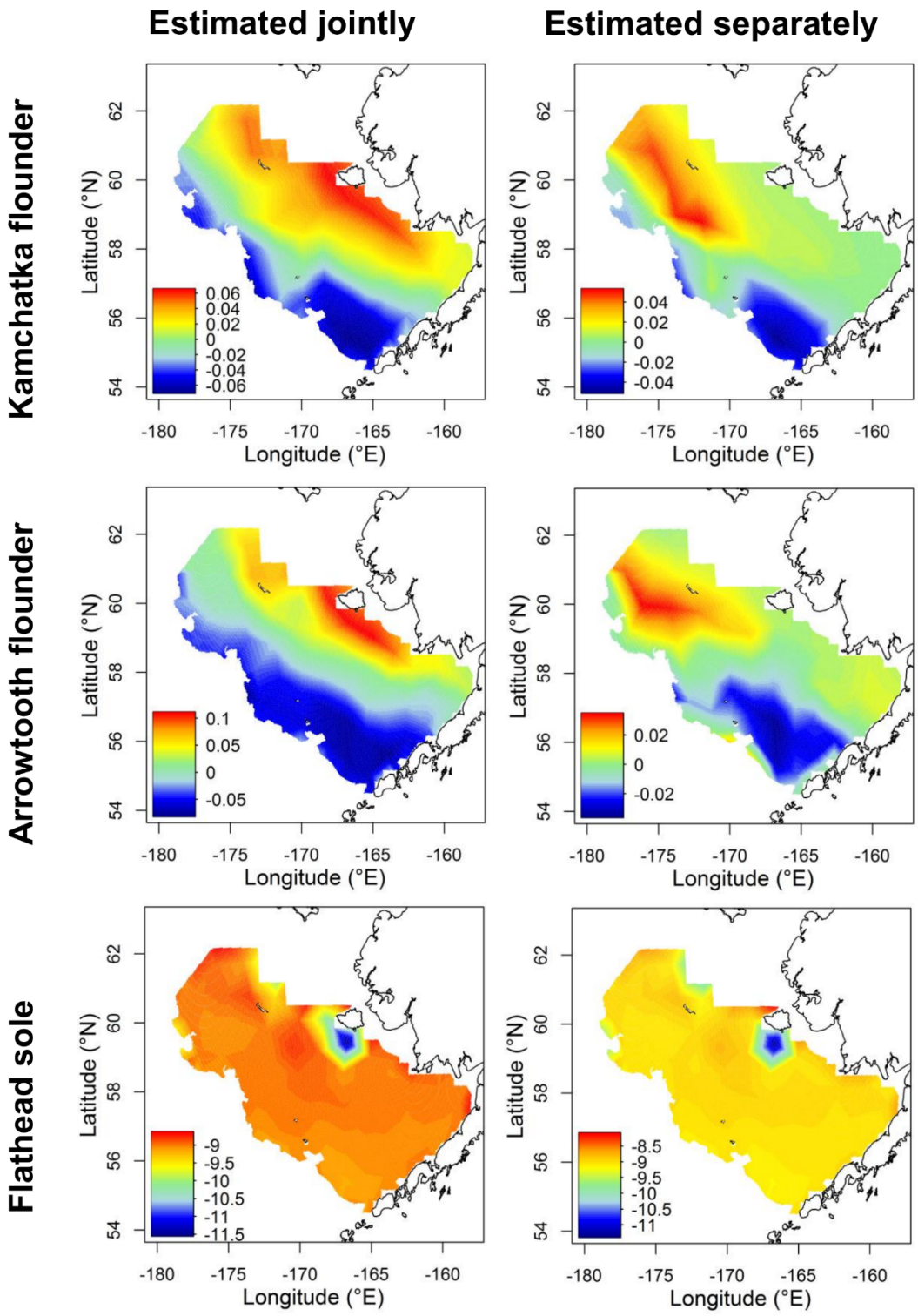
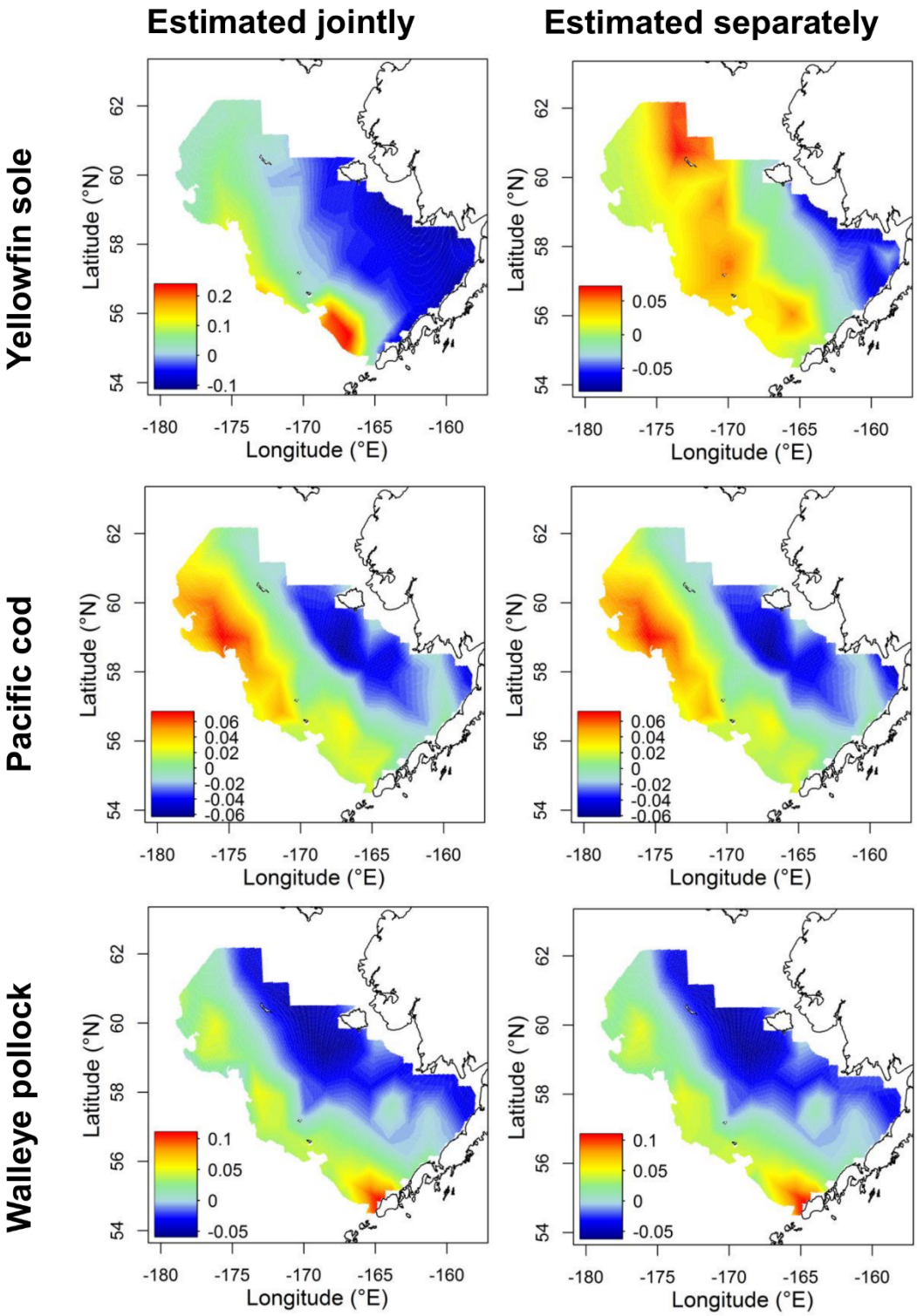

Spatio-temporal variation - 2014
Spatio-temporal variation - 2015
Spatio-temporal variation - 2016
Log-density
Log-condition
Latitude (°N)
Longitude (°E)
54
56
58
60
62
-180
-175
-170
-165
-160
2
1
0
-1
-2
-3
0.1
0.05
0
-0.05
-0.1

Fig. S5. Spatial variation in log-condition (in ln(g)) predicted by the Akaike's Information Criterion (AIC)-selected models of the six study species, when density and condition are estimated jointly versus separately.




Estimated jointly
Estimated separately
Yellowfin sole
Pacific cod
Walleye pollock
Latitude (°N)
Longitude (°E)
54
56
58
60
62
-180
-175
-170
-165
-160
0.2
0.1
0
-0.1
0.05
0
-0.05
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0.1
0.05
0
-0.05