Figure S1. Spatial variation in bottom temperatures (images) and arrowtooth flounder natural log-transformed catch per unit effort (n km^{-2}, bubble sizes) from the groundfish survey during four years with contrasting flounder abundance (B) and bottom temperature (T). The thermometer on the upper right corner of each plot indicates the relative flounder population biomass (from the stock assessment report) in each year. The years shown are (A) 1986, low B and low T, (C) 1987 low B and high T, (D) 2007 high B and low T, and (E) 2003 high B and high T. Also the 2°C isotherm and the 200m isobath are shown in white and grey, respectively.
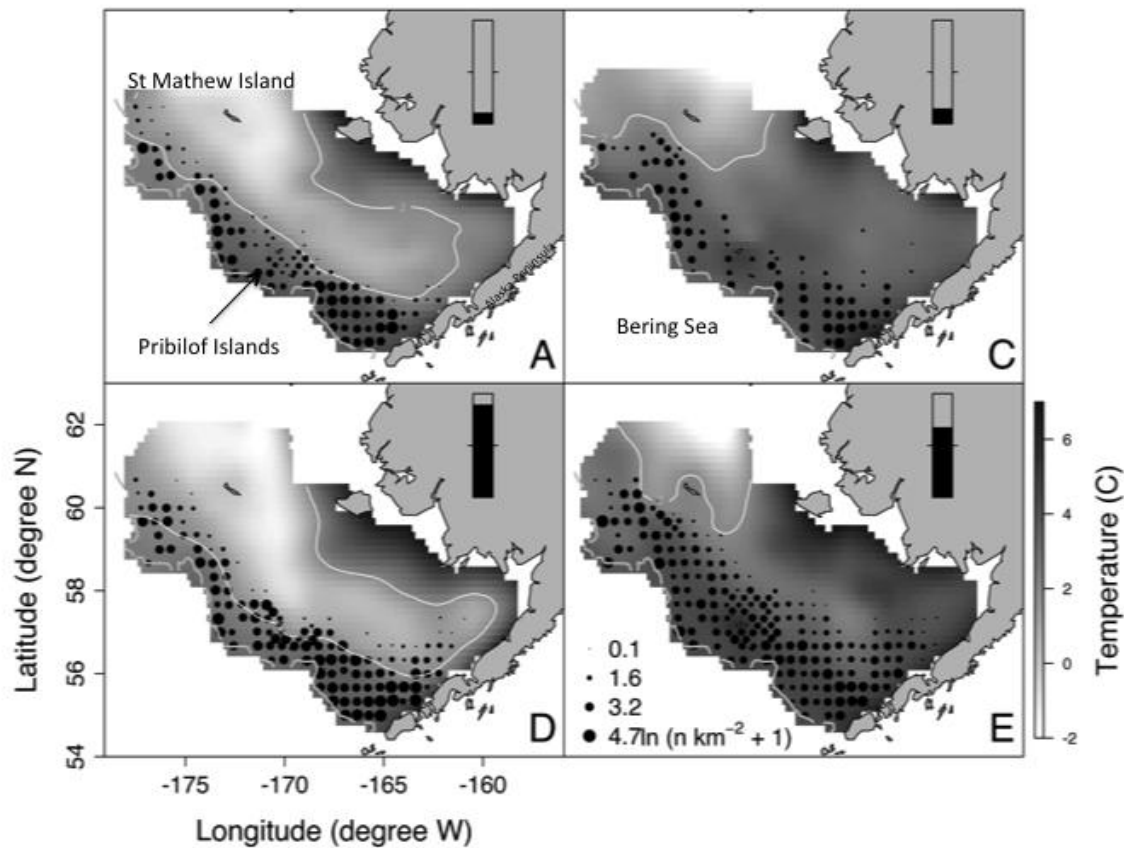
SUPPLEMENT 2: EXPLANATIONS OF GENERALIZED ADDITIVE MIXED MODELS

The additive formulation is:

$$x_{(\varphi,\lambda,y,t)} = \alpha_1 B_y + \alpha_2 T_{(\varphi,\lambda,y,t)} + g_1[K_{(\varphi,\lambda)}] + g_2[D_{(\varphi,\lambda)}] + s_1(\varphi,\lambda) + e_{(\varphi,\lambda,y,t)} \qquad (1)$$

where $x_{y,(\varphi,\lambda)}$ is the natural logarithm of flounder numerical cpue (+ 1) at a particular location φ, λ (identified by longitude and latitude degrees), in year y. α_1 and α_2 are slope coefficients describing the effects of total population biomass (B) and local water temperature (T) on the local flounder cpue, g_{1-2} are univariate smooth functions (thin plate regression splines, Wood 2004, 2006) used to capture the relationship between flounder cpue and sediment size (K), depth (D) where the survey occurred, s_1 is a 2-dimesional smoothing function (thin plate regression spline, Wood 2004) that captures the underlying spatial distribution of flounder which is not otherwise captured by the other covariates.

We can build upon the formulation in (1) by including a nonadditive interaction between B and T and by making their effects spatially variable. Namely,

$$\begin{aligned} x_{(\varphi,\lambda,y,t)} = {} & g_1[K_{(\varphi,\lambda)}] + g_2[D_{(\varphi,\lambda)}] + s_1(\varphi,\lambda) + \\ & + s_2(\varphi,\lambda) \cdot T_{(\varphi,\lambda,y,t)} + s_3(\varphi,\lambda) \cdot B_y + s_4(\varphi,\lambda) \cdot T_{(\varphi,\lambda,y,t)} \cdot B_y + e_{(\varphi,\lambda,y,t)} \end{aligned} \qquad (2)$$

where s_{2-4} are two-dimensional smoothing functions that define the local linear effect of T, B and their interactions (T·B) on x, respectively. In essence s_{2-4} define a landscape of linear slopes for their respective covariate terms. Here, it is assumed that T and B have linear effects on x, but such effects can be nonadditive and spatially variable. The one

constraint imposed by this and the following formulation is that the changes of slopes associated with B, T and T·B are smooth, that is twice differentiable (26).

The third and most complex formulation assumes that the effect of B, T and T·B may change in relation to the overall biomass of flounder (B). It is further assumed that such change occurs abruptly, once the overall flounder biomass (B) crosses a threshold value (B*), to be estimated within the model. Namely,

$$x_{(\varphi, \lambda, y, t)} = g_1[K_{(\varphi, \lambda)}] + g_2[D_{(\varphi, \lambda)}] + s_1(\varphi, \lambda) + e_{y, (\varphi, \lambda)} +$$

$$+ \begin{cases} s_2(\varphi, \lambda) \cdot T_{(\varphi, \lambda, y, t)} + s_3(\varphi, \lambda) \cdot B_y + s_4(\varphi, \lambda) \cdot T_{(\varphi, \lambda, y, t)} \cdot B_y & \text{if } B_y \leq B^* \\ s_5(\varphi, \lambda) \cdot T_{(\varphi, \lambda, y, t)} + s_6(\varphi, \lambda) \cdot B_y + s_7(\varphi, \lambda) \cdot T_{(\varphi, \lambda, y, t)} \cdot B_y & \text{if } B_y > B^* \end{cases}$$

(3)

where s_{2-4} and s_{5-7} are two sets of two-dimensional smoothing functions that define the local linear effect of T, B and their interactions (T·B) on x, before and after the change of phase induced by an increase of flounder population biomass.

Literature cited

Wood, S. N. 2004. Stable and efficient multiple smoothing parameter estimation for generalized additive models. *J. Am. Stat. Ass.* **99**: 637-686.

Wood, S.N. 2006 Generalized additive models: An introduction with R. Chapman and Hall/CRC, Boca Raton, Florida, USA.

Figure S3. Time series of arrowtooth flounder standardized and actual biomass (top panel) from stock assessment reports, average bottom temperature in the middle shelf of the Bering Sea (middle panel) and occupancy of flounder (bottom panel) measured as the number of consistently sampled stations in which at least one individual was caught.
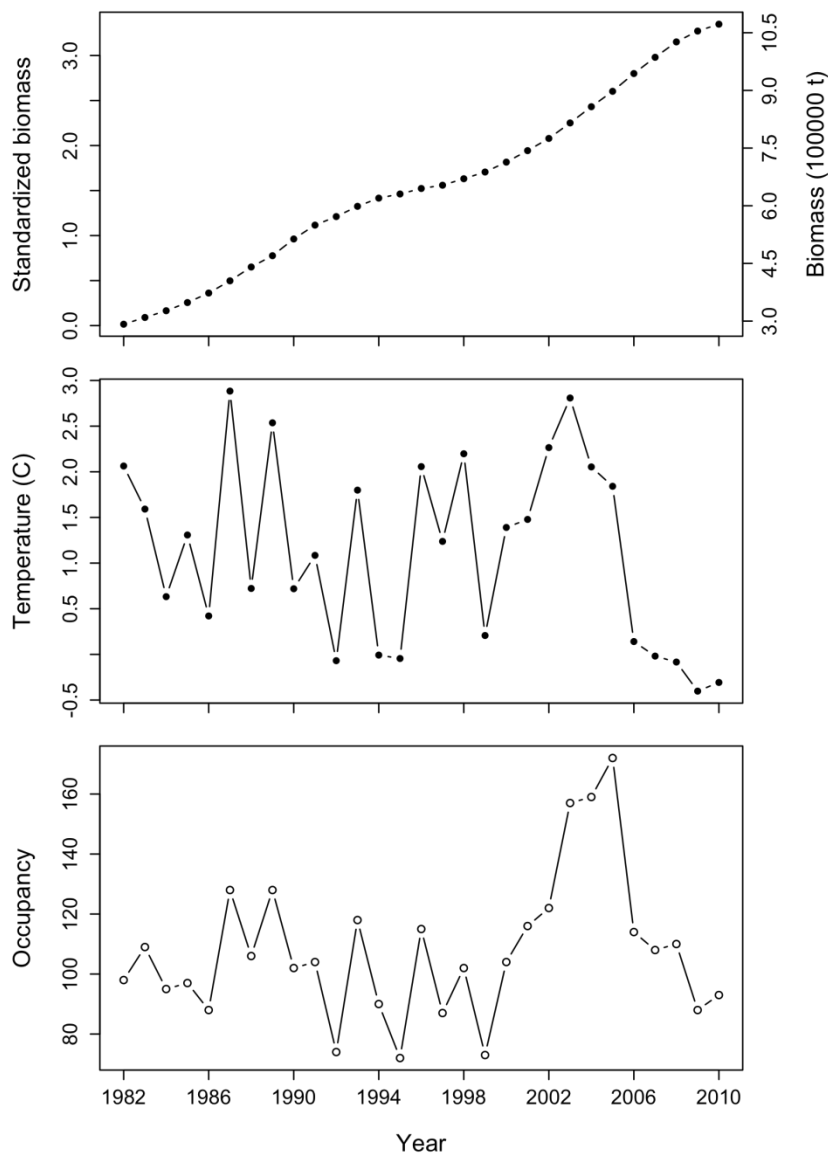
SUPPLEMENT 4: AIC PROFILE OVER POSSIBLE VALUES OF FLOUNDER POPULATION BIOMASS.

Figure S4. AIC profile in relation to different threshold values of standardized flounder
population biomass.
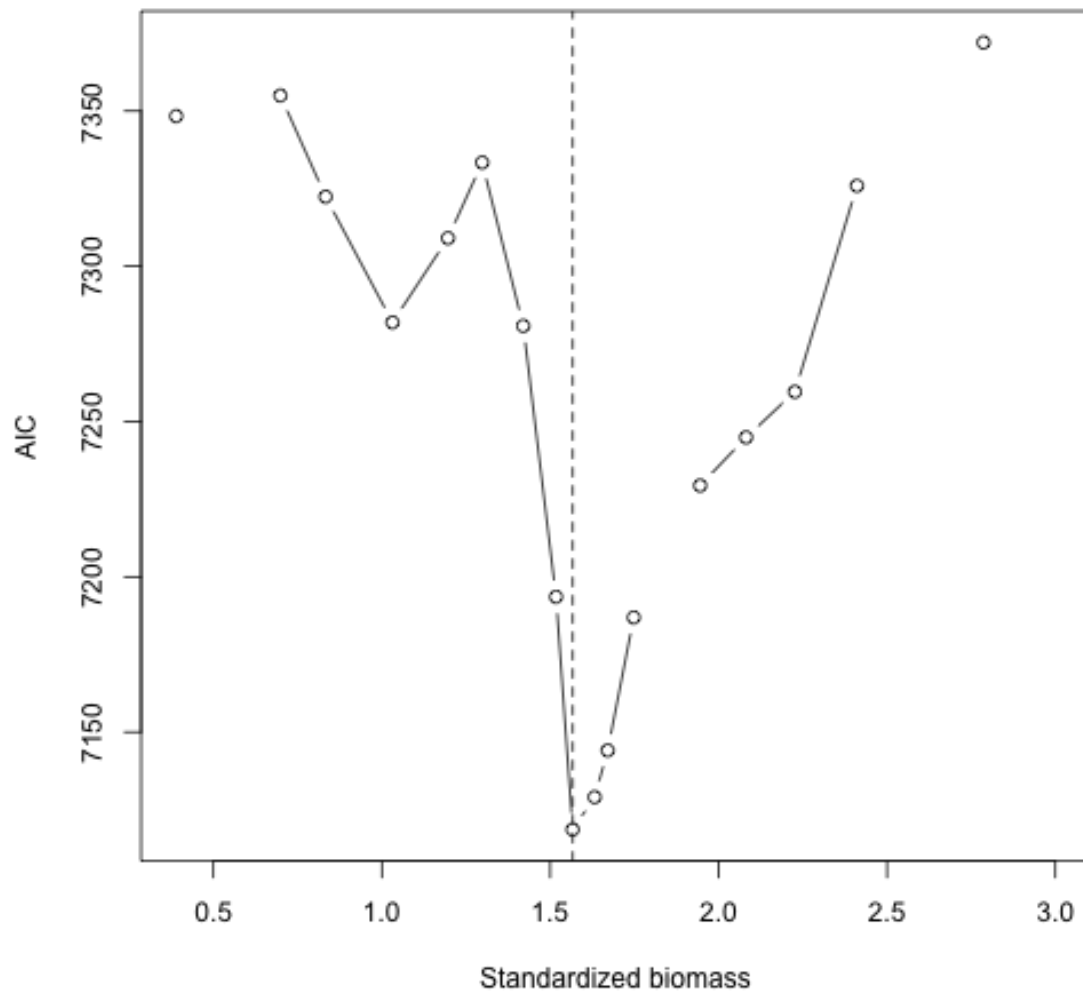
SUPPLEMENT 5: LINEAR MODELS OF FLOUNDER OCCUPANCY

In addition to the GAMM, and as an additional test to the nonadditive species-environment and nonstationary abundance-occupancy hypotheses we fit two linear models to the time series of flounder occupancy, measured as the number of consistently sampled stations occupied by flounder in any given year (Fig. S1). Both models include an effect of flounder biomass and average water temperature and their interactions, but the first model is stationary (i.e., no changes of B and T effects through the time examined) while the second is nonstationary, with a change of the abundance and temperature effects before and after a threshold biomass level, estimated from the model 3 (Supplement 2).

In agreement with the GAMM analysis, the linear models indicate that the time series of flounder occupancy is best and more parsimoniously fit with a nonadditive and nonstationary linear model, which assumes the same threshold of the spatial analysis (Table S1). Before 1995, water temperature was the only significant variable affecting flounder occupancy. In contrast, after 1995, flounder occupancy was significantly affected by water temperature and by its interaction with biomass (Table E1).

TABLE S1. Estimates and significance of coefficients from two linear models fit to the to the time series of flounder occupancy in relation to water temperature (T) and flounder population biomass (B) shown in Fig. S3. Also reported are the respective Akaike Information Criteria (AIC) and adjusted R^2 for each model.

Model	Terms	Estimate	Standard error	P value
Stationary	Intercept	67.79	10.74	<0.001
AIC = 242.82	T	13.79	5.83	0.026
R^2 = 64.2%	B	7.60	4.62	0.113
	B:T	3.47	2.86	0.237
Nonstationary	Intercept	81.24	9.36	<0.001
AIC = 216.20	T|Y≤1995	11.85	4.85	0.046
R^2 = 86.8%	T|Y>1995	-49.98	9.89	<0.001
	B|Y≤1995	-6.08	8.69	0.560
	B|Y>1995	2.24	3.89	0.389
	B:T|Y≤1995	5.08	4.86	0.136
	B:T|Y>1995	32.66	4.49	<0.001