The following supplement accompanies the article

Otolith biochronology reveals factors underlying dynamics in marine fish larvae

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Supporting information

Data

The environmental factors include the drift out of the Gulf of Alaska (GOA) (Transport), sea surface temperature (SST), surface wind speed in Shelikof Strait (WindS) and the Pacific Decadal Oscillation (PDO). The biological factors consist of the spawning biomass of the pollock in GOA (Fig. S1) and the proportion of spawners that are 8 yr or older (Fig. S2). We only had monthly average SST, so we used linear interpolation of the observed SST to approximate daily SST. Transport and WindS are daily data. The first 5 mo SST and WindS in each year from 1981 to 2001 are shown in Figs. S3 & S4.

For the environmental factors SST and WindS, we compute their anomalous daily values by subtracting the daily average from the observed daily values. For each of the covariates: anomalous SST and anomalous WindS, we computed 2 auxiliary variables. One auxiliary variable is calculated as the average covariate over the 30 d prior to a hatchdate, which attempts to quantify the effects of environmental conditions relevant to the spawning pattern and the hatching process. The second auxiliary variable attempts to quantify the environmental conditions on larval pollock survival, which is computed as the average of a given covariate over the period from the hatchdate to the catch date. The auxiliary variables for the anomalous SST from 1981 to 2001 are shown in Figs. S5 & S6, where SSTB measures the average 30 d anomalous SST before a hatchdate, while SSTA measures the average anomalous SST between the hatchdate and the corresponding catch date. As transport is postulated to affect larval survival but not mature fish, we compute the average transport from the hatchdate to the catch date in order to assess the transport effect on larval survival. PDO mainly affects pollock spawning patterns, so the mean anomalous PDO from January to March was computed for each year.

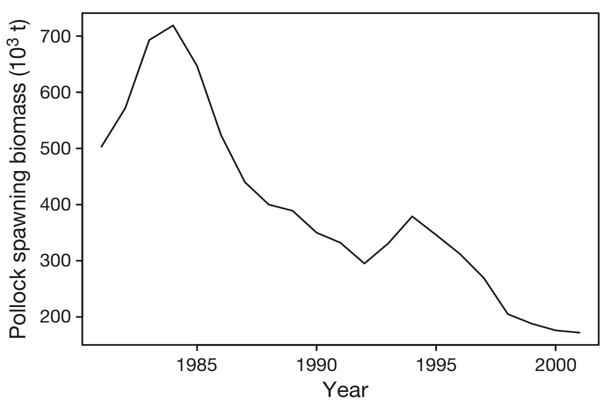

Fig. S1. *Theragra chalcogramma*. Time plot of the spawning biomass of walleye pollock in the Gulf of Alaska

Fig. S2. *Theragra chalcogramma*. Time plot of the annual proportions of older spawners

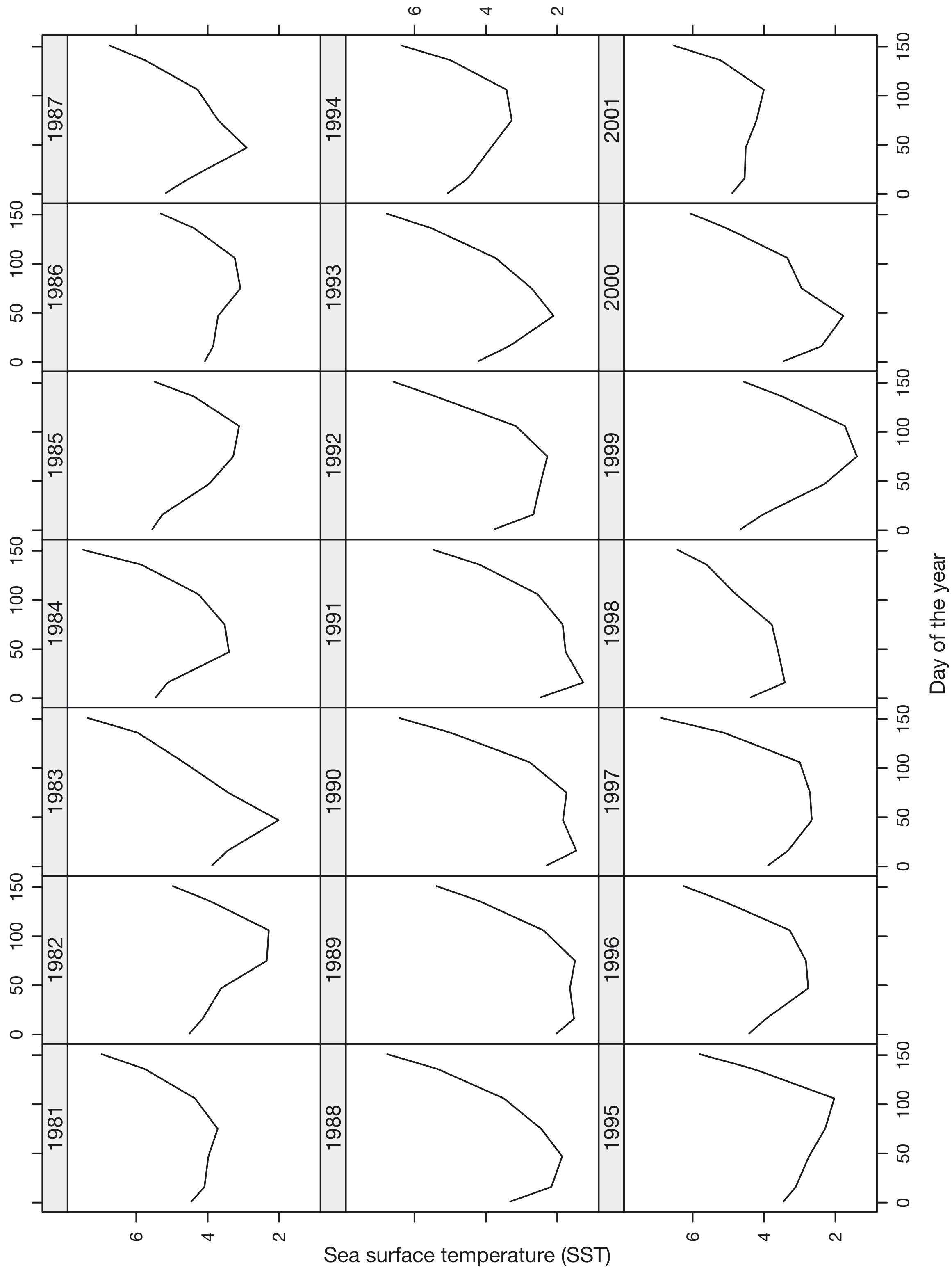

Fig. S3. Sea surface temperature from January to May (in days of the year)

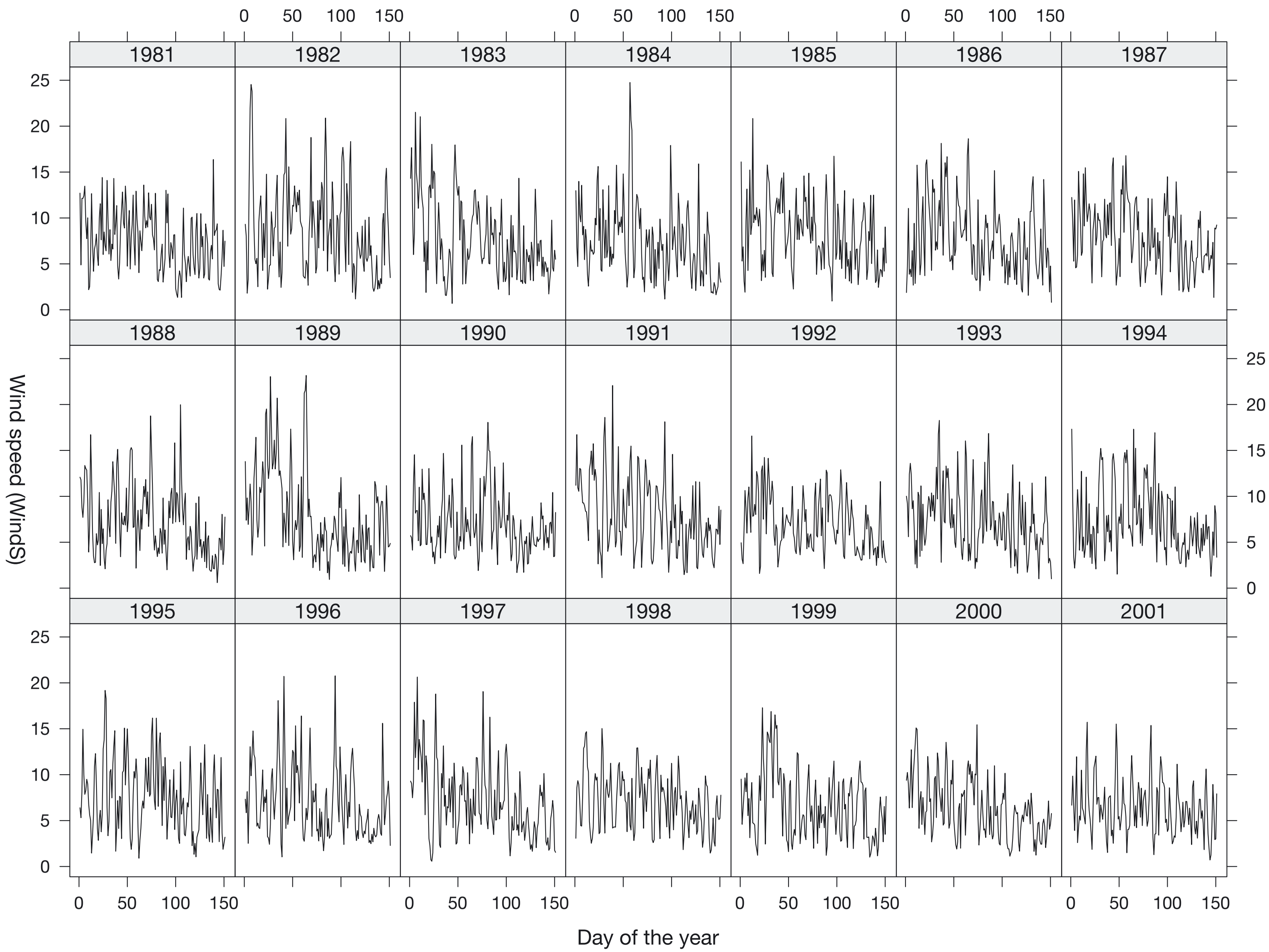

Fig. S4. Wind speed from January to May (in days of the year)

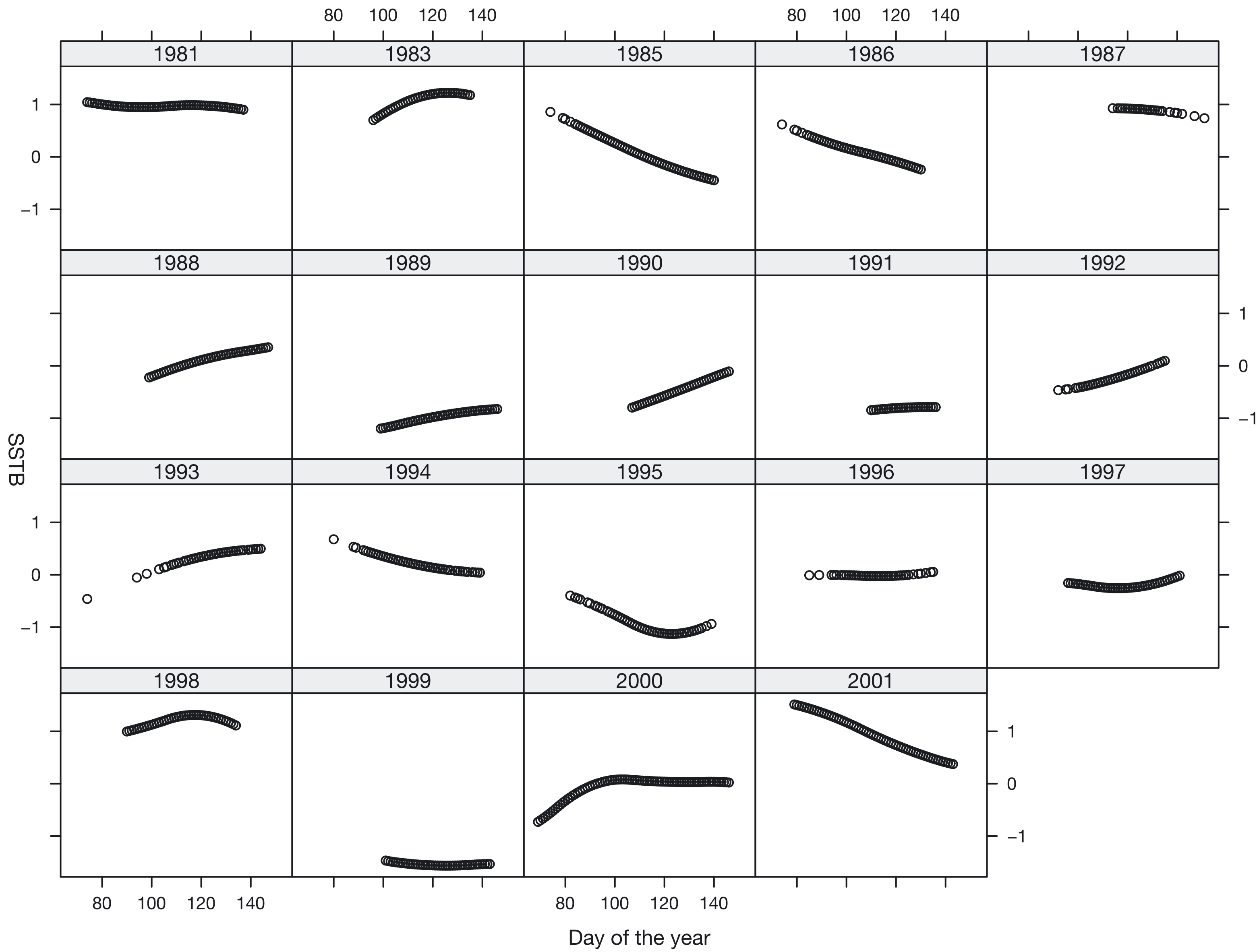

Fig. S5. Time plot of SSTB (average 30 d anomalous SST before a hatchdate) for hatchdates (in days of the year)

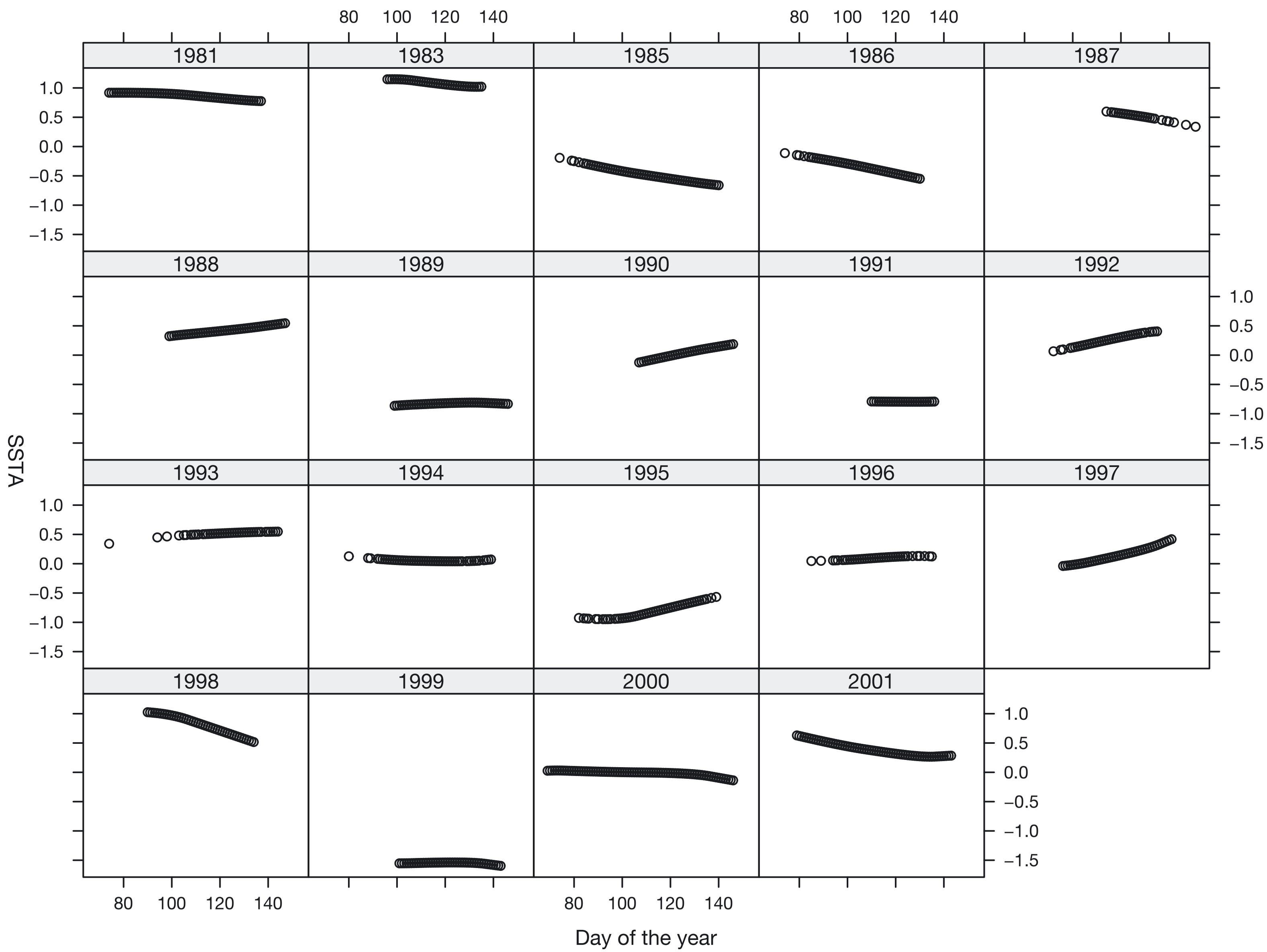

Fig. S6. Time plot of SSTA (average anomalous SST between the hatchdate and the corresponding catch date) for hatchdates (in days of the year)

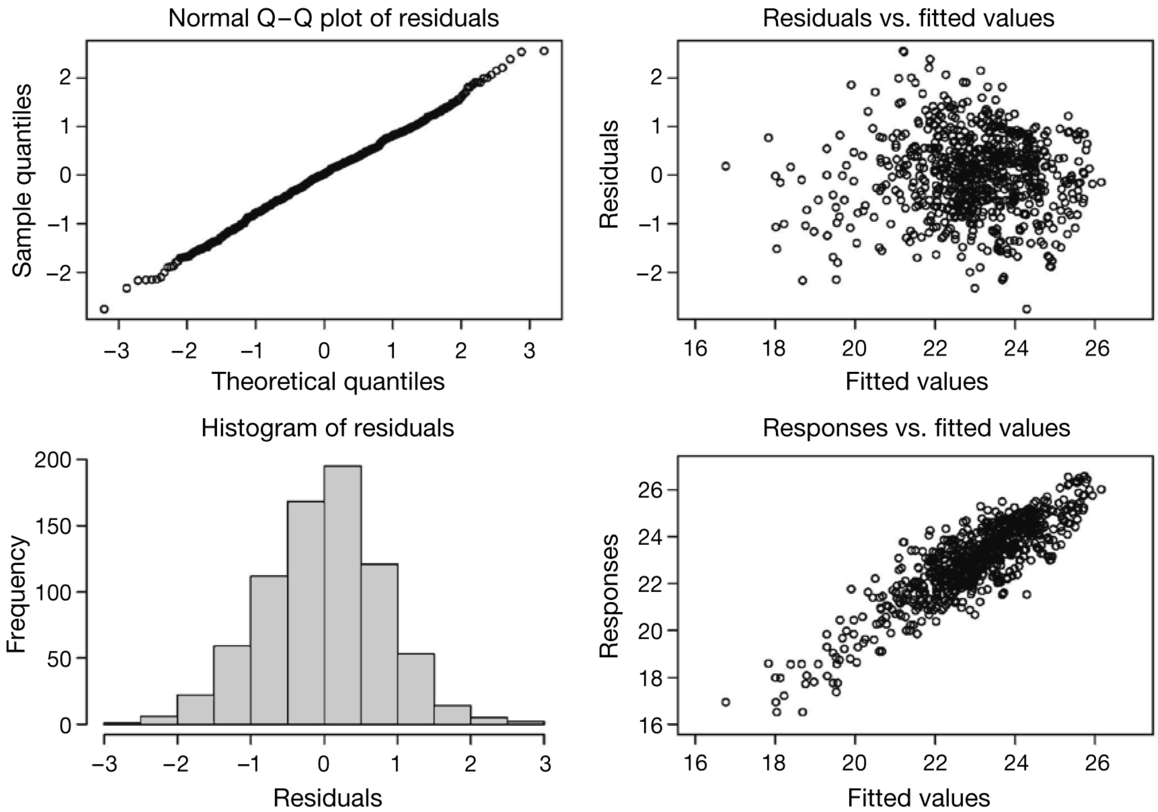

Fig. S7. Residual diagnostic checks. Upper left diagram is the quantile-quantile normal score plot of the residuals. Lower left diagram is the histogram of the residuals. Upper right is the residuals versus the fitted values plot. Lower right is the fitted values versus the responses

Mixture approximation

Recall that $\alpha_{y,a}$ is the proportion of Group-α in Year y and the hatchdate distribution of eggs (as determined by the underlying spawning distribution) from the Group-α equals $s_a(t), a = 1, 2$ on the log scale, up to some additive constant. For hatchdate distributions that are not strongly peaked, $s_a(t), a = 1, 2$ may be assumed to be close to some central values which can be taken to be zero, by absorbing these central values into the additive constants. The probability of a random larva being hatched on Day t is then proportional to

$$\begin{aligned}&\alpha_{y,1}\exp(s_1(t)) + \alpha_{y,2}\exp(s_2(t))\\ &\approx 1 + \alpha_{y,1}s_1(t) + \alpha_{y,2}s_2(t) \approx \exp(\alpha_{y,1}s_1(t) + \alpha_{y,2}s_2(t))\end{aligned} \tag{S1}$$

for small $s_a(t), a = 1, 2$, where we twice make use of the approximation $\exp(x) \approx 1 + x$, for x with small magnitude.

Intervention models

In the text, we mainly consider the situation that the intervention effect began in 1989 and it might decline geometrically afterwards. Another scenario is that the intervention was only effective in 1989 and left no memory afterwards, i.e.

$$\begin{aligned}l_{t,k,y} &= n_y + \alpha_{y,1}s_1(t) + \alpha_{y,2}s_2(t)\\ &+ \sum_{j=1}^{p_1} B_{y,j}s_{Bj}(t) + \sum_{j=p_1+1}^{p} s(B_{t,y,j}) - \log\{1 + [(1+\psi_{1989}1_{(y=1989)})\lambda k]^{\gamma}\}\\ &+ \sum_{l=1}^{q} s(A_{t,k,y,l}) + \varepsilon_{t,k,y}\end{aligned} \tag{S2}$$

These scenarios with the intervention effects modeled by Eqs. (3) & (S2) were compared to the null case that there are no intervention effects, i.e. ψ_{1989} in Eq. (S2) equals zero (see Table S1).

Model diagnostics

We checked whether the fitted model provides a good fit to the data after dropping the 4 outliers. The upper left quantile-quantile normal score plot and the bottom left histogram plot in Fig. S7 suggest that the errors are approximately normal. The plot of residuals against fitted values in the upper right diagram in Fig. S7 indicates that the variance of the errors is approximately constant. The bottom right plot shows that the responses have a positive linear relationship with the fitted values. Altogether these model diagnostics suggest that the final model provides a good fit to the data.

Table S1. Log marginal likelihood of various models, computed with the 4 outliers deleted. The marginal likelihoods were approximately computed via the Laplace approximation (T. Zhang & K. S. Chan unpubl.). The marginal likelihood of a model is proportional to the posterior probability of the model assuming identical prior model probabilities

Environmental covariates	Intervention specification	Log marginal likelihood
Transport, SST and Wind Speed	No intervention effects on larval survival	−1127.7
Transport, SST and Wind Speed	Intervention was only effective in 1989	−1125.5
Transport, SST and Wind Speed	Intervention effects began in 1989 and diminished geometrically afterwards	−1122.4
Transport, SST, Wind Speed and PDO	No intervention effects on larval survival	−1065.8
Transport, SST, Wind Speed and PDO	Intervention was only effective in 1989	−1075.8
Transport, SST, Wind Speed and PDO	Intervention effects began in 1989 and diminished geometrically afterwards	−1032.7