Coastwide analsis of forestry on BC Pacific Salmon

Apr. 2024

Overview

We're including here the initial model constructions and outputs in this as a sort of living appendix.

These models relate River-level (subscript r) productivity to ECA (logit transformed and standardized) with varying effects of ECA at the CU-level (subscript c). We include spawner-recruitment model forms as either the Ricker (model 1), Beverton-Holt (model 2), or Cushing structure (model 3).

Models

Ricker formulation:

$log(R_{t,r}/S_{t,r}) = \alpha_r - \beta_r * S_{t,r} + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$

Where residual productivity is autocorrelated by 1-year:

$w_{1,r} \sim N(0, \sigma_r)$

$w_{t,r} \sim N(\rho_r * w_{t-1,r}, \sigma_r * \sqrt{(}1 - \rho_r^2))$

$\rho \sim U(-1, 1)$

And stock-specific parameters are drawn hierarchically for productivity and forestry effects:

$\alpha_r \sim N(\alpha_c, \sigma_{ar}^2)$

$\alpha_c \sim N(\alpha, \sigma_{ac}^2)$

$\alpha \sim N(1.5, 2)$

$\beta_{eca,c} \sim N(\beta_{eca}, \sigma_{eca})$

$\beta_{eca} \sim N(0, 1)$

$\sigma_{eca} \sim N[0, 0.5)$

$\sigma_r \sim N(\sigma_c, \sigma_{\sigma,r})$

$\sigma_c \sim N(\sigma, \sigma_{\sigma,c})$

$\sigma \ N[0.5, 0.5)$

Stock-specific density-dependence is estimated independently at the river level, but with informative priors for S_{max} ($=1/\beta$; density where total predicted recruitment is maximized) based on observed spawner counts (S_r):

$\beta \sim lognormal(0.5 * max(S_r), max(S_r))$

For the Beverton Holt model, the linearized form is altered to:

$log(R_{t,r}/S_{t,r}) = \alpha_r - log(1 + (e^{\alpha_r})/R_{k,r}) * S_{t,r}) + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$

Where the new parameter $R_{k,r}$ is the stock-specific equilibrium recruitment, sampled with informative priors based on observed recruitment (R):

$R_{k,r} \sim lognormal(0.75 * max(R_r), max(R_r))$

For the Cushing model, the linearized form is:

$log(R_t, r/S_{t,r}) = \alpha_r + \beta_r * log(S_{t,r}) + \beta_{eca,c} * ECA_{t,r} + w_{t,r}$

A version of each model was fit to the Chum dataset.

Proposed to do/future tweaks:

1. Shared year effects or shared latent productivity trends
2. Watershed area & interaction with ECA
3. non-linear function for ECA?

Model form comparison

Overall model likelihood across the 3 model forms assessed by approximate leave-one-out cross-validation:

```
##        elpd_diff  se_diff  elpd_loo se_elpd_loo    p_loo se_p_loo
## model2     0.000  0.00000 -12590.08    82.87004 851.6476 19.15519
## model1 -2601.199 82.57776 -15191.28    90.19241 763.8891 18.50376
## model3 -4627.793 93.88754 -17217.87    83.63883 420.8408 11.47561
```

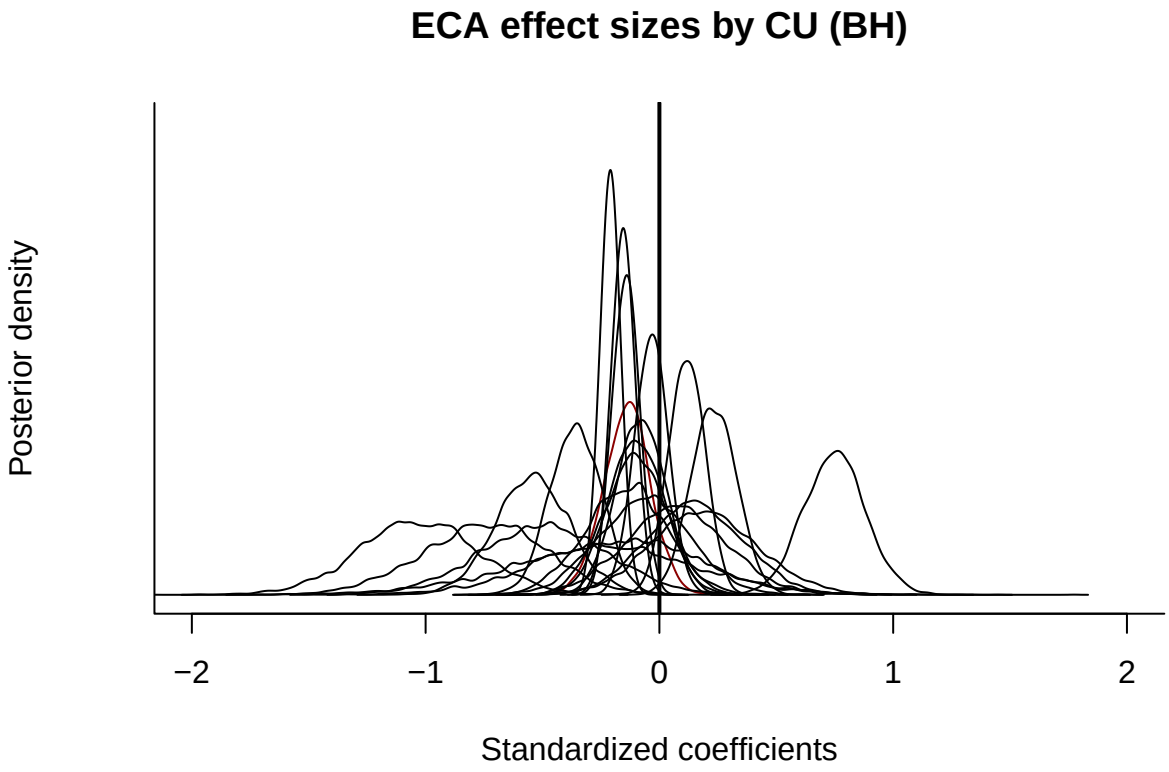
From this the Beverton-Holt model appears to have substantially better predictive performance compared to the Ricker/Cushing model forms. We will proceed with results for both BH/Ricker however.

Forestry effects

The overall among population effect size (b_ECA) for ECA, and varying effects of ECA by CU (b_ECA_cu), from the Beverton-Holt fit. The plot shows density of effect sizes among CUs and the red line indicates the global effect:

```
##        variable        mean         sd           q5         q95     rhat
## 1         b_ECA -0.13879772 0.10085593 -0.305988750  0.02639130 1.002367
## 2   b_ECA_cu[1] -0.21034937 0.04033780 -0.277363750 -0.14382020 1.000624
## 3   b_ECA_cu[2] -0.09972521 0.12092379 -0.297617800  0.09747117 1.001087
## 4   b_ECA_cu[3]  0.19622800 0.22661923 -0.167274050  0.57906645 1.002111
## 5   b_ECA_cu[4] -1.03350397 0.25522140 -1.456413000 -0.60827685 1.000835
## 6   b_ECA_cu[5]  0.11607719 0.07602802 -0.009585427  0.23857715 1.000795
## 7   b_ECA_cu[6] -0.10243741 0.13561212 -0.327632500  0.11879520 1.000805
## 8   b_ECA_cu[7]  0.23370864 0.09635575  0.076933600  0.39103720 1.000977
## 9   b_ECA_cu[8] -0.07994321 0.10497158 -0.254018800  0.09110415 1.001313
## 10  b_ECA_cu[9]  0.74839562 0.13196956  0.532932750  0.96647380 1.001664
## 11 b_ECA_cu[10] -0.15521445 0.04754386 -0.232677850 -0.07622366 1.002234
## 12 b_ECA_cu[11] -0.03501775 0.06997465 -0.152214700  0.07918511 1.001014
## 13 b_ECA_cu[12] -0.14445076 0.05564470 -0.235724300 -0.05264579 1.000711
## 14 b_ECA_cu[13] -0.35739594 0.10904456 -0.534152750 -0.18085810 1.001660
## 15 b_ECA_cu[14]  0.07363328 0.21558917 -0.276502550  0.43280385 1.000320
```

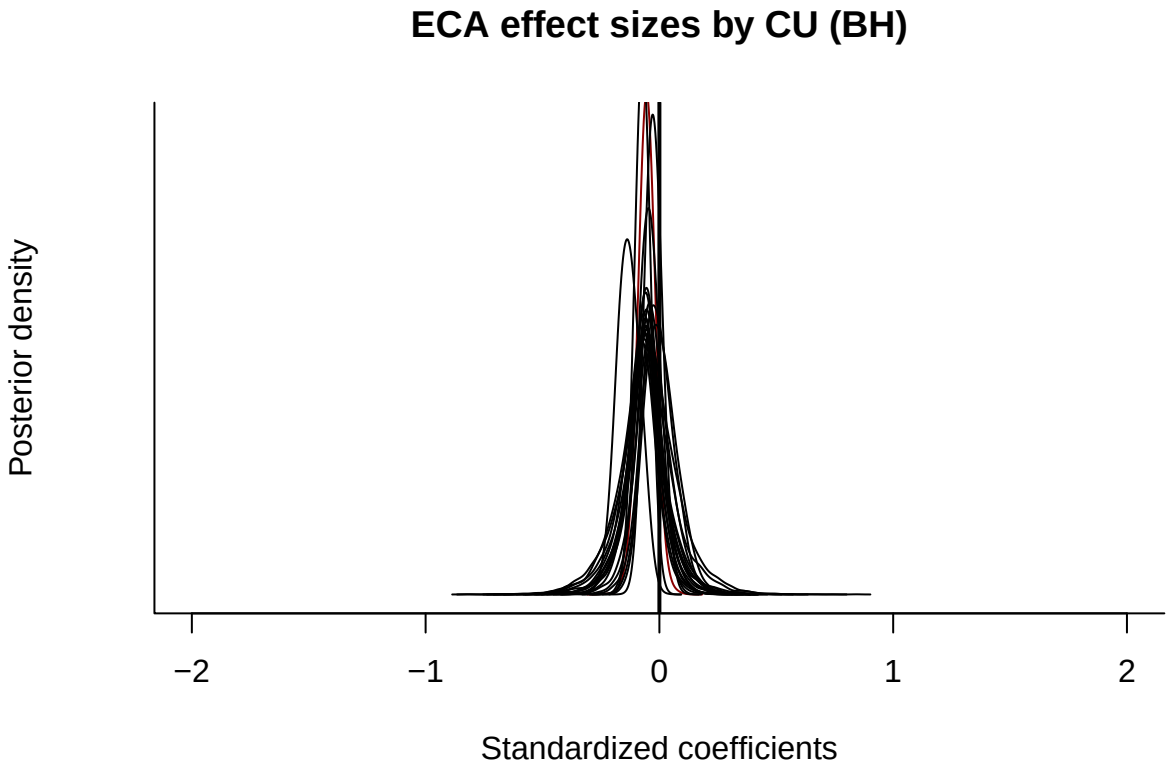
```
## 16 b_ECA_cu[15] -0.25473382 0.41069973 -0.951373550  0.39580490 1.002172
## 17 b_ECA_cu[16] -0.06430381 0.19514377 -0.385830600  0.25831465 1.000671
## 18 b_ECA_cu[17]  0.15162132 0.20856538 -0.187642600  0.49681865 1.000894
## 19 b_ECA_cu[18] -0.75204648 0.26747251 -1.207662500 -0.32893680 1.001349
## 20 b_ECA_cu[19] -0.54249877 0.15995007 -0.804557650 -0.27771420 1.002582
## 21 b_ECA_cu[20] -0.16421068 0.35021556 -0.736258250  0.40618440 1.000095
## 22 b_ECA_cu[21] -0.14361452 0.17376956 -0.436148200  0.13583375 1.001410
## 23 b_ECA_cu[22] -0.49528788 0.27566849 -0.952325950 -0.04610943 1.001660
```



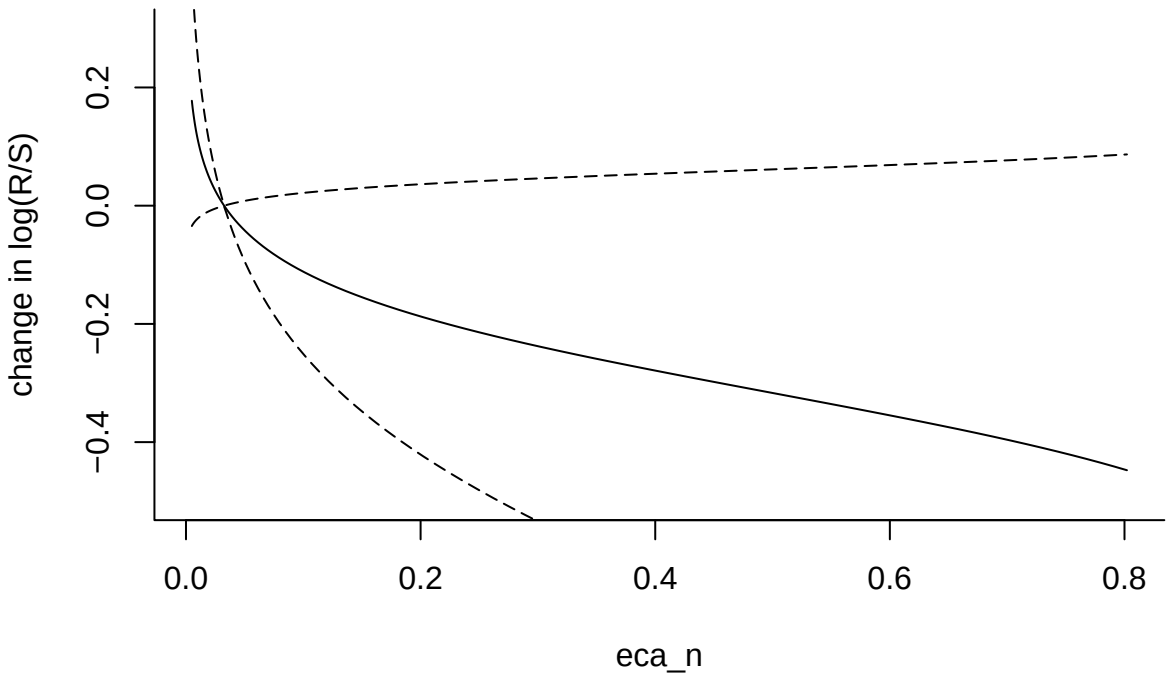
and alternatively with the Ricker model form:

```
##        variable         mean         sd          q5           q95     rhat
## 1         b_ECA -0.054333662 0.03459698 -0.10966230  0.0009919693 1.002793
## 2   b_ECA_cu[1] -0.072371922 0.02884070 -0.12057840 -0.0253834200 1.000183
## 3   b_ECA_cu[2] -0.024131374 0.07169905 -0.12915355  0.1030647500 1.001175
## 4   b_ECA_cu[3] -0.013897533 0.10056040 -0.14976155  0.1717358500 1.002141
## 5   b_ECA_cu[4] -0.090058266 0.09535613 -0.26322540  0.0449054600 1.005591
## 6   b_ECA_cu[5] -0.004070840 0.06455412 -0.10048495  0.1079735000 1.004470
## 7   b_ECA_cu[6]  0.007319455 0.06895826 -0.09297971  0.1308671500 1.003829
## 8   b_ECA_cu[7] -0.059914191 0.08566169 -0.20472390  0.0772574600 1.004292
## 9   b_ECA_cu[8] -0.056094021 0.07861854 -0.18859355  0.0755901250 1.004899
## 10  b_ECA_cu[9]  0.009591035 0.09721453 -0.11468455  0.1948060500 1.002496
## 11 b_ECA_cu[10] -0.026344081 0.03335694 -0.07978288  0.0291210200 1.002066
## 12 b_ECA_cu[11] -0.044957400 0.04561646 -0.12039335  0.0312637600 1.003401
## 13 b_ECA_cu[12] -0.132912620 0.04813456 -0.21127420 -0.0528107300 1.008975
## 14 b_ECA_cu[13] -0.106682990 0.09551370 -0.28825595  0.0222931100 1.004217
```

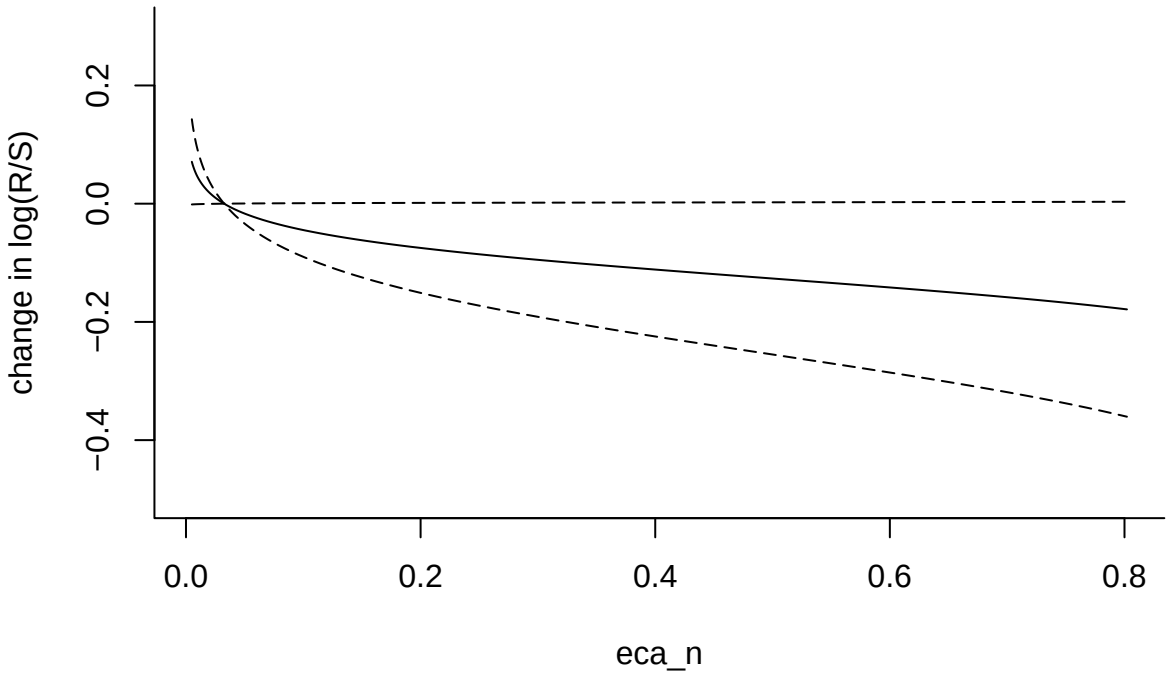
```
## 15 b_ECA_cu[14] -0.078974193 0.07892060 -0.21791705  0.0412813600 1.003187
## 16 b_ECA_cu[15] -0.057971053 0.09890730 -0.21759945  0.0977015650 1.004827
## 17 b_ECA_cu[16] -0.059188685 0.09123195 -0.21024190  0.0877996050 1.004137
## 18 b_ECA_cu[17] -0.051800878 0.09374111 -0.19829310  0.1009114000 1.004657
## 19 b_ECA_cu[18] -0.098816039 0.09492052 -0.27070260  0.0310442400 1.006573
## 20 b_ECA_cu[19] -0.063649378 0.07187560 -0.18260235  0.0520365550 1.002750
## 21 b_ECA_cu[20] -0.044413909 0.09518136 -0.19415205  0.1157807000 1.003376
## 22 b_ECA_cu[21] -0.057618487 0.06848823 -0.17194800  0.0558957350 1.005447
## 23 b_ECA_cu[22] -0.076366171 0.09784881 -0.24623830  0.0635329850 1.003332
```



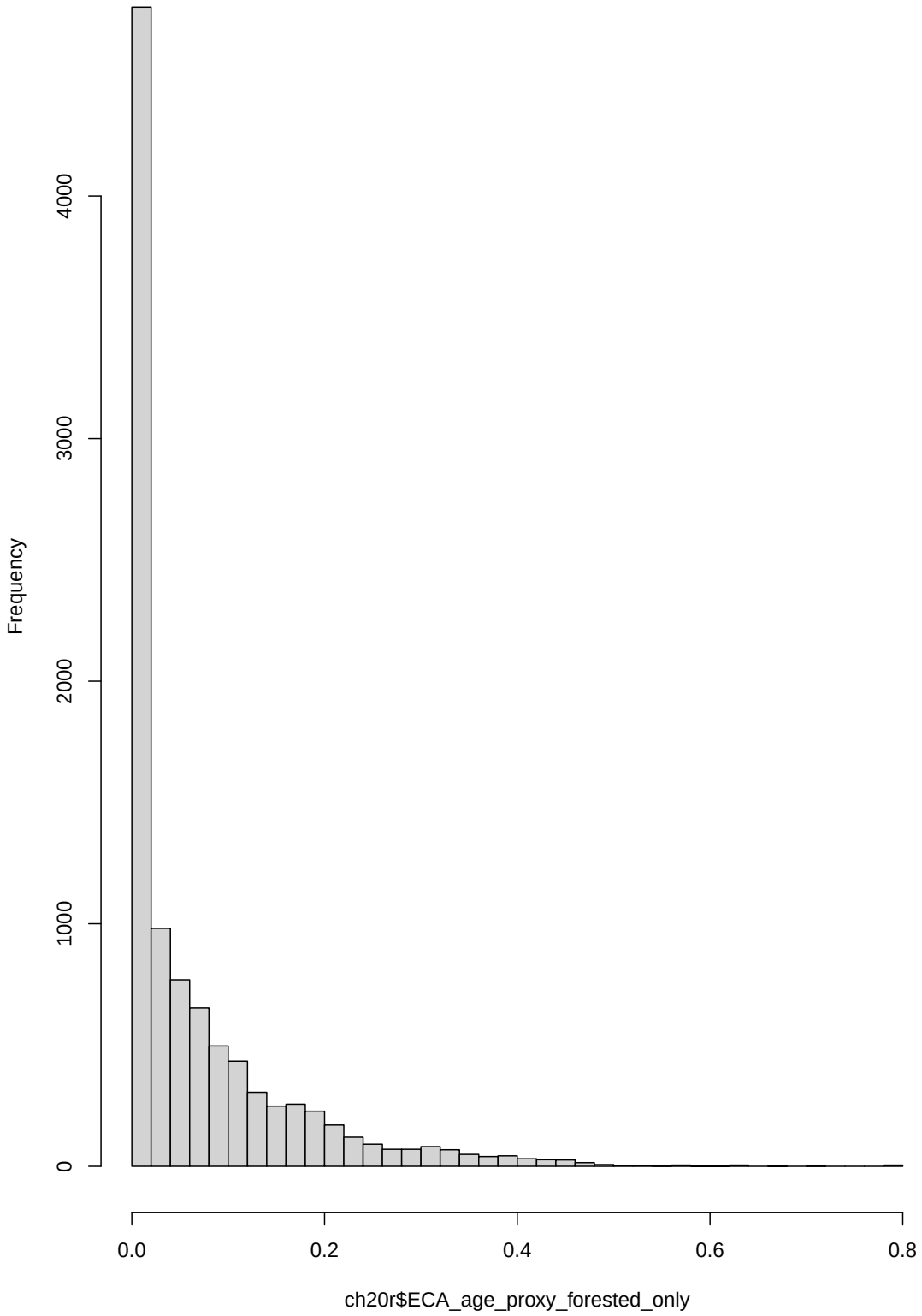
Visualized (back converted from logit scale to original ECA) for the Beverton-Holt model:

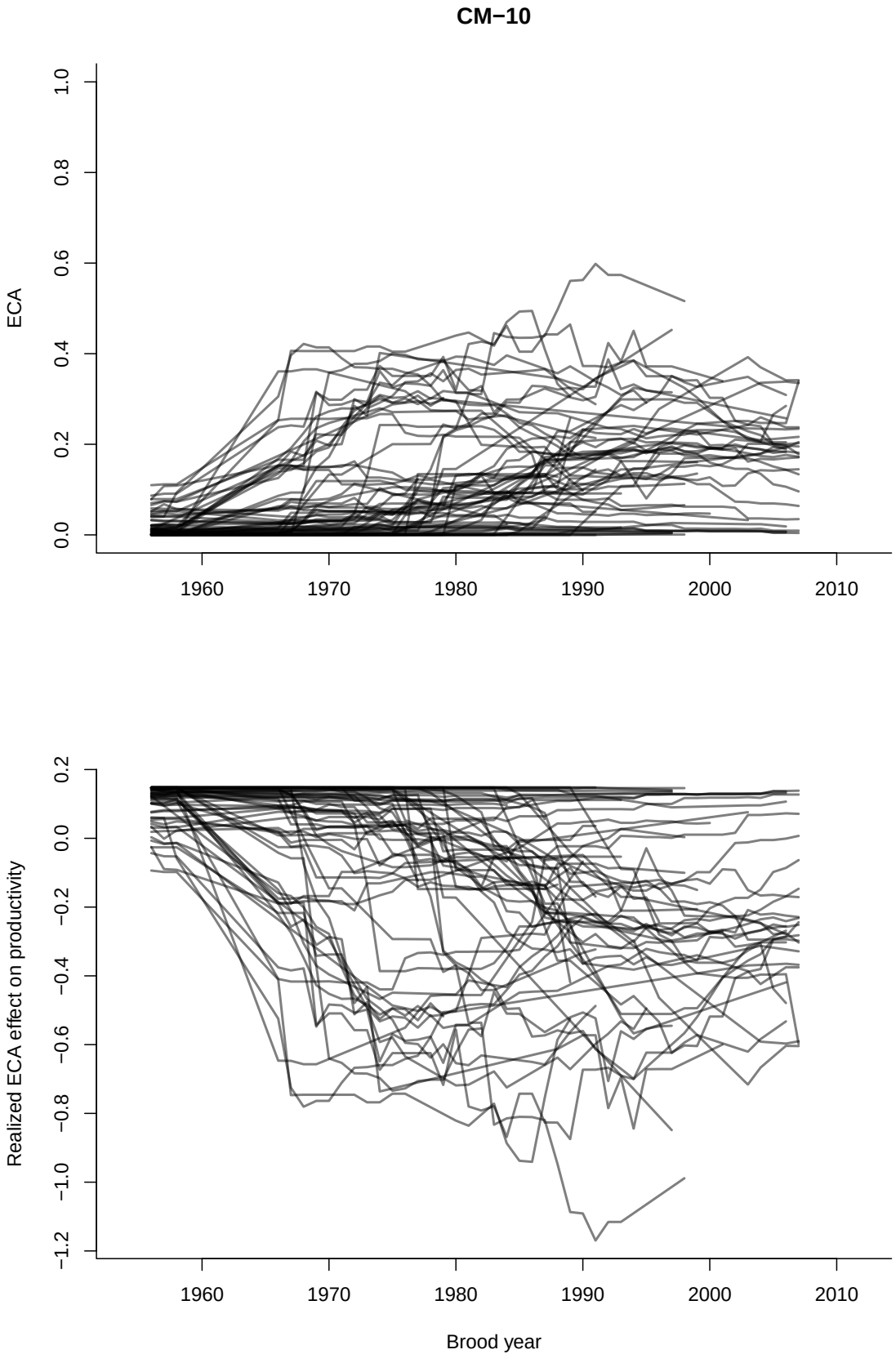


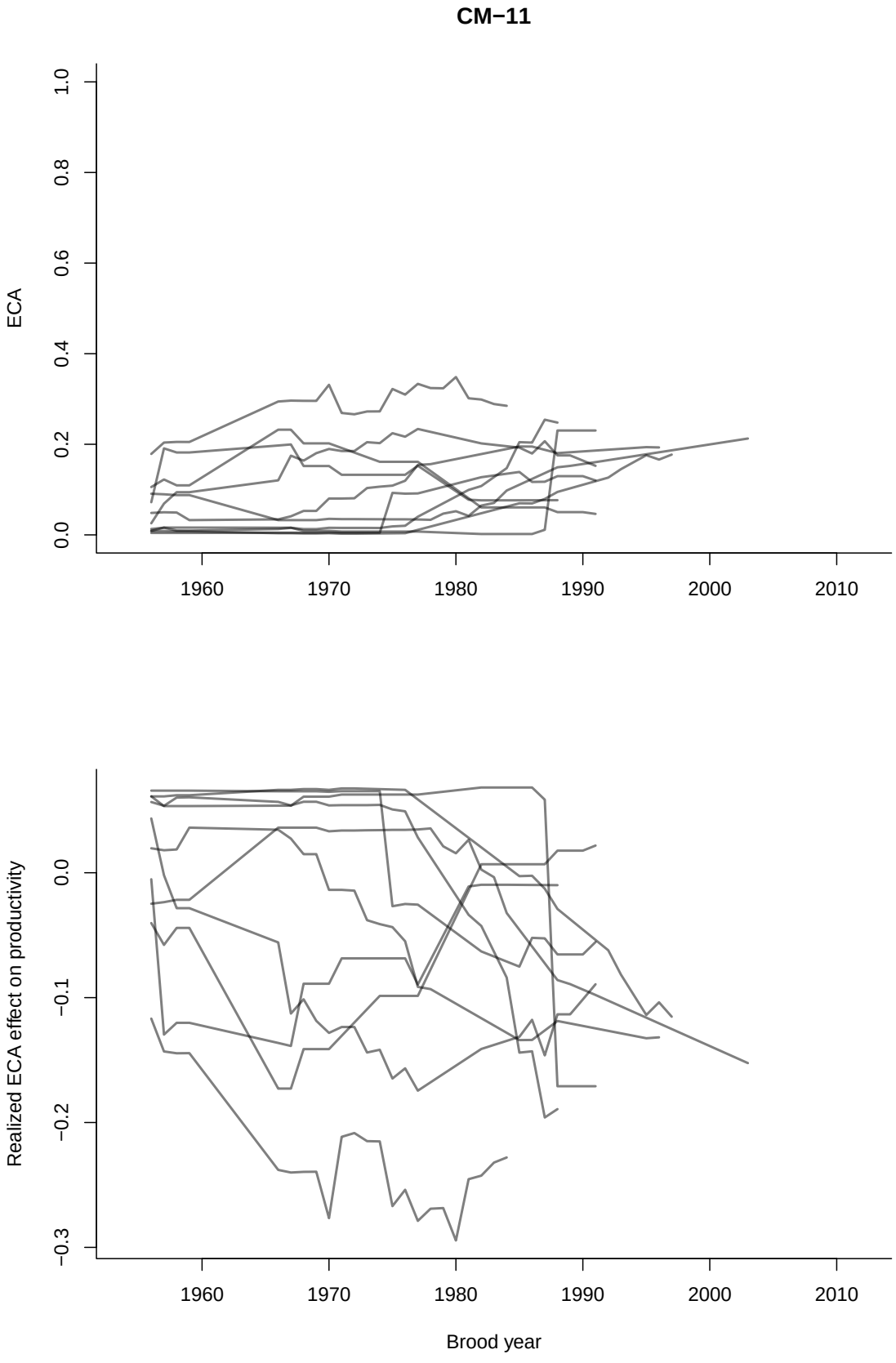
And Ricker model:

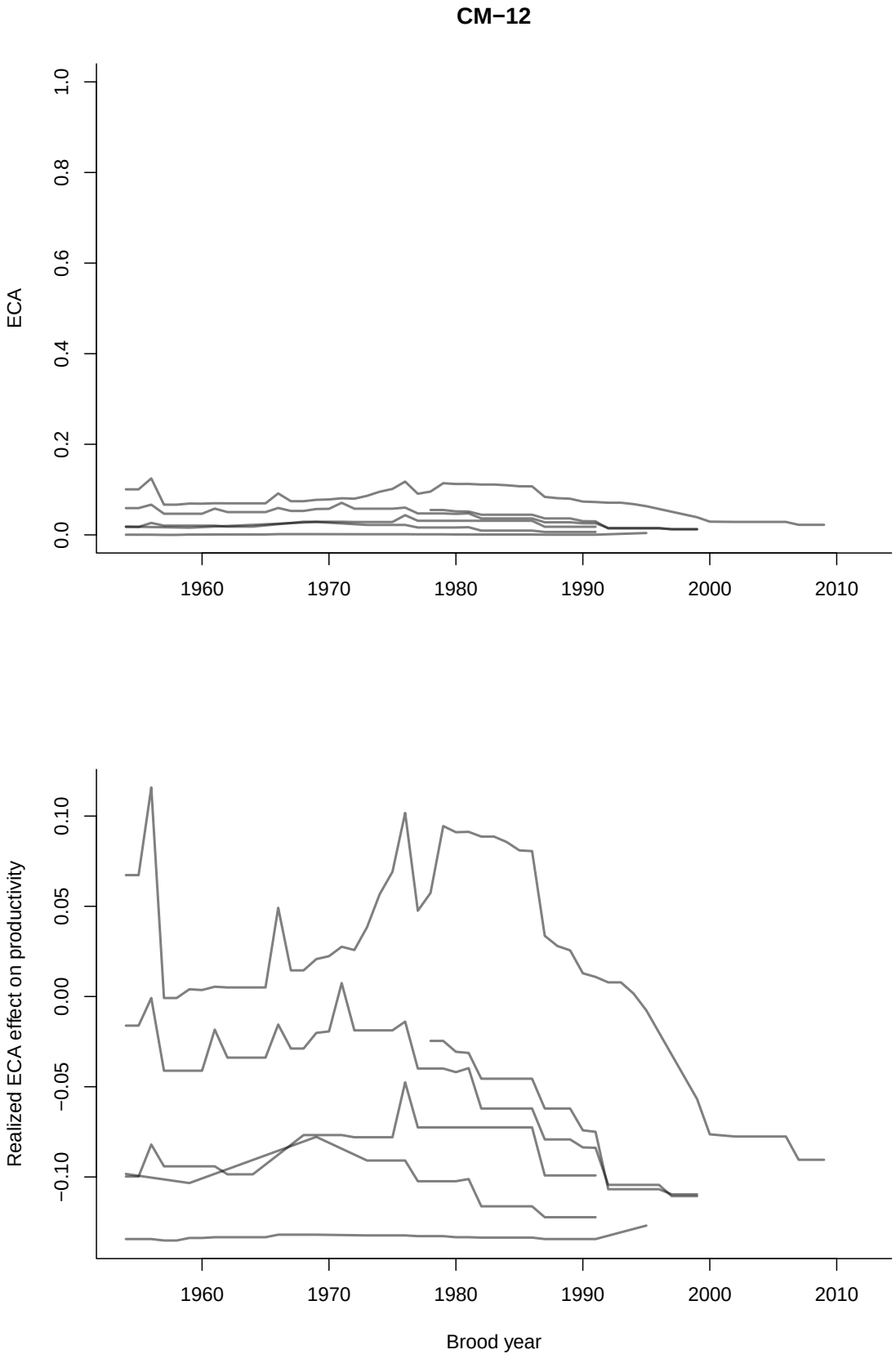


River-level ECA and effect on productivity through time by CU (BH model):

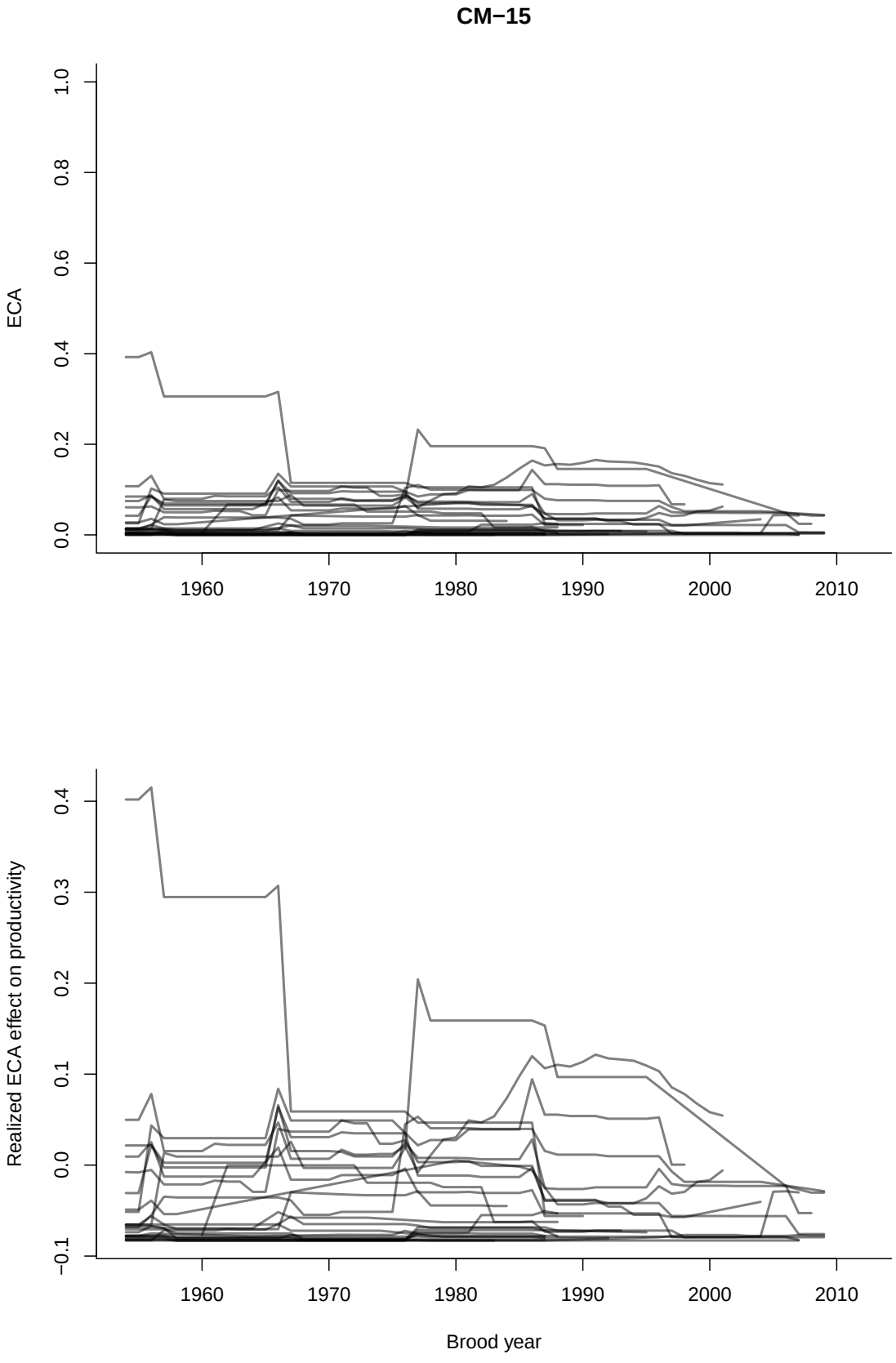

ECA for all observations
Frequency
0
1000
2000
3000
4000
0.0
0.2
0.4
0.6
0.8
ch20r$ECA_age_proxy_forested_only

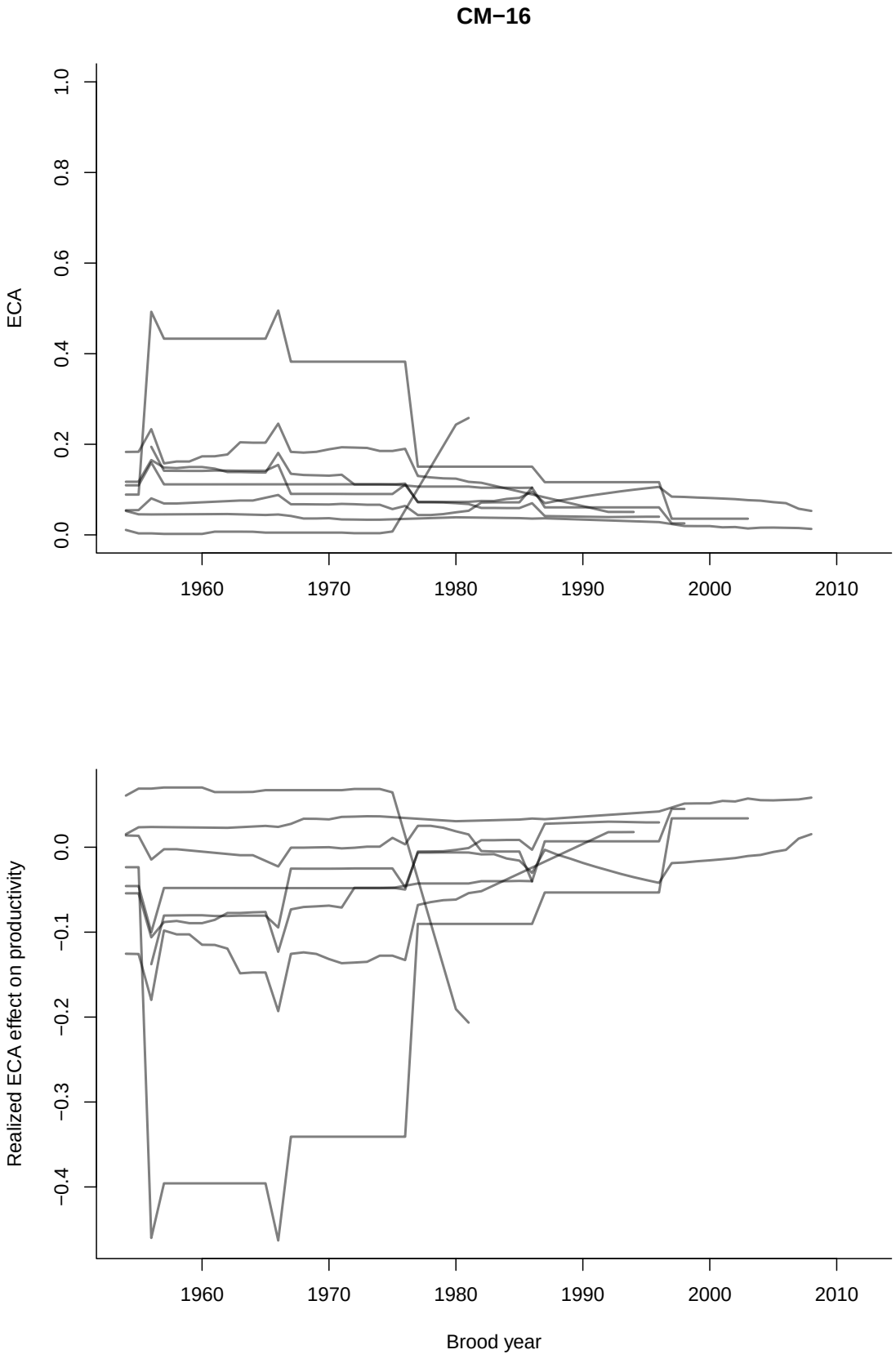

CM−10
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
0.2
1960
1970
1980
1990
2000
2010
Brood year

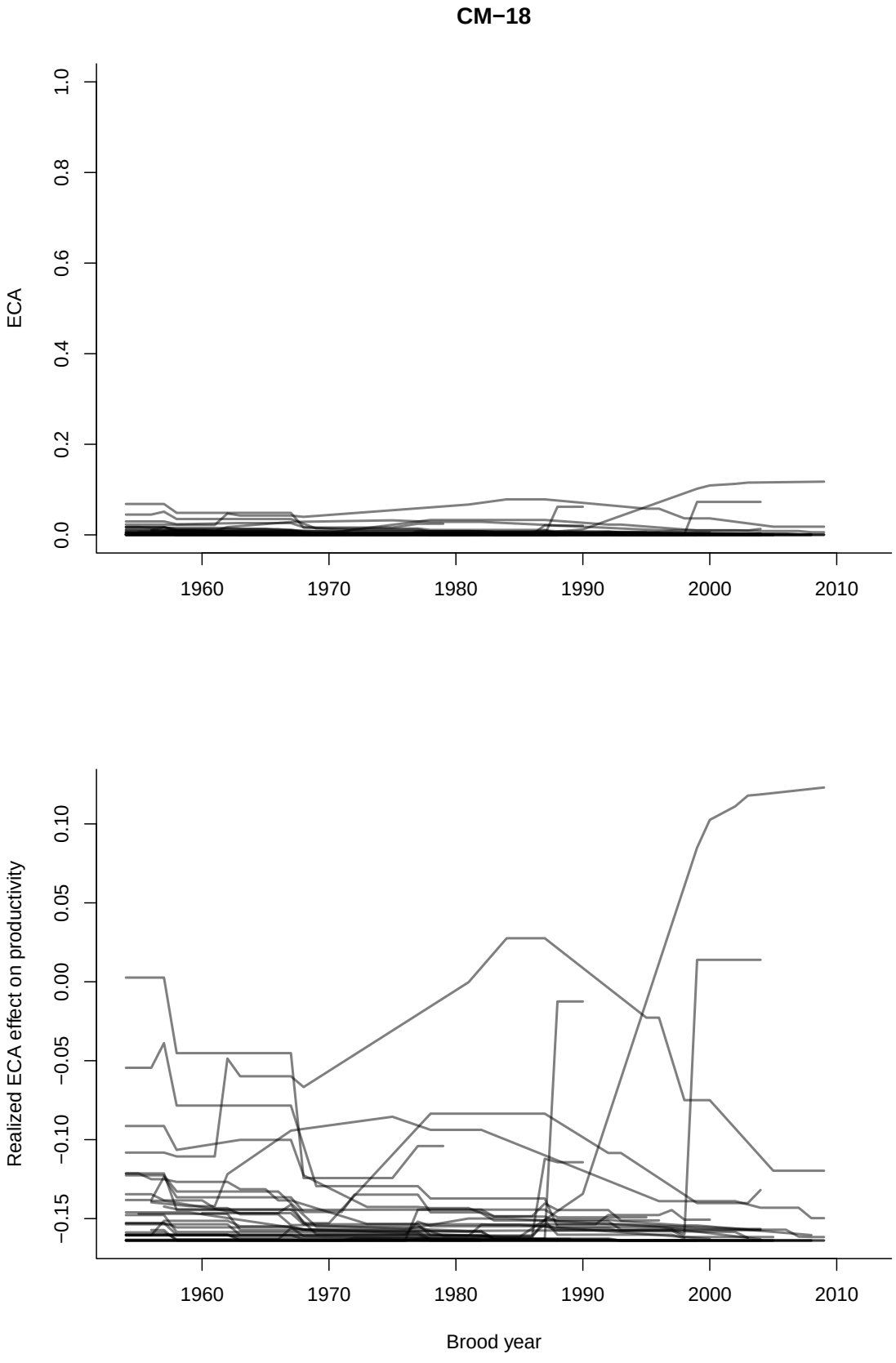

CM−11
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.3
−0.2
−0.1
0.0
1960
1970
1980
1990
2000
2010
Brood year

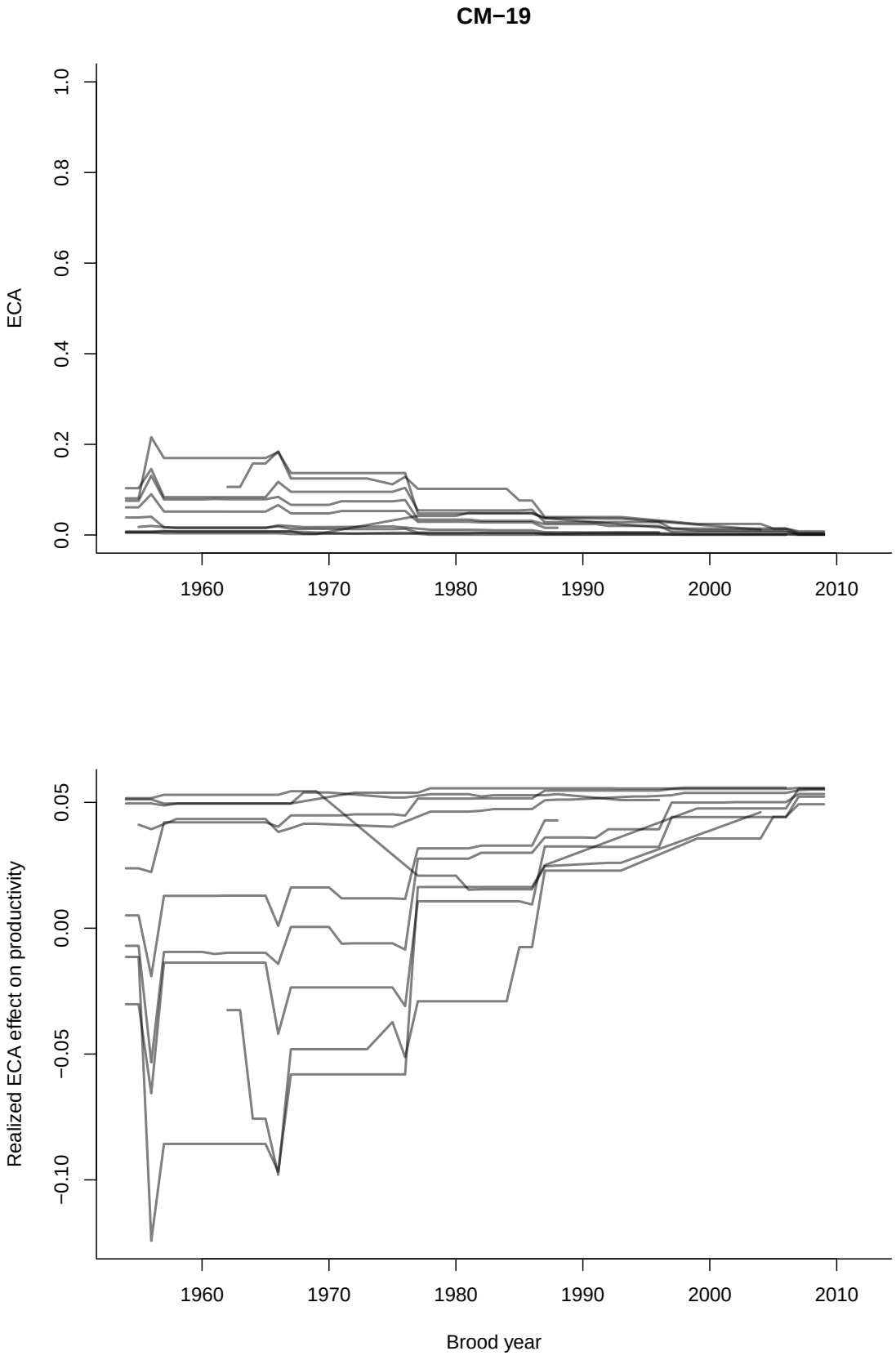

CM−12
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.10
−0.05
0.00
0.05
0.10
1960
1970
1980
1990
2000
2010
Brood year

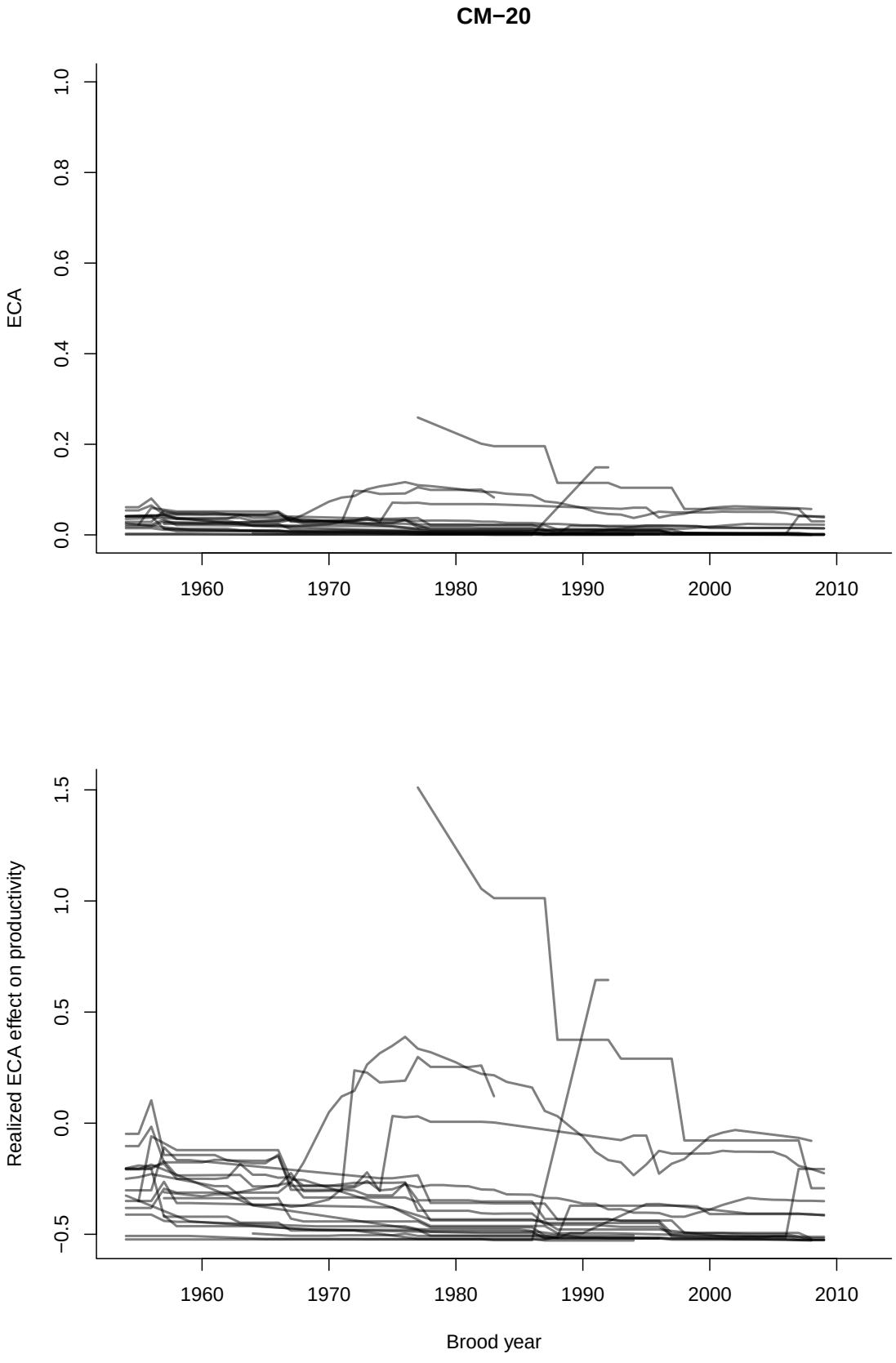

CM−13
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−1.0
−0.5
0.0
0.5
1960
1970
1980
1990
2000
2010
Brood year

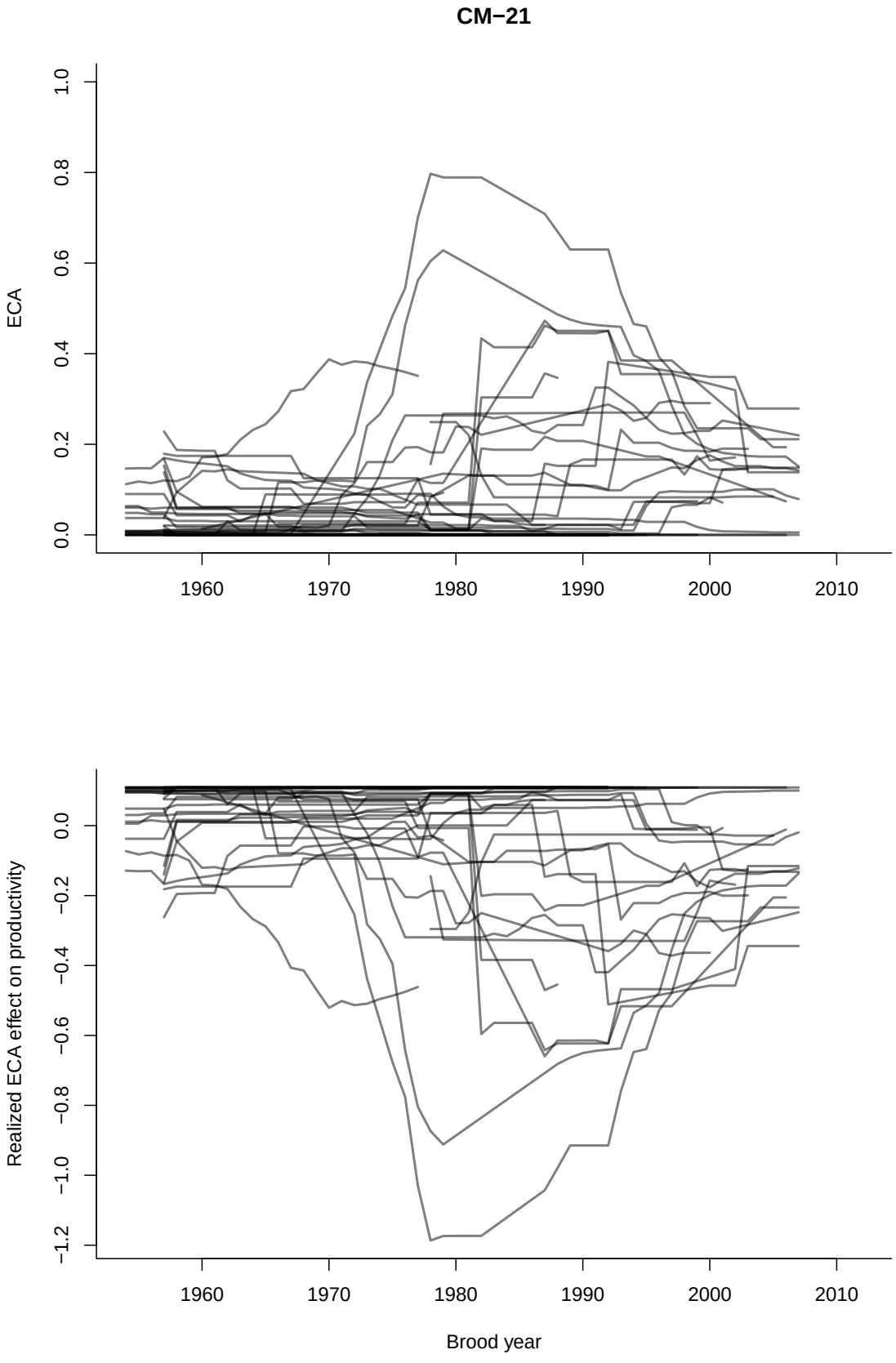

CM−15
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.1
0.0
0.1
0.2
0.3
0.4
1960
1970
1980
1990
2000
2010
Brood year

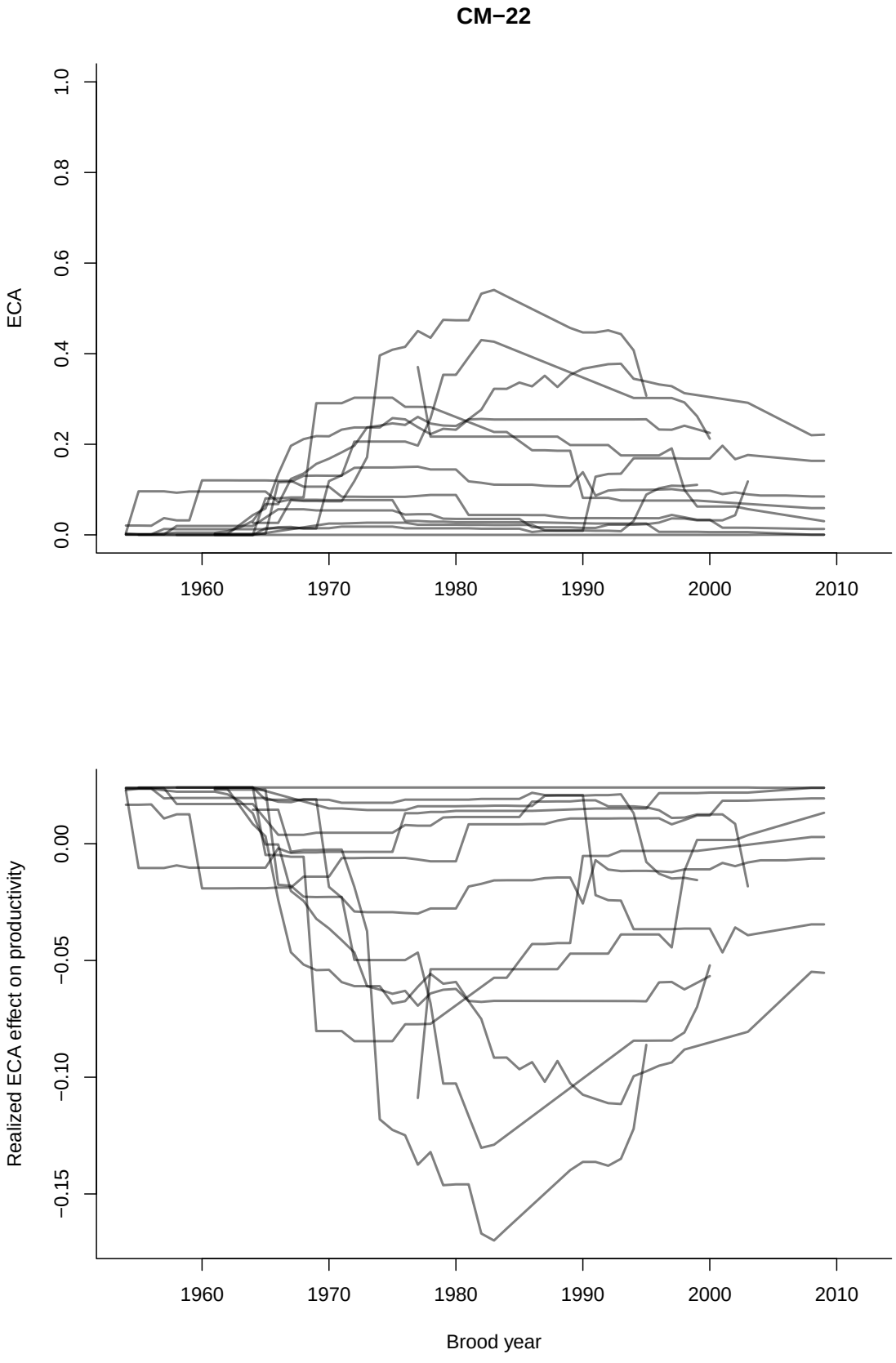

CM−16
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.4
−0.3
−0.2
−0.1
0.0
1960
1970
1980
1990
2000
2010
Brood year

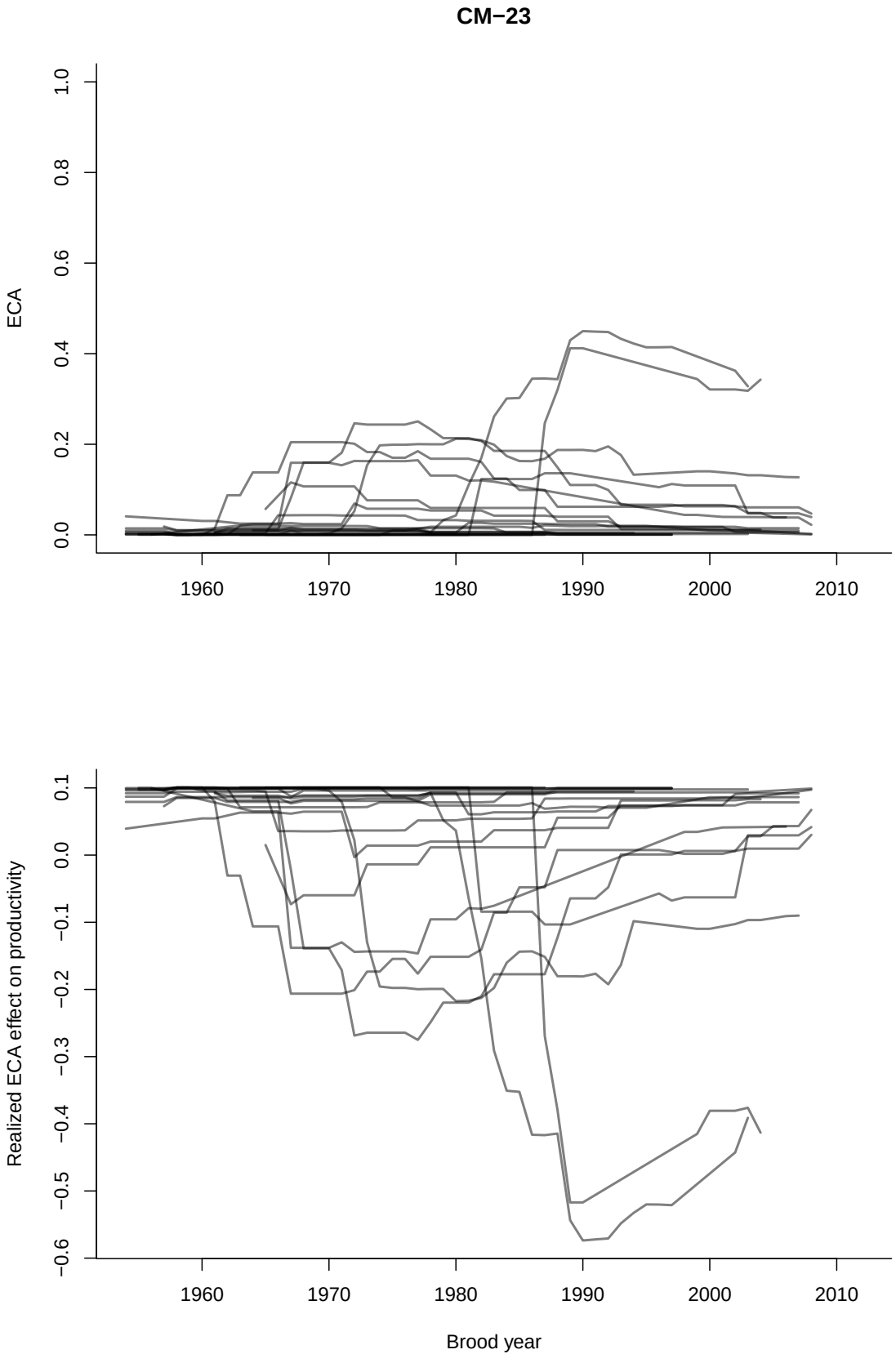

CM−18
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.15
−0.10
−0.05
0.00
0.05
0.10
1960
1970
1980
1990
2000
2010
Brood year

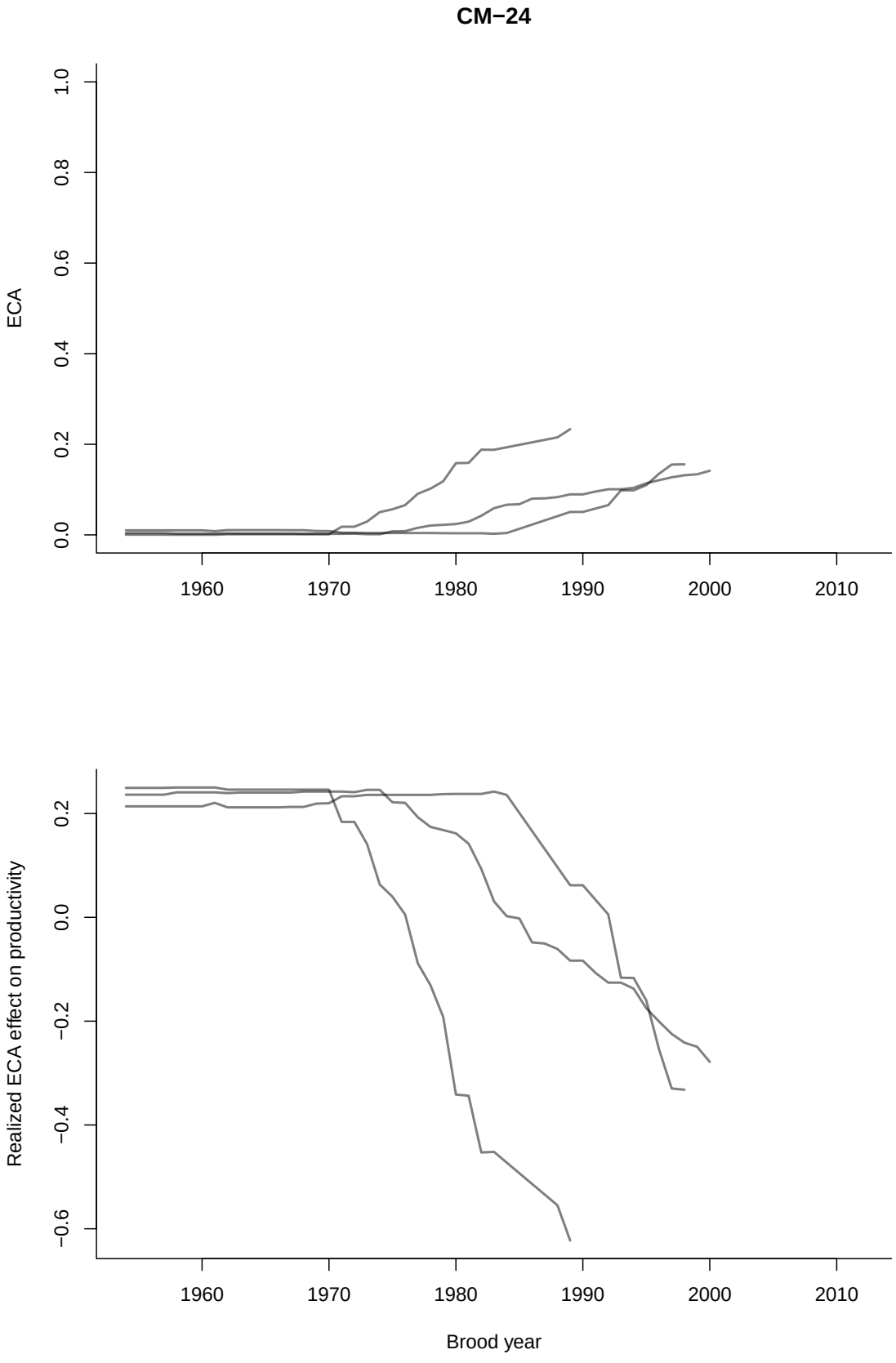

CM−19
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.10
−0.05
0.00
0.05
1960
1970
1980
1990
2000
2010
Brood year

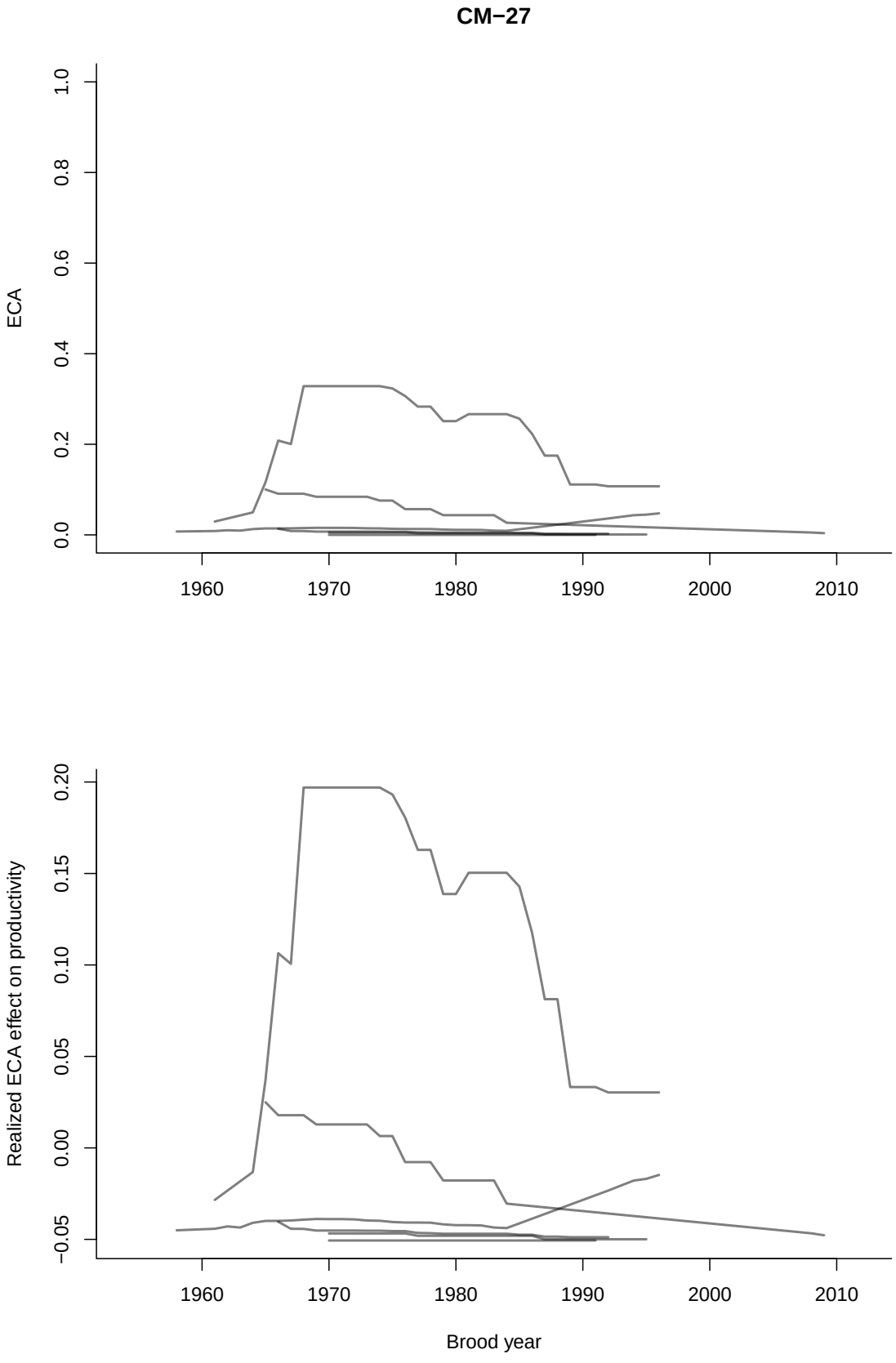

CM−20
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.5
0.0
0.5
1.0
1.5
1960
1970
1980
1990
2000
2010
Brood year

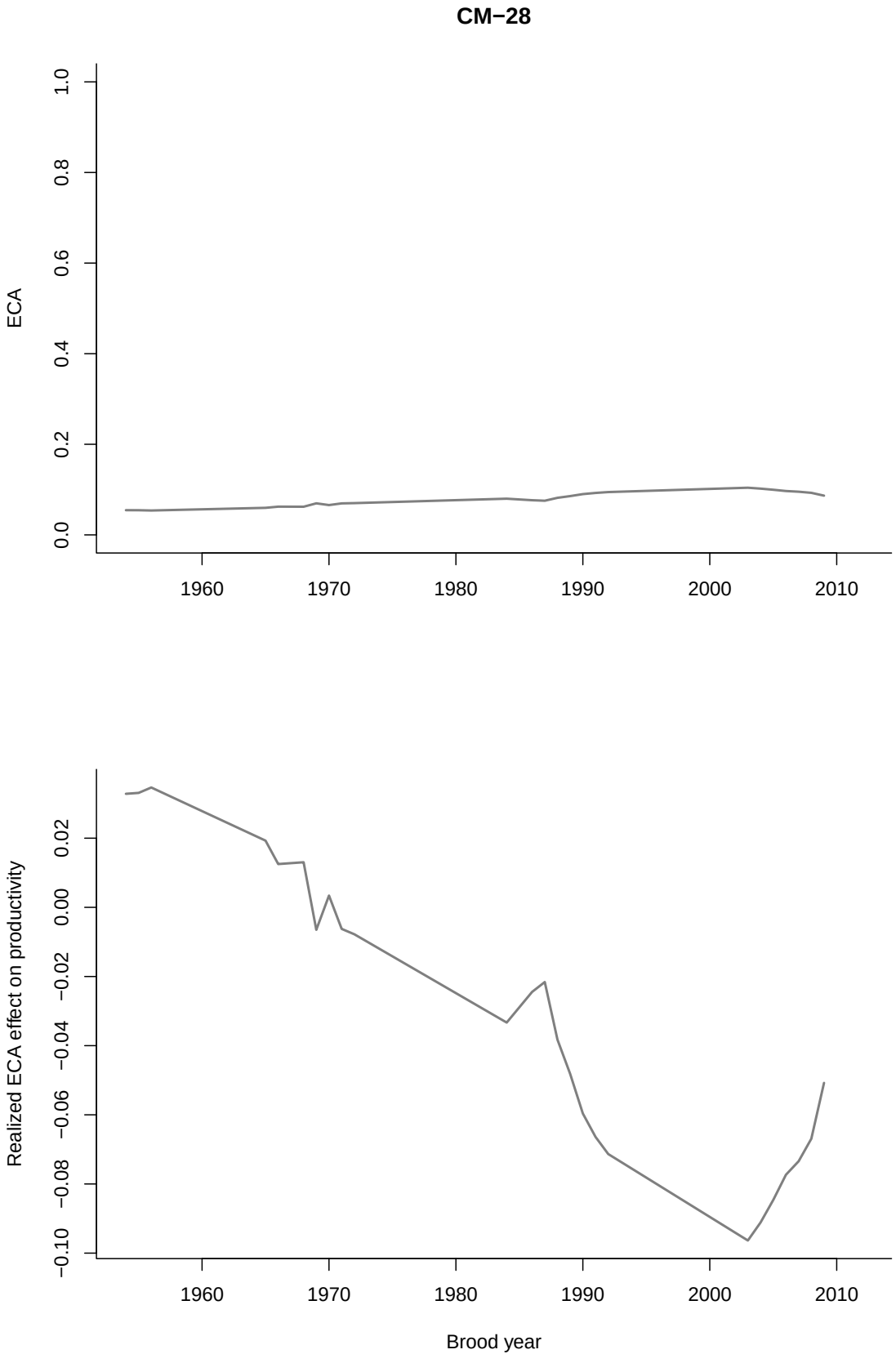

CM−21
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−1.2
−1.0
−0.8
−0.6
−0.4
−0.2
0.0
1960
1970
1980
1990
2000
2010
Brood year

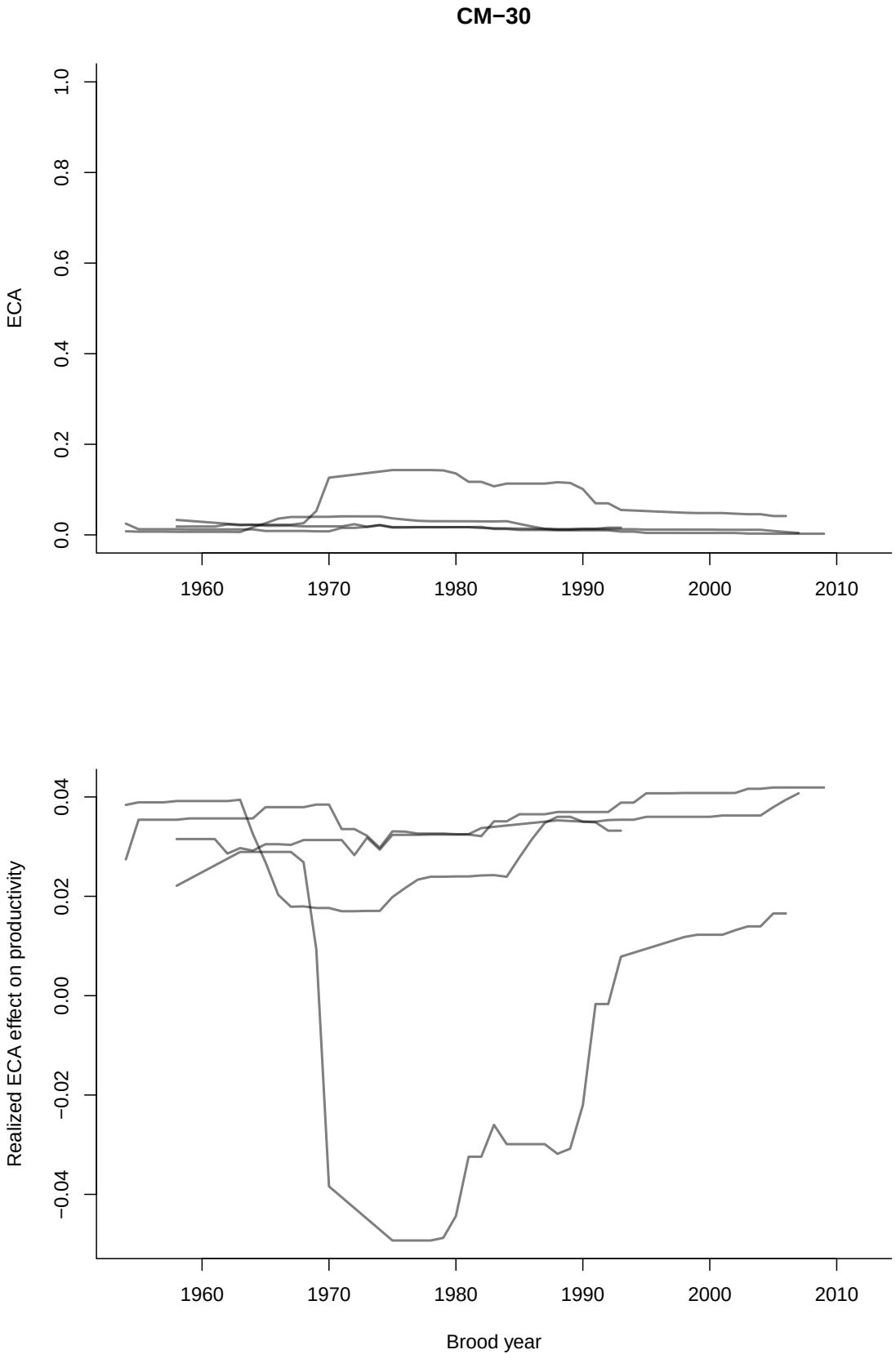

CM−22
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.15
−0.10
−0.05
0.00
1960
1970
1980
1990
2000
2010
Brood year

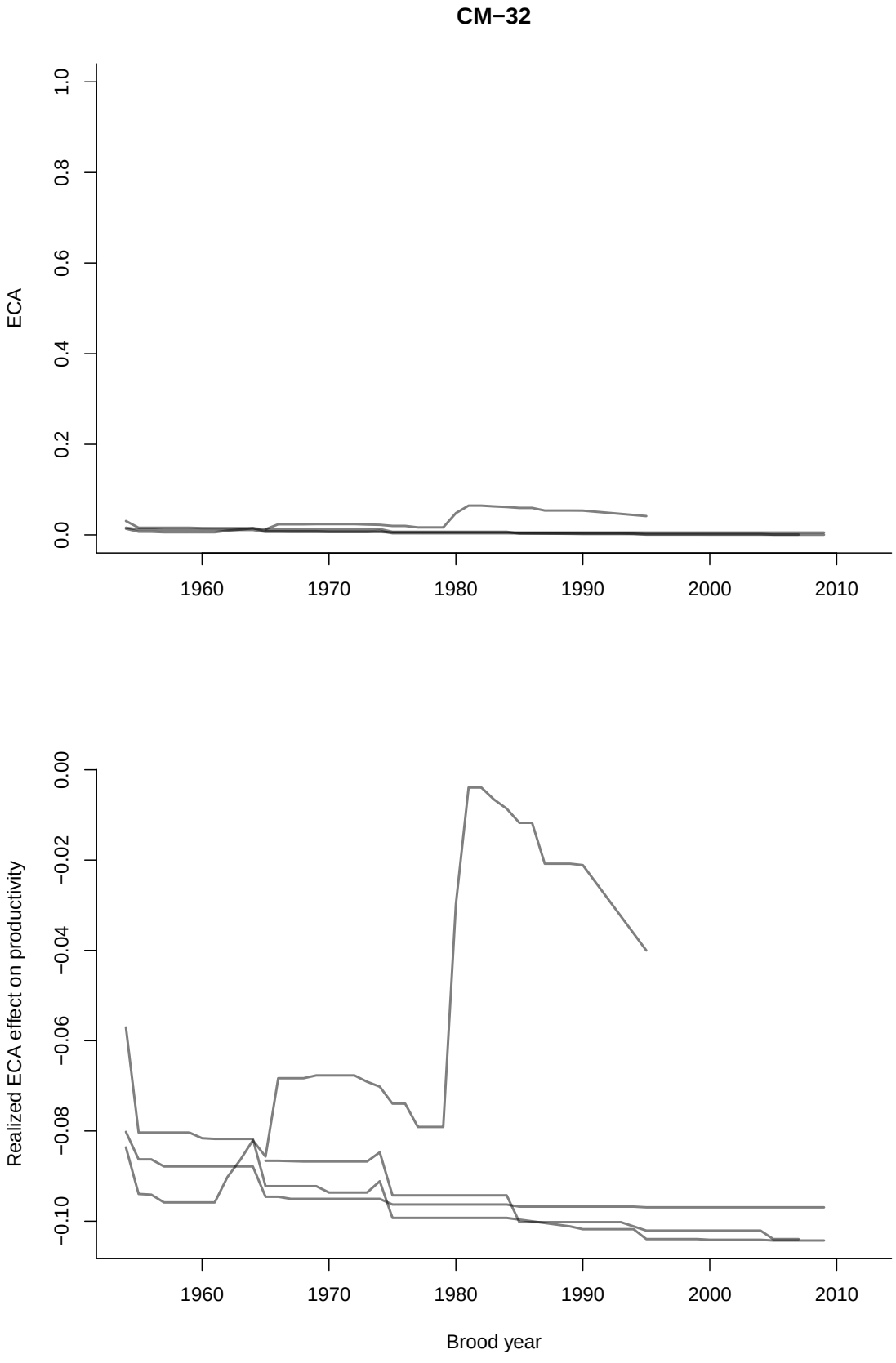

CM−23
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
0.1
1960
1970
1980
1990
2000
2010
Brood year

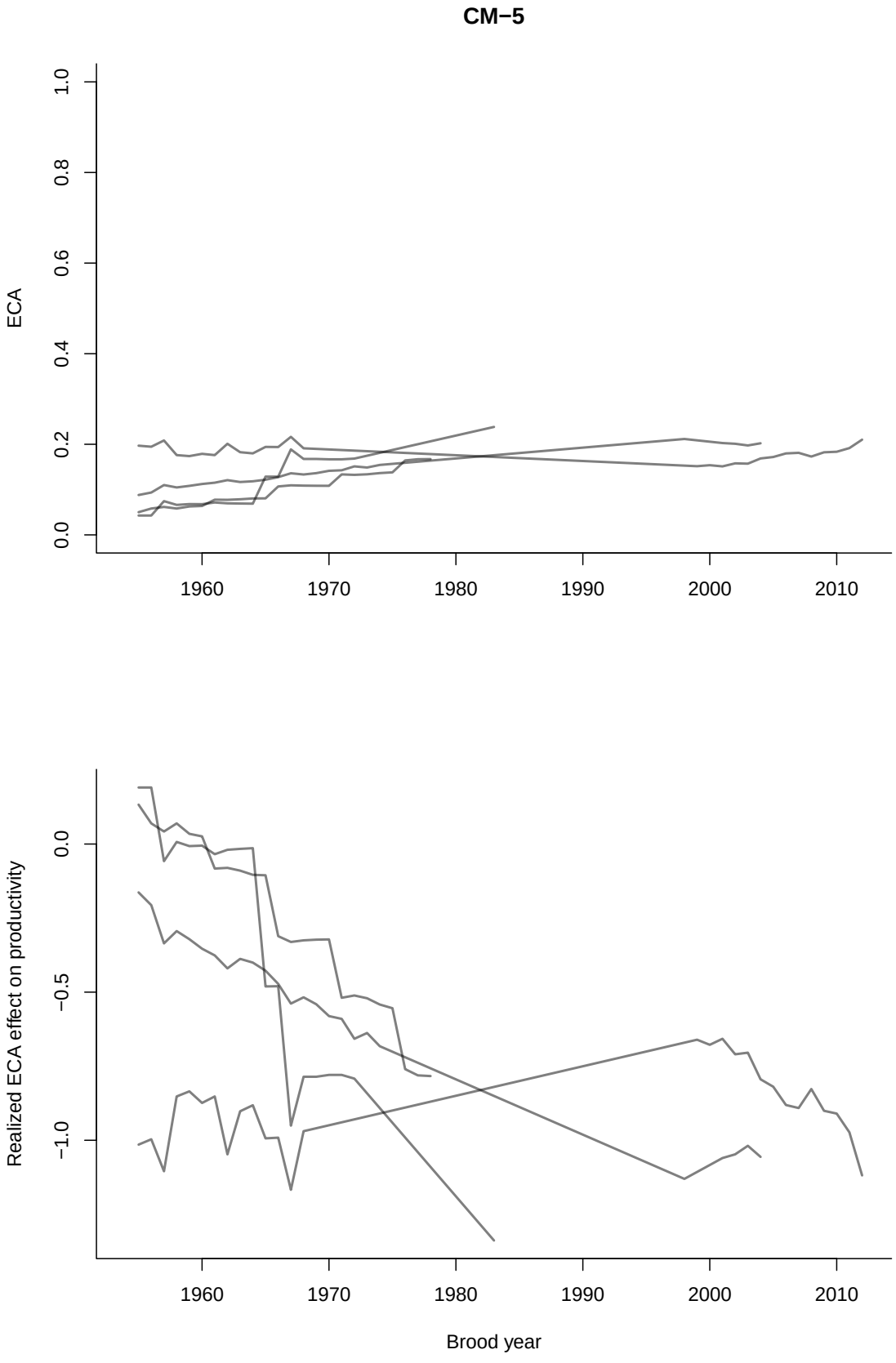

CM−24
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.6
−0.4
−0.2
0.0
0.2
1960
1970
1980
1990
2000
2010
Brood year

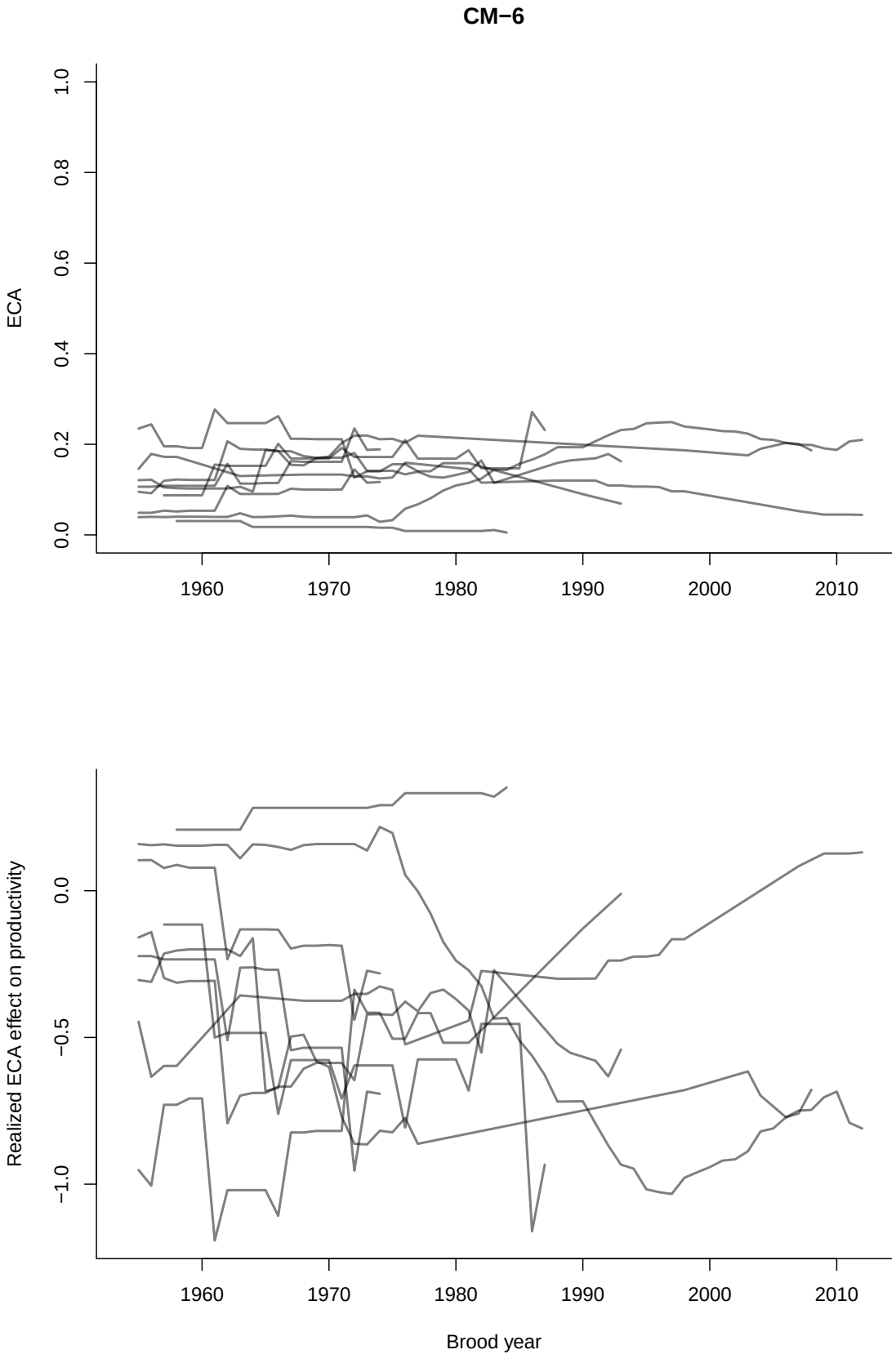

CM−27
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.05
0.00
0.05
0.10
0.15
0.20
Brood year


CM−28
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.10
−0.08
−0.06
−0.04
−0.02
0.00
0.02
1960
1970
1980
1990
2000
2010
Brood year

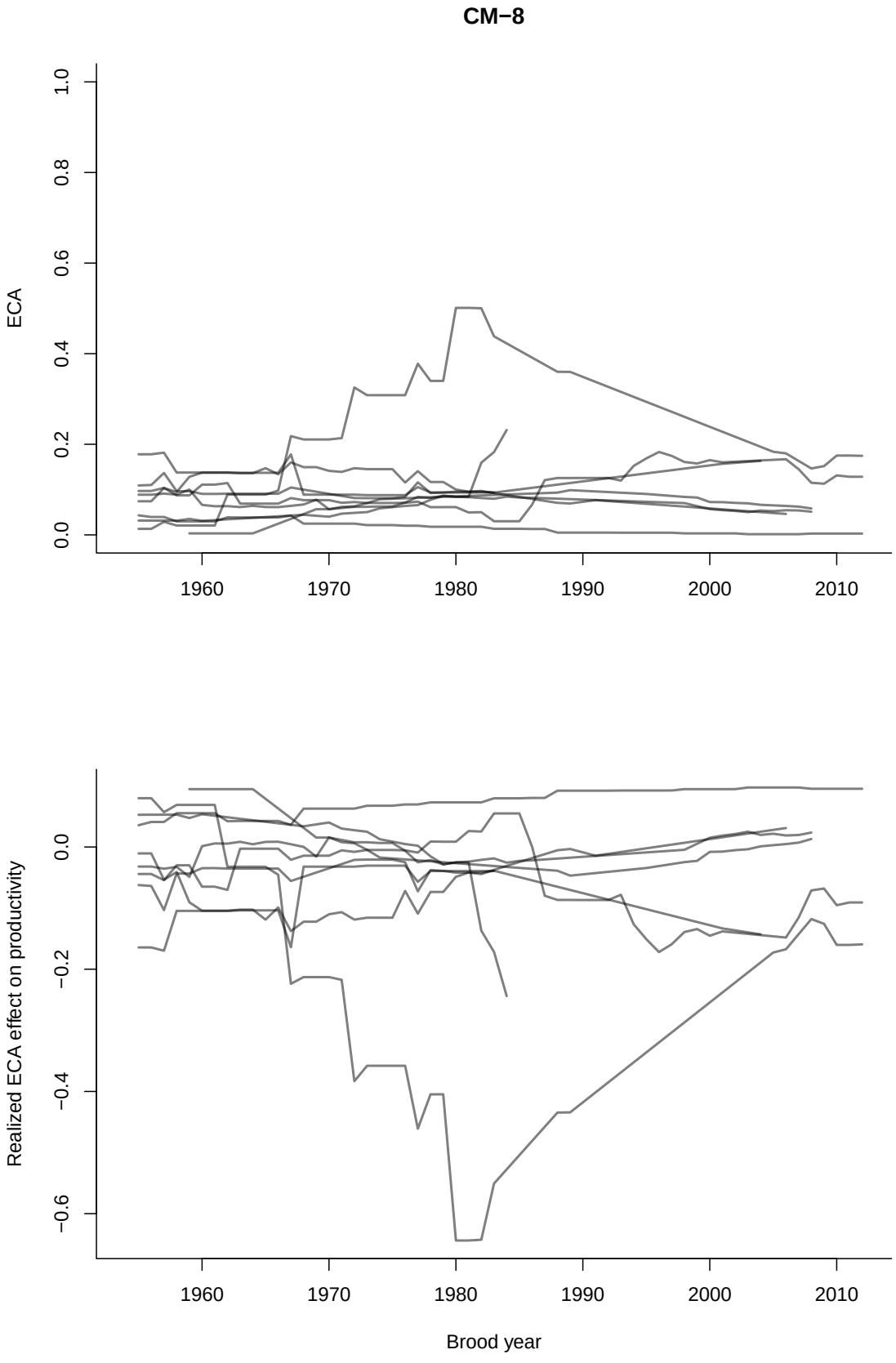

CM−30
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.04
−0.02
0.00
0.02
0.04
1960
1970
1980
1990
2000
2010
Brood year

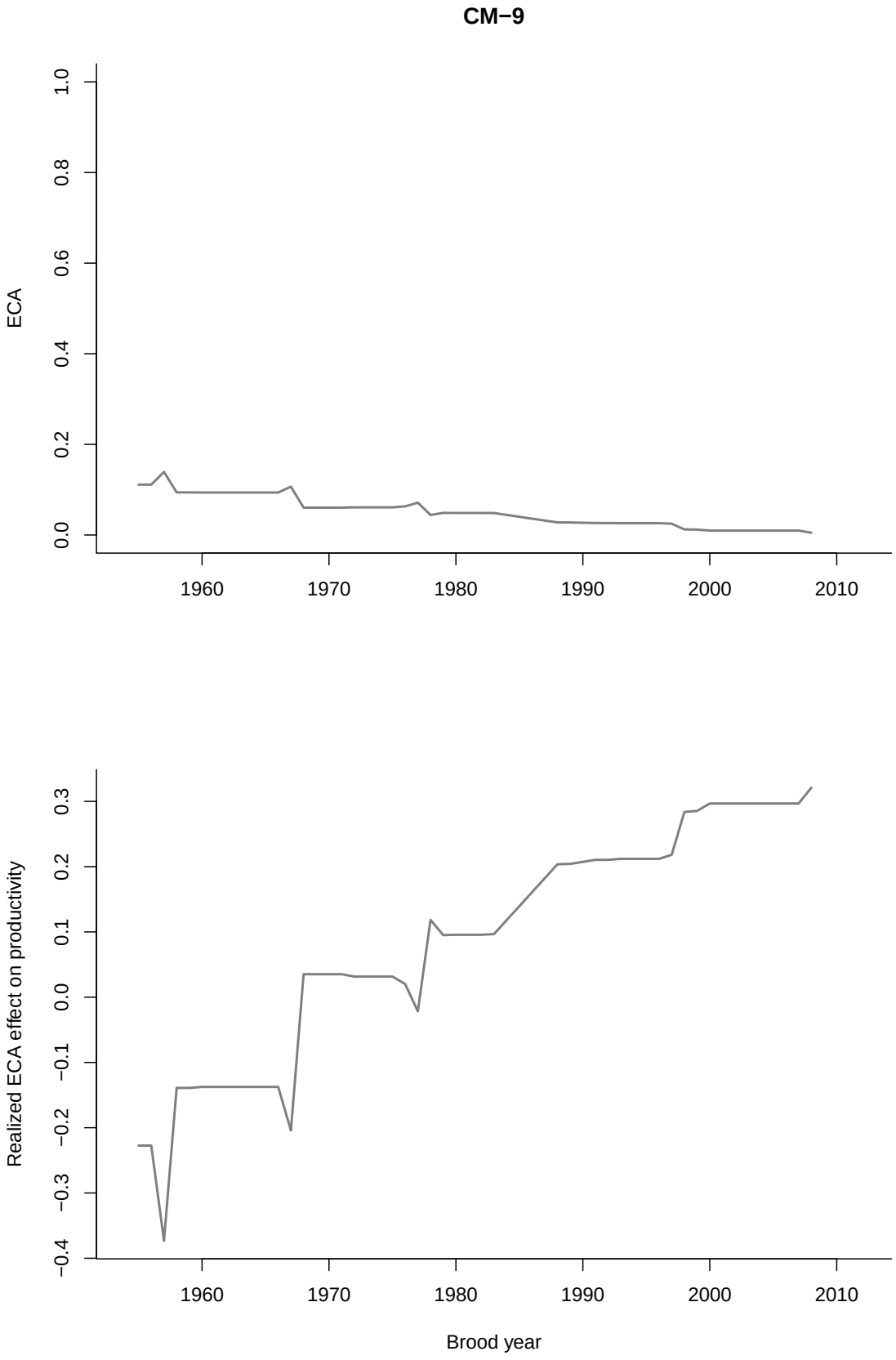

CM−32
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
0.00
−0.02
−0.04
−0.06
−0.08
−0.10
1960
1970
1980
1990
2000
2010
Brood year


CM−5
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−1.0
−0.5
0.0
1960
1970
1980
1990
2000
2010
Brood year


CM−6
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−1.0
−0.5
0.0
1960
1970
1980
1990
2000
2010
Brood year


CM−7
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.10
−0.05
0.00
0.05
1960
1970
1980
1990
2000
2010
Brood year


CM−8
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.6
−0.4
−0.2
0.0
1960
1970
1980
1990
2000
2010
Brood year


CM−9
ECA
0.0
0.2
0.4
0.6
0.8
1.0
1960
1970
1980
1990
2000
2010
Realized ECA effect on productivity
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
1960
1970
1980
1990
2000
2010
Brood year