ESM

A framework for estimating the determinants of spatial and temporal variation in vital rates and inferring the occurrence of unobserved extreme events

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Table ESM 1. Topological characteristics of Upper Volaja. Stream altitude is between 725 (Sector 4) and 683 (Sector 1) m.

| Sector | Length (m) | Area (m²) | Slope | Number of pools | Pool area (m²) |
|--------|------------|-----------|-------|----------------|----------------|
| 1      | 44.52      | 136.57    | 13%   | 5              | 65.59          |
| 2      | 78.53      | 254.59    | 17%   | 5              | 88.55          |
| 3      | 47.72      | 134.57    | 16%   | 3              | 43.46          |
| 4      | 93.87      | 220.54    | 15%   | 4              | 60.74          |
| Total  | 264.64     | 746.27    | 15% (avg) | 17           | 258.34        |
Table ESM 2. Symbols and abbreviations used in the main text.

| Symbol or Abbreviation | Explanation |
|------------------------|-------------|
| $GDDs$                 | Growing degree-days |
| $D_{0+}$               | Density of age-0+ fish |
| $D_{>0+}$              | Density of fish older than 0+ |
| $L_{0+}$, $\bar{L}_{0+}$ | Length and mean length of fish at age 0+ |
| vBGF                   | Von Bertalanffy Growth Function |
| $L_\infty$             | Asymptotic size in the vBGF |
| $k$                    | Growth coefficient in the vBGF |
| $t_0$                  | Age at which size is equal to 0 in the vBGF |
| $u$                    | Individual random effect for vBGF $k$ |
| $v$                    | Individual random effect for vBGF $L_\infty$ |
| $\sigma_u$            | Standard deviation of the distribution of individual random effect for vBGF $k$ |
| $\sigma_v$            | Standard deviation of the distribution of individual random effect for vBGF $L_\infty$ |
| $x_{ij}$               | Continuous predictor of vBGF’s parameters for individual $i$ in group $j$ |
| $\varepsilon_{ij}$    | Error term of the vBGF for individual $i$ in group $j$ |
| Symbol | Description |
|--------|-------------|
| $\sigma^2$ | Variance of the error term for the vBGF |
| $\alpha, \beta$ | Categorical predictors of vBGF’s parameters for individual $i$ in group $j$ |
| $D_{>0^{+},\text{born}}$ | Density of fish older than $0^{+}$ when the fish/cohort was born |
| $D_{>0^{+},m}$ | Mean of $D_{>0^{+}}$ at year $i$ in September and $t+1$ in June |
| Cohort | Year-class |
| Data$_W$ | Whole dataset |
| Data$_S$ | Dataset including (a) trout that were sampled once at age $1^{+}$, and (b) trout that were sampled multiple times in the same sector and were sampled for the first time at age $1^{+}$ |
| Data$_D$ | Dataset including all cohorts for which density and water temperature in the first year of life are known |
| $G_d$ | Daily growth in size |
| Season | Sampling season: June-September (Summer), September-June (Winter) |
| $D_{s,t}$ | Density of spawners at year $t$ |
| $R_t$ | Recruitment (density of age-0$^{+}$ in September) at year $t$ |
| GAM | Generalized Additive Model |
| GAMM | Generalized Additive Mixed-Model |
| $T$ | Mean temperature during a Season |
| Time | Sampling occasion in the model of survival |
| $\phi$ | Apparent survival of tagged fish |
| $p$ | Probability of capture in the model of survival |
| CJS          | Cormack-Jolly-Seber model of survival |
|--------------|---------------------------------------|
| $\sigma_{0+}$ | Apparent survival of fish from age 0+ to age 1+ |
Table ESM 3. Estimates of number and density of fish alive, and probability of capture in each *Year* and *Month* for fish aged 0+ (0) or 1+ and older (1). P_Est, P_Se = point estimate and standard error of probability of capture; N_Obs = number of fish sampled; N_Est, N_LCI, N_UCI = point estimate and lower and upper 95% CI of number of fish. D_Est, D_LCI, D_UCI = point estimate and lower and upper 95% CI of density of fish (fish ha⁻¹). There was complete recruitment failure in 2014.

| Year | Month | P_Est | P_Se | N_Obs | N_Est | N_LCI | N_UCI | D_Est | D_LCI | D_UCI | Age |
|------|-------|-------|------|-------|-------|-------|-------|-------|-------|-------|-----|
| 2004 | Sept  | 0.92  | 0.04 | 59    | 59    | 57.62 | 60.38 | 790.60| 772.11| 809.09| 0   |
| 2005 | Sept  | 0.90  | 0.05 | 60    | 60    | 58.03 | 61.97 | 804.00| 777.64| 830.36| 0   |
| 2006 | Sept  | 0.94  | 0.05 | 30    | 30    | 29.24 | 30.76 | 402.00| 391.79| 412.21| 0   |
| 2007 | Sept  | 0.88  | 0.06 | 38    | 38    | 36.21 | 39.79 | 509.20| 485.26| 533.14| 0   |
| 2008 | Sept  | 0.72  | 0.12 | 31    | 33    | 27.19 | 38.81 | 442.20| 364.41| 519.99| 0   |
| 2009 | Sept  | 0.94  | 0.07 | 15    | 15    | 14.46 | 15.54 | 201.00| 193.78| 208.22| 0   |
| 2010 | Sept  | 0.80  | 0.19 | 8     | 8     | 6.30  | 9.70  | 107.20| 84.46 | 129.94| 0   |
| 2011 | Sept  | 0.81  | 0.13 | 17    | 17    | 14.69 | 19.31 | 227.80| 196.90| 258.70| 0   |
| 2012 | Sept  | 0.88  | 0.05 | 53    | 53    | 50.88 | 55.12 | 710.20| 681.81| 738.59| 0   |
| 2013 | Sept  | 0.77  | 0.13 | 23    | 24    | 20.29 | 27.17 | 321.60| 271.93| 371.27| 0   |
| 2014 | Sept  | 0.00  | 0.00 | 0     | 0     | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0   |
| 2015 | Sept  | 0.86  | 0.05 | 65    | 65    | 62.17 | 67.83 | 871.00| 833.10| 908.90| 0   |
| 2004 | Sept  | 0.90  | 0.01 | 543   | 548   | 542.40| 553.60| 7343.20| 7268.13| 7418.27| 1   |
| 2005 | June  | 0.90  | 0.02 | 464   | 468   | 462.85| 473.15| 6271.20| 6202.23| 6340.17| 1   |
| 2005 | Sept  | 0.95  | 0.01 | 502   | 503   | 500.61| 505.39| 6740.20| 6708.15| 6772.25| 1   |
| 2006 | June  | 0.91  | 0.02 | 385   | 388   | 383.71| 392.29| 5199.20| 5141.73| 5256.67| 1   |
| Year | Month | Value1 | Value2 | Value3 | Value4 | Value5 | Value6 | Value7 |
|------|-------|--------|--------|--------|--------|--------|--------|--------|
| 2006 | Sept  | 0.94   | 0.01   | 373    | 374    | 371.29 | 376.71 | 5011.60 |
| 2007 | June  | 0.92   | 0.02   | 388    | 390    | 386.55 | 393.45 | 5226.00 |
| 2007 | Sept  | 0.94   | 0.01   | 390    | 391    | 388.14 | 393.86 | 5239.40 |
| 2008 | June  | 0.89   | 0.02   | 409    | 413    | 407.69 | 418.31 | 5334.20 |
| 2008 | Sept  | 0.92   | 0.01   | 420    | 422    | 418.26 | 425.74 | 5654.80 |
| 2009 | June  | 0.86   | 0.02   | 329    | 335    | 328.35 | 341.65 | 4489.00 |
| 2009 | Sept  | 0.91   | 0.02   | 363    | 366    | 361.81 | 370.19 | 4904.40 |
| 2010 | June  | 0.94   | 0.01   | 399    | 400    | 397.17 | 402.83 | 5360.00 |
| 2010 | Sept  | 0.90   | 0.02   | 334    | 337    | 332.72 | 341.28 | 4515.80 |
| 2011 | June  | 0.90   | 0.02   | 320    | 323    | 318.48 | 327.52 | 4328.20 |
| 2011 | Sept  | 0.92   | 0.02   | 369    | 371    | 367.45 | 374.55 | 4971.40 |
| 2012 | June  | 0.90   | 0.02   | 323    | 326    | 321.64 | 330.36 | 4368.40 |
| 2012 | Sept  | 0.92   | 0.02   | 355    | 357    | 353.50 | 360.50 | 4783.80 |
| 2013 | June  | 0.91   | 0.02   | 376    | 379    | 374.65 | 383.35 | 5078.60 |
| 2013 | Sept  | 0.90   | 0.02   | 335    | 338    | 333.60 | 342.40 | 4529.20 |
| 2014 | June  | 0.90   | 0.02   | 415    | 419    | 414.08 | 423.92 | 5614.60 |
| 2014 | Sept  | 0.91   | 0.02   | 432    | 435    | 430.43 | 439.57 | 5829.00 |
| 2015 | June  | 0.95   | 0.01   | 331    | 331    | 329.08 | 332.92 | 4435.40 |
| 2015 | Sept  | 0.91   | 0.02   | 325    | 327    | 323.31 | 330.69 | 4381.80 |
Table ESM 4. Proportion of “late incomers” present in the population each year in September. We applied the same ratio of “late incomers” to total number of fish found for cohorts born after the start of sampling to cohorts born before the start of sampling (from 2000 to 2003). Early.inc = “early incomers”, i.e. fish that were either born in Upper Volaja or came into Upper Volaja before age 1+ in September. FP_Coh = number of fish from cohorts born before the start of sampling. N.tot = total number of fish aged 1+ or older sampled each September. Late.inc = “late incomers”, i.e. fish that were born in AW and came into Upper Volaja when 1+ in September or older. Prop.late.inc = proportion of “late incomers” in Upper Volaja each year in September.

| Year | Early.inc | FP_Coh | N.tot | Late.inc | Prop.late.inc |
|------|-----------|--------|-------|----------|---------------|
| 2010 | 198       | 13     | 334   | 128      | 0.38          |
| 2011 | 216       | 8      | 369   | 148      | 0.40          |
| 2012 | 208       | 6      | 355   | 143      | 0.40          |
| 2013 | 226       | 5      | 335   | 106      | 0.32          |
| 2014 | 293       | 6      | 432   | 135      | 0.31          |
| 2015 | 225       | 1      | 325   | 99       | 0.30          |
Table ESM 5. Predictors of vBGF parameters $L_\infty$ and $k$ (*Constant* = no predictors except for individual random effects), number of parameters, and AIC of the tested growth models (dataset Data$_W$; only September data).

| $L_\infty$ | $k$ | npar | AIC    |
|-----------|-----|------|--------|
| Cohort    | Cohort | 32   | 40608.0 |
| Constant  | Cohort | 19   | 40736.2 |
| Cohort    | Constant| 19  | 40831.2 |
| Constant  | Constant| 6   | 41687.4 |
**Table ESM 6.** Cohort-specific vBGF models. Linf_est, Linf_lcl, Linf_ucl = point estimate, lower and upper 95% CI of asymptotic size; k_est, k_lcl, k_ucl = point estimate, lower and upper 95% CI of growth coefficient; to_est, t0_lcl, t0_ucl = point estimate, lower and upper 95% CI of time at length zero; DP = data points; P_L1, P_L2, P_L3 = predicted average size at age 1+, 2+, 3+ in September; O_L1, O_L2, O_L3 = observed average size at age 1+, 2+, 3+ in September. NA means data not available. Avg is for parameters and predictions for the model with no predictors (and observations for all brown trout in the dataset).

| Cohort | Linf_est | Linf_lcl | Linf_ucl | k_est | k_lcl | k_ucl | t0_est | t0_lcl | t0_ucl | DP | P_L1 | P_L2 | P_L3 | O_L1 | O_L2 | O_L3 |
|--------|--------|--------|--------|-----|-----|-----|------|------|------|----|-----|-----|-----|-----|-----|-----|
| C00    | 279.46 | 241.27 | 317.65 | 0.51 | 0.05 | 0.98 | -1.61 | -1.72 | -1.51 | 10 | 206.37 | 235.71 | 253.27 | NA   | NA   | NA   |
| C01    | 246.44 | 234.25 | 258.63 | 0.60 | 0.43 | 0.78 | -1.61 | -1.72 | -1.51 | 58 | 195.73 | 218.74 | 231.32 | NA   | NA   | 232.79 |
| C02    | 228.55 | 223.00 | 234.10 | 0.50 | 0.45 | 0.54 | -1.61 | -1.72 | -1.51 | 382 | 165.91 | 190.37 | 205.29 | NA   | 191.17 | 203.45 |
| C03    | 240.28 | 243.28 | 246.30 | 0.33 | 0.30 | 0.35 | -1.61 | -1.72 | -1.51 | 721 | 137.80 | 166.31 | 186.89 | 137.56 | 164.39 | 184.74 |
| C04    | 227.04 | 221.41 | 232.67 | 0.34 | 0.32 | 0.37 | -1.61 | -1.72 | -1.51 | 501 | 134.15 | 161.05 | 180.17 | 131.20 | 162.88 | 183.16 |
| C05    | 227.11 | 221.55 | 232.67 | 0.33 | 0.30 | 0.35 | -1.61 | -1.72 | -1.51 | 548 | 130.35 | 157.30 | 176.75 | 130.10 | 158.45 | 177.78 |
| C06    | 229.34 | 223.62 | 235.06 | 0.32 | 0.30 | 0.34 | -1.61 | -1.72 | -1.51 | 461 | 129.53 | 156.74 | 176.53 | 130.54 | 155.82 | 174.78 |
| C07    | 226.24 | 219.47 | 233.01 | 0.32 | 0.29 | 0.34 | -1.61 | -1.72 | -1.51 | 322 | 127.98 | 154.83 | 174.34 | 126.97 | 156.38 | 172.34 |
| C08    | 225.68 | 218.99 | 232.37 | 0.32 | 0.30 | 0.35 | -1.61 | -1.72 | -1.51 | 353 | 128.61 | 155.40 | 174.79 | 128.95 | 153.12 | 172.64 |
| C09    | 236.13 | 228.22 | 244.04 | 0.29 | 0.27 | 0.32 | -1.61 | -1.72 | -1.51 | 336 | 126.87 | 154.78 | 175.55 | 125.12 | 155.80 | 176.32 |
| C10    | 252.69 | 240.26 | 265.12 | 0.27 | 0.24 | 0.30 | -1.61 | -1.72 | -1.51 | 258 | 126.86 | 156.32 | 178.89 | 126.35 | 154.69 | 178.09 |
| C11    | 244.56 | 229.16 | 259.96 | 0.30 | 0.26 | 0.34 | -1.61 | -1.72 | -1.51 | 153 | 132.05 | 160.97 | 182.45 | 128.38 | 160.89 | 185.60 |
| C12    | 314.89 | 282.84 | 346.94 | 0.21 | 0.17 | 0.24 | -1.61 | -1.72 | -1.51 | 277 | 130.59 | 165.08 | 192.92 | 128.87 | 168.43 | 192.29 |
| C13    | 258.97 | 235.52 | 282.42 | 0.29 | 0.24 | 0.34 | -1.61 | -1.72 | -1.51 | 210 | 137.58 | 168.13 | 191.00 | 136.31 | 170.46 | NA   |
| Avg    | 224.87 | 222.21 | 227.53 | 0.41 | 0.39 | 0.43 | -1.25 | -1.34 | -1.17 | 4590 | 134.99 | 165.06 | 185.07 | 131.98 | 165.91 | 184.49 |
Table ESM 7. Sector-specific vBGF models. Linf_est, Linf_lcl, Linf_ucl = point estimate, lower and upper 95% CI of asymptotic size; k_est, k_lcl, k_ucl = point estimate, lower and upper 95% CI of growth coefficient; t0_est, t0_lcl, t0_ucl = point estimate, lower and upper 95% CI of time at length zero; DP = data points; P_L1, P_L2, P_L3 = predicted average size at age 1+, 2+, 3+ in September; O_L1, O_L2, O_L3 = observed average size at age 1+, 2+, 3+ in September.

| Sector | Linf_est | Linf_lcl | Linf_ucl | k_est  | k_lcl  | k_ucl  | t0_est | t0_lcl | t0_ucl | DP   | P_L1  | P_L2  | P_L3  | O_L1  | O_L2  | O_L3  |
|--------|----------|----------|----------|--------|--------|--------|--------|--------|--------|------|-------|-------|-------|-------|-------|-------|
| 1      | 213.29   | 204.93   | 221.65   | 0.41   | 0.37   | 0.46   | -1.27  | -1.42  | -1.11  | 328  | 129.69| 158.00| 176.73| 130.53| 157.59| 175.70|
| 2      | 213.10   | 205.55   | 220.65   | 0.42   | 0.37   | 0.47   | -1.27  | -1.42  | -1.11  | 611  | 130.81| 159.03| 177.58| 131.03| 158.67| 177.91|
| 3      | 220.14   | 209.58   | 230.70   | 0.40   | 0.35   | 0.46   | -1.27  | -1.42  | -1.11  | 322  | 132.09| 161.38| 180.93| 132.51| 161.42| 181.00|
| 4      | 230.64   | 220.38   | 240.90   | 0.39   | 0.34   | 0.44   | -1.27  | -1.42  | -1.11  | 378  | 134.82| 165.62| 186.52| 134.99| 166.85| 184.58|
**Table ESM 8.** Recapture models for the “global model” of probability of survival \( \phi(Cohort \times Season) \). The best recapture model was \( p(Time) \).

| Model                                          | npar | AIC       | ΔAIC  | weight | neg2lnl |
|------------------------------------------------|------|-----------|-------|--------|---------|
| \( \phi(Cohort \times Season) p (~Time) \)      | 52   | 13520.62  | 0     | 0.74   | 13416.62|
| \( \phi(Cohort \times Season) p (~Season + Time) \) | 53   | 13522.74  | 2.12  | 0.26   | 13416.74|
| \( \phi(Cohort \times Season) p (~Season \times Time) \) | 63   | 13542.74  | 22.12 | 1.17E-05| 13416.74|
| \( \phi(Cohort \times Season) p (~Season) \)    | 32   | 13594.99  | 74.36 | 5.28E-17| 13530.99|
| \( \phi(Cohort \times Season) p (~bs(Age)) \)    | 34   | 13597.31  | 76.68 | 1.65E-17| 13529.31|
| \( \phi(Cohort \times Season) p (~Age) \)       | 32   | 13600.42  | 79.79 | 3.50E-18| 13536.41|
| \( \phi(Cohort \times Season) p (~1) \)         | 31   | 13605.27  | 84.65 | 3.08E-19| 13543.27|
| \( \phi(Cohort \times Season) p (~Cohort) \)    | 45   | 13608.68  | 88.06 | 5.60E-20| 13518.68|
**Fig. ESM 1.** Maximum annual rainfall recorded in the rainfall station closest to Upper Volaja (Kobarid) along with loess smoothing (gray area delimits 95% CI). Maximum daily rainfall was recorded on November 7th 1997. Daily rainfall similar to that of 1997 was recorded on December 25th 2009 (247 mm)
Fig. ESM 2 Boxplots of water temperature recorded (by month) in Upper Volaja between 2004 and 2014. Dashed lines enclose the range of temperatures allowing growth and the thick solid line identifies the temperature for maximum growth according to Elliott et al. (1995) [1].
Figure ESM 3

**Figure ESM 3.** Individual growth trajectories of brown trout and prediction of the growth model of growth trajectory of the average fish in Eq. (2) in the main text (see Avg in Table ESM 6).
Figure ESM 4. Partial effects on growth between sampling occasions (mm day$^{-1}$) of $L$ and $GDDs$-by-Season as predicted by the best GAMM model.
Fig. ESM 5. Point estimates of probability of survival and 95% CI as a non-linear function of Age in the population of Upper Volaja (fish are aged 1 in June and 1.25 in September of the second year and so on).
When a fish is sampled in September (1+ and older), the following occurrences are possible:

1. Fish was in Upper Volaja when 0+ (fish born in the stream)
   - Fish was sampled when 0+ and the adipose (ad) fin was cut (+)
   - Fish was present and not sampled when 0+ (ad not cut)
     - Fish was sampled at 1+ in June, smaller than 115 mm, and the ad was cut (+)
     - Fish was sampled at 1+ in June, bigger than 115 mm (thus getting tagged), and the ad was not cut (-)
     - Fish was not sampled at 1+ in June (missed in two occasions) and the ad was not cut (-)

2. Fish was in Upper Volaja when 1+ in June but not when 0+
   - Fish was sampled when 1+ in June, smaller than 115 mm, and the ad was cut (+)
   - Fish was sampled when 1+ in June, bigger than 115 mm (thus getting tagged), and the ad was not cut (-)
   - Fish was not sampled when 1+ in June (ad was not cut).

3. Fish was in Upper Volaja when 1+ in September or older, but not when 0+ or 1+ in June.

The two-pass removal and the estimation of capture rates of tagged fish indicate that the probability of sampling a fish when alive and present is between 0.85 and 0.90. Given the very high probability of capturing a fish when present (the point estimate for 0+ is the total number of fish aged 0+ sampled for almost all years) and mortality between sampling occasions, we assumed that 1.b was negligible (see Table ESM 3 for the estimates of density). Since 1+ in June
with $L < 115$ had the ad cut and $\sim 43\%$ of 1+ in June had $L < 115$, we cannot tease apart fish that were sampled when 0+ and fish that were sampled when 1+ in June and had $L < 115$ (we cannot tease apart 1.a from 2.a). Therefore, we have to assign fish to “early incoming” group (which includes fish born in the stream and fish migrating from AW when at max aged 1+ in June, that is 1.a + 2.a + 2.b) and “late incoming” group (fish that migrate into the streams when older than age 1+ in June, that is (3)).

Given the high capture rates, we also assumed that 2.c. was negligible (it will tend to slightly increase the proportion of “early incomers”).
When using shared $k$ and $L_\infty$ among all fish in a population (i.e. no predictors for either $k$ or $L_\infty$) or when using Cohort as predictor, we used the complete tag-recapture dataset for Upper Volaja (datasets Data\textsubscript{W}: $n$ of individuals = 2414, $n$ of length data = 4590).

Some fish were born before both density and temperature data were available. For instance, the oldest fish sampled in Upper Volaja was born in 2000, but $D_{>0+\text{born}}$ and water temperature were first estimated and recorded in 2004. Since we wanted to compare the explanatory power of the growth models when $D_{>0+\text{born}}$, GDDs, Cohort, were used as predictors of vBGF’s parameters, we used a subset of the whole datasets (datasets Data\textsubscript{D}: $n$ of individuals = 1524, $n$ of length data = 2919) when using $D_{>0+\text{born}}$ and GDDs as potential predictors. For both analyses, we used AIC to select the best model.

The inclusion of trout captured in different sectors throughout their lifetime would not allow using sampling sector as predictor of vBGF’s parameters in the formulation in Eq (2). Thus, when including sampling sector as predictor, we used a subset of Data\textsubscript{W} (Data\textsubscript{S}: $n$ of individuals = 912, $n$ of length data = 1639) that included (a) trout that were sampled once at age 1+, and (b) trout that were sampled multiple times in the same sector and were sampled for the first time at age 1+ (the latter due to avoid bias introduced by fish coming into Upper Volaja from AW, thus by fish that had grown for years in a different environment). Although we cannot exclude that fish sampled multiple times in the same sampling sector had moved between sectors outside the days of sampling, we assumed that, in case of (b), trout stayed permanently in the same sector.

When using sampling sector as predictor of VBG’s parameters, we only analyzed model results without comparing model fit to other model formulations.
Our goal was to investigate the effects of mean temperature, early density, season, age, sampling occasion on variation in probability of survival of tagged fish using continuous covariates \( D_{so}, \) mean temperature between sampling intervals \( T \) at the same time of categorical predictors \((Cohort, Time, Season)\).

Two probabilities can be estimated from a capture history matrix: \( \phi \), the probability of apparent survival, and \( p \), the probability that an individual is captured when alive [2]. We used the Cormack–Jolly–Seber (CJS) model as a starting point for the analyses [2]. The global starting model, that is the model with the maximum parameterization for categorical predictors, was different for each population. For both \( \phi \) and \( p \), a multiplicative interaction between \( Cohort \) and \( Time \) (i.e. the interval between two consecutive sampling occasions) was included. We could not use the “true” global model of survival with interaction between \( Cohort \), \( Time \), and \( Season \) as the model failed to converge.

We tested the goodness-of-fit of the CJS model with the program Release. The global model was a good starting point to model survival and capture probabilities. All other survival models tested were simplified versions of this global starting model, with the potential addition of covariates. We modeled the seasonal effect \((Season)\) as a simplification of full time variation, dividing each year in two periods: June to September \((Summer)\) and September to June \((Winter)\). Since the length of the two intervals \((Summer \ and \ Winter)\) was different, we estimated probability of survival on a common annual scale.

We only tested models with a potential biological interpretation. Normalized Akaike weights (AIC weights) represent the relative probability of a model being closest to the unknown process.
that generated the data [3]. From the global model, we first modeled recapture probability by allowing the recapture probability to vary among Cohort, Time, and Season. We then used the recapture model with the lowest AIC to model survival probabilities. Fixing the recapture probability component of the model allowed the survival component of the model to be compared, as any difference in AIC and AIC weight given to individual models would be due to the survival component [4].

Both Age and mean temperature between sampling intervals $T$ were introduced as either non-linear (as B-splines, Boor 2001) or linear predictors, while $D_{>0}$ was introduced only as a linear predictor. In addition, we tested whether, after taking account of Cohort, probability of survival of trout that was born in AW was different from that of fish born in Upper Volaja. In this case, we used a subset of the whole dataset that included cohorts born between 2004 and 2010 included.

Unless otherwise noted, in this work probability of survival $\phi$ refers to an annual temporal scale. We use the symbol $\sigma$ for probability of survival at the population level. We carried out the analysis of probability of survival using the package marked [6] for R. Tag-loss is not taken into account in marked, although the large number of samples and low proportion of fish losing their tag (<10%) should only slightly bias downwards the survival estimates.
Because fish were not tagged when 0+, we assumed a binomial process for estimating the probability \( \sigma_{0+} \) of first overwinter survival (0+ to 1+). We estimated survival by dividing the number of 0+ with the adipose fin cut in September by the estimated number of 1+ with the adipose fin cut in June. We did not use density of 0+ and 1+ the following year since newborns (and 1+ fish the following year before June sampling) can enter the sampling section after the September sampling, thus inflating the estimate of apparent survival. The estimate of the number of 1+ with the adipose fin cut \( (\hat{A}_{dc}) \) is thus \( \hat{A}_{dc} = \frac{A_{dc}}{p_s} \), where \( A_{dc} \) is the sampled number of fish aged 1+ with the adipose fin cut and \( p_s \) is the probability of capture at time \( t \) of fish that were alive at time \( t \). We estimated the standard error of the parameter of the binomial distribution using the delta method [7].
**Ethics statement**

All sampling work was approved by the Ministry of Agriculture, Forestry and Food of Republic of Slovenia and the Fisheries Research Institute of Slovenia. Original title of the Plan: RIBISKO - GOJITVENI NACRT za TOLMINSKI RIBISKI OKOLIS, razen Soce s pritoki od izvira do mosta v Cezsoco in Krnskega jezera, za obdobje 2006–2011. Sampling was supervised by the Tolmin Angling Association (Slovenia).
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