

Electronic Supplementary Material - Oecologia

Neighbouring populations, opposite dynamics: influence of body size and environmental variation on the demography of stream-resident brown trout (*Salmo trutta*).

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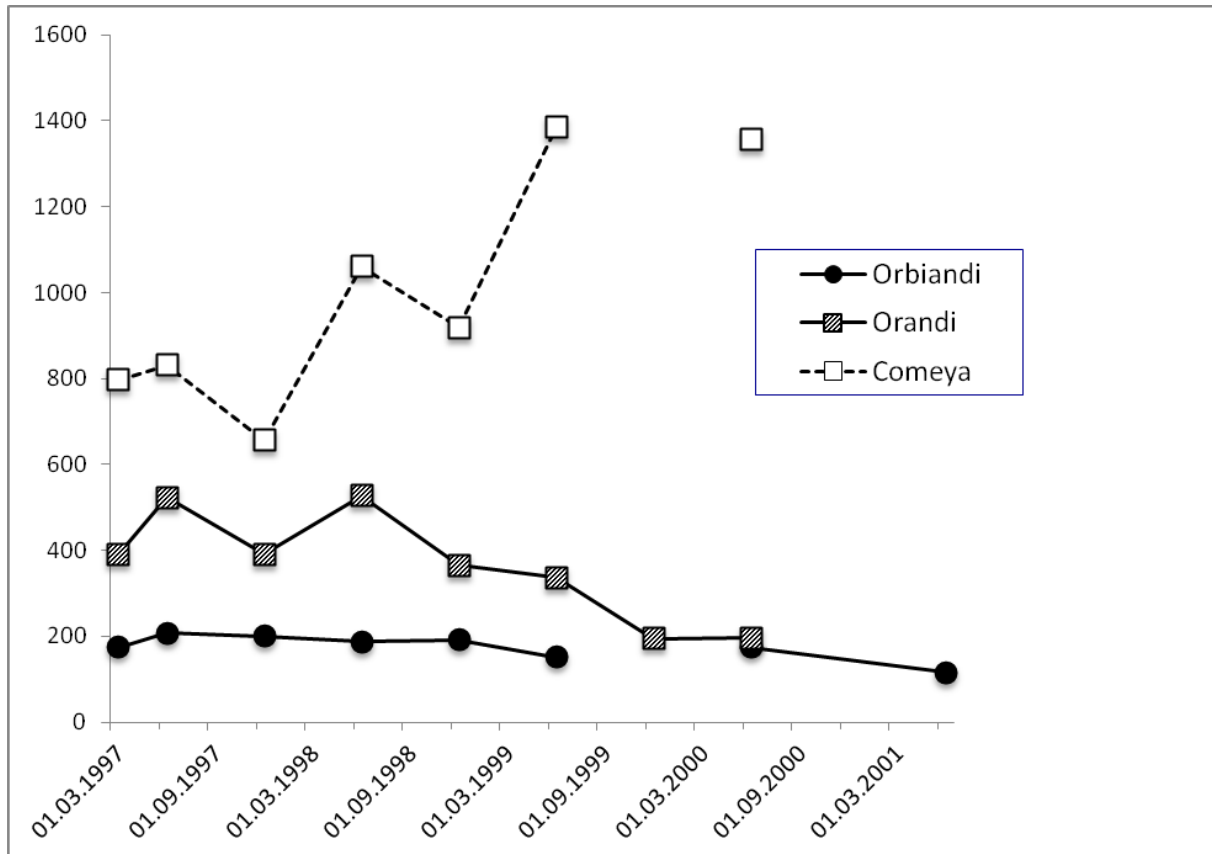
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### **Appendix 1**

#### **Number of captures as a proxy of minimum population size**

In the figure below we show the total number of captures (newly marked individuals + recaptures) per sampling occasion (winter and summer seasons) and stream. In the x-axis, September and March dates are used to broadly mark the boundaries of the two annual sampling seasons. We do not show data from 1996 at Comeya and Orandi as not all stream sections were sampled that year. Note that data for some winter seasons are also lacking at the highest altitude streams (Orbiandi and Comeya), whereas data for summer surveys are always available (and are the records used in our statistical analyses).



The total number of captures in a given season can be considered as a proxy of minimum population size for that time. In our case, population size seems to be higher in summer than in winter at Orbiandi and Comeya streams, but such fluctuations are not seen (or not so evident) at Orbiandi. Because of the lower number of captures recorded at this stream, the lowest population size in our study system would be that of Orbiandi, followed by Orandi and finally Comeya, Given that Orbiandi is the shortest and shallowest stream in our system and Comeya the largest one, with deeper stream areas, the minimum population sizes here reported seem also to reflect stream size.

### **Total population size and population densities**

The Multiple-pass removal method or “Zippin” method was used to estimate total population size in 1999 at Orbiandi stream, but unfortunately this was not replicated over time. This method was also used several times in Orandi to obtain estimates of population density (individuals/m<sup>2</sup>) but such estimates are based on single stream sections and do not reflect total stream densities. In addition, the sections sampled in Orandi correspond to adult trout habitat (deeper sections), with low presence of juveniles. Total catches per pass and section are shown below.

Orbiandi, March 1999

|              | pass 1     | pass 2    | pass 3    | pass 4 | Total      |
|--------------|------------|-----------|-----------|--------|------------|
| Section I    | 34         | 8         | 6         |        | 48         |
| Section II   | 24         | 11        | 3         | 0      | 38         |
| Section III  | 70         | 25        | 11        |        | 106        |
| <b>Total</b> | <b>128</b> | <b>44</b> | <b>20</b> |        | <b>192</b> |

Orandi

| Date       | Section  | pass 1 | pass 2 | pass 3 | total catch | Surface sampled (m <sup>2</sup> ) |
|------------|----------|--------|--------|--------|-------------|-----------------------------------|
| 27.09.1995 | Orandi 1 | 52     | 12     | 8      | 72          | 301,50                            |
|            | Orandi 2 | 18     | 1      |        | 19          | 71,80                             |
| 14.12.1995 | Orandi 1 | 30     | 11     | 4      | 45          | 332,75                            |
|            | Orandi 2 | 14     | 6      | 2      | 22          | 77,00                             |
| 05.06.1996 | Orandi 1 | 31     | 5      | 3      | 39          | 245,00                            |
|            | Orandi 2 | 14     | 5      | 4      | 23          | 77,00                             |
| 28.01.1997 | Orandi 1 | 22     | 5      | 1      | 28          | 245,00                            |
|            | Orandi 2 | 9      | 2      | 2      | 13          | 77,00                             |

Results for Orbiandi are close to a total number of 200 individuals, which is also the average number of total captures obtained per sampling occasion at this stream during the study period (see figure above). Results for Orandi cannot be extrapolated to the whole stream area and may only reflect total abundance and density of large trout in favorable habitats.

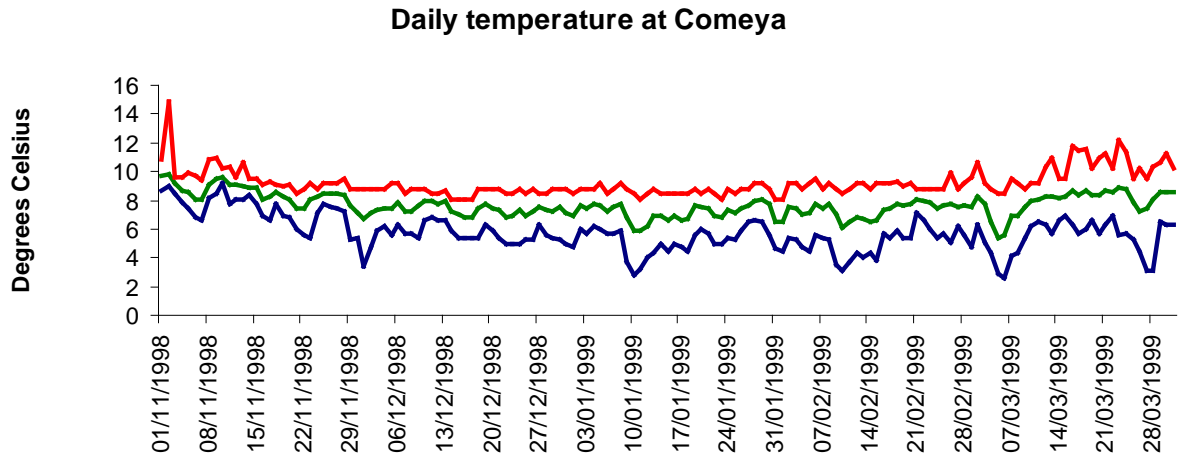
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## **Appendix 2**

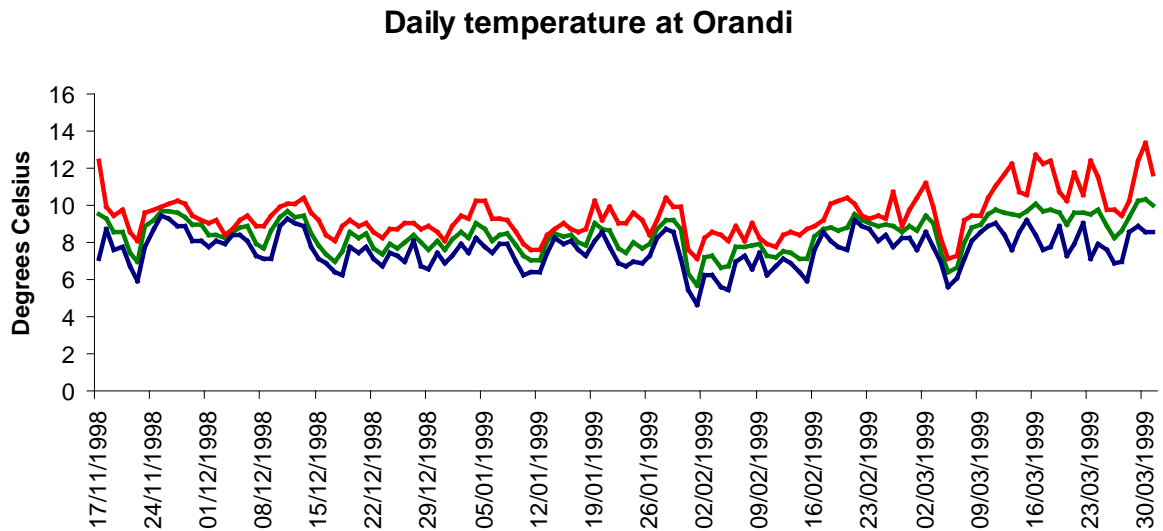
### **Variation in daily water temperature among study sites**

Due to differences in elevation and stream size, daily water temperature values may vary substantially among the study sites. Here, by means of figures S1, S2 and S3, we show, for the same winter period (1998-1999) the daily mean, maximum and minimum water temperature values for each stream. This winter period corresponds to the central part of our entire study period (1996-2001). Although not considered a winter month, November values are also given, to illustrate that water temperature differences are not only restricted to the official (December to March) winter time.

**Figure S1.** Daily water temperature (green=mean, red=maximum and blue=minimum values) at Comeya stream from early November 1998 to late March 1999.

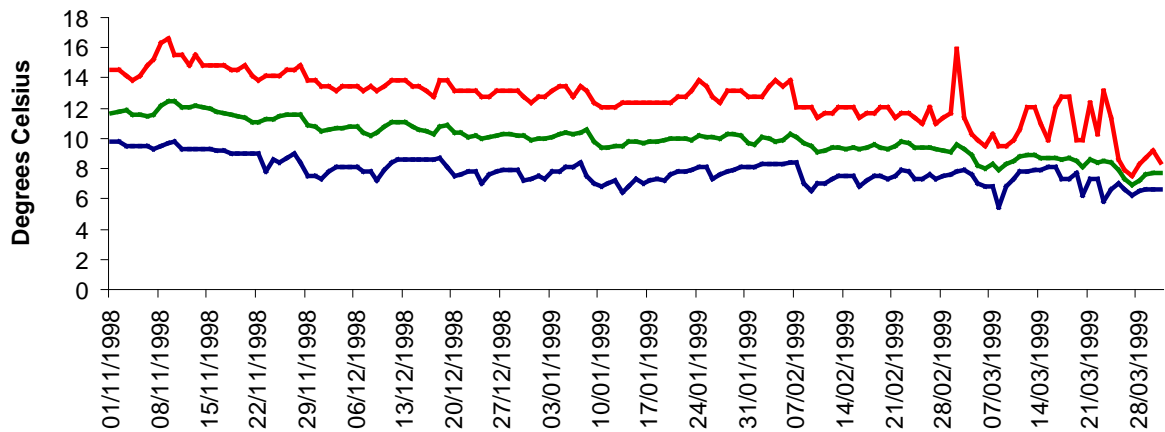


**Figure S2.** Daily water temperature (green=mean, red=maximum and blue=minimum values) at Orandi stream from mid November 1998 to late March 1999.



**Figure S3.** Daily water temperature (green=mean, red=maximum and blue=minimum values) at Orbiandi stream from early November 1998 to late March 1999.

### Daily temperature at Orbiandi



Within this time frame, the smallest differences between daily maximum and minimum temperatures were found at Orandi stream, with an average difference of 2 degrees Celsius. For the same period, average differences between daily minimum and maximum temperatures were of 5 degrees Celsius at Orbiandi, and 3.5 degrees at Comeya, making Orbiandi the stream showing the widest range of daily temperature variation.

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### **Appendix 3**

#### **Size of sexual maturation of brown trout in the study area**

In our capture-recapture analysis, we divided individuals in different size categories reflecting juvenile, immature and mature stages based on an unpublished PhD thesis indicating that, in our study area, the average minimum length at which both male and female trout can be considered sexually mature was 130mm. In order to shed light on the validity of this assumption here we examine our own data on brown trout, which also includes some information about the sex (male/female) of the sampled individuals. Unfortunately, not all the individuals collected during our study period could be sexed successfully. This is because we based sex determination on phenotypic traits that become more obvious once the individuals have reached sexual maturity. Therefore, all individuals classified as male or female in our data must be also sexually mature, and because the length of captured trout was always recorded, we can examine the length of the sexed fish and validate, in terms of maturation status, the size-based states used in our analysis by looking at the proportion of successfully sexed (i.e. sexually mature) individuals per size category.

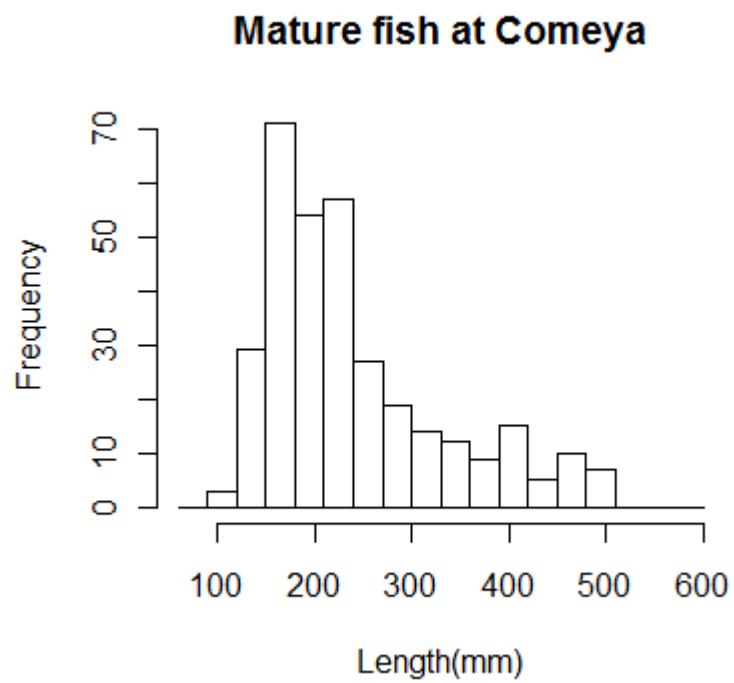


## Results

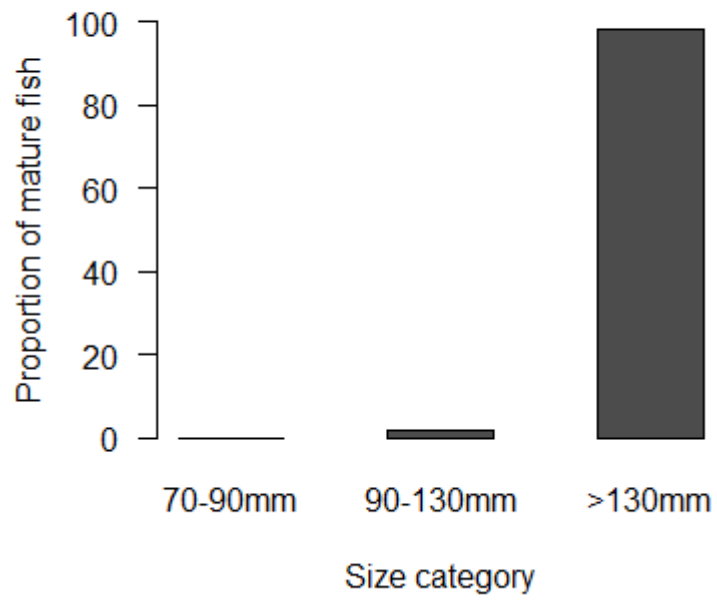
*Comeya river*

Number of sexed individuals = 333

Length distribution of sexed individuals



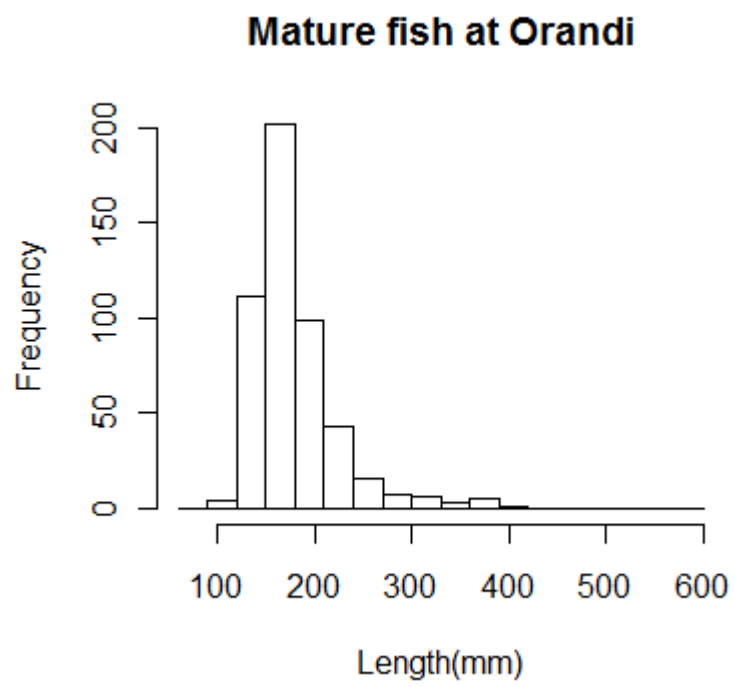
Proportion of sexually mature individuals per size category at Comeya



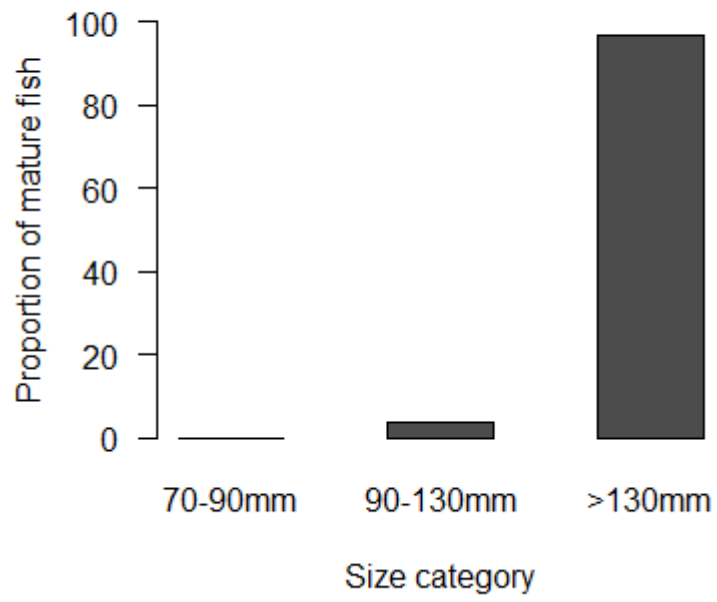
*Orandi river*

Number of sexed individuals = 497

Length distribution of sexed individuals



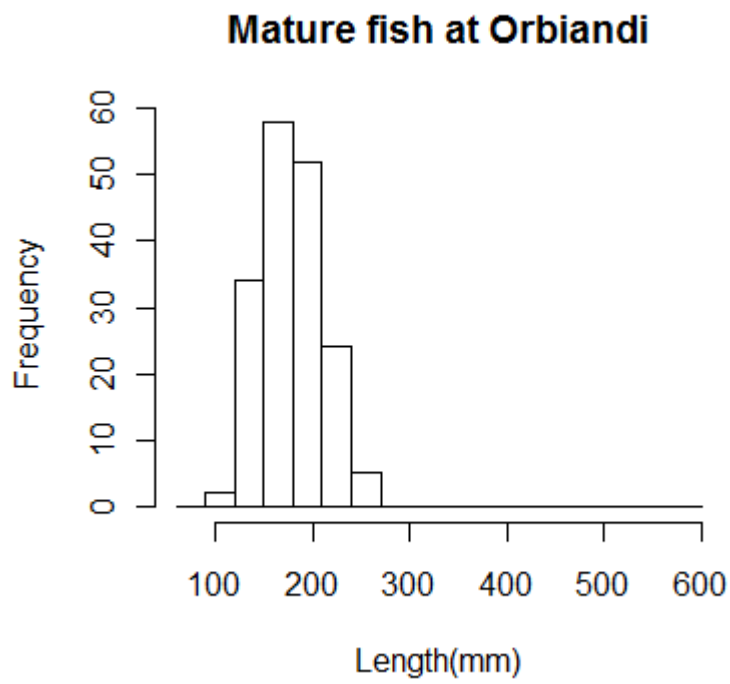
Proportion of sexually mature individuals per size category at Orandi



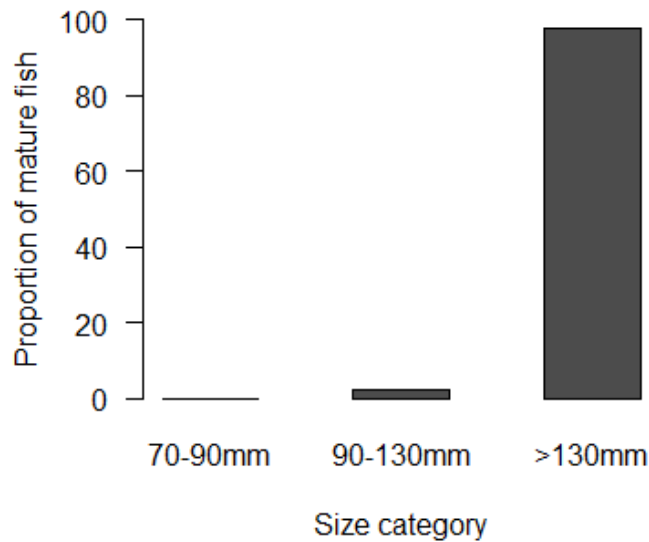
*Orbiandi river*

Number of sexed individuals = 175

Length distribution of sexed individuals



## Proportion of sexually mature individuals per size category at Orbiandi



### Discussion

Results show that none of the sexed trout belonged to size class 1 (70-90mm). However, some sexed individuals did belong to class 2 (90-130mm). In all rivers, the minimum body length recorded for mature fish was below our boundary of 130mm (100mm at Comeya, 115 at Orandi and 111 at Orbiandi), but mature fish of size class 2 represented a low proportion (between 1.5 and 3.4%) of all mature fish recorded at all sites, with Orandi river showing the highest proportion of mature fish below 130mm in length (3.4% of sexed fish). In fact, almost all sexed fish (between 96.5 and 98.2%) measured more than 130mm in length, validating this category as the one containing sexually mature individuals in our study populations. In addition, these results also reflect spatial differences in the length distribution of sexually mature fish, with individuals from Comeya and Orandi reaching sizes well above 300mm, whereas those at Orbiandi never reached sizes above 258mm.

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#### **Appendix 4**

##### **Specification of the multistate modelling approach in program E-SURGE**

Multistate models were built in several stages using program E-SURGE (Choquet and Nogue 2010). Each step represents one of the different parameters to estimate ( $\Phi$ ,  $\psi$ ,  $p$ , see below). This is done by means of row-stochastic matrices, i.e. each row corresponds to a multinomial. Consequently, the total of cell probabilities is 1. Because of this constraint, one and only one cell probability in each row will be calculated as the complement to 1 of the others. This particular cell is denoted with a '\*' symbol. Inactive cells, i.e. cells whose associated probability is structurally 0 are denoted with a '-' symbol. An active cell receives an arbitrary letter. Note that the same letter/symbol in two cells does not mean that the two values should be equal.

The individual states (size classes) considered are:

**O**, Juvenile (size class 1).

**I**, Immature (size class 2).

**M**, Mature (size class 3).

†, Dead.

The possible events (field observations) are:

- 1, seen measuring less than 90mm.
- 2, seen measuring between 90 and 130mm.
- 3, seen measuring more than 130mm.
- 0, not seen.

The symbols for parameters are:

**Y**, Initial state probability

**Φ**, survival probability

**ψ**, transition probability

**p**, event probability (=recapture probability)

Initial State probabilities ( “Dead” cannot be an initial state)

1x3

| <b>O</b> | <b>I</b> | <b>M</b> |
|----------|----------|----------|
| <b>Y</b> | <b>Y</b> | *        |

State transitions, step 1: Survival probability (Note: E-SURGE refers to both survival and transition steps as “transitions” as they are defined using transition matrices)

4x4

| From/to  | <b>O</b> | <b>I</b> | <b>M</b> | † |
|----------|----------|----------|----------|---|
| <b>O</b> | <b>Φ</b> | -        | -        | * |
| <b>I</b> | -        | <b>Φ</b> | -        | * |
| <b>M</b> | -        | -        | <b>Φ</b> | * |
| †        | -        | -        | -        | * |



State transitions, step 2: Transition probabilities conditional on survival (Note: because fish do not shrink in length, transitions from a bigger size-state to a smaller size-state are impossible and fixed to zero using symbol “-“. Juvenile fish that have survived a winter may transition either to state I or M, but cannot stay in O. In this case, direct transitions from O to M were considered as the complement of growth transitions from O to I)

5x5

| From/to  | <b>O</b> | <b>I</b> | <b>M</b> | † |
|----------|----------|----------|----------|---|
| <b>O</b> | -        | $\psi$   | *        | - |
| <b>I</b> | -        | *        | $\psi$   | - |
| <b>M</b> | -        | -        | *        | - |
| †        | -        | -        | -        | * |

Event (= recapture) probabilities

8x5

| From/to  | Not seen ( <b>0</b> ) | Measuring less than 90 mm ( <b>1</b> ) | Measuring between 90 and 130 mm ( <b>2</b> ) | Measuring more than 130 mm ( <b>3</b> ) |
|----------|-----------------------|--|--|---|
| <b>O</b> | *                     | $p$                                    | -  | -                                       |
| <b>I</b> | *                     | -                                      | $p$  | -                                       |
| <b>M</b> | *                     | -                                      | -  | $p$                                     |
| †        | *                     | -                                      | -  | -                                       |

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## **Appendix 5**

### **List of the models tested in the analysis of capture-recapture data for each stream.**

For each stream, models are ranked in a sequential order: those below the horizontal line are the ones containing external covariates and correspond to the second modelling step, departing from the consensus model (the best model above the horizontal line). The structure of each model is partitioned in Survival (S), growth transitions (T1) maturation transitions (T2) and recapture probabilities (p), over which time (t), constancy (.), state effects (size), and state\*time interactions (size.t) are tested. “winter” corresponds to the proportion of optimal winter days from December to March, whereas “spring” corresponds to the mean temperature from April to June. For each model of the set, the number of identifiable parameters (np), Deviance, QAIC values and the difference in QAIC ( $\Delta$ QAIC) between a particular model and the best model of the set are given.

## ORANDI

| Model           | S                             | T1         | T2         | p        | np        | Deviance         | QAIC            | $\Delta$ QAIC |
|-----------------|-------------------------------|------------|------------|----------|-----------|------------------|-----------------|---------------|
| Full model      | size.t                        | t          | t          | t        | 30        | 4011,332         | 3363,466        | 4,9873        |
| Model 2         | size.t                        | t          | t          | (.)      | 28        | 4017,948         | 3364,914        | 6,4356        |
| Model 3         | size                          | t          | t          | t        | 24        | 4050,278         | 3383,539        | 25,0605       |
| Model 4         | t                             | t          | t          | t        | 23        | 4056,096         | 3386,33         | 27,8516       |
| Model 5         | (.)                           | t          | t          | t        | 21        | 4084,73          | 3405,911        | 47,4325       |
| Model 6         | S1(.),S2(t),S3(t)             | t          | t          | t        | 29        | 4020,593         | 3369,092        | 10,6138       |
| Model 7         | S2(.),S1(t),S3(t)             | t          | t          | t        | 29        | 4021,167         | 3369,565        | 11,0868       |
| Model 8         | S3(.),S1(t),S2(t)             | t          | t          | t        | 28        | 4034,603         | 3378,63         | 20,1519       |
| Model 9         | size.t                        | (.)        | t          | t        | 28        | 4012,429         | 3360,369        | 1,8906        |
| Model 10        | size.t                        | t          | (.)        | t        | 28        | 4013,899         | 3361,579        | 3,101         |
| <b>Model 11</b> | <b>size.t</b>                 | <b>(.)</b> | <b>(.)</b> | <b>t</b> | <b>26</b> | <b>4014,99</b>   | <b>3358,478</b> | <b>0</b>      |
| Model 12        | size.winter                   | (.)        | (.)        | t        | 19        | 4054,319         | 3376,867        | 18,3883       |
| Model 13        | <b>S1(winter),S2(t),S3(t)</b> | <b>(.)</b> | <b>(.)</b> | <b>t</b> | <b>25</b> | <b>4019.2655</b> | <b>3359,999</b> | <b>1,5206</b> |
| Model 14        | S2(winter),S1(t),S3(t)        | (.)        | (.)        | t        | 26        | 4021.4435        | 3363,793        | 5,3143        |
| Model 15        | S3(winter),S1(t),S2(t)        | (.)        | (.)        | t        | 25        | 4027.0787        | 3366,433        | 7,9551        |

## ORBIANDI

| Model           | S                   | T1         | T2            | p          | np        | Deviance        | QAIC            | $\Delta$ QAIC |
|-----------------|---------------------|------------|---------------|------------|-----------|-----------------|-----------------|---------------|
| Full model      | size.t              | t          | t             | t          | 33        | 2059,341        | 1769,681        | 11,0962       |
| Model 2         | size.t              | t          | t             | (.)        | 31        | 2060,637        | 1766,753        | 8,1681        |
| Model 3         | size                | t          | t             | (.)        | 22        | 2107,14         | 1787,225        | 28,6402       |
| Model 4         | t                   | t          | t             | (.)        | 23        | 2078,344        | 1765,402        | 6,8174        |
| Model 5         | (.)                 | t          | t             | (.)        | 20        | 2111,11         | 1786,509        | 27,9247       |
| Model 6         | S1(.), S2(t), S3(t) | t          | t             | (.)        | 28        | 2074,691        | 1772,38         | 13,7951       |
| Model 7         | S2(.), S1(t), S3(t) | t          | t             | (.)        | 28        | 2076,214        | 1773,64         | 15,0552       |
| Model 8         | S3(.), S1(t), S2(t) | t          | t             | (.)        | 28        | 2076,782        | 1774,11         | 15,5251       |
| Model 9         | t                   | t          | (.)           | (.)        | 20        | 2087,75         | 1767,183        | 8,599         |
| <b>Model 10</b> | <b>t</b>            | <b>(.)</b> | <b>t</b>      | <b>(.)</b> | <b>20</b> | <b>2079,155</b> | <b>1760,073</b> | <b>1,4881</b> |
| Model 11        | t                   | (.)        | (.)           | (.)        | 17        | 2088,664        | 1761,939        | 3,3547        |
| Model 12        | winter              | (.)        | t             | (.)        | 18        | 2088,621        | 1763,904        | 5,3197        |
| <b>Model 13</b> | <b>t</b>            | <b>(.)</b> | <b>spring</b> | <b>(.)</b> | <b>18</b> | <b>2082,191</b> | <b>1758,584</b> | <b>0</b>      |
| Model 14        | winter              | (.)        | spring        | (.)        | 15        | 2103,319        | 1770,063        | 11,4787       |

## COMEYA

| Model           | S                               | T1         | T2            | p          | np        | Deviance        | QAIC            | $\Delta$ QAIC |
|-----------------|---------------------------------|------------|---------------|------------|-----------|-----------------|-----------------|---------------|
| Full model      | size.t                          | t          | t             | t          | 30        | 7859,028        | 7278,727        | 10,1513       |
| Model 2         | size.t                          | t          | t             | (.)        | 28        | 7860,242        | 7275,842        | 7,2664        |
| Model 3         | size                            | t          | t             | (.)        | 21        | 7920,559        | 7317,245        | 48,6696       |
| Model 4         | (.)                             | t          | t             | (.)        | 18        | 7935,426        | 7324,9          | 56,325        |
| Model 5         | t                               | t          | t             | (.)        | 21        | 7935,158        | 7330,654        | 62,0789       |
| Model 6         | S1(.), S2(t), S3(t)             | t          | t             | (.)        | 26        | 7874,099        | 7284,57         | 15,9949       |
| Model 7         | S2(.), S1(t), S3(t)             | t          | t             | (.)        | 26        | 7881,617        | 7291,476        | 22,9004       |
| Model 8         | S3(.), S1(t), S2(t)             | t          | t             | (.)        | 25        | 7884,854        | 7292,449        | 23,8739       |
| <b>Model 9</b>  | <b>size.t</b>                   | <b>(.)</b> | <b>t</b>      | <b>(.)</b> | <b>26</b> | <b>7863,163</b> | <b>7274,525</b> | <b>5,9493</b> |
| Model 10        | size.t                          | t          | (.)           | (.)        | 26        | 7874,383        | 7284,831        | 16,2555       |
| Model 11        | size.t                          | (.)        | (.)           | (.)        | 24        | 7877,301        | 7283,511        | 14,9358       |
| Model 12        | size.winter                     | (.)        | t             | (.)        | 20        | 7926,456        | 7320,661        | 52,0857       |
| Model 13        | S1(winter), S2(t), S3(t)        | (.)        | t             | (.)        | 25        | 7874,956        | 7283,357        | 14,782        |
| Model 14        | S2(winter), S1(t), S2(t)        | (.)        | t             | (.)        | 25        | 7866,327        | 7275,431        | 6,856         |
| Model 15        | S3(winter), S1(t), S2(t)        | (.)        | t             | (.)        | 24        | 7863,203        | 7270,562        | 1,9867        |
| <b>Model 16</b> | <b>S3(winter), S1(t), S2(t)</b> | <b>(.)</b> | <b>spring</b> | <b>(.)</b> | <b>23</b> | <b>7863,218</b> | <b>7268,575</b> | <b>0</b>      |

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## **Appendix 6**

### **E-SURGE model syntax: GEMACO**

Constructing models in E-SURGE requires first to define the transition matrices and parameters to be estimated using the GEnerator of model PATterns (GEPAT; see appendix 4) and secondly to define the structure of the model we want to run (i.e. the effects that are to be tested in each model parameter) by means of the GEnerator of MATrices of COncstraints (GEMACO). Both are tools incorporated into the E-SURGE program in a user-friendly way. The GEMACO interface allows incorporating the desired effects or constraints automatically into a design matrix by writing phrases (or keywords) using a particular syntax. This syntax or “gemaco language” is explained in detail in the E-SURGE 1.8. manual and makes explicit reference to the structure previously defined in the GEPAT step (i.e. numbers and words such as “from” or “f” and “to” are used to identify row and matrix columns). Each parameter in the model has an associated “gemaco expression” or phrase, so the complete model syntax is divided in “steps” representing the different parameter-associated phrases that conform the structure of the mathematical model. Therefore, because we constructed different models departing from a general structure and tested effects one parameter at a time, usually two models will have identical syntax in all but one parameter. Here we provide the syntax for the following model structures:

### General full model

Phrase for initial state : to.t

Phrase for survival probability : f.t

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

### Model with constant recapture probability

Phrase for initial state : to.t

Phrase for survival probability : f.t

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4)

### Model with state-effects on survival, but constancy over time

Phrase for initial state : to.t

Phrase for survival probability : f

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

### Model without state-effects on survival, but time dependence

Phrase for initial state : to.t

Phrase for survival probability : t

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

#### Model with constancy in survival rates

Phrase for initial state : to.t

Phrase for survival probability : i

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

#### Model with constancy in survival for one size state but time dependence for others\*

Phrase for initial state : to.t

Phrase for survival probability : f(1)+f(2,3).t

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

\*In this case, the syntax means that there are no time effects in survival for state 1 (smallest size-state) but there are time effects in survival for states 2 and 3 (immature and mature states)

#### Model with constancy in growth transitions

Phrase for initial state : to.t

Phrase for survival probability : f.t

Phrase for transition probabilities : f(1)+f(2).t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

#### Model with constancy in maturation transitions

Phrase for initial state : to.t



Phrase for survival probability : f.t

Phrase for transition probabilities : f(1).t+f(2)

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

Model with constancy in both growth and maturation transitions

Phrase for initial state : to.t

Phrase for survival probability : f.t

Phrase for transition probabilities : f(1)+f(2)

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

Model with temperature effects on survival (valid for transition probabilities alike)\*

Phrase for initial state : to.t

Phrase for survival probability : f.[i+t\*x(1)]

Phrase for transition probabilities : f.t

Phrase for recapture probabilities : firste+nexte.to(2)+nexte.to(3 4).t

\* The phrase in brackets shows a multiplicative function between time and the external covariate (temperature). In this phrase, the external covariate (x) has an associated number (1) that indicates the row containing the values (i.e. seasonal temperature values) in the covariate file. Thus, to write this syntax, first we have to link an external covariate file to the GEMACO interface of E-SURGE. At the same time, this phrase is interacting with state ("f" makes reference to the rows in the matrix, which represent the number of states), so here we are testing whether temperature has an effect on survival in all size-states.

Model with temperature effects on survival in one size-state but not in others\*

Phrase for initial state : to.t

Phrase for survival probability :  $f(2).[i+t*x(1)]+f(1,3).t$

Phrase for transition probabilities : f.t

Phrase for recapture probabilities :  $firste+nexte.to(2)+nexte.to(3\ 4).t$

\*In this case, we are testing for temperature effects on the survival of size-state 2 but time dependence on the survival of states 1 and 3. Alternative combinations can be tested by replacing numbers 1, 2 and 3 in the phrase for survival.

#### Model with temperature effects on one of the transition parameters

Phrase for initial state : to.t

Phrase for survival probability : f.t

Phrase for transition probabilities :  $f(1).[i+t*x(1)]+f(2).t$

Phrase for recapture probabilities :  $firste+nexte.to(2)+nexte.to(3\ 4).t$

\*In this case, we are testing for temperature effects on growth but time dependence on maturation transitions; such transitions occur from state 1 and from state 2 respectively, hence the expressions  $f(1)$  and  $f(2)$ .

**Neighbouring populations, opposite dynamics: influence of body size and environmental variation on the demography of stream-resident brown trout (*Salmo trutta*).** Albert Fernández-Chacón, Merixell Genovart, David Álvarez, José M. Cano, Alfredo F. Ojanguren, Rolando Rodriguez-Muñoz, Alfredo G. Nicieza.

## Appendix 7

### **Encounter history datasets**

Here, by means of 3 encounter history datasets, we show the longitudinal data collected at each stream (Orandi, Orbiandi and Comeya) during the study period.

Rows in each dataset contain information regarding a single tagged individual. The total number of rows in the dataset gives the total number of individuals sampled during the study period at this particular stream. Each individual row contains 2 types of information:

i) Encounter history: corresponds to the first sequence of 5 numbers. Each number in the sequence corresponds to an observed event and events are displayed in chronological order, being the first event the one corresponding to the first sampling occasion (1996 for Orandi and Comeya but 1997 for Orbiandi) and the last event the one corresponding to the last year of the study, in this particular stream (which can be year 2000 or 2001, depending on the stream). Event codes are as follows:

**1**, seen measuring less than 90mm.

**2**, seen measuring between 90 and 130mm.

**3**, seen measuring more than 130mm.

**0**, not seen.

- ii) Frequency: an extra column that validates the encounter history and can be used to calculate the number of individuals with the same type of encounter history.

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