Modelling biogeochemical fluxes across a Mediterranean fish cage farm
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Supplement 1. Further details on individual-based growth models

Fig. S1. Schematic representation of processes covered by the seabream and seabass growth models
Table S1. Functional expressions used in the individual growth models

**State variable:**

$w$: fresh weight (g)

**Growth equation:**

$$\frac{dw}{dt} = \left( \frac{A - C}{\varepsilon_T} \right)$$  \hspace{1cm} (S1)

$A$: net anabolism (J d$^{-1}$)

$C$: fasting catabolism (J d$^{-1}$)

$\varepsilon_T$: energy content of somatic tissue (kJ g$^{-1}$)

**Forcings:**

$T_w$: water temperature (°C)

$R$: amount of feed provided by the farmer per individual (g d$^{-1}$)

$C_P$: % of proteins in the ingested feed

$C_C$: % of carbohydrates in the ingested feed

$C_L$: % of lipids in the ingested feed

1. Functional expressions for net anabolism

$$I = I_{max} \cdot H(T_w) \cdot w^m$$  \hspace{1cm} (S2)

$I$: daily ingestion rate (g d$^{-1}$)

$I_{max}$: maximum ingestion rate (g d$^{-1}$ g$^{-m}$)

$m$: weight exponent for the anabolism

$H(T_w)$: see Eq. S7

\begin{align*}
I &= R \quad \text{, when } I \geq R \\
I &= 0 \quad \text{, when } T < T_a
\end{align*}  \hspace{1cm} (S3)

$T_a$: lowest feeding temperature

$$A = (1 - \alpha) \cdot I \cdot (C_P \cdot \varepsilon_P \cdot \beta_P + C_C \cdot \varepsilon_C \cdot \beta_C + C_L \cdot \varepsilon_L \cdot \beta_L)$$  \hspace{1cm} (S4)

$$F = I \cdot \left[ C_P \cdot (1 - \beta_P) + C_C \cdot (1 - \beta_C) + C_L \cdot (1 - \beta_L) \right]$$  \hspace{1cm} (S5)

$F$: faeces production (g d$^{-1}$)

$\alpha$: feeding catabolism coefficient

$\beta_P, \beta_C, \beta_L$: assimilation coefficients for protein, carbohydrate and lipid

$\varepsilon_P, \varepsilon_C, \varepsilon_L$: energy content of protein, carbohydrate and lipid (kJ g$^{-1}$)
2. Functional expressions for fasting catabolism

\[ C = \varepsilon_{O2} \cdot k_0 \cdot K(T_w) \cdot w^n \]  
(S6)

\( \varepsilon_{O2} \): energy consumed by the respiration of 1 g of oxygen (kJ g\(^{-1}\))

\( k_0 \): fasting catabolism at 0°C (d\(^{-1}\) g\(^{-n}\))

\( n \): weight exponent for the catabolism

\[ H(T_w) = \left( \frac{T_m - T_w}{T_m - T_o} \right)^{b(T_m - T_o)} \cdot e^{b(T_m - T_o)} \]  
(S7)

\( b \): shape coefficient for the \( H(T_w) \) function

\( T_o \): optimal temperature (°C)

\( T_m \): maximum lethal temperature (°C)

\[ K(T_w) = e^{p_k \cdot T_w} \]  
(S8)

\( p_k \): temperature coefficient for the fasting catabolism (°C\(^{-1}\))

\( O \): daily respiration rate (d\(^{-1}\))

\( E_{N,P} \): daily dissolved N,P excretion rates (d\(^{-1}\))

\[ O = k_0 \cdot K(T_w) \cdot w^n \]  
(S9)

\[ E_{N} = O \cdot k_{N,O} \]  
(S10)

\[ E_{P} = O \cdot k_{P,O} \]  
(S11)

3. Wasted feed

\( W \): uneaten feed [g d\(^{-1}\)]

\[ W = R - I \quad \text{, when } R \geq I \]  
(S12)

\[ W = 0 \quad \text{, when } R < I \]
Parameterization of the European seabass *Dicentrarchus labrax* model

The fasting catabolism parameters $k_0$ and $pk$ were estimated on the basis of the oxygen consumption measurements by Claireaux & Lagardère (1999). A value of 1 for the weight exponent for the catabolism, $n$, was used (Ursin 1967). $I_{\text{max}}$, defining the ingestion rate at the optimal temperature, and the coefficient $m$, which quantifies the dependence of the ingestion rate on the individual weight, were estimated with ingestion data reported by Lupatsch et al. (2001). The feeding catabolism coefficient, $\alpha$, quantifying the energy costs for digestion, assimilation, transportation, biochemical treatment and incorporation of food, was estimated by Stirling (1977). The protein digestibility coefficient, $\beta_P$, fixed at 88%, was set on the basis of the results obtained by Dosdat (2001) and Moreira et al. (2008). The lipid digestibility coefficient, $\beta_L$, was set at 97% according to Dosdat (2001) and Boujard et al. (2004). For carbohydrates, $\beta_C$ at a value of 84% was used according to Boujard et al. (2004) and Krokdahl et al. (2005). Energy contents for proteins, $\varepsilon_P$, lipids, $\varepsilon_L$, and carbohydrates, $\varepsilon_C$, were measured by Brett & Groves (1979). Energy loss associated with the respiration of 1 g of oxygen, $\varepsilon_{O_2}$, was quantified by Brafield & Solomon (1972) and then corrected by Elliott & Davison (1975) for ammoniotelic animals. The energy content of somatic tissue, $\varepsilon_T$, was estimated from caloric content measurements reported by Lupatsch et al. (2003). An optimal temperature ($T_o$) of 22°C and a maximum lethal temperature ($T_m$) of 32°C were selected according to Barnabé (1990). A lower feeding threshold of 7°C was considered, below which fish have no appetite (Tesseyre 1979, Pastoureaud 1991).

**LITERATURE CITED**


<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{max}}$</td>
<td>Maximum ingestion rate</td>
<td>0.09</td>
<td>(g feed g fish$^{-m}$ d$^{-1}$)</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Feeding catabolism coefficient</td>
<td>0.3</td>
<td>–</td>
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<tr>
<td>$\beta_P$</td>
<td>Assimilation coefficient for protein</td>
<td>0.85</td>
<td>–</td>
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<tr>
<td>$\beta_C$</td>
<td>Assimilation coefficient for carbohydrate</td>
<td>0.50</td>
<td>–</td>
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<tr>
<td>$\beta_L$</td>
<td>Assimilation coefficient for lipid</td>
<td>0.95</td>
<td>–</td>
</tr>
<tr>
<td>$\varepsilon_P$</td>
<td>Energy content of protein</td>
<td>23.6</td>
<td>(kJ g$^{-1}$)</td>
</tr>
<tr>
<td>$\varepsilon_C$</td>
<td>Energy content of carbohydrate</td>
<td>17.2</td>
<td>(kJ g$^{-1}$)</td>
</tr>
<tr>
<td>$\varepsilon_L$</td>
<td>Energy content of lipid</td>
<td>36.2</td>
<td>(kJ g$^{-1}$)</td>
</tr>
<tr>
<td>$\varepsilon_{O_2}$</td>
<td>Energy consumed by the respiration</td>
<td>13.6</td>
<td>(kJ g O$_2^{-1}$)</td>
</tr>
<tr>
<td>$\varepsilon_T$</td>
<td>Energy content of somatic tissue</td>
<td>9.90</td>
<td>(kJ g$^{-1}$)</td>
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<tr>
<td>$p_k$</td>
<td>Temperature coefficient for the fasting catabolism</td>
<td>0.06</td>
<td>(°C$^{-1}$)</td>
</tr>
<tr>
<td>$k_0$</td>
<td>Fasting catabolism at 0°C</td>
<td>0.00072</td>
<td>(g O$_2$ g fish$^{-m}$ d$^{-1}$)</td>
</tr>
<tr>
<td>$M$</td>
<td>Weight exponent for the anabolism</td>
<td>0.6</td>
<td>–</td>
</tr>
<tr>
<td>$N$</td>
<td>Weight exponent for the catabolism</td>
<td>1.0</td>
<td>–</td>
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<tr>
<td>$b$</td>
<td>Shape coefficient for the $H(T_w)$ function</td>
<td>0.16</td>
<td>–</td>
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<tr>
<td>$T_a$</td>
<td>Lowest feeding temperature for $Sparus$ $aurata$</td>
<td>12</td>
<td>(°C)</td>
</tr>
<tr>
<td>$T_o$</td>
<td>Optimal temperature for $S. aurata$</td>
<td>25</td>
<td>(°C)</td>
</tr>
<tr>
<td>$T_m$</td>
<td>Maximum lethal temperature for $S. aurata$</td>
<td>32.9</td>
<td>(°C)</td>
</tr>
</tbody>
</table>
Supplement 2. Farming cycle at the Bisceglie farm and *Dicentrarchus labrax* model validation

As concerns *Sparus aurata*, 2 cycles of approximately 15 mo were carried out in Cage 2; a single cycle lasting approximately 8 mo occurred in Cages 3 and 4; and a single cycle of 22 mo in Cage 6. For *Dicentrarchus labrax*, a total of 9 rearing cycles in 5 of the 6 cages were simulated according to the husbandry practices information: 2 rearing cycles of 17 and 9 mo each in Cage 1; 2 cycles of 15 and 2 mo each in Cage 2; a cycle of 21 mo in Cage 4; 2 cycles of 12 and 18 mo each in Cage 5; and 2 cycles of 22 and 6 mo each in Cage 6.

Fig. S2. Comparison between *in situ* measured water temperature (T) and remotely sensed water temperature (downloaded from the EMIS-JRC website at http://emis.jrc.ec.europa.eu/)
Fig. S3. Validation of the *Dicentrarchus labrax* growth model for 3 available periods of data in Porto Ercole, Tyrrehenian Sea (see Fig. 1 in the main text). Dashed lines: water temperature (°C); dotted lines: the daily amount of feed available by individual fish per day (g); continuous lines: the wet weight (g) predicted by the model; dots: the wet weight from field observations (g)
Fig. S4 (continued on next page). Validation of the *Dicentrarchus labrax* growth model for 6 available periods of data in Bisceglie, southern Adriatic Sea (see Fig. 1 in the main text). Dashed lines: water temperature (°C); dotted lines: the daily amount of feed available by individual fish per day (g); continuous lines: the wet weight (g) predicted by the model; dots: the wet weight from field observations (g)
Fig. S4 (continued)