Bioaccumulation of persistant organic contaminants in the common sole (*Solea solea*)

Utilisation of contaminants as food tracers

M. Eichinger, V. Loizeau, F. Roupsard, O. Gastineau, A.M. Le Guellec and C. Bacher
marie.eichinger@ifremer.fr

Context

*Solea solea* (Deniel, 1981):

- large repartition in European, especially in Atlantic Ocean
- 3 life stages: larvae (pelagic), juvenile and adult (benthic)
- lifespan: about 25 years
- reproduction: annual reproduction cycle, 1 laying/year

- juvenile phase: in coastal and estuarine sites
- species vulnerable to chronic pollution

from: http://www.fishbase.org
Main goal:
• fate of organic contaminants and their effects from the individual to the population levels
• predict the potential response of fishes to chemical contamination

Pluri- and inter-disciplinary approach:
• contaminant chemistry (organic compounds initially)
• physiology
• halieutic ecology
• ecotoxicology
• modelling

Objectives
SoleBEMol project

Main goal:
• fate of organic contaminants and their effects from the individual to the population levels
• predict the potential response of fishes to chemical contamination

Pluri- and inter-disciplinary approach:
• contaminant chemistry (organic compounds initially)
• physiology
• halieutic ecology
• ecotoxicology
• modelling
Objectives
SoleBEMol project - modelling

- construct, calibrate and validate a mechanistic model of sole biology
  Dynamic Energy Budget (DEB) theory (Kooijman 2000)

- couple this model to a bioaccumulation model of organic contaminants:
  PolyChlorinated Biphenyls (PCB)

PCB:
- used in electric industry, forbidden in France since 1987
- 209 congeners, more or less toxic according to their chemical properties, linked to the number and position of chlorine atoms substitution
- broad spectrum of toxicological responses (immunotoxicity, depression of reproduction, reduction in growth rate and in fecundity)

Other (metabolisable) contaminants studied:
- PBDE = PolyBrominated Diphenyl Esthers
- PAH = Polycyclic Aromatic Hydrocarbons
Outlines

description of the experiments

growth and bioaccumulation models

simulations of the growth model
  ➢ control tank SoleB1

simulations of the growth + bioaccumulation models
  ➢ PCB tank SoleB1

an individual approach
  ➢ control tank SoleB2

conclusion and perspectives
### Experiment description

**Juvenile fishes (G0 – 10 cm) obtained from a farm (Solea BV, NL)**

<table>
<thead>
<tr>
<th>No of tanks</th>
<th>Physico-chemical parameters</th>
<th>Food</th>
<th>Chemical analyses</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T° C</td>
<td>[PCB] ng g⁻¹</td>
<td>% water</td>
<td>% water</td>
</tr>
<tr>
<td></td>
<td>[O2] (%)</td>
<td>(CB105)</td>
<td>Lipid weight</td>
<td>% water</td>
</tr>
<tr>
<td></td>
<td>Photoperiod (h)</td>
<td>(CB118)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fish density (kg.m⁻²)</td>
<td>(CB149)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(CB153)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**C** control; **PCB** growth model

<table>
<thead>
<tr>
<th>Optimal conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>T° C 19°C</td>
</tr>
<tr>
<td>[O2] (%) &gt; 80%</td>
</tr>
<tr>
<td>Photoperiod (h) 12:12</td>
</tr>
<tr>
<td>Fish density (kg.m⁻²) 2.3</td>
</tr>
<tr>
<td>Food Ad libitum</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Duration (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007-2008</td>
<td>6</td>
</tr>
</tbody>
</table>

**Chemical analyses**

- [PCB] ng g⁻¹
- (CB105)
- (CB118)
- (CB149)
- (CB153)

**Measurements**

- TL (cm)
- SL (cm)
- Wet weight (WW) (g)

### Notes

- PCB removal
- Optimal conditions
- Fish density
- Growth model
- Laboratory conditions
- Chemical analyses
- Measurements

**DEB Symposium** 20-22 April 2009
### Experiment description

**Juvenile fishes (G0 – 10 cm) obtained from a farm (Solea BV, NL)**

<table>
<thead>
<tr>
<th></th>
<th>Solea1</th>
<th>Solea2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb of tanks</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

#### Physico-chemical parameters

- **T° C**: 19°C 19°C 19°C 19°C
- **[O2] (%)**: > 80% > 80% > 80% > 80%
- **Photoperiod (h)**: 12:12 12:12 12:12 12:12
- **Fish density (kg.m⁻²)**: 2.3 2.1 3.6 3.7

#### Food

- Ad libitum Ad libitum Ad libitum + PCB

#### PCB concentrations (ng.g⁻¹)

<table>
<thead>
<tr>
<th>PCB</th>
<th>Solea1</th>
<th>Solea2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB105</td>
<td>0</td>
<td>225</td>
</tr>
<tr>
<td>CB115</td>
<td>0</td>
<td>450</td>
</tr>
<tr>
<td>CB149</td>
<td>0</td>
<td>852</td>
</tr>
<tr>
<td>CB153</td>
<td>0</td>
<td>876</td>
</tr>
</tbody>
</table>

#### Measurements

- Biometry
  - TL (cm): x x x x
  - SL (cm): x x
  - Wet weight (WW) (g): x x x x

- Chemical analyses
  - % water: x x x x
  - Lipid weight: x x x x
  - [CPB] (ng.g⁻¹): x x x x

#### Experimental conditions

- **f = 1**
- **growth model**
- **bioaccumulation model**

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**Final joint meeting of the DEB community, 20-22 April 2009**
### Experiment description

**Juvenile fishes (G0 – 10 cm) obtained from a farm (Solea BV, NL)**

<table>
<thead>
<tr>
<th></th>
<th>SoleB1</th>
<th>SoleB2</th>
<th>SoleB3</th>
<th>SoleB4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nb of tanks</strong></td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Physico-chemical parameters</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T° C</td>
<td>19°C</td>
<td>19°C</td>
<td>Variable&gt;12°C</td>
<td>Variable&gt;12°C</td>
</tr>
<tr>
<td>(O2) (%)</td>
<td>&gt; 80%</td>
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</tr>
<tr>
<td>Photoperiod (h)</td>
<td>12:12</td>
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<td>12:12</td>
<td>12:12</td>
</tr>
<tr>
<td>Fish density (kg.m⁻²)</td>
<td>2.3</td>
<td>2.1</td>
<td>3.6</td>
<td>3.7</td>
</tr>
<tr>
<td>Food</td>
<td>Ad libitum +PCB</td>
<td>Ad libitum</td>
<td>Ad libitum +PCB</td>
<td></td>
</tr>
<tr>
<td>[PCB] ng.g⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[CB105]</td>
<td>0</td>
<td>225</td>
<td>0</td>
<td>73</td>
</tr>
<tr>
<td>[CB115]</td>
<td>0</td>
<td>450</td>
<td>0</td>
<td>147</td>
</tr>
<tr>
<td>[CB149]</td>
<td>0</td>
<td>412</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>[CB153]</td>
<td>0</td>
<td>876</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td><strong>Time parameters</strong></td>
<td></td>
<td></td>
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<td>2007-2008</td>
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<td>2008-2010</td>
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<td><strong>Measurements</strong></td>
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<td><strong>Biometry</strong></td>
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</tr>
<tr>
<td>TL (cm)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SL (cm)</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet weight (WW) (g)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td><strong>Chemical analyses</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% water</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lipid weight [CB1] (ng.g⁻¹)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>how pooled</td>
<td>pooled</td>
<td>individual</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Arrhenius function**

\[ f = 1 \]

**Structural compartment**

**Reserve compartment**

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**DEB Symposium**

20-22 April 2009
Outlines

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- simulations of the growth model
  - control tank SoleB1
- simulations of the growth + bioaccumulation models
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- conclusion and perspectives

The growth model

**Solea DEB parameters: experiments from literature or SoleBeMol data**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter name</th>
<th>Unity</th>
<th>Parameter value</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>δ</td>
<td>shape coefficient</td>
<td></td>
<td>0.203</td>
<td>SoleBeMol, leaner individuals</td>
</tr>
<tr>
<td>(P_{m1})</td>
<td>max ingestion rate</td>
<td>J.cm$^{-2}$.d$^{-1}$ at 10°C</td>
<td>463</td>
<td>ingestion experiments</td>
</tr>
<tr>
<td>[P_{m2}]</td>
<td>maintenance rate</td>
<td>J.cm$^{-2}$.d$^{-1}$ at 10°C</td>
<td>18.1</td>
<td>respiration experiments</td>
</tr>
<tr>
<td>$T_A$</td>
<td>Arrhenius $T^*$</td>
<td>K</td>
<td>4700</td>
<td>Fonds and Saksena, 1977</td>
</tr>
<tr>
<td>$Y_{ex}$</td>
<td>assimilation efficiency</td>
<td></td>
<td>0.63</td>
<td>SoleBeMol, CB153 as a tracer</td>
</tr>
</tbody>
</table>

Van der Veer et al, 2001

!![](https://example.com/growth_model_diagram.png)
The growth model

**Solea DEB parameters:** numerical regression against growth (length, total gonad weight) data

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<tr>
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<td>463</td>
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<tr>
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<td>K</td>
<td>4700</td>
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</tr>
<tr>
<td>$\gamma_{cx}$</td>
<td>assimilation efficiency</td>
<td></td>
<td>0.63</td>
<td>SoleBeMol, CB153 as a tracer</td>
</tr>
<tr>
<td>[$E_a$]</td>
<td>costs for growth</td>
<td>J.cm$^{-3}$.d$^{-1}$</td>
<td>23820</td>
<td>growth data Deniel, 1981</td>
</tr>
<tr>
<td>[$E_m$]</td>
<td>max energy capacity</td>
<td>J.cm$^{-3}$.d$^{-1}$</td>
<td>13760</td>
<td>growth data Deniel, 1981</td>
</tr>
<tr>
<td>$k$</td>
<td>kappa</td>
<td></td>
<td>0.49 0.54</td>
<td>growth data Deniel, 1981</td>
</tr>
<tr>
<td>$V_p$</td>
<td>volume at puberty</td>
<td>cm$^3$</td>
<td>28 102</td>
<td>Deniel, 1981</td>
</tr>
</tbody>
</table>

**The bioaccumulation model: PCB**

**Assumptions:**
- contaminants are lipophilic:
  - contamination only from food
  - contaminants bound to the reserve compartment
- same assimilation efficiency ($y_{EX}$) than food
- no physiological effect: accumulation

Bodiguel et al. In Press
The bioaccumulation model: PCB

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The bioaccumulation model: PCB

**Assumptions:**
- Contaminants are lipophilic:
  - Contamination only from food
  - Contaminants bound to the reserve compartment
- Same assimilation efficiency ($v_{EX}$) than food
- No physiological effect: accumulation
- Implementation in the model:

\[
\frac{d\text{CB}_{EX}}{dt} = \left(\text{CB}_{\text{food}} \cdot A_{E,T_{\text{BA}}}/\mu_{\text{spec}}\right) J \text{d}^{-1} \text{g}^{-1} \quad \text{known}
\]

\[
\left(\text{CB}_{153}\right)_{\text{measured}} = \frac{\text{CB}_{EX}}{W_s} \text{ng} \text{g}^{-1}
\]

CB153 may be used as a food tracer

---

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Model simulations: SoleB1 control tank

CB153 \( y_{153} = 0.63 \)

Estimated on pooled fish:
- 4 to 11 fish/pool
- 3 pools/sampling time
- 1 [CB153] measurement/pool

Only juveniles
Same parameter values

Global good agreement with experimental data
Energy repartition not well simulated

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Application to data of SoleB1: PCB tank

Storage weight α
lipids weight

• accumulation + decontamination phases
• model overestimation
  measured [CB153] underestimated
  effect on $Y_{EX}$

BUT: great individual variability due to:
 ➢ initial variability
 ➢ different access to food
Application to data of SoleB1: PCB tank

• accumulation + decontamination phases
• model overestimation
  - measured [CB153] underestimated effect on $y_{EX}$

BUT: great individual variability due to:
  - initial variability
  - different access to food

mean weight $= 54$ g
$[CB153] = 138$ ng.g$^{-1}$

mean weight $= 63$ g
$[CB153] = 50$ ng.g$^{-1}$

BUT: great individual variability due to:
  - initial variability
\textbf{Application to data of SoleB1: PCB tank}

\begin{itemize}
  \item mean weight = 54 g \[ \text{[CB153]} = 138 \text{ng.g}^{-1} \]
  \item mean weight = 55 g \[ \text{[CB153]} = 97 \text{ng.g}^{-1} \]
\end{itemize}

\textbf{BUT:} great individual variability due to:
- different access to food

\textbf{Outlines}

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Application to data of SoleB2: **control tank**

**Assumption 1: initial variability**

**INDIVIDUAL GROWTH TRAJECTORIES: taged sole**

- **length (cm)**
- **total weight (g)**

---

**Assumption 2: different access to food**

**INDIVIDUAL APPROACH: taged sole**

**mean \( y_{EX} = 0.93 \)** estimated with individual measurements

- Fish with the same initial conditions
  - **mean \( y_{EX} = 0.93 \)** estimated with individual measurements
Application to data of SoleB2: **PCB tank**

Assumption 2: different access to food

**INDIVIDUAL APPROACH:** tagged sole

\[ f = 0.65 \]

allows an accurate representation of individual growth and PCB accumulation

---

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Conclusion

DEB theory allows to manage data obtained from different experiments but also from different environments (experiments vs in situ sampling)

- PCB may be used as food tracers: different $y_{\text{EX}}$

- certainly a bias due to pooled measurements vs individual mean of measurements $\neq$ mean trajectory of individuals

- assumption: sole biology captured by a unique parameter set

growth variability due to $f$

 Perspectives

- growth model
  - experiments without contaminants: calibration of energetic parameters
  - continuation of SoleB2 until 2 years
  - calibration of $f$ for each fish: distribution?

- bioaccumulation model: continuation of SoleB2 until 2 years
  - contamination + decontamination phases
  - effects of contaminants on growth + reproduction ?
  - application of the model to other contaminants (PBDE and PAH)

  addition of metabolic costs (DEB-tox) individual variability of the potential response?

- application to in situ data:
  - validation of the growth model
  - estimation of contamination level in the medium ($\neq$ sampling sites)
Thank you for your attention !!!

And many thanks to:

Anne-Marie  François  Nicolas  Vincent  Olivier

And to…..

Roberta  Momo  Gilberto  Rodrigo  Gertrude  Ginette