Mechanistic and ecophysiologic study of carbon 14 transfer in fish

Supervisor : Jean-Christophe Poggiaie (MIO)
Tutor : Frederic Alonzo (IRSN)
PSE-ENV/SRTE/LECO

SOULOUMIAC Audrey
Context

- Natural sources: reaction of cosmic rays on nitrogen neutrons in the high atmosphere → carbon dating...

- With $^3$H, $^{14}$C is one of the radionuclides rejected in greatest amounts by Nuclear Power Plant in French rivers.

- Assimilated $^{14}$C contributes in a major part to estimated – small – doses received by local populations, essentially through fish ingestion.

Need to better assess the environmental (both health and ecological) risks
**Problem:** Current models used to predict $^{14}$C transfer in aquatic ecosystems are very simplistic:

- Unability to explain the variability in $^{14}$C activity observed in fish samples collected from different rivers.

- Great variations in $^{14}$C releases $\rightarrow$ No equilibrium in concentration (Sheppard et al., 2006; Smith, 2006).

- Models of fish do not take account of the potential influence of fish physiology and environnemntal factors, depending on species.

$\rightarrow$ **DEB model** is a physiology-based dynamic model = more adequate to describe variation in $^{14}$C activity in different compartments of the aquatic ecosystem.
DIB model: Dynamic isotope budget

- Used in ecology to study the dynamics and structure of trophic networks and trace elements fluxes in ecosystems. (Post, David M. 2002. « Using Stable Isotopes to Estimate Trophic Position: Models, Methods, and Assumptions ». Ecology 83 (3): 703-18.).

- Aim to quantify dynamics of four biogenic elements (C, H, N and O) and their isotopes within organism by coupling fluxes of elements with those of molecules involved in metabolism.

Energy flux

- Increase in stable isotopes with trophic level

- DIB model is used for stable isotope analyses
Important processes for isotope allocation during metabolic reactions

\[ S_1 + S_2 \rightarrow P_1 + P_2 \]

1) Mobilisation: Mobilisation of atoms from a pool of atoms. **Does not change isotopic ratio**

2) Molecular selection

Selection for anabolic or catabolic routes. Probability depends on fate of atoms (heavy for catabolic route).

3) Molecular reshuffling

The concept of atom reshuffling recognizes that molecules are not completely disassembled into elements during chemical reactions.
Molecular reshuffling

Molecular selection

Trophic resource $X$

$X + O \rightarrow E + P + C + H + N$

$\dot{X}_A = \kappa_{Aa} \dot{X}_A$

$(1 - \kappa_{Aa}) \dot{X}_A$

$\dot{E}_A = -\gamma_{EX} \dot{X}_A$

Catabolism

Anabolism

Energy

$\text{C, H, N, P}$

$\text{Réserve E}$
Molecular reshuffle

Molecular selection

\[ E + O \rightarrow V + C + H + N \]

\[ \dot{J}_{EG} = (1 - \kappa_{Ga}) \dot{J}_{EG} \]

\[ \dot{J}_{EGA} = \kappa_{Ga} \dot{J}_{EG} \]

\[ \dot{J}_{VG} = -\gamma_{VE} \dot{J}_{EG} \]

Catabolism

Anabolism

Energy

Structure V
E + V + O $\rightarrow$ V + C + H + N
E + V + O $\rightarrow$ C + H + N

Molecular reshuffle
Molecular selection

Réserve E

J_{EM}

(1 - \kappa_L)J_{EM}

C, H, N

Energie

J_{EL} = \kappa_L J_{EM}

J_{ELa} = \kappa_{L1a} J_{EL}

C, H, N

O

Structure turnover

C, H, N

O

Energy

Catabolism

Anabolism

Structure V

J_{VL1} = \kappa_{L2a} J_{VL2}

J_{VL2}

O

J_{VrL}
Theoretical values of DIB parameters are available for stable isotopes $^{15}$N and $^{13}$C and are validated in *Crassostrea gigas* (Pacific oyster).

→ Parameterize values for the case of $^{14}$C in two fish species of fish
→ Improvement of DEB model for Common carp (literature search)
→ Validation of predictive capacity in Zebrafish

Measurements of $^{14}$C assimilation, incorporation and elimination kinetics depending the biochemical composition of $^{14}$C sources.
Different sources of $^{14}$C

- Amino acid: Arginine
- Glycerol
- Glucose

PROTEIN METABOLISM
LIPID METABOLISM
CARBOHYDRATE METABOLISM
Conception of contaminated food

→ 5mL water

→ Mineralisation in NaOH for **48 hours**

→ Quantification by liquid scintillation analysis

**Direct loss of $^{14}$C into water**

![Graph showing the direct loss of $^{14}$C into water over time (minutes). The graph shows an increasing trend in radioactivity (Bq) with time.](graph.png)
Preliminary experiment

Contamination duration: range of 1 to 4 days
Dissection 24h after last food supply
Mass-specific activity of $^{14}$C

- Digestive tract
- Liver
- Gills
- Muscle

- Carp #1
- Carp #2
- Carp #3
Distribution of $^{14}$C activity among organs

- Digestive tract
- Liver
- Gills
- Muscle

Bq

Carp #1
Carp #2
Carp #3
Résultats

Proportion of $^{14}$C activity among organs

- Digestiv tract
- Liver
- Gills
- Muscle

Carp #1
Carp #2
Carp #3
Experimental plan

- $^{14}\text{C}$ kinetics in Common carp
  
  ![Diagram showing the experimental plan with steps for contamination and elimination.](image)

- Model validation on a simple trophic chain
**Objectif**: Quantification of $^{14}$C released through respiration

- To obtain $^{14}$C complete budget among all metabolic processes.
- $\text{CO}_2$ gas traps will be set up with air bubbling in NaOH solution (1M).
Thank for attention!
Scientific communication

- IRSN PhD congress 2018 (Poster) and 2019 (platform)
- Congress of Doctoral school (Aix-Marseille University)(Poster)
- Sixth International Symposium on DEB theory (Brest)
<table>
<thead>
<tr>
<th>Espèces</th>
<th>Min</th>
<th>Max</th>
<th>Moyenne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silure glane</td>
<td>237</td>
<td>334</td>
<td>286</td>
</tr>
<tr>
<td>Perche</td>
<td>234</td>
<td>931</td>
<td>466</td>
</tr>
<tr>
<td>Lamproie marine</td>
<td></td>
<td>247</td>
<td></td>
</tr>
<tr>
<td>Hotu</td>
<td>202</td>
<td>212</td>
<td>207</td>
</tr>
<tr>
<td>Grande alose</td>
<td></td>
<td>249</td>
<td></td>
</tr>
<tr>
<td>Gardon</td>
<td>231</td>
<td>1262</td>
<td>453</td>
</tr>
<tr>
<td>Chevesne</td>
<td>200</td>
<td>2000</td>
<td>465</td>
</tr>
<tr>
<td>Carpe commune</td>
<td>559</td>
<td>581</td>
<td>570</td>
</tr>
<tr>
<td>Brochet</td>
<td>234</td>
<td>340</td>
<td>270</td>
</tr>
<tr>
<td>Brème commune</td>
<td>201</td>
<td>2830</td>
<td>1138</td>
</tr>
<tr>
<td>Barbeau fluvial</td>
<td>204</td>
<td>2300</td>
<td>528</td>
</tr>
<tr>
<td>Anguille</td>
<td>213</td>
<td>1393</td>
<td>587</td>
</tr>
</tbody>
</table>
Among four compartments: food (X), Feces (P), Reserve (E), structure (V)

- One elemental composition each

Stochiometric equilibrium

Two reactions at a time: Energy for anabolism is brought by catabolism: We detail the catabolic and anabolic routes of each chemical transformation to allow selection of substrate molecules depending on their isotopic composition. The catabolic route of a transformation uses substrates to produce energy for the anabolic route of the transformation. The anabolic route of a transformation uses this energy and substrates as a source of building blocks to produce a given compound. In the growth transformation for instance, reserve is used as a source of energy as well as building blocks to produce structure.
Different sources of $^{14}$C

Amino acid: Arginine

Structure (collagen)
Contraction (myosin)
Transport (albumin)
Immune system (immunoglobulin)

Glycerol

LIPID METABOLISM

Mono-, Di- and Tri-glycerids, Phospholipids

Glucose

CARBOHYDRATE METABOLISM

Glycogen or triglycérid (muscle, liver)

PROTEIN METABOLISM

GLYCOLYSIS

CARBOHYDRATE METABOLISM

LIPID METABOLISM

PROTEIN METABOLISM