Dynamics of stable isotopes in fluctuating environments

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A slight difference in weight

\[ ^1\text{H} \quad 99.984\% \quad ^2\text{H} \quad 0.0156\% \]

- \( \delta^2\text{H} \) : Reconstruction of temperature for 400,000 years
- \( \delta^{18}\text{O} \) and \( \delta^{13}\text{C} \)
  - Use of recent rain or deep groundwater by a plant
  - Tuna migration
- \( \delta^{13}\text{C} \) and \( \delta^{15}\text{N} \): Food web structure

\( \rightarrow \) Isotope as a tracer for processes and dynamics
Biological transformations impact incorporation rates and fractionation

Diet: print of the food within the organism. How do we interpret this print?
- Incorporation and elimination rates
- Discrimination factor $\delta ^{13}C + 1 \%$; $\delta ^{15}N + 3.4 \%$

• Assumption that the organism is in equilibrium with its food sources

• BUT
  - Incorporation rates vary (body size, growth, protein turn-over)
  - Large variability of discrimination factors between tissues and diet
  - these organisms live in fluctuating environments
Research question

- What is the effect of a fluctuating food environment on stable isotope ratios at the individual level?

- DEB framework:
  - Full mass balance and
  - Dynamic energy budget

→ Coupling of isotope dynamics within the DEB framework
Outline

• Development of concepts in the DEB framework
  – Turn-over of structure
  – Fractionation, Reshuffling

• Scenarios to analyze the impact of food density on incorporation rate and fractionation
  – Shift in food isotope ratio ($\delta X$) at different lengths
  – Shift in $\delta X$ at different food levels
  – Same $\delta X$ Food cycle,
DEB processes

- Food processes
  - Assimilation
  - Reserve
    - Somatic maintenance
    - Growth
    - Structure
  - Maturity
    - Development, reproduction
    - Reproduction buffer
DEB processes

- Food
- Assimilation
- Reserve
- Somatic maintenance
- Growth
- Structure
- Faeces

Elements: κ

Flows:
- Food to assimilation
- Assimilation to reserve
- Reserve to somatic maintenance and growth
- Growth to structure
- Faeces from food
Turn-over of structure is the main fraction of somatic maintenance.
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structure

reserve

\[ \kappa_M \]

e.g. activity, gradients, …

Turn-over of structure
There is no net production of structure
Part of the structure is recycled

Energy to fuel the reaction = catabolism

Building blocks = anabolism

minerals

structure

y_VD^a

minerals

reserve
Light isotopes are allocated to catabolic routes with a higher probability.
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Fractionation from fluxes

Turn-over of structure

minerals

reserve

structure

minerals
Fractionation occurs during assimilation and growth as well.
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Fractionation occurs during assimilation and growth as well.
Reshuffling: a mechanism for isotope routing

- Photosynthesis
  \[ \text{CO}_2 + 2 \text{H}_2\text{O} + \text{light} \rightarrow \text{CH}_2\text{O} + \text{H}_2\text{O} + \text{O}_2 \]

- Molecules are not disassembled into elements and then reassembled, reaction mechanisms are fixed

- Same principle for macro-chemical reactions
  i.e. bookkeeping of the atoms of a given substrate: to which product(s) are they going?
Shift in food isotope signature ($\delta X$): measurement of incorporation rate and discrimination factor
1. A small individual has a faster incorporation rate
2. At low food level, fractionation is higher
2. At low food level, fractionation is higher
3. The relative amount of reserve and structure matters
3. The relative amount of reserve and structure matters.
Without changing $\delta X$, the signature of the organism can vary in a fluctuating environment.

\[ \delta^{13}C \]

\[ \text{whole body} \]

\[ \text{Food} \]

\[ \text{Time} \]
Conclusions

• Explicit turn-over of structure
  – 2 extra parameters
  – But provides a continuity with shrinking
    (avoid switch in extreme starvation conditions)
  – Respiration is not tightly coupled to protein turn-over (Martinez del Rio et al. 2009) -> further support for DEB theory

• Fractionation → test of the theory is required, needs for applications and experiments driven by the theory
  (→ PhD Antoine Emmery)

• Isotopic signature of an individual might vary during the season due to seasonal food availability
Challenges

• Population --> ecosystem
  – Food conditions impacts signature of an organism, which in turn is eaten by another consumer, which in turn…structured population feeding on a structured population
  – isotope dynamics to study mass transfers at the ecosystem level; Body size scaling relationships

• Tissue / organ level
  – Different turn-over rates
  – Experiments - Validation with data
  – Reshuffling: Difficult to access at the individual level but answer for isotope routing (call for more theory from Martinez del Rio et al. 2009)
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