Consumer Carbon
Elemental Ecology
Week Five
δ\textsuperscript{13}C Trophic Discrimination Factors (Δ\textsuperscript{13}C)

Δ\textsuperscript{13}C is typically positive

This means the δ\textsuperscript{13}C values of an animal’s tissues are typically slightly higher than the δ\textsuperscript{13}C values of its dietary items

Δ\textsuperscript{13}C varies across tissue types

Red Blood Cells
Collagen
Hair
Feather

Caut et al. 2009
Animal metabolism in terms of $\delta^{13}C$

Diet
- $\delta^{13}C_{\text{Protein}}$
- $\delta^{13}C_{\text{Carbohydrates}}$
- $\delta^{13}C_{\text{Lipids}}$

Assimilation:
- Isotopic Incorporation & Protein Routing

Biosynthesis:
- Proteins, Lipids, Carbohydrates

Tissues
- (Proteins)
- ($^{13}C$-enriched)

Respiration
- ($^{12}CO_2$)

Tissue-Diet
Isotopic Discrimination ($\Delta^{13}C$)
Animal Carbon Metabolism

Amino Acid Pool ↔ Body Protein ↔ Glucose Pool ↔ Glycogen → Neutral Fat ← Glycerol ↔ Fatty Acids

Food

3-Phosphoglycerate ↓ Glycolysis → Pyruvate

Acetyl CoA

TCA Cycle

$^{13}$C

$^{12}$CO$_2$ ↔ Enzymatic isotope effects are really important here!

Gluconeogenesis

Lipid Synthesis

Discrimination ($\Delta^{13}$C): Decarboxylation (Lose $^{12}$CO$_2$)

$\Delta^{13}$C...you are what you eat + 0 – 2‰
Animal Carbon Metabolism

Amino Acid Pool → Glucose Pool → Glycogen
Body Protein

Glycerol → Fatty Acids

Food

Gluconeogenesis

Acetyl Group

Enzymatic isotope effects are really important here!

Δ¹³C...you are what you eat + 0 – 2%°
Why do we extract the lipids from our consumer tissue samples?

Lipid $\delta^{13}C$ values are $\sim6\%$ lower than protein $\delta^{13}C$ values!

If we didn’t extract the lipids from fatty consumer tissues, our dietary estimates would be way off.

DeNiro and Epstein 1977, Cherry et al. 2011
**Δ\(^{13}\)C varies across tissue types**

Table 2. Isotope ratios of total protein in diet, bone and muscle of C\(_3\) and C\(_4\) pigs

<table>
<thead>
<tr>
<th></th>
<th>Isotopic compositions of controlled-diet pigs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\delta^{13})C</td>
</tr>
<tr>
<td><strong>C(_4) pigs</strong></td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>(-12.4)</td>
</tr>
<tr>
<td>Muscle</td>
<td>(-11.4)</td>
</tr>
<tr>
<td>Collagen</td>
<td>(-9.2)</td>
</tr>
<tr>
<td>Faeces</td>
<td>(-12.8)</td>
</tr>
<tr>
<td><strong>C(_3) pigs</strong></td>
<td></td>
</tr>
<tr>
<td>Diet</td>
<td>(-25.3)</td>
</tr>
<tr>
<td>Muscle</td>
<td>(-23.8)</td>
</tr>
<tr>
<td>Collagen</td>
<td>(-23.9)</td>
</tr>
<tr>
<td>Faeces</td>
<td>(-25.7)</td>
</tr>
</tbody>
</table>

\[\Delta = \delta \text{ pig or faeces sample } - \delta \text{ diet.}\]
Amino acid concentrations vary across tissue types

Wolf et al. 2015
Amino Acids: The Building Blocks of Proteins

Non-Essential Amino Acids

• Simple
• Can be synthesized by all organisms using carbohydrates, lipids, and other amino acids

Essential Amino Acids

• More complex
• Can only be synthesized by plants, bacteria, and fungi
• Animals must acquire them in their diet OR from their symbiotic gut microbes

Glycine
non-essential amino acid

Ala, Arg, Asn, Asp, Cys, Gln, Glu, Gly, Pro, Ser, Tyr

Valine
essential amino acid

His, Ile, Leu, Lys, Met, Phe, Thr, Try, Val
Collagen contains a lot of glycine.
Non-essential amino acids are easier to synthesize, and animals have retained this ability.

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>TYPE</th>
<th>ATP</th>
<th>NADP</th>
<th># steps to synthesize</th>
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<td>Alanine</td>
<td>NE</td>
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<td>1</td>
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<tr>
<td>Glutamate</td>
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<td>Aspartate</td>
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<td>Tyrosine¹</td>
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<tr>
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<td>Glycine</td>
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<tr>
<td>Proline</td>
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<tr>
<td>Tryptophan</td>
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<td>5</td>
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</table>

60–72% of amino acids in animal tissues are non-essential.
$\Delta^{13}C$ varies by amino acid

Modified from McMahon et al. 2015
$\delta^{13}C$ values vary among amino acids

Additionally, some of these amino acids have different origins (direct routing vs. \textit{de novo} synthesis).
Plants and animals are made of different macromolecules.

**Average Animal or Bacteria**
- Protein
- Lipids
- Carbs

**Average Plant or Protist**
- Carbohydrates
- Lipids
- Protein
A lion is easy, but how do you make a moose?

Lion (~180kg)
Consumes ~10 kg/day
Meat: ~15% Nitrogen
1.5 kg/day of N (~0.8% of body weight)

Moose (~500kg)
Consumes ~30 kg/day
Vegetation: ~2% Nitrogen
0.5 kg/day N (~0.1% of body weight)

Do herbivores, omnivores, and even carnivores use non-protein dietary macromolecules to build proteinaceous tissues?
The Omnivore’s Dilemma: Protein Routing

Berries
(carbohydrates)

Salmon
(proteins & lipids)

Grizzly Bear Tissues
(muscle/hair/blood)
**Perfect Mixing vs. Perfect Routing**

**Berries**
(carbohydrates)

Scenario #1: Perfect Mixing

Mixing Models Assume Perfect Mixing

\[ \delta^{13}C_{\text{tissues}} = (p)\delta^{13}C_{\text{salmon}} + (1-p)\delta^{13}C_{\text{berries}} \]

**Salmon**
(protein & lipid)

Scenario #2: Perfect Routing

Sample Preparation Protocols (e.g., lipid extraction)

Assume Perfect Routing of Protein
Why would we expect protein routing?

Textbook Animal Ecophysiology

Dietary Carbohydrates Lipids

Dietary Proteins

Energy + Lipid Storage

Tissue Synthesis

Direct routing decreases the cost of *de novo* (non-essential) amino acid synthesis. But in reality, the size of arrows depends on relative supply versus demand...
Relative Supply vs. Demand

DIET
- Carbohydrates
- Lipids
- Protein

CONSUMER
- Carbohydrates
- Lipids
- Protein

OMNIVORE
Relative Supply vs. Demand

**DIET**
- Lipids
- Protein

**CONSUMER**
- Carbohydrates
- Lipids
- Protein

**MARINE CARNIVORE**
Relative Supply vs. Demand

DIET

- Carbohydrates
- Lipids
- Protein

CONSUMER

- Carbohydrates
- Lipids

HERBIVORE

- Protein
Increased variability in diet macromolecular δ¹³C can lead to increased Δ¹³C protein digestibility could also impact Δ¹³C
Rapidly growing animals/tissues are expected to have decreased $\Delta^{13}C$
Prey type impacts sea otter whisker $\delta^{13}$C TDFs

Sea urchins have high lipid contents

Newsome et al. 2010

$$y = -0.03x + 3.6; \ r^2 = 0.48$$

Fisher's test, $P = 0.03$
Prey type impacts sea otter whisker $\delta^{13}$C TDFs

Whiskers are made up of keratin, which contains a lot of glycine and serine.

These non-essential amino acids are synthesized from 3-phosphoglycerate.
Consumer Carbon Take-Aways: Assumptions

What’s on the menu?  **Baseline/Dietary $\delta^{13}$C Values**

- Can vary spatiotemporally
- Must be well-constrained via study design

What did the animal eat?  **Trophic Discrimination**

- There is an offset between the $\delta^{13}$C values of an animal’s dietary items and its tissues
- This offset (TDF; $\Delta^{13}$C) varies with diet quality, nutritional status, growth rate, and across tissues types

When did the animal eat it?  **Isotopic Incorporation and Tissue Turnover Rates**

- Different animal tissues grow at different rates and thus, tell you about diet over different lengths of time
- Additionally, some tissues are metabolically active (blood plasma) while others are metabolically inert (hair)