DEB theory and stable isotope dynamics:

exploring alternative ways

Sébastien Lefebvre, Marine Ballutaud, Carlos Martinez Del Rio, Laure Pecquerie

DEB Symposium 2019 April 10th Brest, France

Characters….

Sébastien Lefebvre,

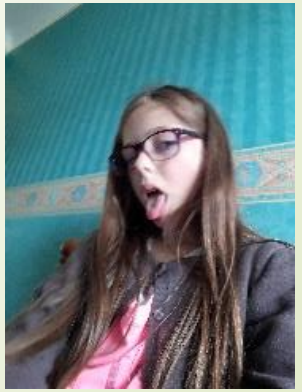
Marine Ballutaud,

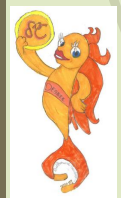
Carlos Martinez Del Rio,

Laure Pecquerie

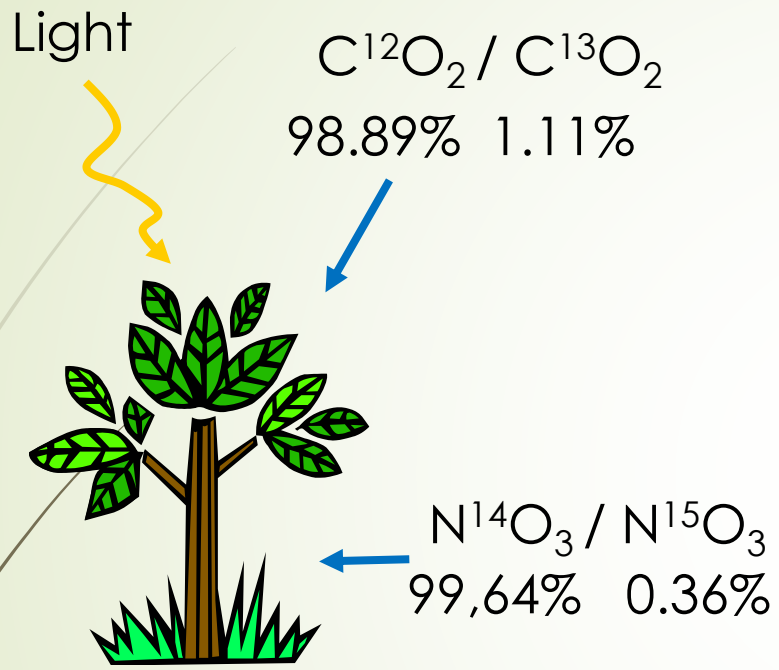
Debbie the special guest

Created by Anthonine

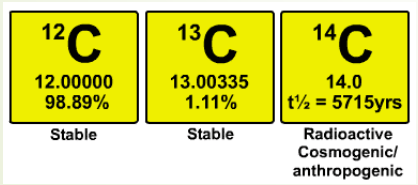


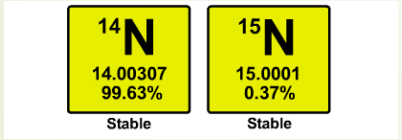


Introduction: basics on stable isotopes



- Stable isotopes are twins with one extra neutron
- Usually the heavier is the rarer
- Carbon and nitrogen are the most used ones





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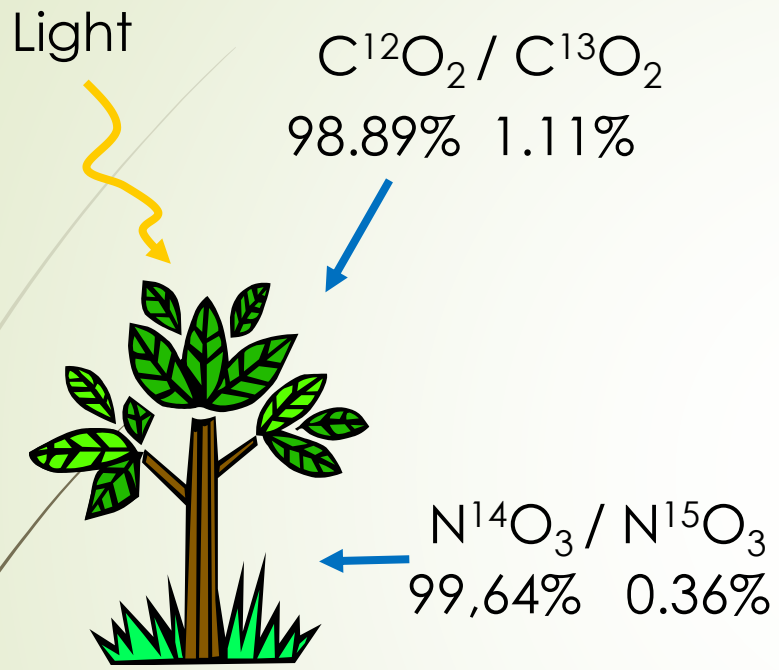

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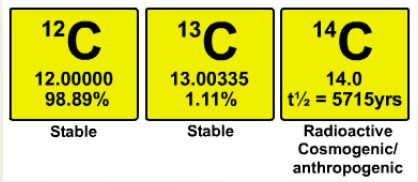

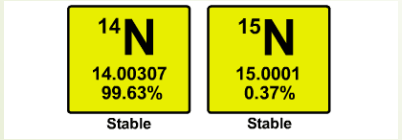

The delta (δ) notation

- Variations in proportion are very little (For ^{13}C: between 1.07 and 1.1 % !!)
- δ notation is a ratio (between sample and a reference/standard) of ratios (fraction of Heavy or Light isotopes)

$$\delta^{H}X = \left[\frac{R_{sample}}{R_{standard}} - 1\right] * 1000 \qquad R = \frac{F_H}{F_L}$$

Introduction: basics on stable isotopes

You are what you eat (δ)

De Niro and Epstein, 1976

Diet

(& trophic position)

Introduction: basics on stable isotopes

You are what you eat (δ) + a few per mil (Δ)

De Niro and Epstein, 1976

Diet

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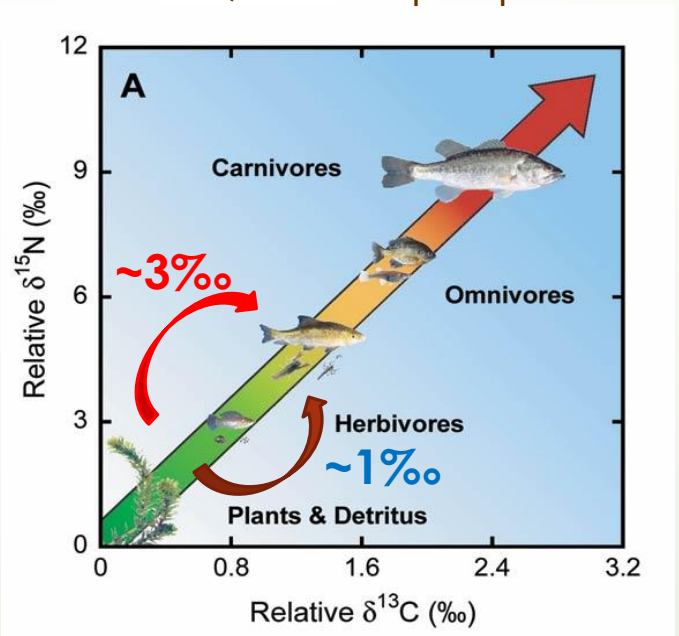
Discrimination factor

Excretion form

Diet quality and quantity…

Dual C, N isotopic plot



Introduction: basics on stable isotopes

You are what you eat (δ) + a few per mil (Δ) [+ time lag (λ)]

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Diet quality and quantity…

Incorporation rate

Metabolic rate

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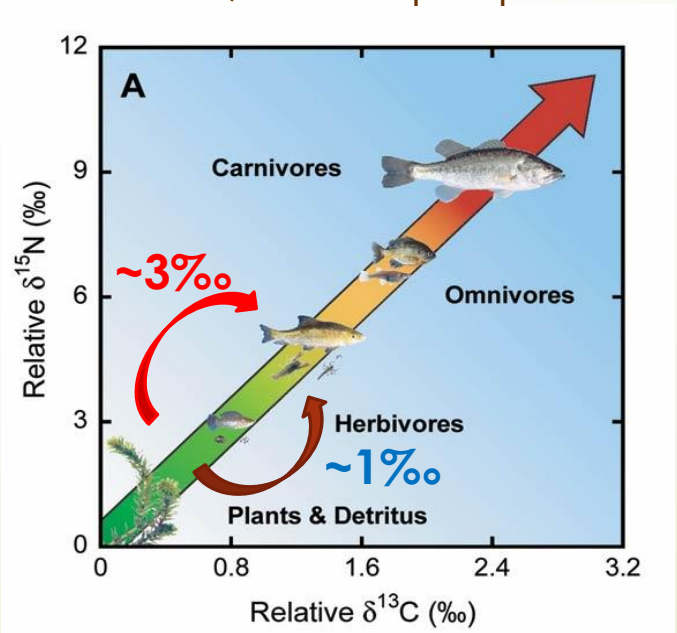

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Diet quality and quantity…

Incorporation rate

Metabolic rate

Quantification of diet (or trophic position) is possible provided that:

1) Prey have different stable isotope ratios (or trophic baseline known)

2) The discrimination factor for each food source is known and constant

3) Isotopic equilibrium is reached

Introduction: basics on stable isotopes

You are what you eat (δ) + a few per mil (Δ) [+ time lag (λ)]

De Niro and Epstein, 1976

Diet
(& trophic position)

Discrimination factor
Excretion form
Diet quality and quantity…

Turnover rate
Metabolic rate

Quantification of diet (or trophic position) is possible provided that:

1) Prey have different stable isotope ratios (or trophic baseline known)

2) The discrimination factor for each food source is known and constant

3) Isotopic equilibrium is reached

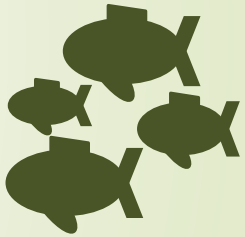
Unlikely!
The tricky part……

Burying our heads in the sand?

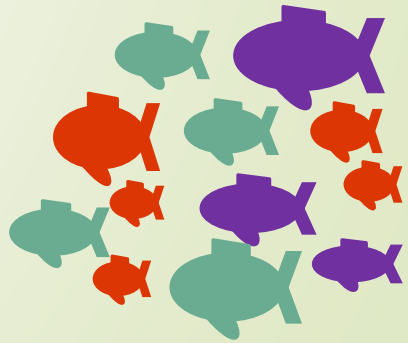
Introduction: basics on stable isotopes

Level of organisation	Trophic inferences	Methods
Individual	Diet, Trophic position	Mixing models (Philipps and Gregs, 2003) Trophic position (Post 2002)
Population	Between and within individuals	Niche variation hypothesis, (Araujo et al., 2010)
Community	Structure of the food web	Isotope metrics (Layman et al., 2012)

individual



population

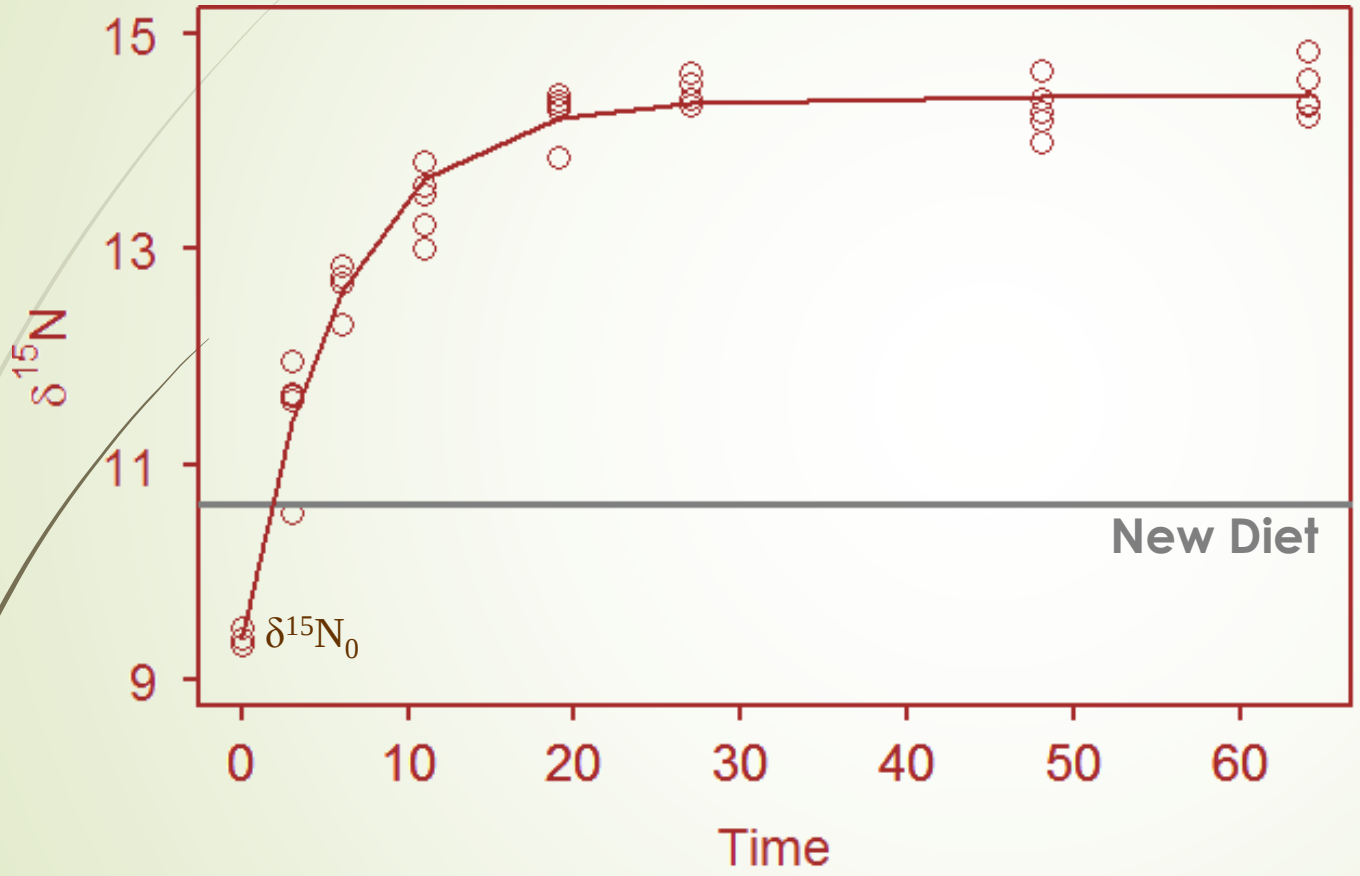


community

More than 600 papers a year (isotope* and trophic ISI WOS)

How to estimate discrimination and turnover

Diet Switch Experiments + « phenomenological » incorporation models



How to estimate discrimination and turnover

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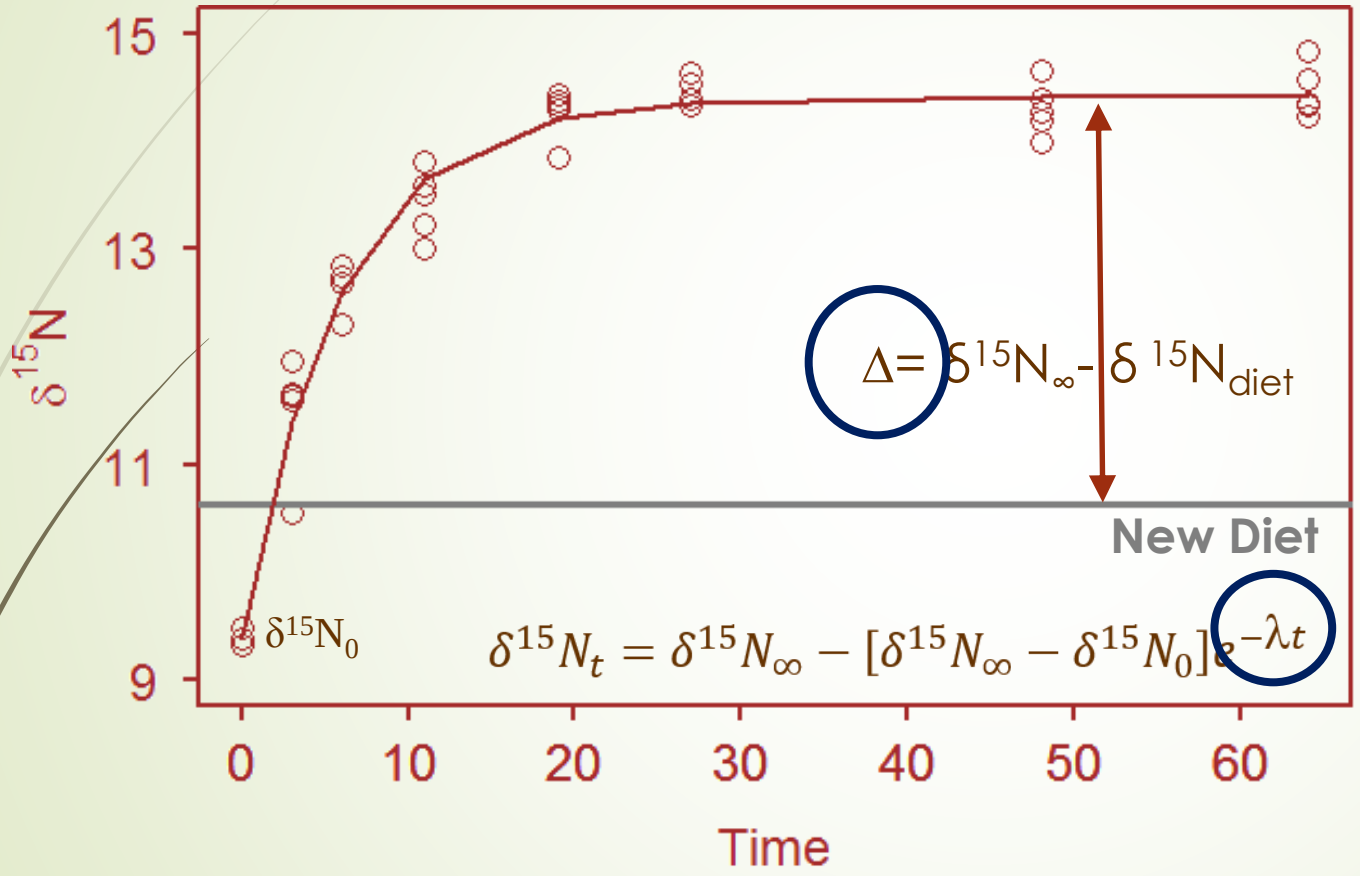


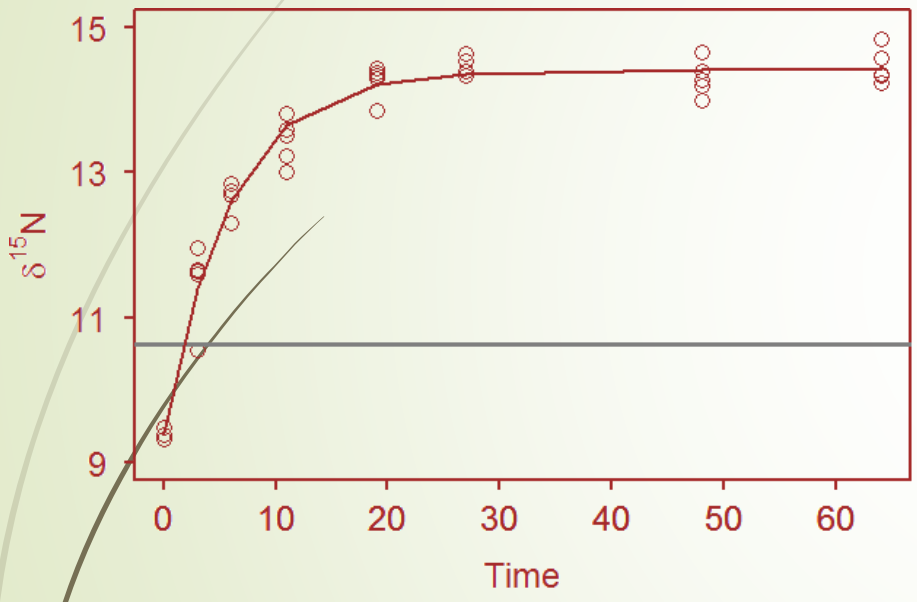
$$\lambda = \frac{1}{W}\frac{dW}{dt} - \alpha W^{\beta}$$

Turnover = growth term + catabolic term

<u>Time- or growth-dependent models:</u>
Fry and Arnold, 1982, Hobson et al., 1992,
Heisslein et al., 1993, Carleton & Martinez Del Rio, 2010

How to estimate discrimination and turnover

Diet Switch Experiments + « phenomenological » incorporation models



<u>Few studies:</u> Only 2% of experimental studies (on average 12 on 600 per year)

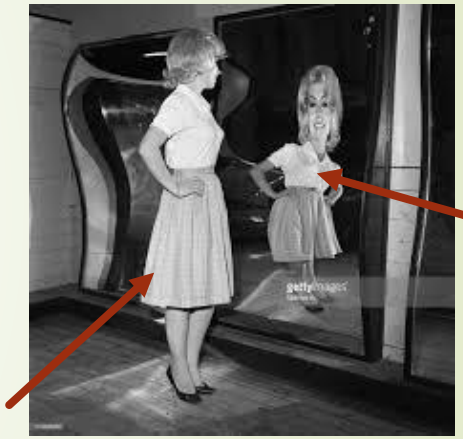
Isotopists then refer to meta-analyses and crude mean values for discrimination and turnover rate

Isotopic distorsion?

Diet = You are what you eat (δ) + a few per mil (Δ) + time lag (λ)

Sources of distorsion

Assuming mean Δ and high λ → distorsion



Distorted mirror

In reality, **Δ** and **λ** are dynamic and depend on several confounding factors of which metabolism

But few mechanistic rules were put in evidence

→ **Need for mechanistic modelling**

Mechanistic DIB modeling

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

2010

The impact of metabolism on stable isotope dynamics: a theoretical framework

Laure Pecquerie, Roger M. Nisbet, Ronan Fablet, Anne Lorrain and Sebastiaan A. L. M. Kooijman

Contents lists available at SciVerse ScienceDirect

Journal of Sea Research

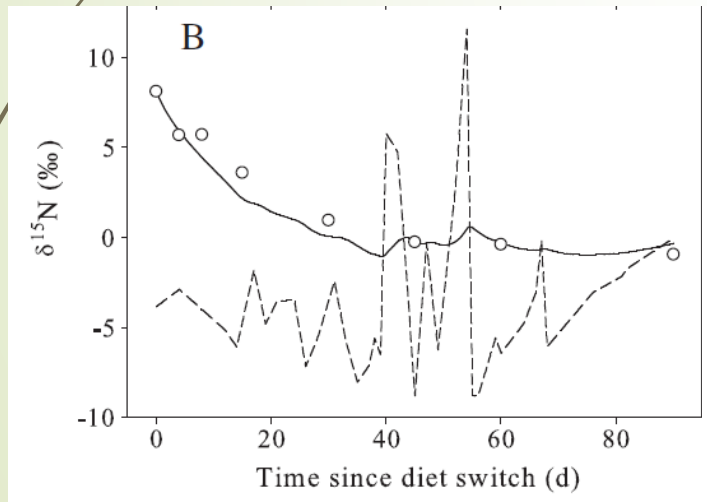
journal homepage: www.elsevier.com/locate/seares

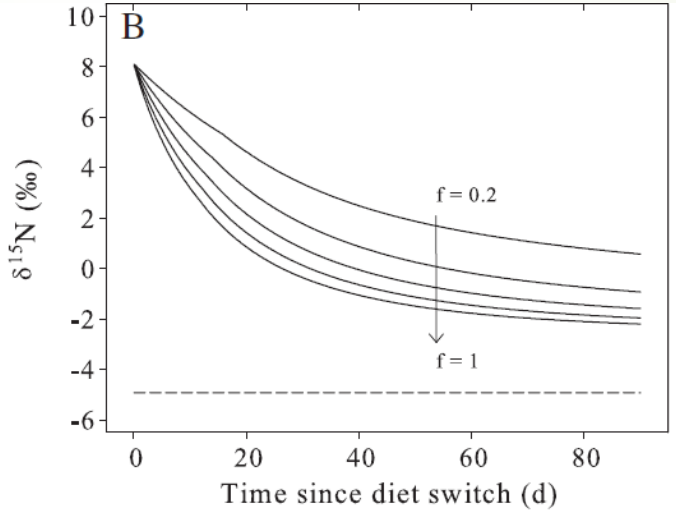
ELSEVIER

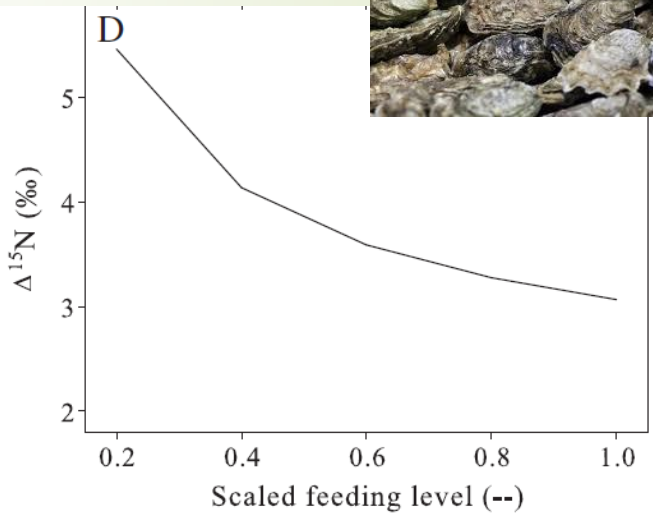
2011

Understanding the dynamics of $\delta^{13}C$ and $\delta^{15}N$ in soft tissues of the bivalve *Crassostrea gigas* facing environmental fluctuations in the context of Dynamic Energy Budgets (DEB)

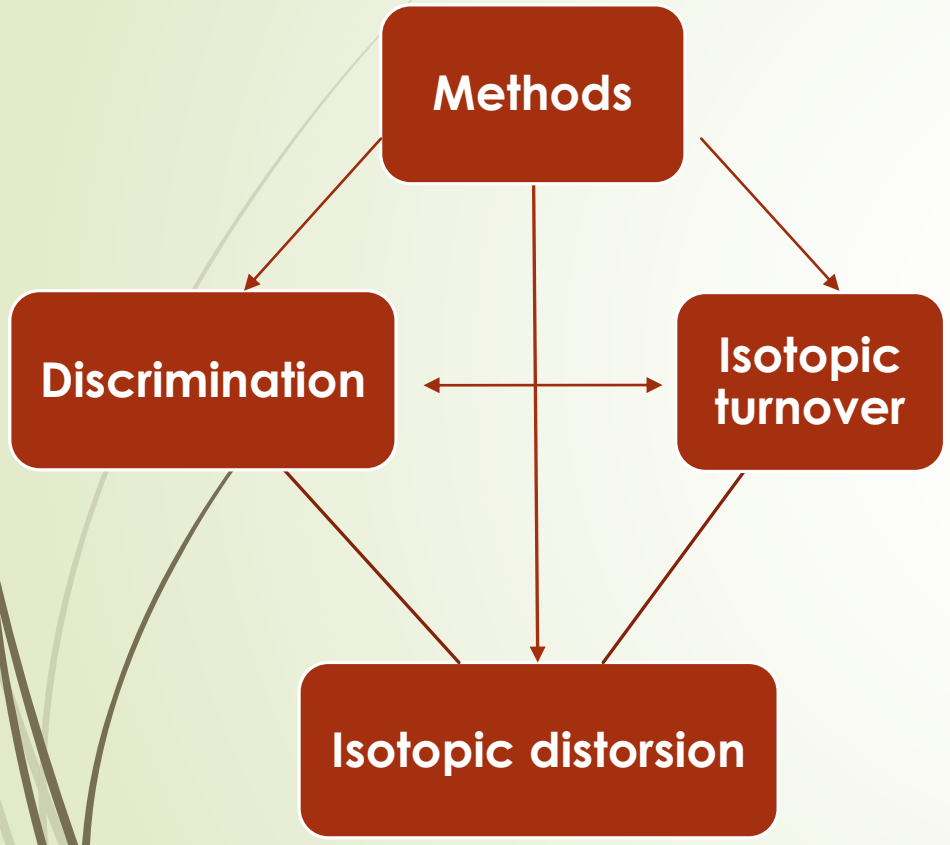
A. Emmery [a,b,c,*], S. Lefebvre [c], M. Alunno-Bruscia [a], S.A.L.M. Kooijman [d]







Aims

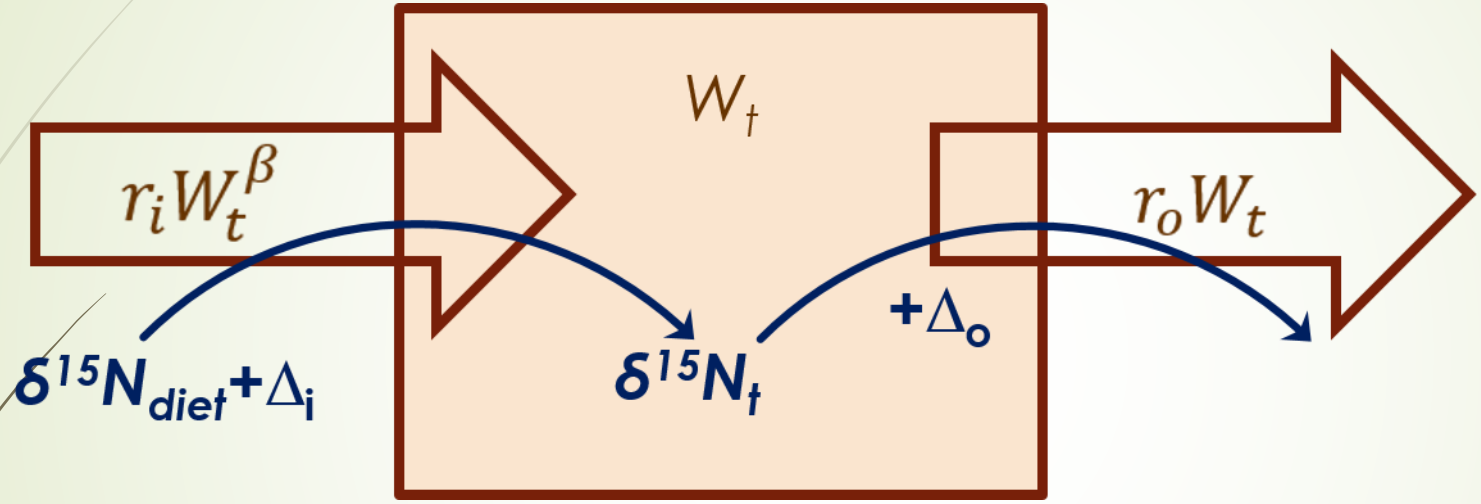


- Large number of factors and complexities of their interactions
- DIB mechanistic modelling is a comprehensive framework
- Portability of DIB in community applications is questionable (also populations in some extent?)
- Aim: developing a more simple model that can be paramatrised with DEB theory

Coming out the fog….

IsoDyn model (a new model)

Nitrogen mass balance model



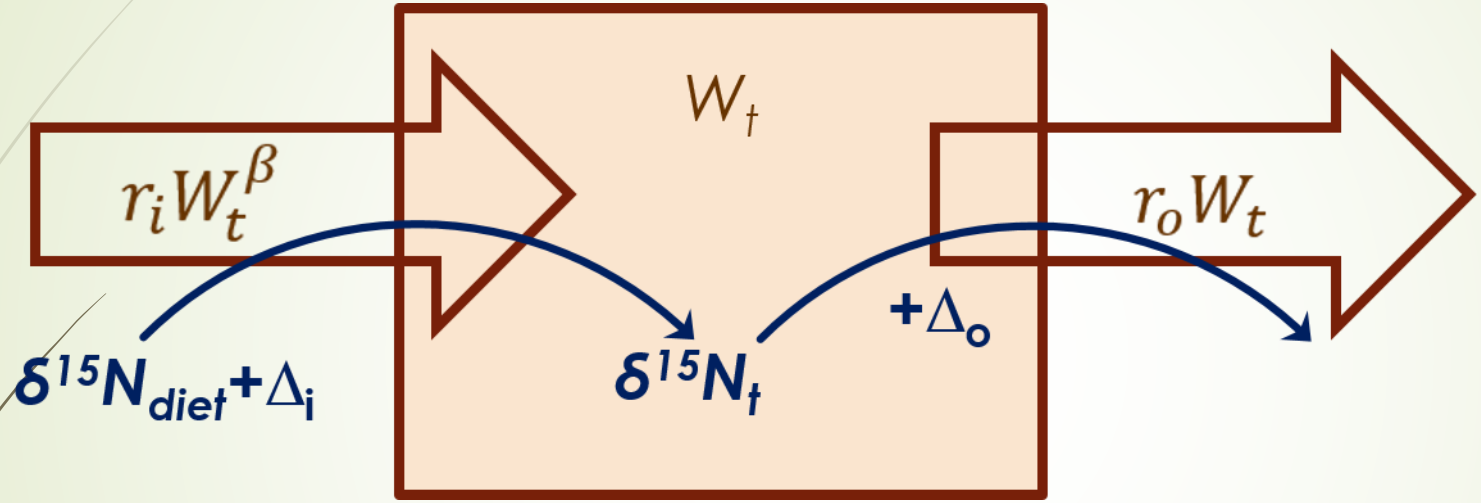
New features:

- Allometric growth (β)
- Two fractionations
- 4 parameters

Lefebvre et al., in preparation for Am Nat

IsoDyn model

Nitrogen mass balance model



New features:

- Allometric growth (β)
- Two fractionations
- 4 parameters

Determinate growth: 0.5<β<1
For 2/3 then Von Bertalanffy as explained by DEB theory

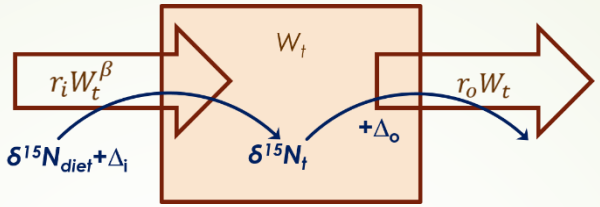
A system of two equations

$$W_t = \left\{ W_\infty^{1/3} + \left(W_0^{1/3} - W_\infty^{1/3} \right) e^{-\frac{r_0}{3} t} \right\}^3 \qquad W_\infty^{1/3} = \frac{r_i}{r_0}$$

$$\frac{d\delta^{15}N}{dt} = r_i W_t^{1-\beta} \left(\delta^{15}N_{diet} - \delta^{15}N + \Delta_i \right) - \Delta_o$$

Lefebvre et al., in preparation for Am Nat

How to calibrate IsoDyn from DEB?



β=2/3

Two-step process

1

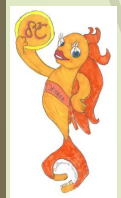
Ananolic and catabolic parameters: r_i and r_o

Von Bertalanffy (1957)

Dynamic energy budget theory (Kooijman, 2010)

AMP collection

Experiments



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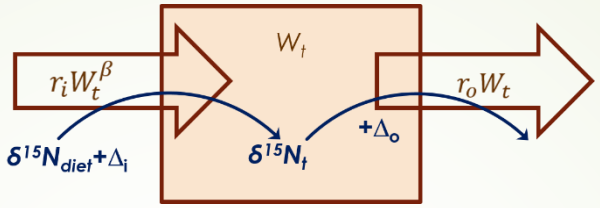


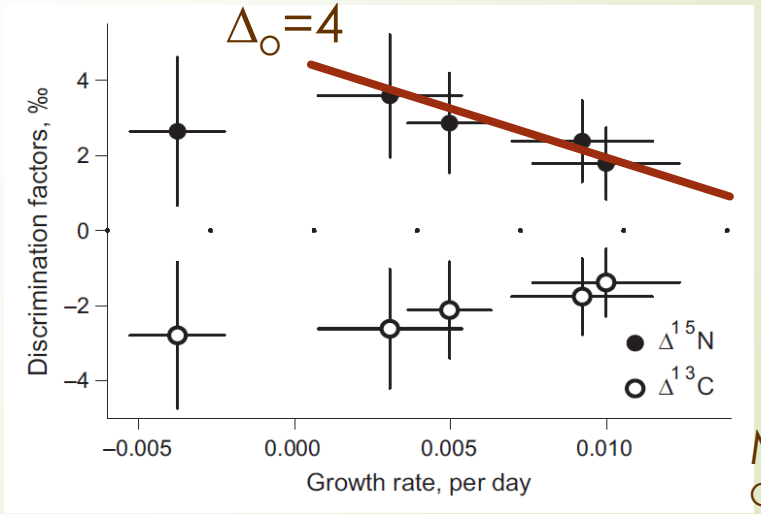
β=2/3

Two-step process

1 → **Ananolic and catabolic parameters: r_i and r_o** **INDEPENDENT** 2 → **Fract. Δ_i and Δ_o**

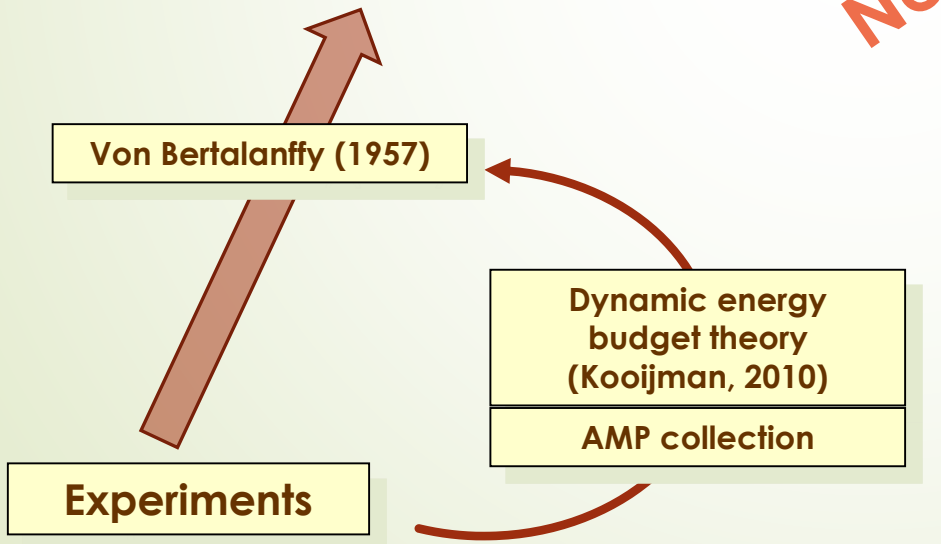
New

Diet switch experiments
At several growth rates with comparable diets or species



$\Delta_i \approx 0$

Mysids
Gorokhova 2017



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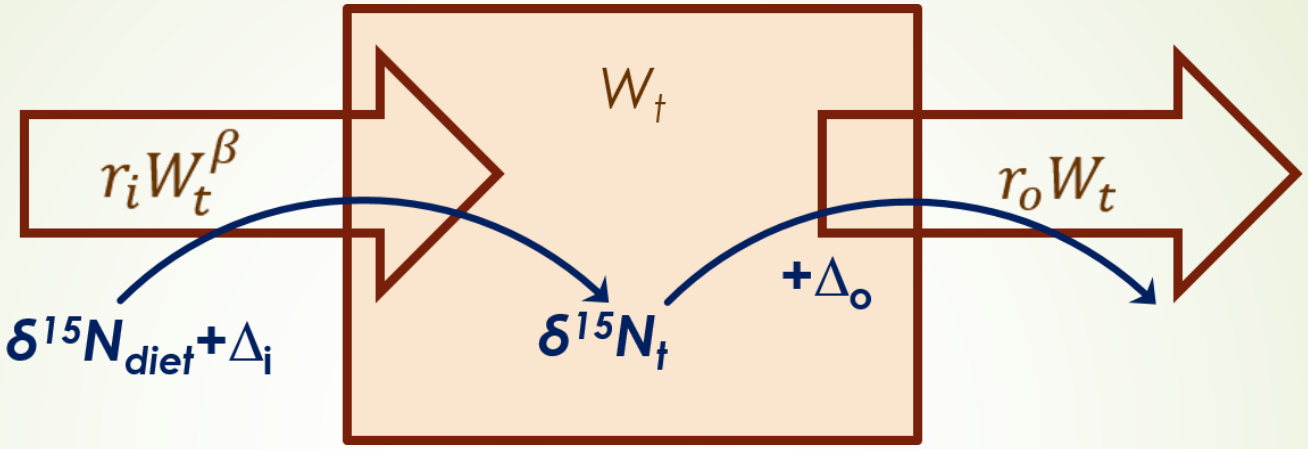


5 DEB parameters
+Temp correction

« Anabolic » parameter

$$r_i = \frac{k_M}{f+g} W_i^{\frac{1}{3}}$$

Infinite weight

$$W_i = (f s_M L m)^3 (1+fw)$$

« Catabolic » parameter

$$r_o = \frac{k_M}{f+g}$$

Isotopic turnover (λ)

$$\lambda = \frac{k_M}{f+g} W^{-\frac{1}{3}} W_i^{\frac{1}{3}}$$

Discrimination (Δ)

$$\Delta = \Delta_i + \Delta_o \frac{r_o}{\lambda}$$

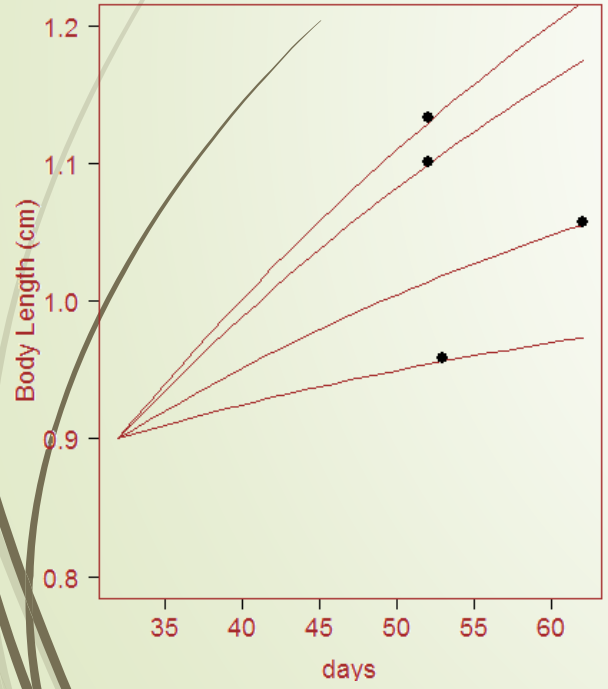
Example: *Neomysis integer* (Opossum shrimp)

Data from Gorokhova 2018

An experiment with several food levels and isotopic incorporation dynamics

Parameters from AMP (abj model)

Adj functional scaled response



f=1
f= 0.91

f= 0.74

f= 0.65

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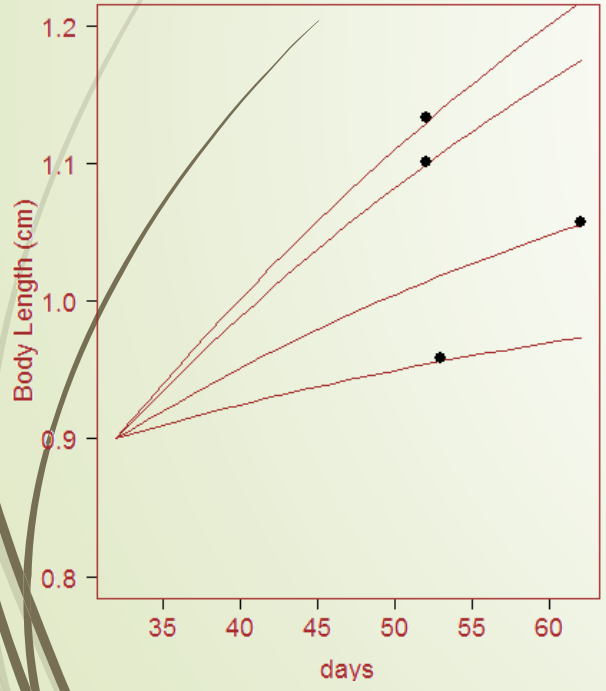

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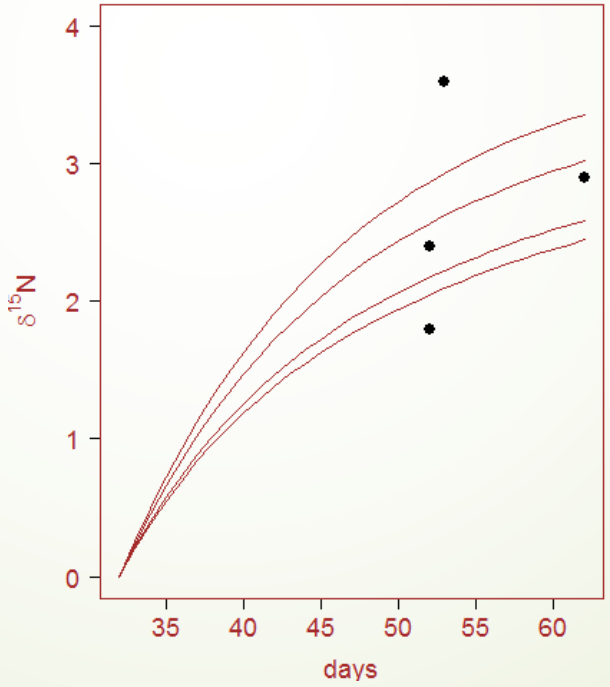
$\delta^{15}N$ dynamics



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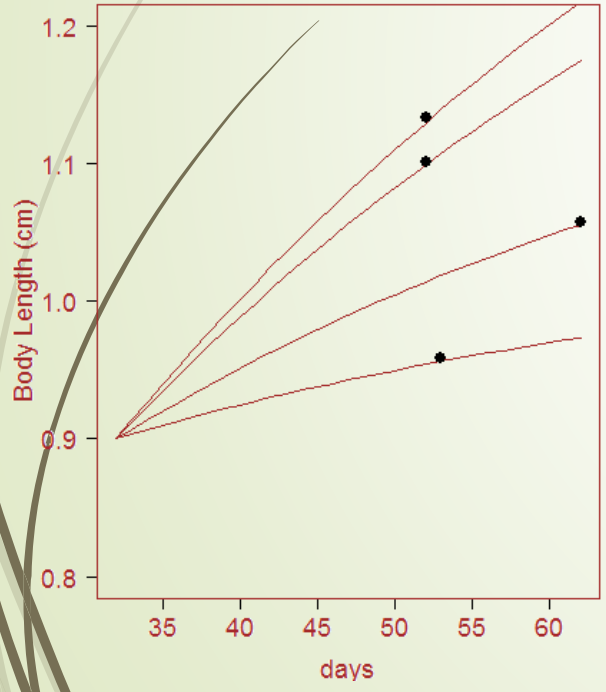

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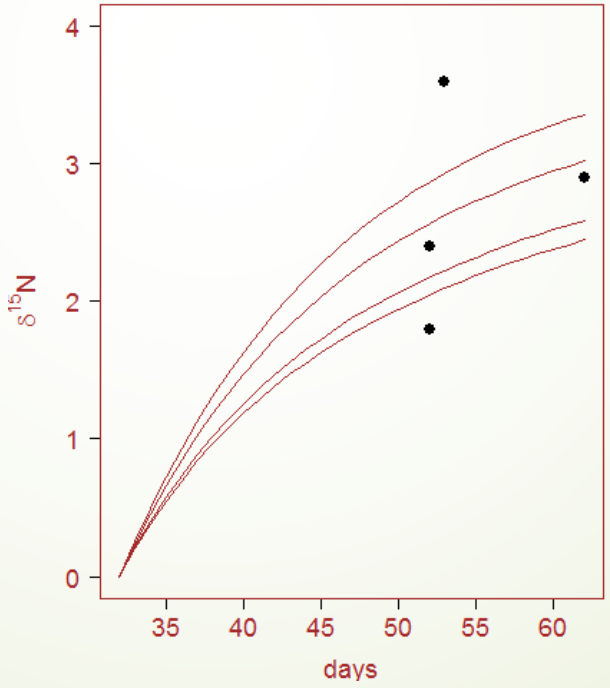
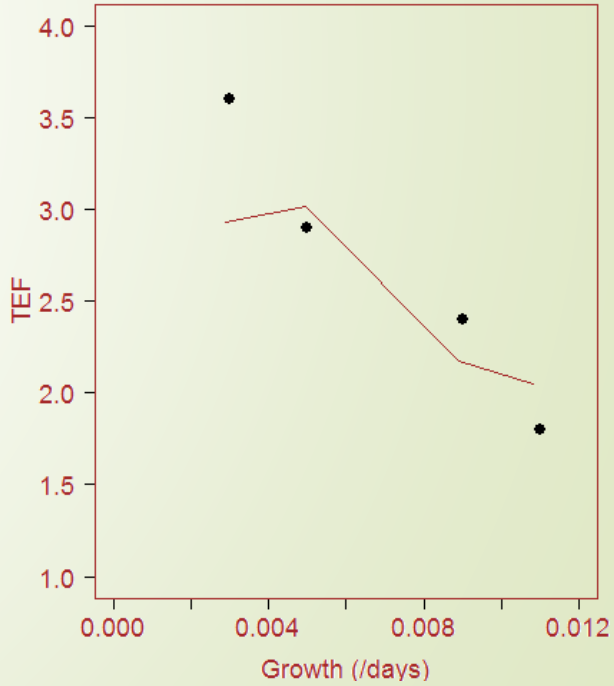


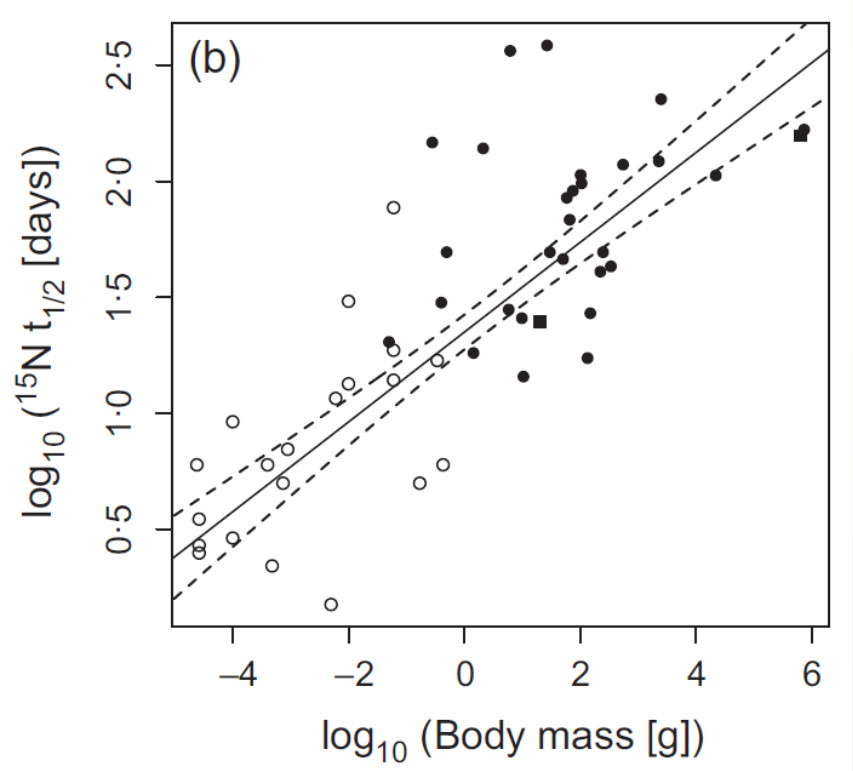
Δ vs growth rate



Isotopic half life (inverse of turnover rate)

$$t_{\frac{1}{2}} = \frac{ln\,2}{\lambda}$$

Isotopic Half-life vs body mass (Muscle)
→ Allometric rule (slope=0.19)



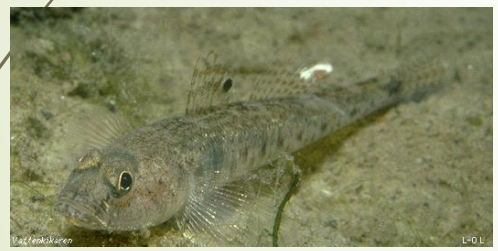
Each point one exp and one species

Ectotherms (empty circles)
Endotherms (full circles)

Thomas and Crowther, 2015

Isotopic half life (through IsoDyn and DEB)

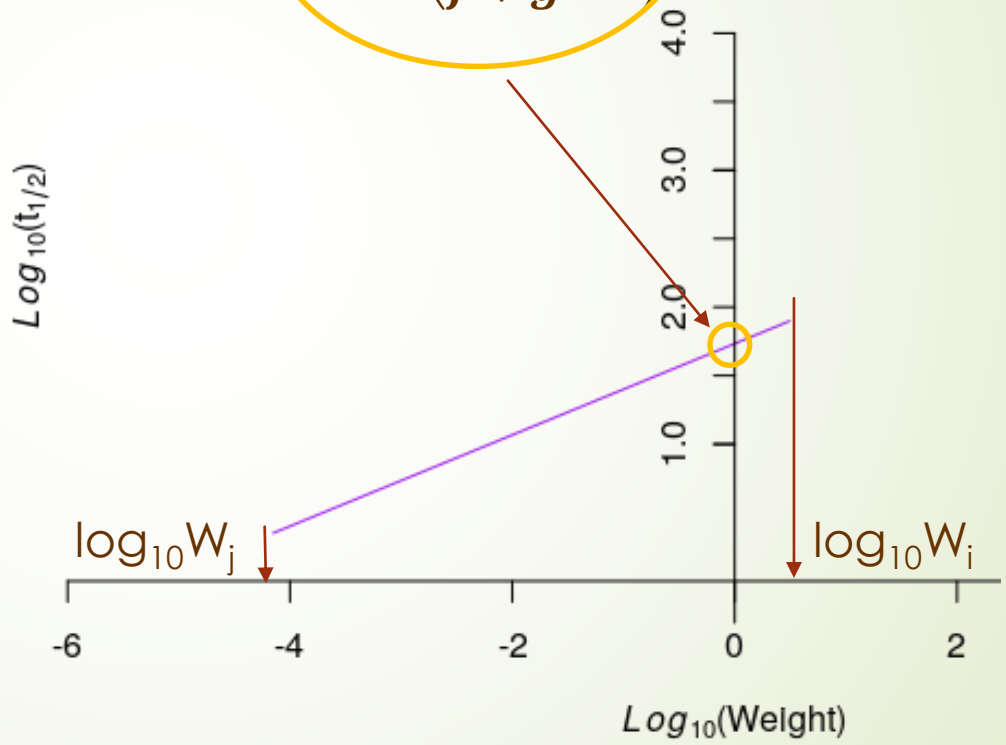
$$t_{\frac{1}{2}} = \frac{ln\,2}{\lambda}$$



Sand goby

$$log_{10}\left(t_{\frac{1}{2}}\right) = log_{10}\left(\frac{ln\,2}{\frac{k_M}{f+g}W_i^{\frac{1}{3}}}\right) + \frac{1}{3}log_{10}W$$

f=0.8



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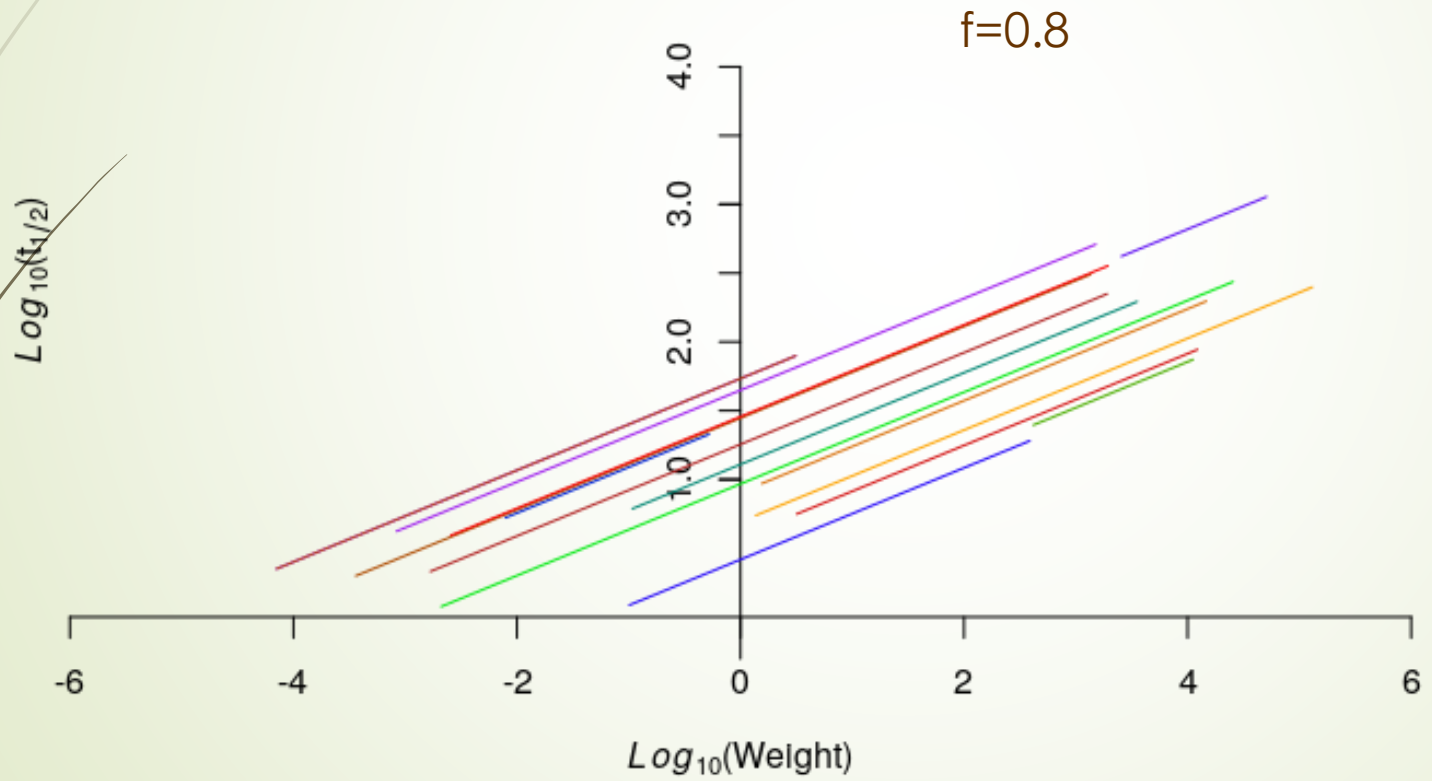

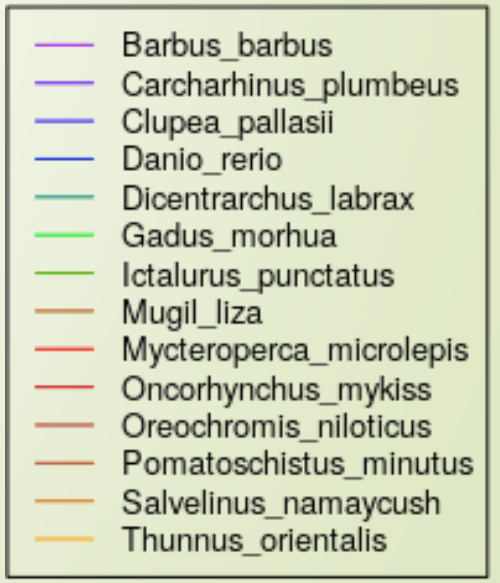

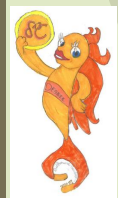

Isotopic half life (through IsoDyn and DEB)

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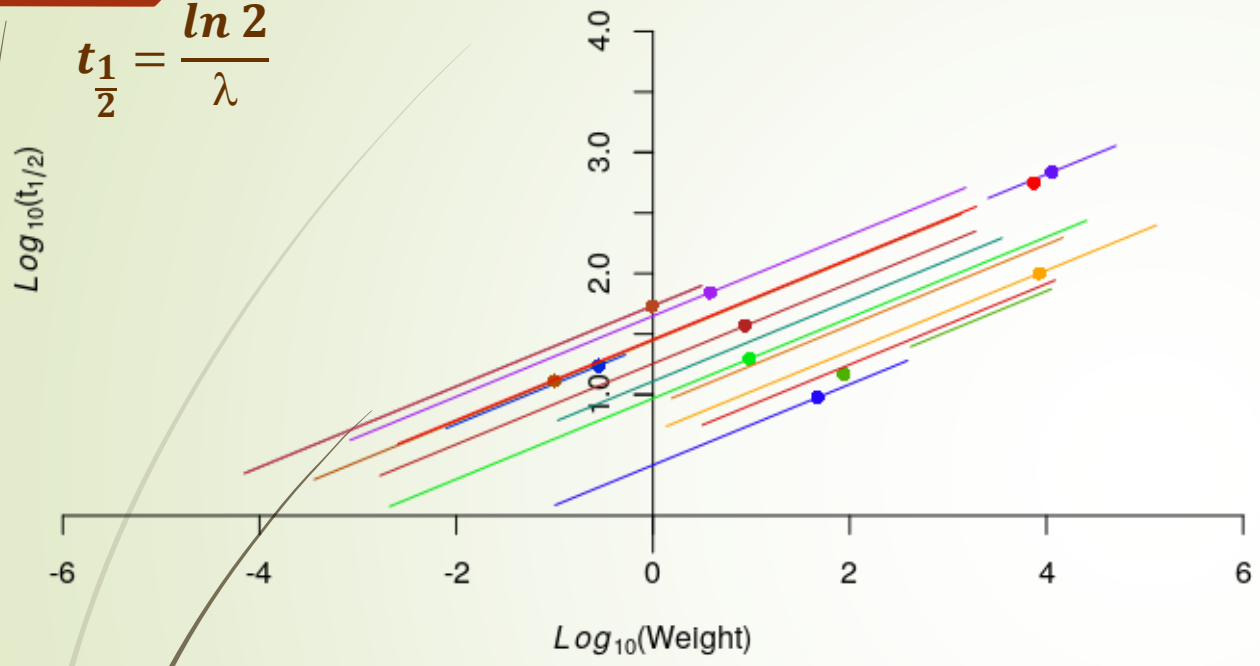
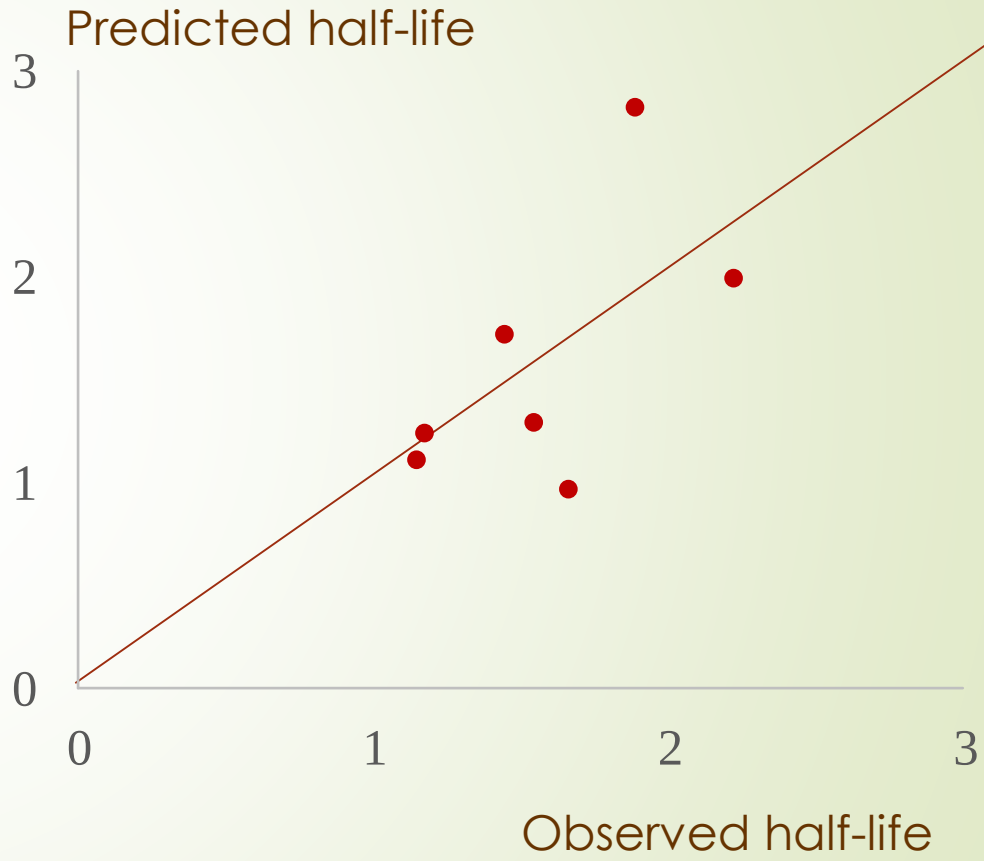
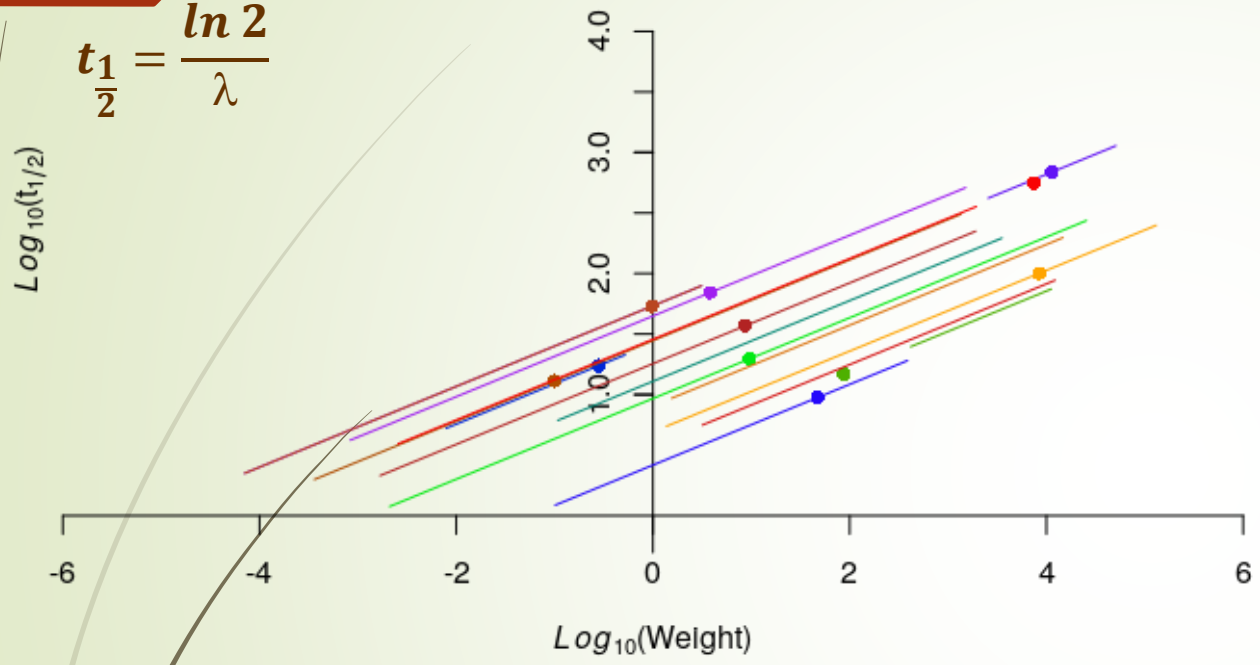


f=0.8 (not adjusted)



Isotopic half life (through IsoDyn and DEB)

$$t_{\frac{1}{2}} = \frac{ln\ 2}{\lambda}$$



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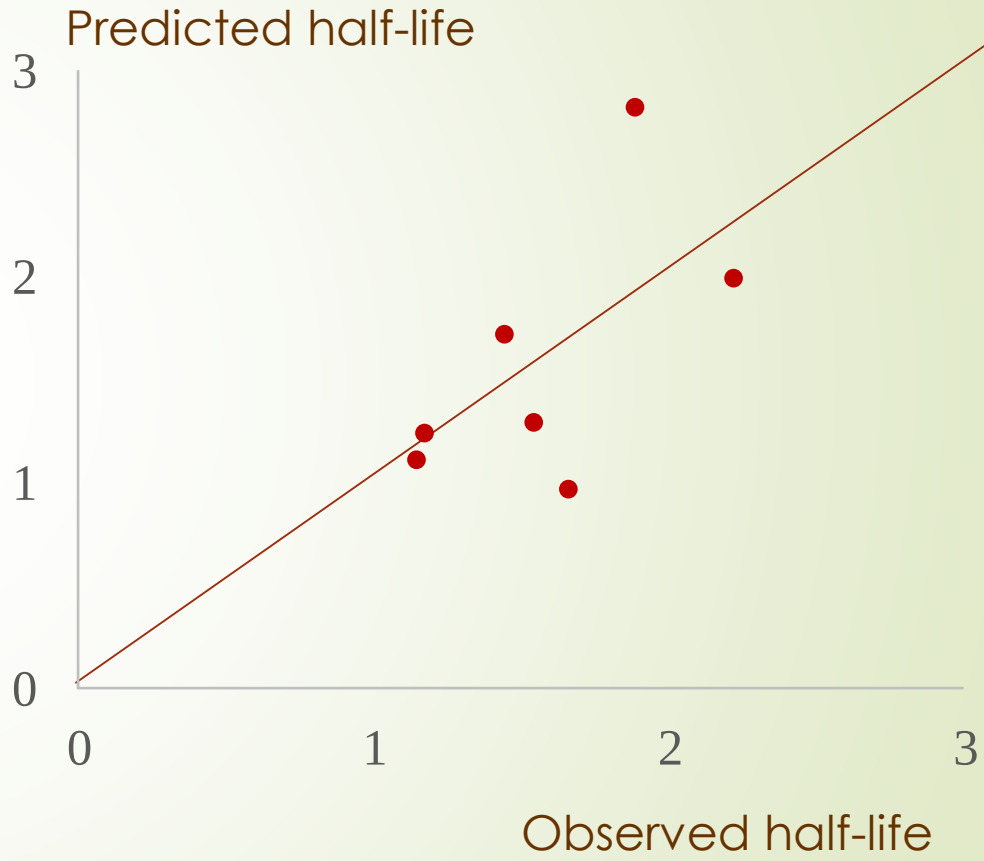
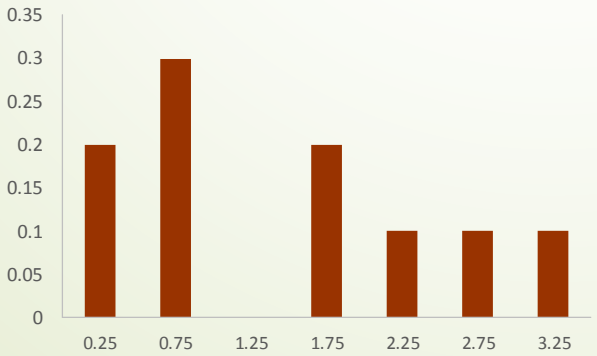


Freq of Discrimination

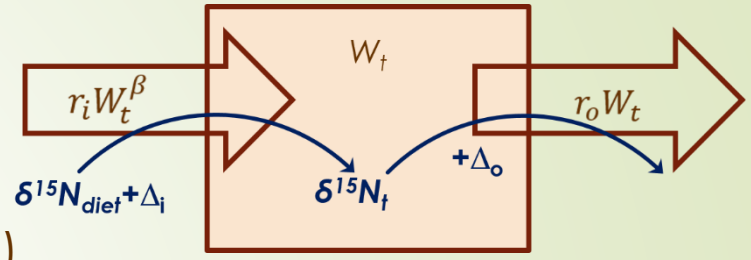


$$\Delta = \Delta_i + \Delta_o \frac{r_o}{\lambda}$$

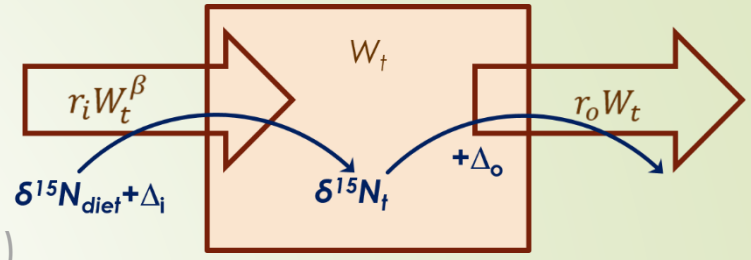
Take home messages

- New model with allometry rules and two fractionations (in and out)
- All dynamics:

  Discrimination (Δ) + incorporation rate (λ) + their interactions ($\Delta \cap \lambda$)
- Portability is high



Take home messages



- New model with allometry rules and two fractionations (in and out)
- All dynamics:

  Discrimination (Δ) + incorporation rate (λ) + their interactions ($\Delta \cap \lambda$)
- Portability is high

Future directions

- Continue to re-interpret meta-analysis results (Δ and λ) using DEB through IsoDyn
- Add isotope dynamics in AMP (add my « iso »Pet)
- Produce R packages with links to AMP collection
- Using DIB as a reference to Isodyn (comparison)
- Most experimental studies done on tissues not on whole body…need for an extension of the DIB model (several structures)
- Isotopic routing (several reserves)

Join the team ! (Post–doc position offer http://log.cnrs.fr/Post-Doc-Position-ISIT_U)

Thanks

Thanks for your attention

Sébastien Lefebvre,

Marine Ballutaud,

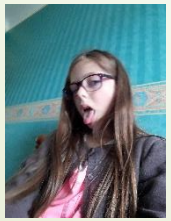
Thanks to DEB2019 organizing committee

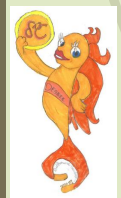
Carlos Martinez Del Rio,

Laure Pecquerie

Debbie the special guest

Created by Anthonine





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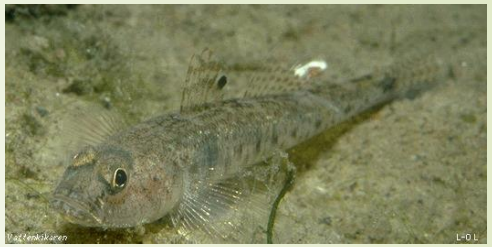
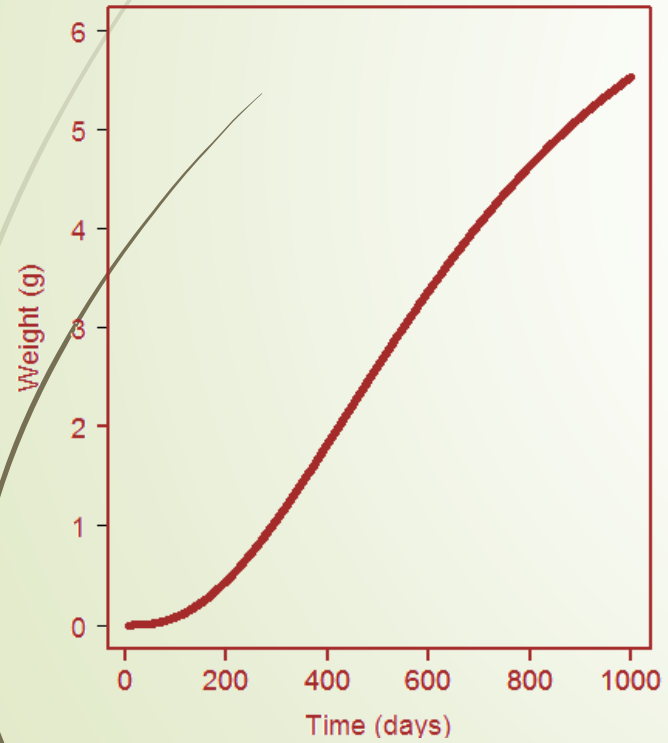
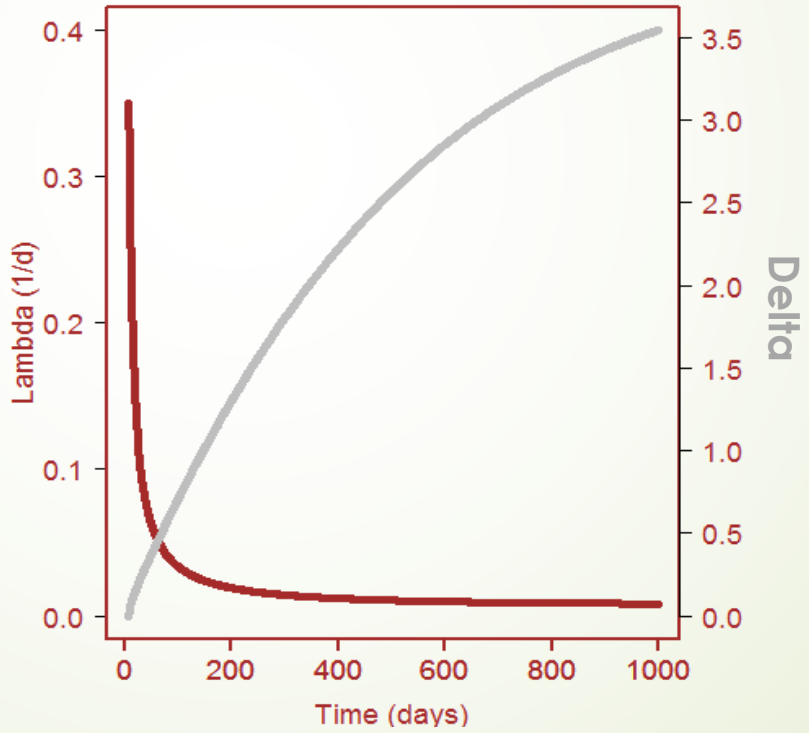
Funding

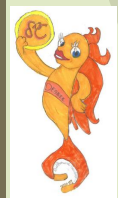
Example: *Pomatoschistus minutus* *(Sand goby)*



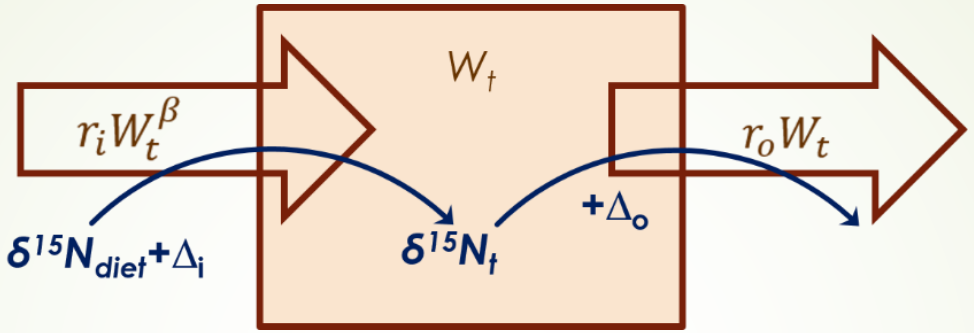
Parameters from AMP (std model)

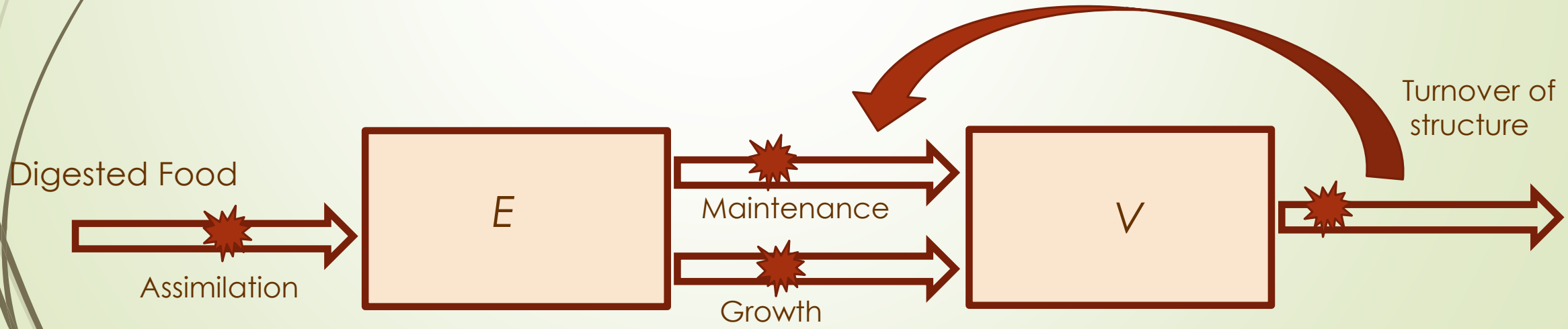






Comparing IsoDyn (DEB) with DIB

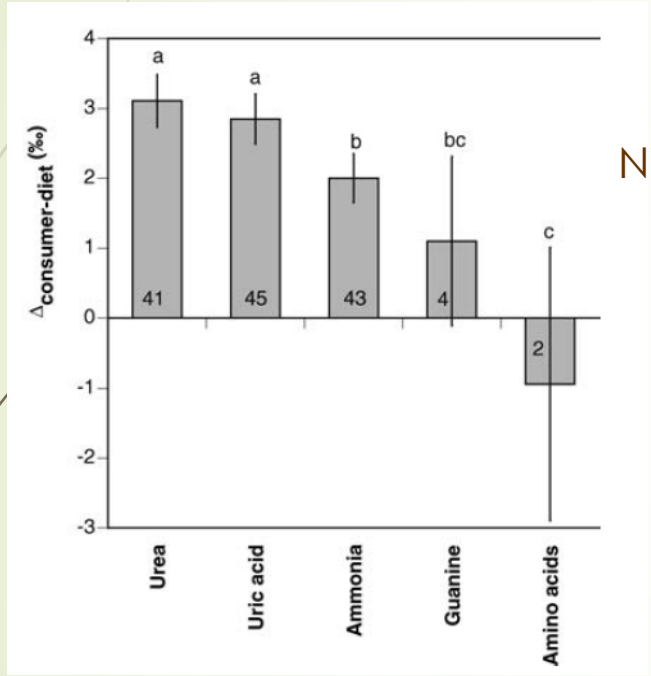




Sources of isotopic anamorphosis: Δ

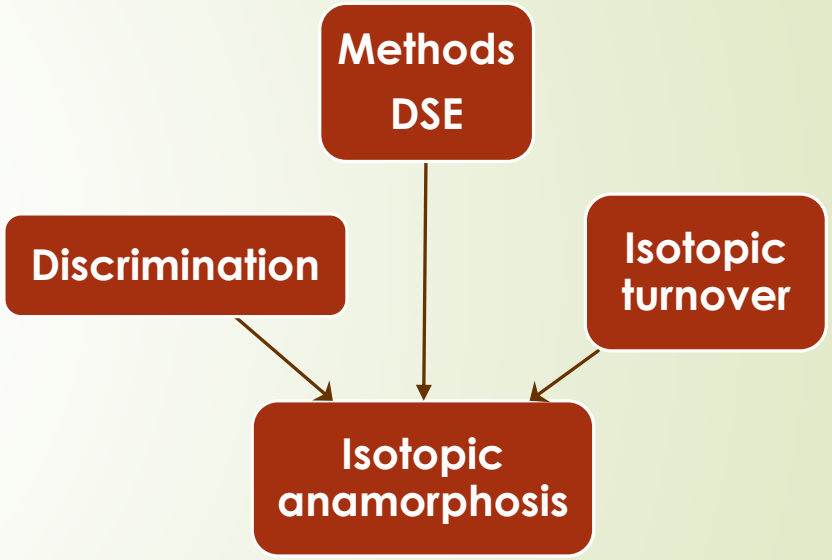
Discrimination factor (or TEF or trophic fractionation…)

- Quite numerous and descriptive values but **few mechanistic rules**



Vanderklift and Ponsard, 2003

Nitrogen excretion types



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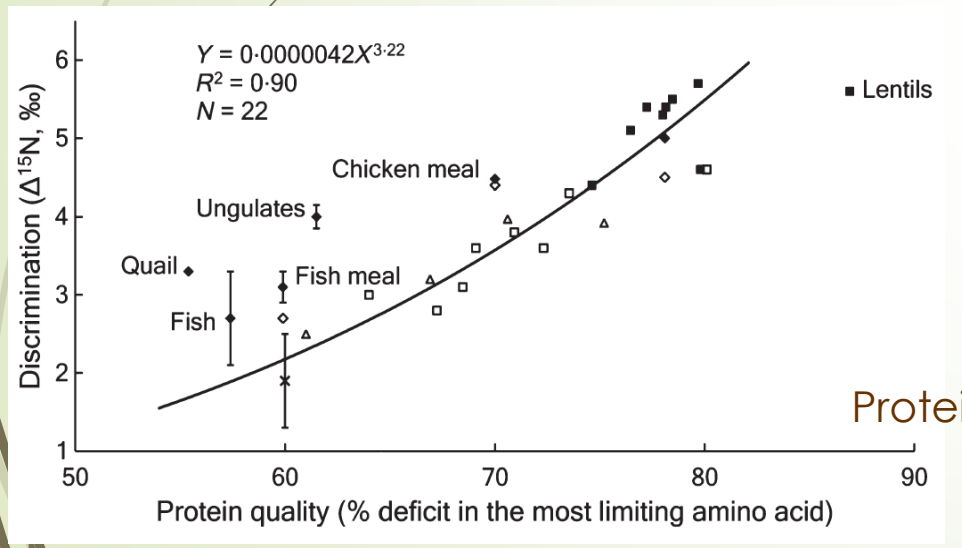


Florin et al., 2011

Nitrogen excretion types

Protein quality and quantity

Methods DSE

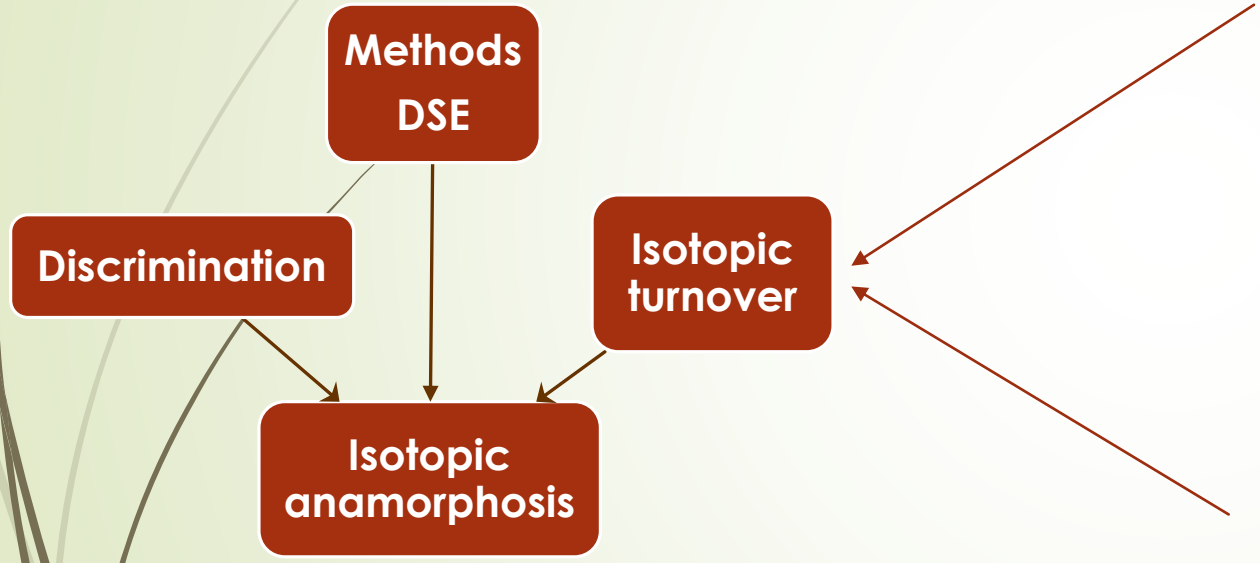
Discrimination

Isotopic turnover

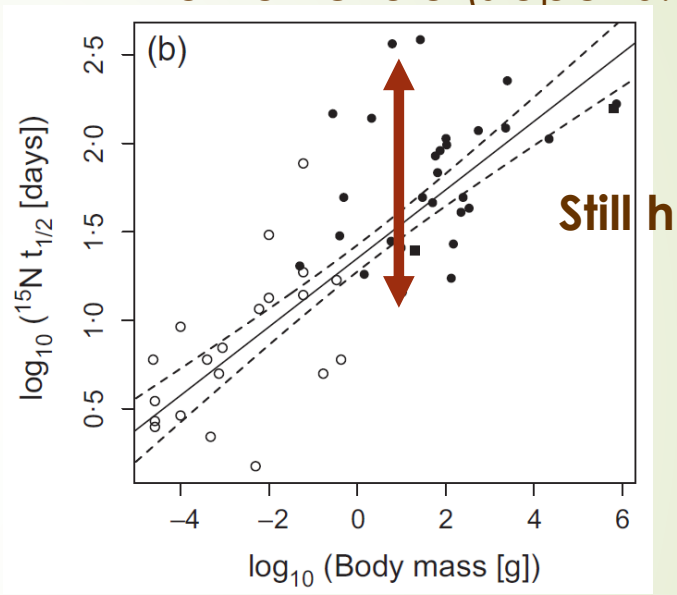
Isotopic anamorphosis

Sources of isotopic anamorphosis: λ

Isotopic turnover rate



Isotopic Half-life vs body mass (Muscle)
→ Allometric rule (slope=0.19)



Still huge variation

Thomas and Crowther, 2015

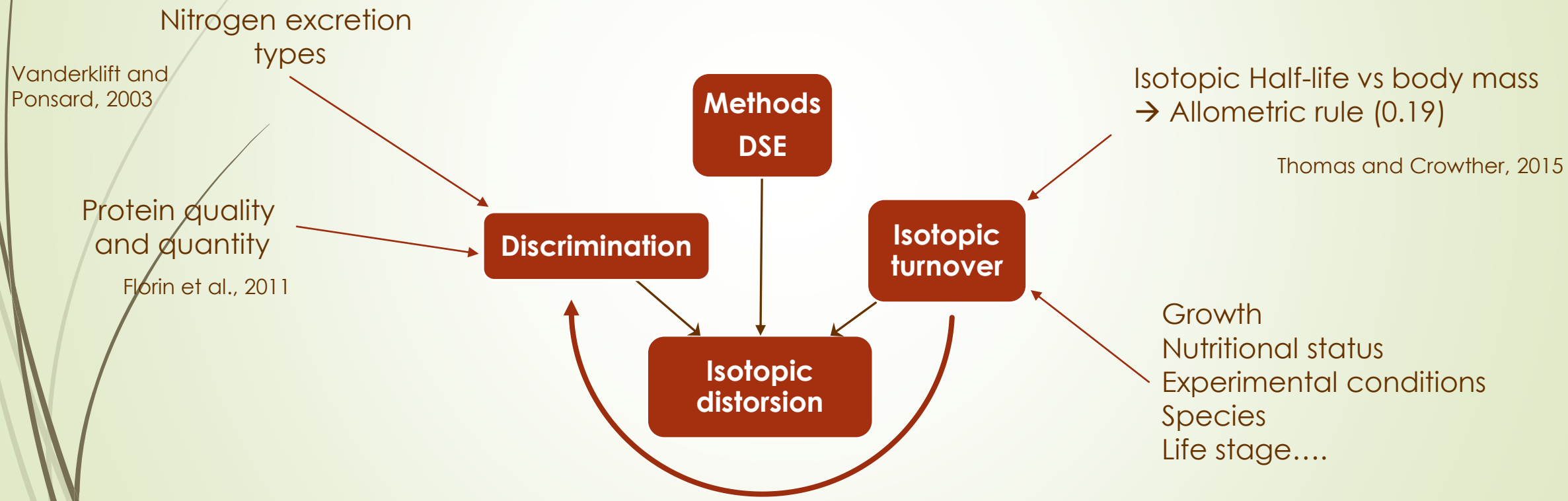
Growth
Nutritional status
Experimental conditions
Species
Life stage….

Vander Zanden et al., 2015

Sources of isotopic distorsion: Δ and λ

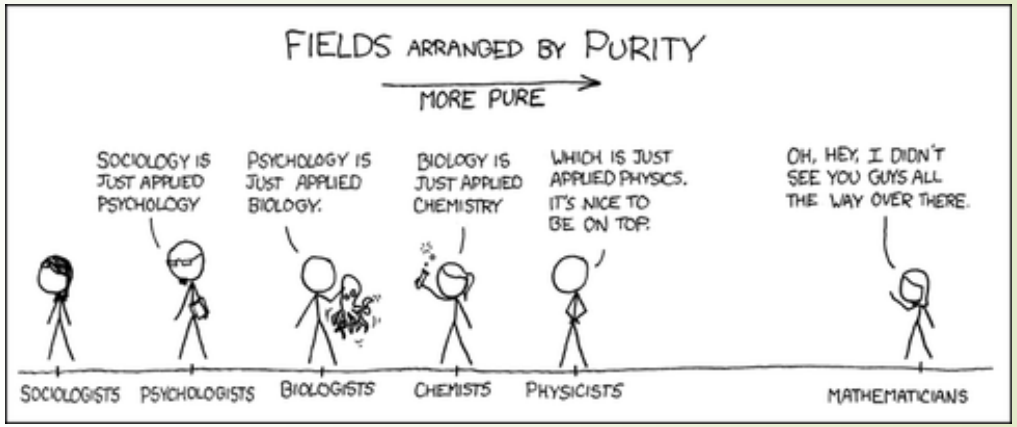
Discrimination factor and Isotopic turnover rate

- Quite numerous and descriptive values but **few mechanistic rules**



$$t_{\frac{1}{2}} = \frac{ln\,2}{\lambda} = \frac{ln\,2}{\frac{k_M}{f+g} W_i^{\frac{1}{3}}} W^{\frac{1}{3}}$$

Existing models



Empirical
2-3 parameters

Hesslein et al. (1993)

Carleton & Martinez Del Rio (2010)

1 compartment
Growth steady state
4-5 parameters
No explicit bioenergetics

Olive et al. (2003)

Ponsard and Averbuch (1999)

Martinez del Rio and Wolf (2005)

IsoDyn

1 compartment
4 parameters

Lefebvre et al. (2019?)

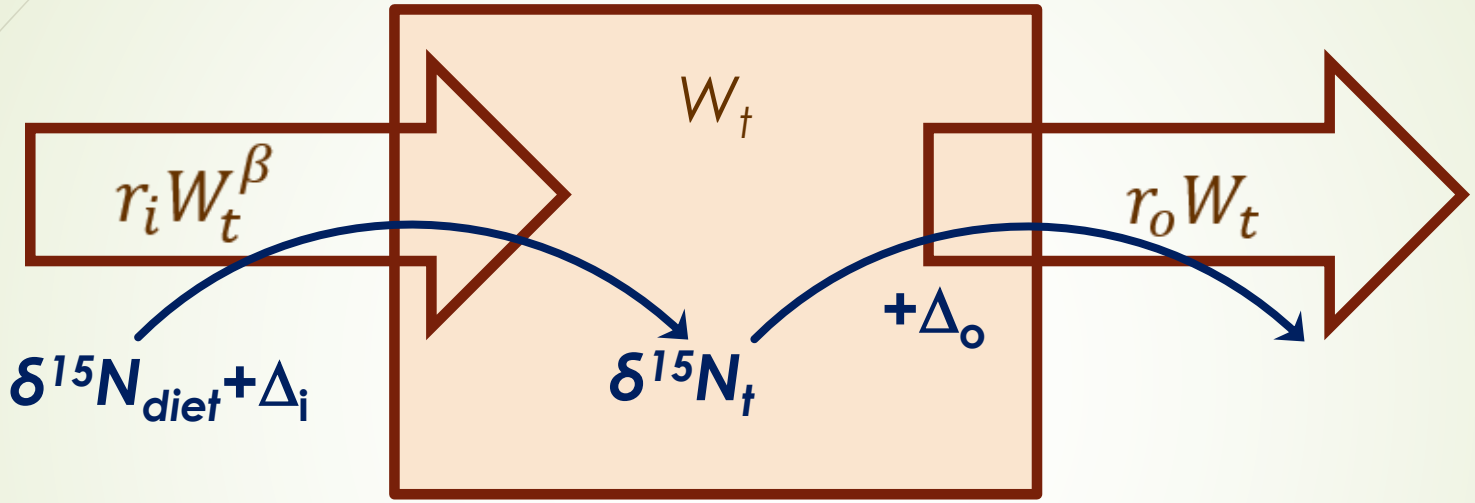
Dynamic isotopic budget
DEB theory

3 compartments
15 parameters
Zoo of 1000 species

Pecquerie et al. (2010)

Phenomenological

Mechanistic



$$\begin{cases} W_t = \left\{ W_\infty^{1-\beta} + \left(W_0^{1-\beta} - W_\infty^{1-\beta} \right) e^{-r_0(1-\beta)t} \right\}^{\frac{1}{1-\beta}} \\ \dfrac{d\delta^{15}N}{dt} = r_i W_t^{1-\beta} \left(\delta^{15}N_{diet} - \delta^{15}N + \Delta_i \right) - \Delta_O \end{cases} \qquad W_\infty^{1-\beta} = \frac{r_i}{r_0}$$