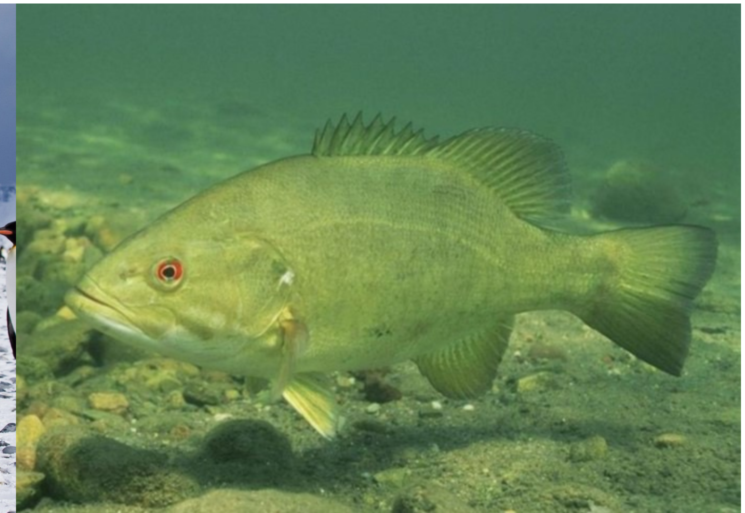
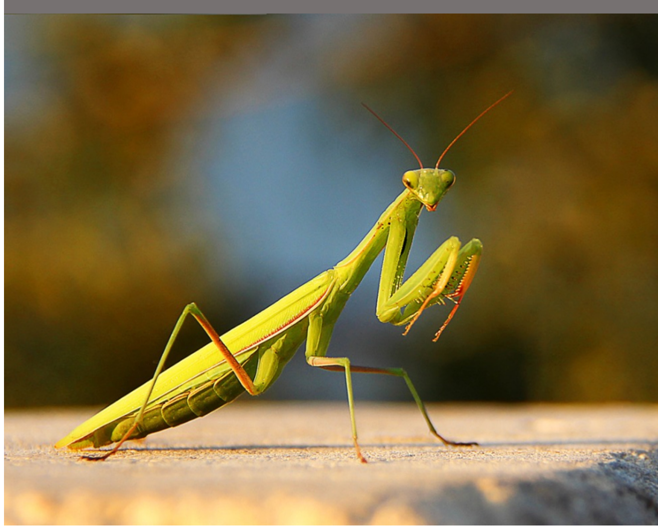




Consumer Carbon

Elemental Ecology

Week Five

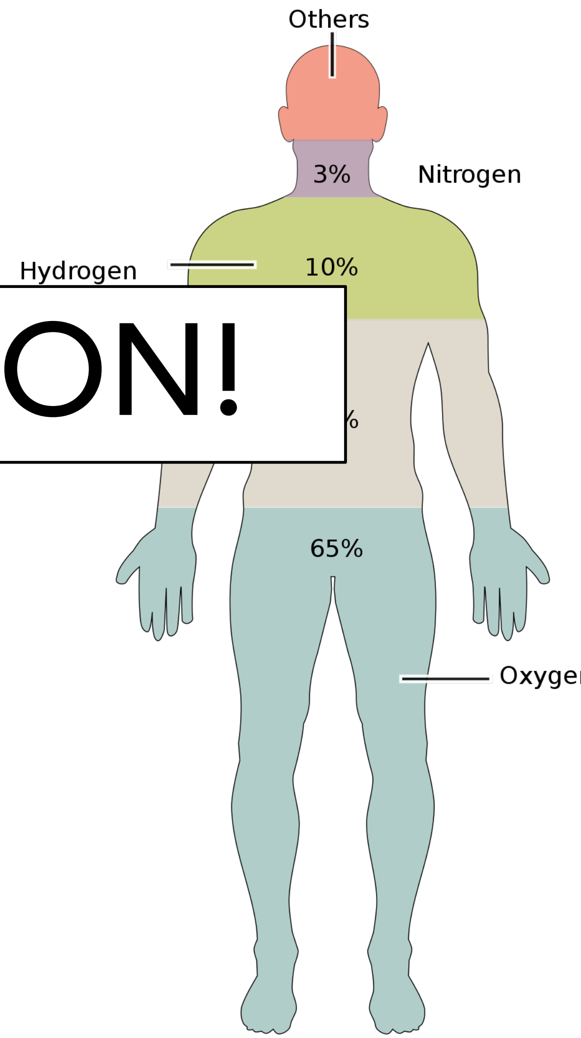


Transition metals

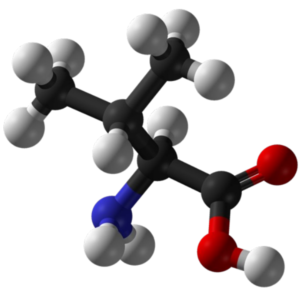
1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	8A
1 **H** 1.00794																	2 **He** 4.00260
3 **Li** 6.941	4 **Be** 9.01218											5 **B** 10.81	6 **C** 12.011	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.998403	10 **Ne** 20.1797
11 **Na** 22.98977	12 **Mg** 24.305											13 **Al** 26.98154	14 **Si** 28.0855	15 **P** 30.97376	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.9559	22 **Ti** 47.88	23 **V** 50.9415	24 **Cr** 51.996	25 **Mn** 54.9380	26 **Fe** 55.847	27 **Co** 58.9332	28 **Ni** 58.69	29 **Cu** 63.546	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.61	33 **As** 74.9216	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.9059	40 **Zr** 91.224	41 **Nb** 92.9064	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.9055	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.710	51 **Sb** 121.757	52 **Te** 127.60	53 **I** 126.9045	54 **Xe** 131.29
55 **Cs** 132.9054	56 **Ba** 137.33	57 ***La** 138.9055	72 **Hf** 178.49	73 **Ta** 180.9479	74 **W** 183.85	75 **Re** 186.207	76 **Os** 190.2	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.9665	80 **Hg** 200.59	81 **Tl** 204.383	82 **Pb** 207.2	83 **Bi** 208.9804	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0254	89 **†Ac** 227.0278	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (269)	109 **Mt** (268)	110 (271)	111 (272)	112 (277)		114 (289)		116 (289)		118 (293)

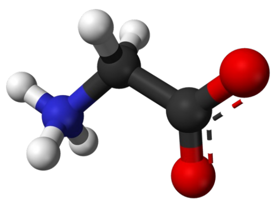
*Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.9077	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.9254	66 **Dy** 162.50	67 **Ho** 164.9304	68 **Er** 167.26	69 **Tm** 168.9342	70 **Yb** 173.04	71 **Lu** 174.967
†Actinide series	90 **Th** 232.0381	91 **Pa** 231.0359	92 **U** 238.0289	93 **Np** 237.048	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

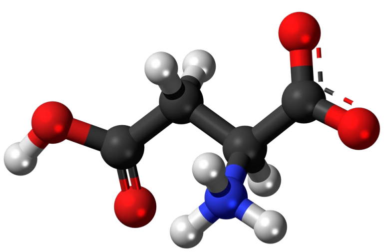
What are animals made of?

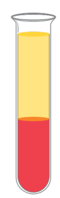


LOTS OF CARBON!



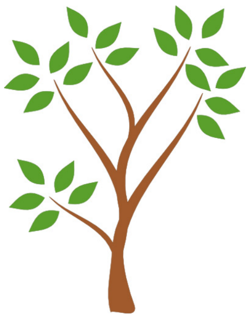






Important things to consider when interpreting consumer $\delta^{13}C$ values:

What's on the menu?



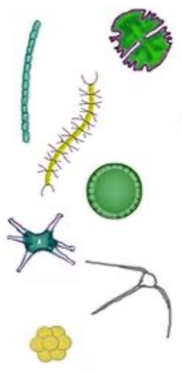


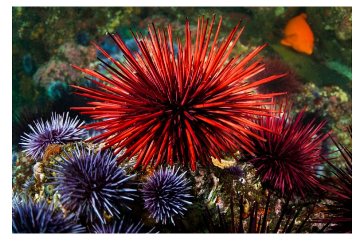
What did the animal eat?

What are you analyzing?

Important things to consider when interpreting consumer $\delta^{13}C$ values:

What's on the menu?





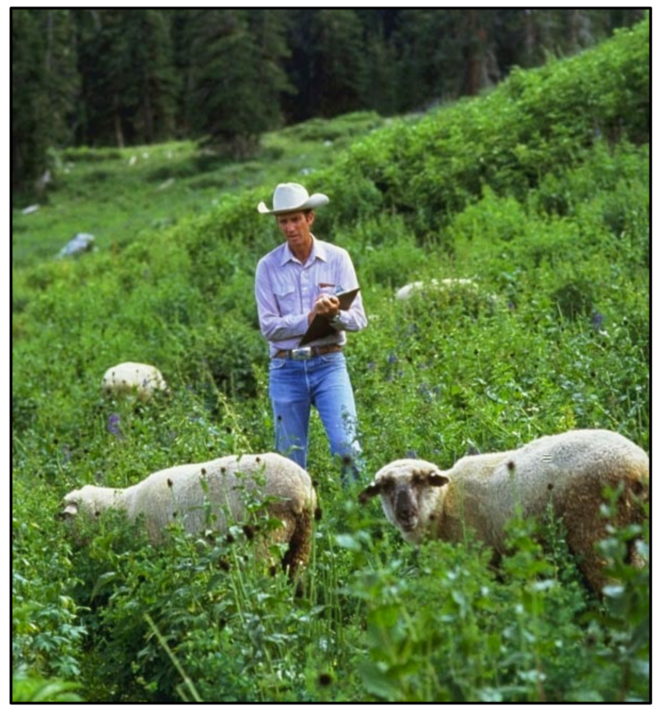
What did the animal eat?

What are you analyzing?

Why use stable isotope analysis to study animal diet?

Direct Observation

- Pros: detailed data, dietary information for individuals
- Cons: time- and cost-intensive, difficult for some species



Why use stable isotope analysis to study animal diet?

Gut Content Analysis

- Pros – can be high-resolution, dietary information for individuals
- Cons – invasive, only a snapshot of diet, biased

Fecal Analysis

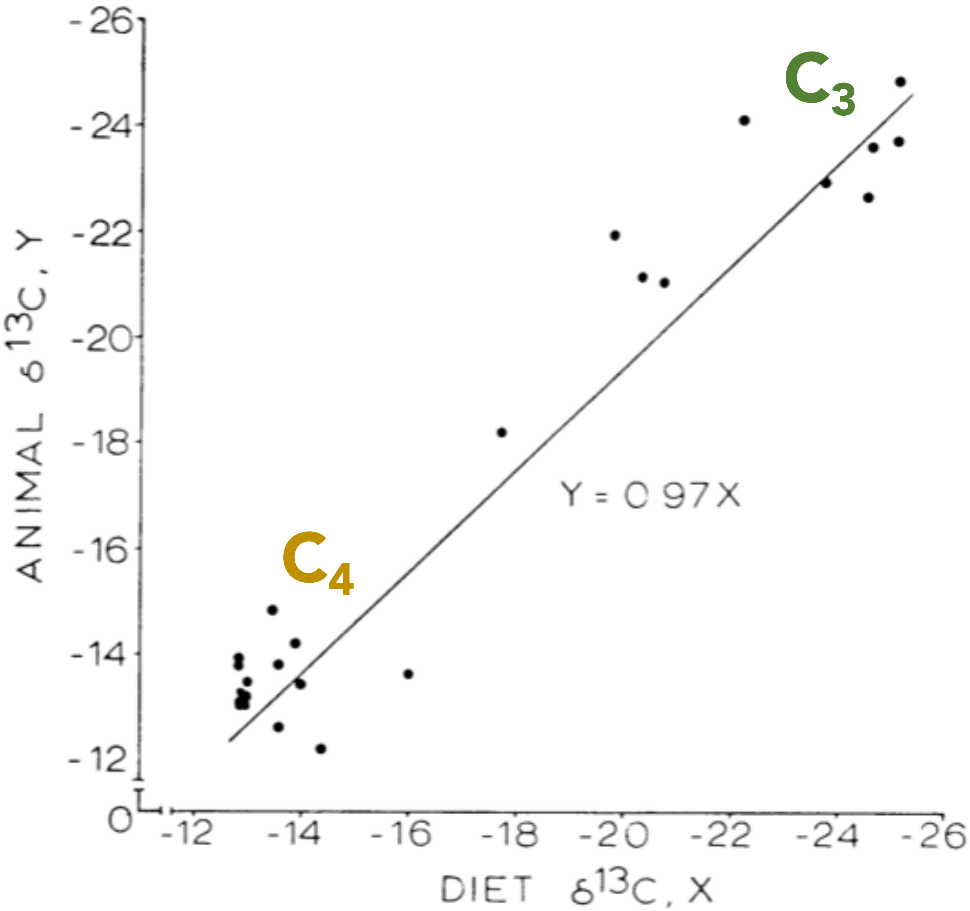
- Pros – can be high-resolution
- Cons – only a snapshot of diet, biased, no individual information

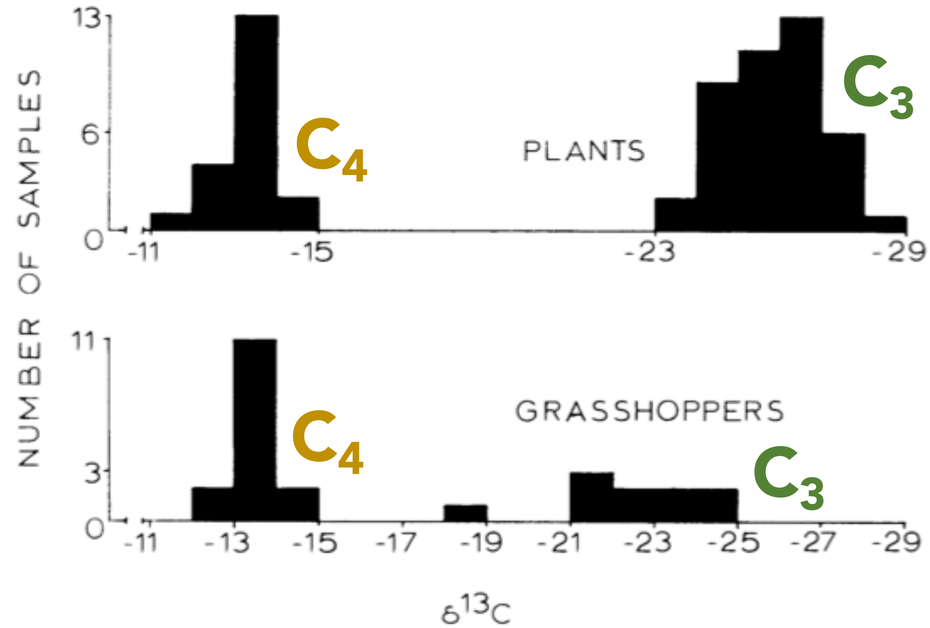
Why use stable isotope analysis to study animal diet?

Chemistry (Stable Isotope Analysis!)

- Pros – *assimilated* diet, integrates over a variety of timescales, can be non-invasive
- Cons – lower resolution

$\delta^{13}C$ values of C_3 vs C_4 consumers

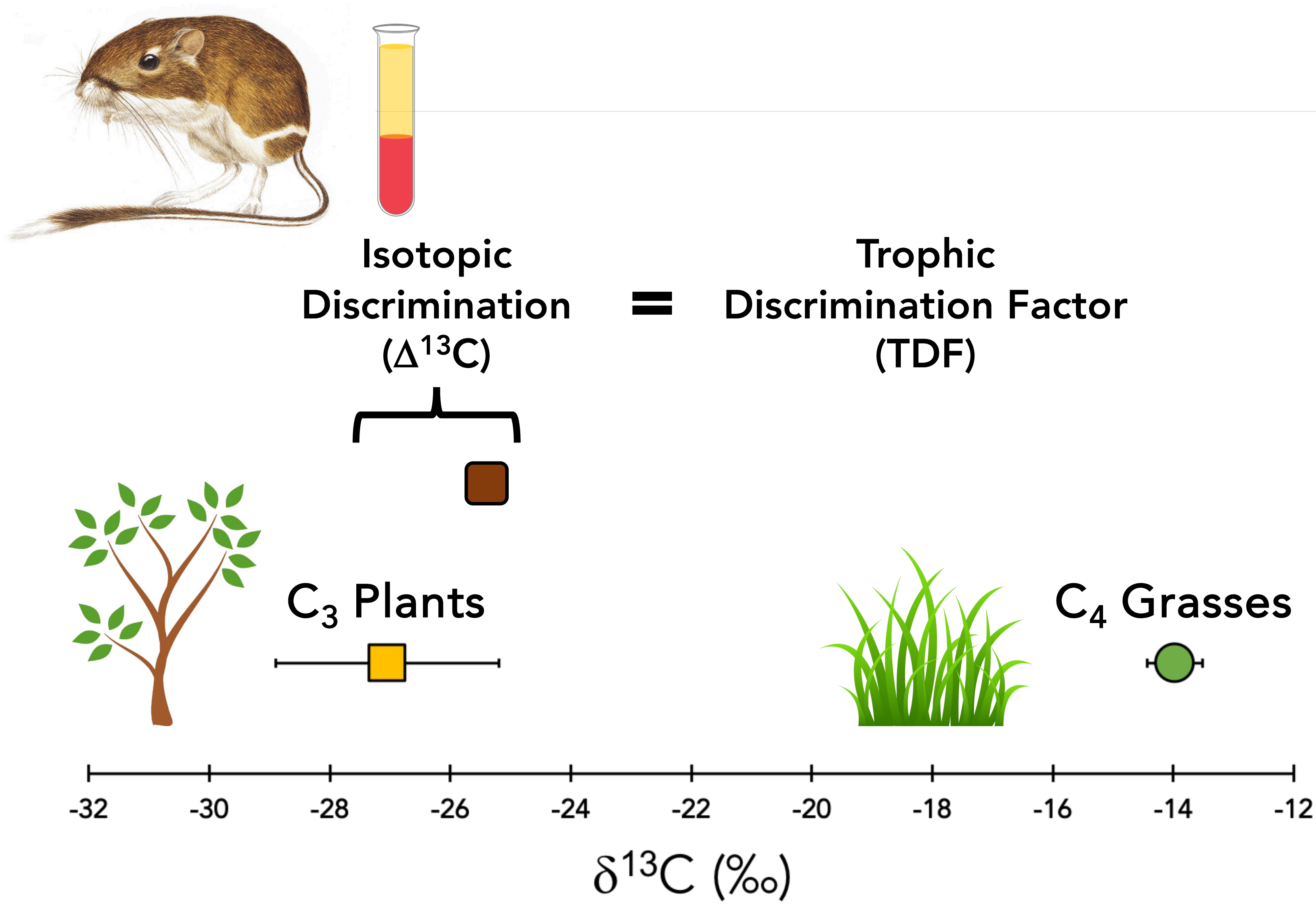




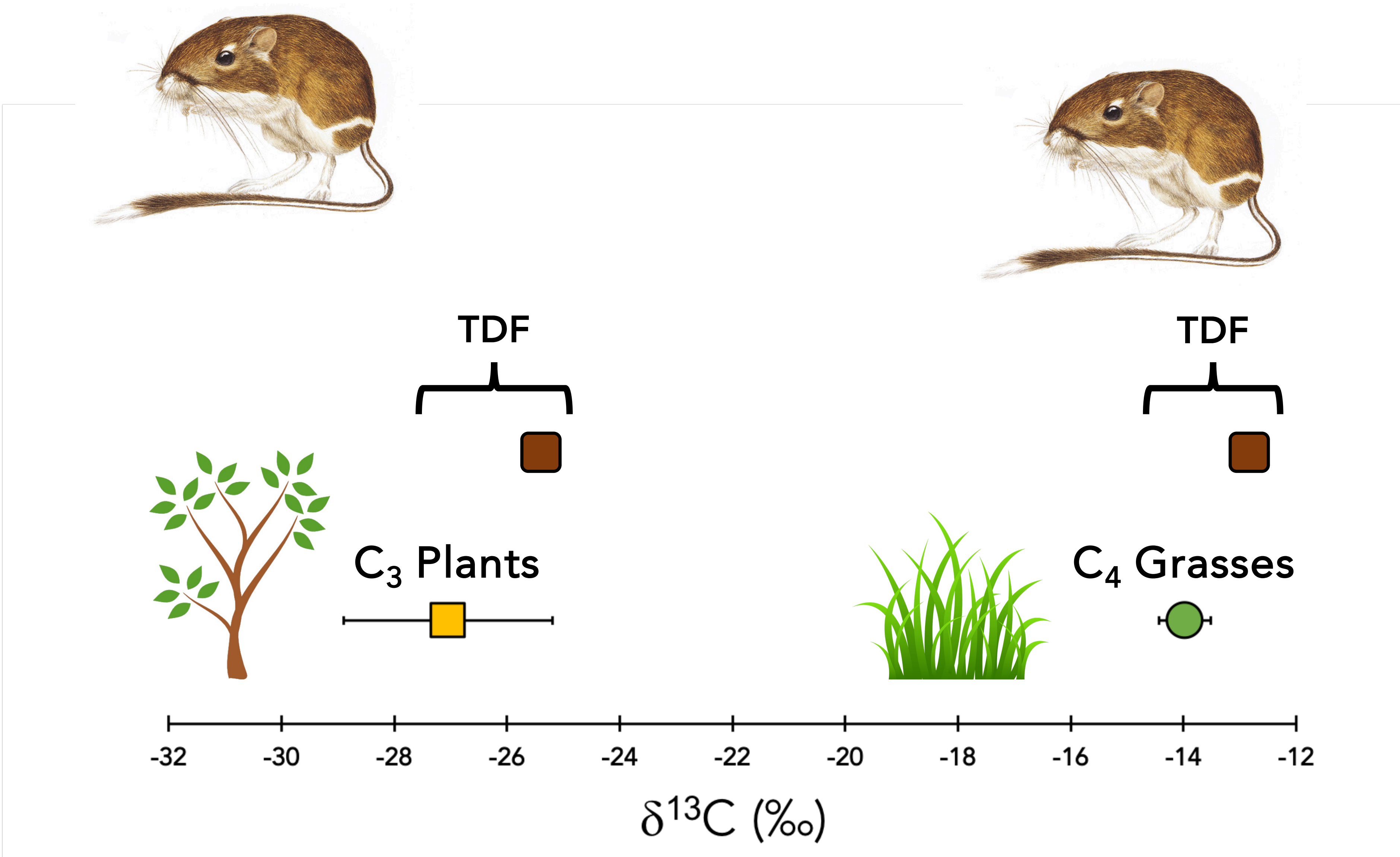
Fry et al. 1978

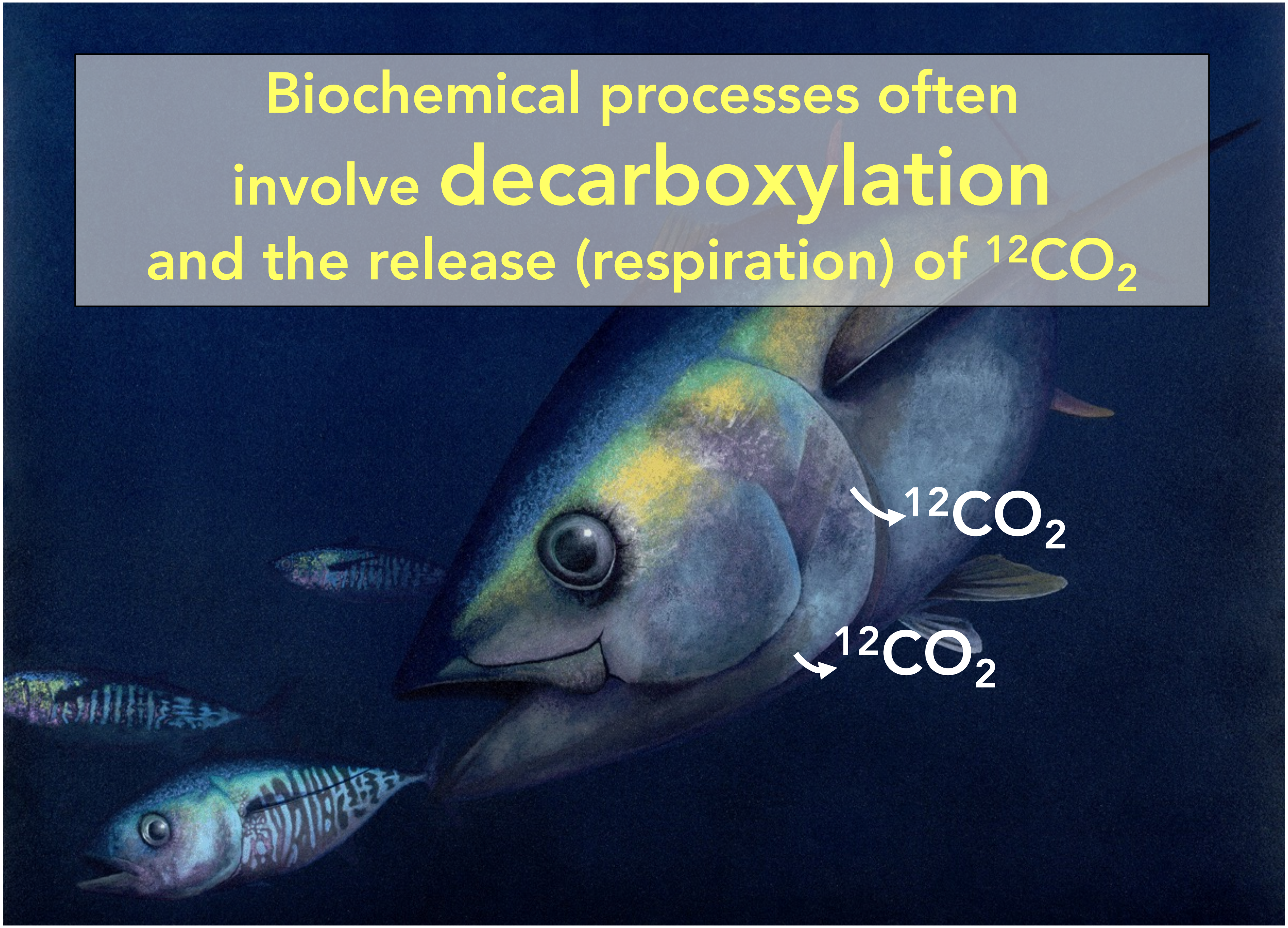

You are what you eat….

...sort of.


Isotopic
Discrimination
(Δ13C)
=
Trophic
Discrimination Factor
(TDF)
C3 Plants
C4 Grasses
-32
-30
-28
-26
-24
-22
-20
-18
-16
-14
-12
δ13C (‰)

Where is the fractionation?

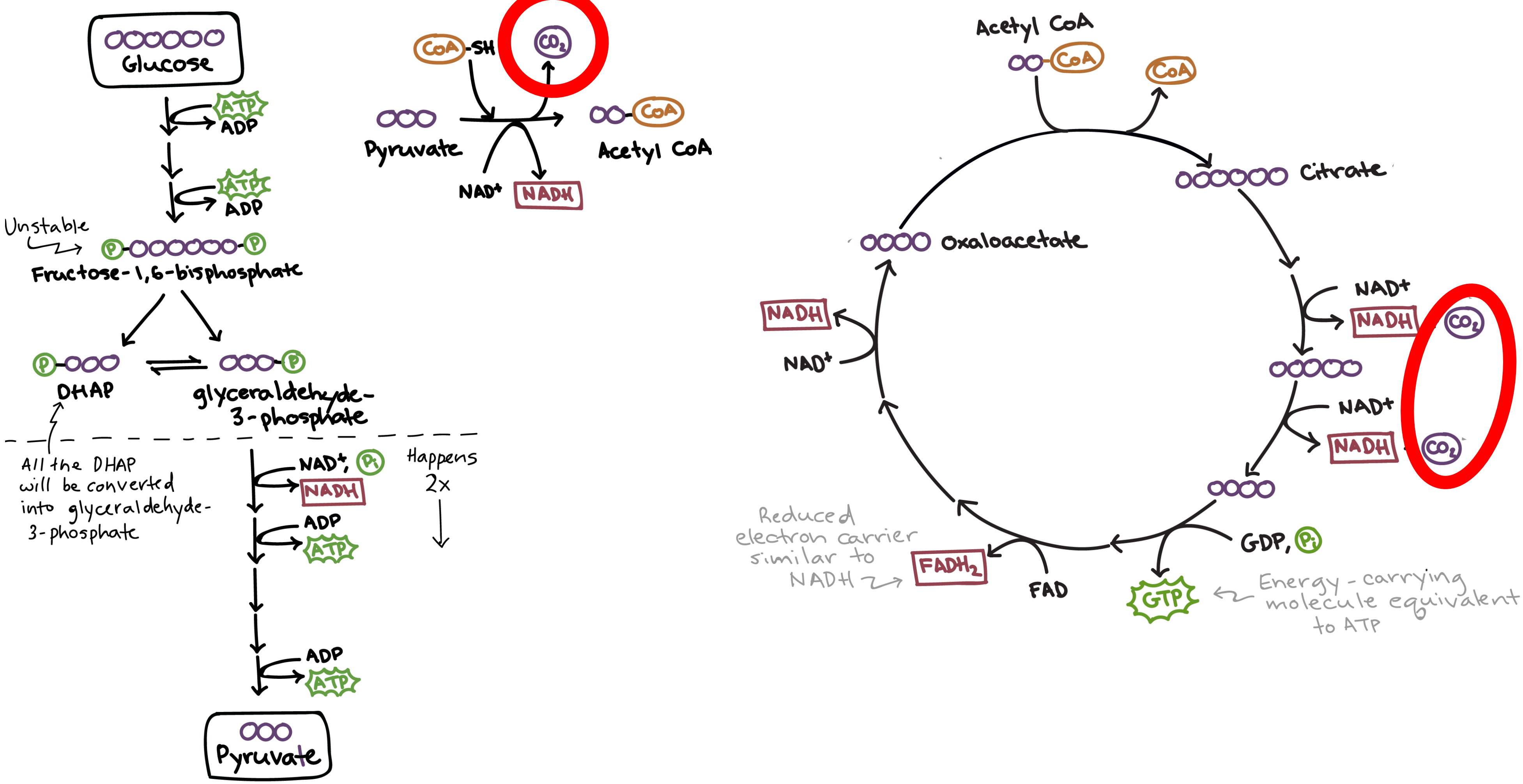




$\delta^{13}C_{Prey}$ = -16‰ ⟵ $\Delta^{13}C$ ⟶ $\delta^{13}C_{Tuna}$ = -15‰

Cellular Respiration

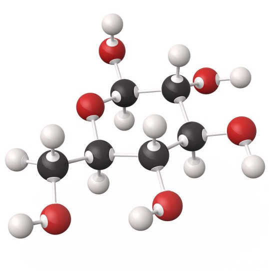
Glycolysis → Pyruvate Oxidation → Citric Acid Cycle

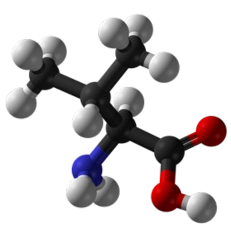


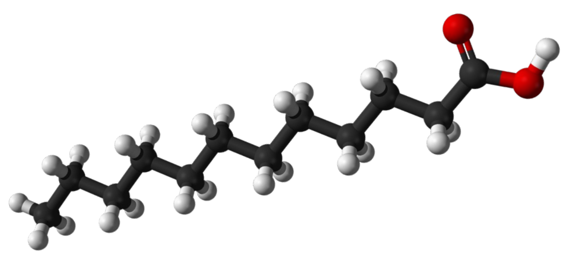
$C_6H_{12}O_6 + 6O_2$ -> $6CO_2 + 6H_2O$ + energy

I’m going to use some of the carbon from this lizard to grow big and strong and I will burn the rest for energy so I can catch more lizards!

Heterotrophs use **multiple macromolecular sources of carbon** for metabolism (energy) and growth/tissue synthesis.







Speedy McRoadrunner
Interview by Dr. Besser

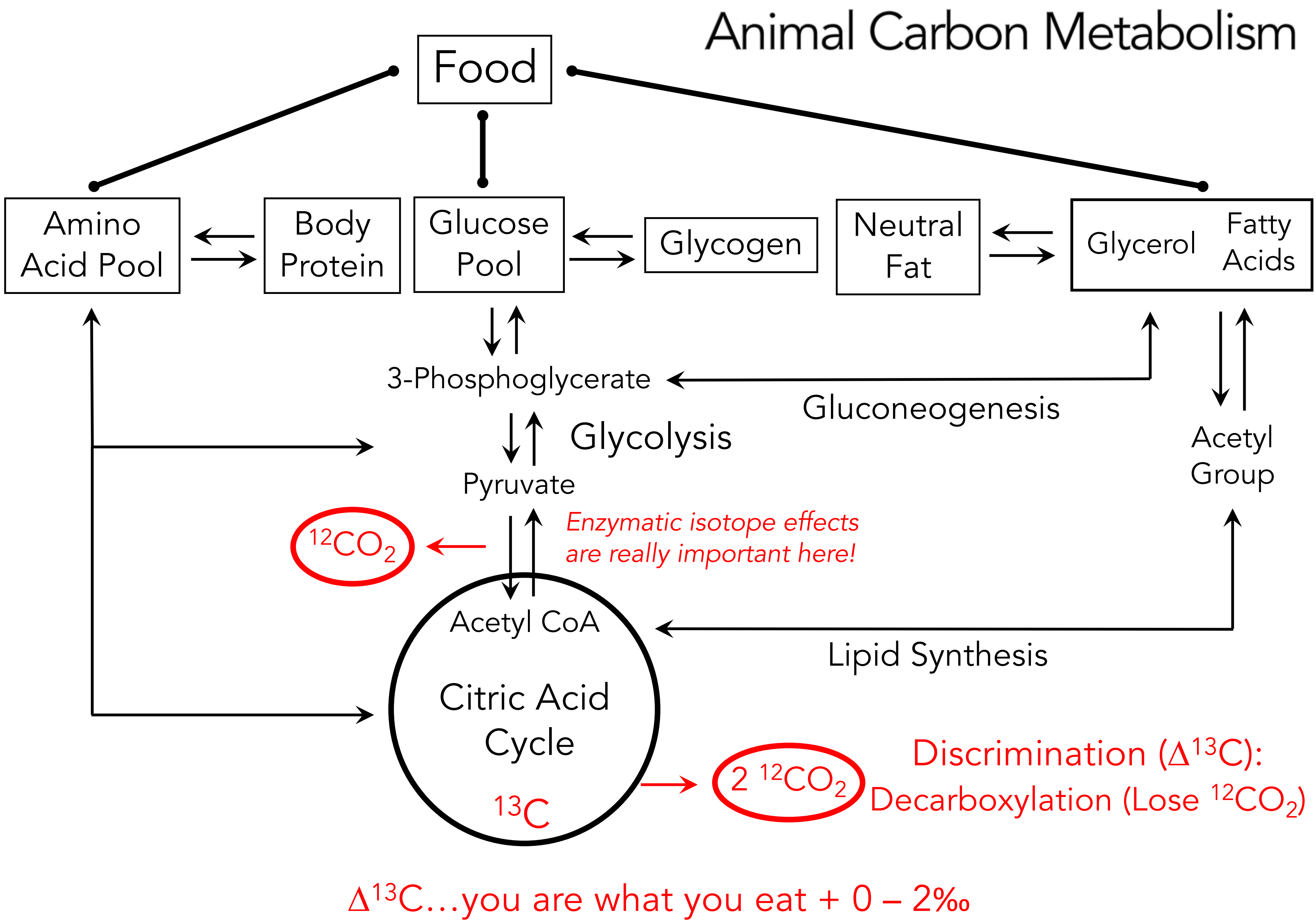
Plants and animals are made of different macromolecules

Average Animal or Bacteria

Protein	Lipids	Carbs

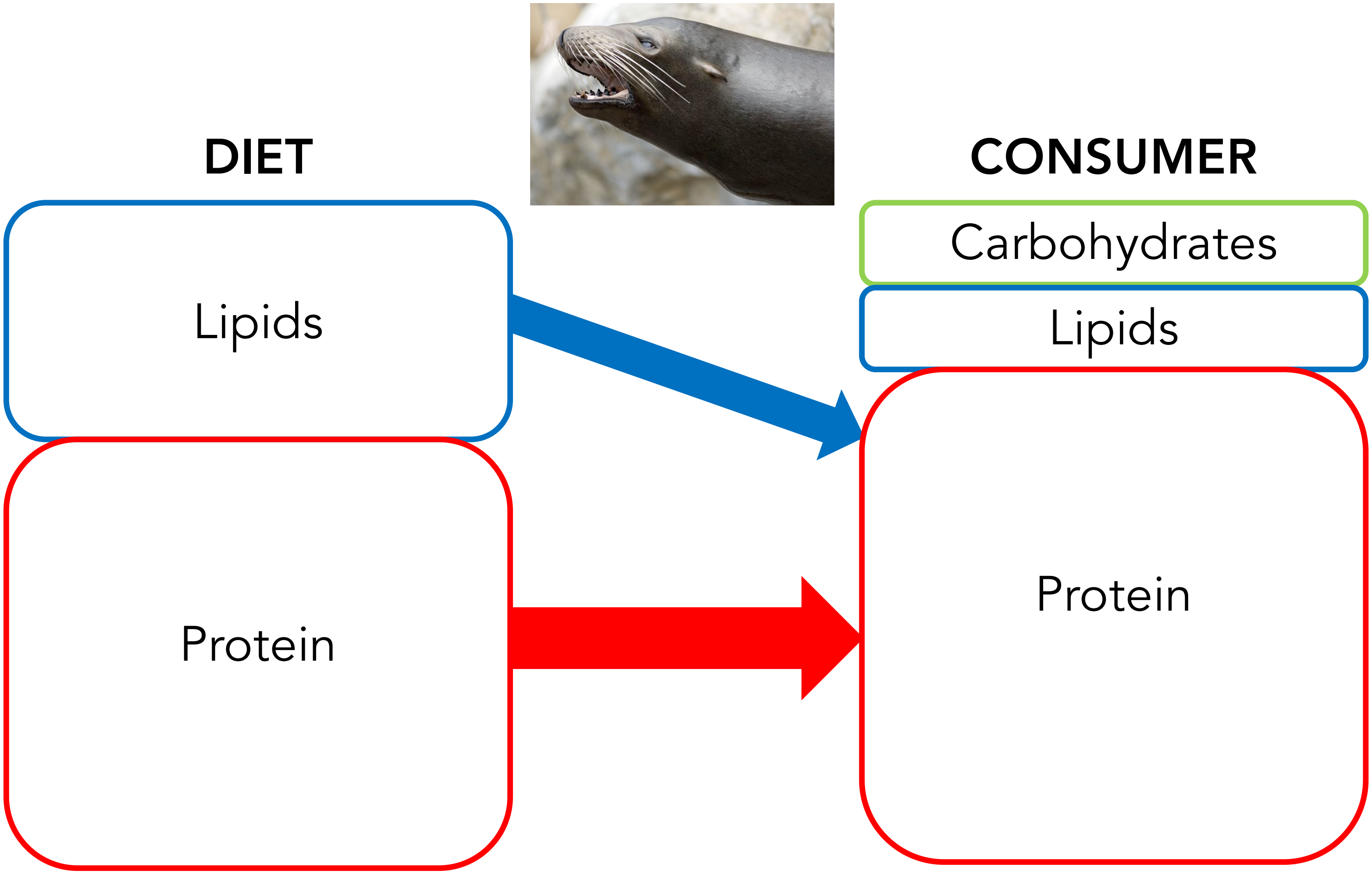
Average Plant or Protist

Carbohydrates	Lipids	Protein



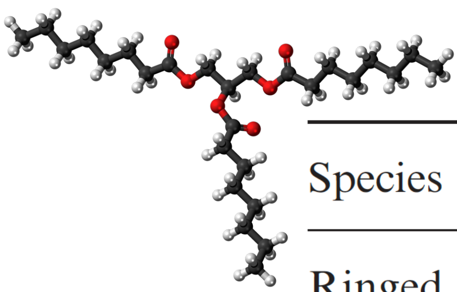
Animal Carbon Metabolism
Food
Amino Acid Pool
Body Protein
Glucose Pool
Glycogen
Neutral Fat
Glycerol
Fatty Acids
3-Phosphoglycerate
Gluconeogenesis
Glycolysis
Acetyl Group
Pyruvate
$^{12}CO_2$
Enzymatic isotope effects are really important here!
Acetyl CoA
Citric Acid Cycle
^{13}C
Lipid Synthesis
2 $^{12}CO_2$
Discrimination ($\Delta^{13}C$):
Decarboxylation (Lose $^{12}CO_2$)
$\Delta^{13}C$…you are what you eat + 0 – 2‰

Relative Supply vs. Demand

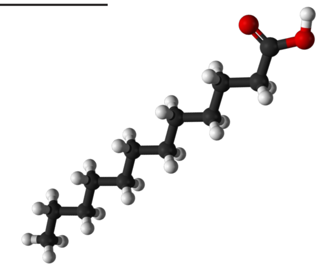


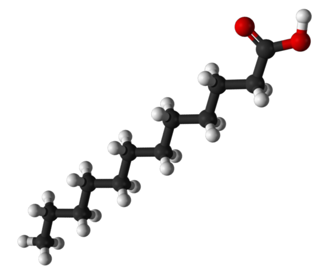
MARINE CARNIVORE

Lipid $\delta^{13}C$ values are ~6‰ lower than protein $\delta^{13}C$ values!



Species	Tissue	*n*	Mean $\delta^{13}C$ (‰) ±SE
Ringed seal	Muscle	45	−20·6 ± 0·1
	Blubber	34	−27·0 ± 0·1
Bearded seal	Muscle	10	−17·8 ± 0·4
	Blubber	7	−25·5 ± 0·5
Beluga whale	Muscle	11	−18·1 ± 0·1
	Blubber	10	−24·4 ± 0·1
Bowhead whale	Muscle	3	−19·2 ± 0·2
	Blubber	3	−26·1 ± 0·6
Polar bear (male)	Whole blood	21	−19·3 ± 0·1
	Adipose	21	−25·7 ± 0·1
Polar bear (female)	Whole blood	26	−19·6 ± 0·1
	Adipose	26	−26·2 ± 0·1



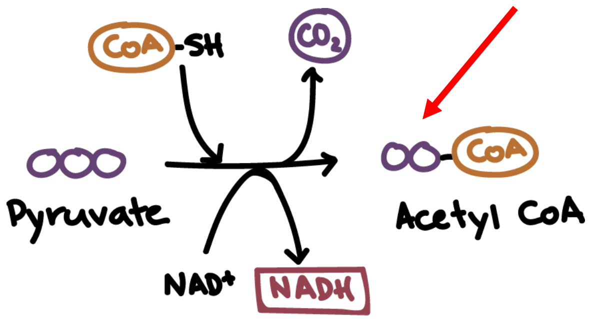


If we didn't extract the lipids from fatty consumer tissues, our dietary estimates could be way off.

Cherry et al. 2011

Isotopic fractionation during lipid synthesis

main source of carbon for lipid biosynthesis

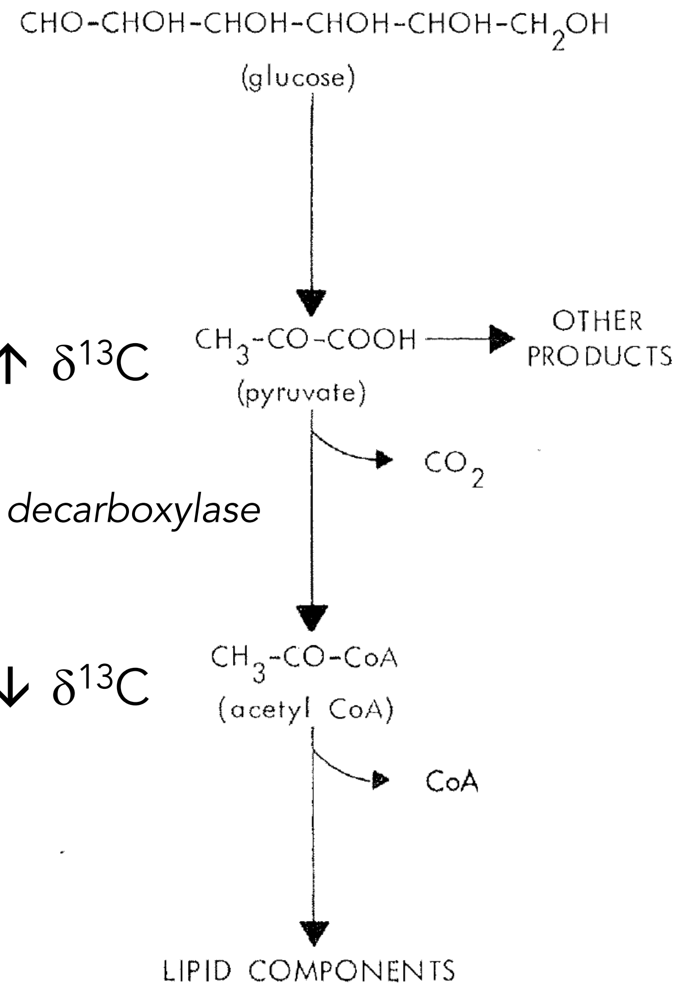


Carbon source	$\delta^{13}C$ (per mil)	
	Carbon source	Lipid
Glucose	−9.5	−15.7
		−16.3
Sodium pyruvate	−20.5	−28.9
		−28.9
Sodium acetate	−20.1	−21.5
		−20.7

↑ $\delta^{13}C$

pyruvate decarboxylase

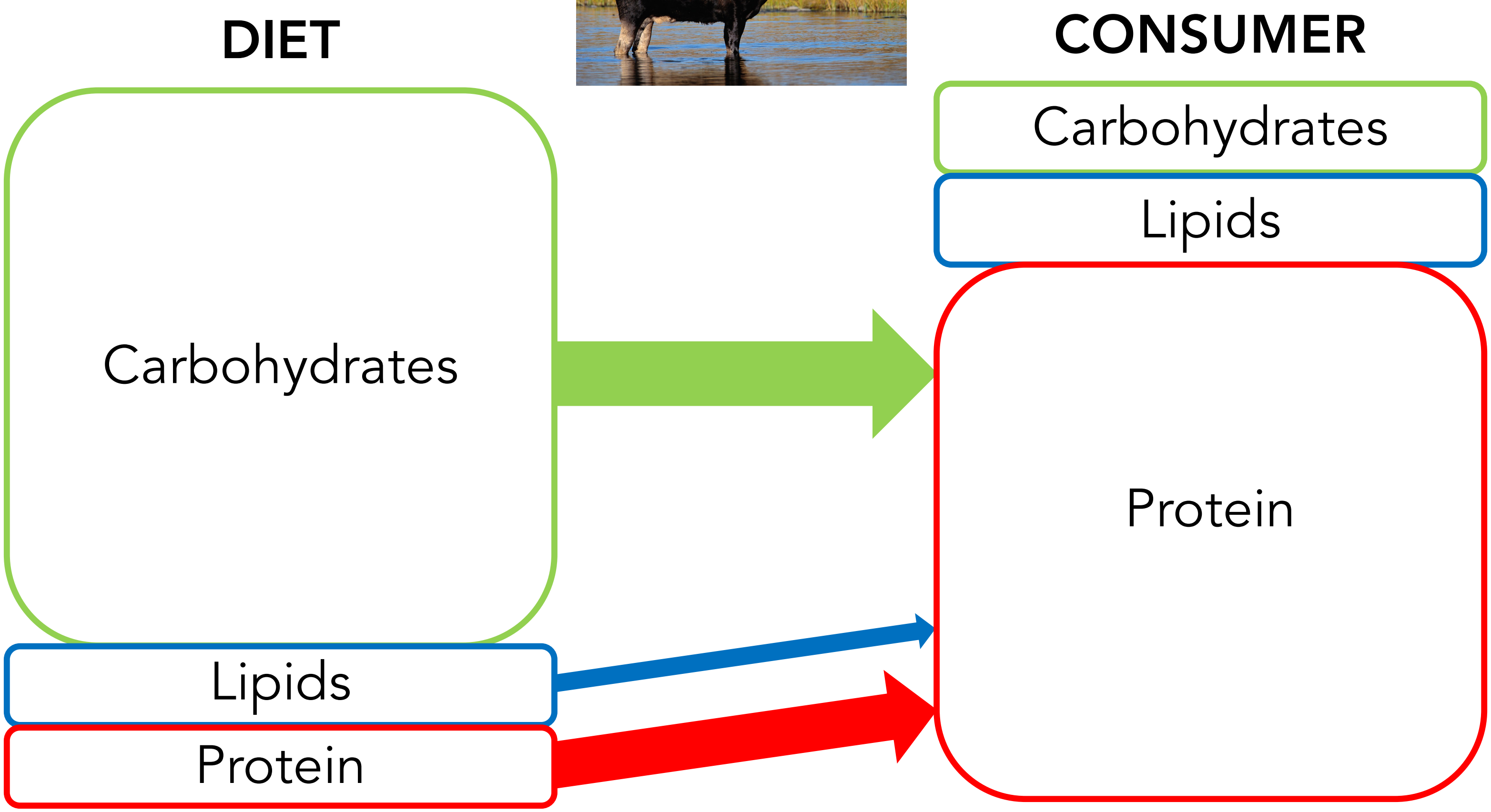
↓ $\delta^{13}C$



Decarboxylation = losing a CO_2 molecule

DeNiro and Epstein 1977

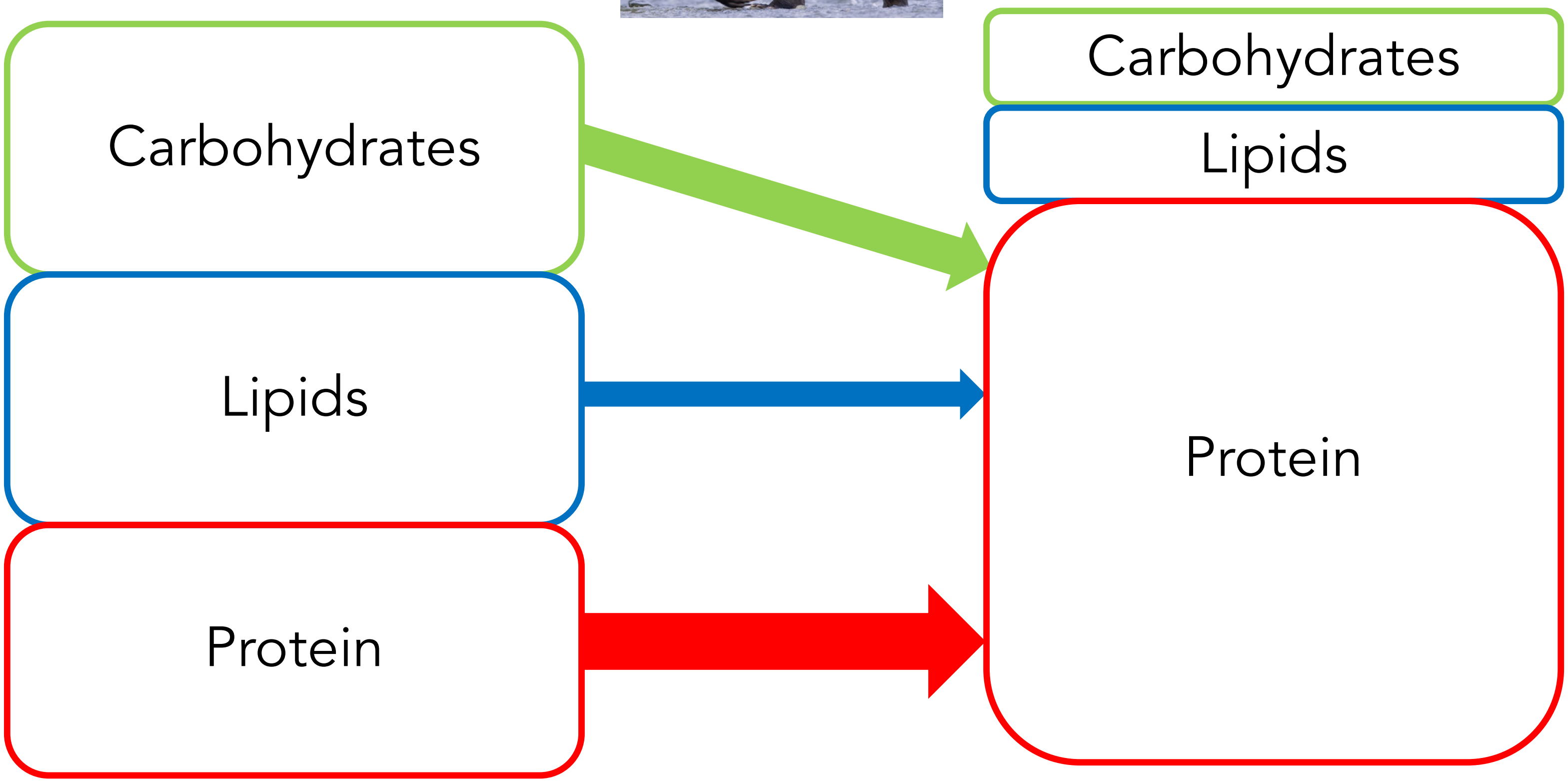
Relative Supply vs. Demand



HERBIVORE

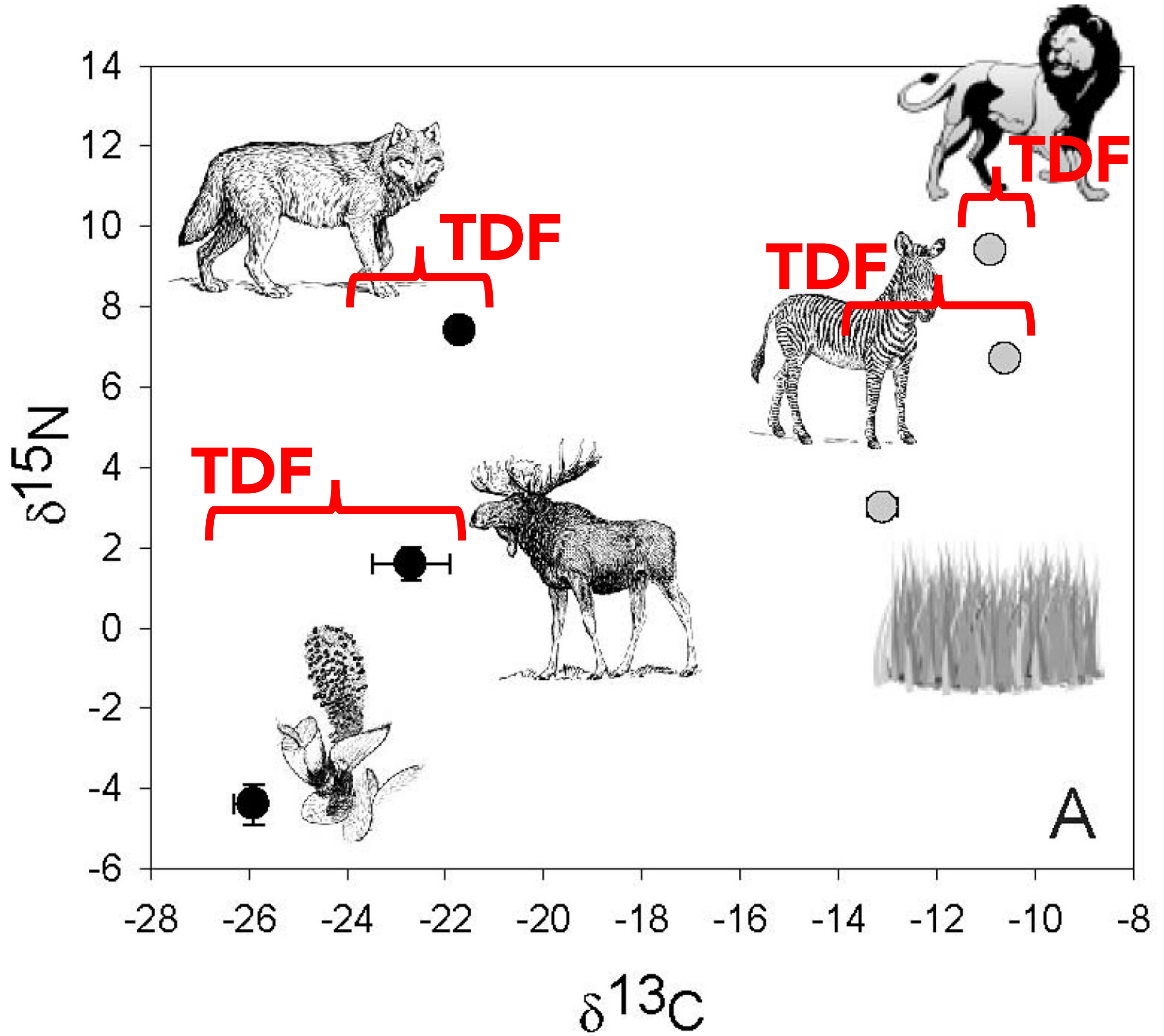
Relative Supply vs. Demand

DIET **CONSUMER**



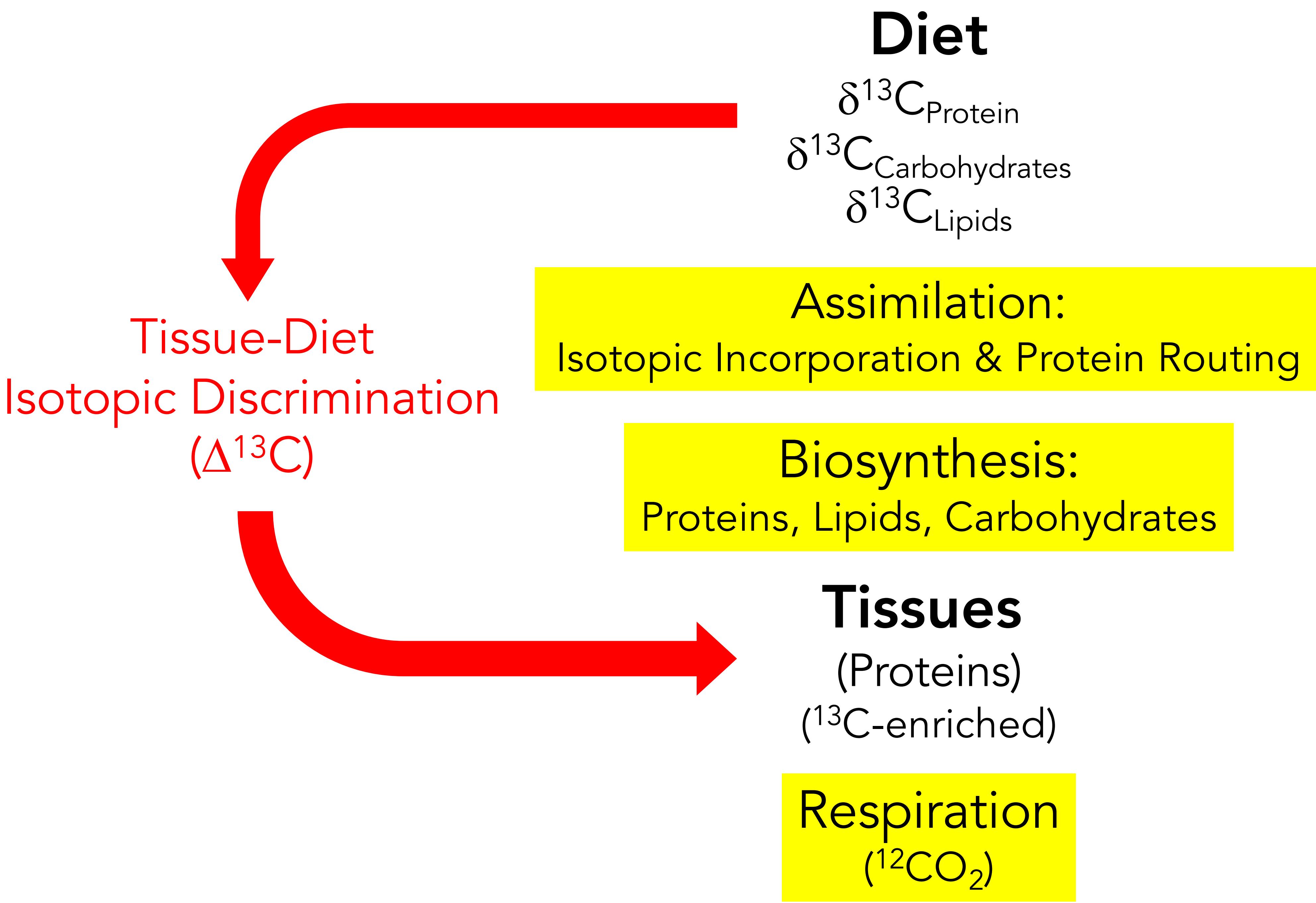
OMNIVORE

Okay… back to trophic discrimination factors ($\Delta^{13}C$)

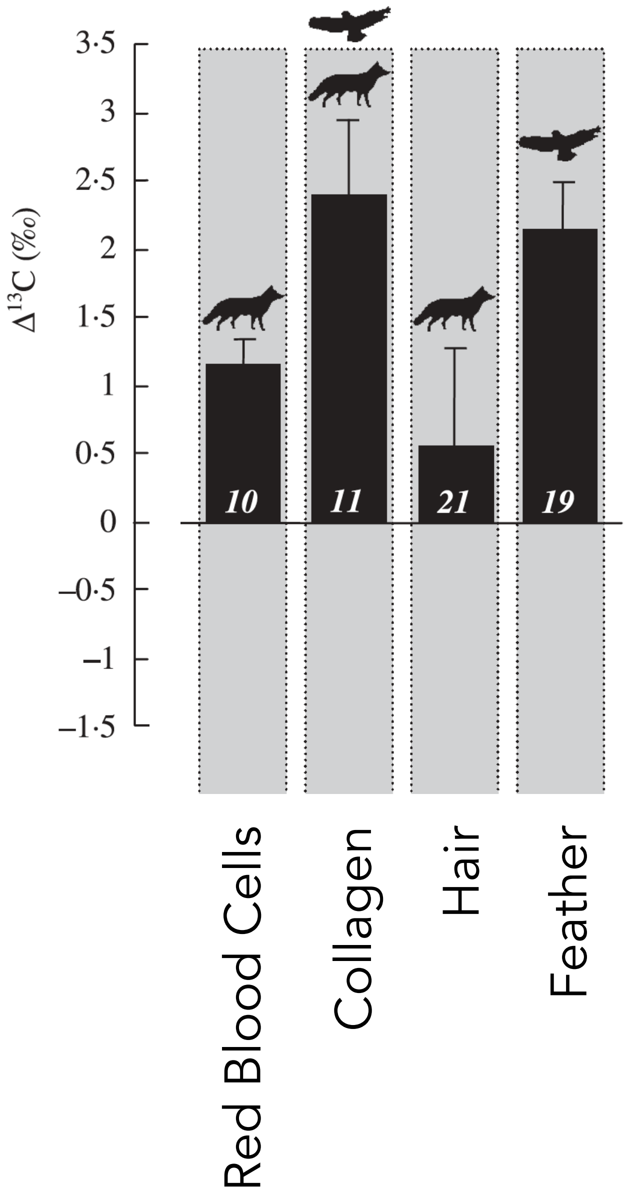


$\Delta^{13}C$ varies from ~0.5 – 4.0‰!

Ben-David and Flaherty 2012


Diet
$\delta^{13}C_{Protein}$
$\delta^{13}C_{Carbohydrates}$
$\delta^{13}C_{Lipids}$
Tissue-Diet
Isotopic Discrimination
($\Delta^{13}C$)
Assimilation:
Isotopic Incorporation & Protein Routing
Biosynthesis:
Proteins, Lipids, Carbohydrates
Tissues
(Proteins)
(^{13}C-enriched)
Respiration
($^{12}CO_2$)

$\delta^{13}C$ Trophic Discrimination Factors ($\Delta^{13}C$)



$\Delta^{13}C$ is typically positive

This means the $\delta^{13}C$ values of an animal's tissues are typically slightly higher than the $\delta^{13}C$ values of its dietary items

$\Delta^{13}C$ varies across tissue types

Caut et al. 2009

$\Delta^{13}C$ varies across tissue types

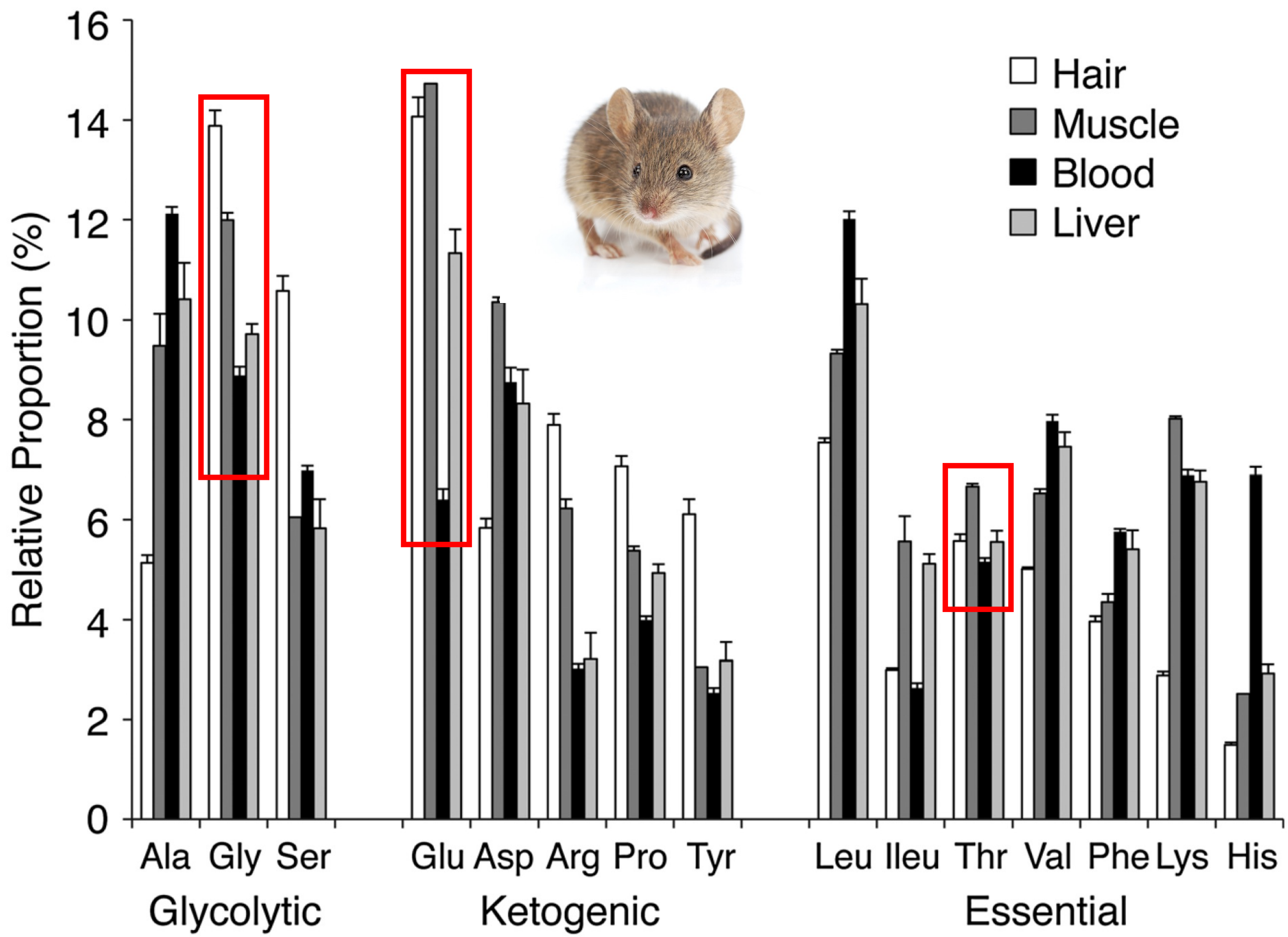
Table 2. Isotope ratios of total protein in diet, bone and muscle of C_3 and C_4 pigs

	Isotopic compositions of controlled-diet pigs			
	$\delta^{13}C$	$\Delta^{13}C$	$\delta^{15}N$	$\Delta^{15}N$
C_4 pigs				
Diet	−12·4		+3·2	
Muscle	−11·4	1·0	+5·0	1·8
Collagen	−9·2	3·2	+5·5	2·3
Faeces	−12·8	−0·4	+2·3	−0·9
C_3 pigs				
Diet	−25·3		+1·8	
Muscle	−23·8	1·5	+2·7	0·9
Collagen	−23·9	1·4	+4·0	2·2
Faeces	−25·7	−0·4	+5·1	3·3

$\Delta = \delta$ pig or faeces sample $- \delta$ diet.

Hare et al. 1991

Amino acid concentrations vary across tissue types



Wolf et al. 2015

$\delta^{13}C$ values vary among amino acids

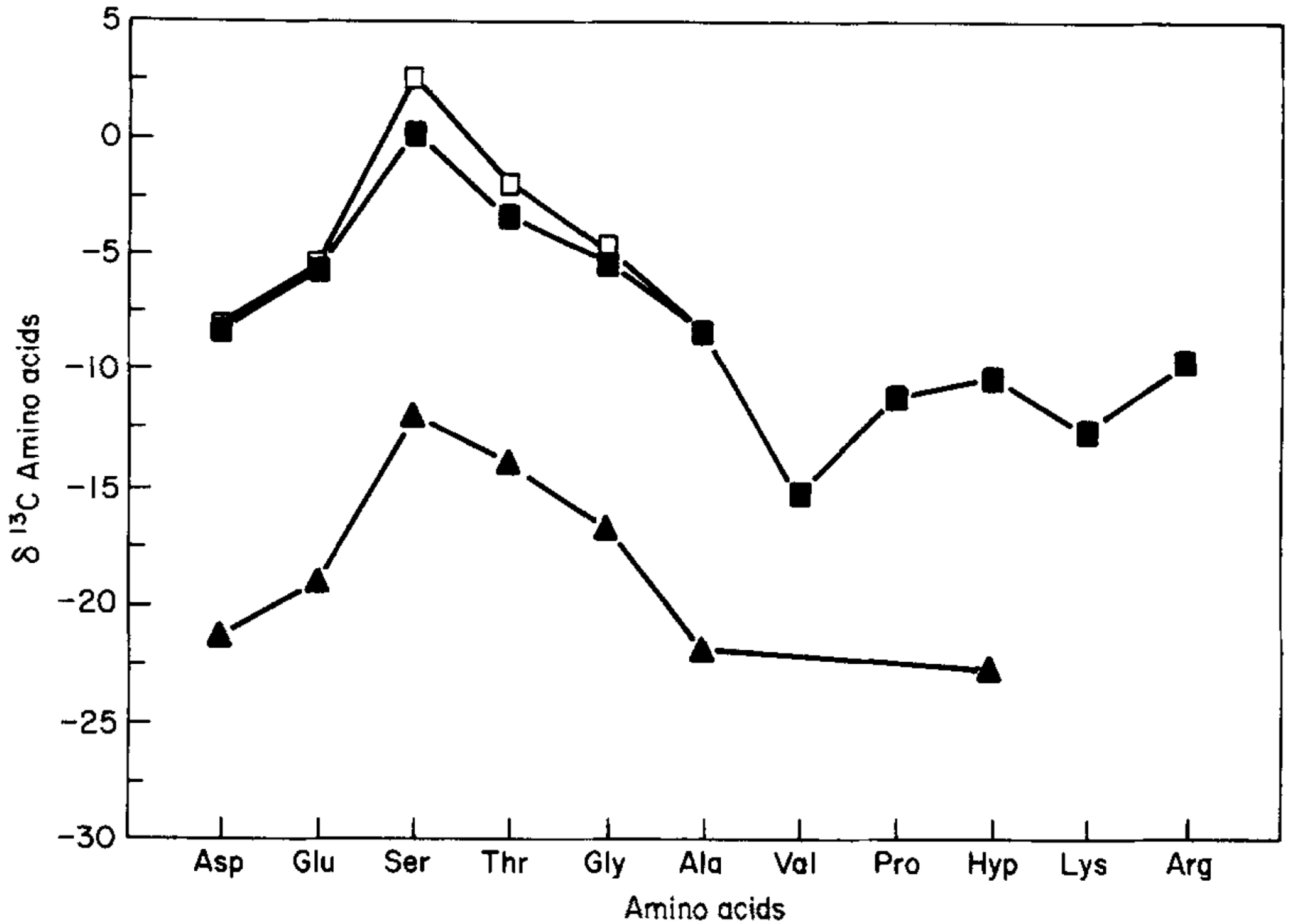
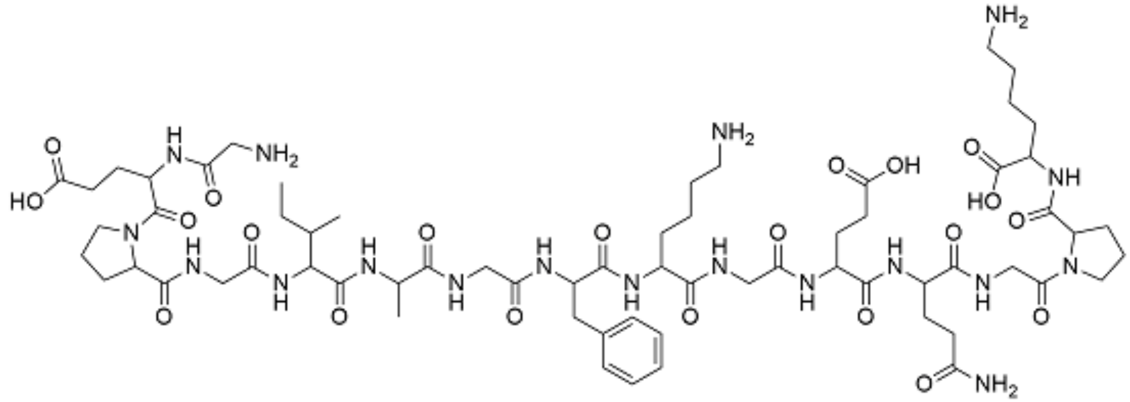


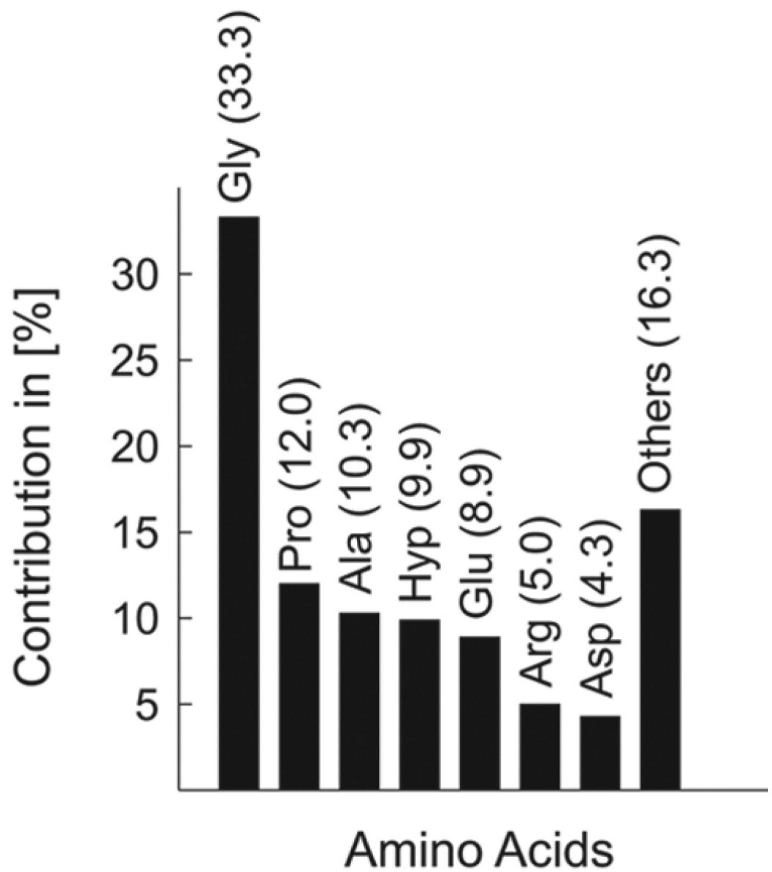
Figure 4. Carbon isotope ratios of individual amino acids separated from bone collagen of C_3 and C_4 pigs. (—□—), C_4 pig no. 1; (—▲—), C_3 pig; (—■—), C_4 pig no. 2.

Additionally, some of these amino acids have different origins (direct routing vs. *de novo* synthesis).

Hare et al. 1991

Collagen contains **a lot** of glycine

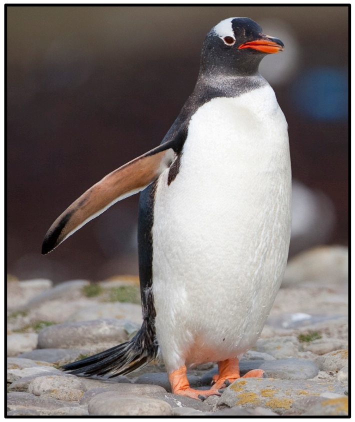




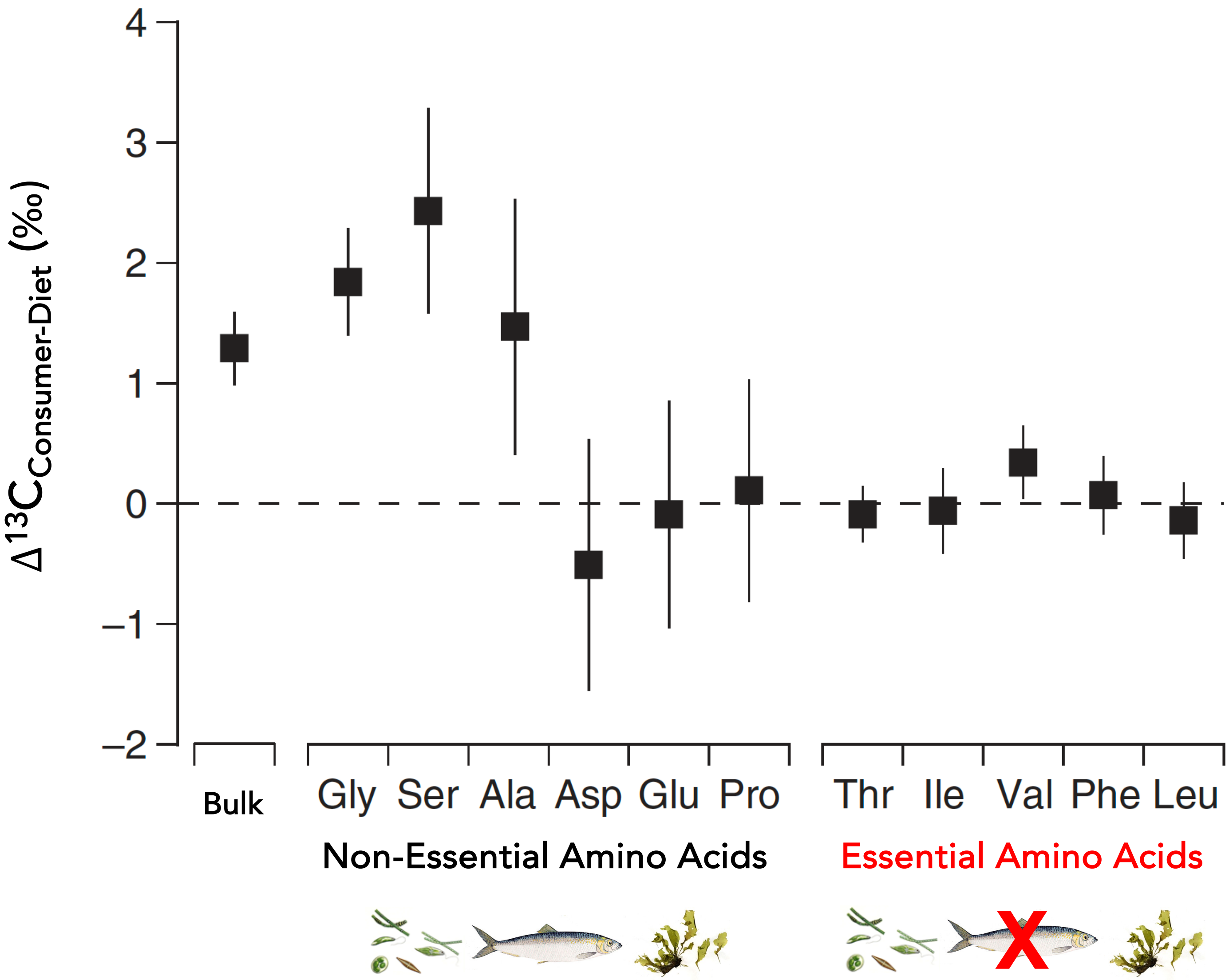
Schiller and Huster 2012

$\Delta^{13}C$ also varies by amino acid

consumer



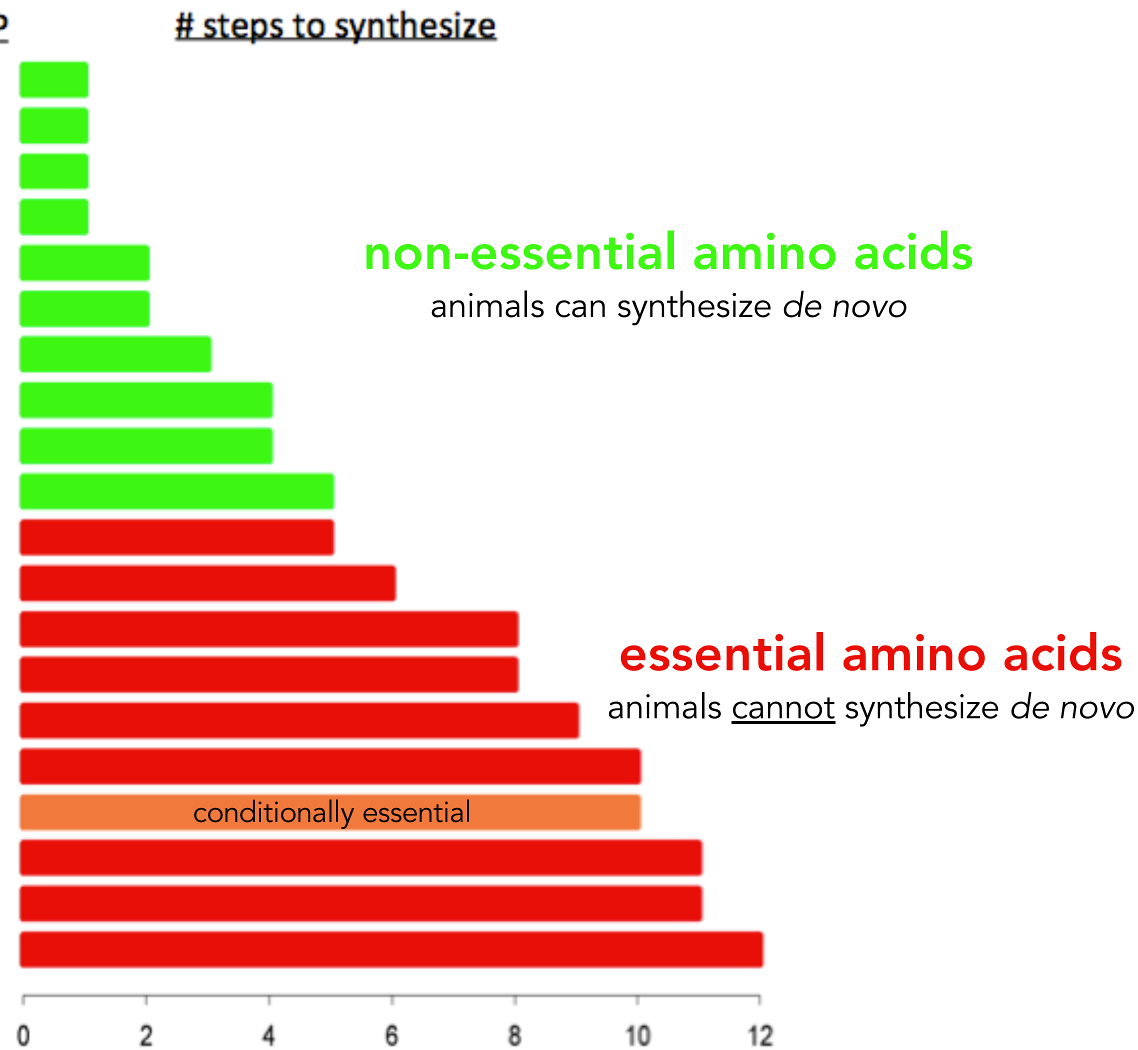
diet



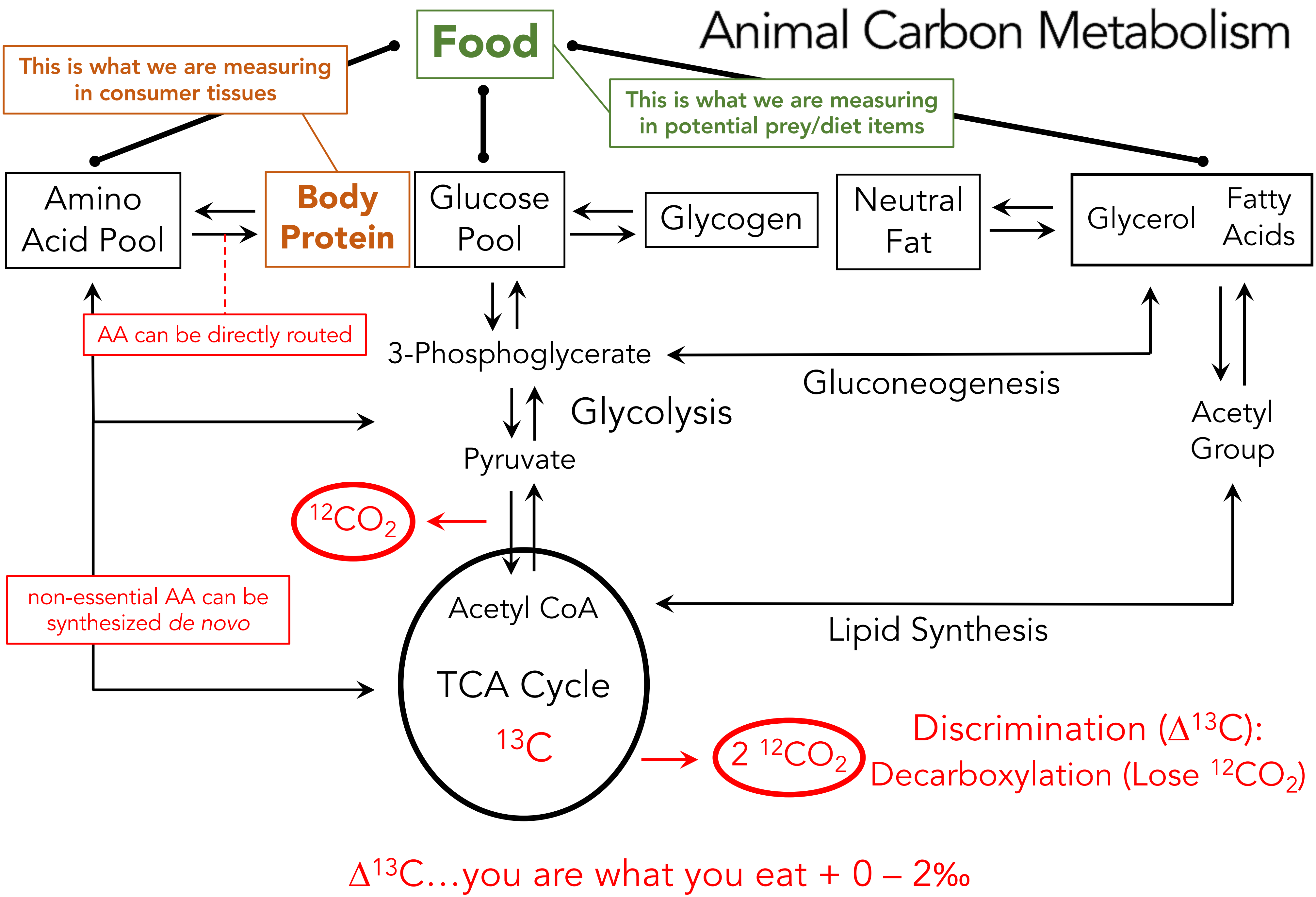
Modified from McMahon et al. 2015

Non-essential amino acids are easier to synthesize, and animals have retained this ability

Amino acid	TYPE	ATP	NADP
Alanine	NE	0	1
Glutamate	NE	0	1
Aspartate	NE	0	1
Tyrosine[1]	NE	0	1
Glutamine	NE	1	1
Asparagine	NE	3	1
Serine	NE	0	1
Glycine	NE	0	1
Proline	NE	1	3
Cysteine[2]	NE	0	1
Valine	E	0	2
Threonine	E	2	3
Leucine	E	0	2
Methionine	E	7	8
Lysine	E	3	4
Phenylalanine	E	1	2
Arginine	E	7	4
Histidine	E	6	1
Isoleucine	E	2	5
Tryptophan	E	5	3

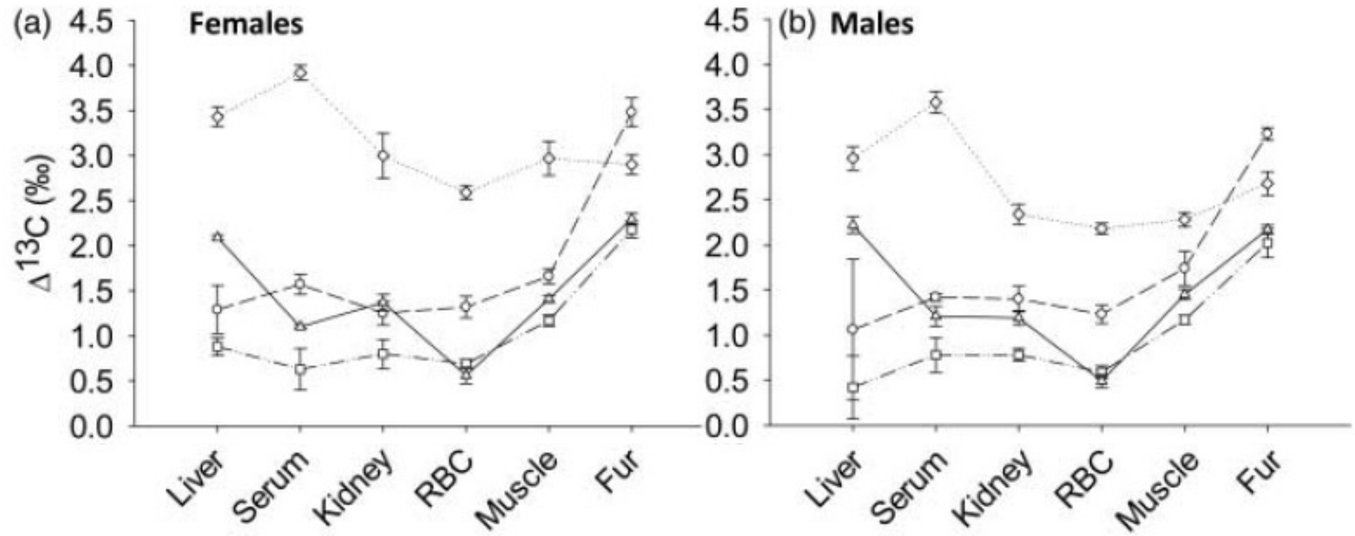


60–72% of amino acids in animal tissues are non-essential



Animal Carbon Metabolism
Food
This is what we are measuring in consumer tissues
This is what we are measuring in potential prey/diet items
Amino Acid Pool
Body Protein
Glucose Pool
Glycogen
Neutral Fat
Glycerol
Fatty Acids
AA can be directly routed
3-Phosphoglycerate
Gluconeogenesis
Glycolysis
Pyruvate
Acetyl Group
$^{12}CO_2$
non-essential AA can be synthesized *de novo*
Acetyl CoA
TCA Cycle
^{13}C
Lipid Synthesis
$2\ ^{12}CO_2$
Discrimination ($\Delta^{13}C$):
Decarboxylation (Lose $^{12}CO_2$)
$\Delta^{13}C$…you are what you eat + 0 – 2‰

Increased variability in diet macromolecular $\delta^{13}C$ can lead to increased $\Delta^{13}C$

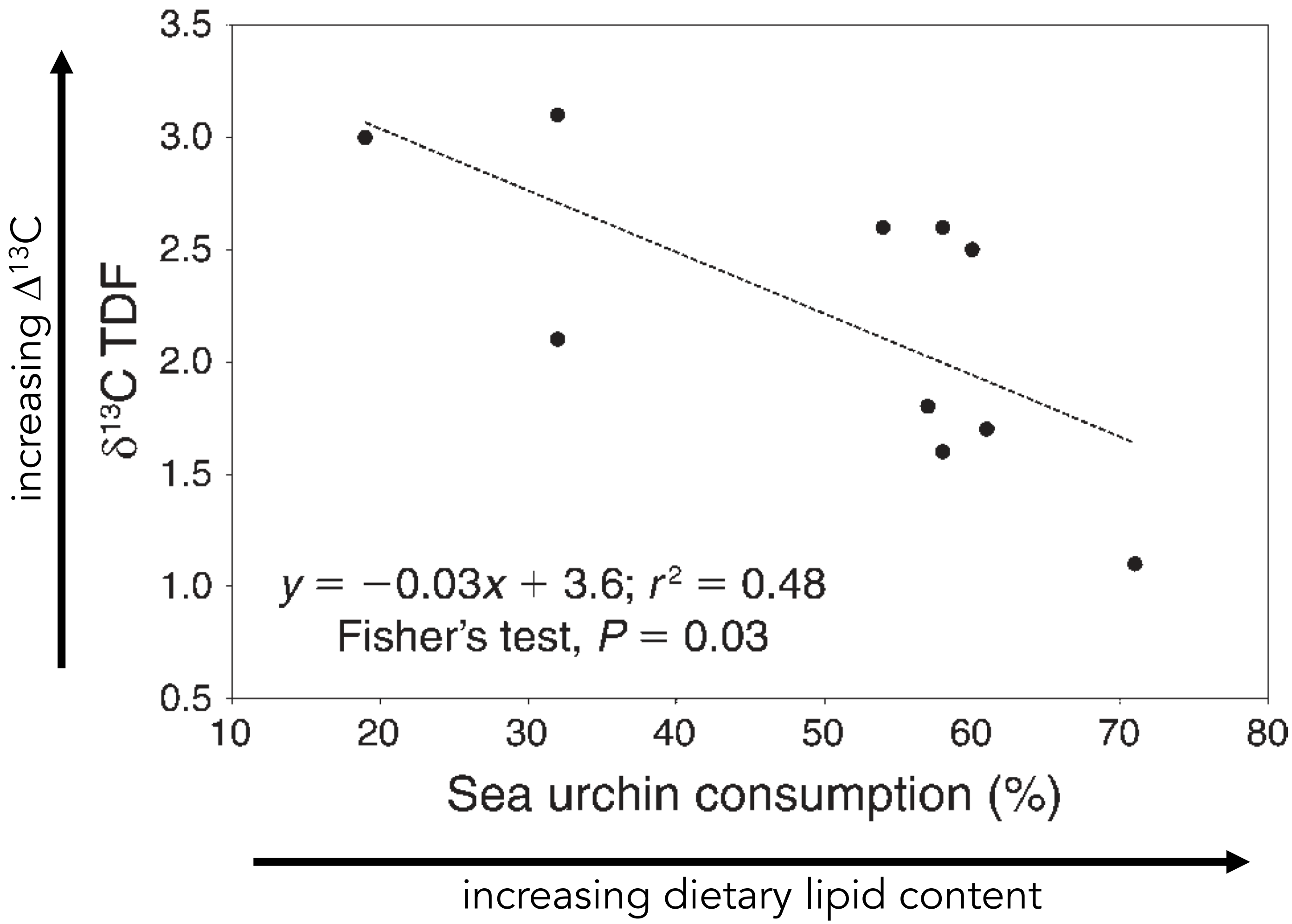


protein digestibility could also impact $\Delta^{13}C$

Kurle et al. 2014

Prey type impacts sea otter whisker $\delta^{13}C$ TDFs

sea urchins have high lipid contents



Newsome et al. 2010

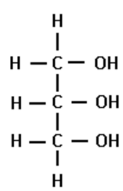
Prey type impacts sea otter whisker δ^{13}C TDFs

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

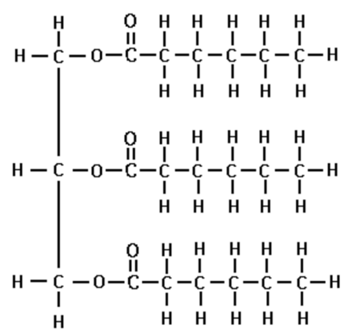
These non-essential amino acids are synthesized from 3-phosphoglycerate.

Food → Dietary Fatty Acids → Glycerol → 3-Phosphoglycerate → Serine → Glycine

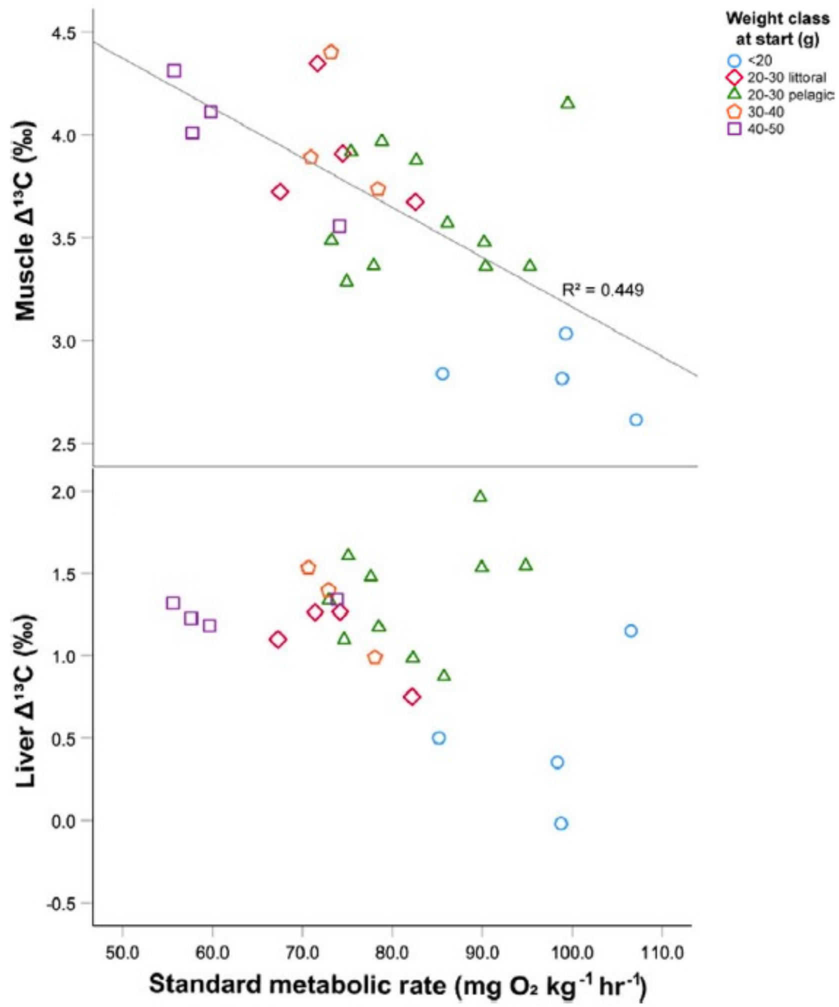
lower δ^{13}C than dietary protein



Glycerol



Rapidly growing animals/tissues are expected to have decreased $\Delta^{13}C$



Scharnweber et al. 2021

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)