Introduction to herbivore digestive physiology

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Wildlife Digestive Physiology Vienna 2013

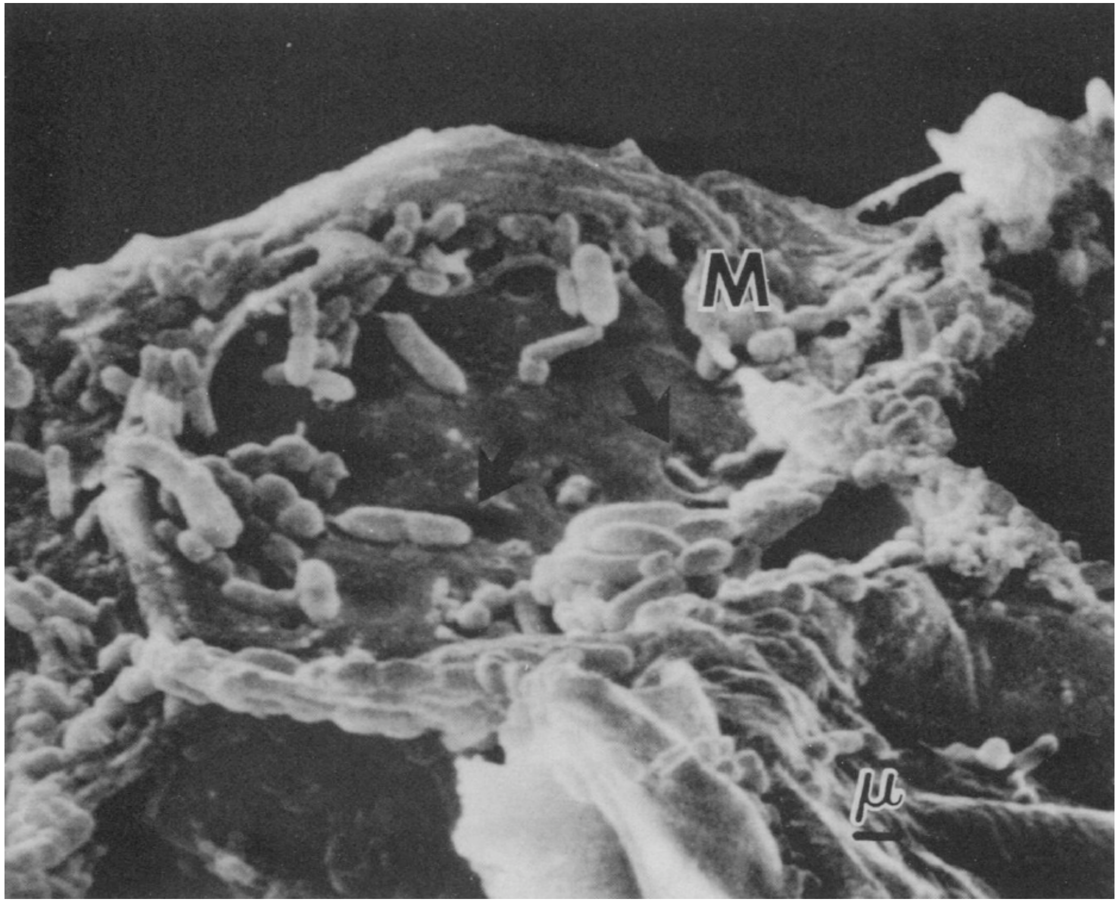
University of Zurich
Vetsuisse Faculty

Clinic
of Zoo Animals, Exotic Pets and Wildlife

A green world

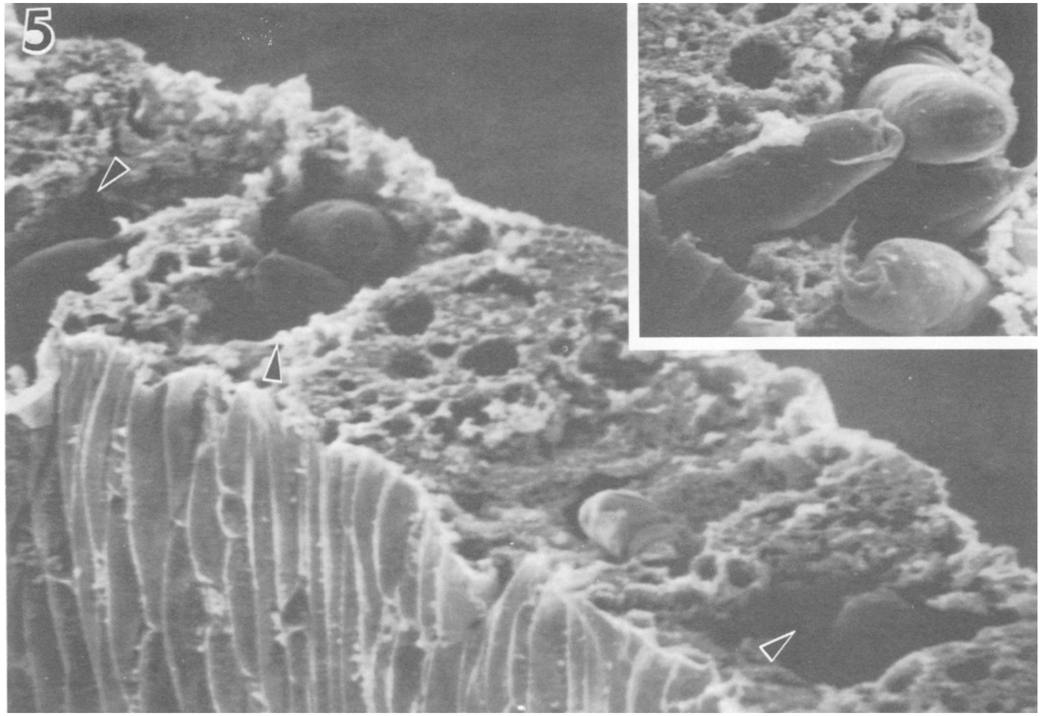
Primary consumers

Primary consumers



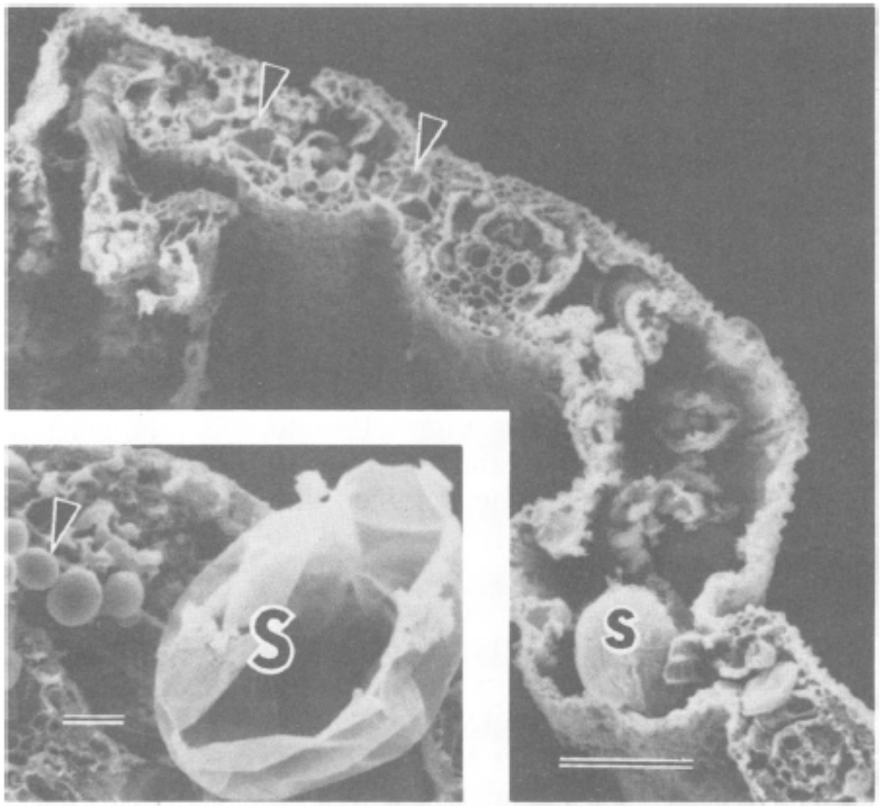
from Akin & Amos (1975)

Primary consumers



from Amos & Akin (1978)

Primary consumers



from Akin & Benner (1988)

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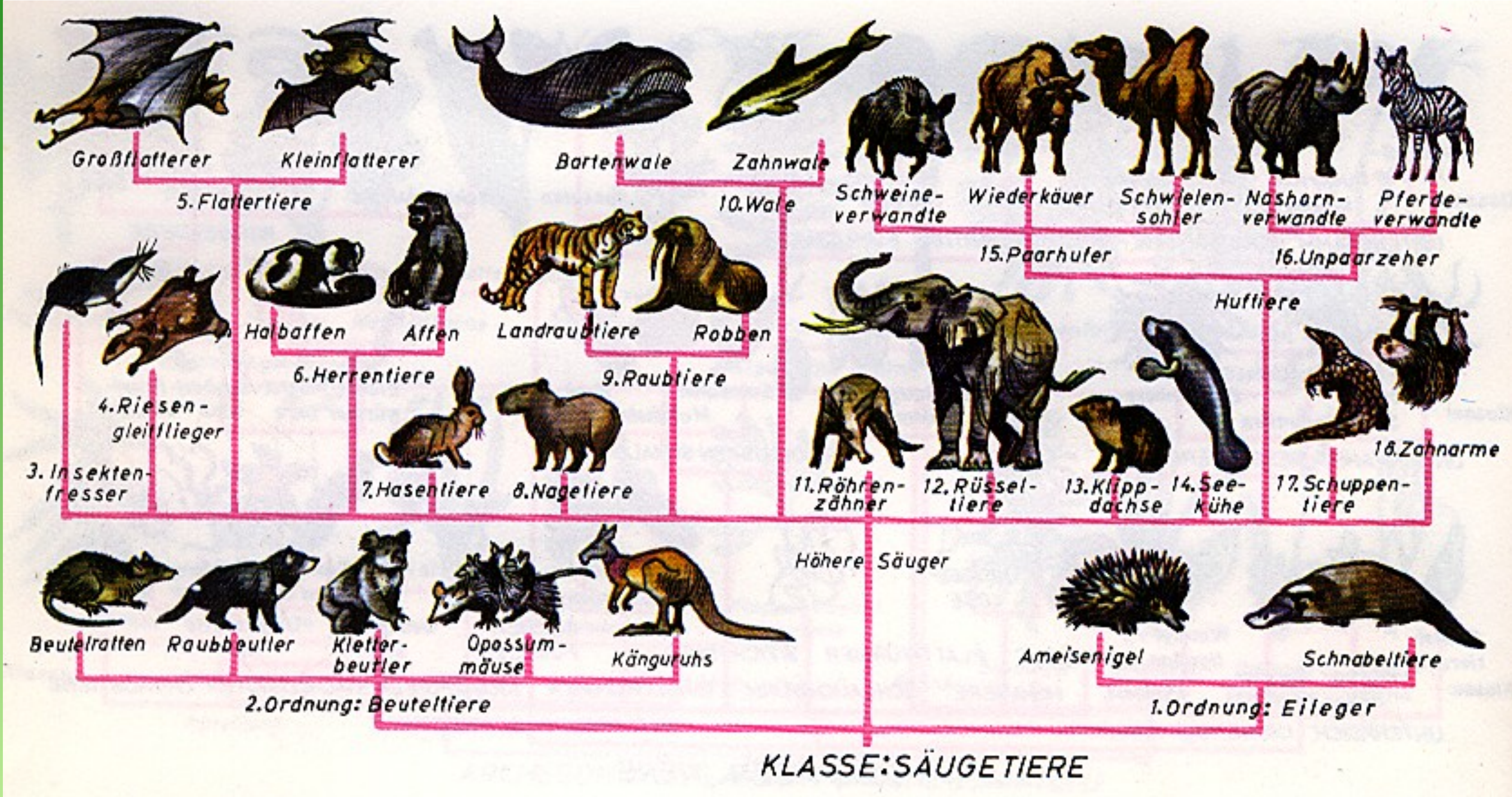
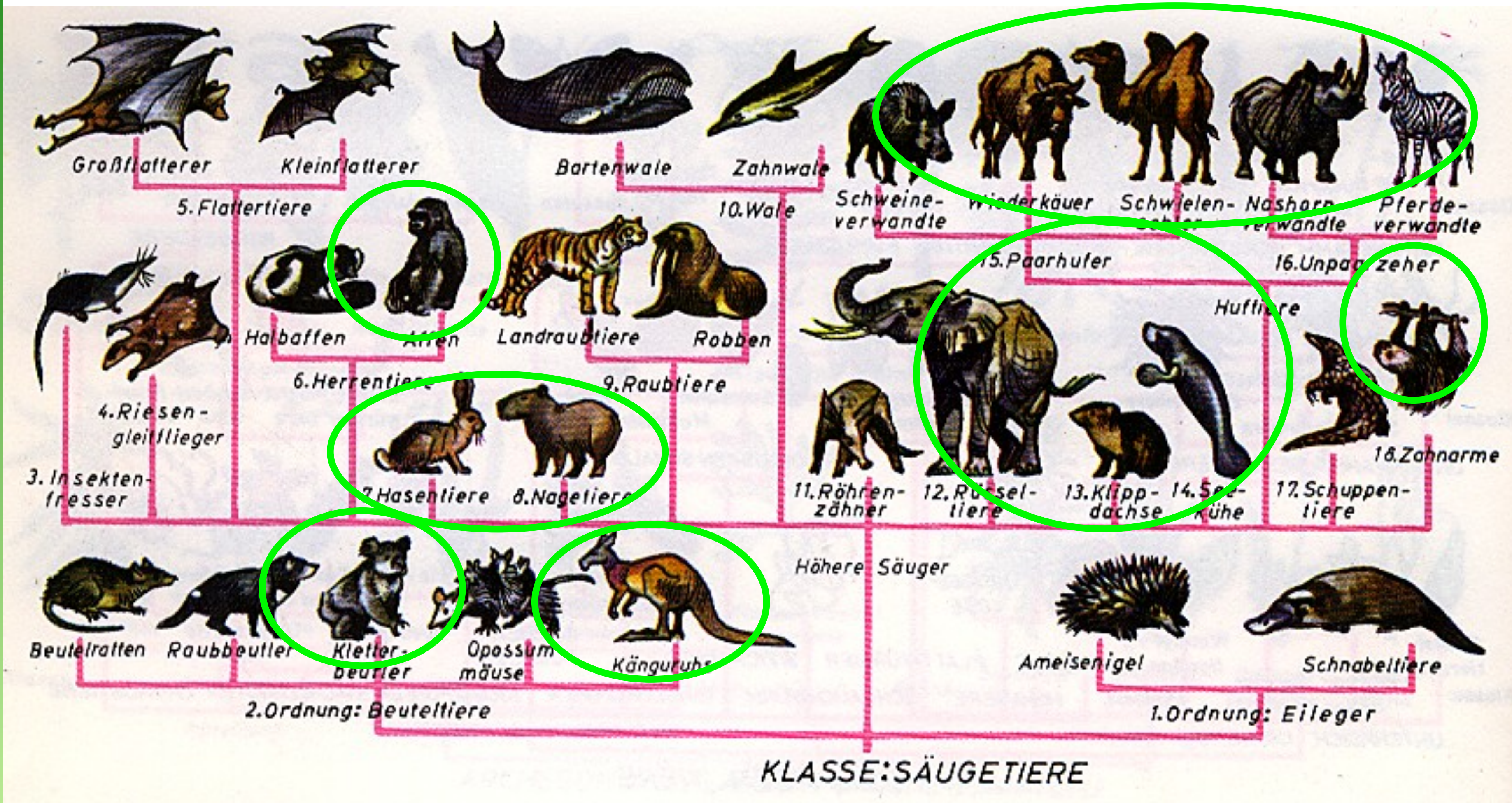
Herbivory


Großflatterer
Kleinflatterer
5. Flattertiere
Bartenwale
Zahnwale
10. Wale
Schweine-verwandte
Wiederkäuer
Schwielen-sohler
Nashorn-verwandte
Pferde-verwandte
15. Paarhufer
16. Unpaarzeher
Huftiere
3. Insekten-fresser
4. Riesen-gleitflieger
Halbaffen
Affen
6. Herrentiere
Landraubtiere
Robben
9. Raubtiere
7. Hasentiere
8. Nagetiere
11. Röhren-zähner
12. Rüssel-tiere
13. Klipp-dachse
14. See-kühe
17. Schuppen-tiere
18. Zahnarme
Höhere Säuger
Beutelratten
Raubbeutler
Kletter-beutler
Opossum-mäuse
Känguruhs
2. Ordnung: Beuteltiere
Ameisenigel
Schnabeltiere
1. Ordnung: Eileger
KLASSE: SÄUGETIERE

Herbivory



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KLASSE: SÄUGETIERE

Herbivory

- Vertebrates cannot digest plant fibre by their own enzymes (aut-enzymatically); they have to rely on symbiotic gut microflora (allo-enzymatic digestion).
- Bacterial digestion = "fermentation"
- The host has to supply this microflora with a habitat (so-called "fermentation chambers").

Carnivory ...

- *... is no physiological challenge*
- *... but a biomechanical and logistical one!*

- ***Digesting prey is easy - catching prey is the hard part!***

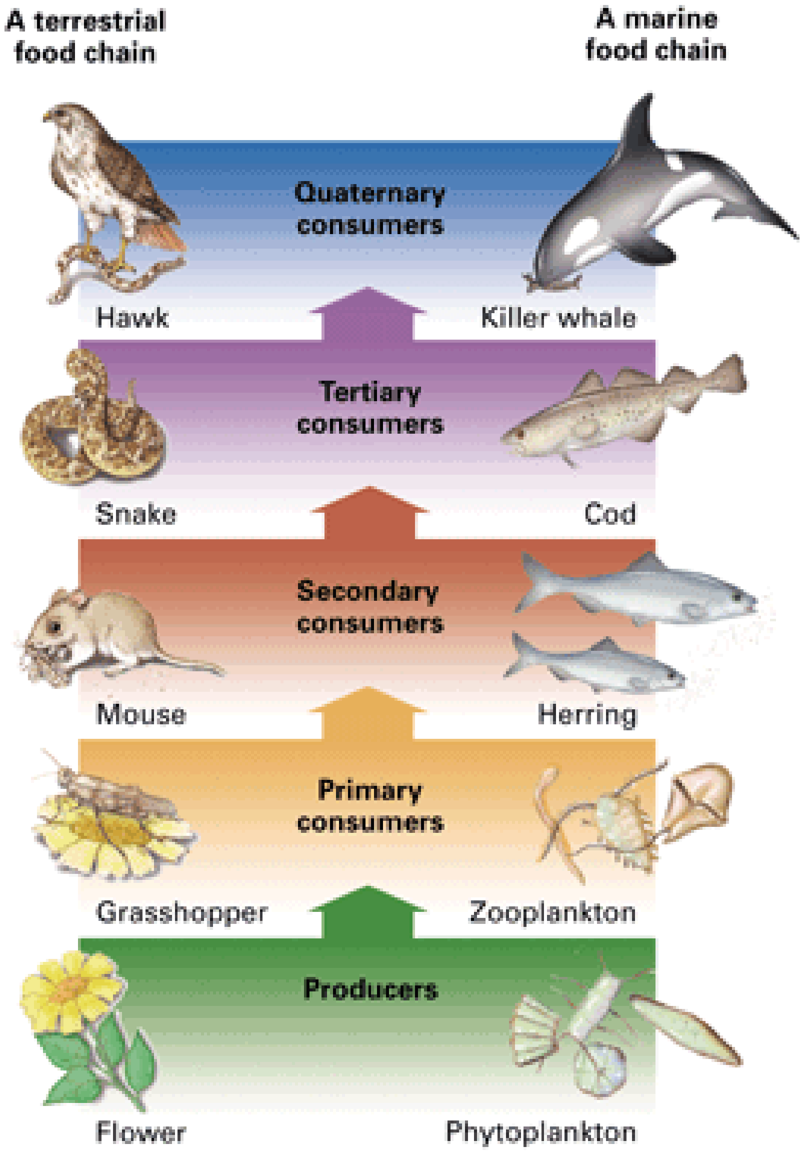
Herbivory ...

- *... is no logistical challenge*
- *... but a digestive one!*

- ***Catching plants is easy - digesting plants is the hard part!***

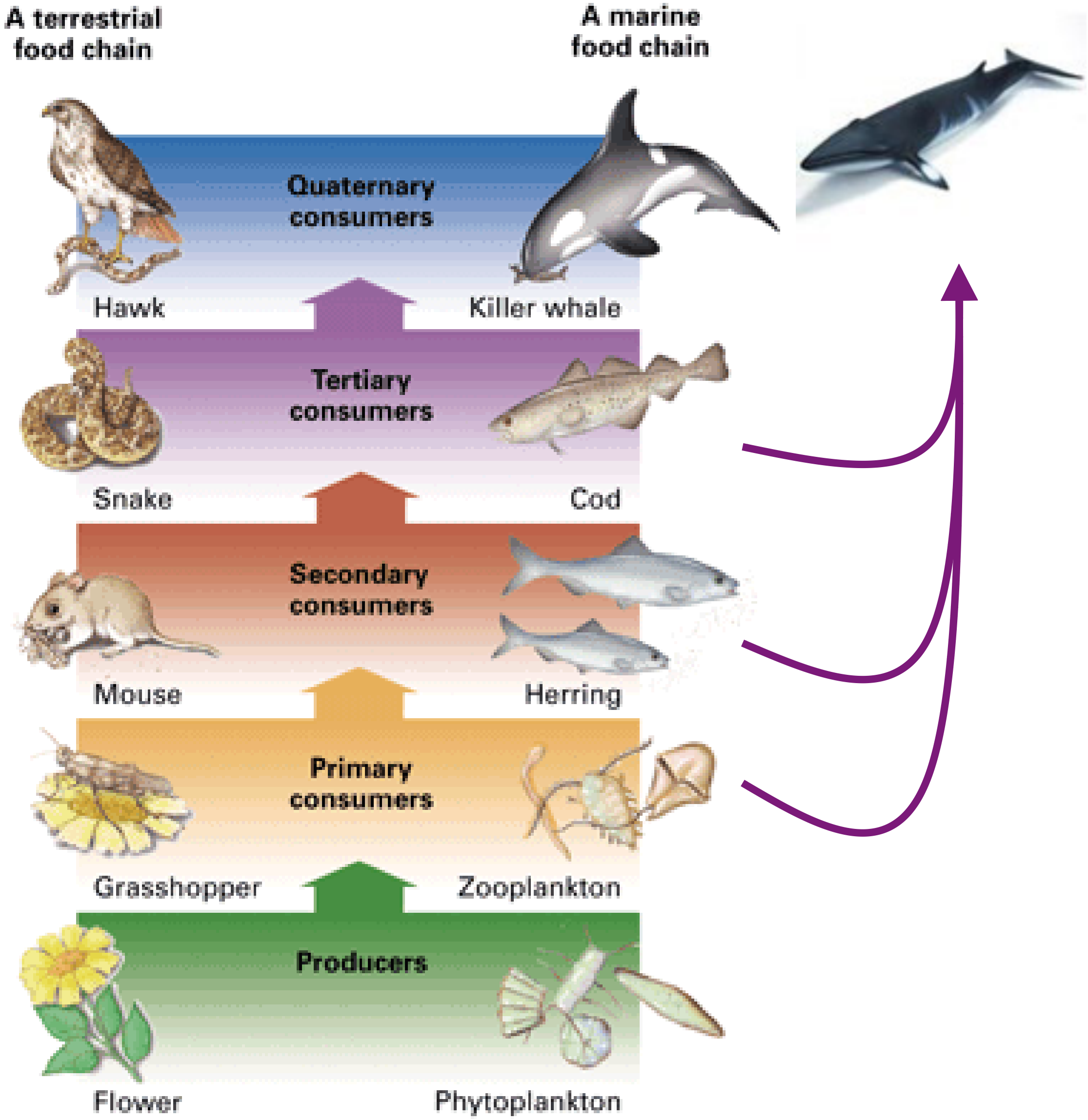
Food chains

Food chains



A terrestrial food chain
A marine food chain
Quaternary consumers
Hawk
Killer whale
Tertiary consumers
Snake
Cod
Secondary consumers
Mouse
Herring
Primary consumers
Grasshopper
Zooplankton
Producers
Flower
Phytoplankton

Food chains - and shortcuts



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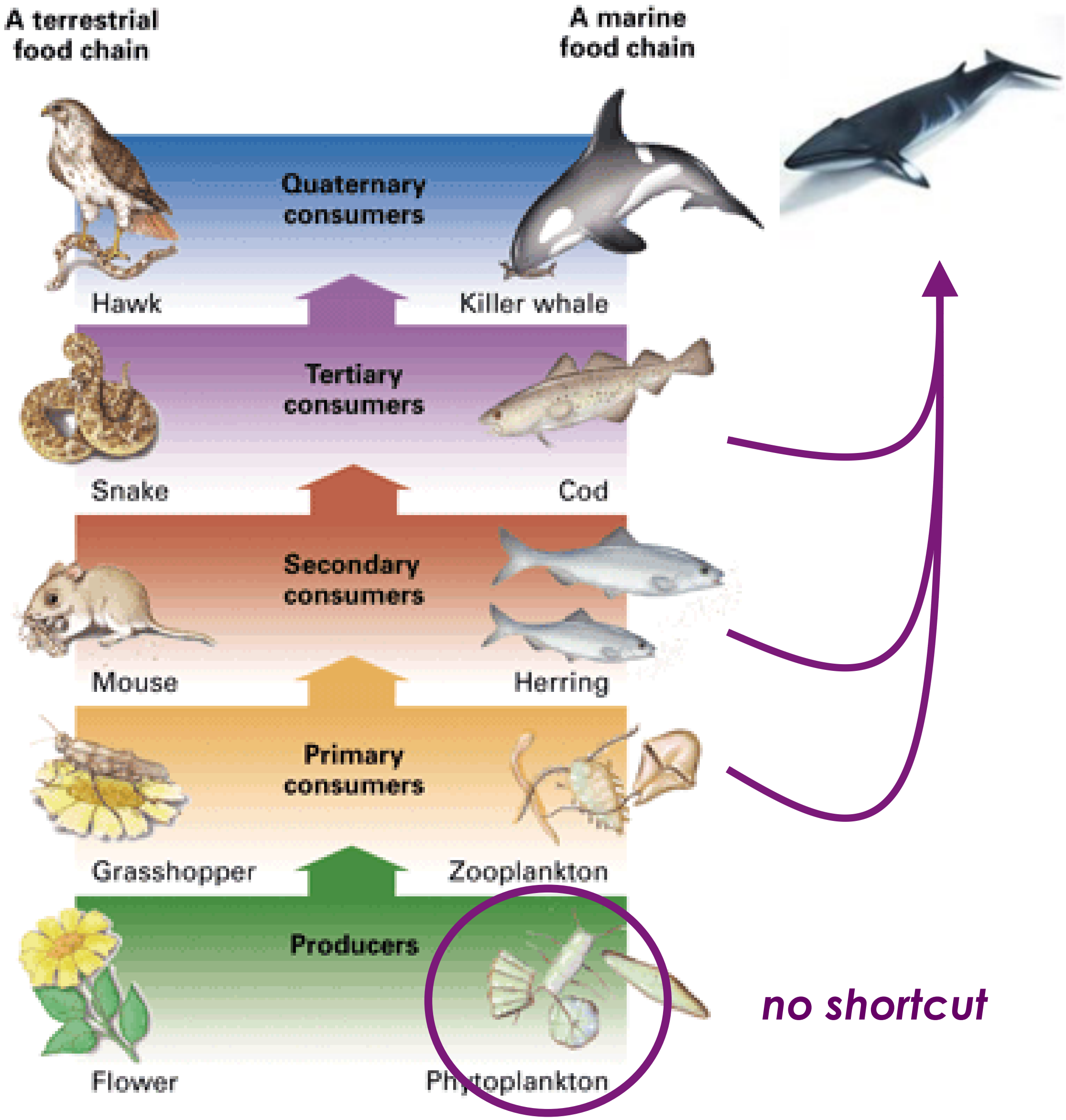

Productive yet minute packages of plant food in marine systems

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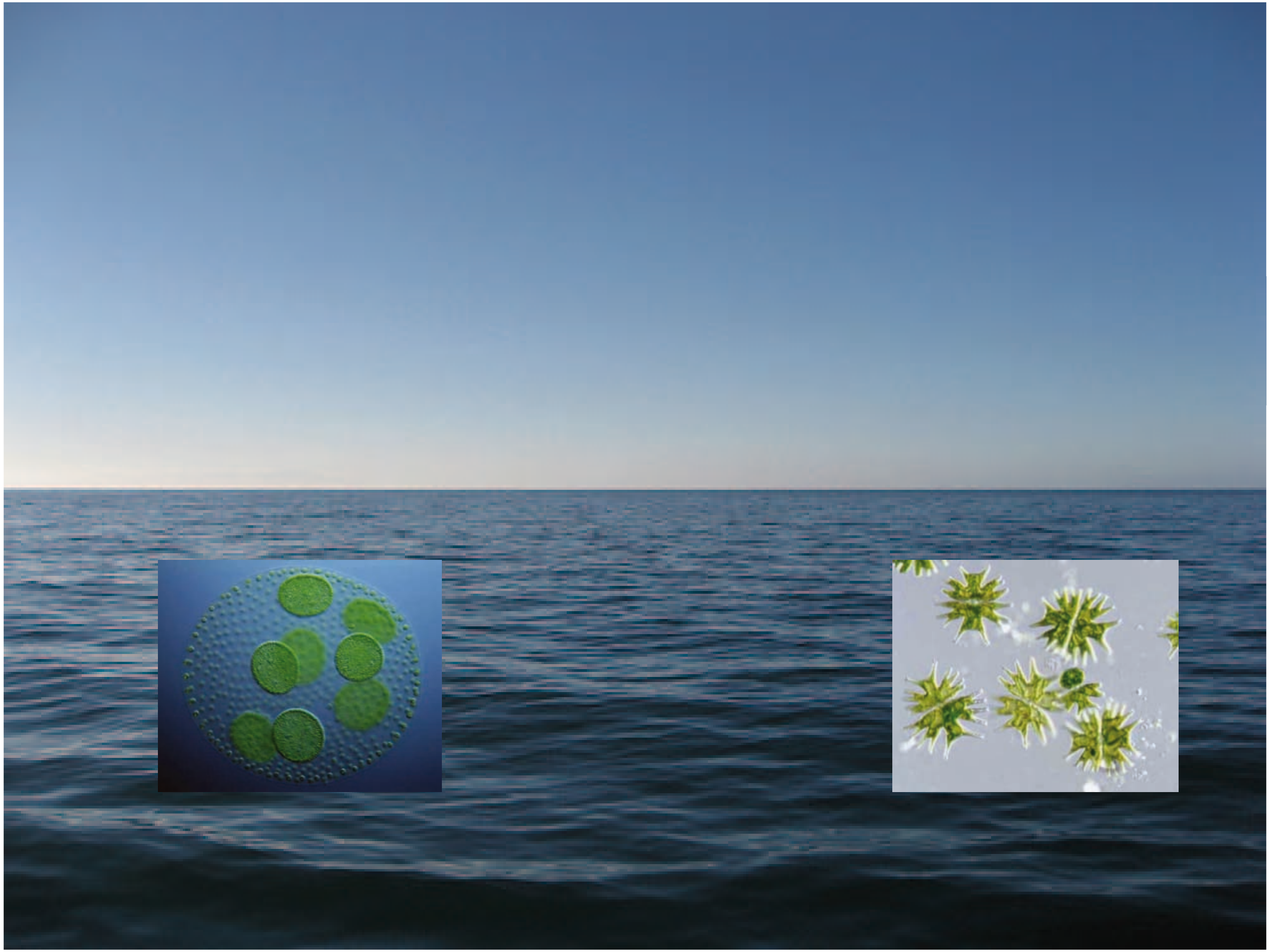
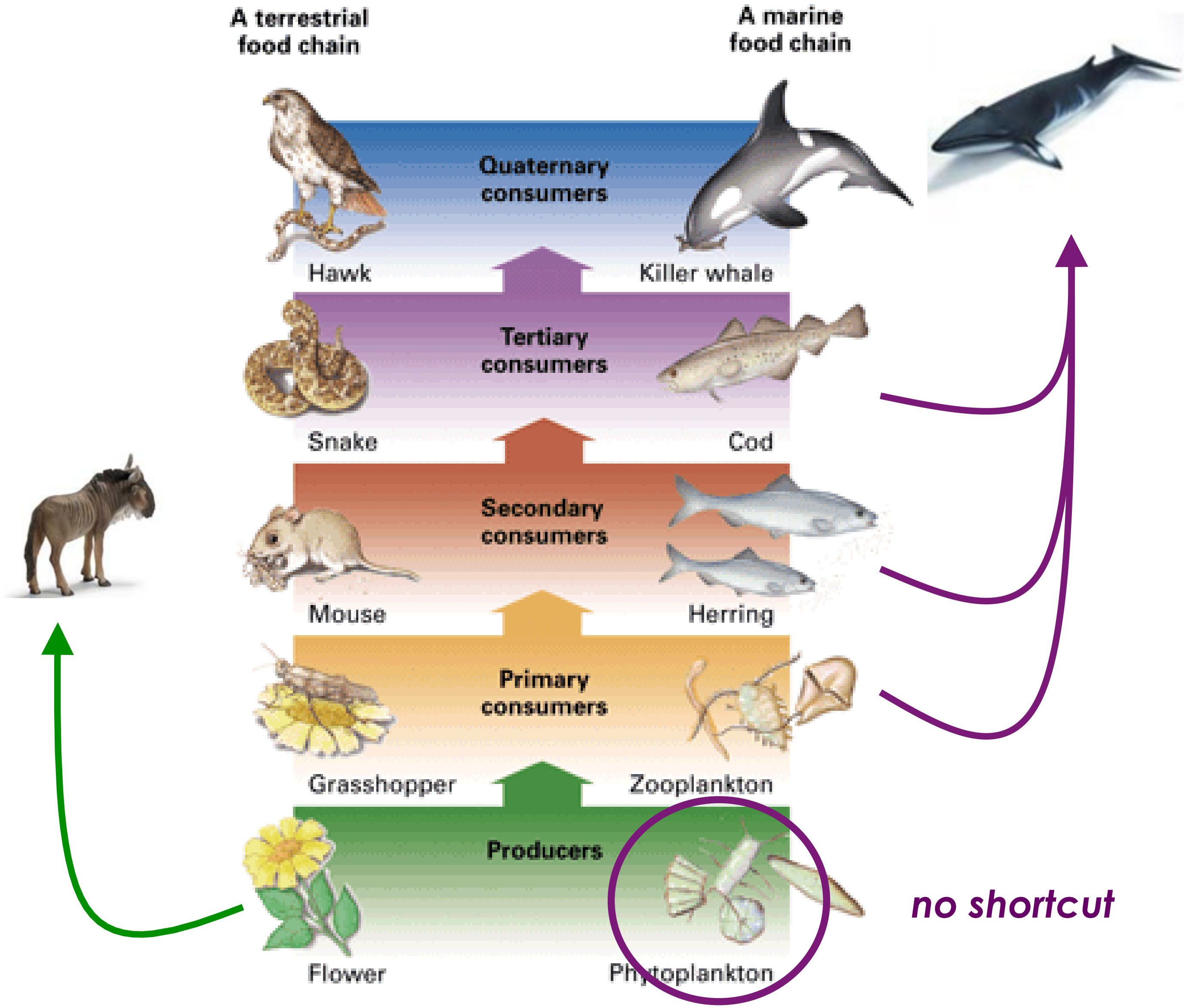


Rare large marine herbivores

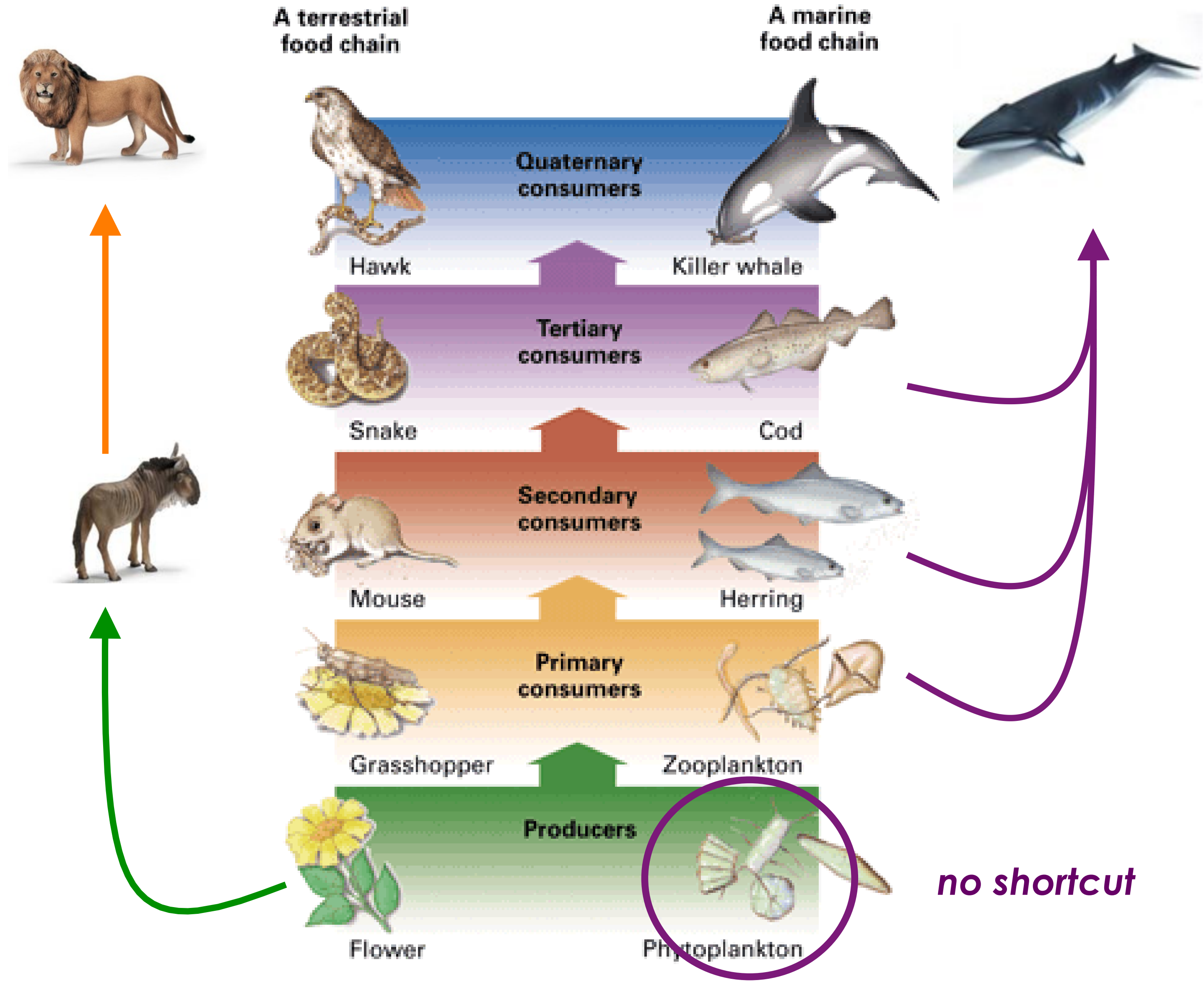
Rare large marine herbivores

Food chains - and shortcuts



Ubiquitous dense large packages of plant food in terrestrial systems

Food chains - and shortcuts



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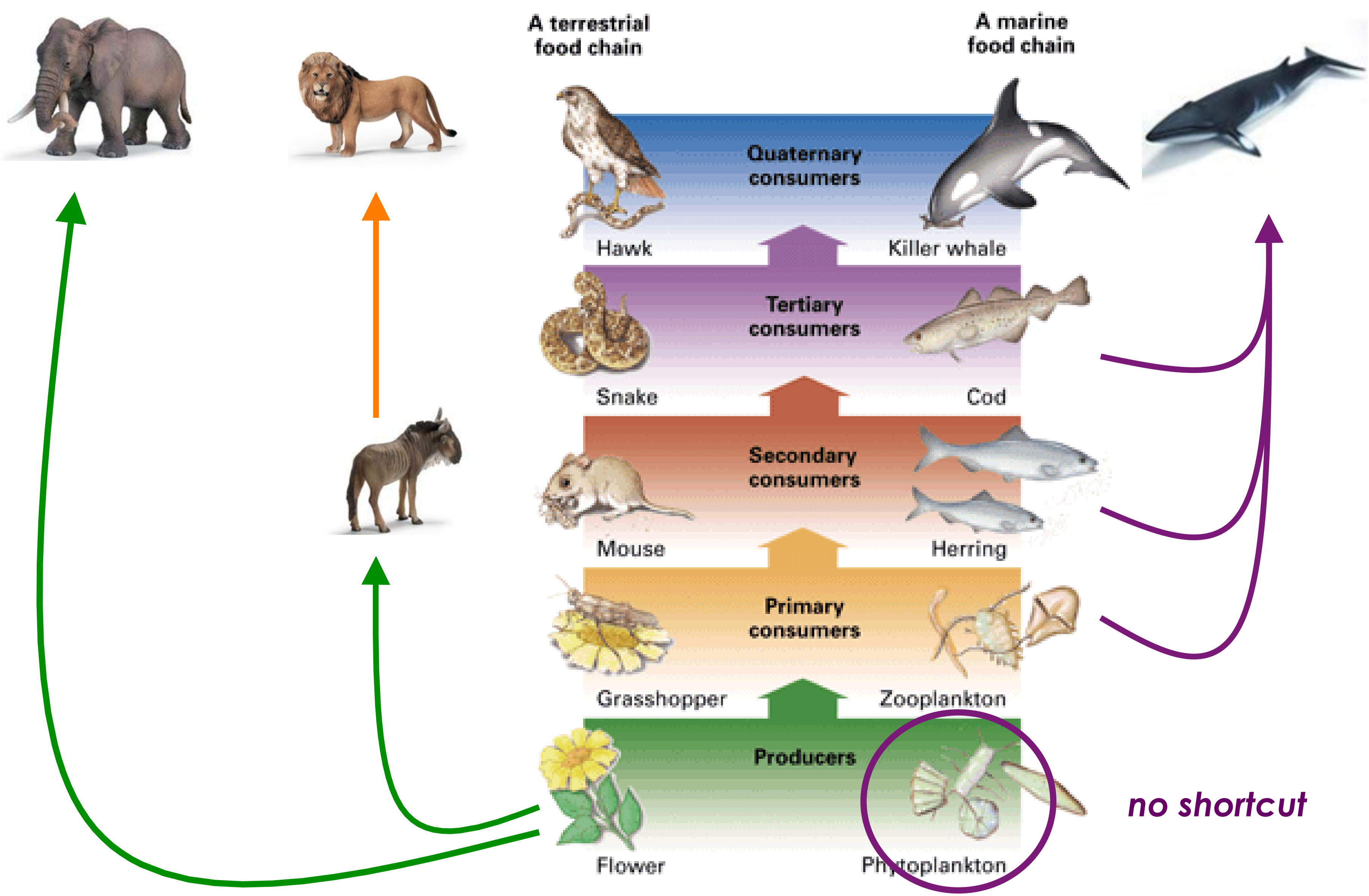


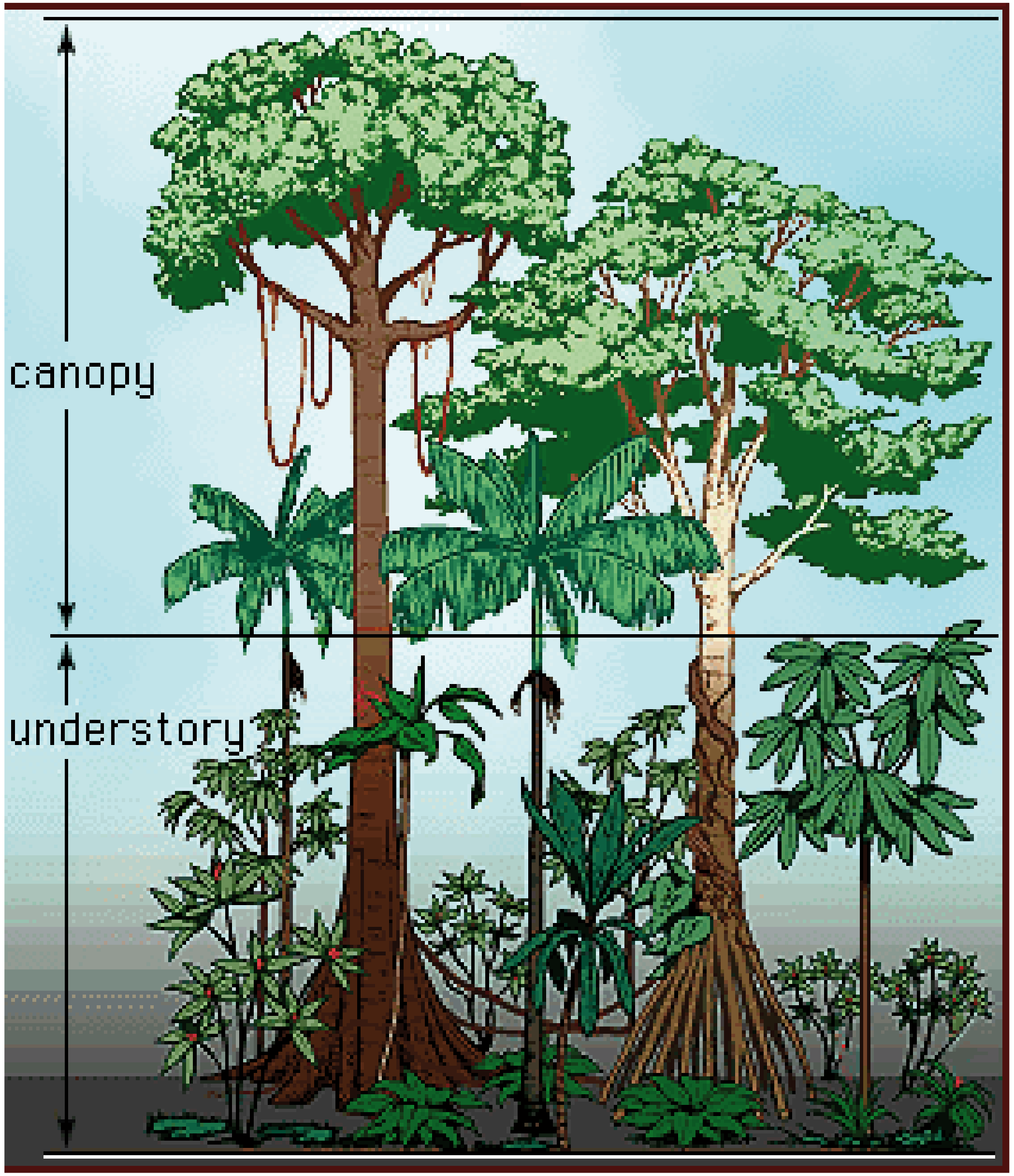
Herbivory

-

Principles
(fibre digestion)

Competition for light ...

Competition for light ...



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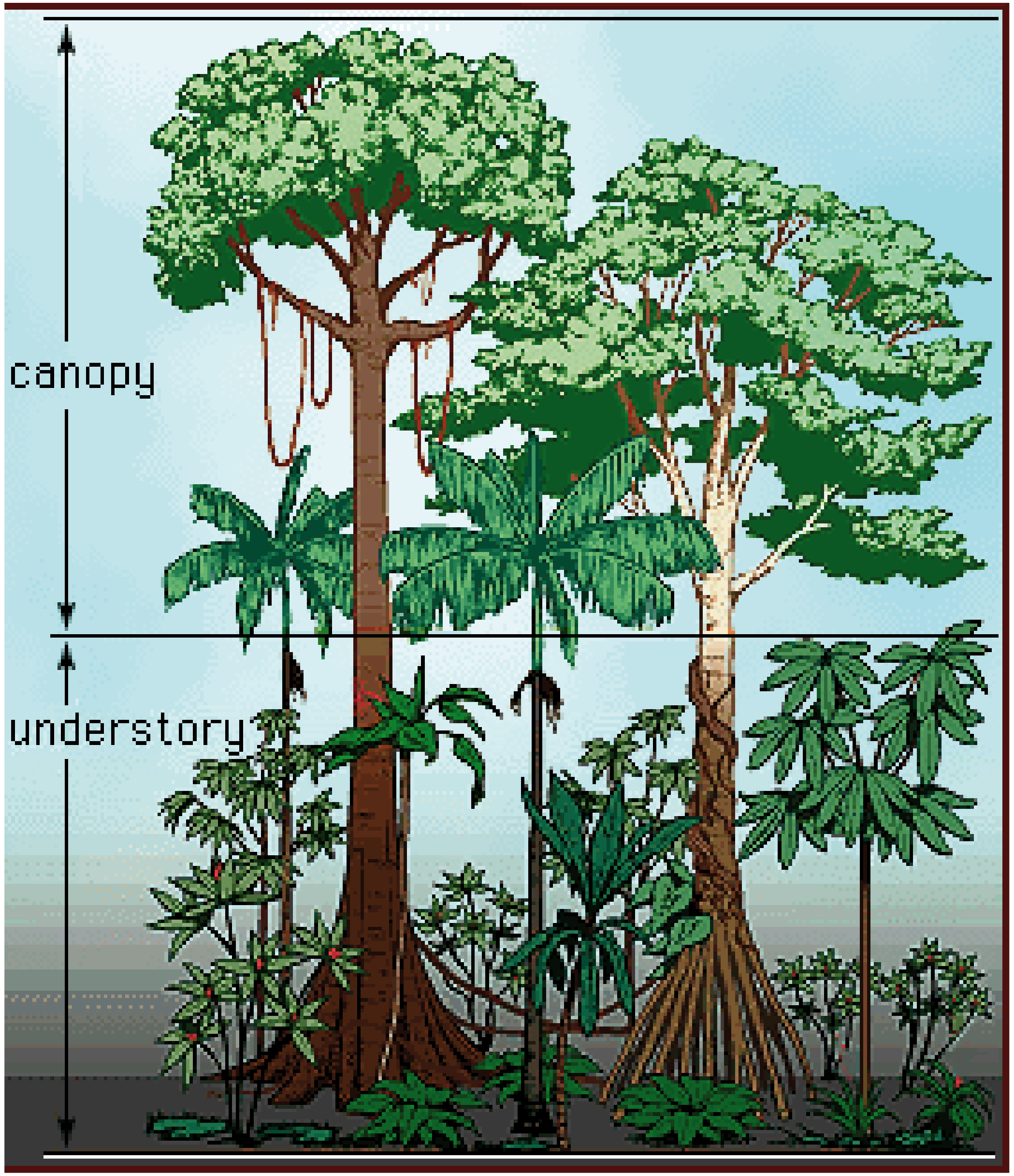
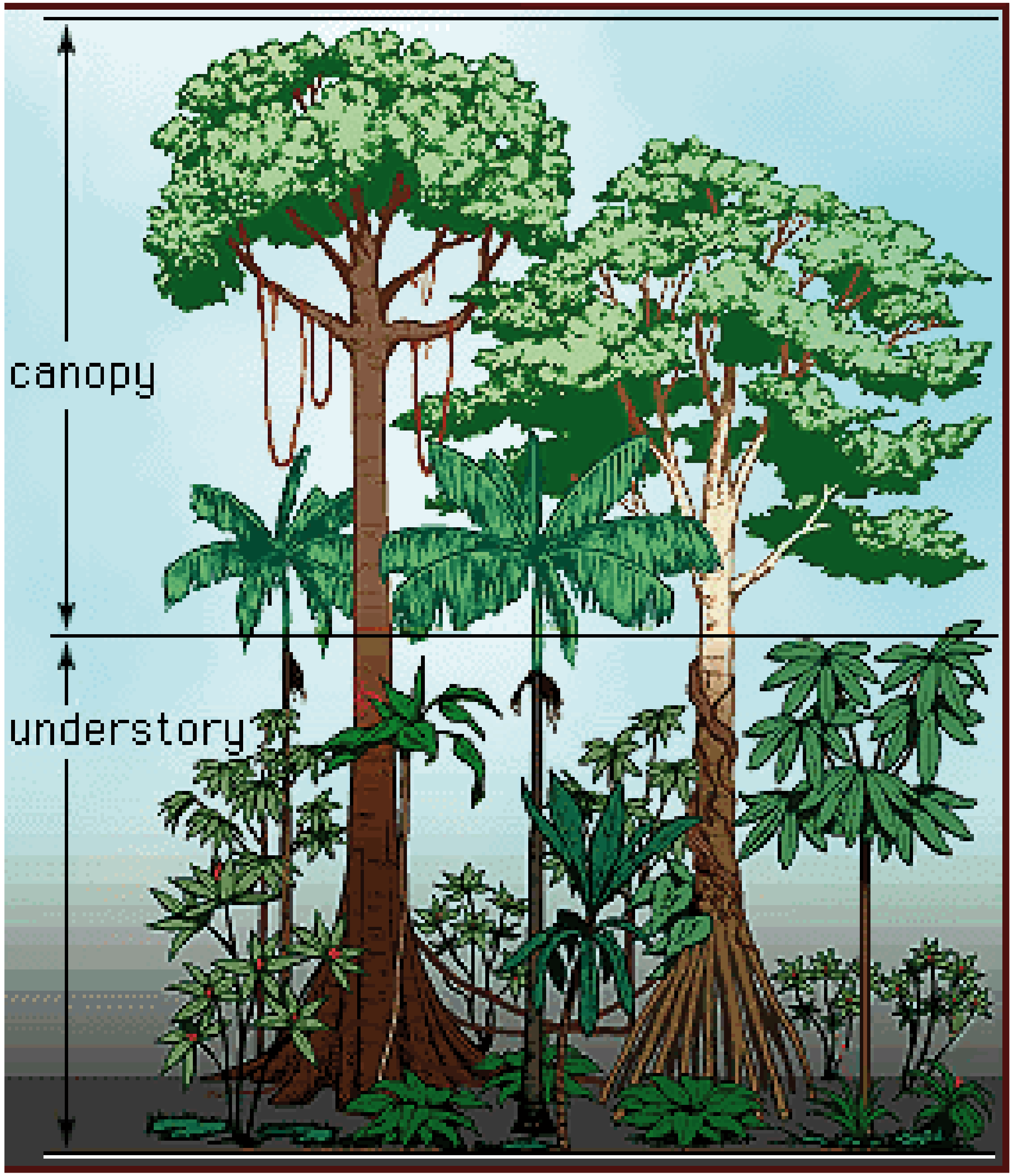


... results in a struggle against gravity in terrestrial systems:

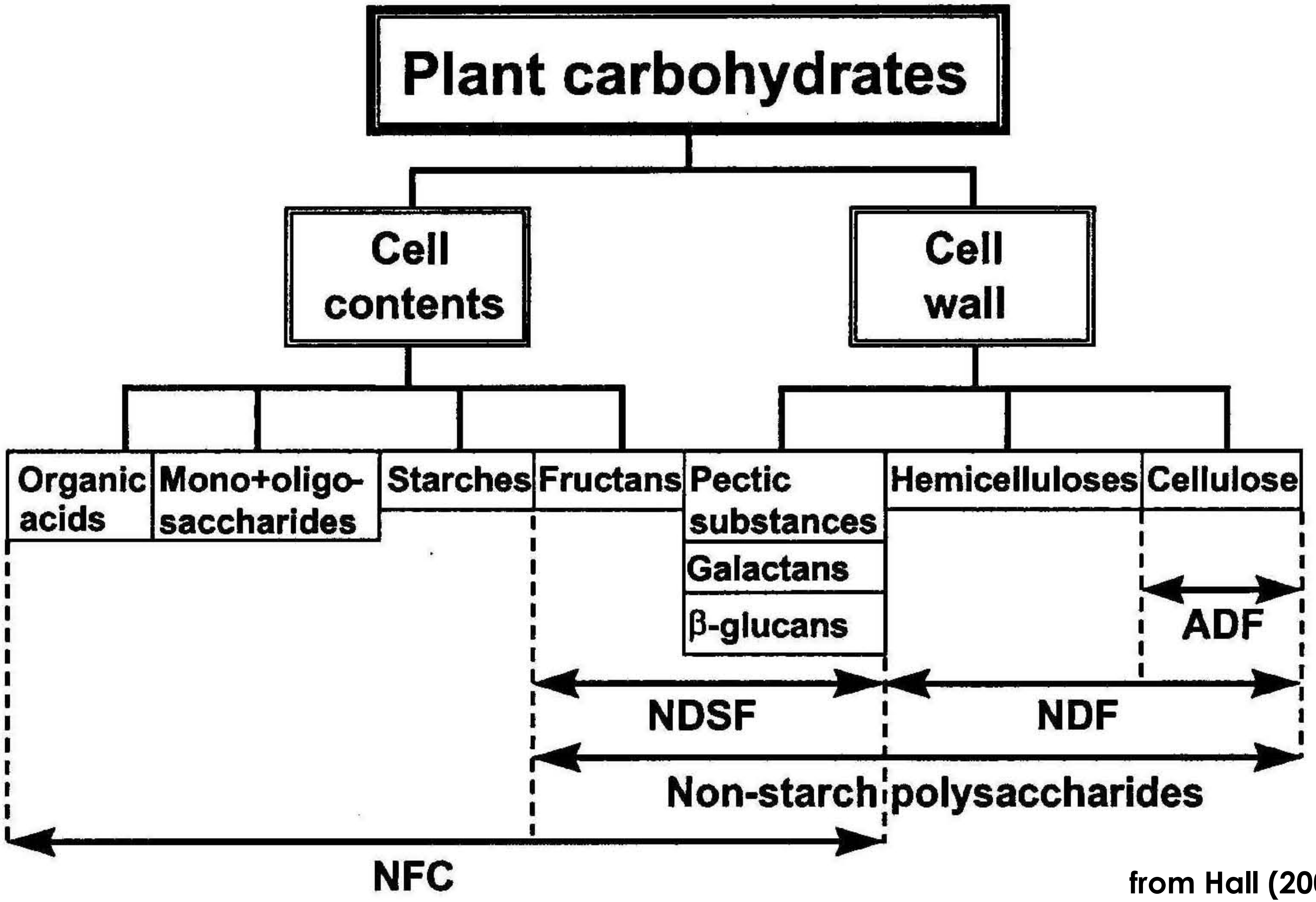
Competition for light ...



... results in a struggle against gravity in terrestrial systems:

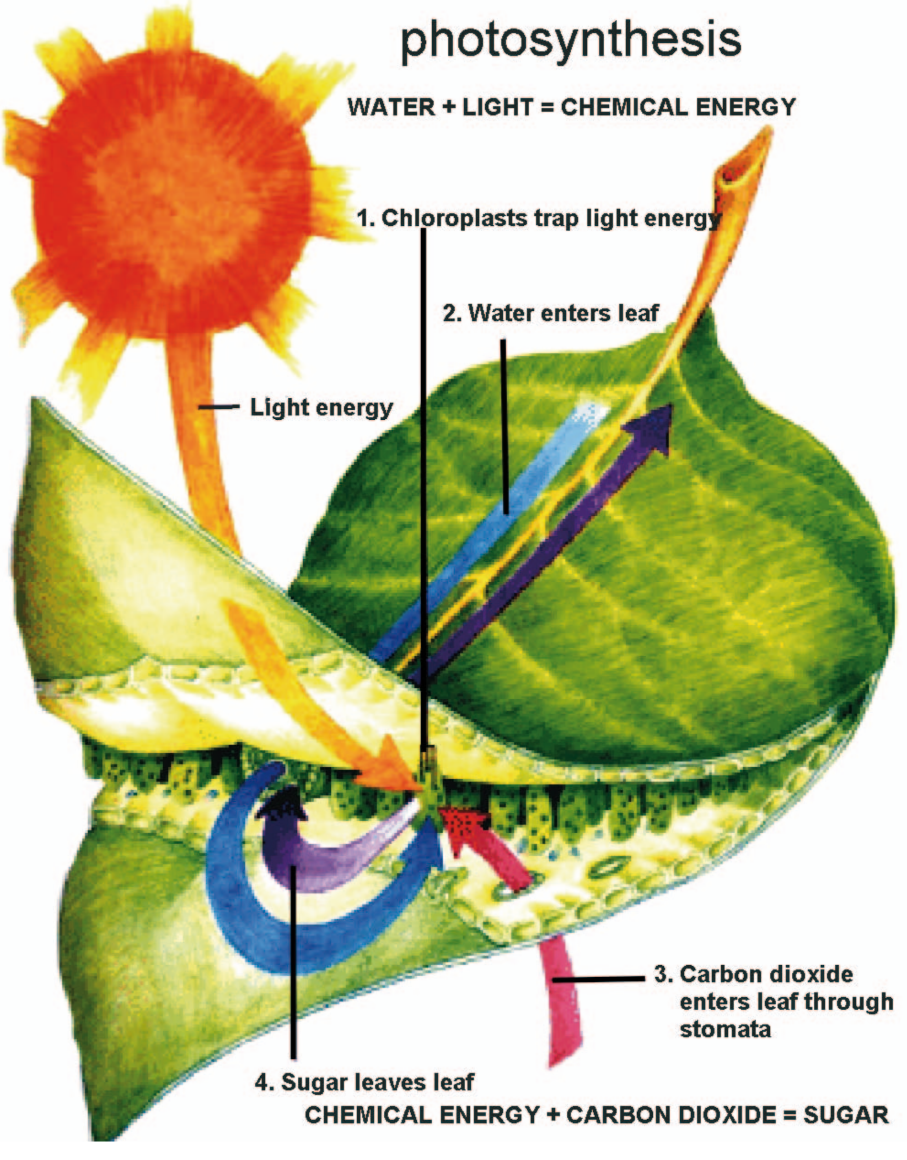
the evolution of 'fibre'

Fibre analysis



from Hall (2003)

Photosynthesis



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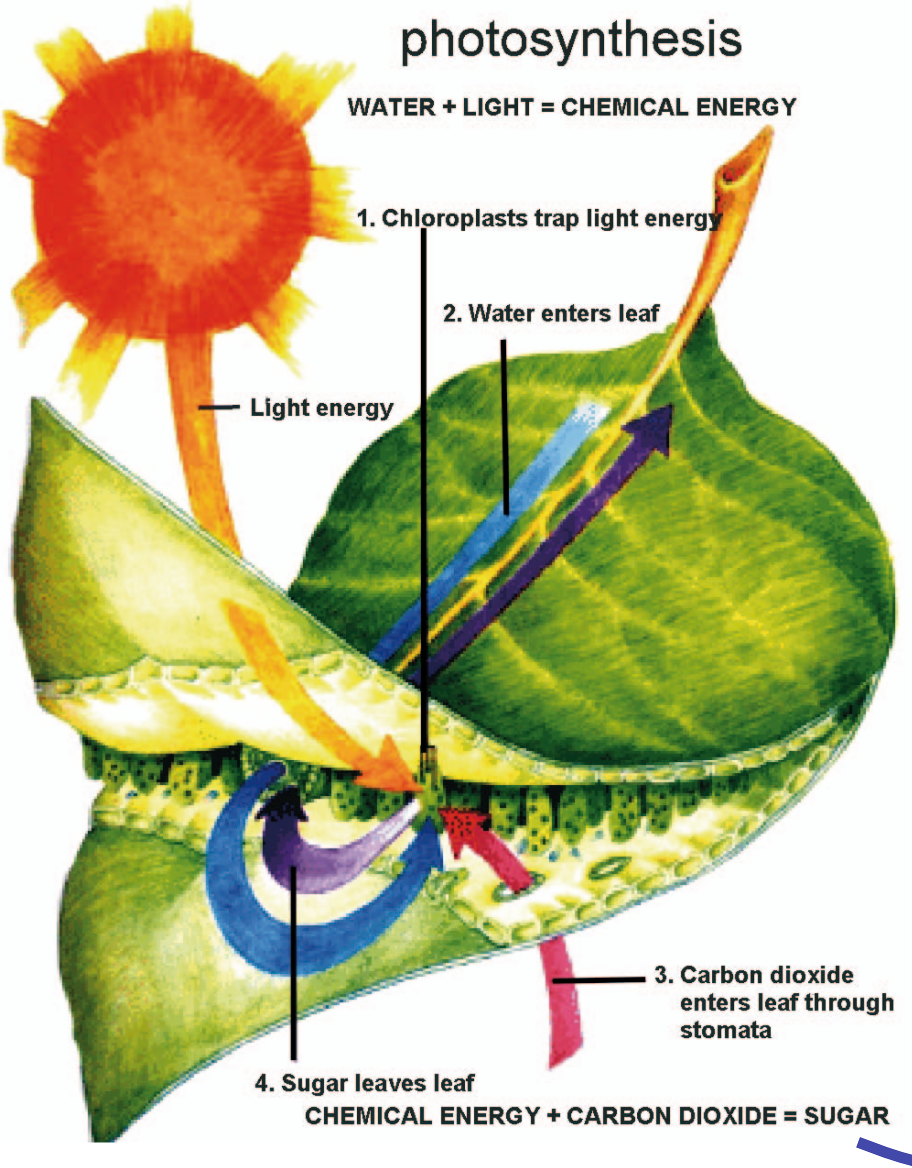

O_2

First fundamental question

Do you want to use plant fibre or only the plant cell contents?

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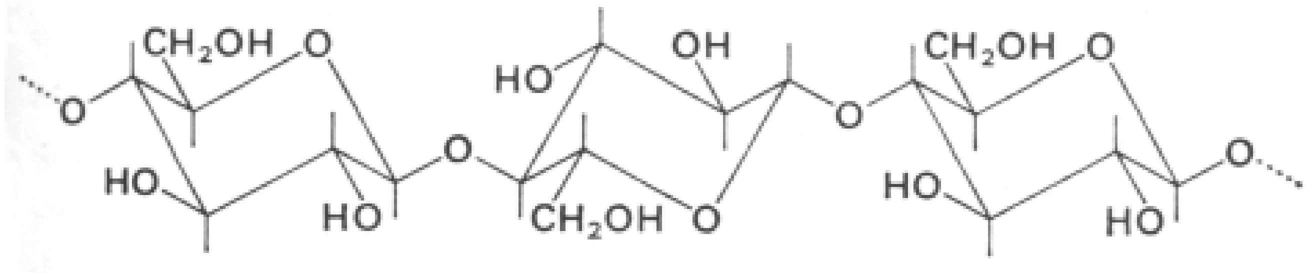
Fibre digestion

Organic polymers
(cellulose, hemicellulose)



from Karasov & Martinez del Rio (2007)

Fibre digestion

Organic polymers
(cellulose, hemicellulose)

↓

Hydrolysis
(soluble sugars)

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Fibre digestion

Organic polymers
(cellulose, hemicellulose)

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Hydrolysis
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Primary fermentation
(lactate, succinate)

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Fibre digestion

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Hydrolysis
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Fibre digestion

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Hydrolysis
(soluble sugars)

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Secondary fermentation

acetate, propionate, butyrate | **H_2** | **CO_2**

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Fibre digestion

Organic polymers
(cellulose, hemicellulose)

↓

Hydrolysis
(soluble sugars)

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Primary fermentation
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acetate, propionate, butyrate **H_2** **CO_2**

Removal ('sinks')?

from Karasov & Martinez del Rio (2007)

Fibre digestion

Organic polymers
(cellulose, hemicellulose)

↓

Hydrolysis
(soluble sugars)

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Primary fermentation
(lactate, succinate)

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Secondary fermentation

acetate, propionate, butyrate | **H_2** | **CO_2**

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Methanogenesis
(CH_4, H_2O)

from Karasov & Martinez del Rio (2007)

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($C_2H_3O_2$, H_2O)

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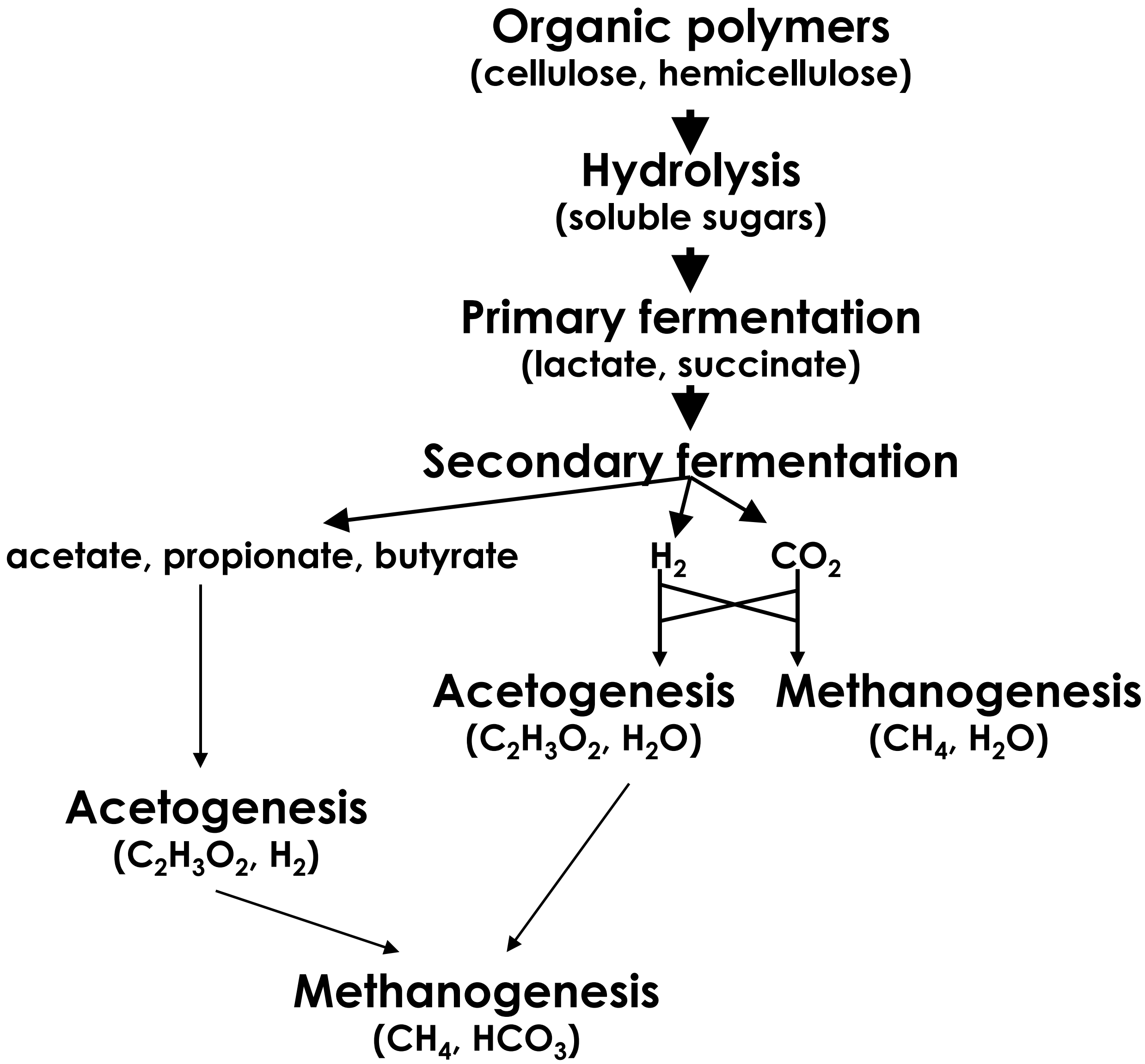

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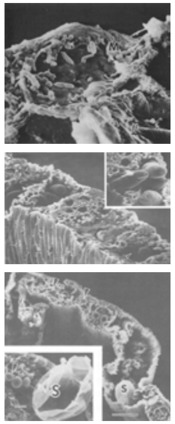

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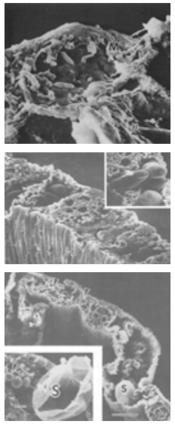

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Microbial biomass

from Karasov & Martinez del Rio (2007)

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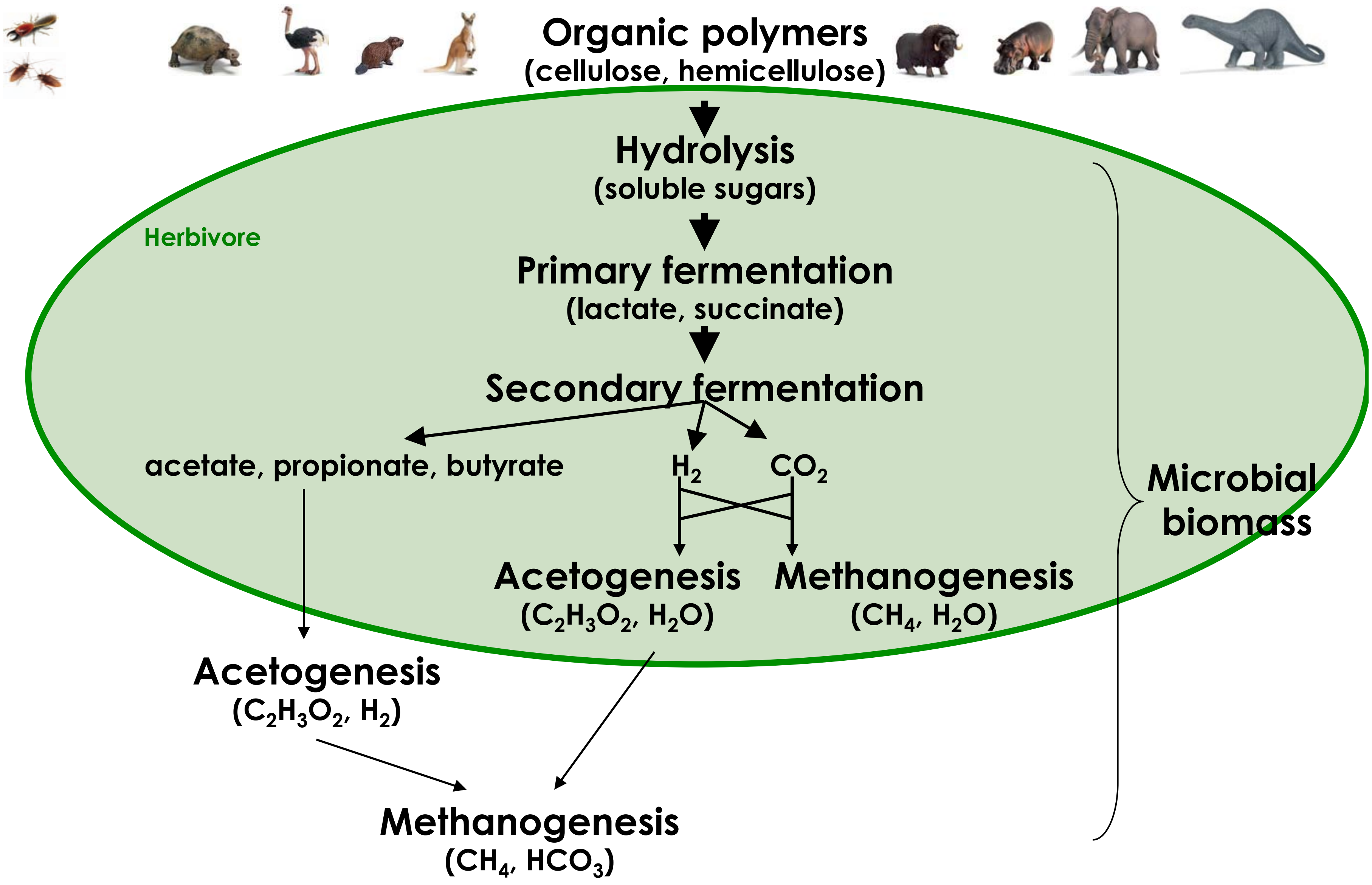

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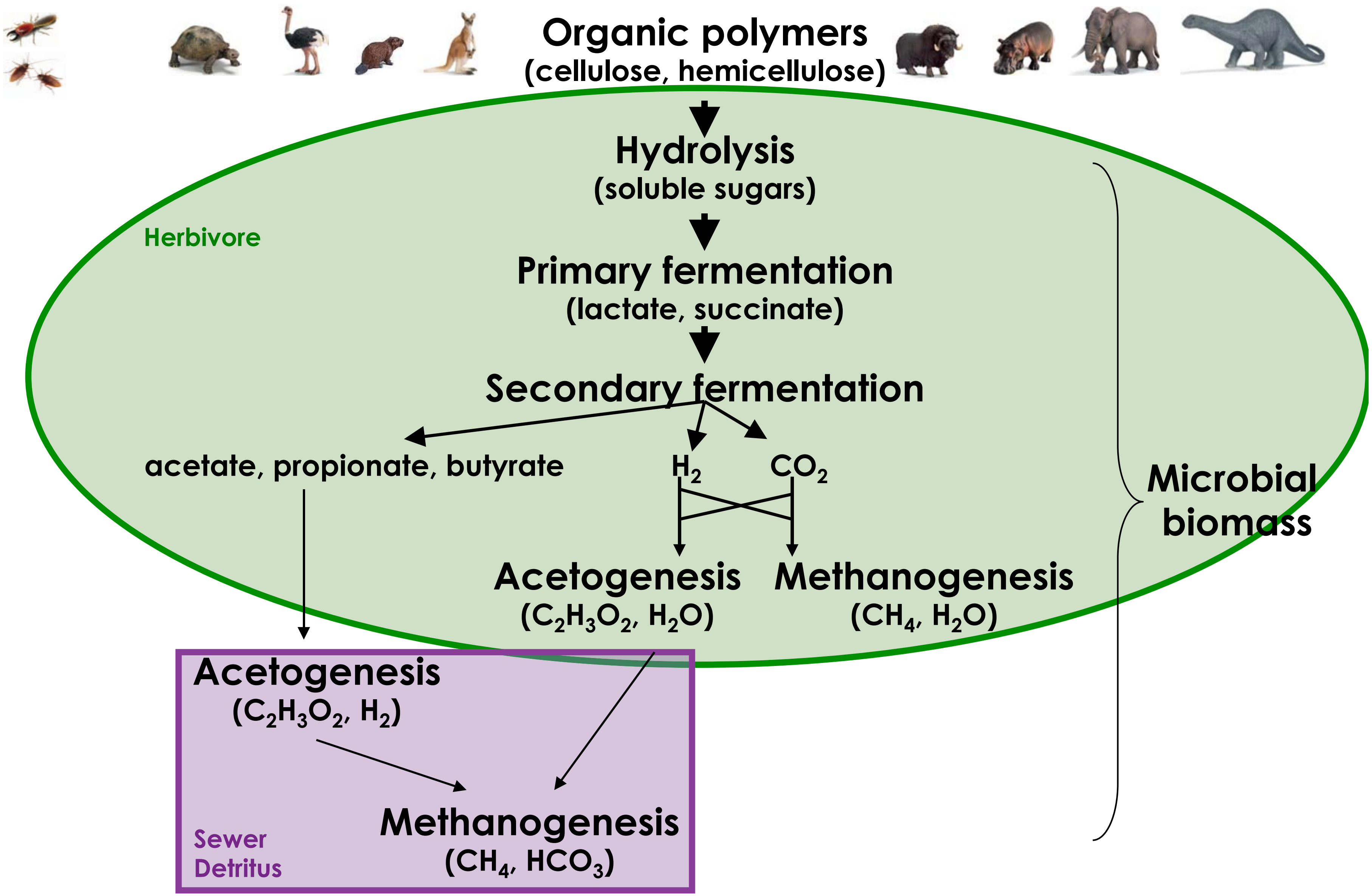

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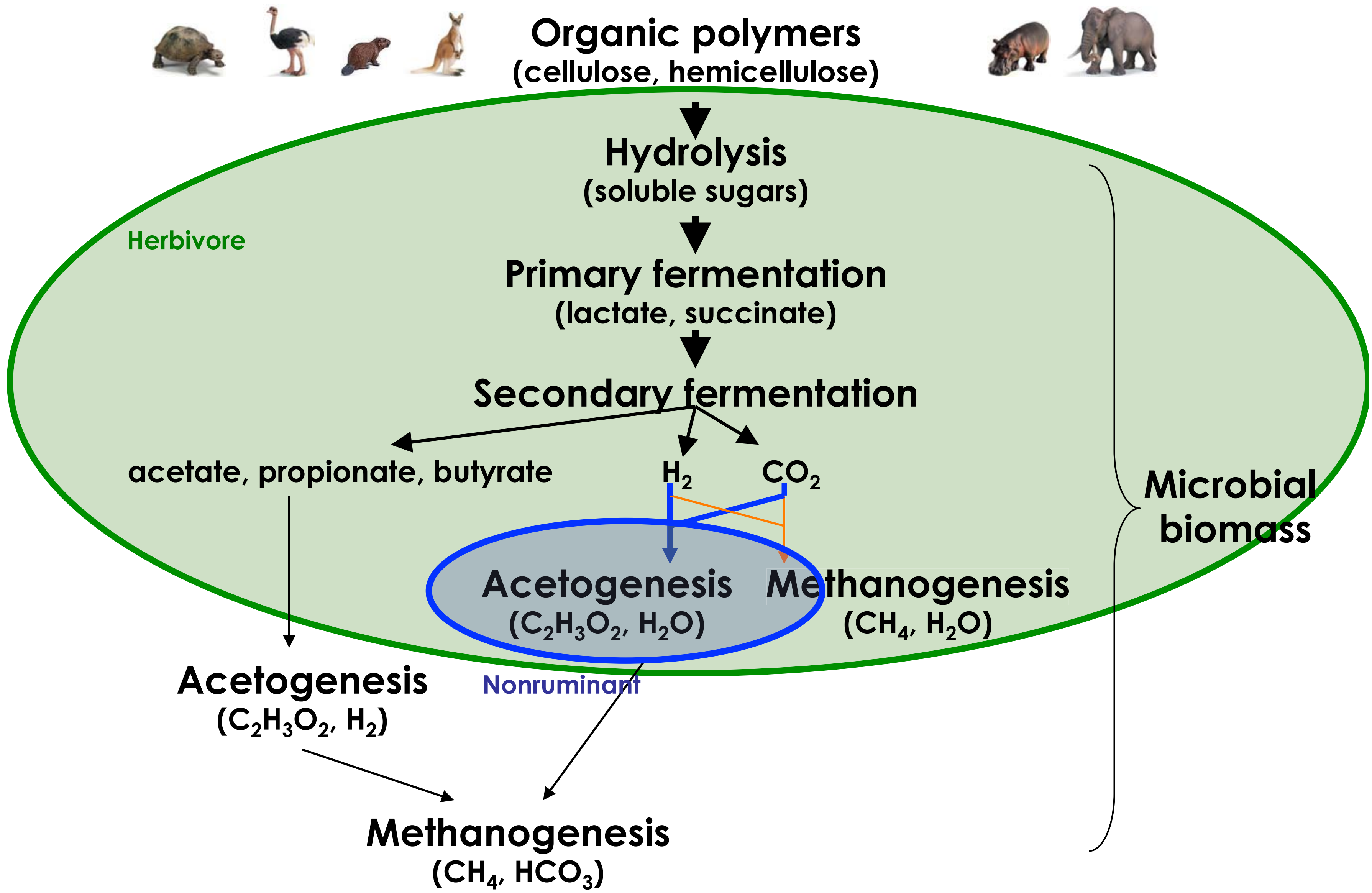

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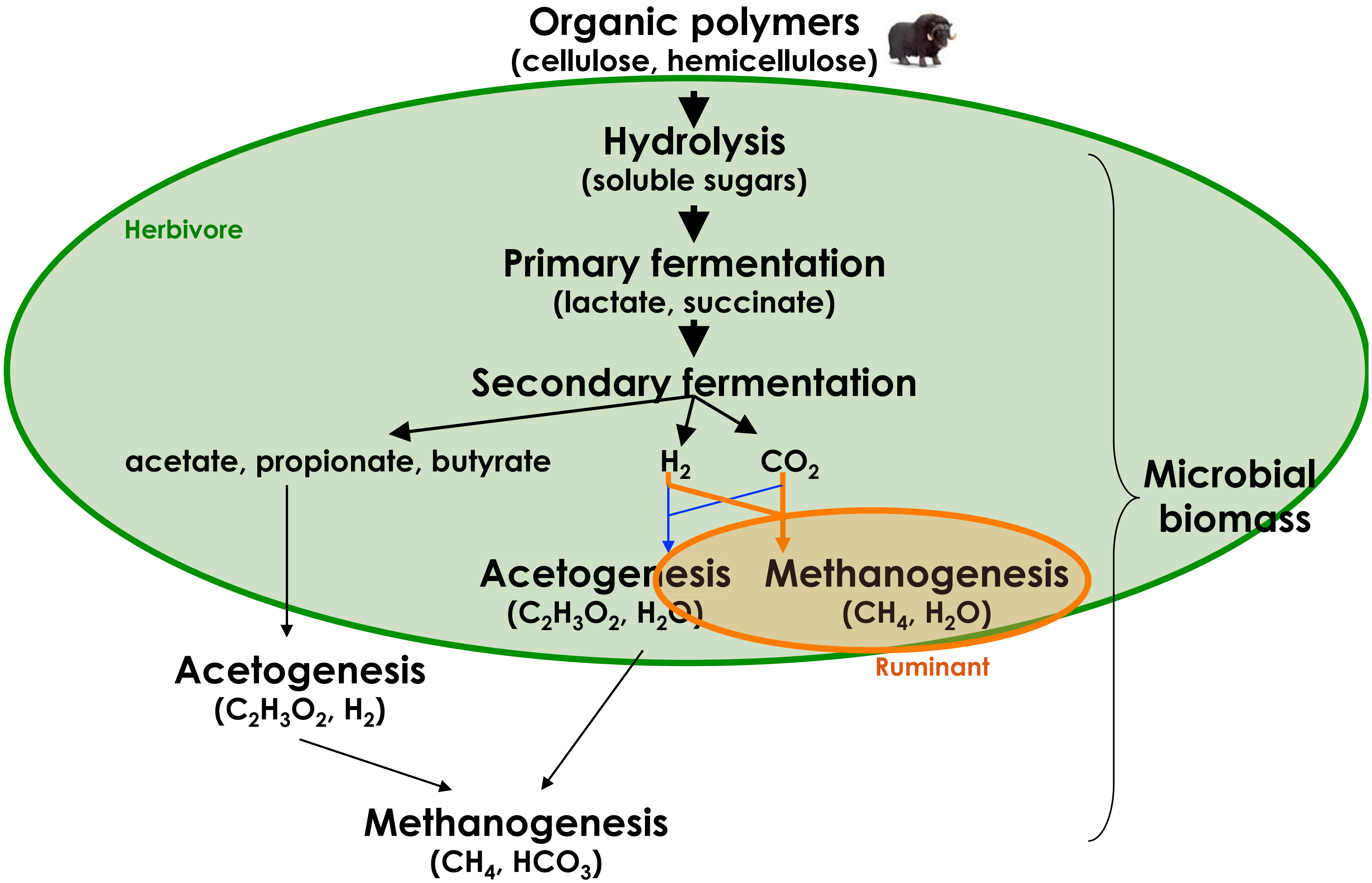

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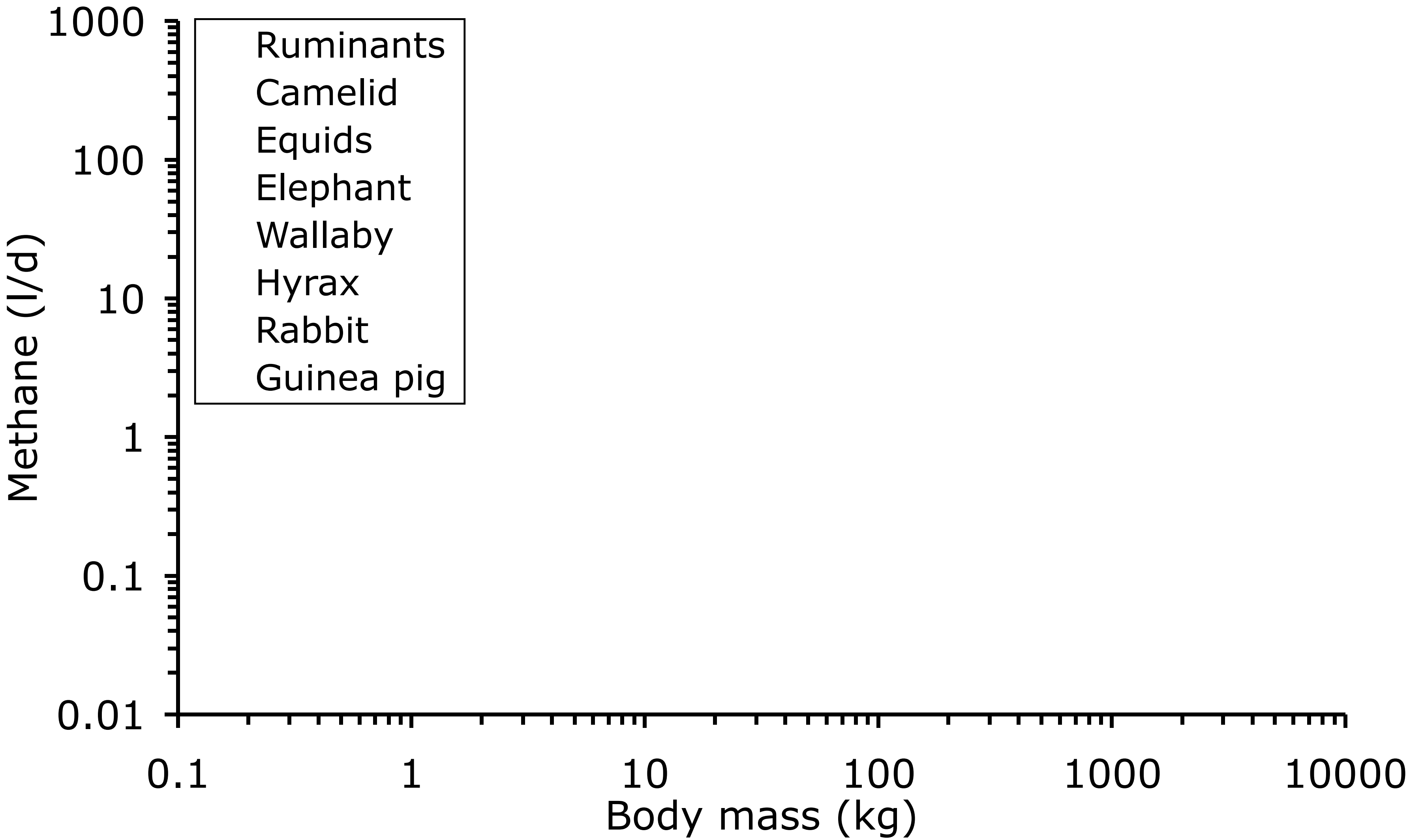
Methane allometry in herbivores



from Franz et al. (2011)

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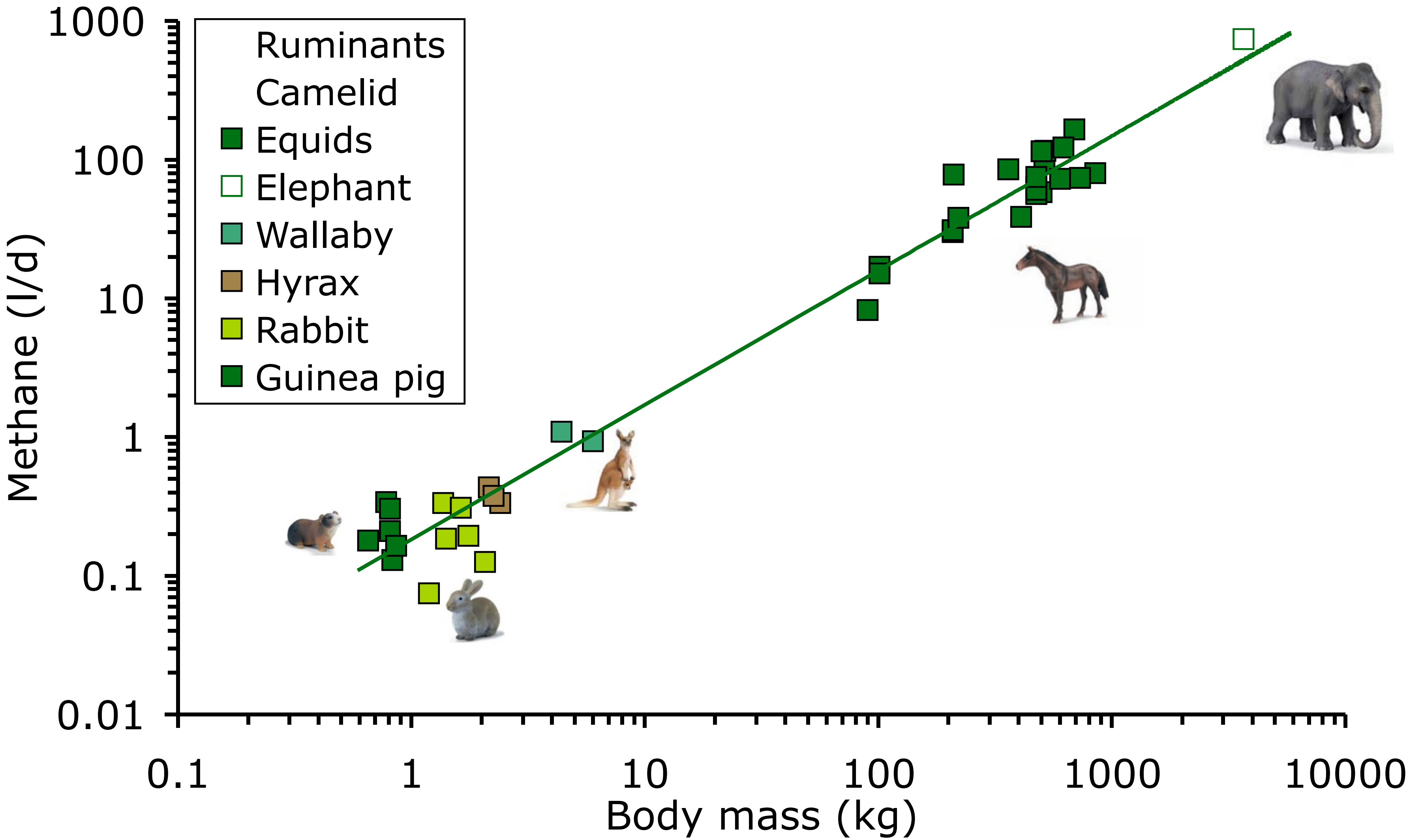

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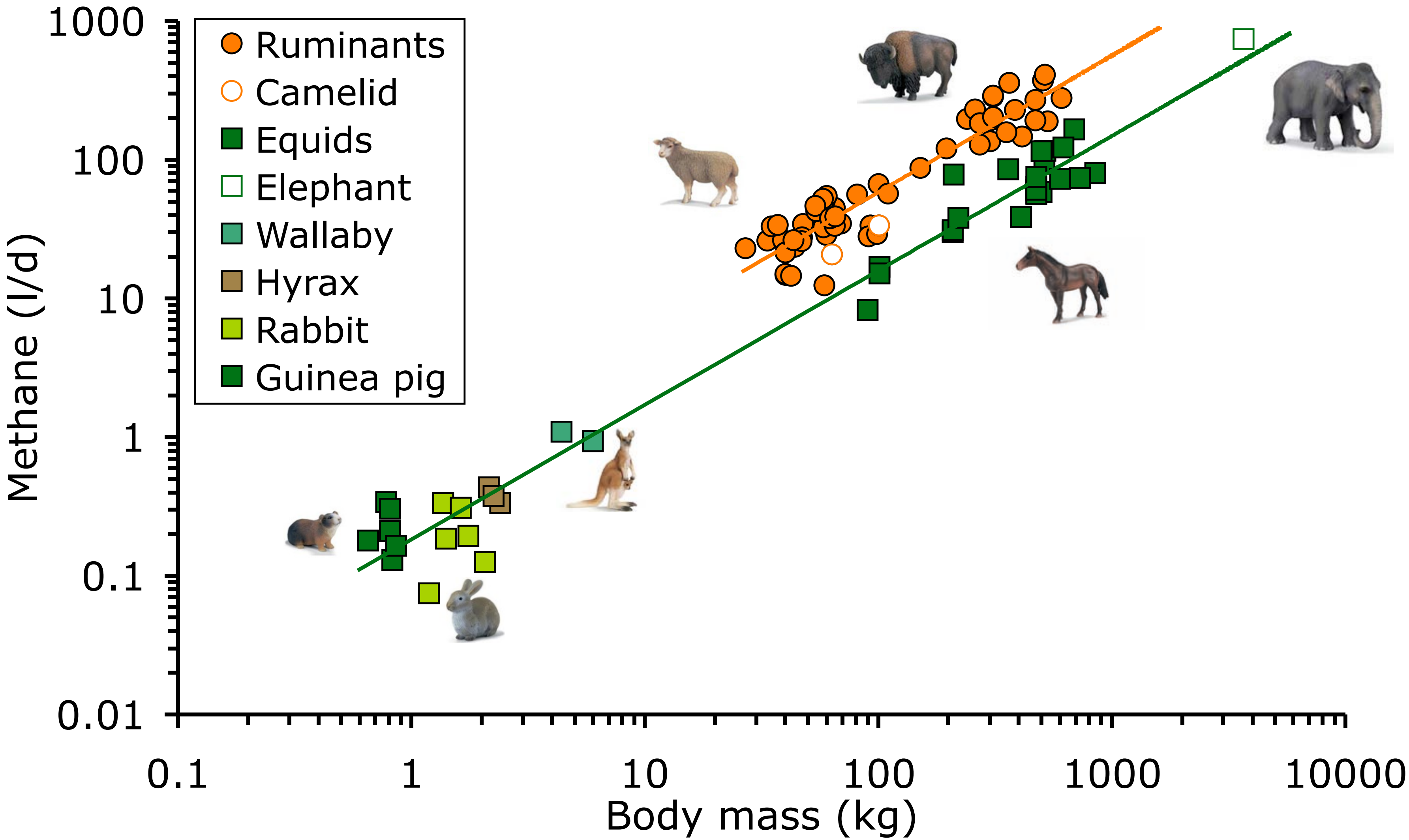

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Herbivory

-

Principles

(body size)

Two fundamental questions

1. **‘In-house’ or outsourcing of fibre digestion?**

2. **What sequence of fibre digestion and auto-enzymatic digestion?**

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   'In-house' fibre digestion necessitates anatomical and physiological adaptations that might be costly in some circumstances.

2. **What sequence of fibre digestion and auto-enzymatic digestion?**

Detritivory, coprophagy, and the evolution of digestive mutualisms in Dictyoptera

C. A. Nalepa[1], D. E. Bignell[2] and C. Bandi[3]

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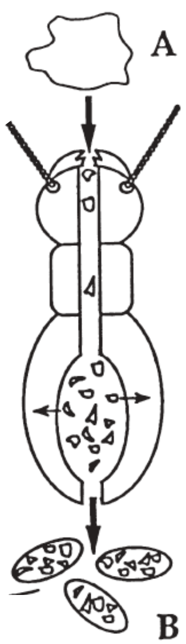

Refractory
food item

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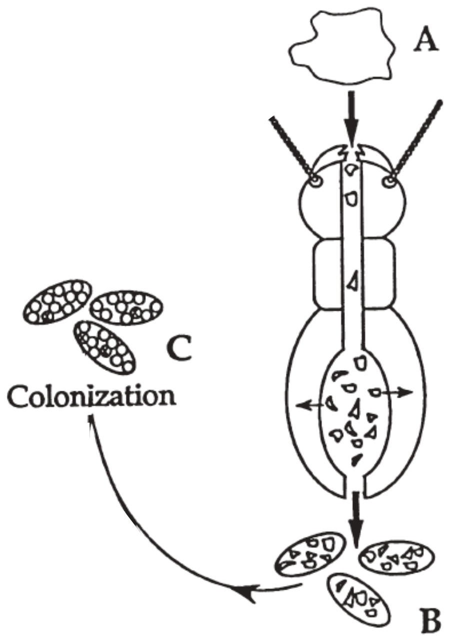

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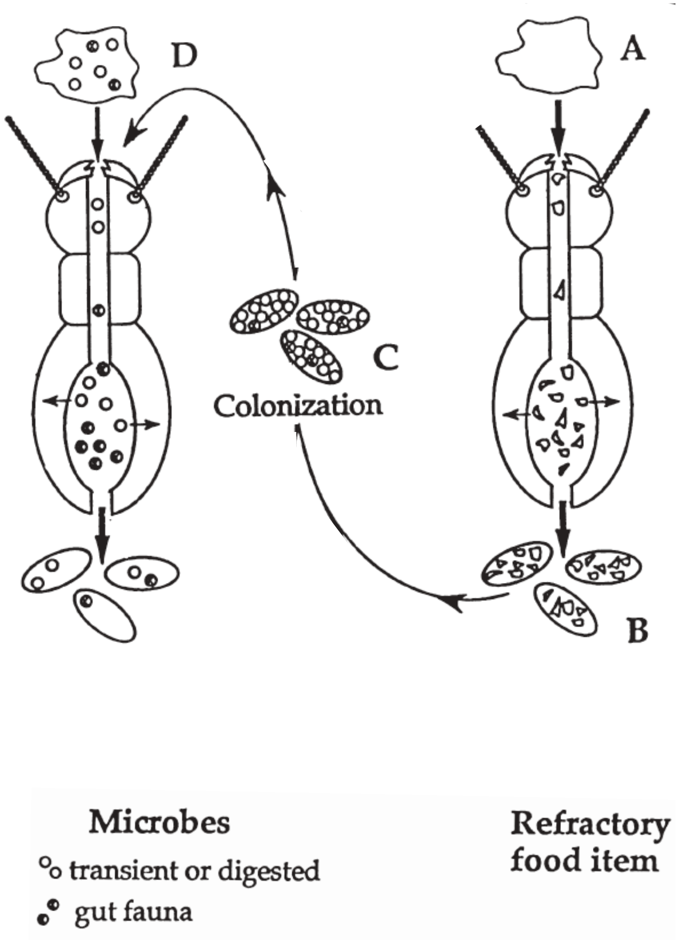

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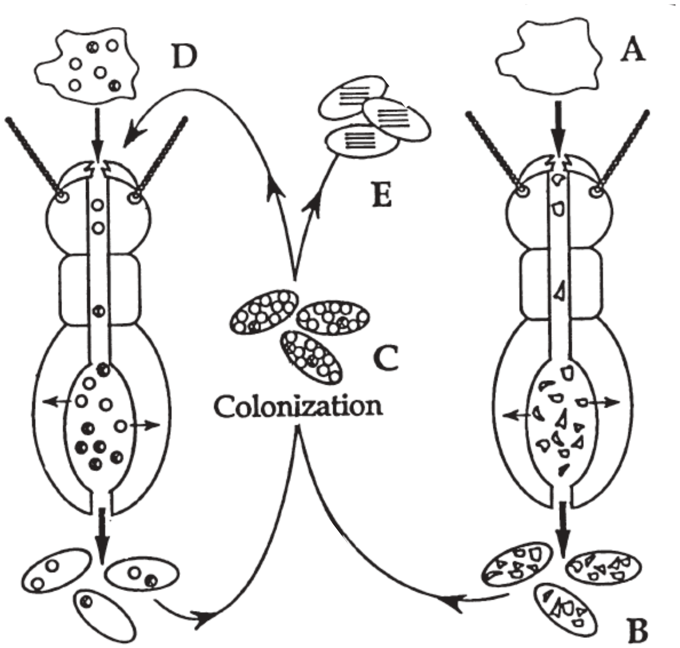

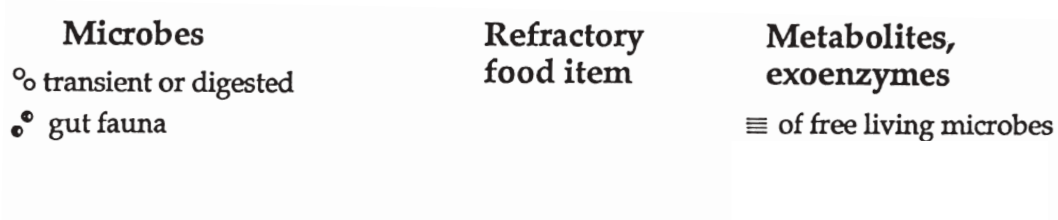

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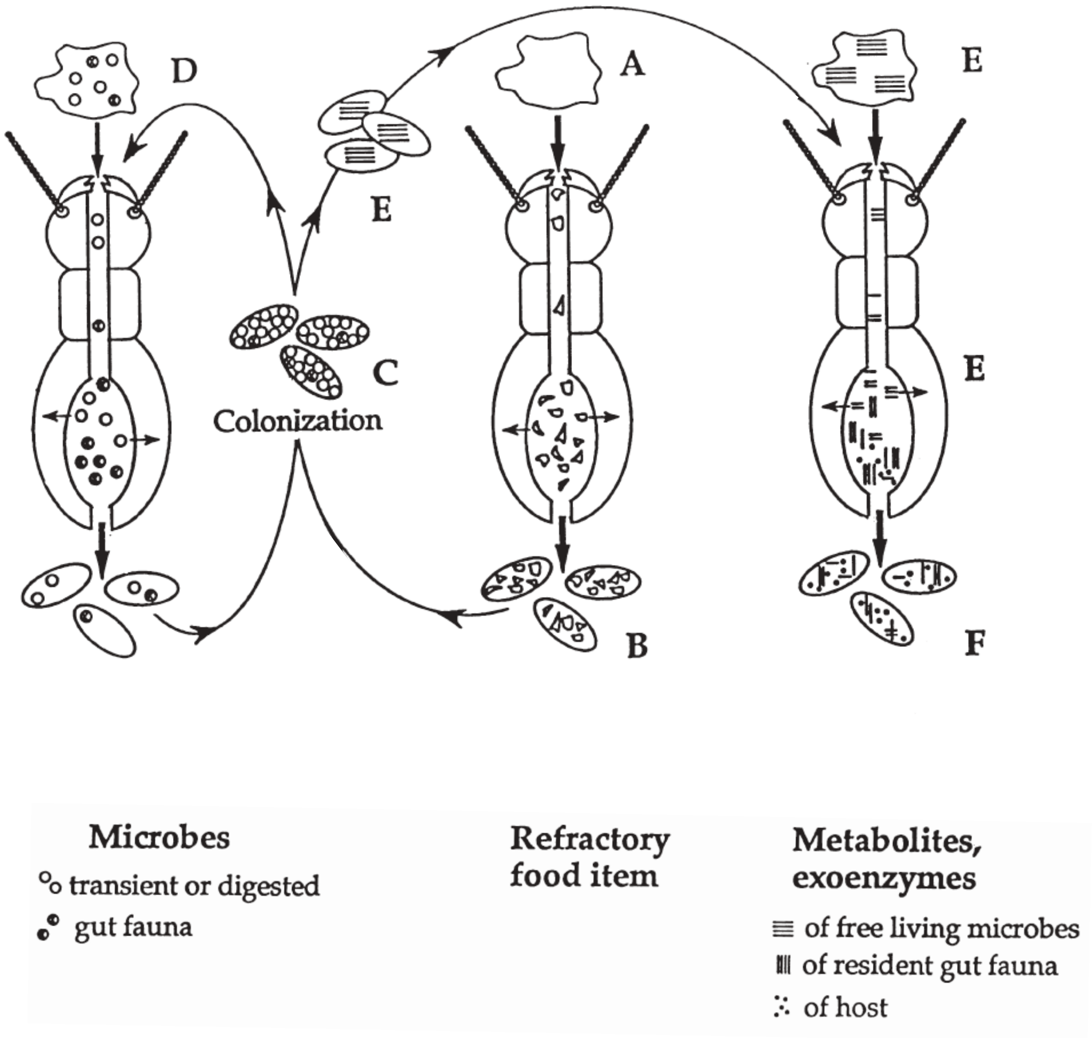

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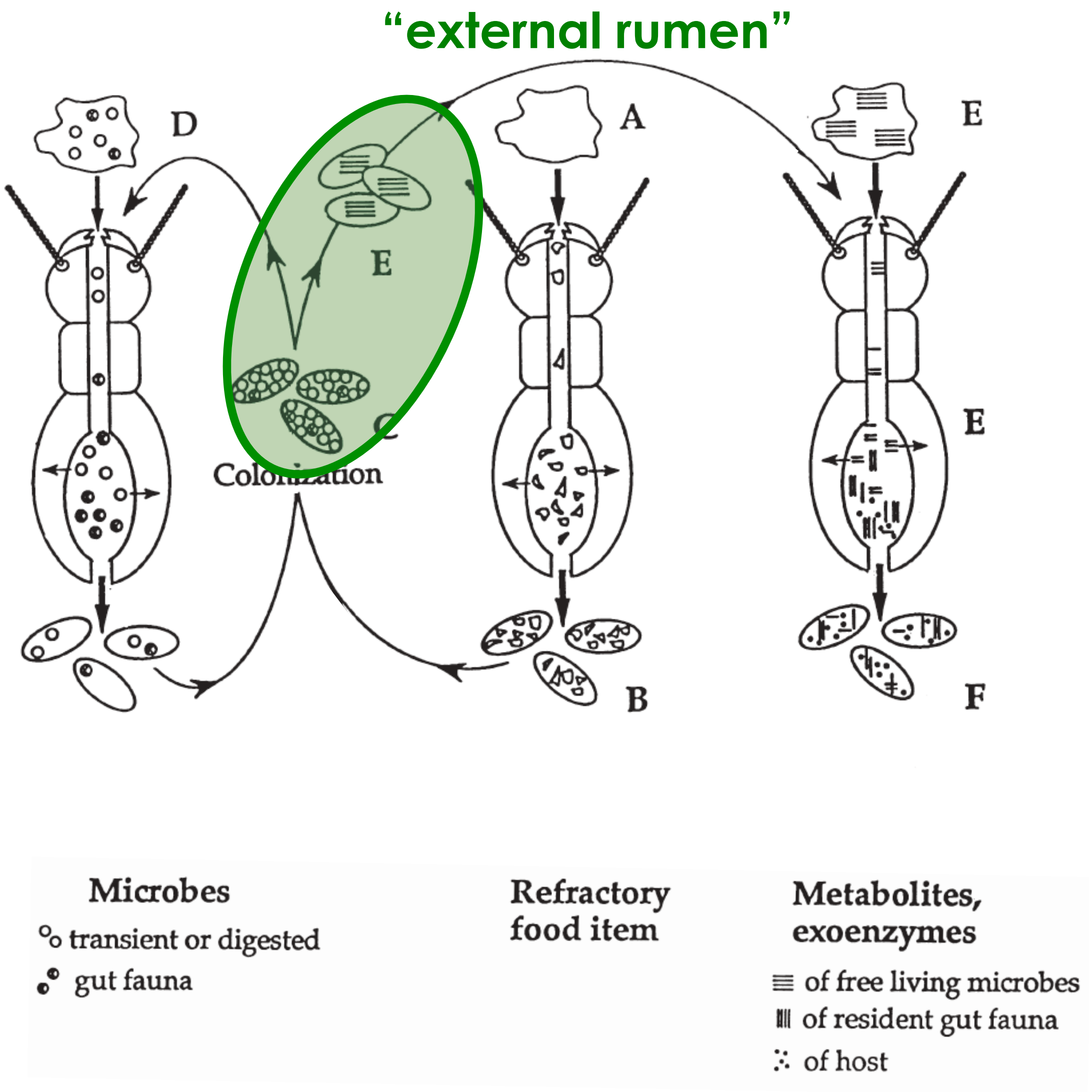

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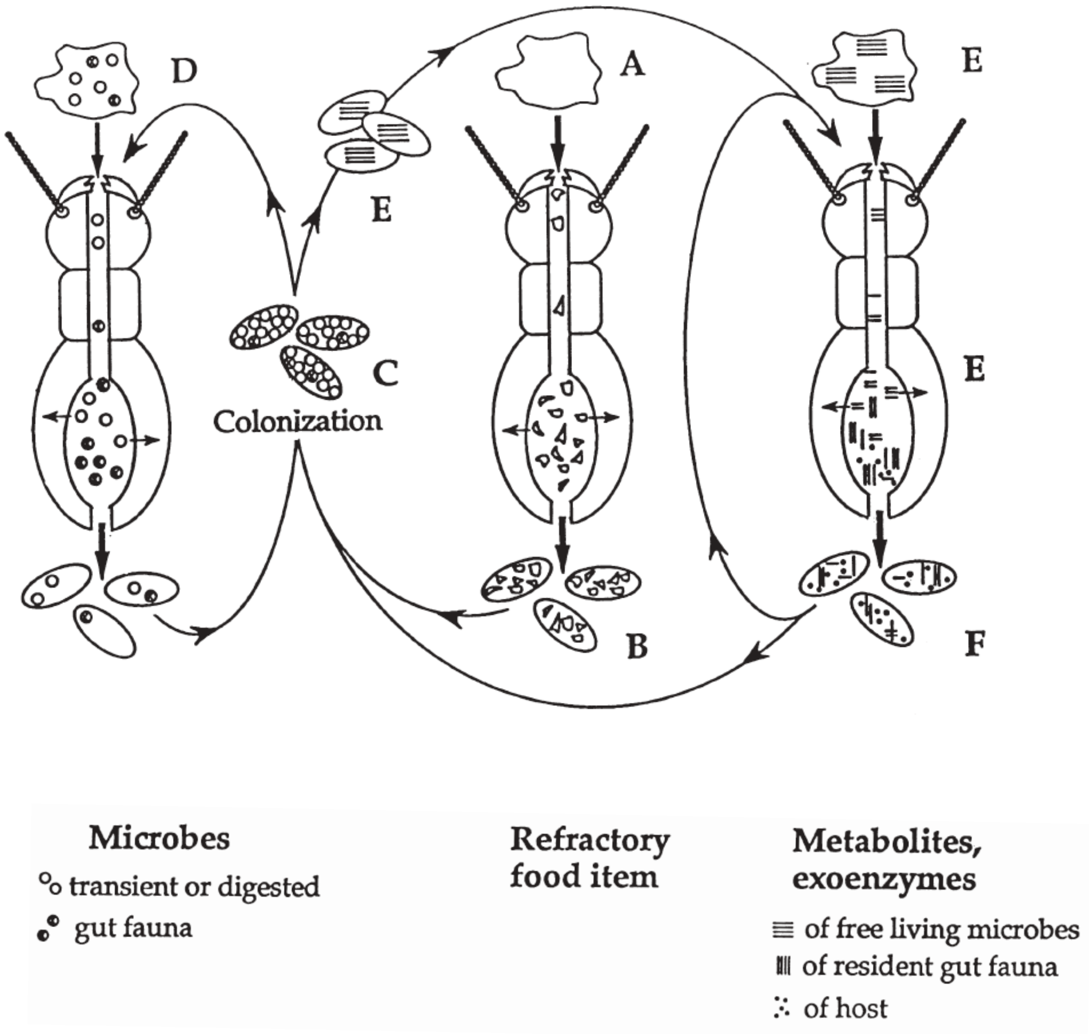
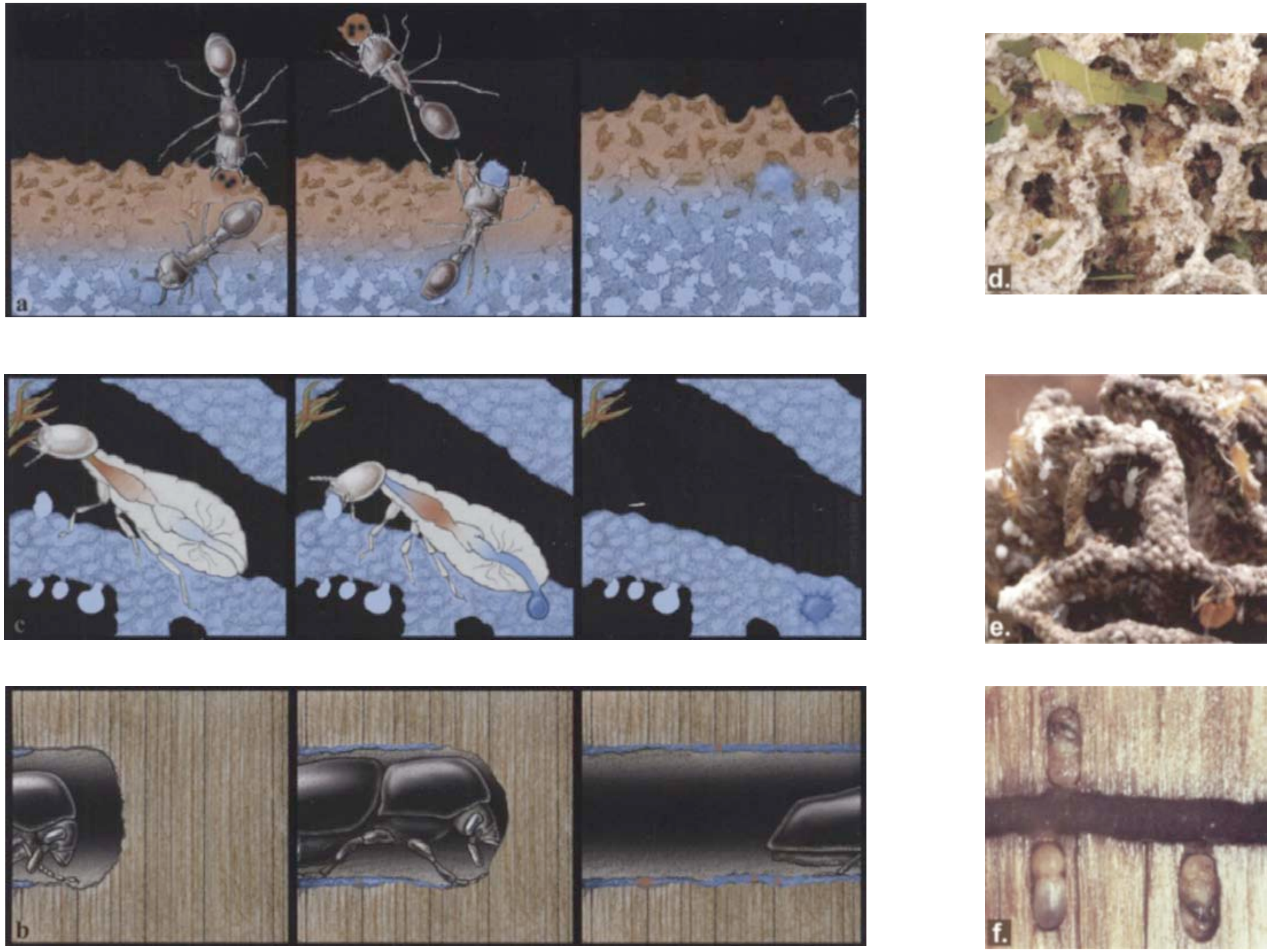


The Evolution of Agriculture in Insects

Ulrich G. Mueller,[1,2] Nicole M. Gerardo,[1,2,3]
Duur K. Aanen,[4] Diana L. Six,[5] and Ted R. Schultz[6]

Annu. Rev. Ecol. Evol. Syst. 2005. 36:563–95

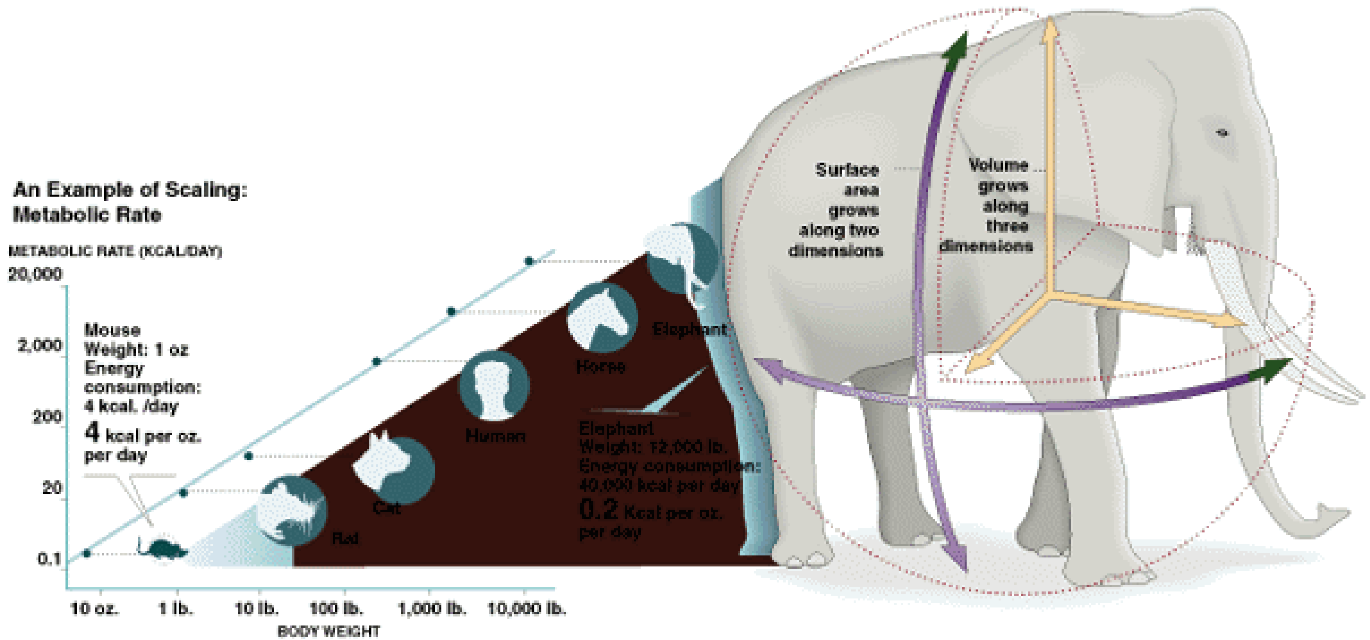


Body size

Most biologists consider body mass the most important characteristic of an organism. It is also (mostly) easy to measure.

All morphological and physiological traits scale somehow with body mass.

"Scaling is interesting because, aside from natural selection, it is one of the few laws we really have in biology." John Gittleman



Two fundamental questions

1. "In-house" or outsourcing of fibre digestion?

"In-house" fibre digestion necessitates anatomical and physiological adaptations that might be costly in some circumstances.

Outsourcing is only feasible at small body sizes where you have high encounter rates with nutritionally relevant amounts of microorganisms.

(although there are billions of microorganisms in this room, their mass is not enough to meet the daily energy requirements of a single member of the audience)

Fibre digestion

Organic polymers
(cellulose, hemicellulose)

↓

Hydrolysis
(soluble sugars)

↓

Primary fermentation
(lactate, succinate)

↓

Secondary fermentation

acetate, propionate, butyrate | H_2 | CO_2

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($C_2H_3O_2$, H_2O)

Methanogenesis
(CH_4, H_2O)

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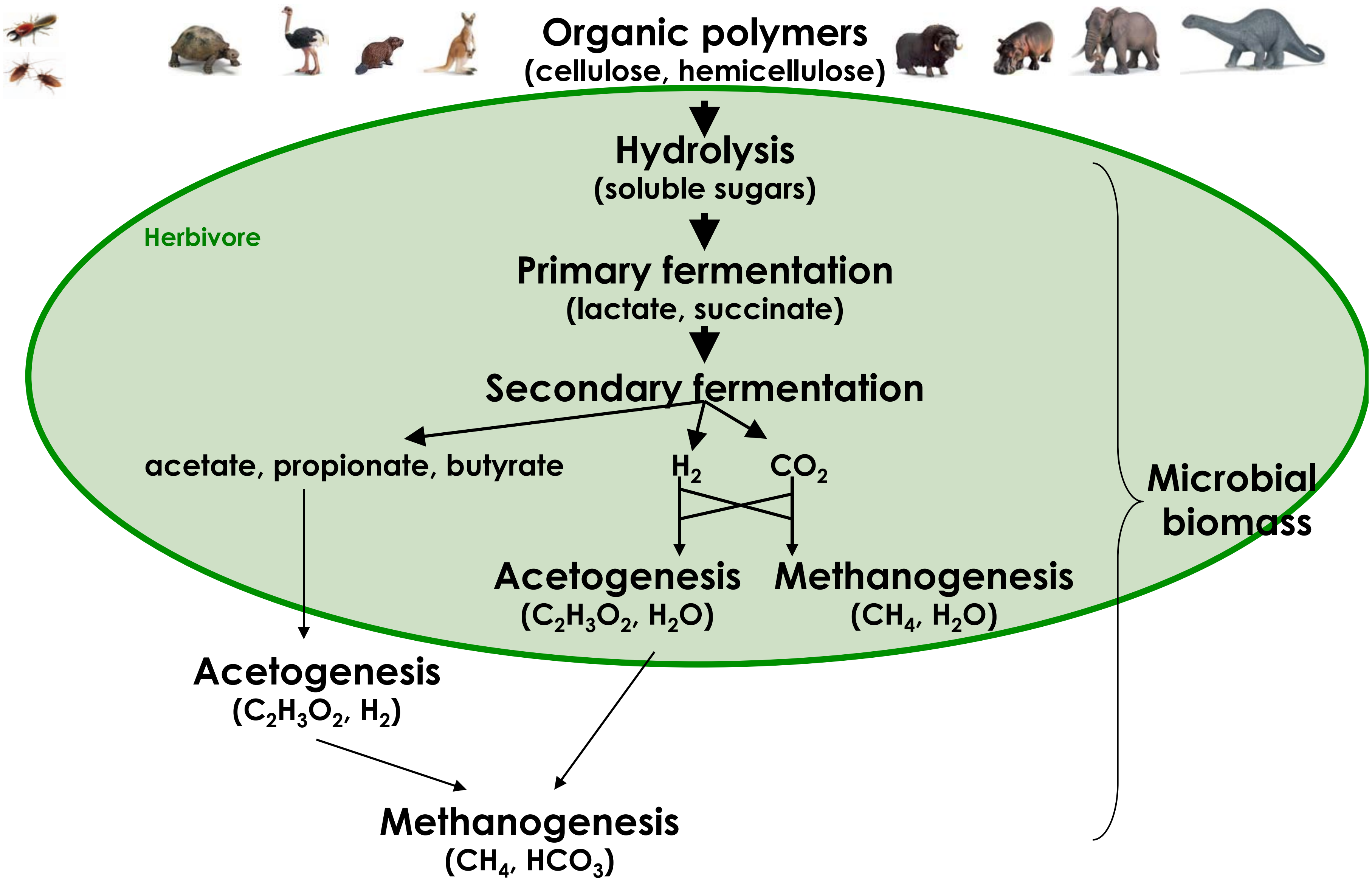
Methanogenesis
(CH_4, HCO_3)

Microbial biomass

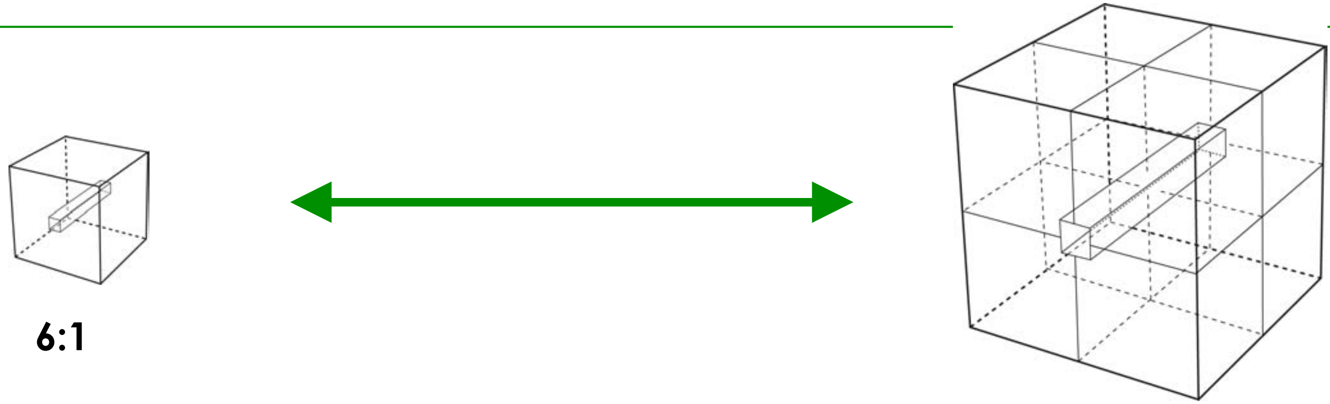
from Karasov & Martinez del Rio (2007)

Fibre digestion



from Karasov & Martinez del Rio (2007)

Surface/volume geometry



6:1

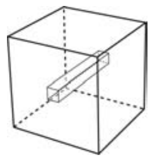
24:8=3:1

... affects all surface-related processes

heat loss - - - -► **energy requirements** - - - -► **food intake**

from Clauss & Hummel (2005)

Surface/volume geometry



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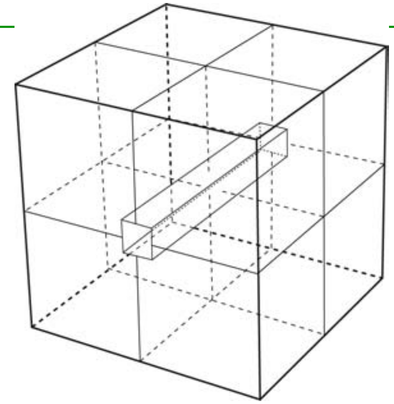
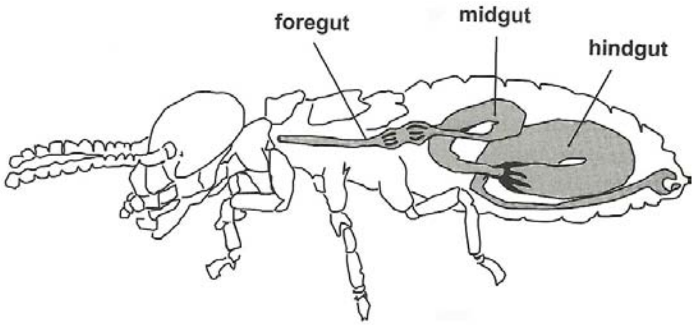
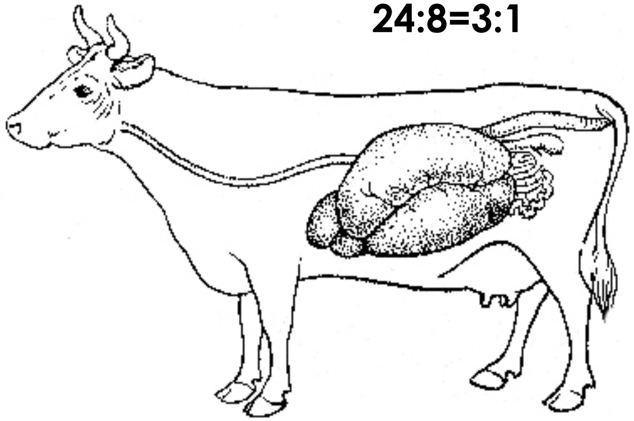


24:8=3:1

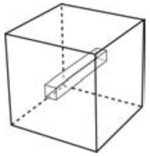
... affects all surface-related processes





from Karasov & Martinez del Rio (2007)

Surface/volume geometry



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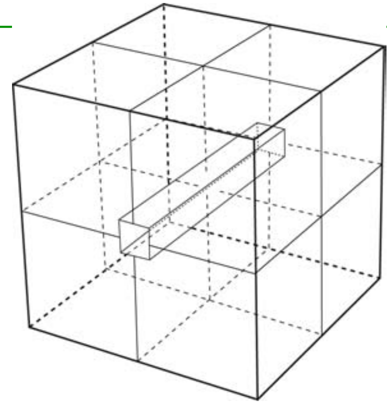

24:8=3:1

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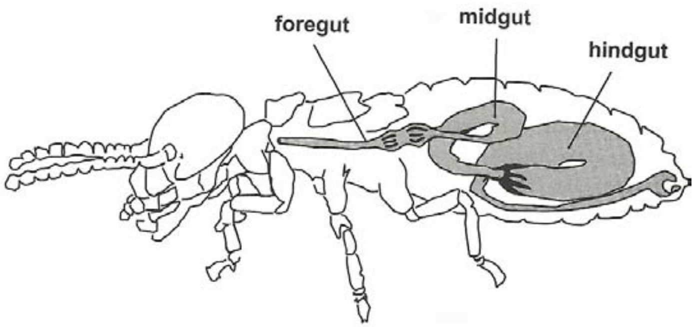
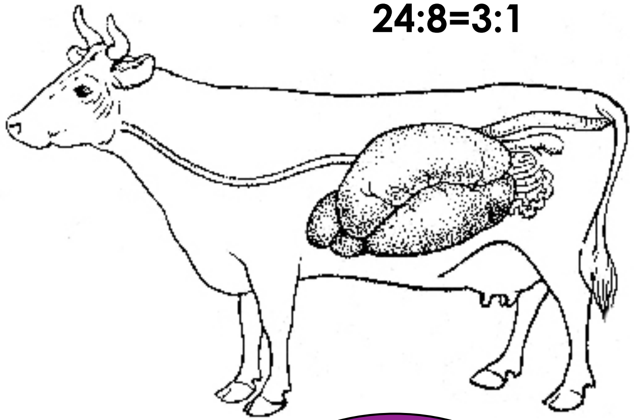
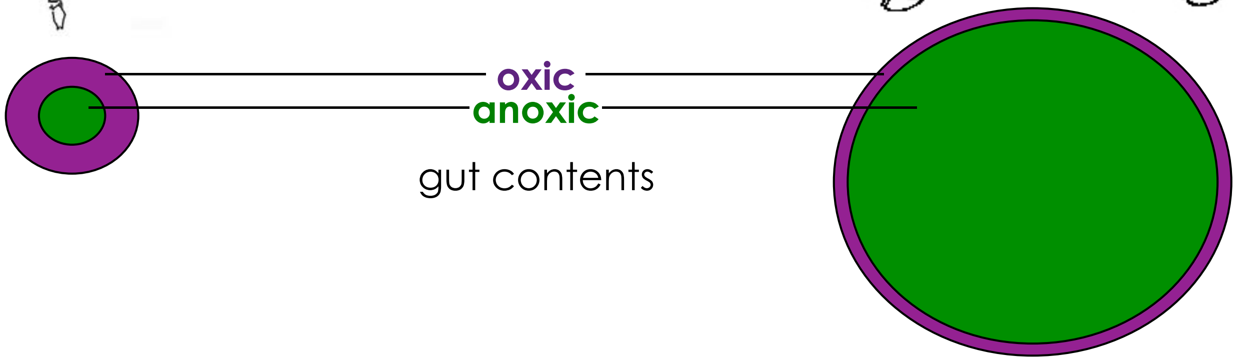
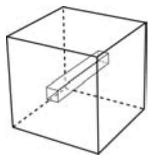






from Karasov & Martinez del Rio (2007)

Surface/volume geometry



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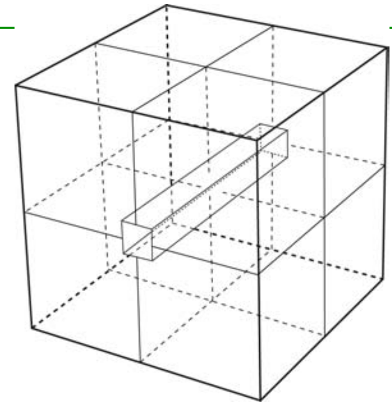

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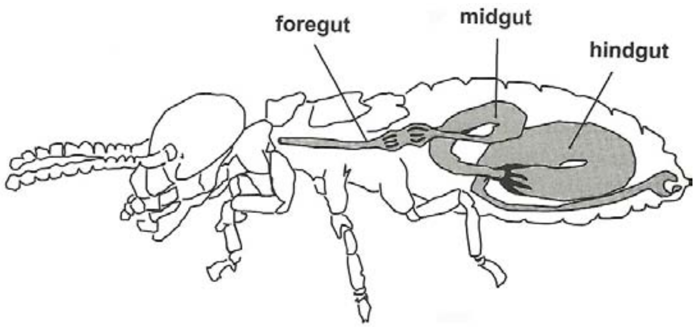
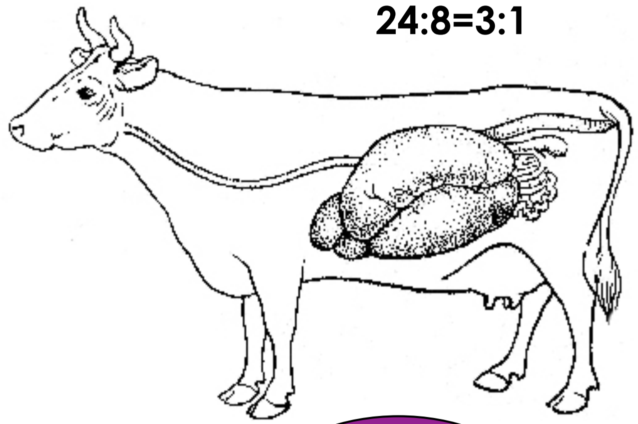
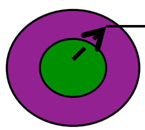
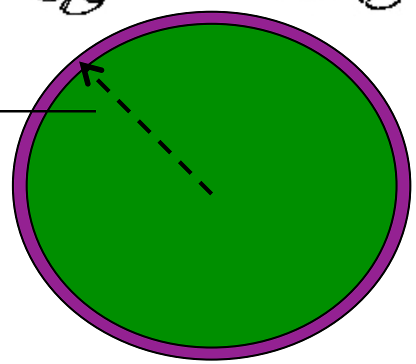






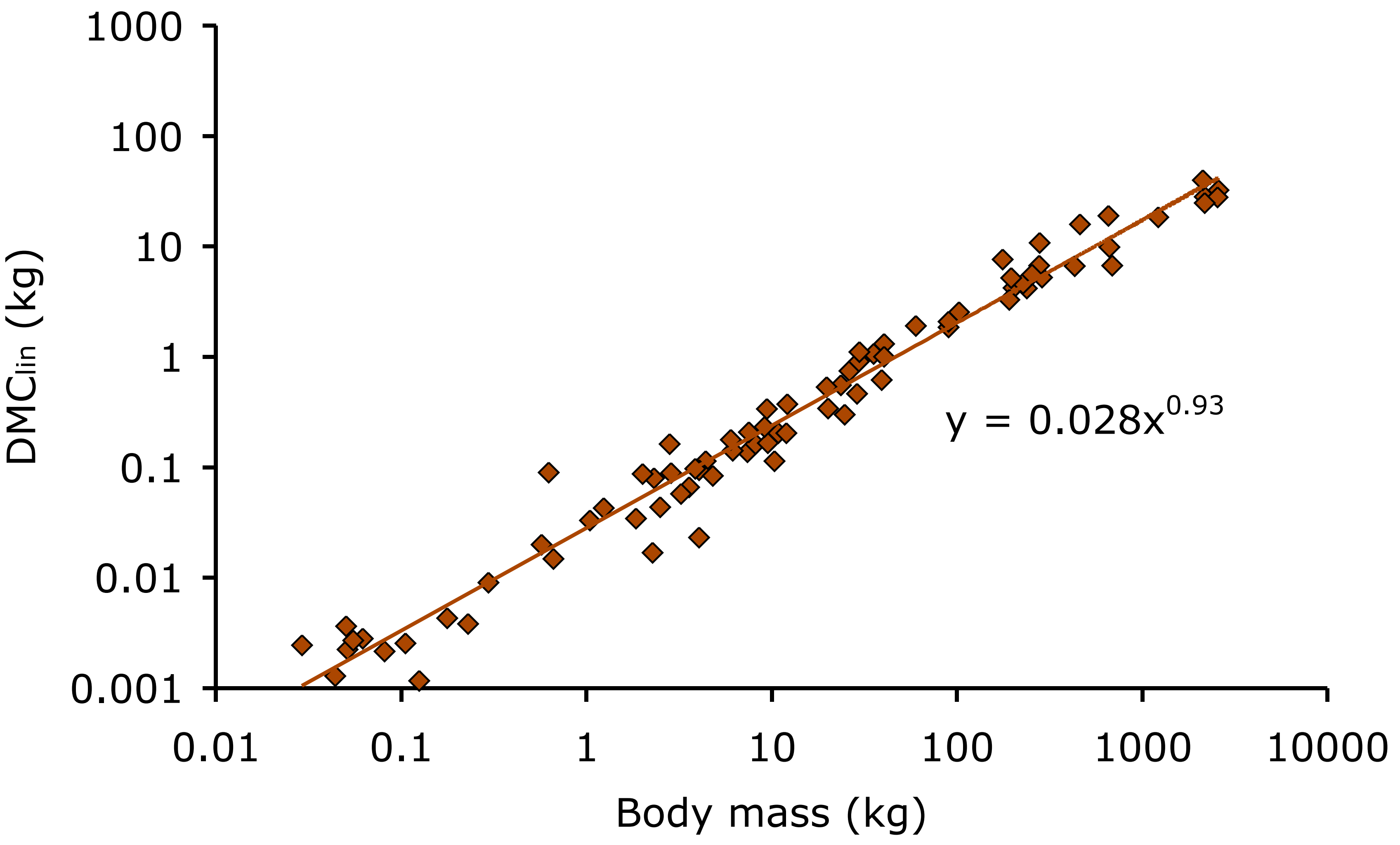
short
long

diffusion ways



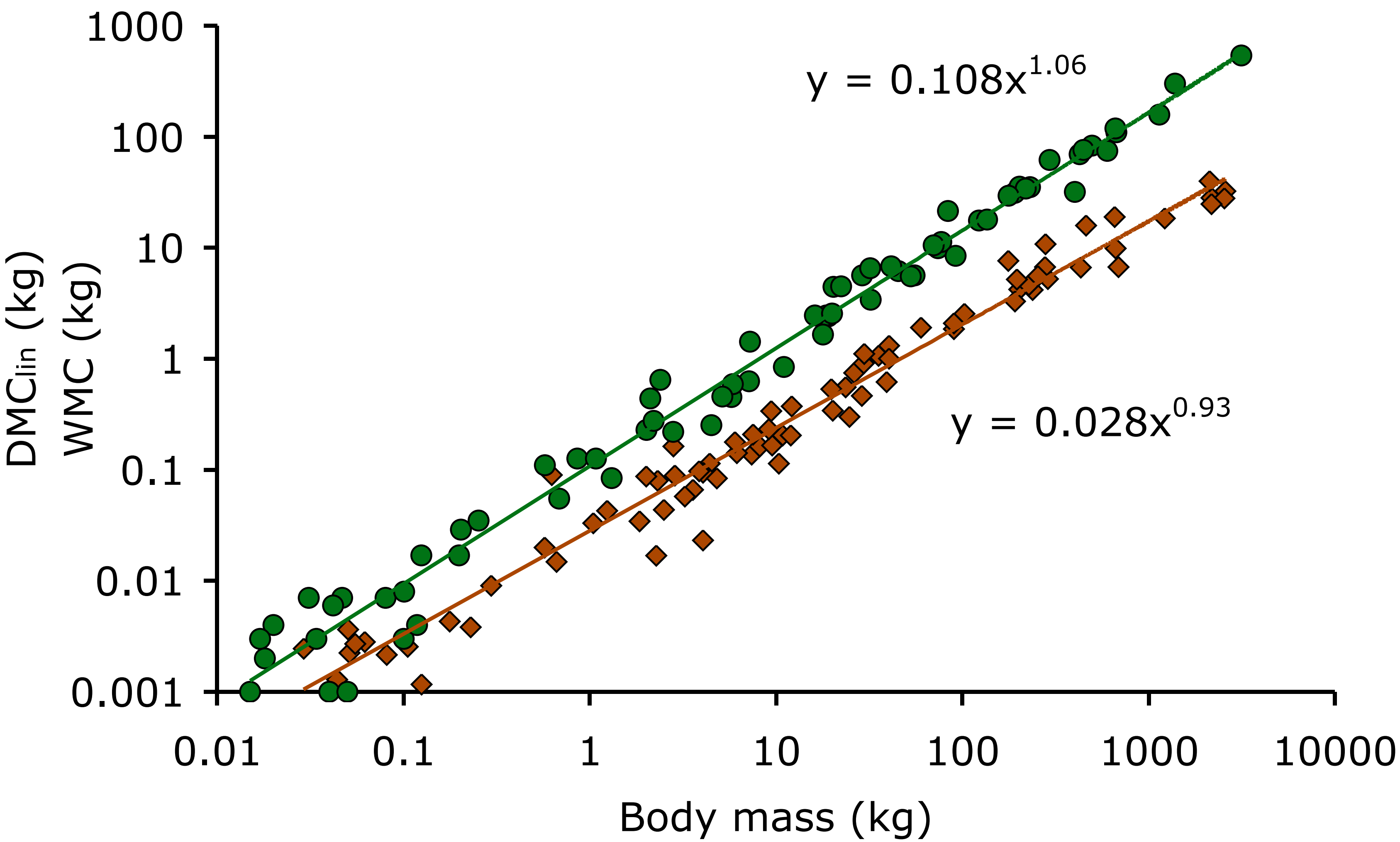
from Karasov & Martinez del Rio (2007)

Gut moisture content



from Müller et al. (2013)

Gut moisture content



from Müller et al. (2013)

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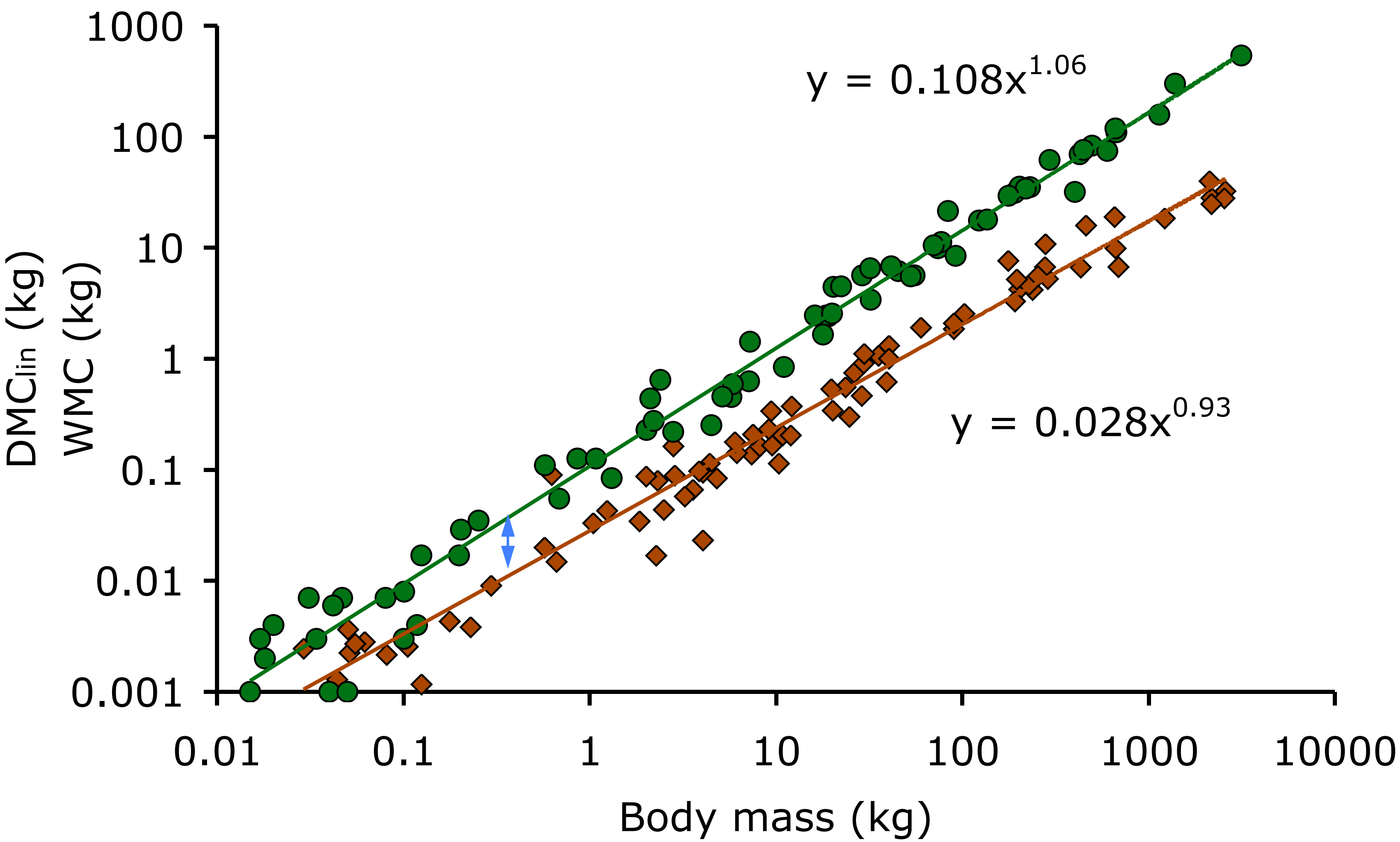
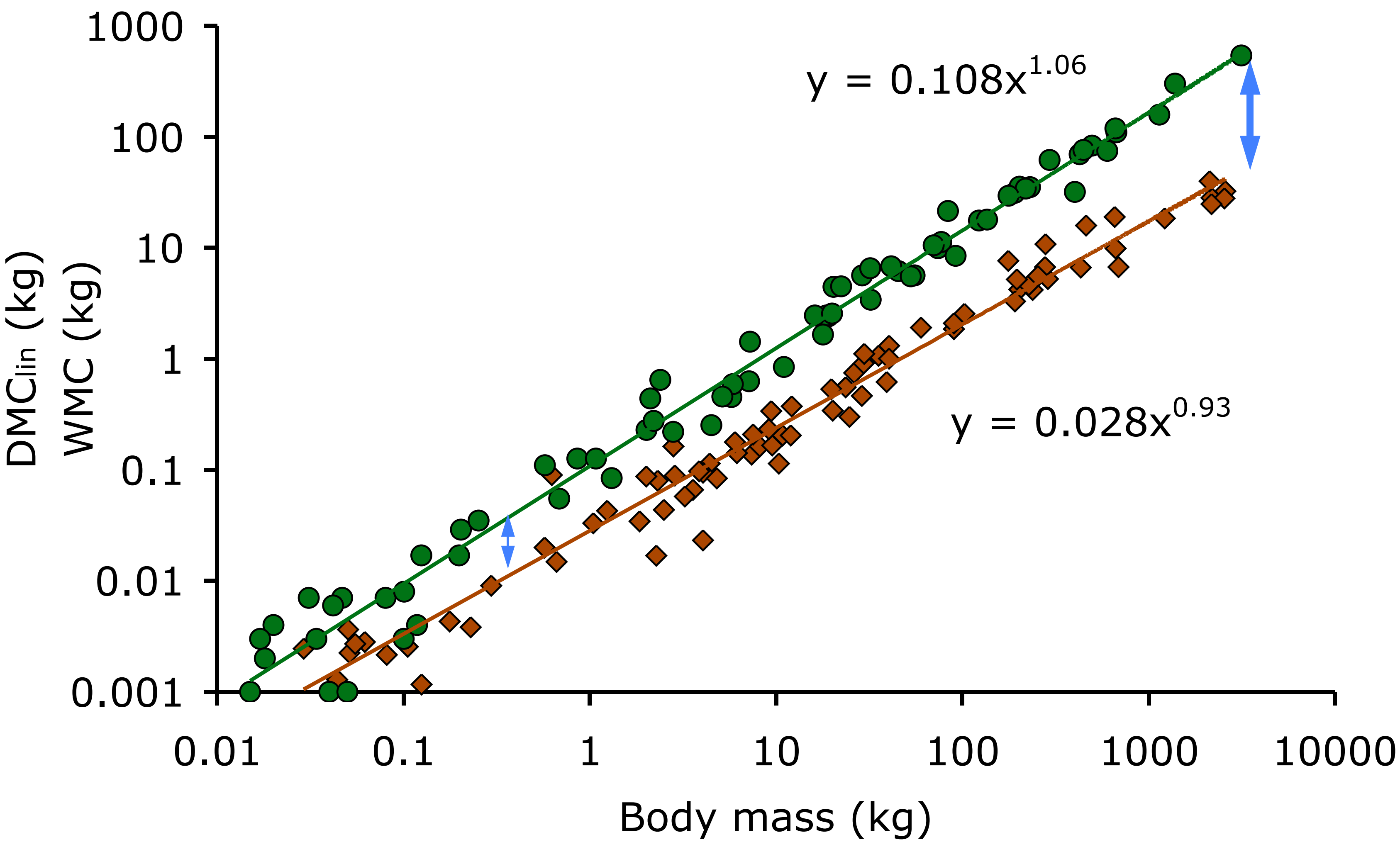


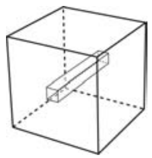
from Müller et al. (2013)

Gut moisture content



from Müller et al. (2013)

Surface/volume geometry



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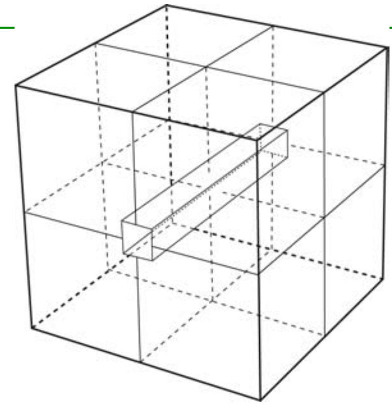

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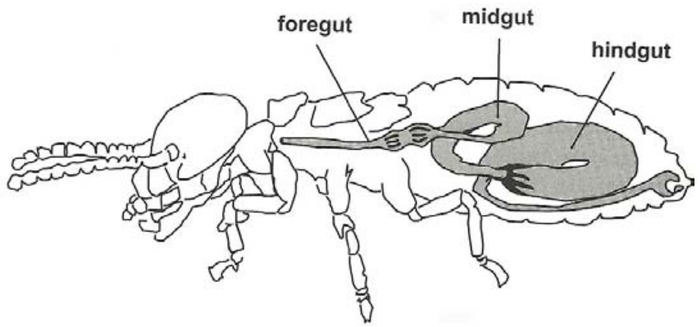

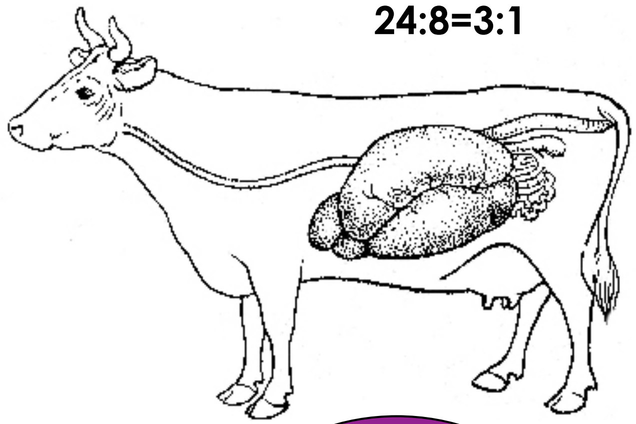

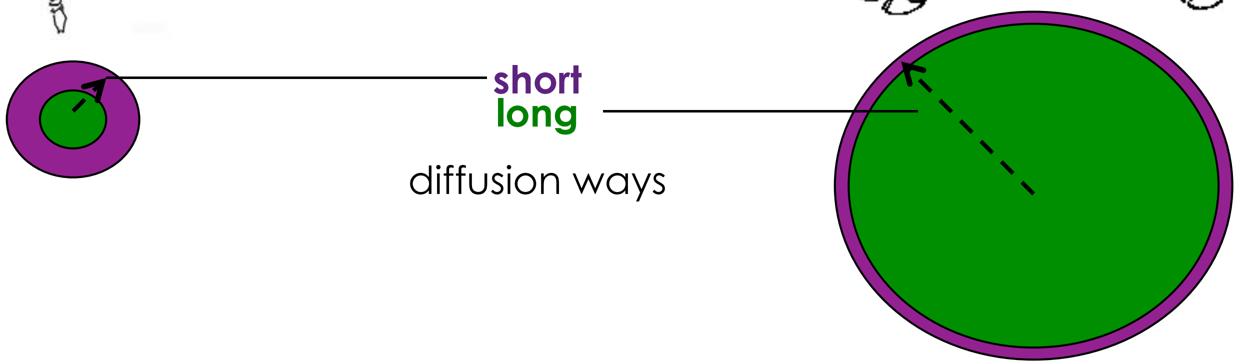

from Karasov & Martinez del Rio (2007)

Herbivory
-
Principles
(digestive tracts)

Two fundamental questions

2. What sequence of fibre digestion and auto-enzymatic digestion?

- fibre digestion prior to auto-enzymatic digestion allows the use of bacterial biomass

- bacterial digestion after auto-enzymatic digestion allows more efficient use of those substrates that can be digested auto-enzymatically

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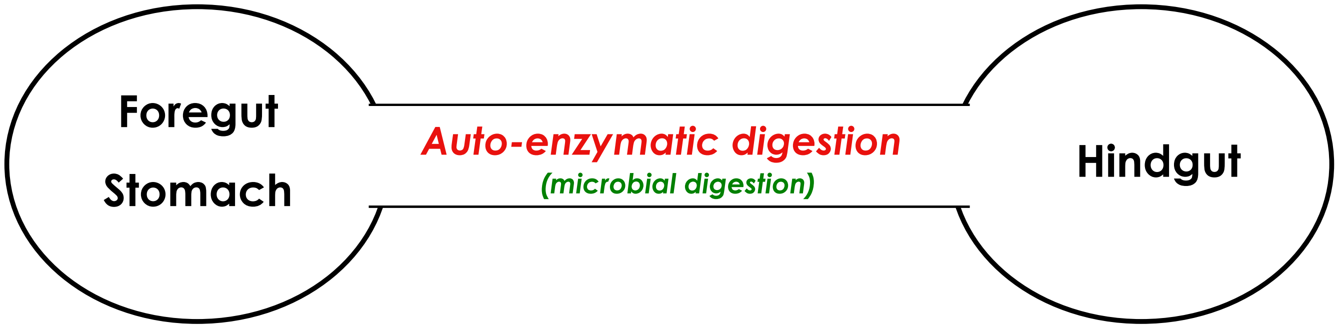

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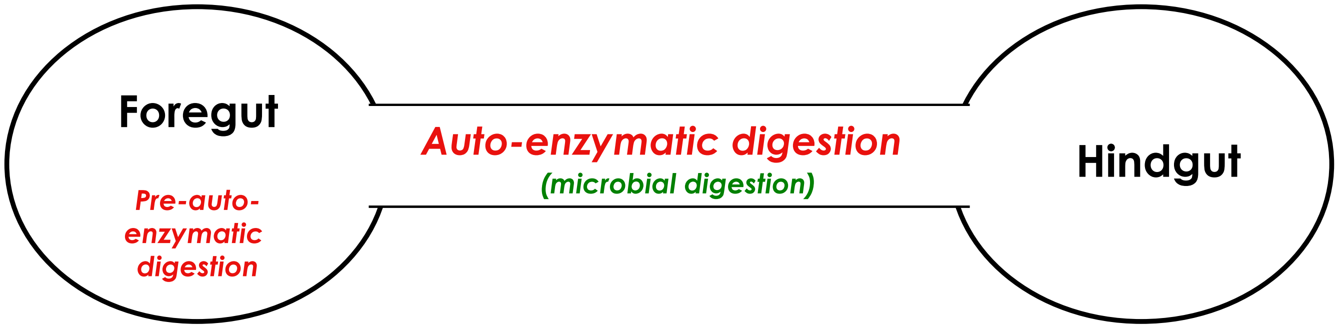

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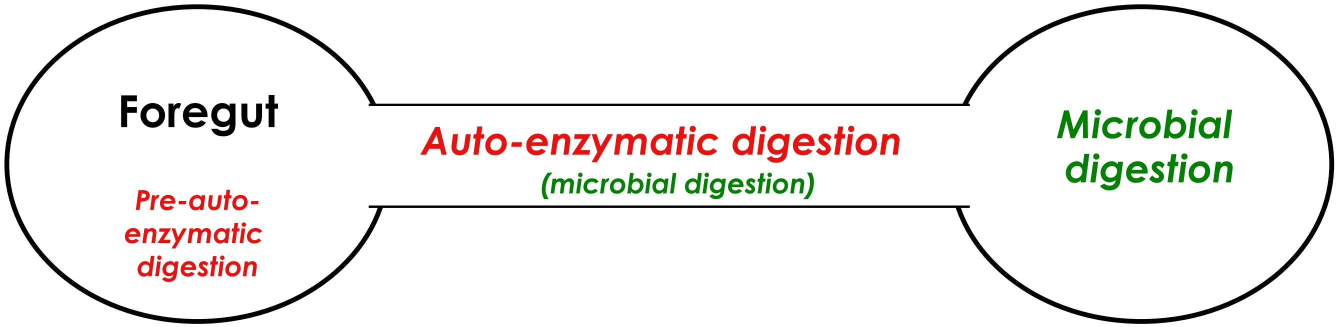

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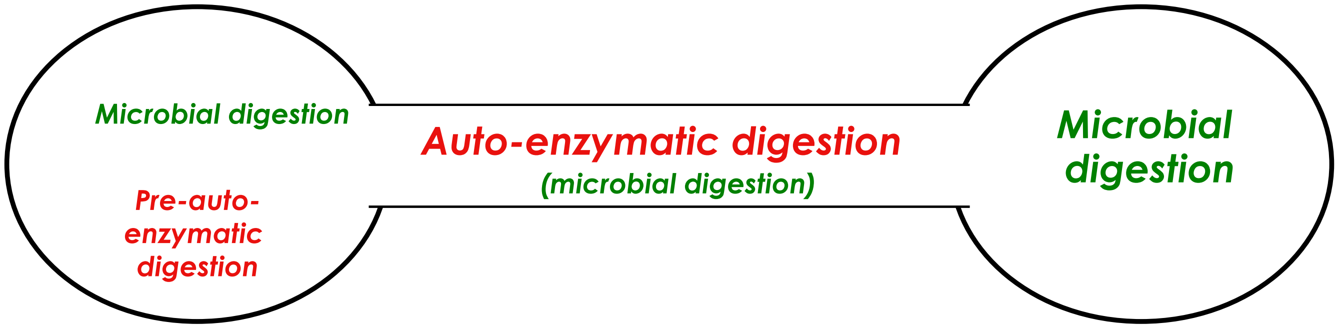

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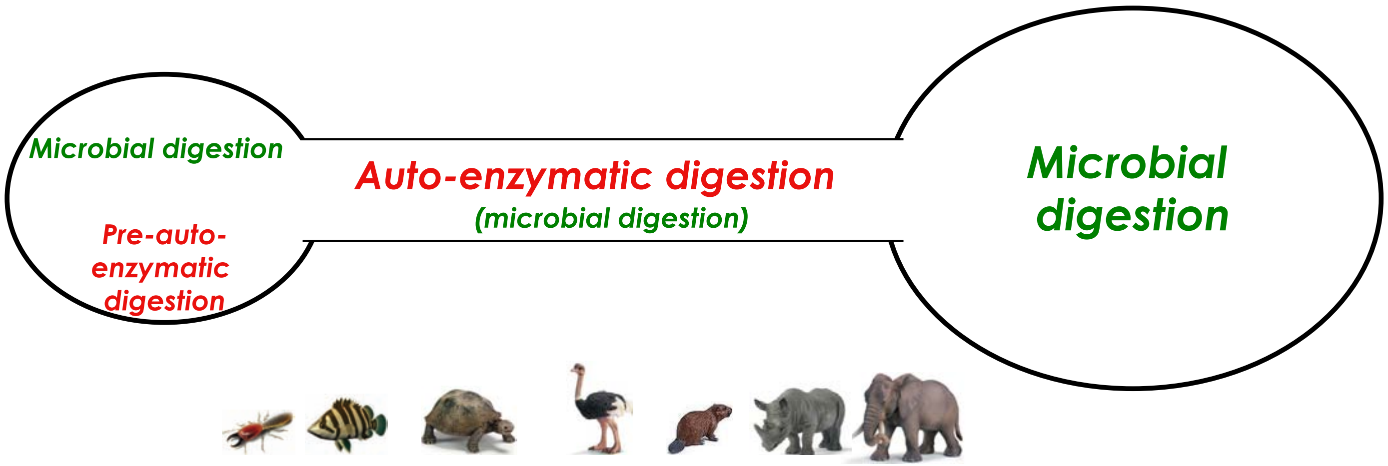

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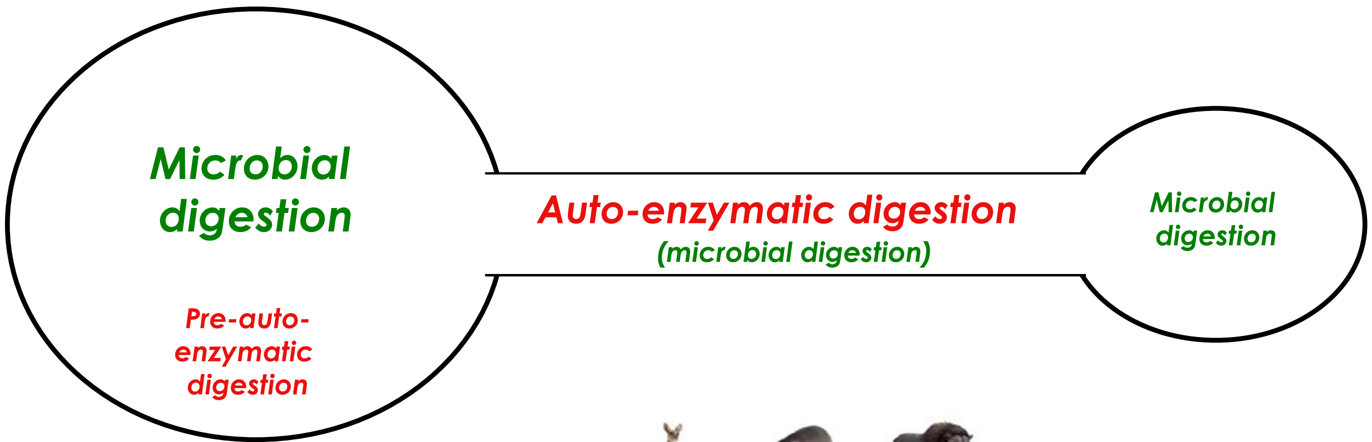

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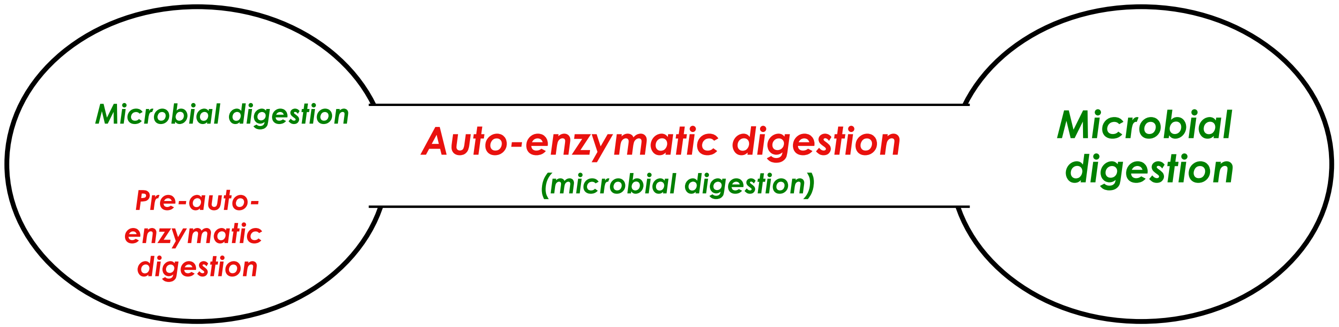

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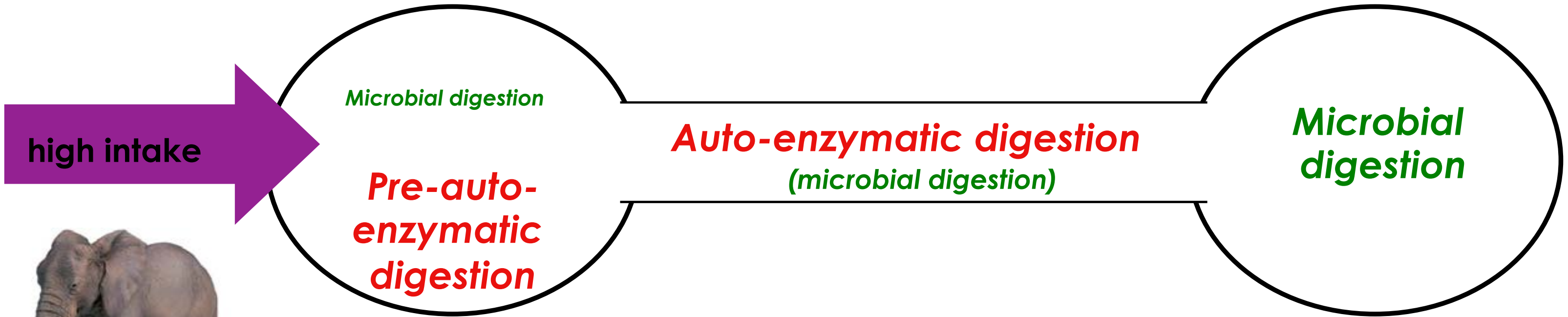

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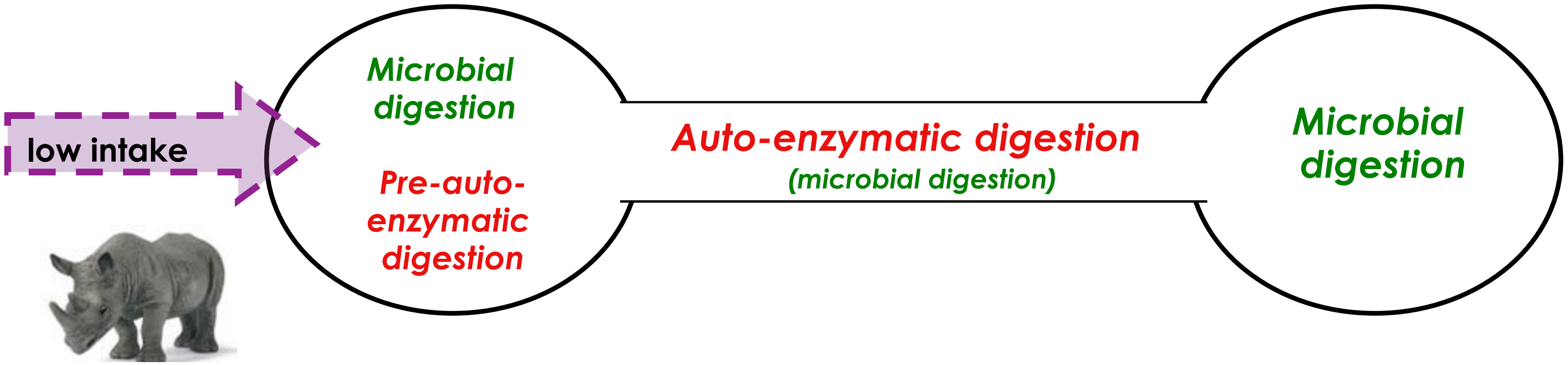
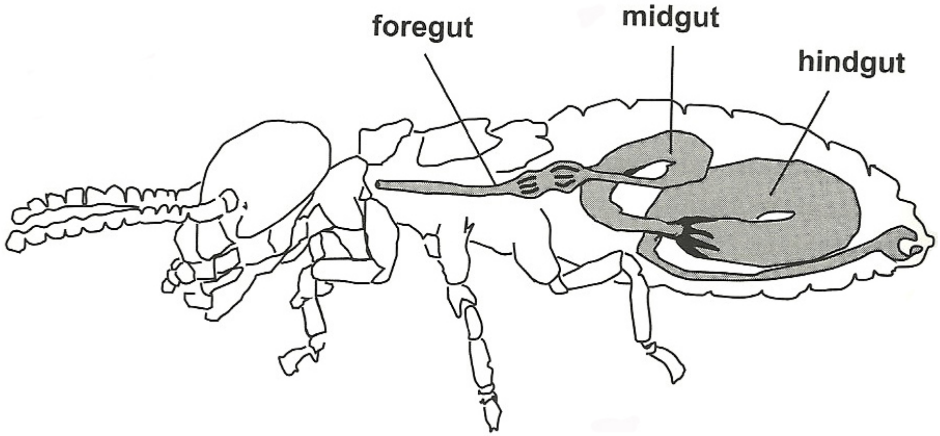


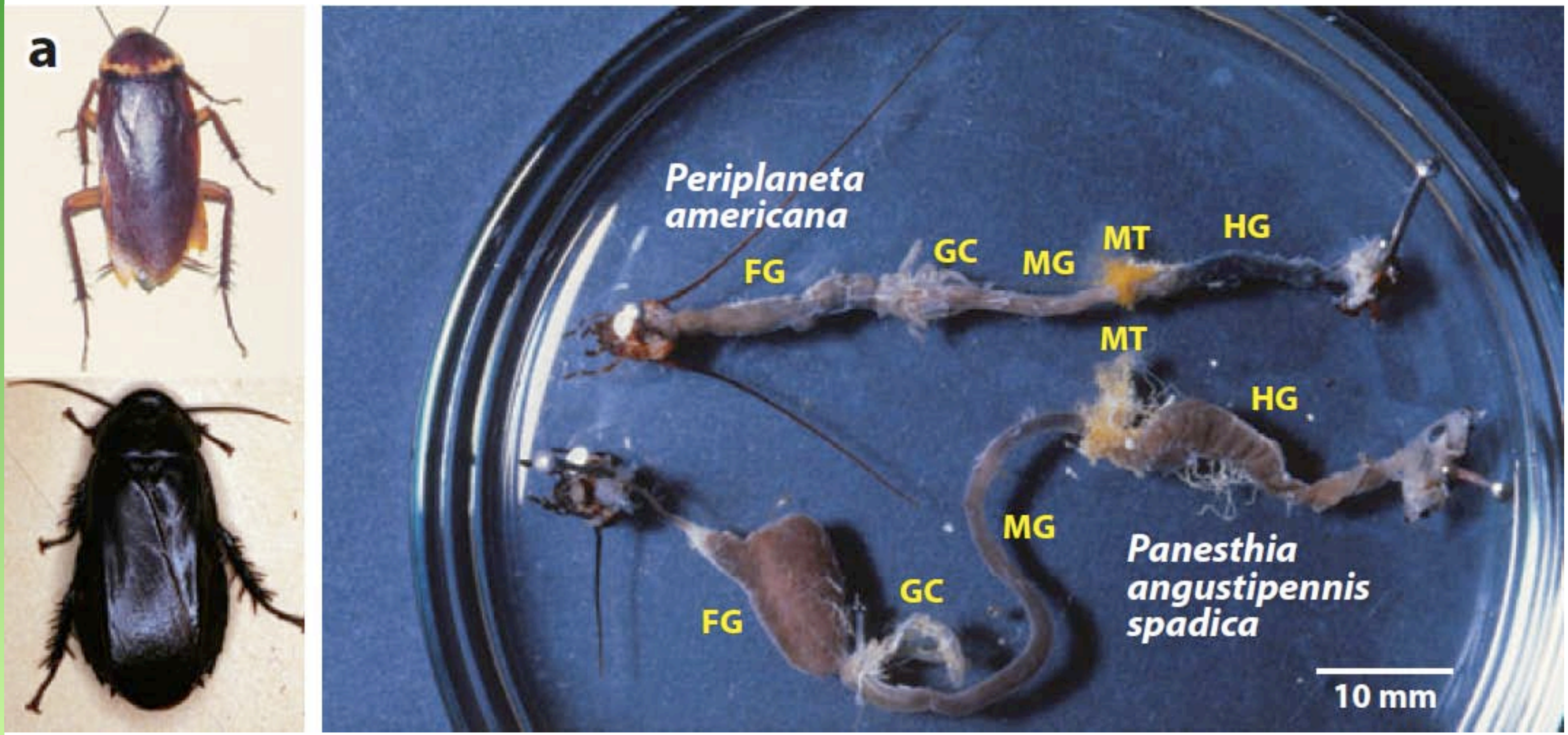
Hindgut fermentation - ‘the conventional approach’



Cellulolytic Systems in Insects

Hirofumi Watanabe[1] and Gaku Tokuda[2]

Annu. Rev. Entomol. 2010. 55:609–32



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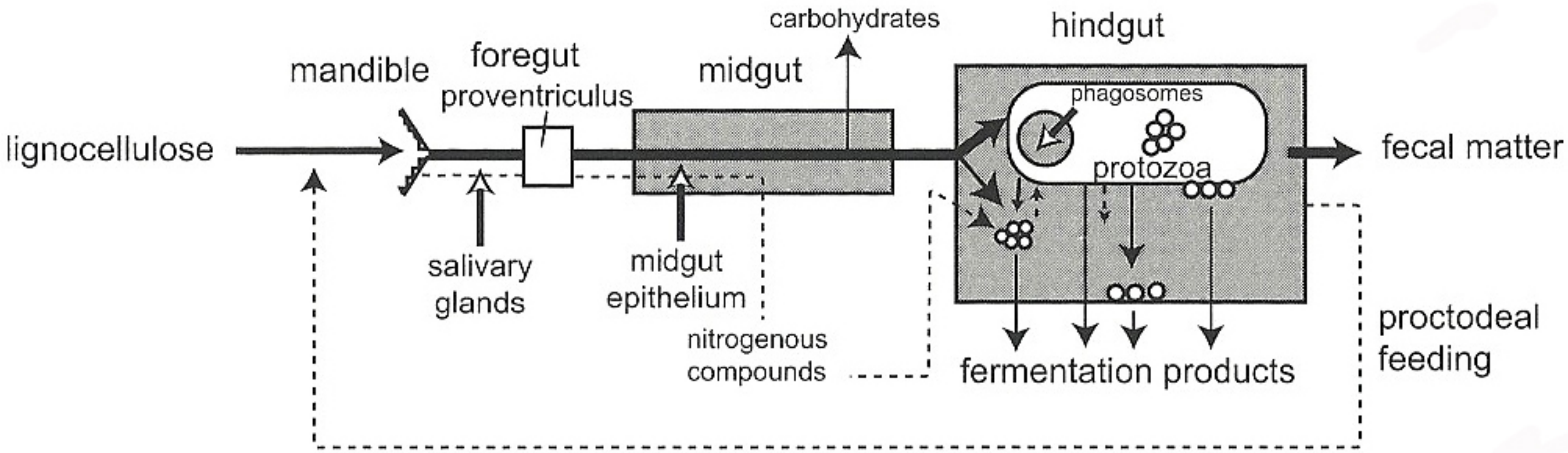
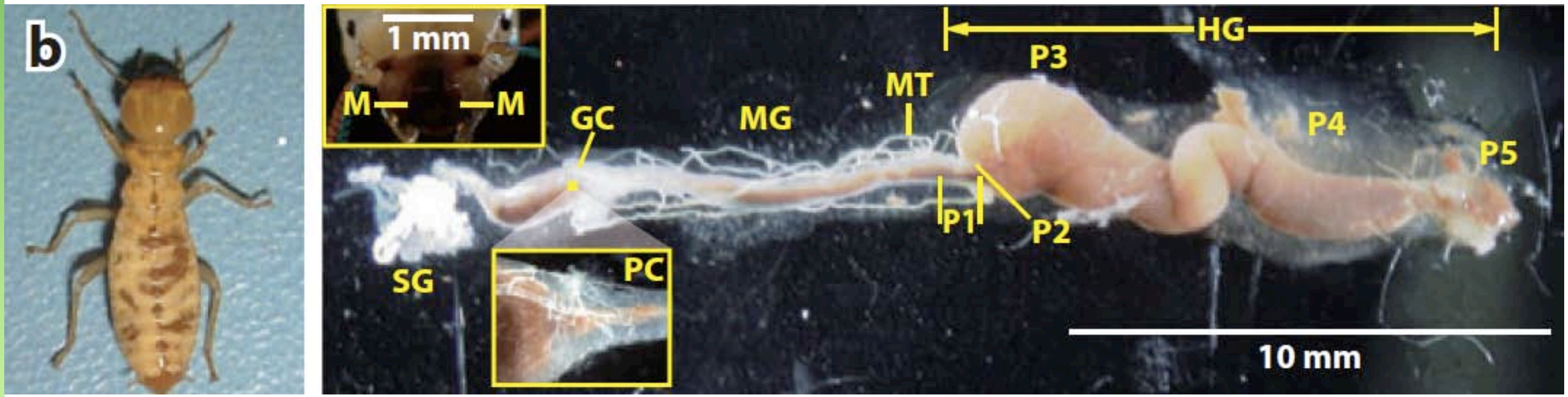


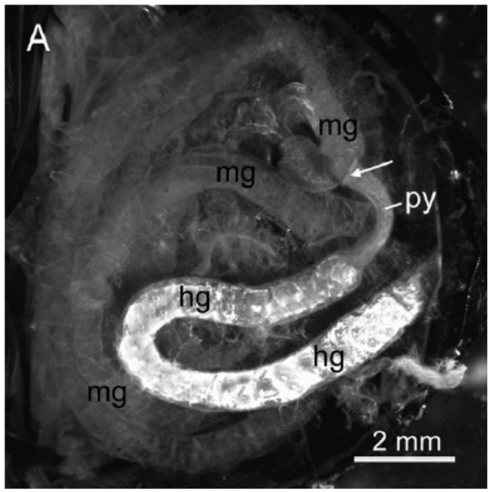


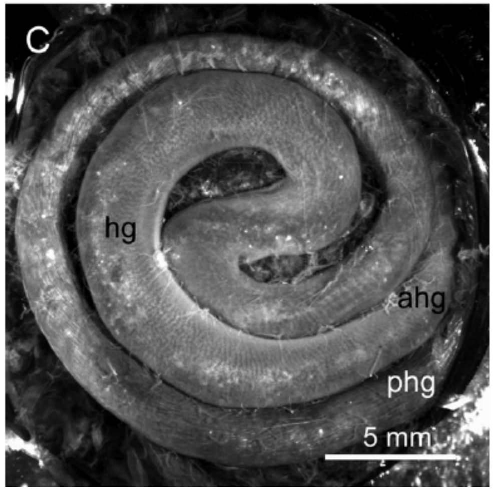
scheme from Karasov & Martinez del Rio (2007)

Elongated Hindguts in Desert-Living Dung Beetles (Scarabaeidae: Scarabaeinae) Feeding on Dry Dung Pellets or Plant Litter

Peter Holter[1]* and Clarke H. Scholtz[2]

JOURNAL OF MORPHOLOGY 274:657–662 (2013)





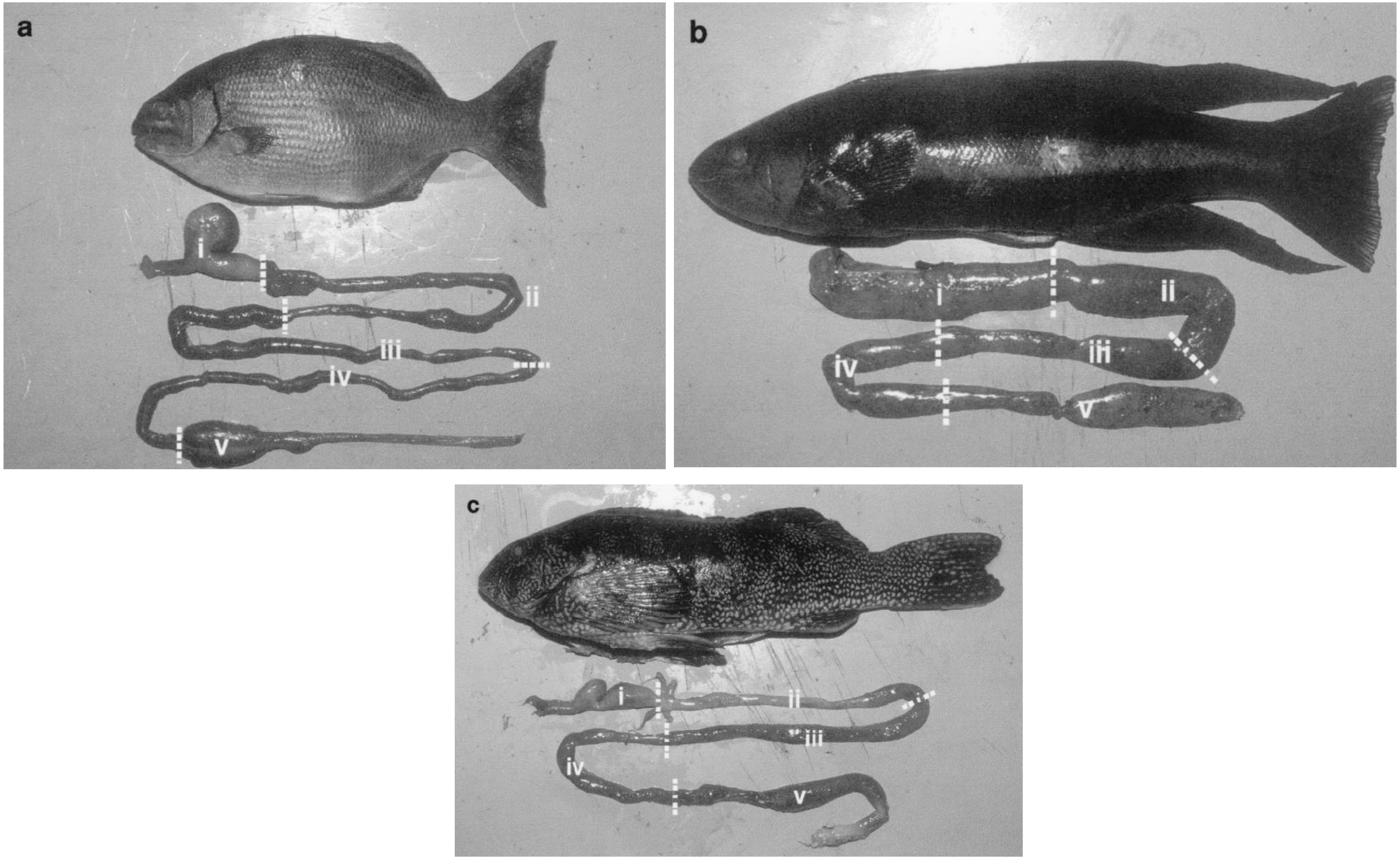
Scarabaeus spp.
(fresh dung)

Pachysoma spp.
(plant litter)

Hindgut Fermentation in Three Species of Marine Herbivorous Fish

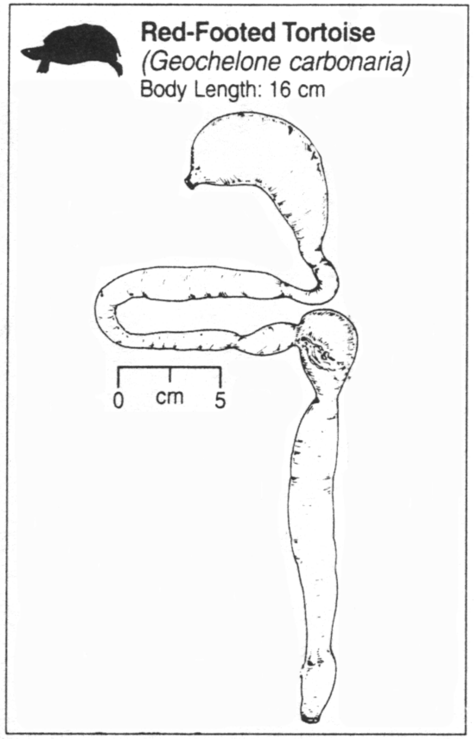
Douglas O. Mountfort,[1*] Jane Campbell,[2] and Kendall D. Clements[2]

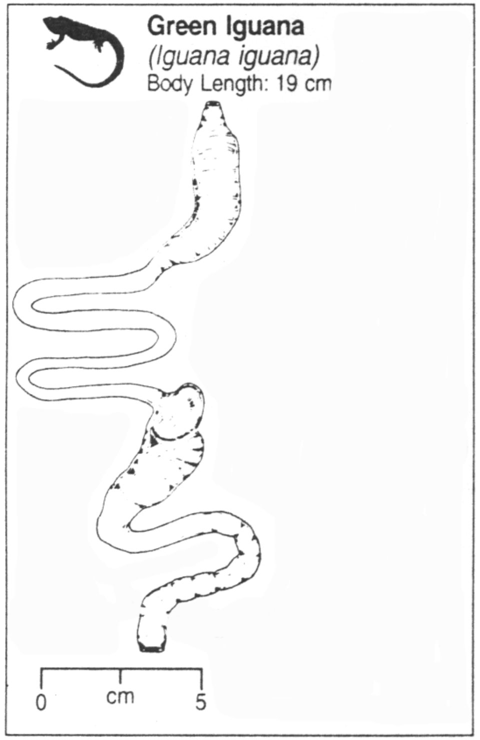
APPLIED AND ENVIRONMENTAL MICROBIOLOGY, Mar. 2002, p. 1374–1380



Herbivorous fish

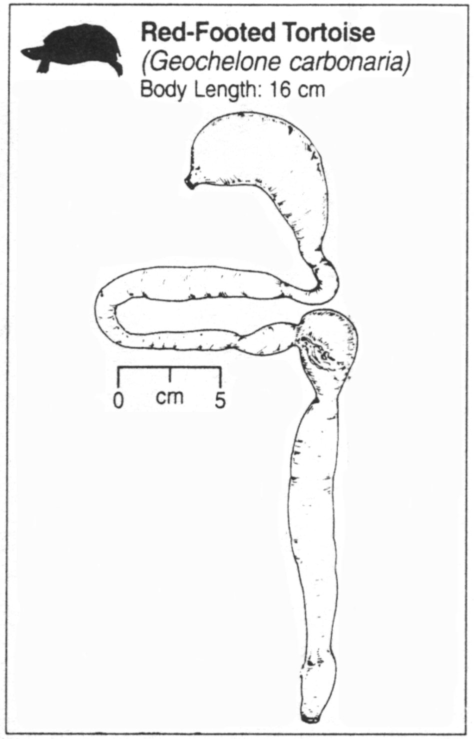
Hindgut Fermentation - Reptiles

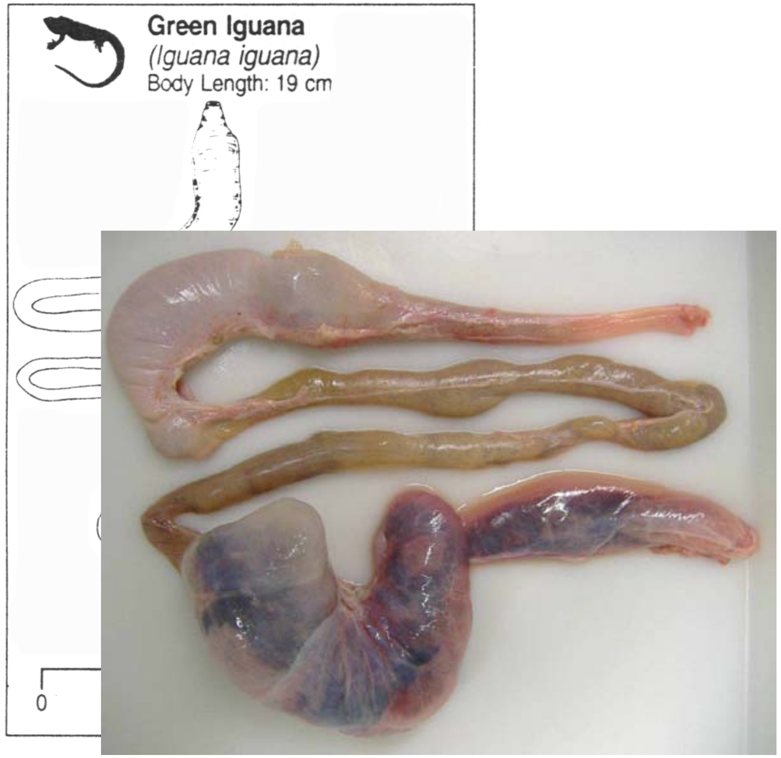




from Stevens & Hume (1995)

Hindgut Fermentation - Reptiles

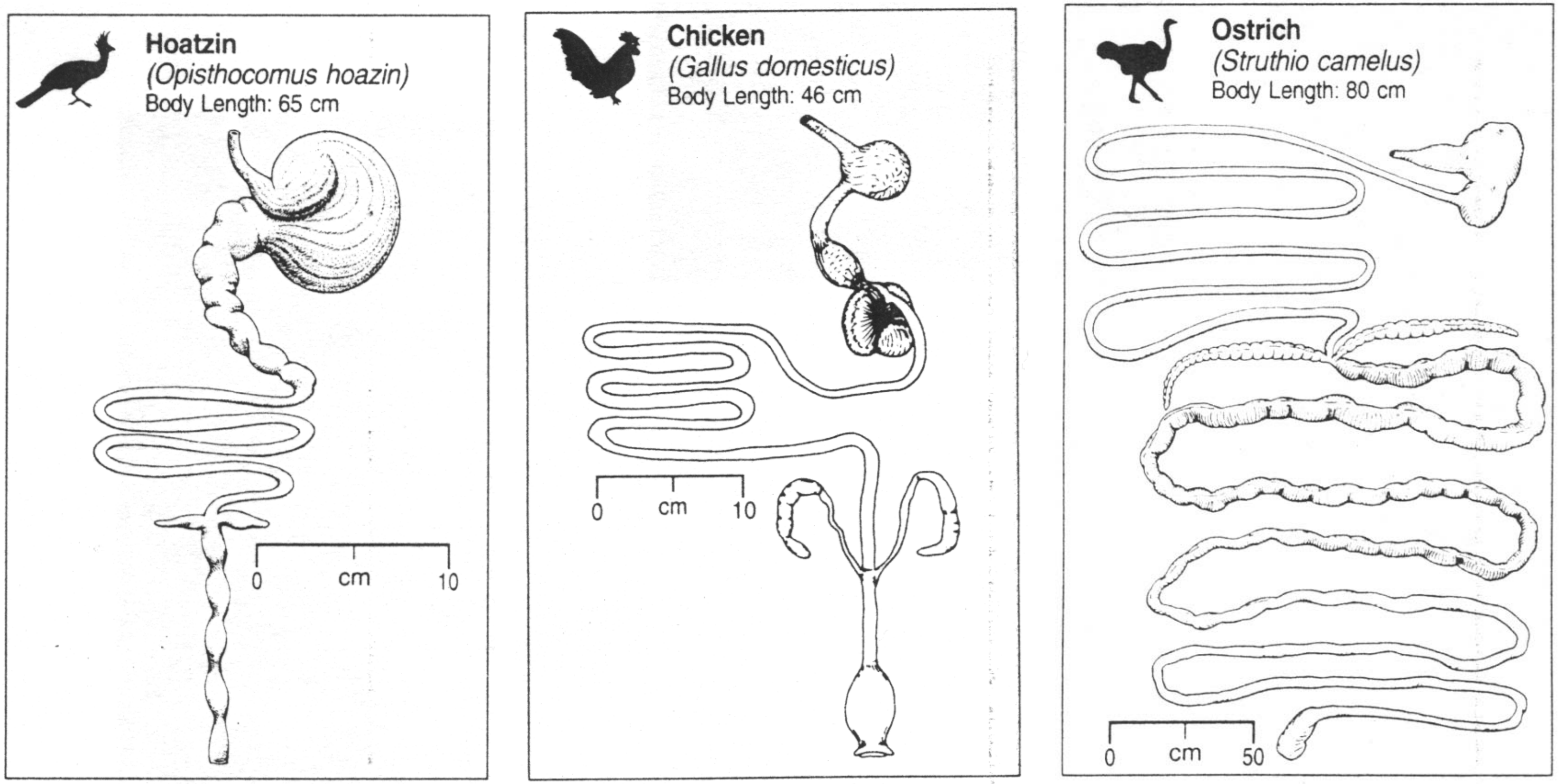




from Stevens & Hume (1995)

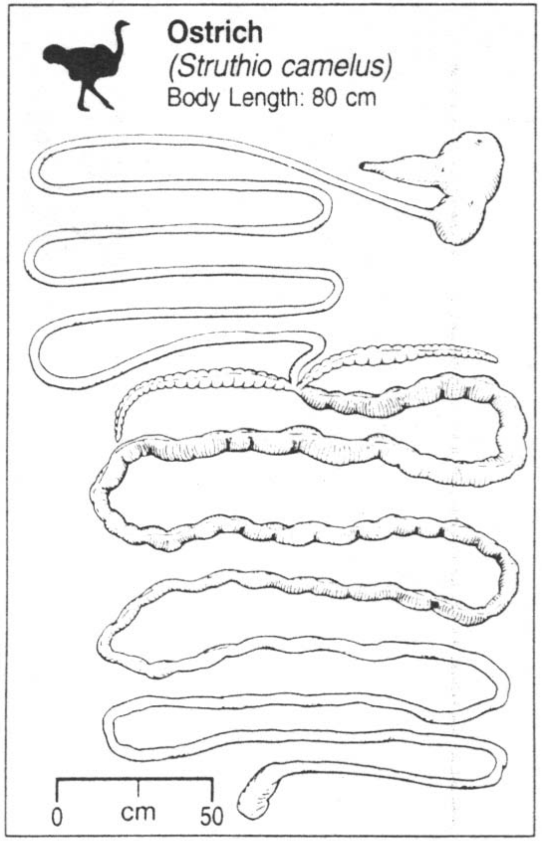
Photo: J. Fritz

Herbivores - Birds



from Stevens und Hume (1995)

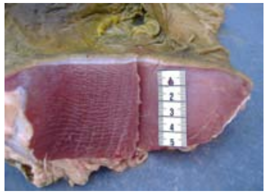
Herbivores - Birds



from Stevens und Hume (1995)
Photo: J. Fritz

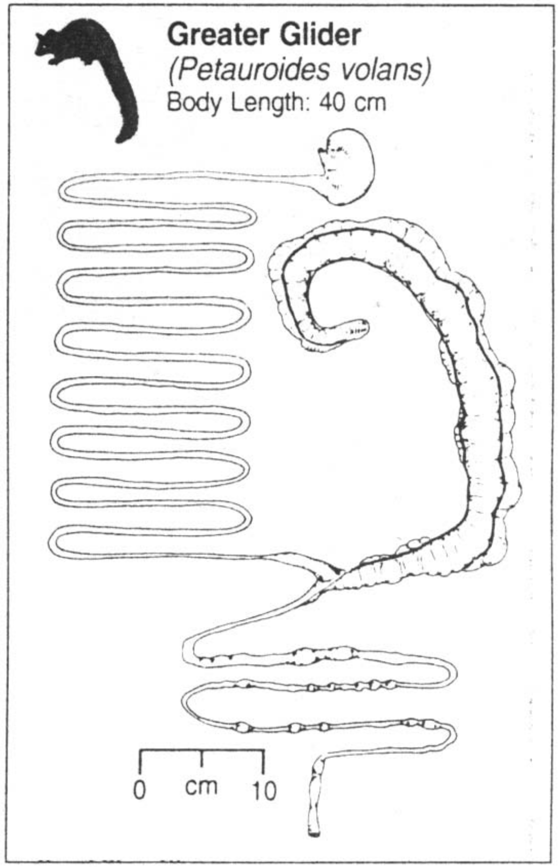
Herbivores - Birds

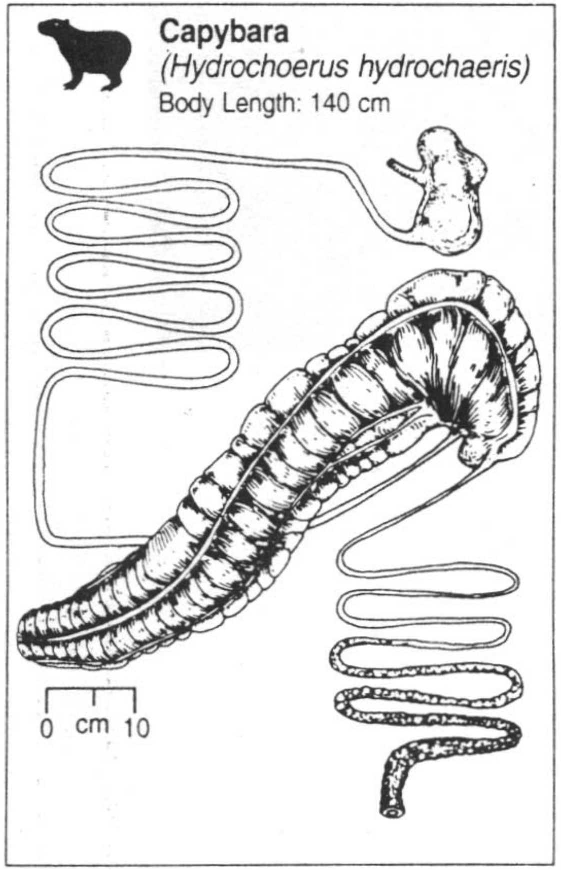


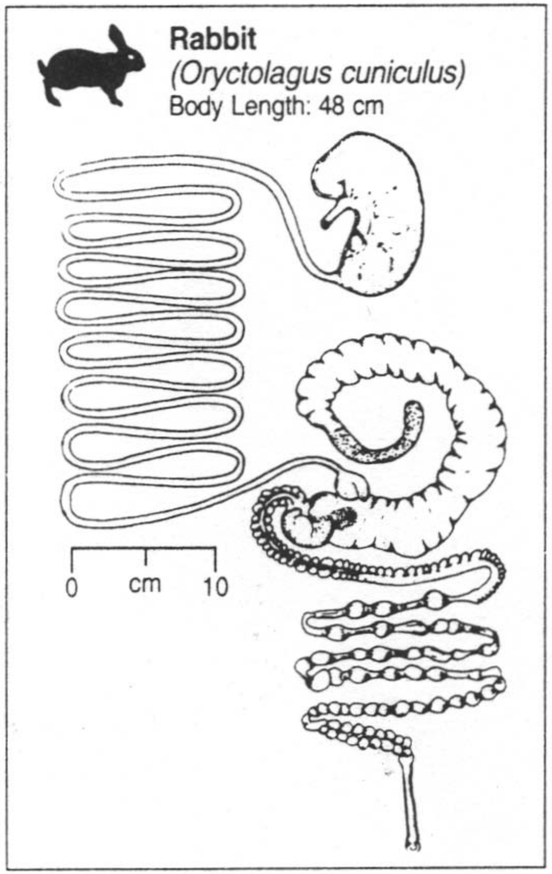



Photos: J. Fritz

Hindgut Fermentation - Caecum

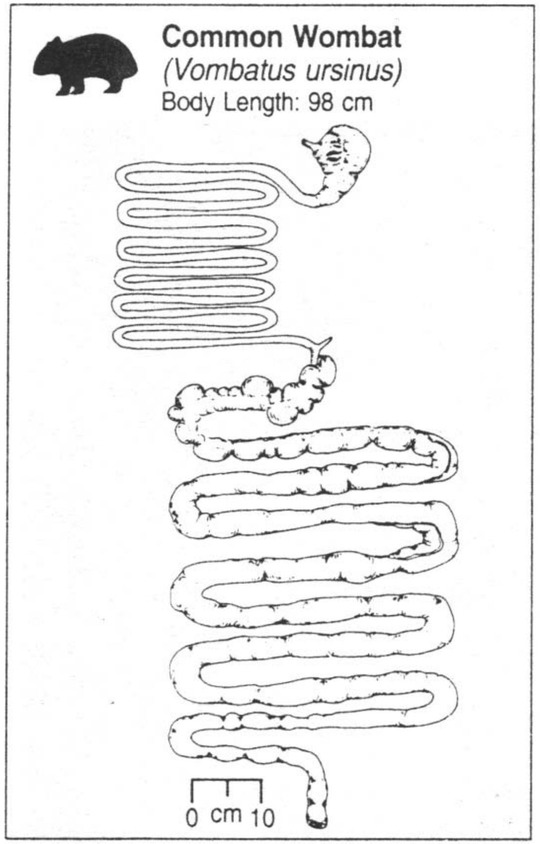


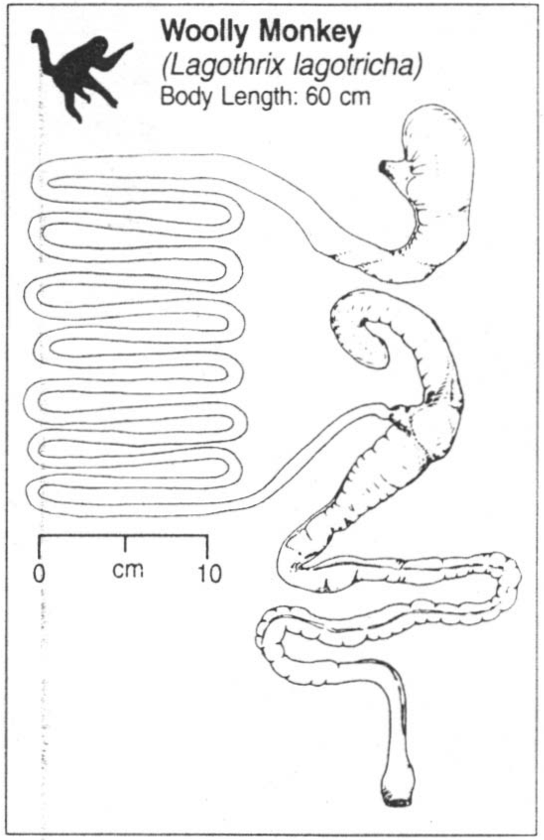


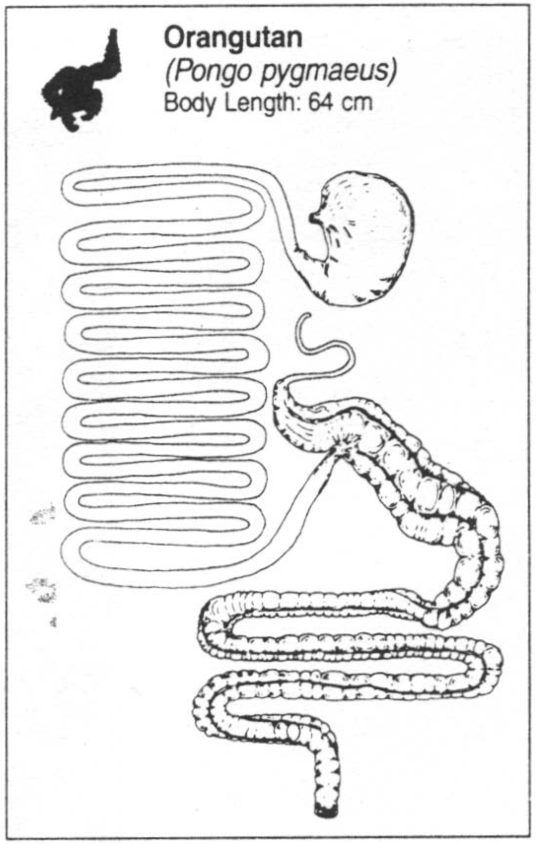


from Stevens & Hume (1995)

Herbivores - Colon fermenters







from Stevens und Hume (1995)

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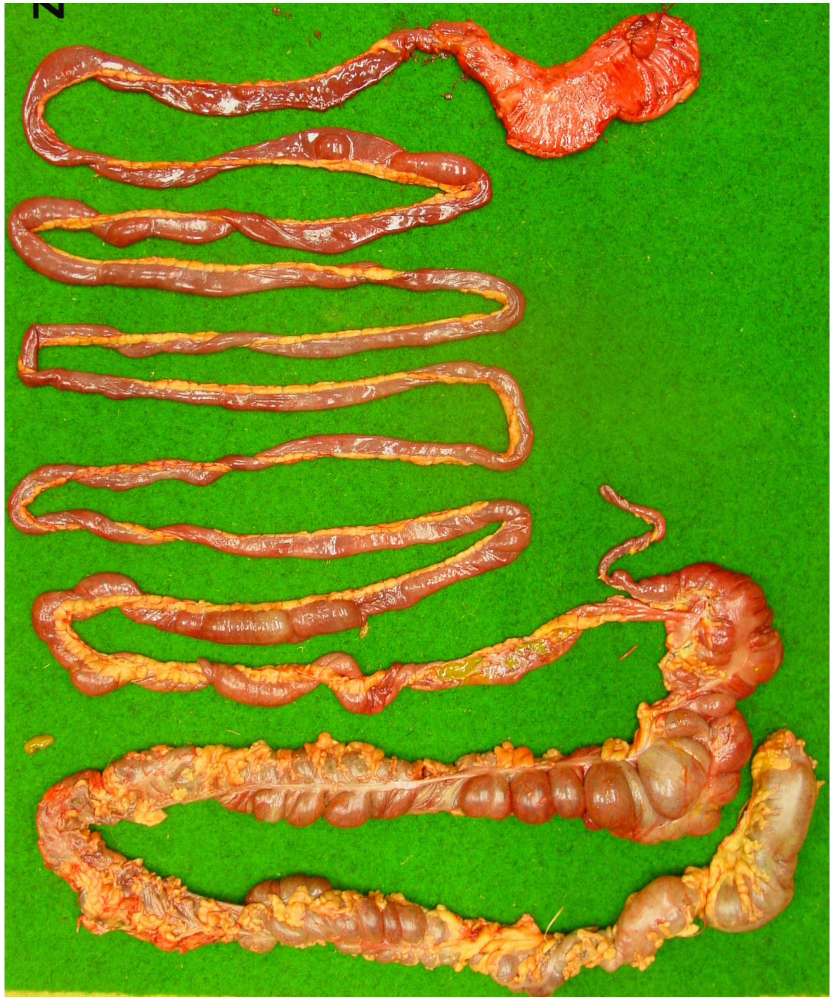
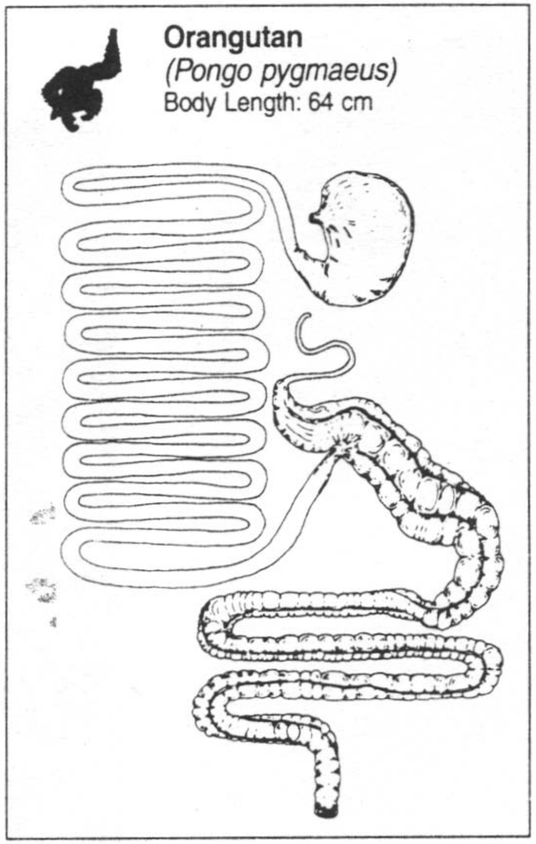
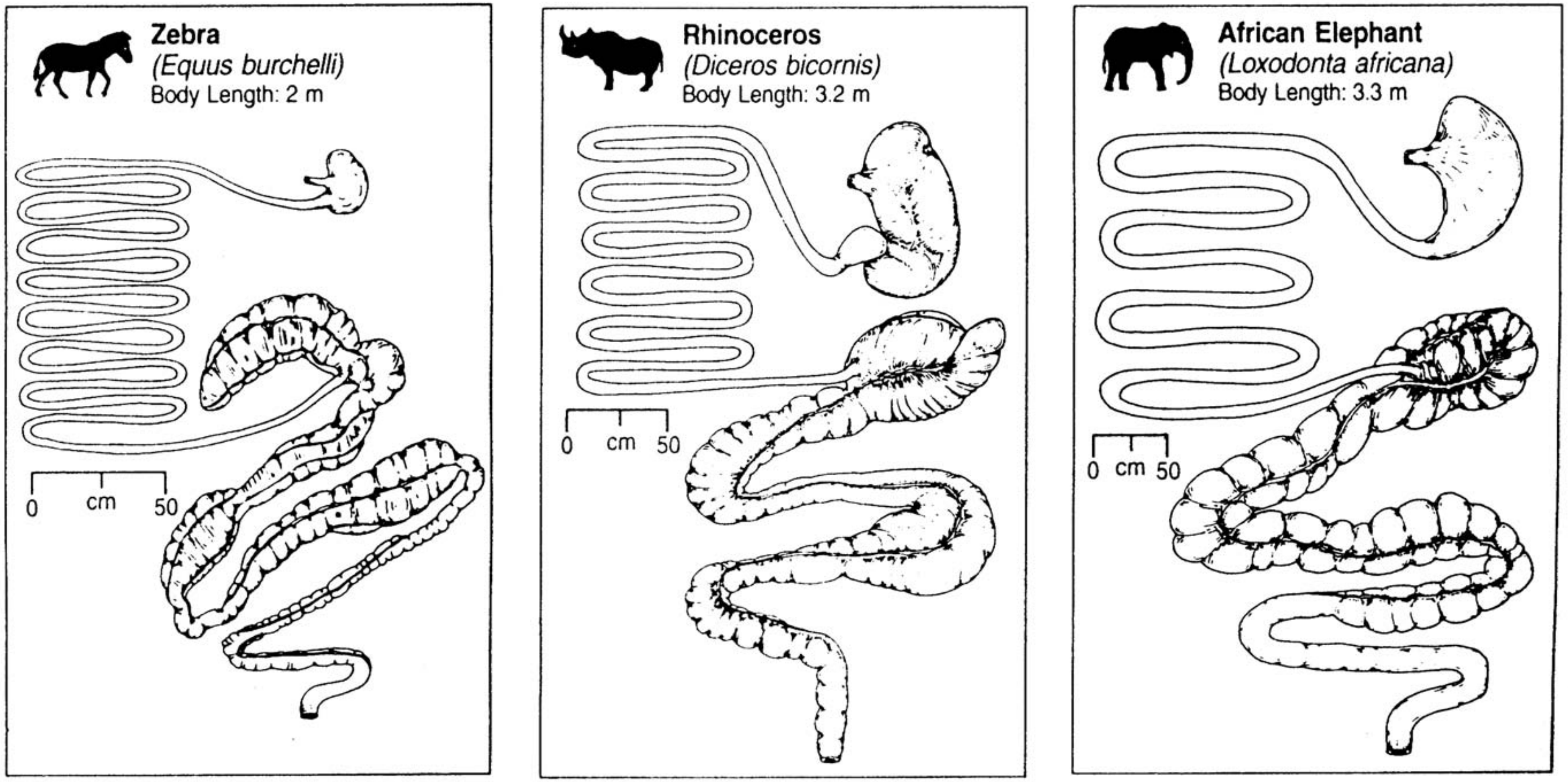




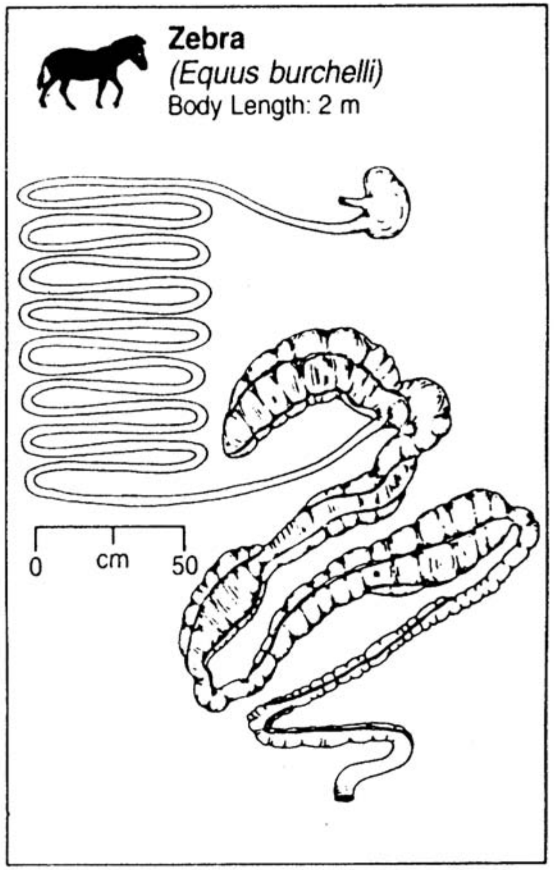
from Stevens und Hume (1995)
Photo: M. Clauss

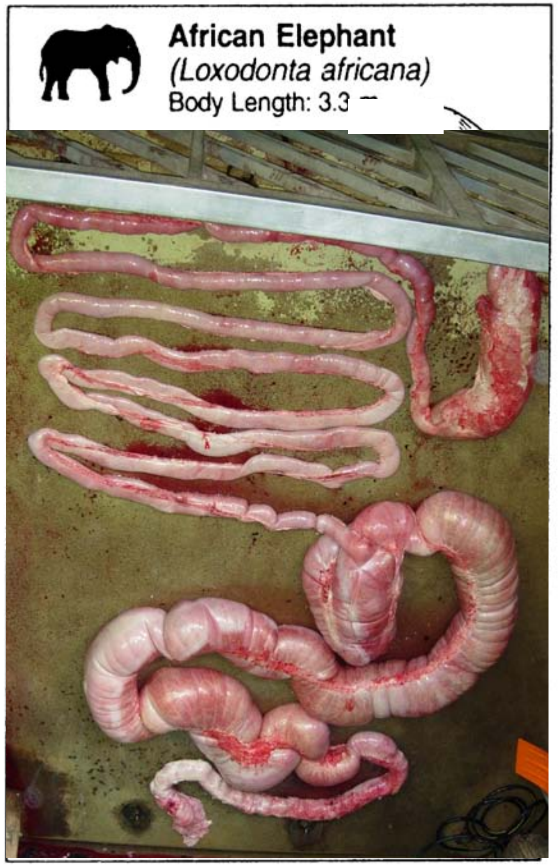
Hindgut Fermentation - Colon



from Stevens & Hume (1995)

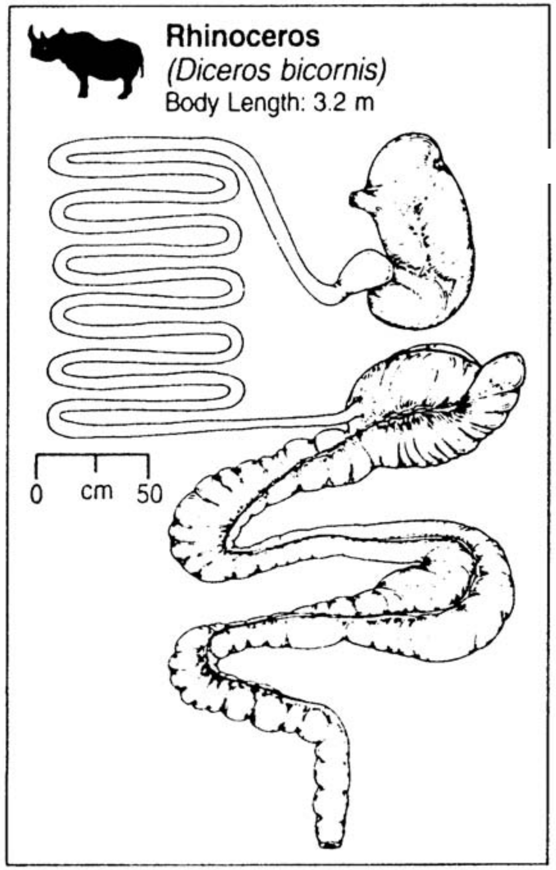
Hindgut Fermentation - Colon





from Stevens & Hume (1995)

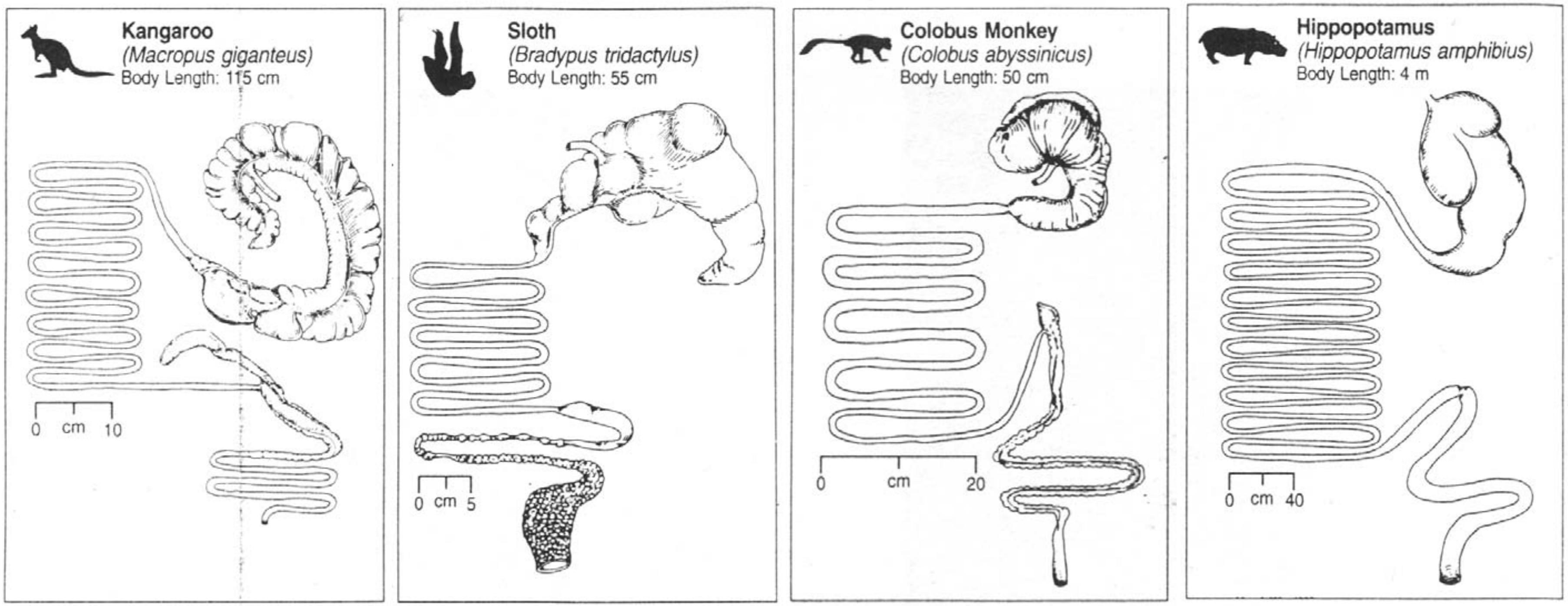
Hindgut Fermentation - Colon



from Stevens & Hume (1995)

White rhino photo: D. Müller

Foregut Fermentation



from Stevens & Hume (1995)

Foregut Fermentation

Photos A. Schwarm/ M. Clauss

Foregut Fermentation

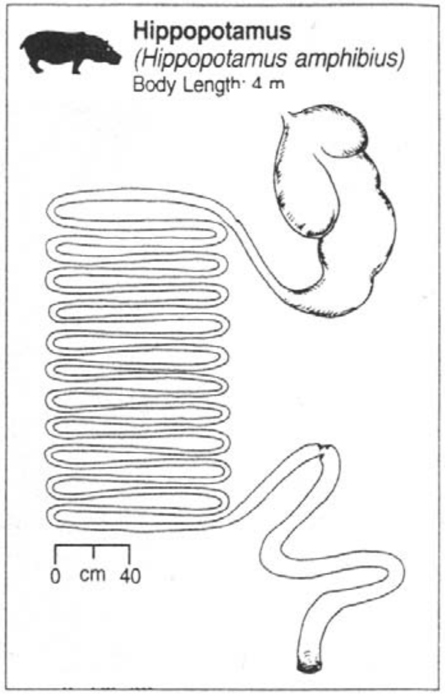


Photo M. Clauss

Foregut Fermentation

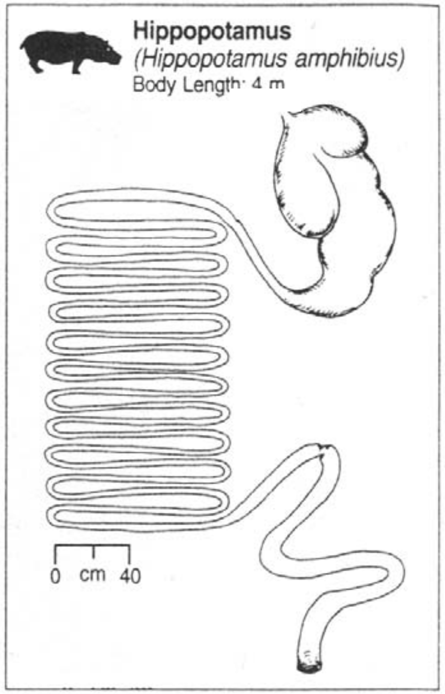
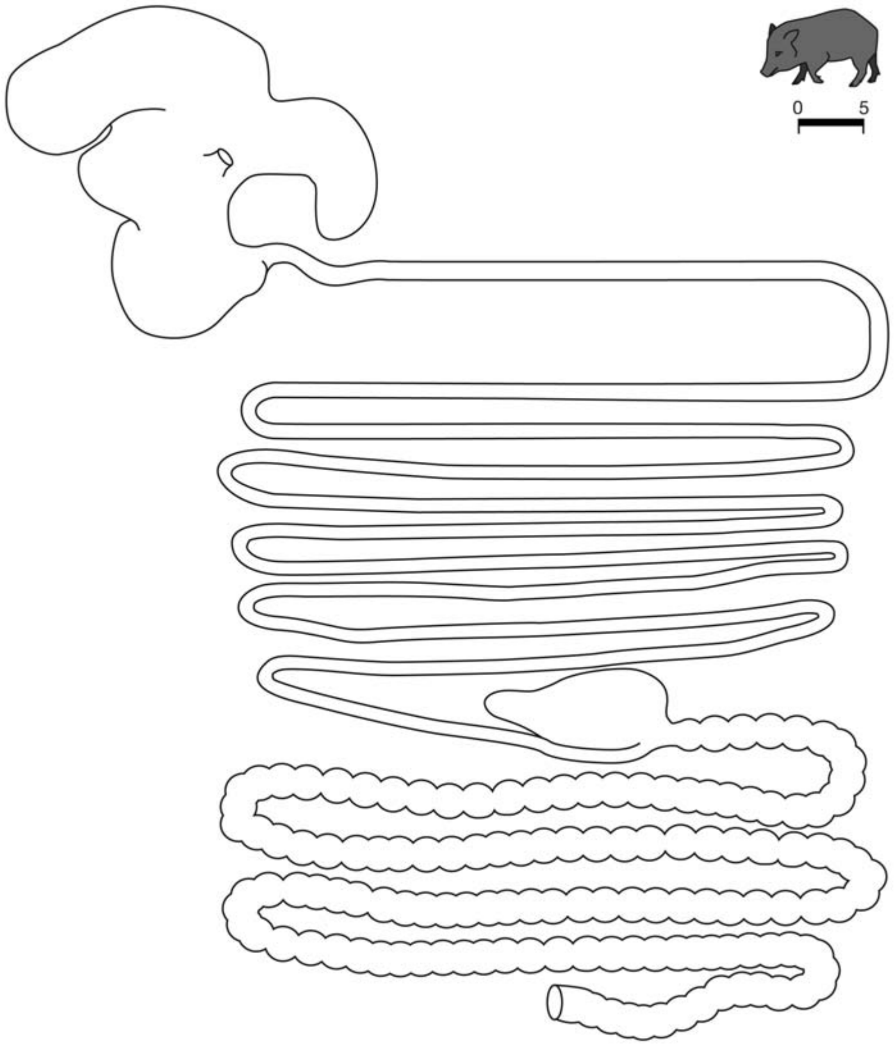


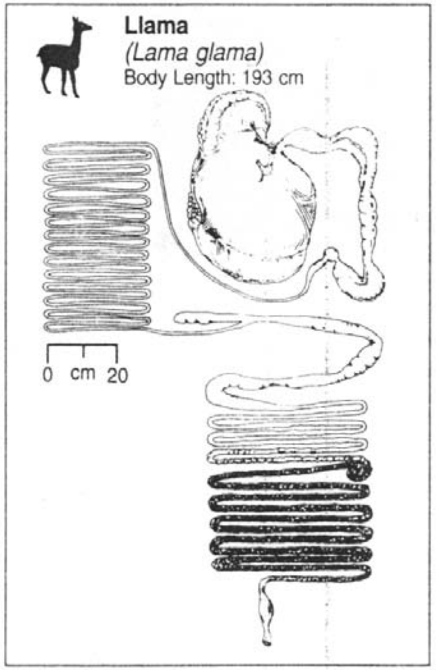
Photo M. Clauss

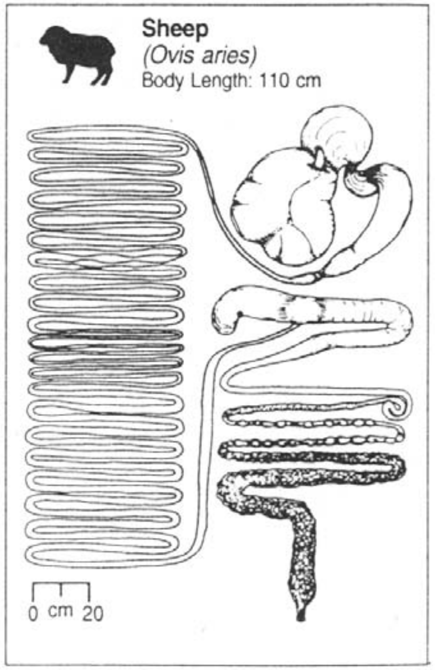
Herbivores - Foregut fermenters



from Schwarm et al. (in prep.))
Photo: A. Schwarm

Foregut Fermentation - Ruminant

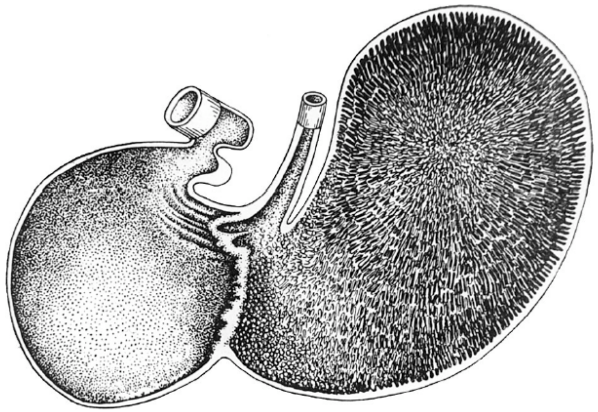




aus Stevens & Hume (1995)
Photo Llama: A. Riek

Foregut/Hindgut Fermenters

With the majority of rodent species un-studied, we have not grasped the variability, and adaptive significance, of foregut and hindgut fermentation yet.



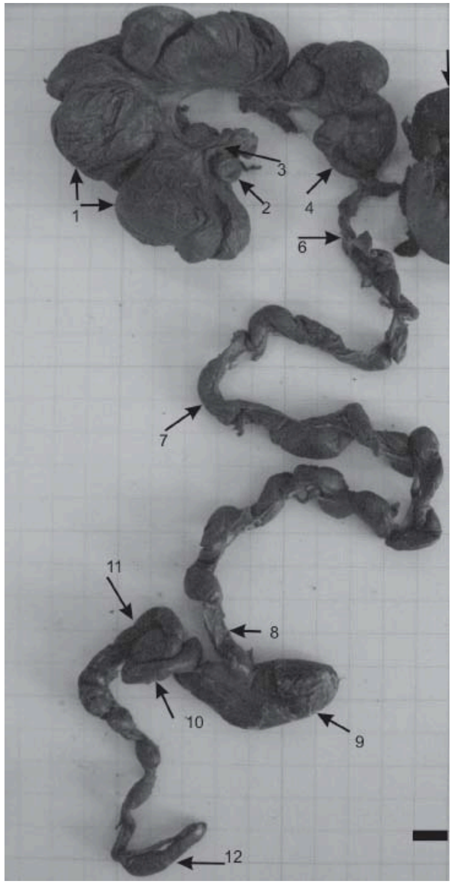
Demon mole rat
(*Tachyoryctes daemon*)
papillated forestomach

from Vrontsov (2003)

Foregut/Hindgut Fermenters

With the majority of rodent species un-studied, we have not grasped the variability, and adaptive significance, of foregut and hindgut fermentation yet.

**Laotian rock rat
(*Laonastes aenigmamus*)
kangoroo-like forestomach**

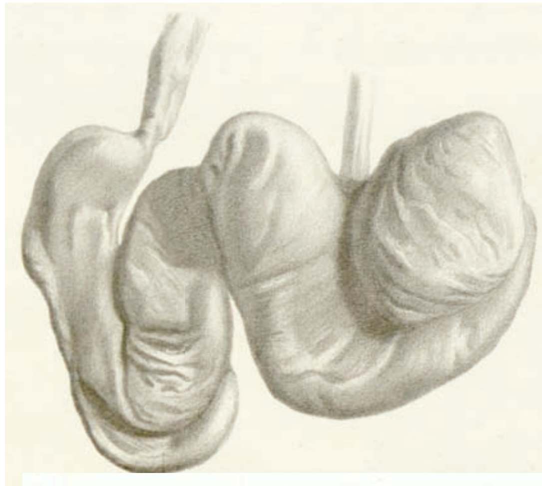


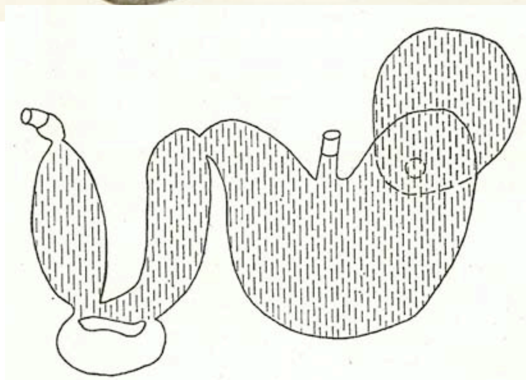
from Scopin et al. (2011)

Foregut/Hindgut Fermenters

With the majority of rodent species un-studied, we have not grasped the variability, and adaptive significance, of foregut and hindgut fermentation yet.

Maned (crested) rat (*Lophiomys imhausi*) complex forestomach





from Vrontsov (1967)

Foregut/Hindgut Fermenters

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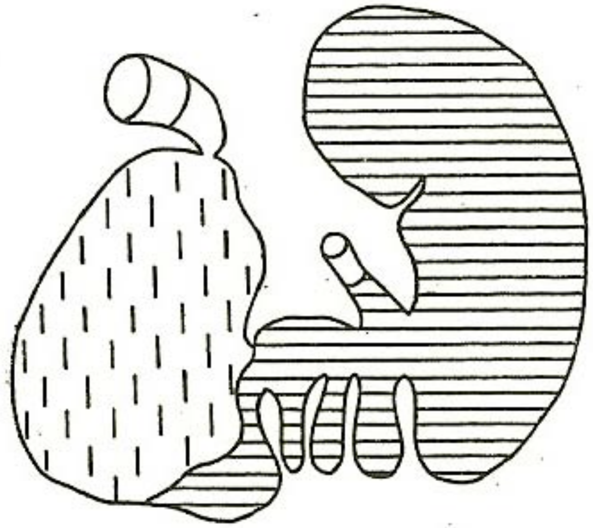
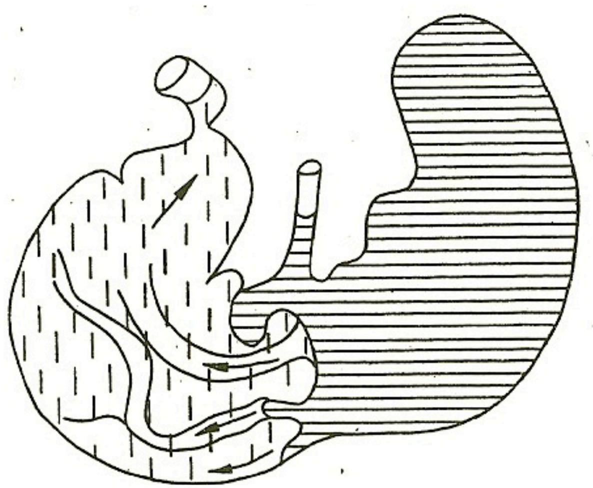


White-tailed antsangy (*Brachytarsomys albicauda*) complex forestomach

from Vrontsov (1967)

Foregut/Hindgut Fermenters

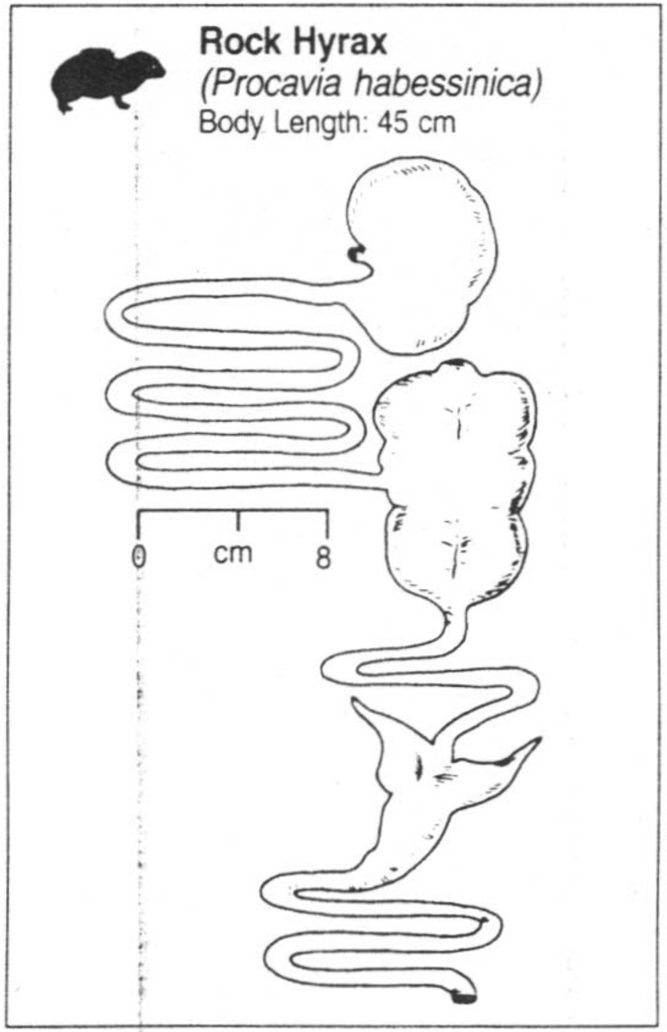
With the majority of rodent species un-studied, we have not grasped the variability, and adaptive significance, of foregut and hindgut fermentation yet.



Malagas giant rat (*Hypogeomys antimena*) complex forestomach

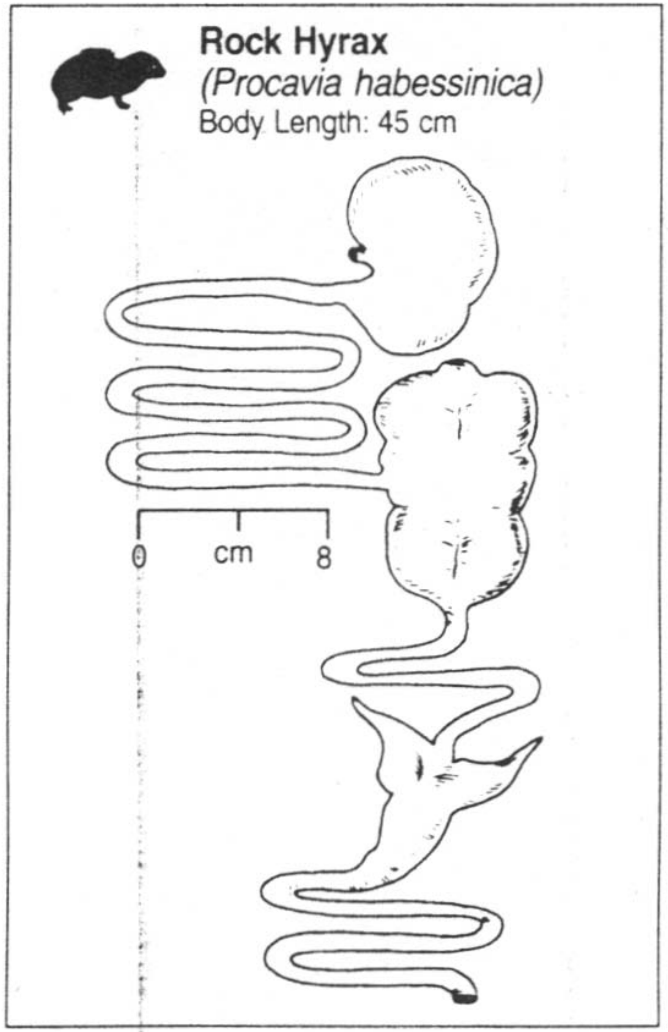
from Vrontsov (1967)

Herbivores - Hyrax



from Stevens und Hume (1995)

Herbivores - Hyrax



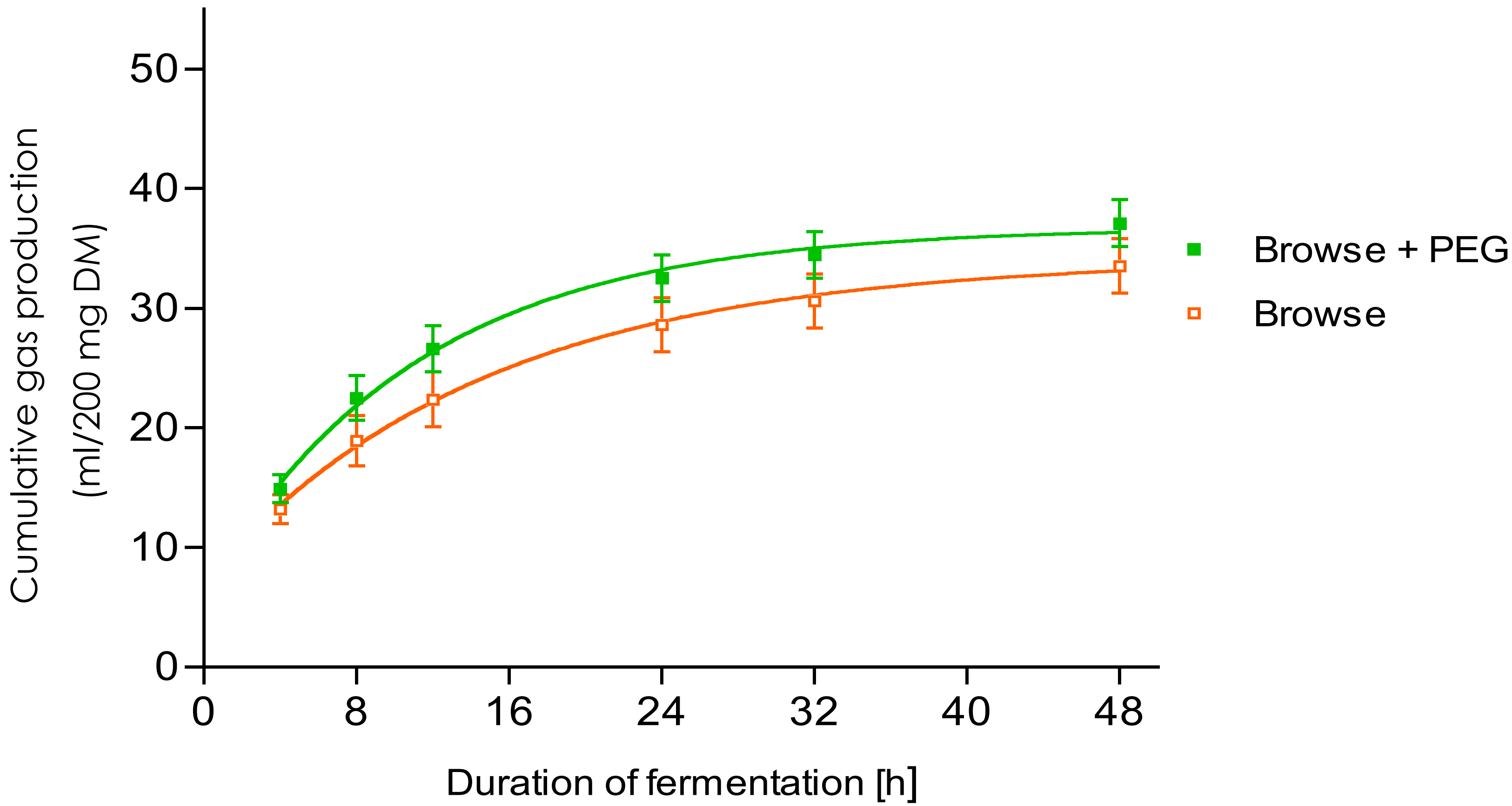
from Stevens und Hume (1995)

Analysing for energy in plant material

in vitro **fermentation (gas production)**

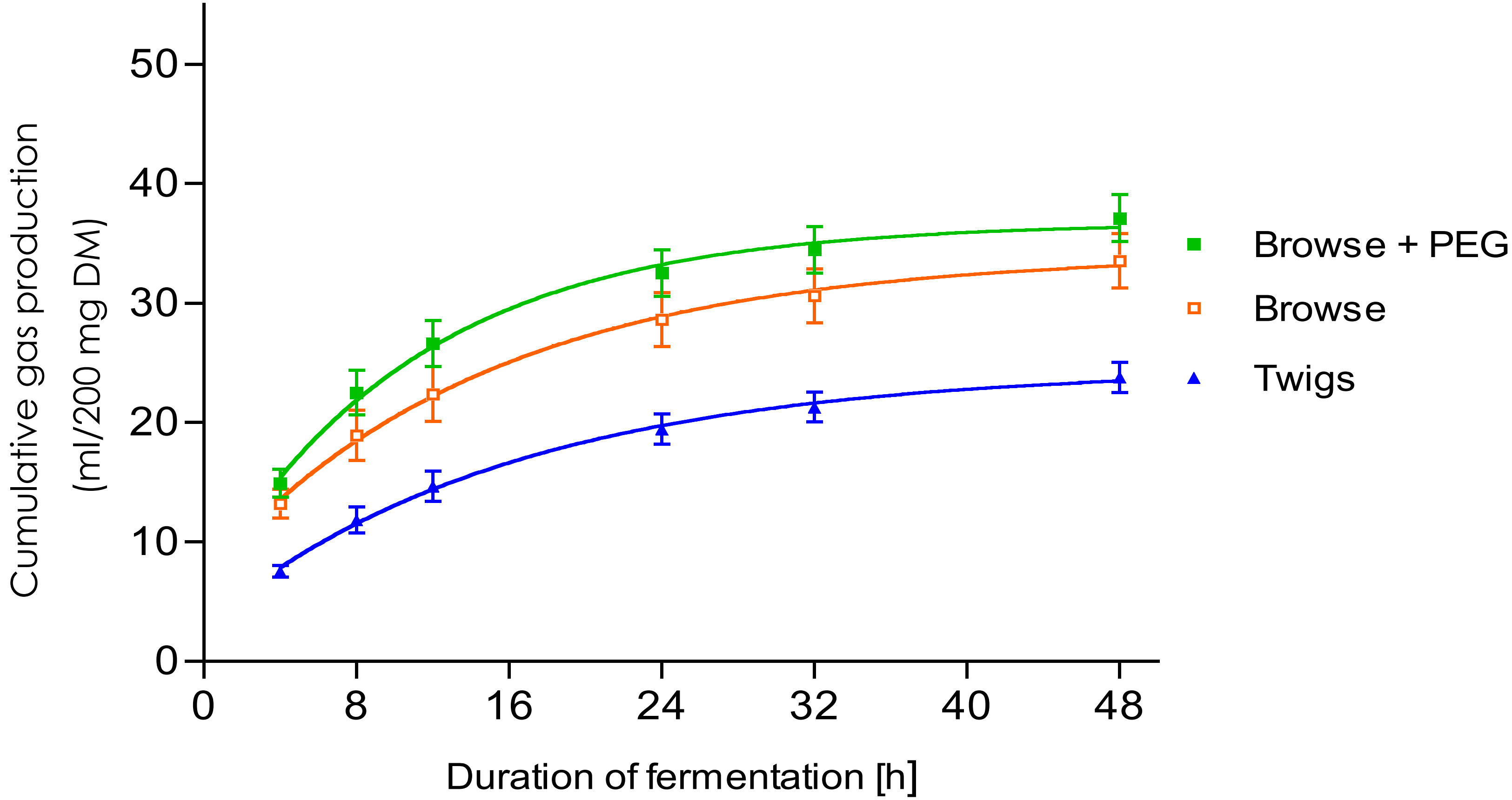
- May give a more "biological" estimation (compared to bomb calorimetry) of digestibility of energy - but higher variability
- Based on the use of enzymes (in vitro digestion) or gut microbes (in vitro fermentation), or a combination of both
- In vitro fermentation can be used to simulate foregut fermentation or other sections of the GIT with fermentative capacity

Forage fermentation patterns



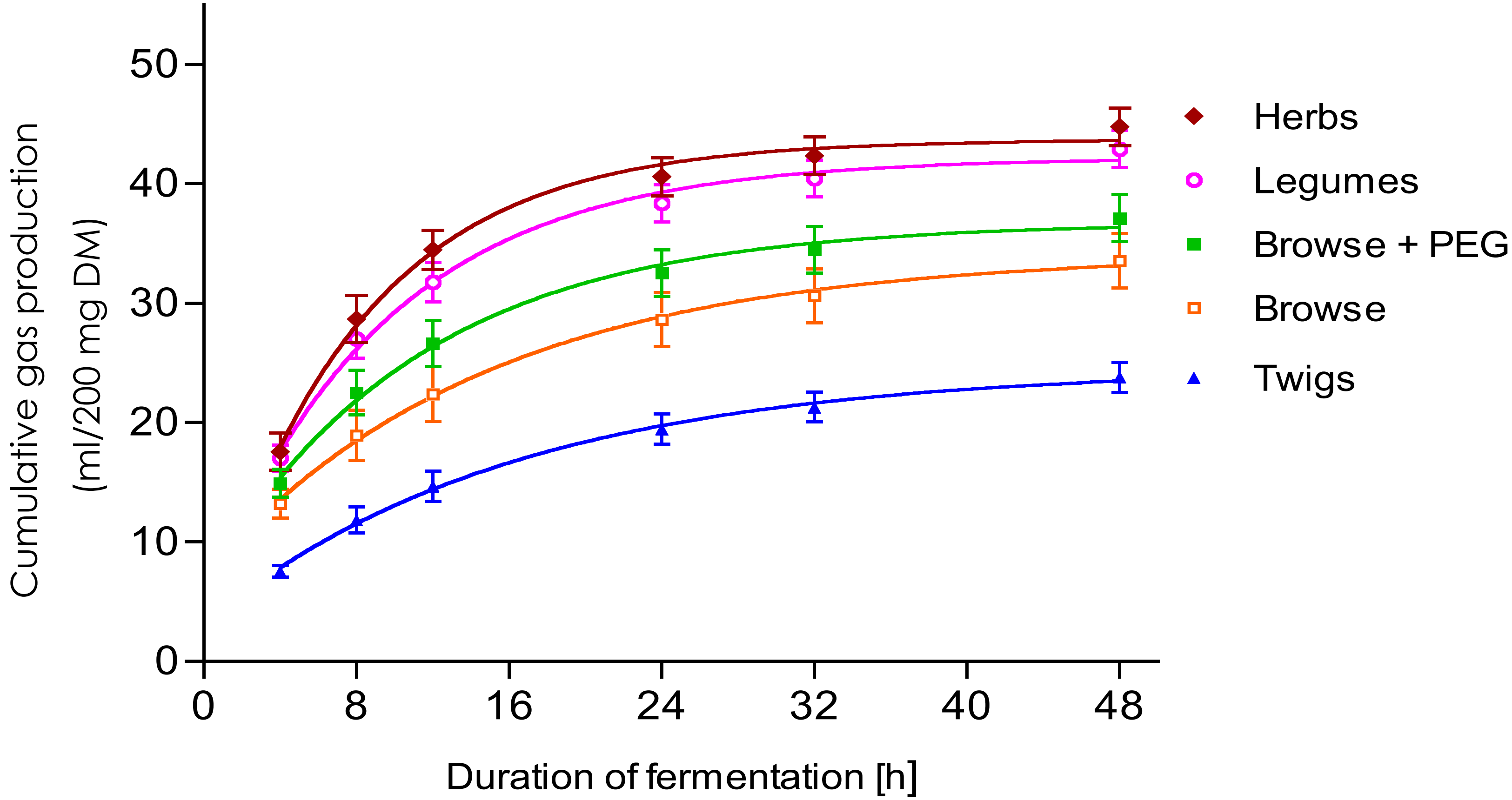
from Hummel et al. (2006)

Forage fermentation patterns



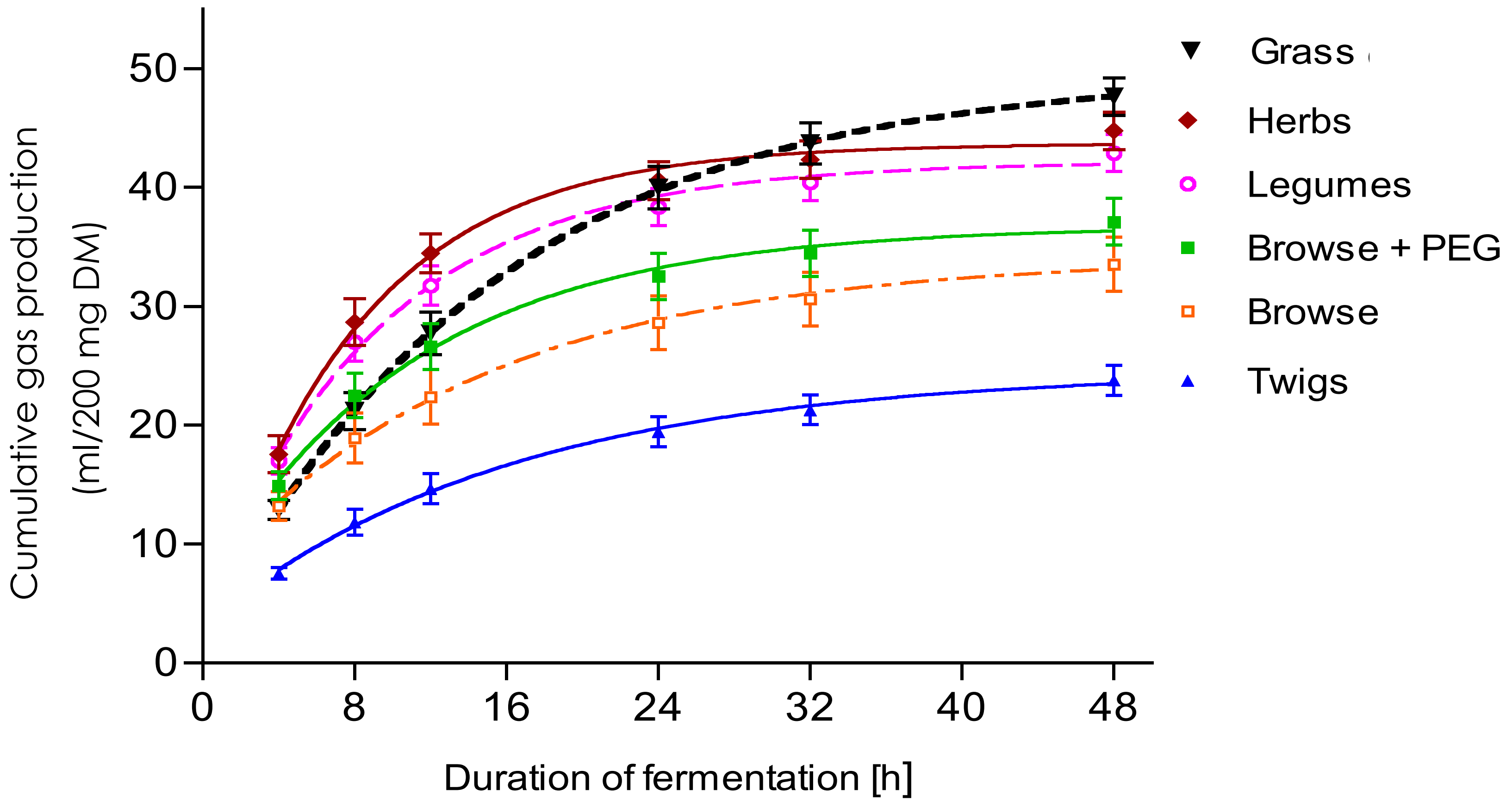
from Hummel et al. (2006)

Forage fermentation patterns



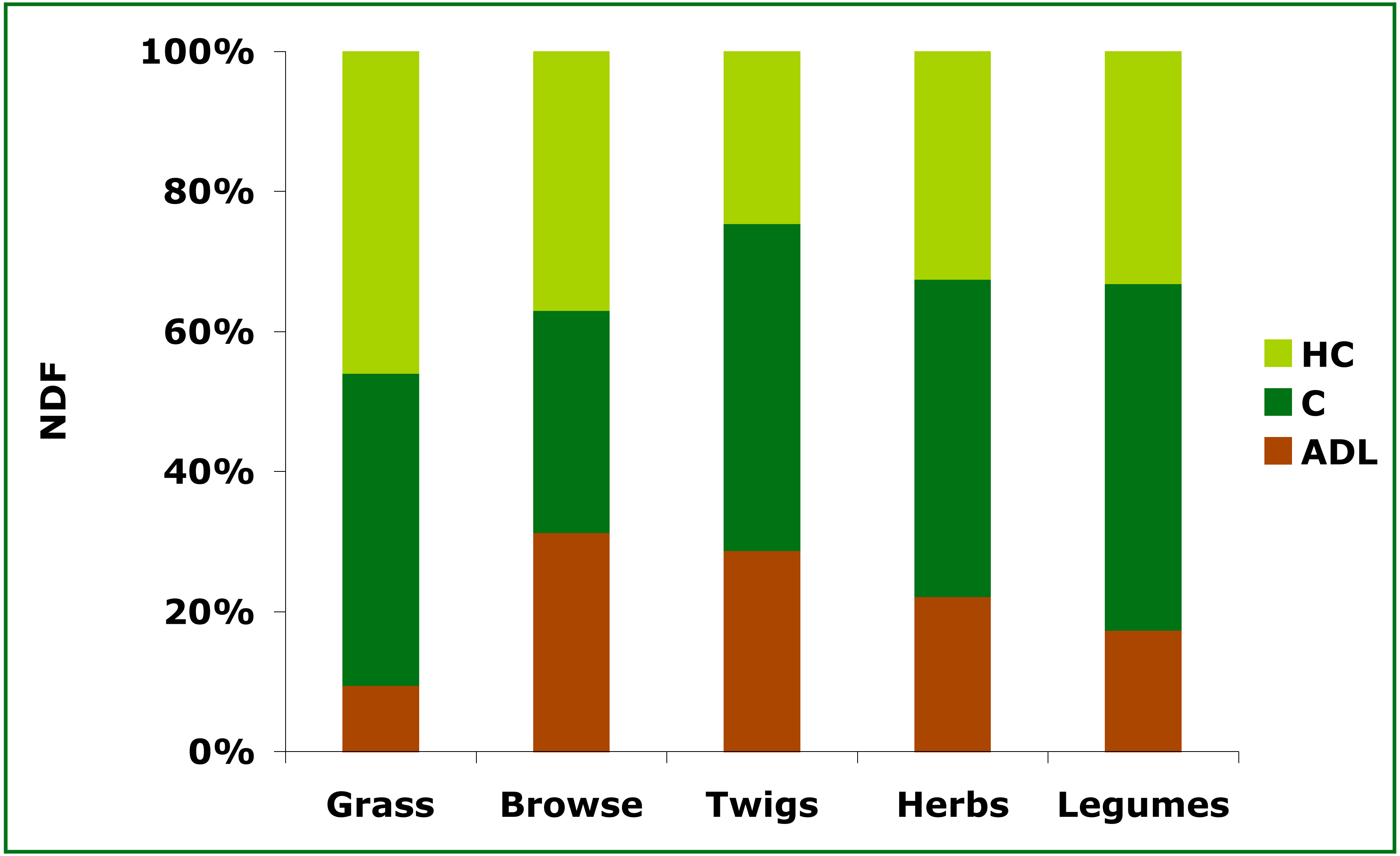
from Hummel et al. (2006)

Forage fermentation patterns



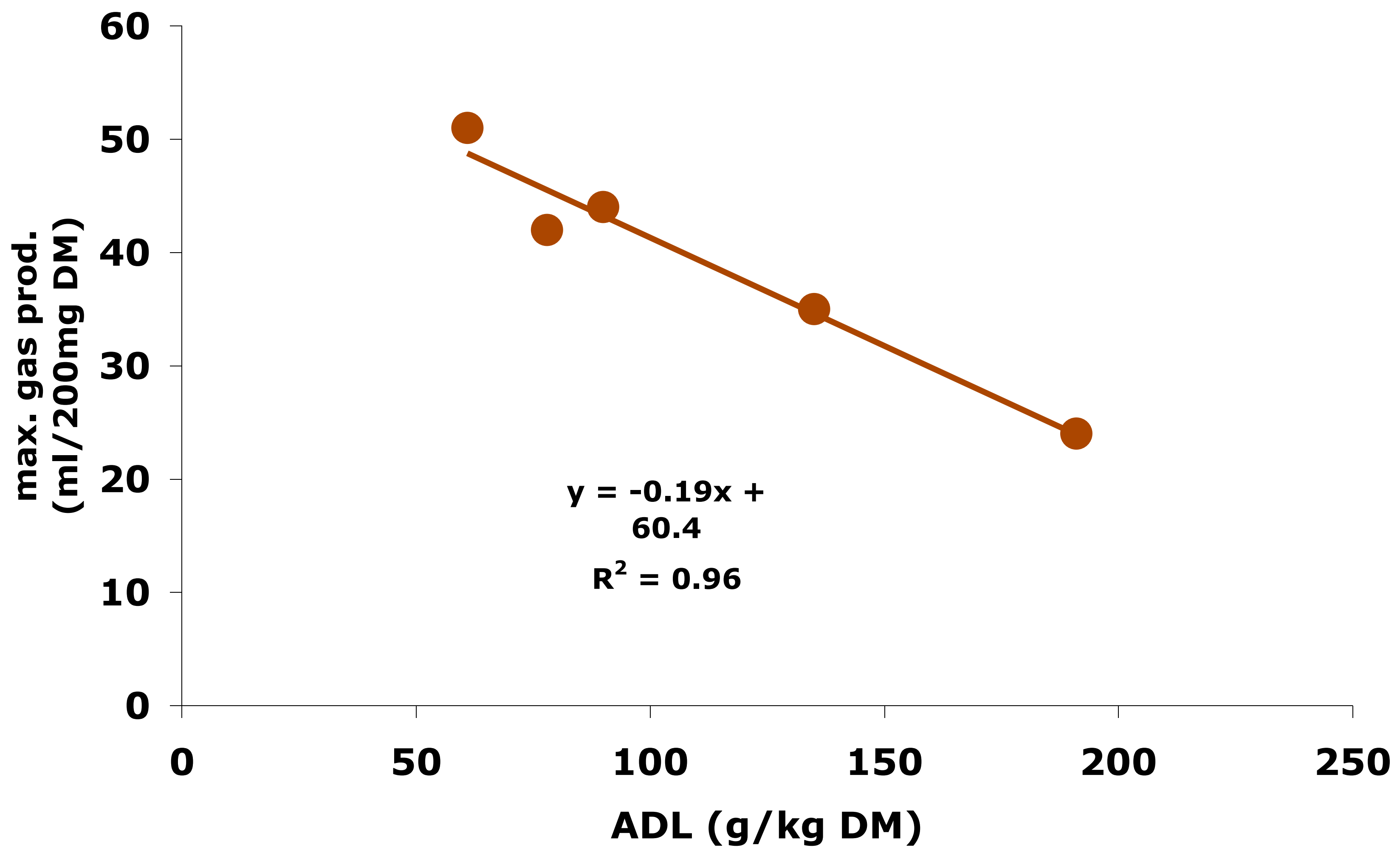
from Hummel et al. (2006)

Fibre composition of forages



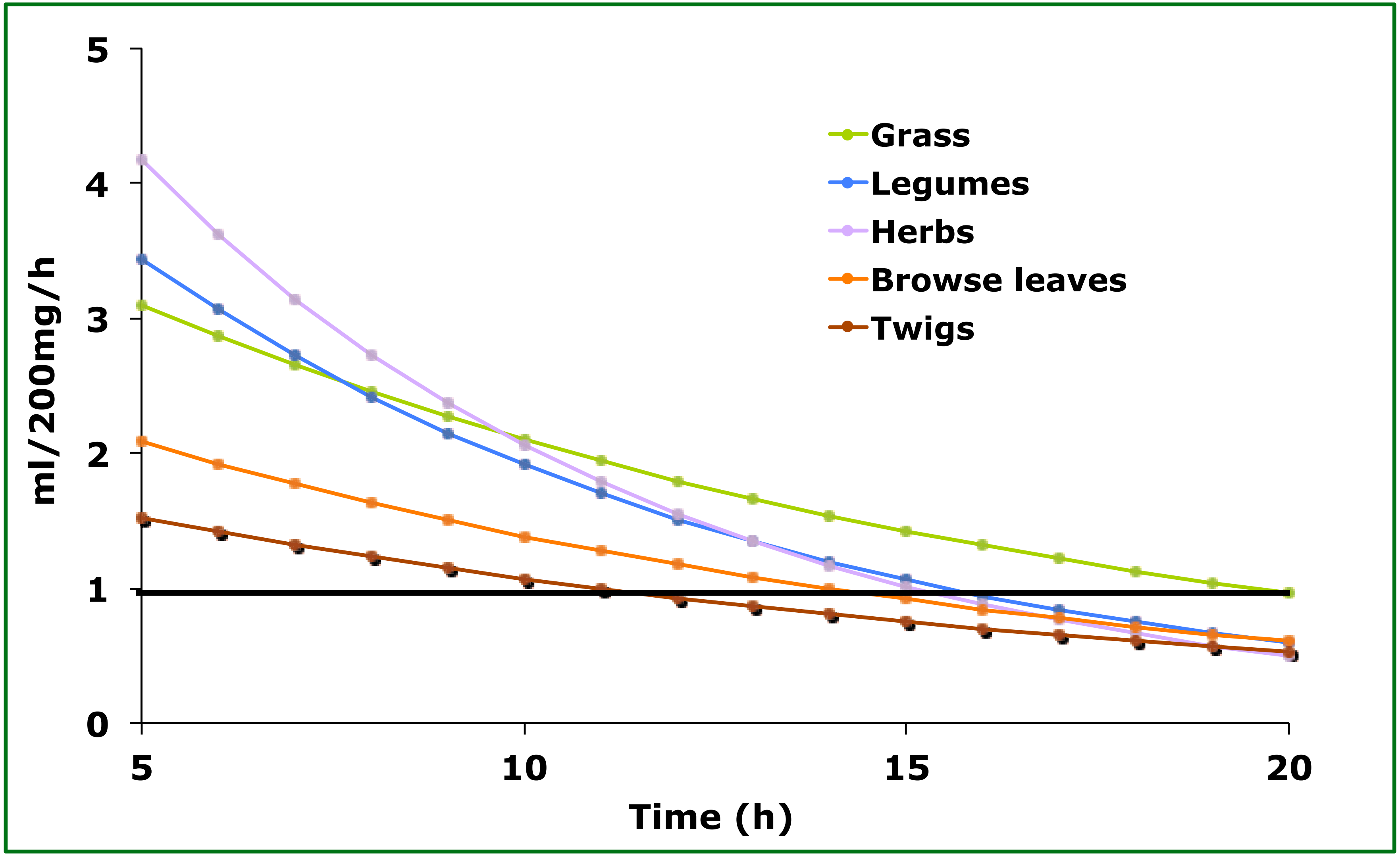
from Hummel et al. (2006)

Lignin is a major constraint on digestibility



from Hummel et al. (2006)

Forage fermentation patterns



from Hummel et al. (2006)

thank you
for your attention