How can we increase chewing efficiency ?

surprising morphophysiological solutions

Marcus Clauss

Clinic for Zoo Animals, Exotic Pets and Wildlife, Vetsuisse Faculty, University of Zurich, Switzerland

Evolutionary Biology 2021

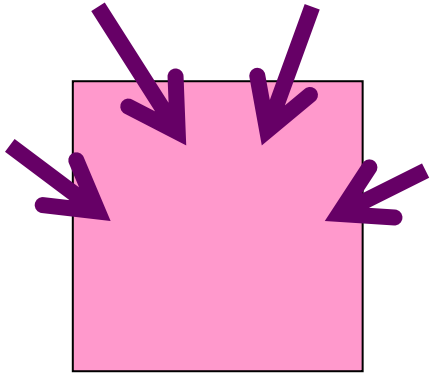
University of Zurich[UZH]

Clinic of Zoo Animals, Exotic Pets and Wildlife

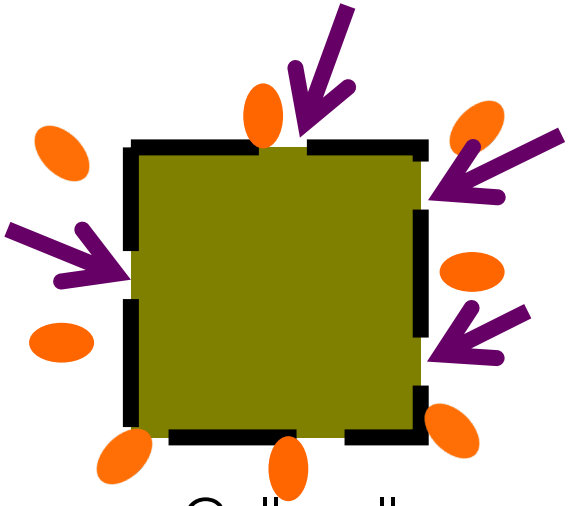
Why is chewing important ?

Digestion takes time …

Animal cell – Plant cell



Cell membrane



Cell wall

Evidence for a tradeoff between retention time and chewing efficiency in large mammalian herbivores

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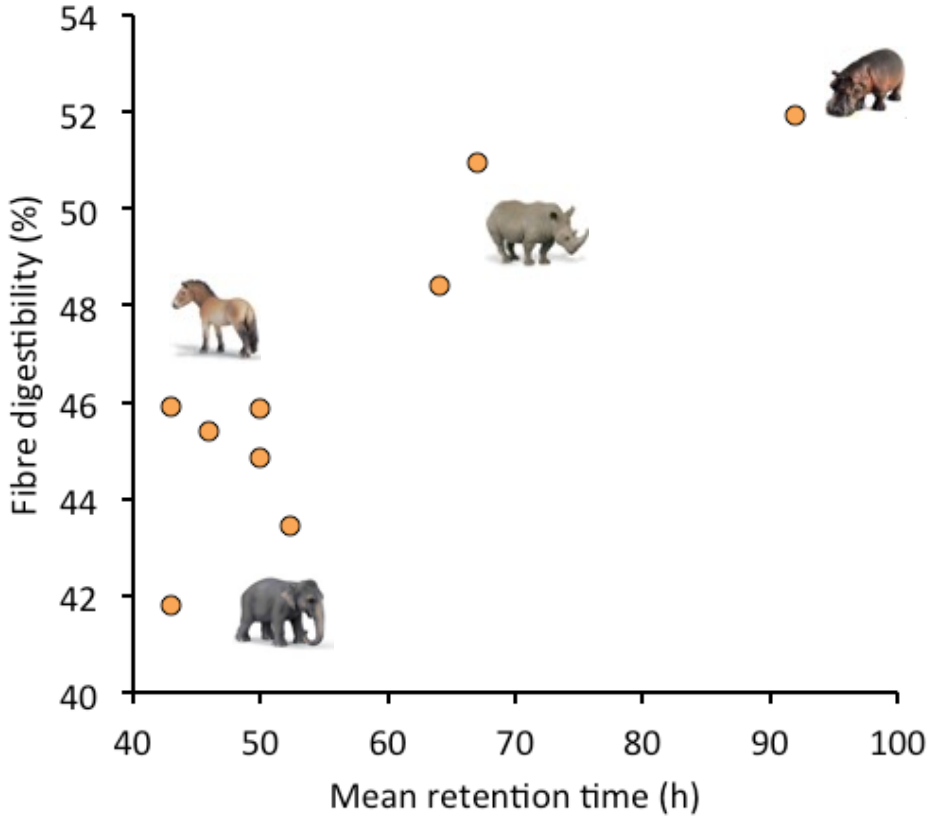
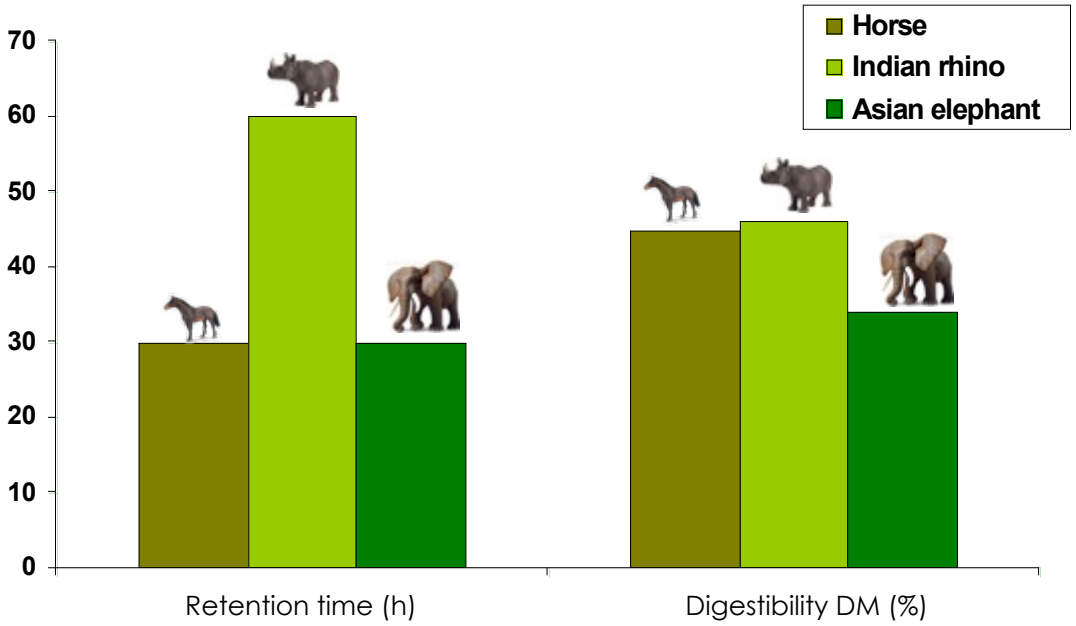
Comparative Biochemistry and Physiology, Part A 154 (2009) 376–382



Studies on digestive physiology and feed digestibilities in captive Indian rhinoceros (*Rhinoceros unicornis*)

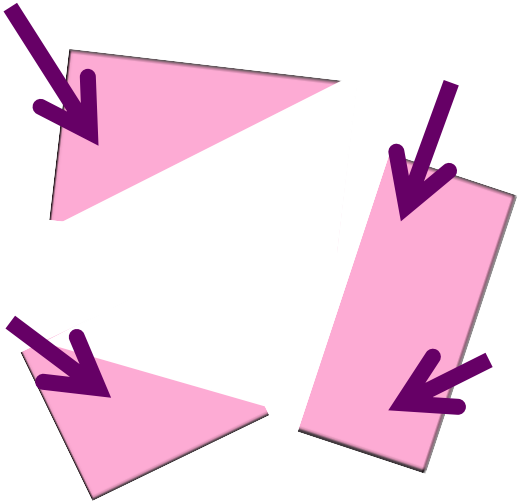
M. Clauss[1], C. Polster[1], E. Kienzle[1], H. Wiesner[2], K. Baumgartner[3], F. von Houwald[4], S. Ortmann[5], W. J. Streich[5] and E.S. Dierenfeld[6]

Journal of Animal Physiology and Animal Nutrition **89** (2005) 229–237



Digestion takes time …

Animal cell – Plant cell



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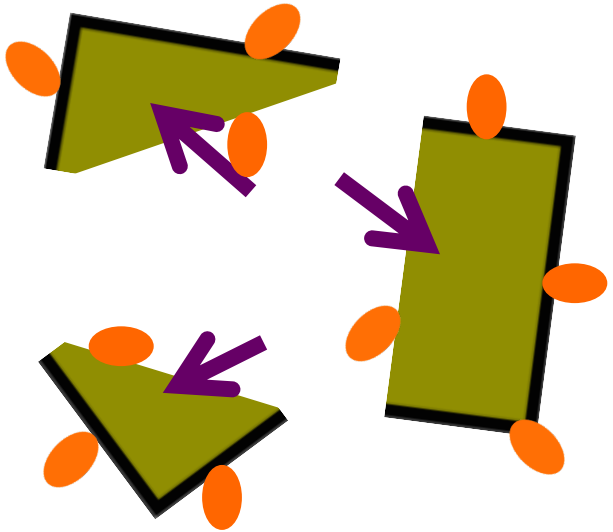
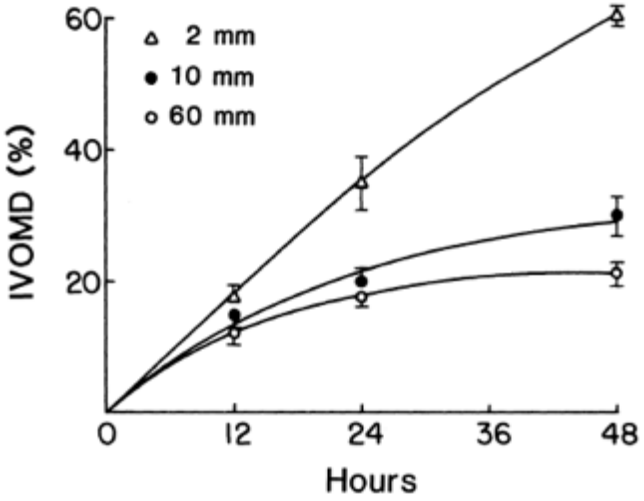


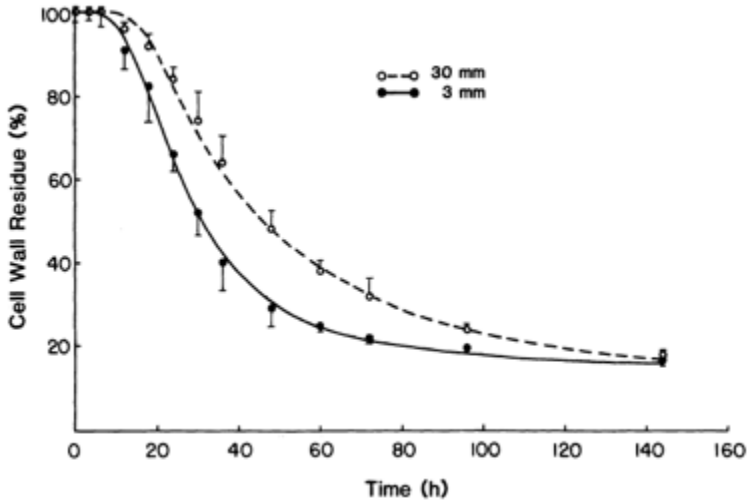
Cell wall

Digestive Fermentation in Herbivores: Effect of Food Particle Size

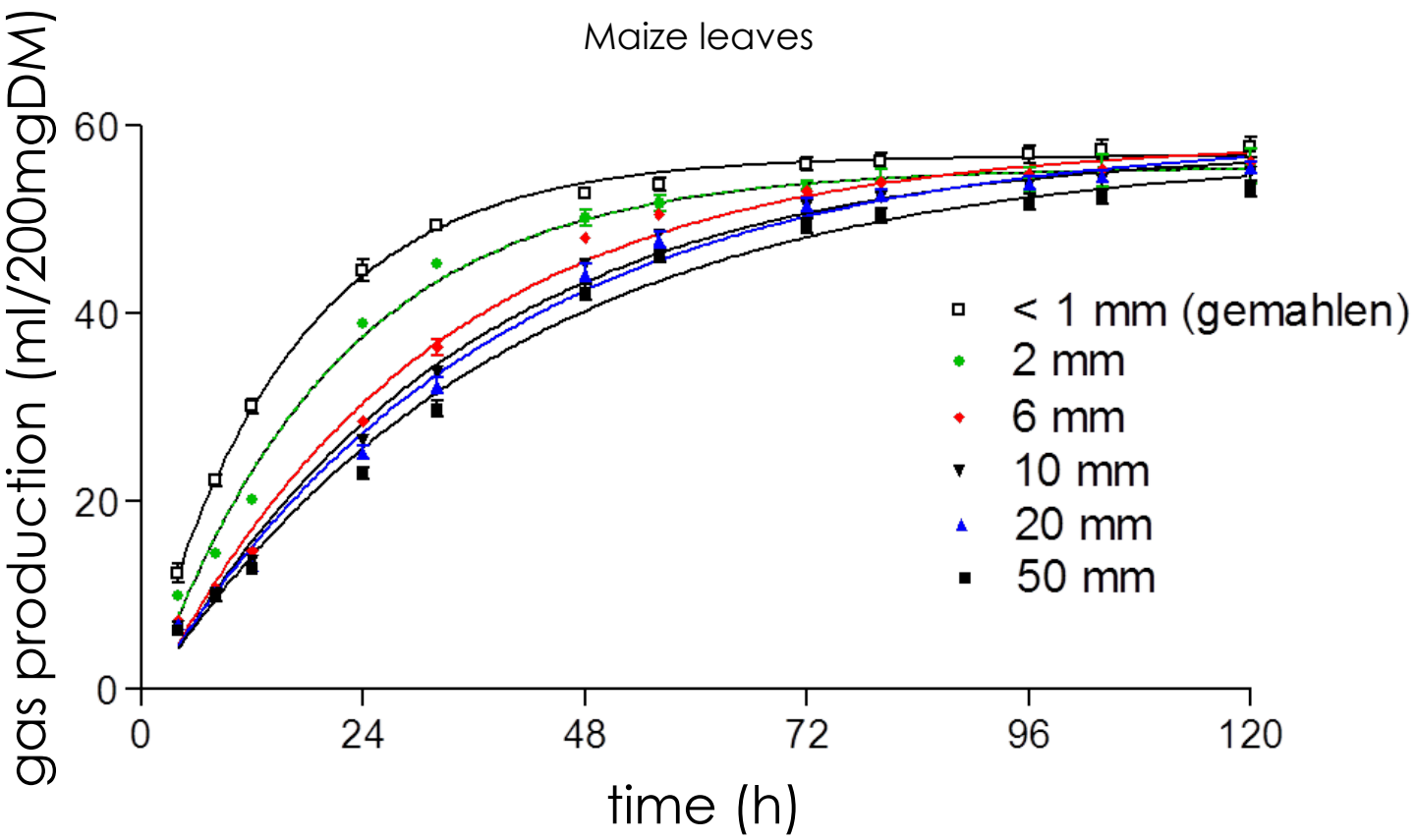
Physiological Zoology 63(4):710–721. 1990.

Karen A. Bjorndal[1]
Alan B. Bolten[1]
John E. Moore[2]





In vitro fermentation and particle size



Hummel (unpubl.)

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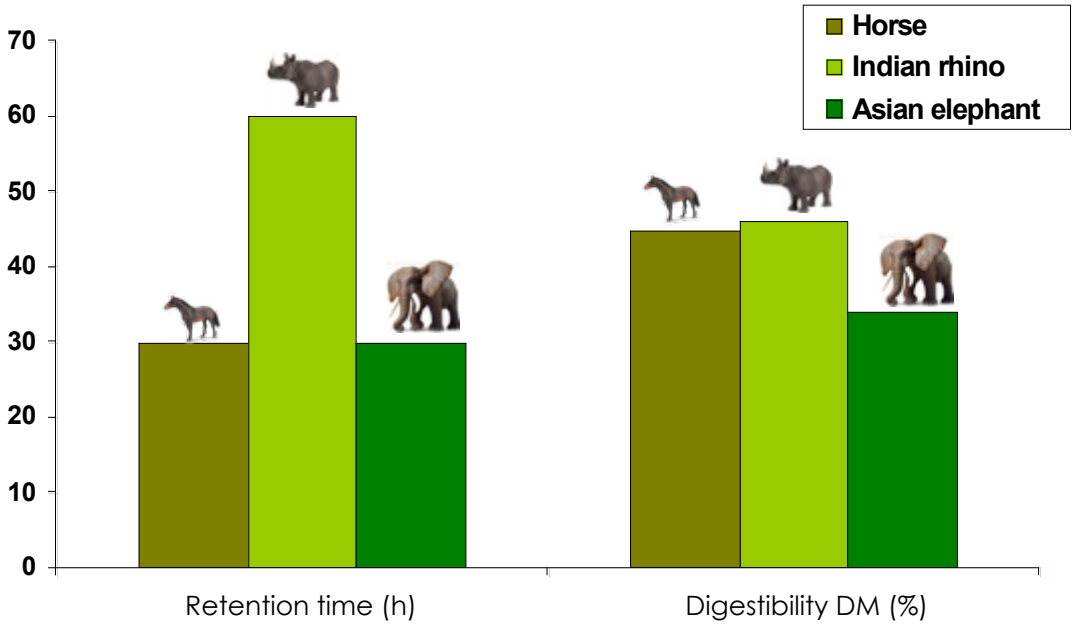
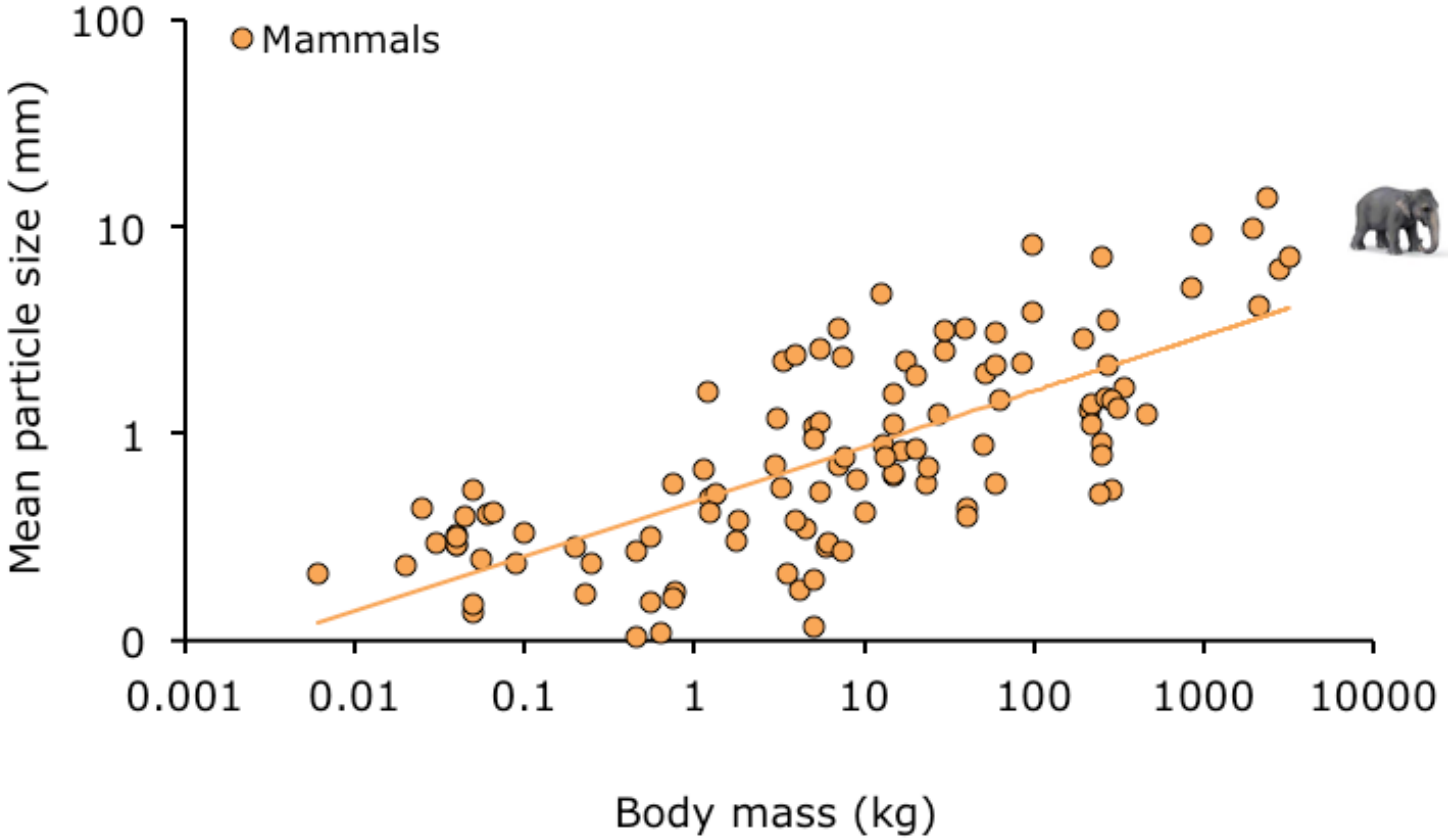


Quantifying particle size reduction

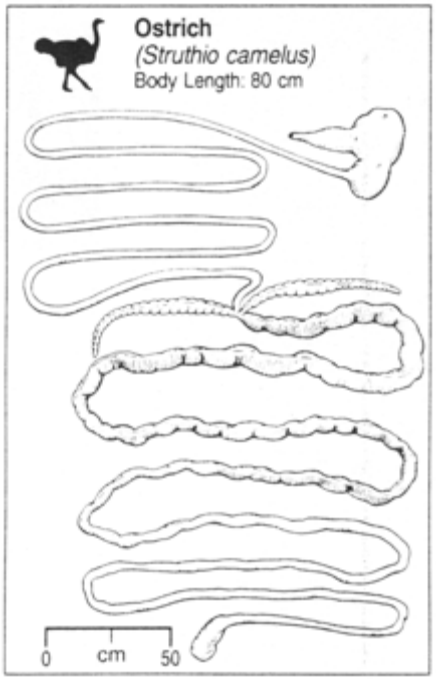
Comparative chewing efficiency in mammalian herbivores

Julia Fritz, Jürgen Hummel, Ellen Kienzle, Christian Arnold, Charles Nunn and Marcus Clauss

Oikos 118: 1623–1632, 2009



Avian herbivores ?



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

Avian herbivores ?

Photos: J. Fritz

Gizzard vs. teeth, it's a tie: food-processing efficiency in herbivorous birds and mammals and implications for dinosaur feeding strategies

Julia Fritz, Jürgen Hummel, Ellen Kienzle, Oliver Wings, W. Jürgen Streich, and Marcus Clauss

Paleobiology, 37(4), 2011, pp. 577–586

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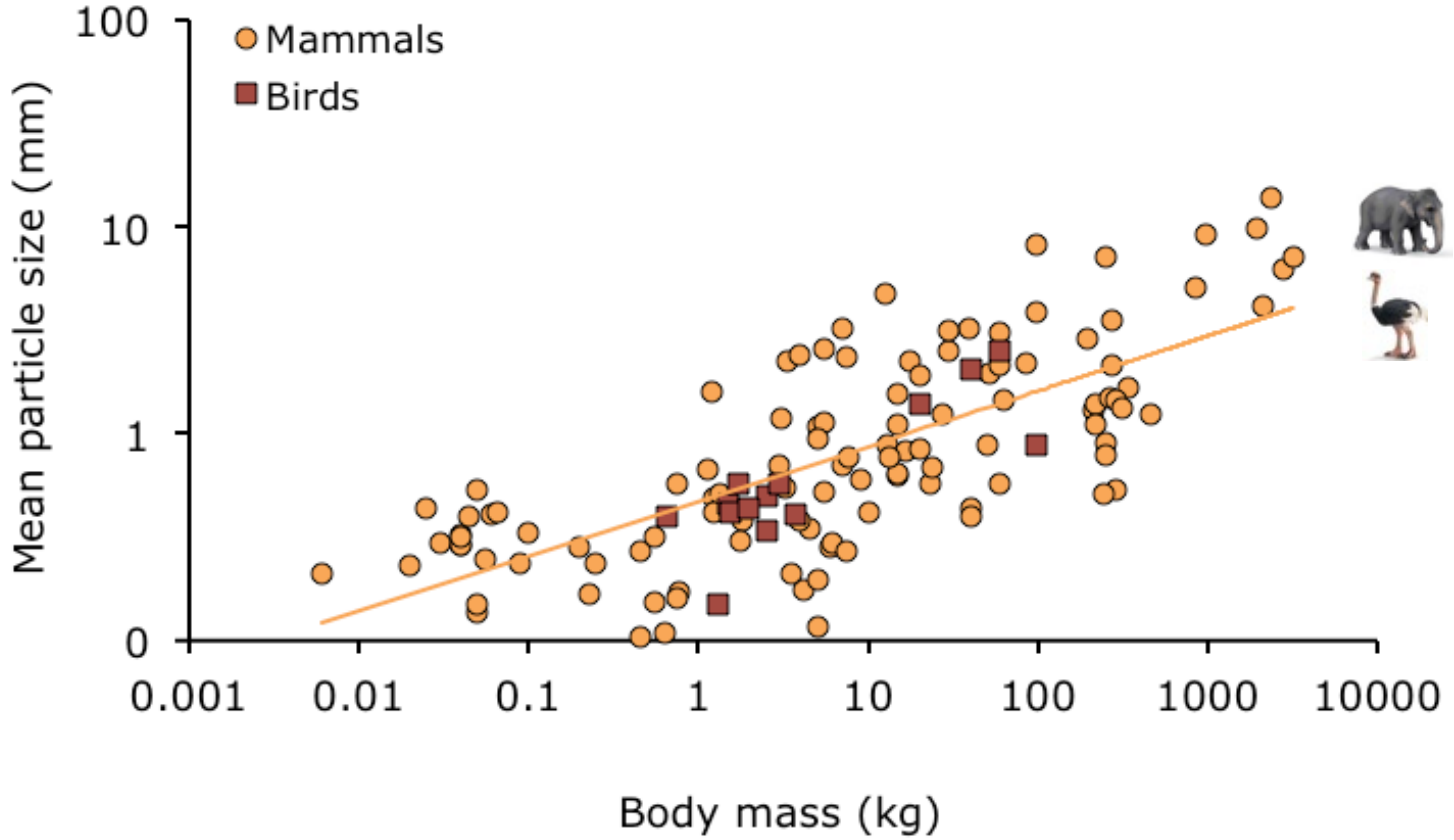


To Chew or Not to Chew

To Chew or Not to Chew: Fecal Particle Size in Herbivorous Reptiles and Mammals

J. Exp. Zool. 313A:579–586, 2010

JULIA FRITZ[1]*, JÜRGEN HUMMEL[2], ELLEN KIENZLE[1], W. JÜRGEN STREICH[3], AND MARCUS CLAUSS[4]

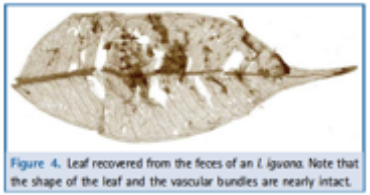
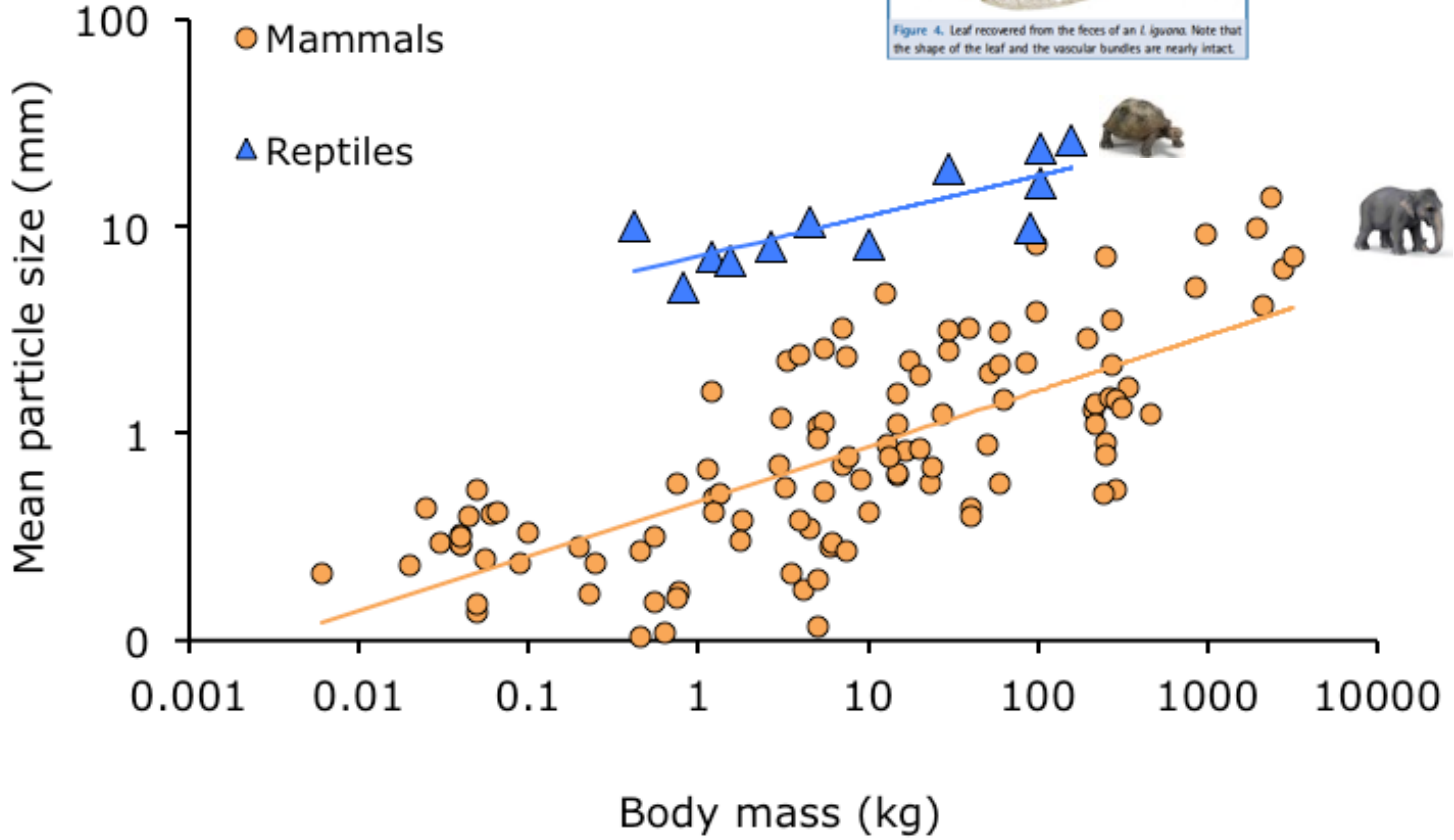


Figure 4. Leaf recovered from the feces of an *I. iguana*. Note that the shape of the leaf and the vascular bundles are nearly intact.



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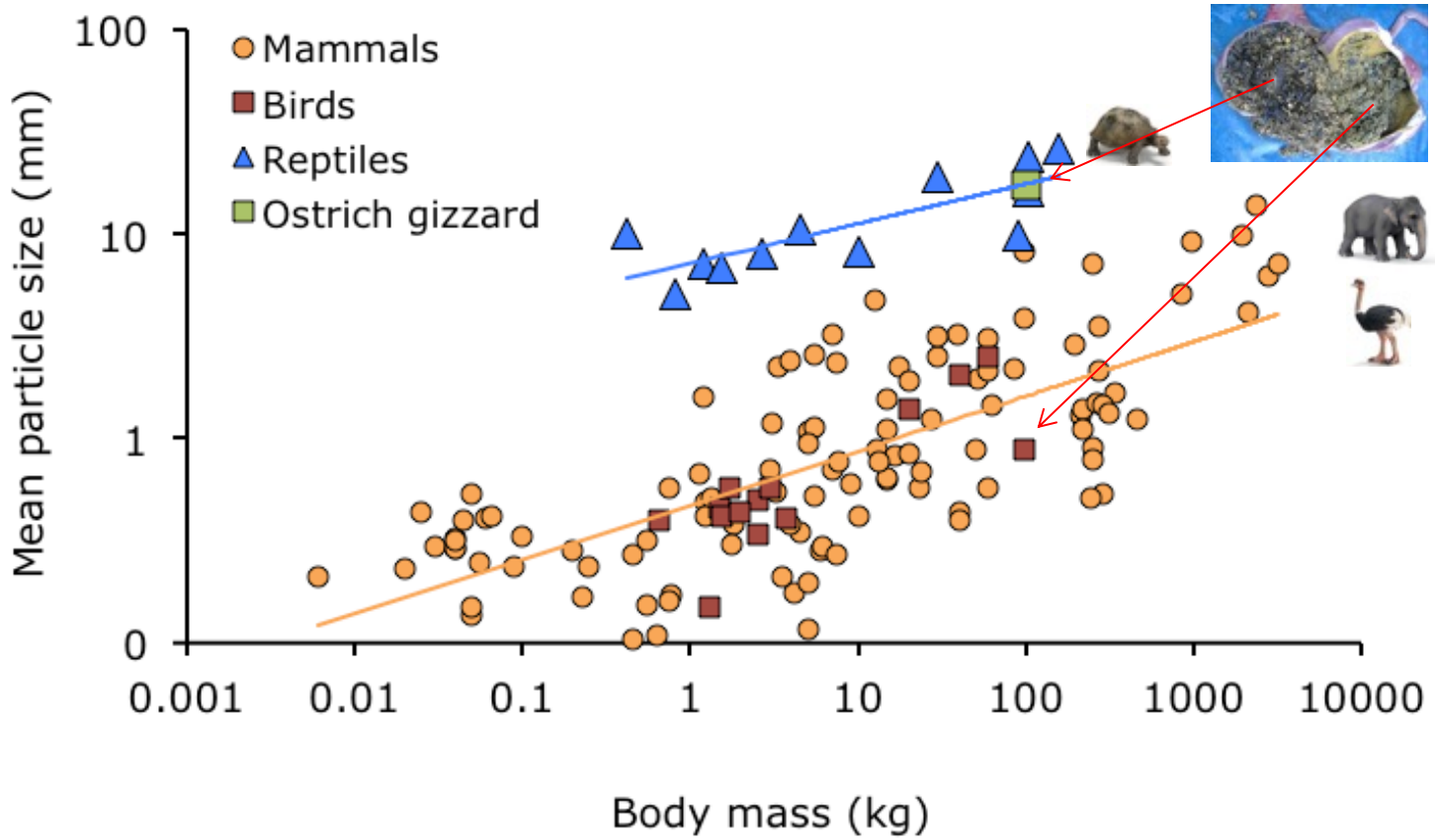

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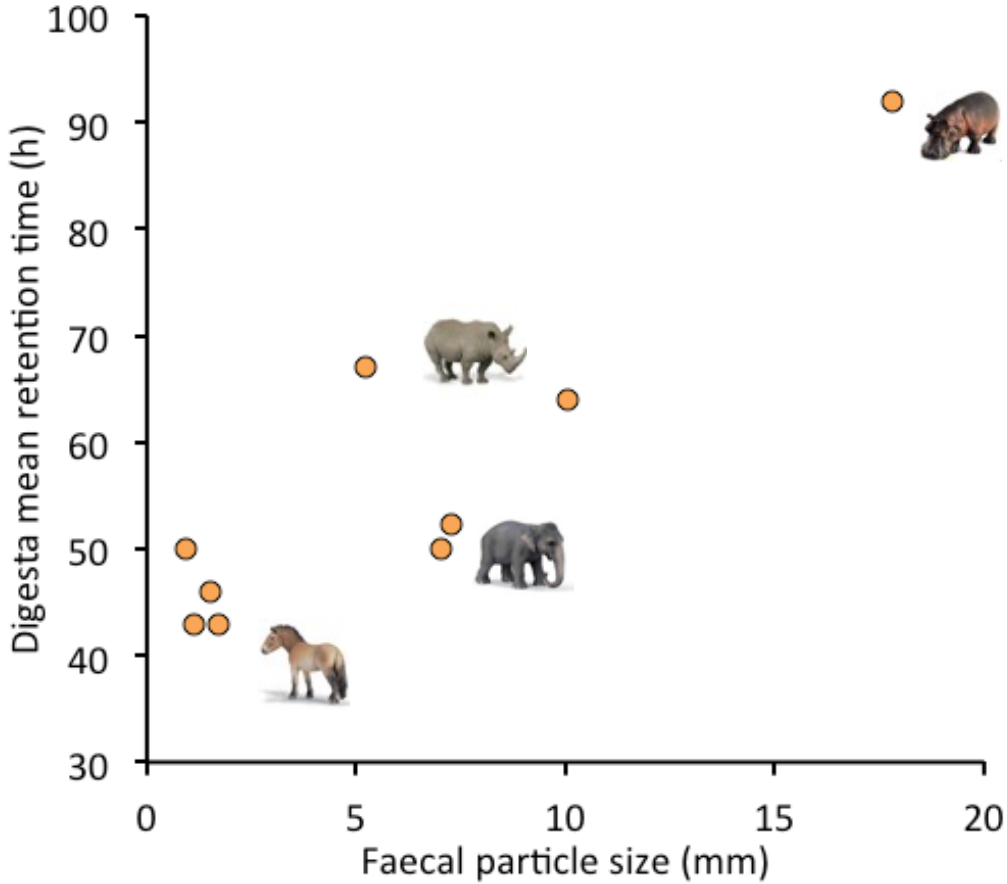
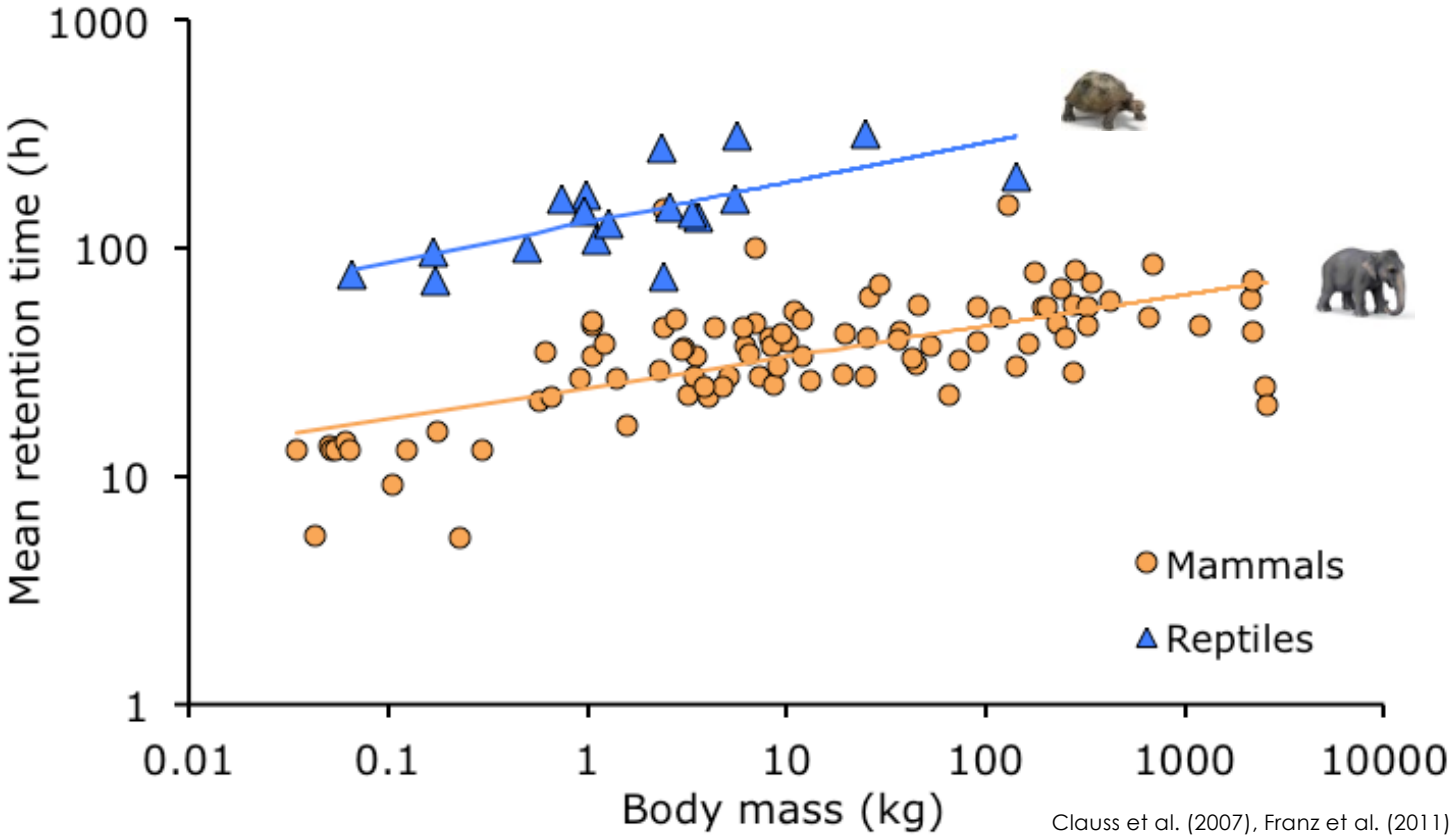


How long does food stay in the gut ?



Clauss et al. (2007), Franz et al. (2011)

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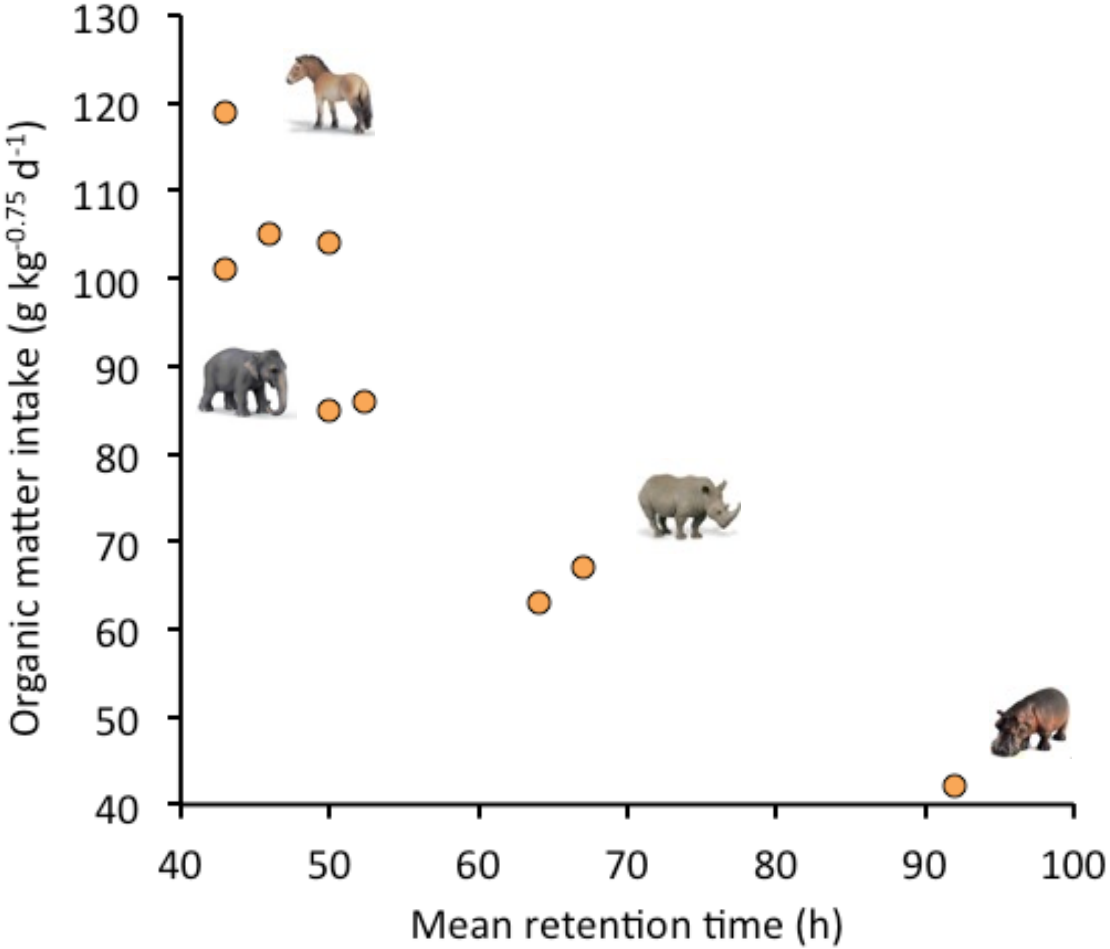
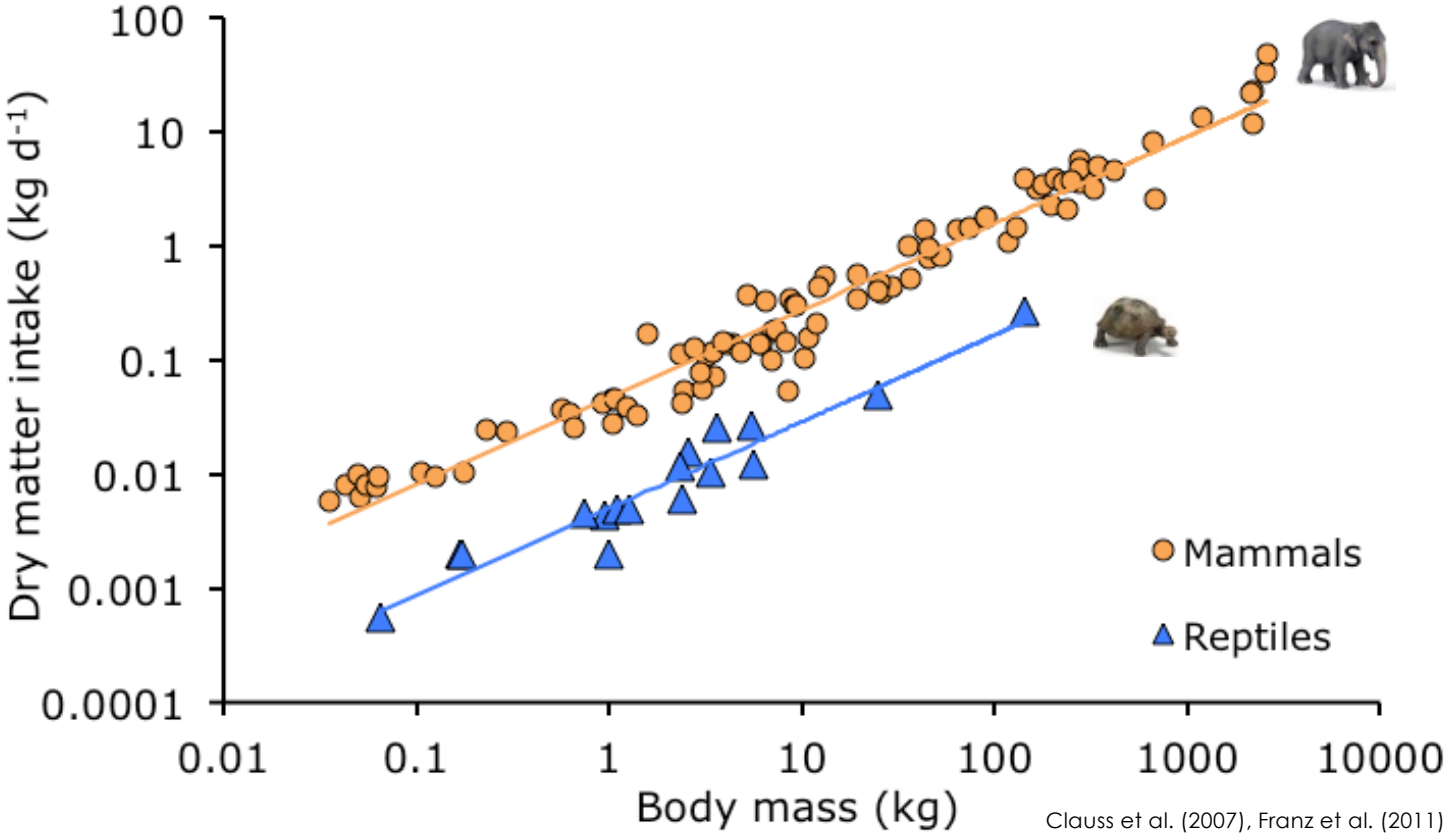
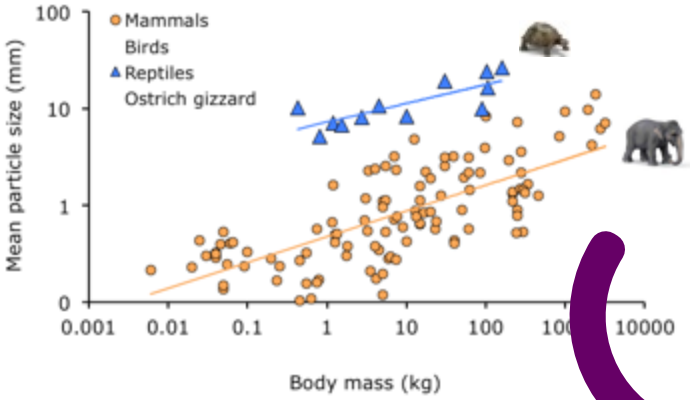


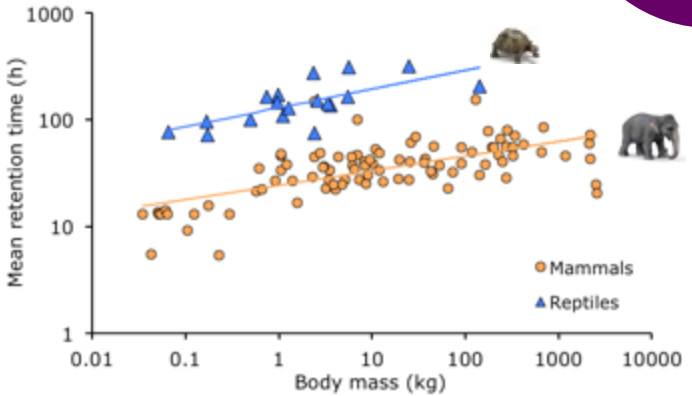
Food intake

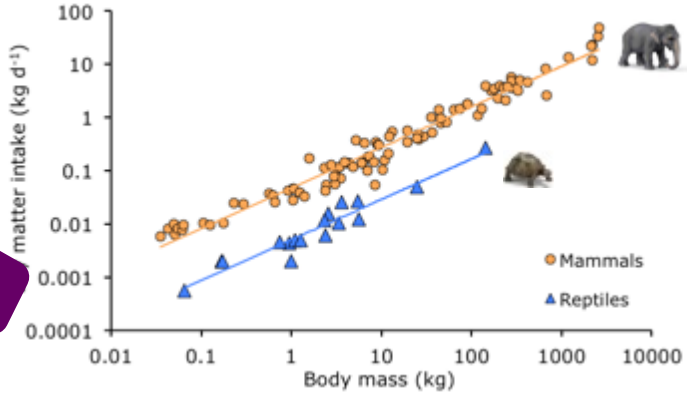


Clauss et al. (2007), Franz et al. (2011)

Chewing … facilitates higher intake



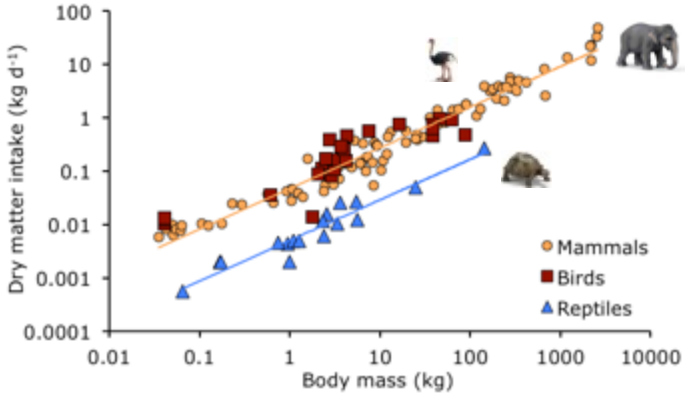




Clauss et al. (2007), Fritz et al. (2009, 2010), Franz et al. (2011)

Particle size reduction … facilitates higher intake

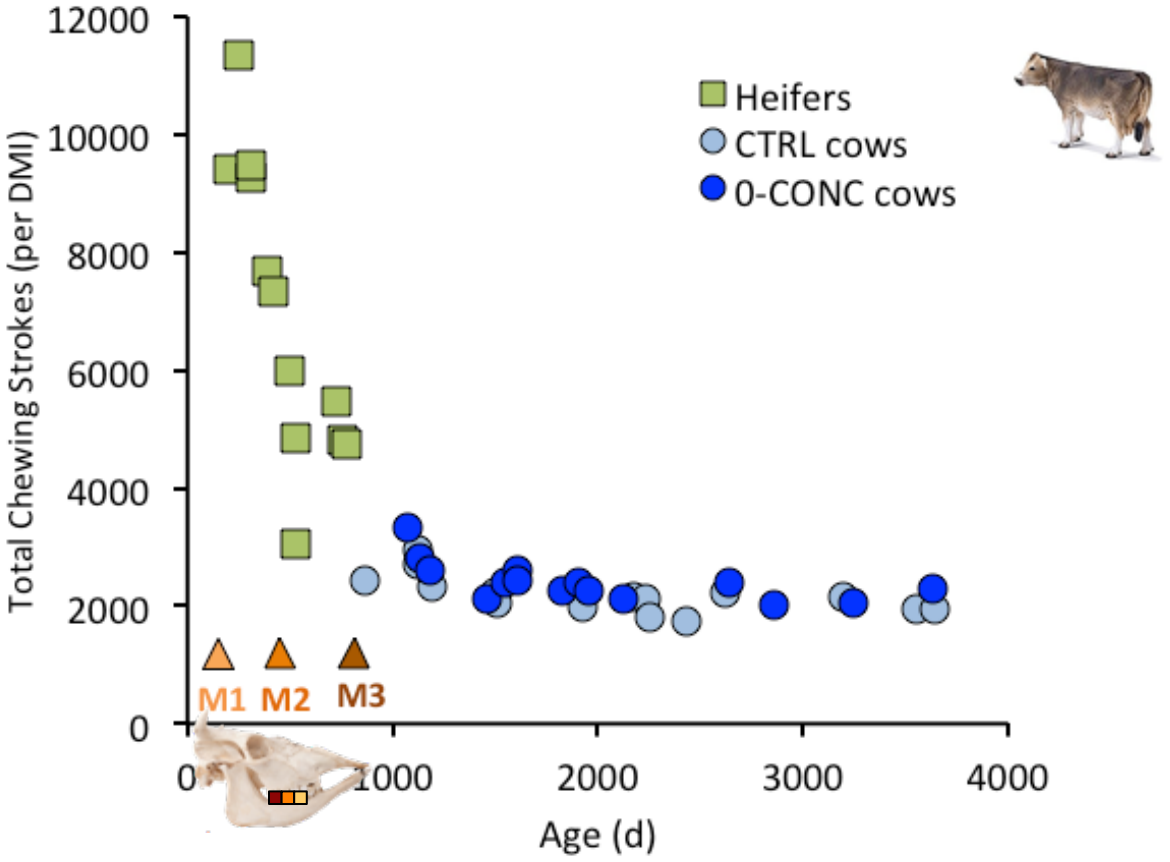
in herbivores, particle size reduction is a prerequisite for endothermy



Clauss et al. (2007), Franz et al. (2011), Fritz et al. (2012)

Quiz

Chewing surface matters



Age effect on chewing intensity
(due to molar eruption) from Grandl et al. (2019)

How can we increase chewing efficiency?

more chewing surface

Third molar prolongation suids

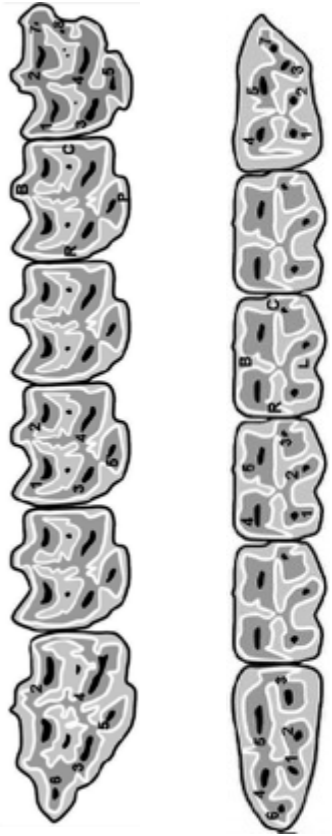
from Souron et al. (2014)

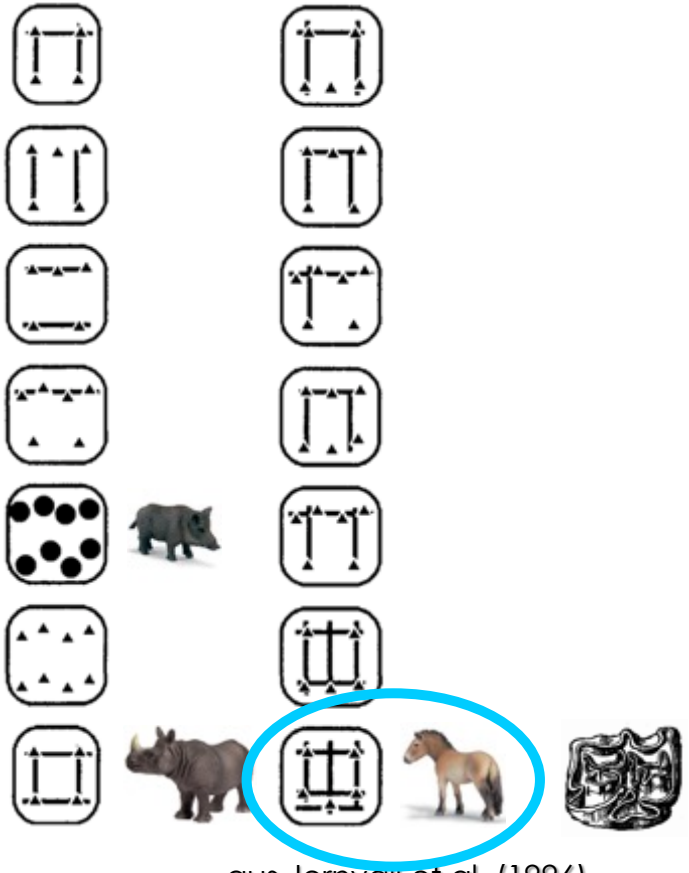
‘Molarisation‘ or premolars

How can we increase chewing efficiency?

dental design

Chewing surfaces – enamel ridges





aus Jernvall et al. (1996)

https://www.sciencedaily.com/releases/2011/04/110404151341.htm

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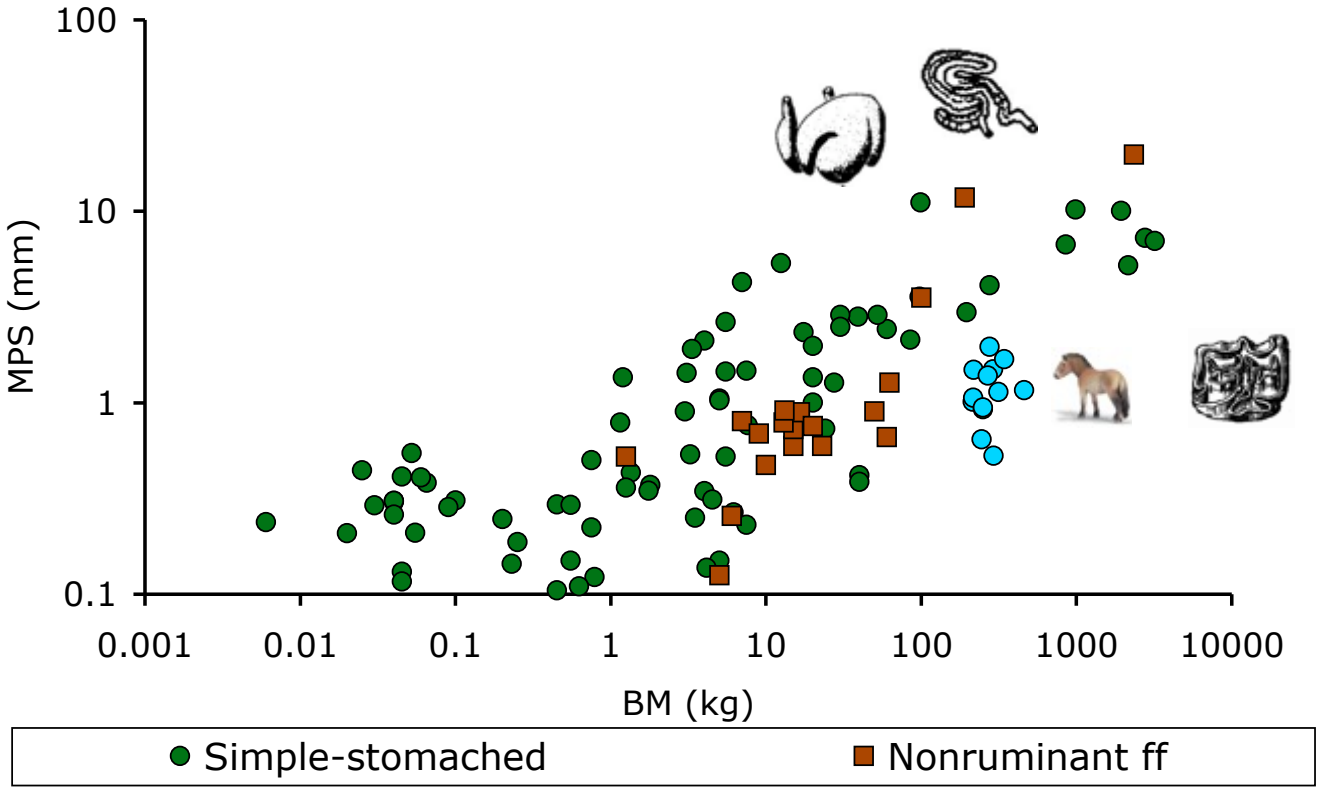
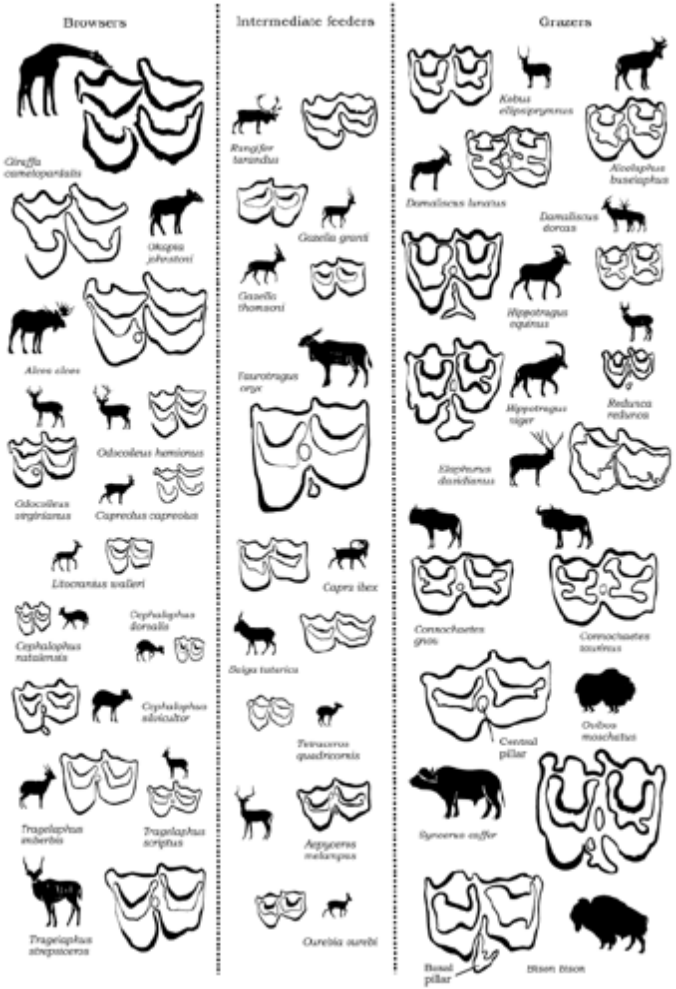


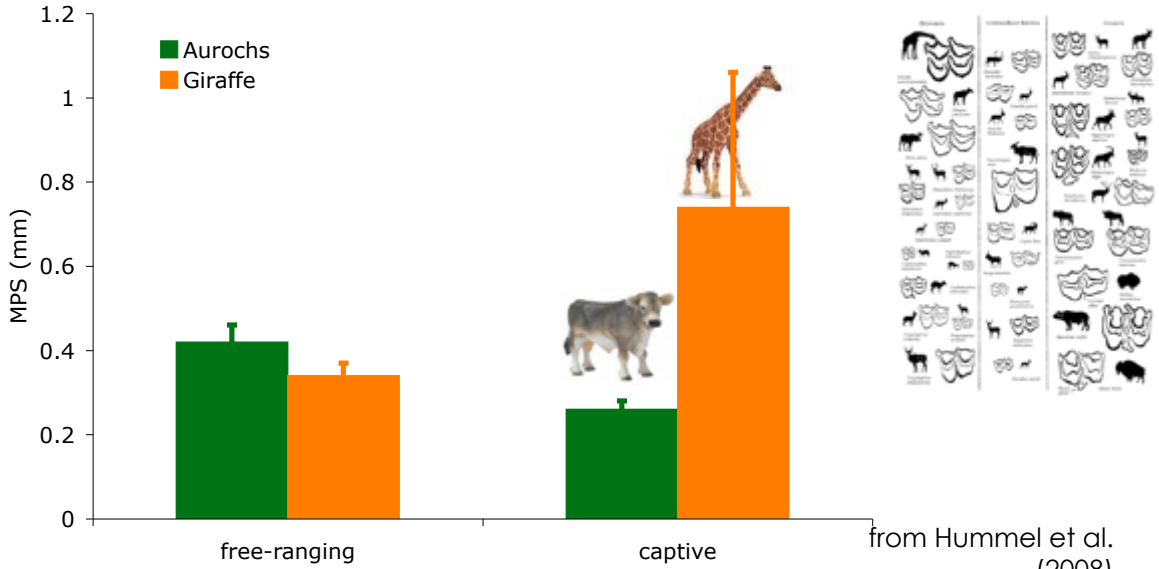
Chewing surfaces – enamel ridges



Kaiser et al. (2010)

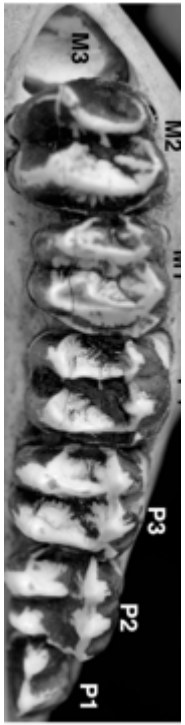
Chewing surfaces – enamel ridges

- We expect captive herbivores to have finer faecal particles than free-ranging conspecifics (due to pellet feeding)
- This is confirmed in Aurochs but not in giraffes!
- Indication that giraffe teeth are adapted to chewing something else - not the diets offered in captivity.



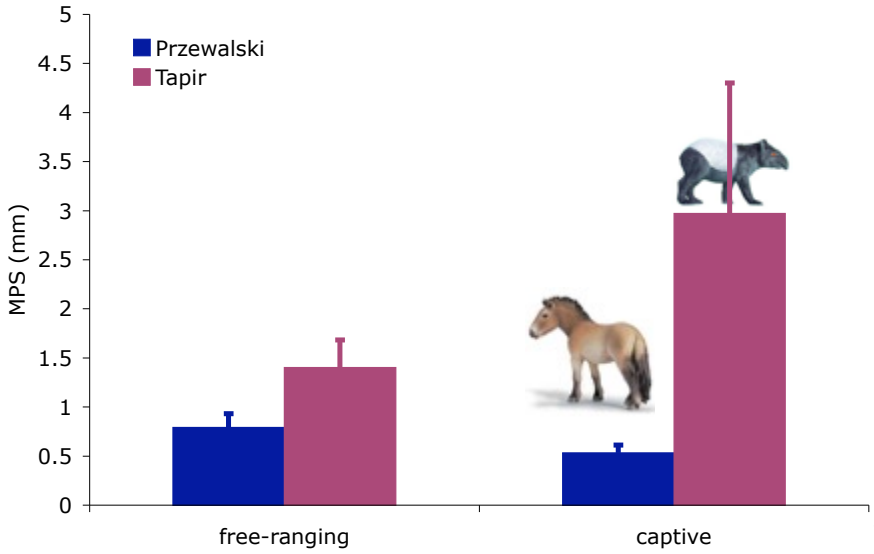
from Hummel et al. (2008)

Chewing surfaces – enamel ridges



Chewing surfaces – enamel ridges

- We expect captive herbivores to have finer faecal particles than free-ranging conspecifics (due to pellet feeding)
- This is confirmed in Przewalski horse but not in tapirs!
- Indication that tapir teeth are adapted to chewing something else - not the diets offered in captivity.

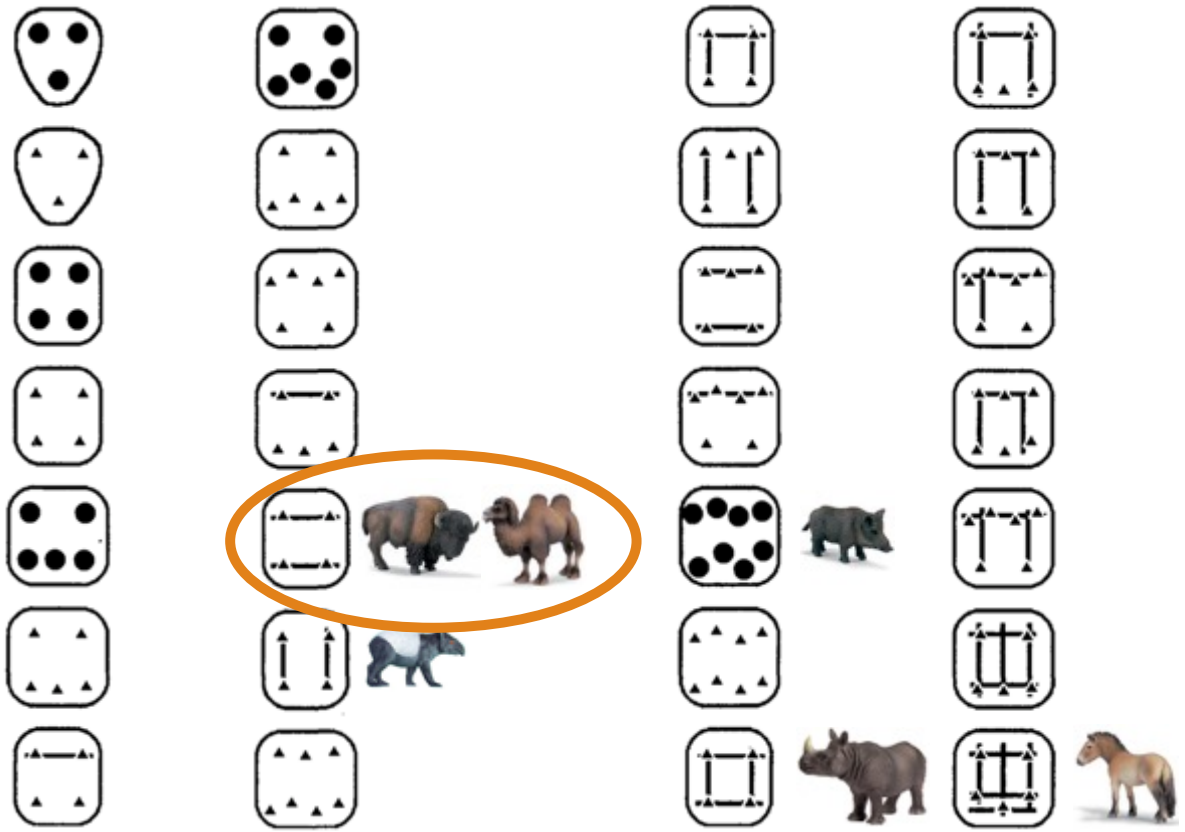


from Hummel et al. (2008)

How can we increase chewing efficiency?

something completely different

Chewing surfaces – enamel ridges



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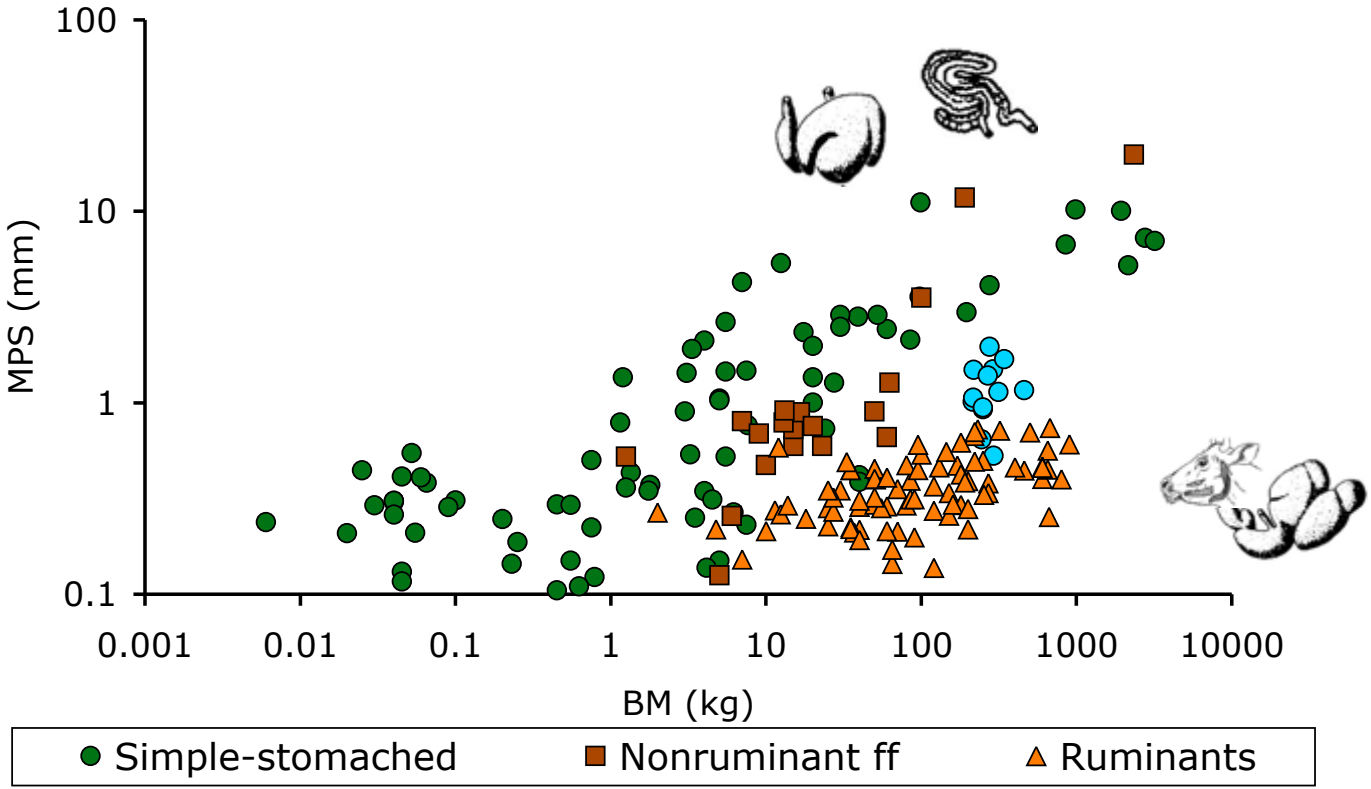

… just chew more … ?

Faecal particles in a ruminant and a nonruminant

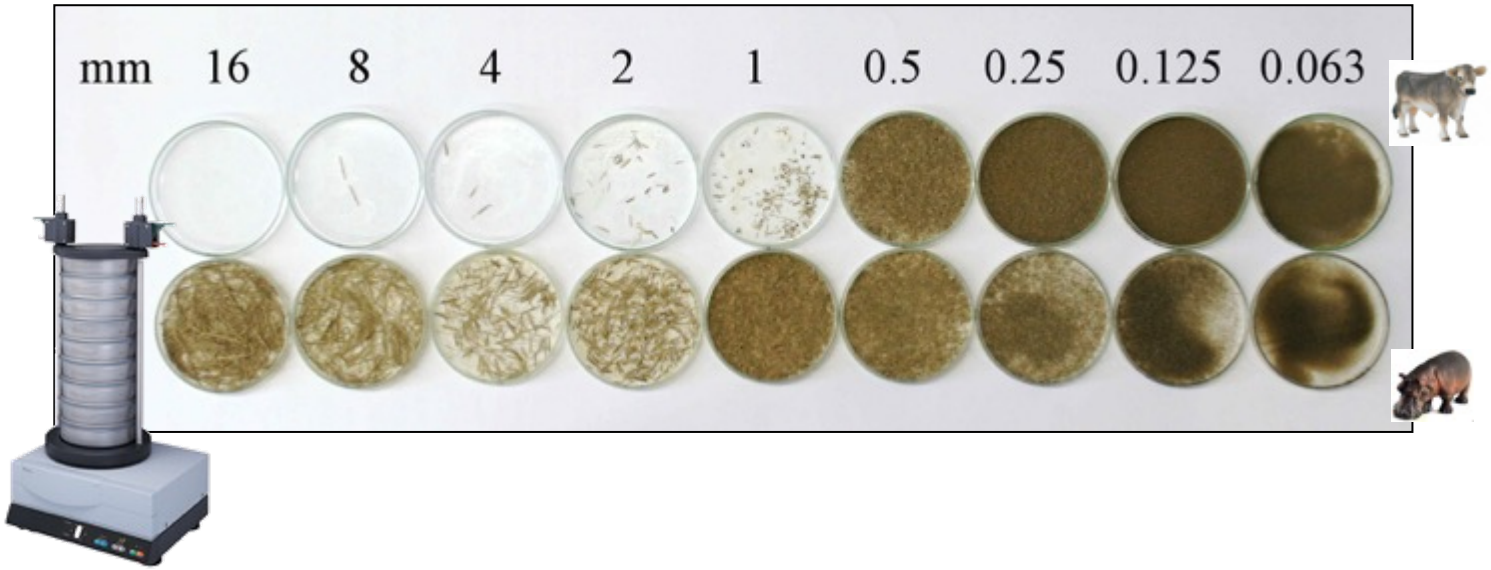

Photo A. Schwarm

Why rumination ?

- Anti-predation strategy
  - *"Rumination seems to allow herbivores to ingest in haste and masticate at leisure"* (Karasov & Del Rio 2007)

    => Ruminants should ingest similar amounts of food as other herbivores and just 'chew later' - or become time-constrained in intake

Life cycle period and activity of prey influence their susceptibility to predators

A. Molinari-Jobin, P. Molinari, A. Loison, J.-M. Gaillard and U. Breitenmoser

ECOGRAPHY 27: 323–329, 2004

We found more chamois predated when feeding, whereas roe deer were predated mainly when ruminating.

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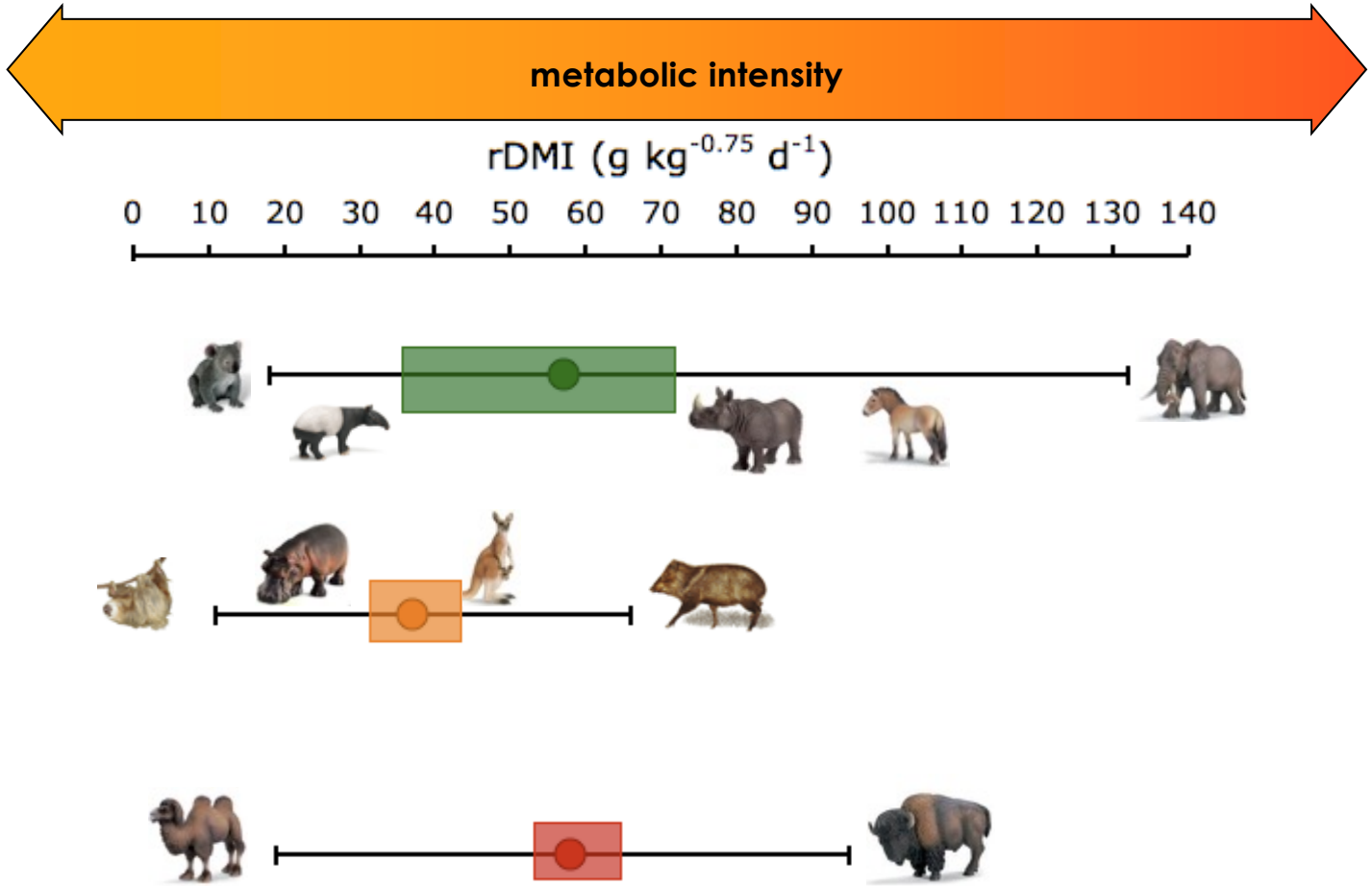
- Energy-saving mechanism
  - Rumination occurs in a state of 'drowsiness' similar to rest; may represent an energy-saving strategy - less time spent 'wide awake' (Gordon 1968)

    => Ruminants should have lower energy requirements/higher productivity than other herbivores
- Enhancement of digestive efficiency and intake
  - Rumination reduces particle size and hence allows faster digestion at constant intake

    => Ruminants should have smaller digesta particle sizes (and higher intakes) than other herbivores

Herbivore diversity



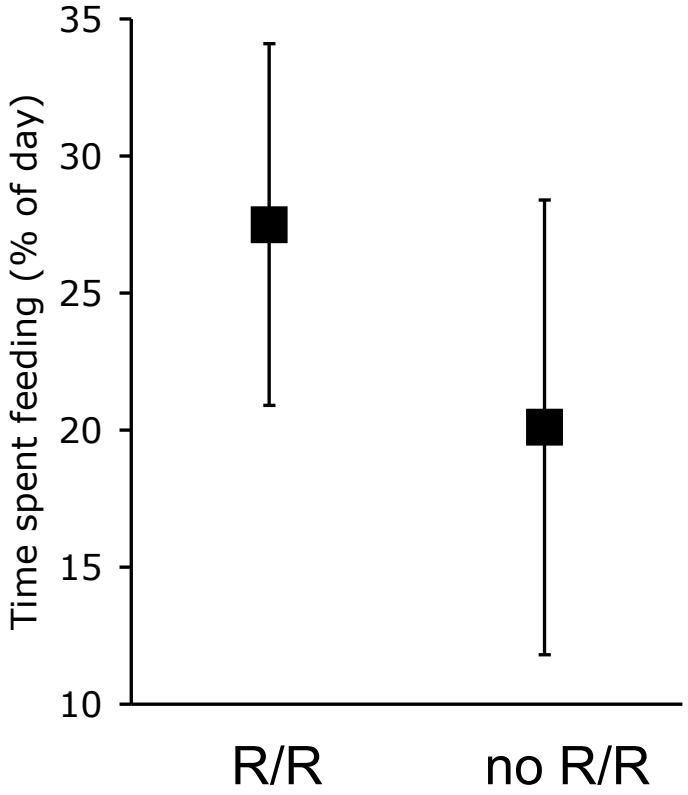
from Clauss et al. (2010)

biology letters
Physiology

Biol. Lett. (2011) 00, 1–4
doi:10.1098/rsbl.2011.0197
Published online 00 Month 0000

Regurgitation and remastication in the foregut-fermenting proboscis monkey (*Nasalis larvatus*)

Ikki Matsuda[1,*], Tadahiro Murai[1], Marcus Clauss[2], Tomomi Yamada[3], Augustine Tuuga[4], Henry Bernard[5] and Seigo Higashi[6]

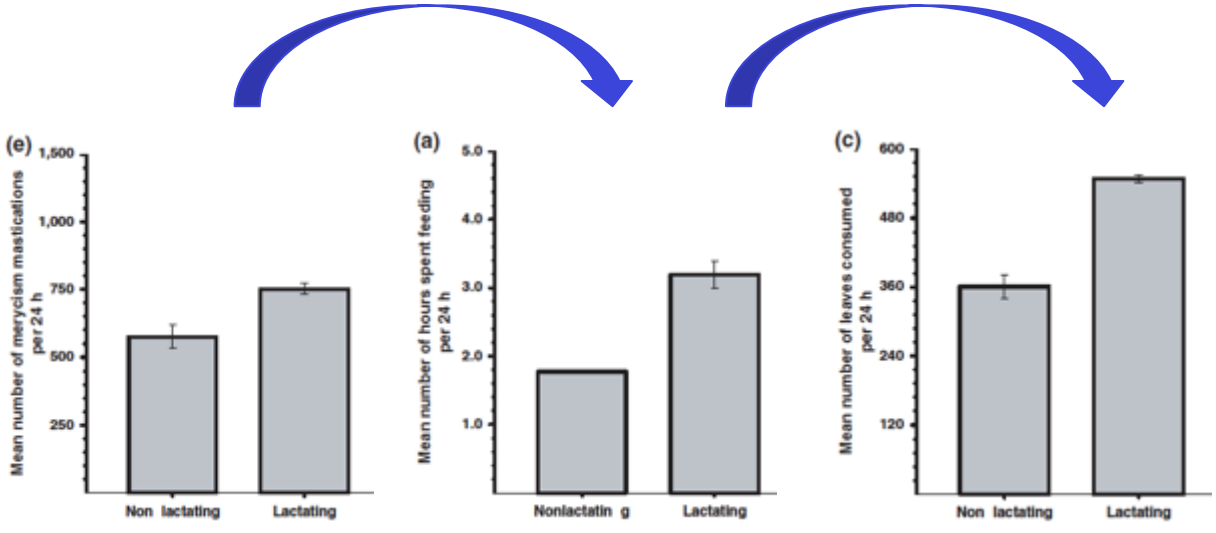


The example of the koala

The effects of lactation on the feeding behaviour and activity patterns of free-ranging female koalas (*Phascolarctos cinereus* Goldfuss)

Australian Journal of Zoology, 2003, **51**, 415–428

M. Logan and G. D. Sanson



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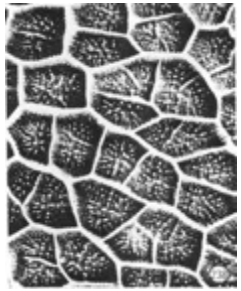
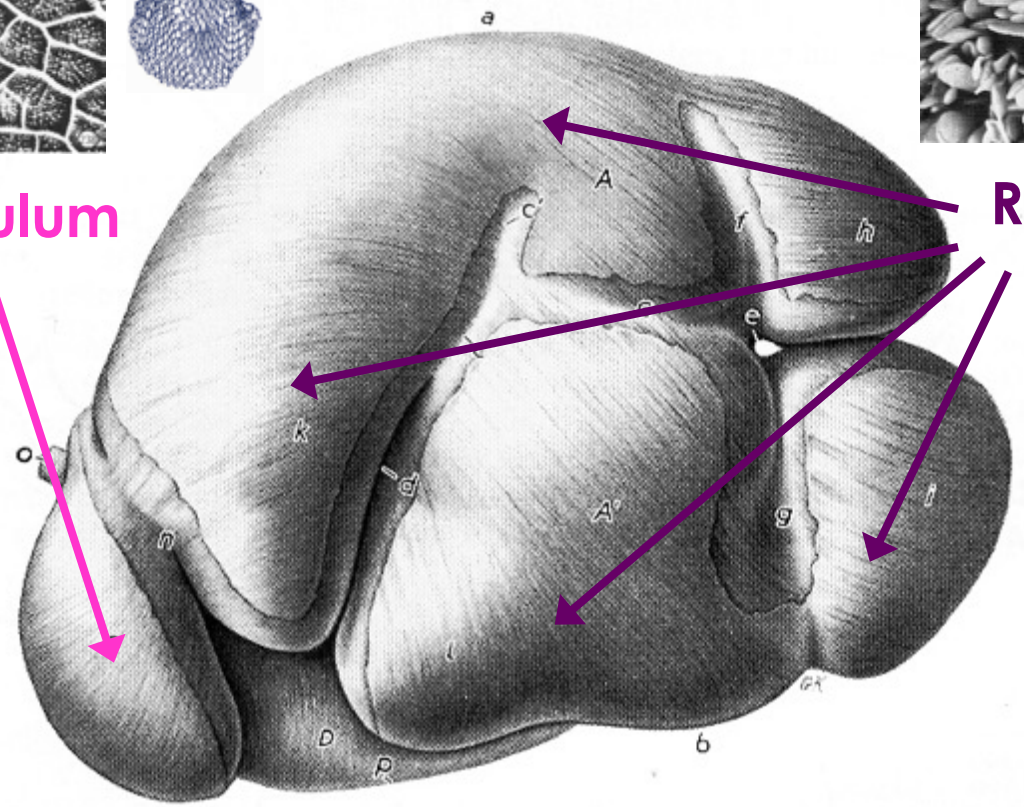
Sorting in the forestomach

an interplay of fermentation characteristics, anatomy, and gravity

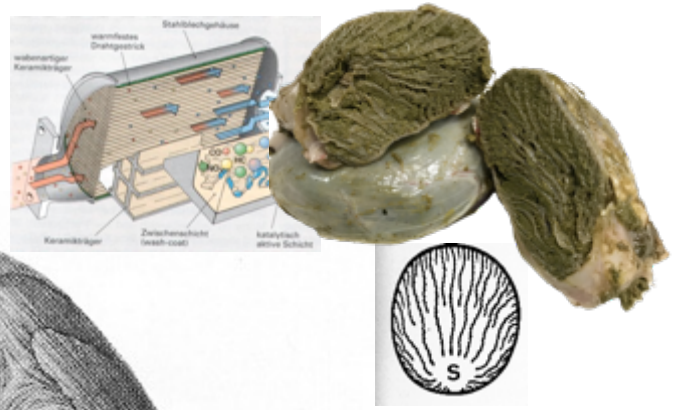


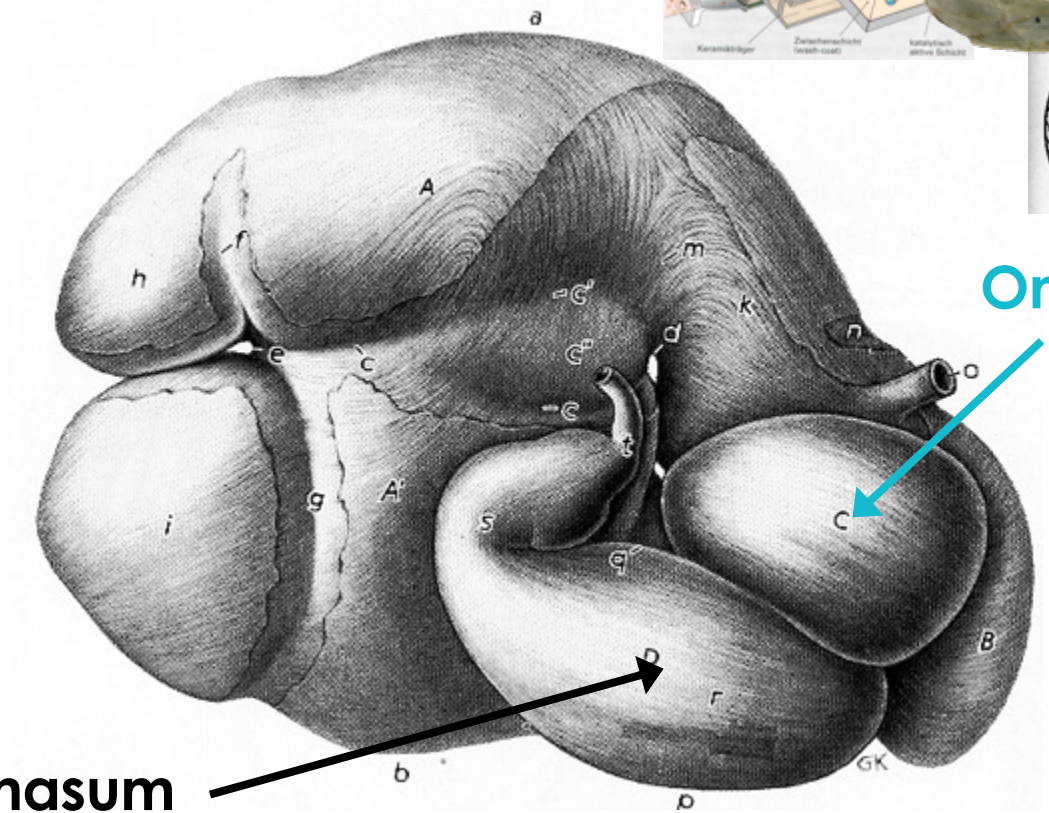
Reticulum

Rumen



(Nickel-Schummer-Seiferle 1967)

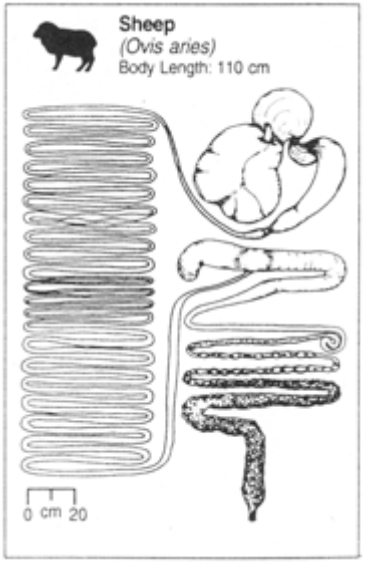


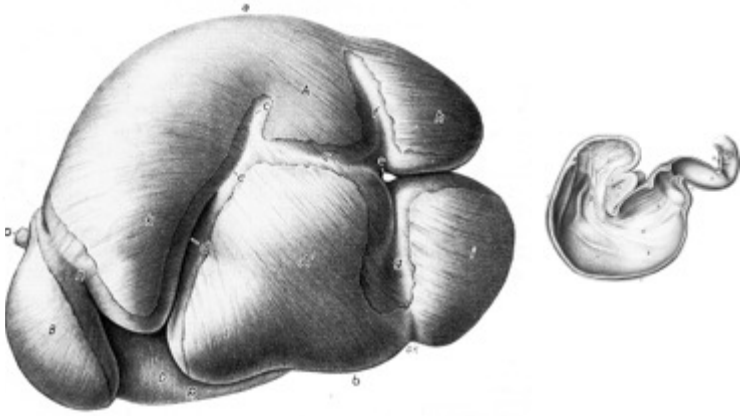


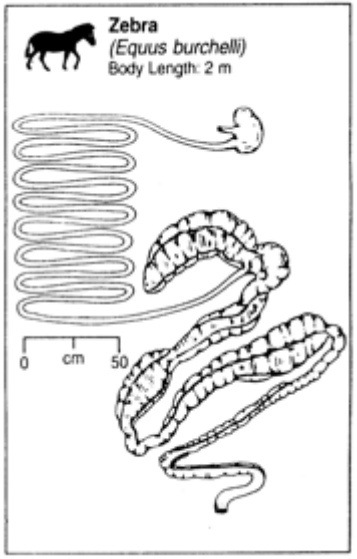
Omasum

Abomasum

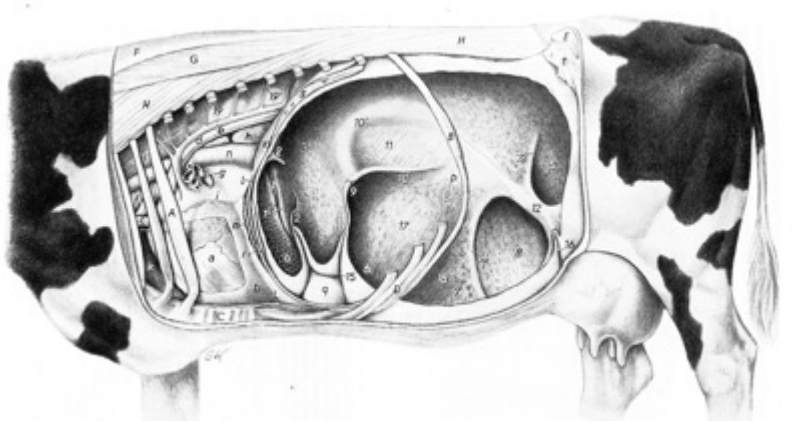
(Nickel-Schummer-Seiferle 1967)

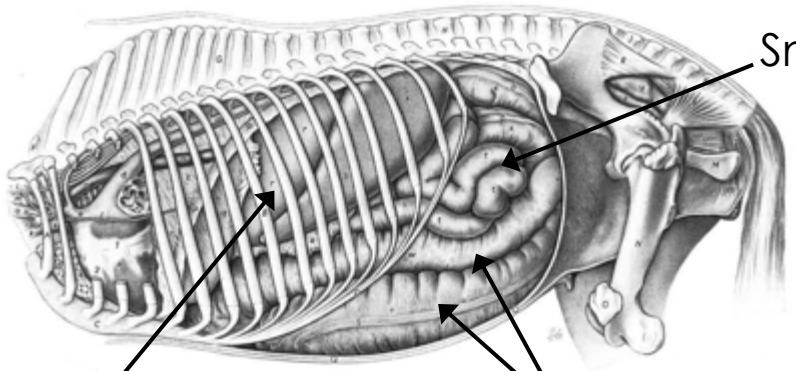




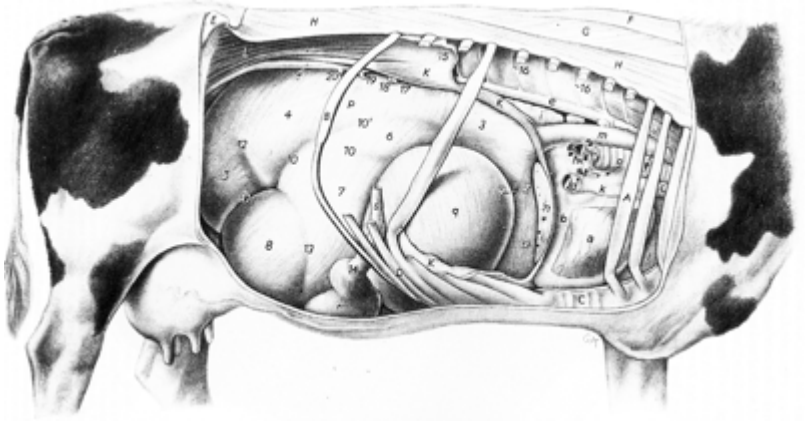


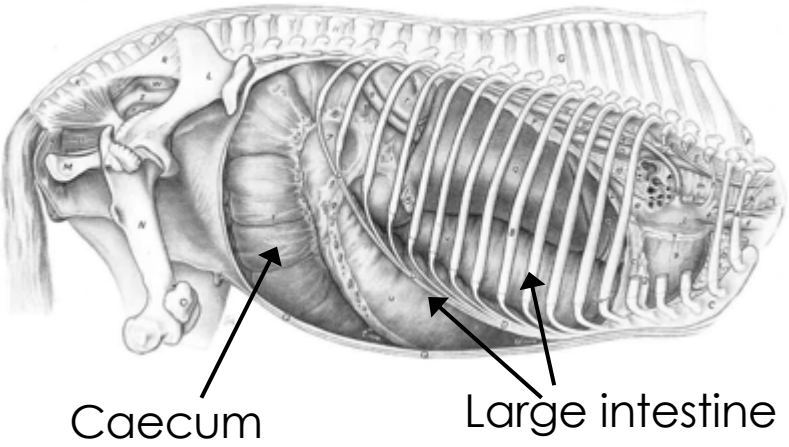
(Nickel-Schummer-Seiferle 1967, Stevens & Hume 1995)





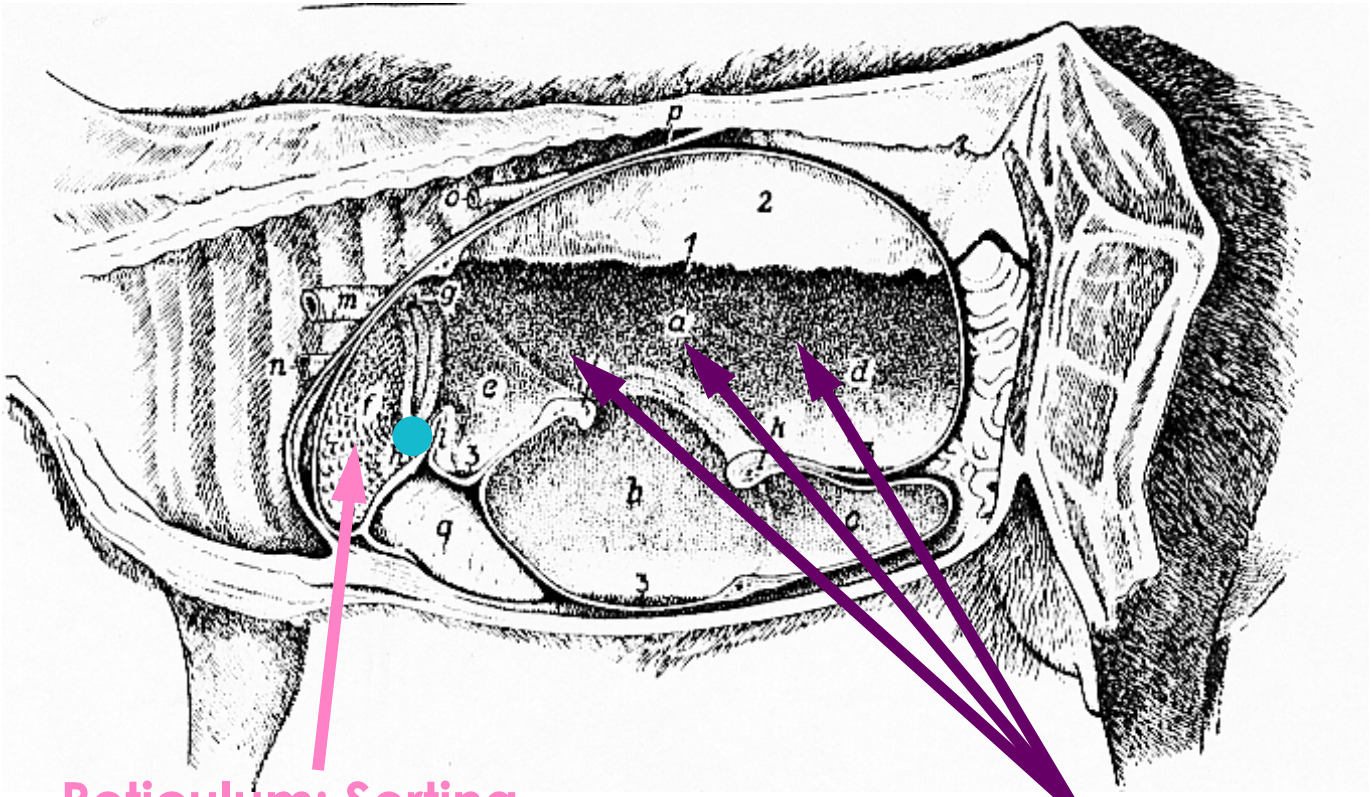
(Nickel-Schummer-Seiferle 1967)





(Nickel-Schummer-Seiferle 1967)

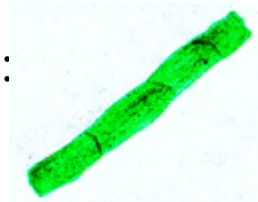
Digest and sort !

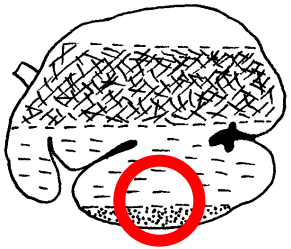


(from Grau 1955)

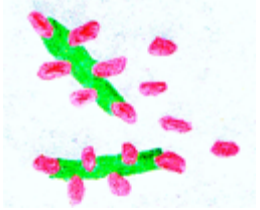
Functional density

un-fermented ingesta particle:
entangles in fibre mat

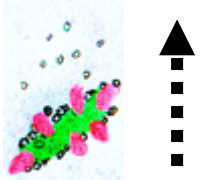




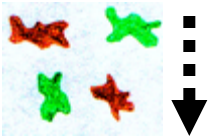
size reduction by rumination/
attachment of bacteria



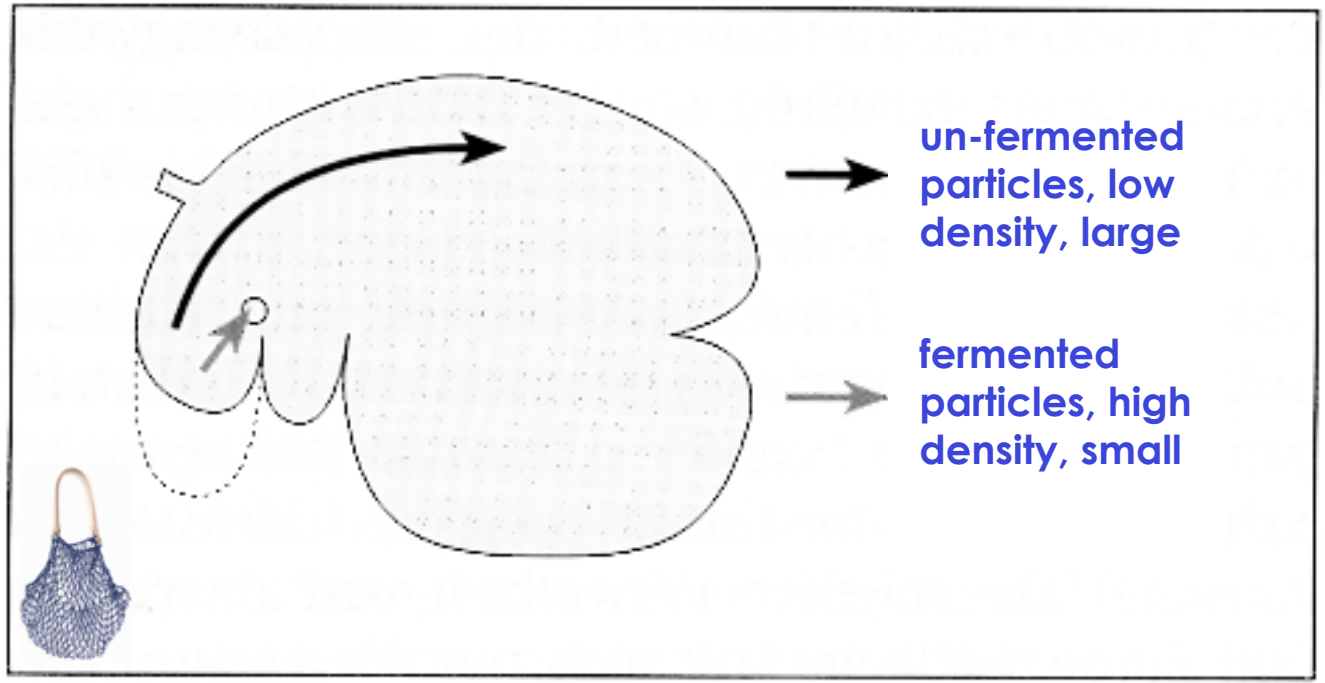
fermentation activity = gas production
=> adhesion of gas bubbles
=> updrift/low density



fermented particles:
high density

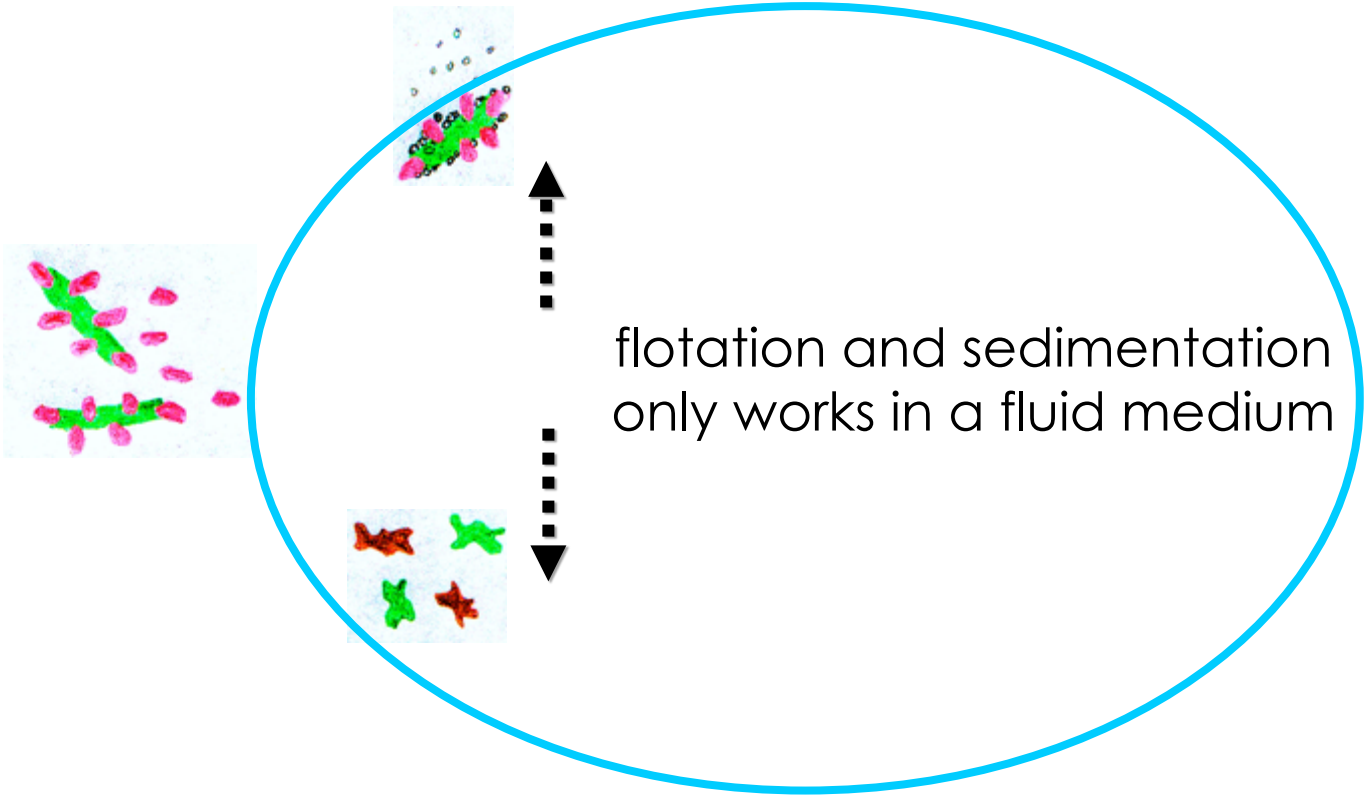


Sorting in the reticulum



(from von Engelhardt & Breves 2000)

Sorting by density



Sorting by density

Photo I. Lechner

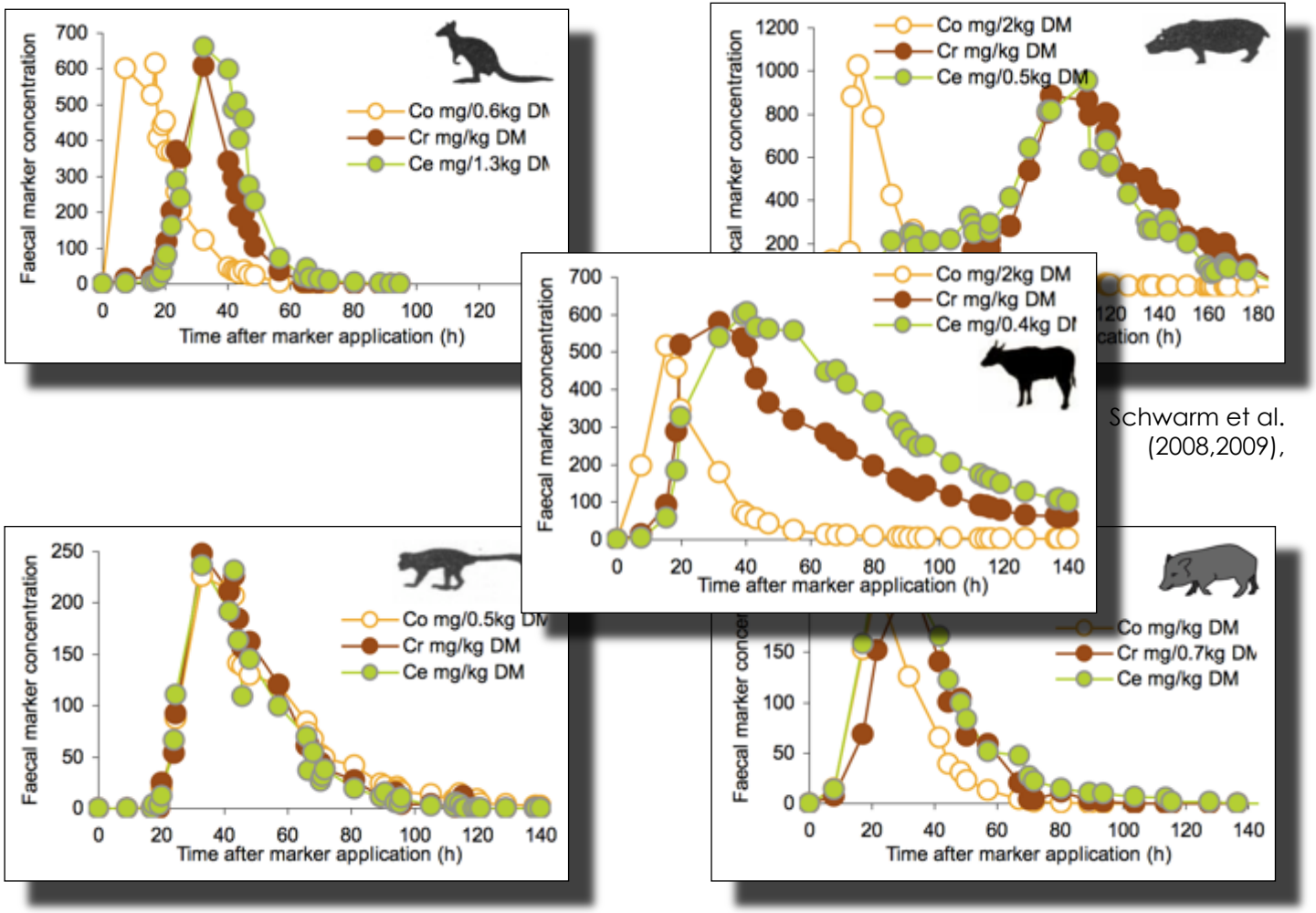
Ruminants rest in sternal recumbency

(there may be pigs in space, but no sheep on the moon!)

Demonstration of sorting

Photo J. Derix

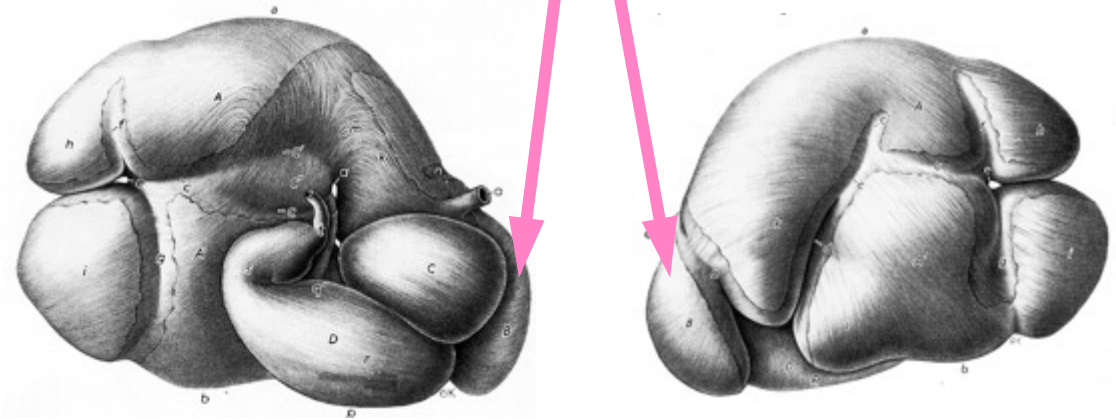
Demonstration of sorting



Schwarm et al. (2008,2009),

Fluid is a problem

high fluid content in
Reticulum

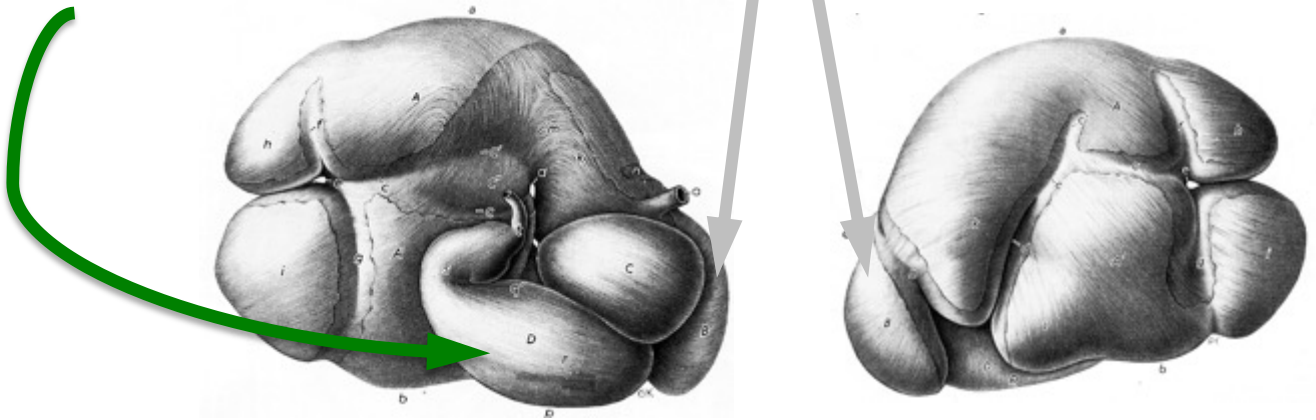


(from Nickel-Schummer-Seiferle 1967)

Fluid is a problem

high fluid content in
Reticulum

it would be hard for the
Abomasum to fight against
the dilution



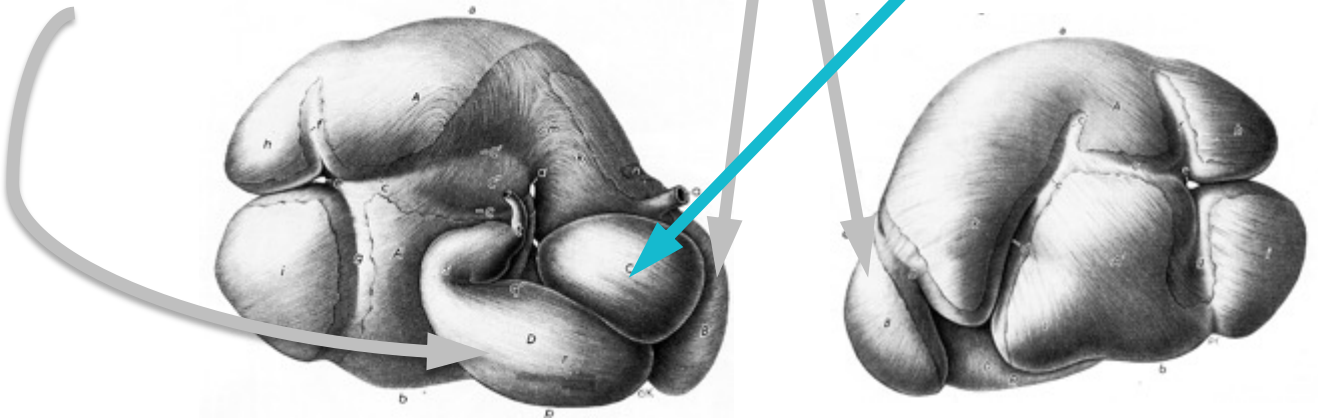
(from Nickel-Schummer-Seiferle 1967)

Fluid is a problem

high fluid content in
Reticulum

it would be hard for the **Abomasum** to fight against the dilution

therefore the **Omasum** removes the fluid



(from Nickel-Schummer-Seiferle 1967)