Evolutionary adaptations of ruminants and their potential relevance for modern production systems

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University of Zurich
Vetsuisse Faculty

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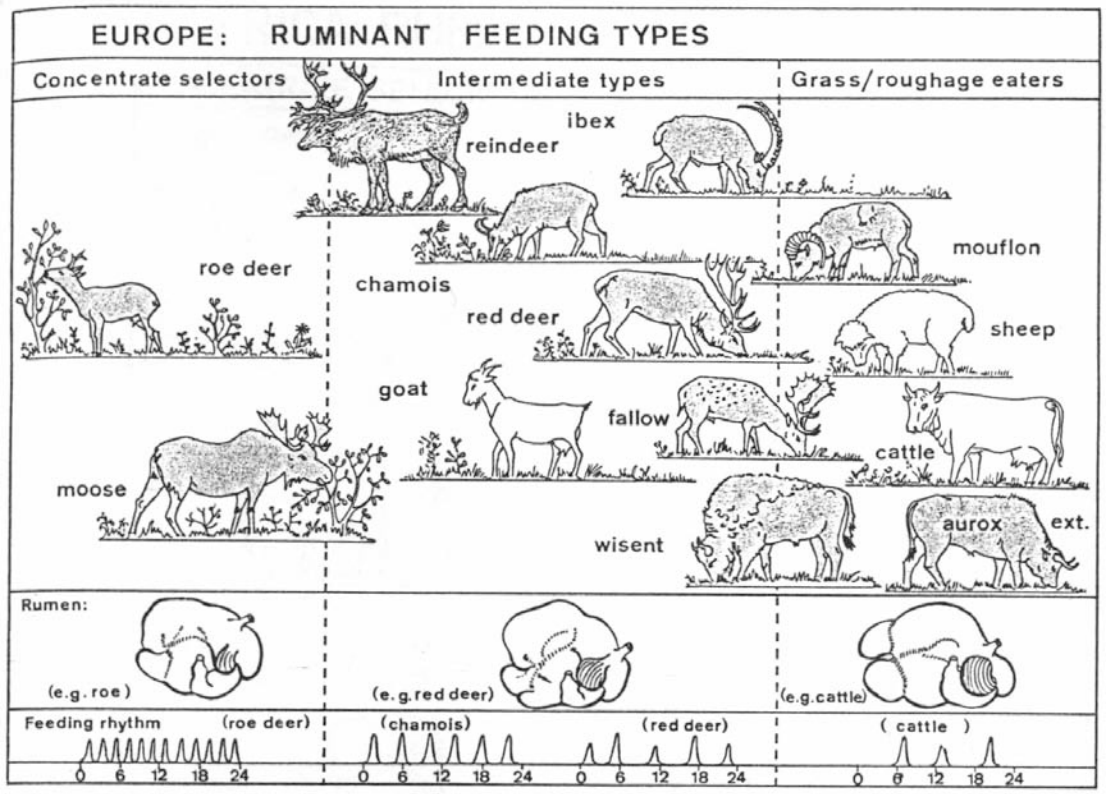
Comparative physiology

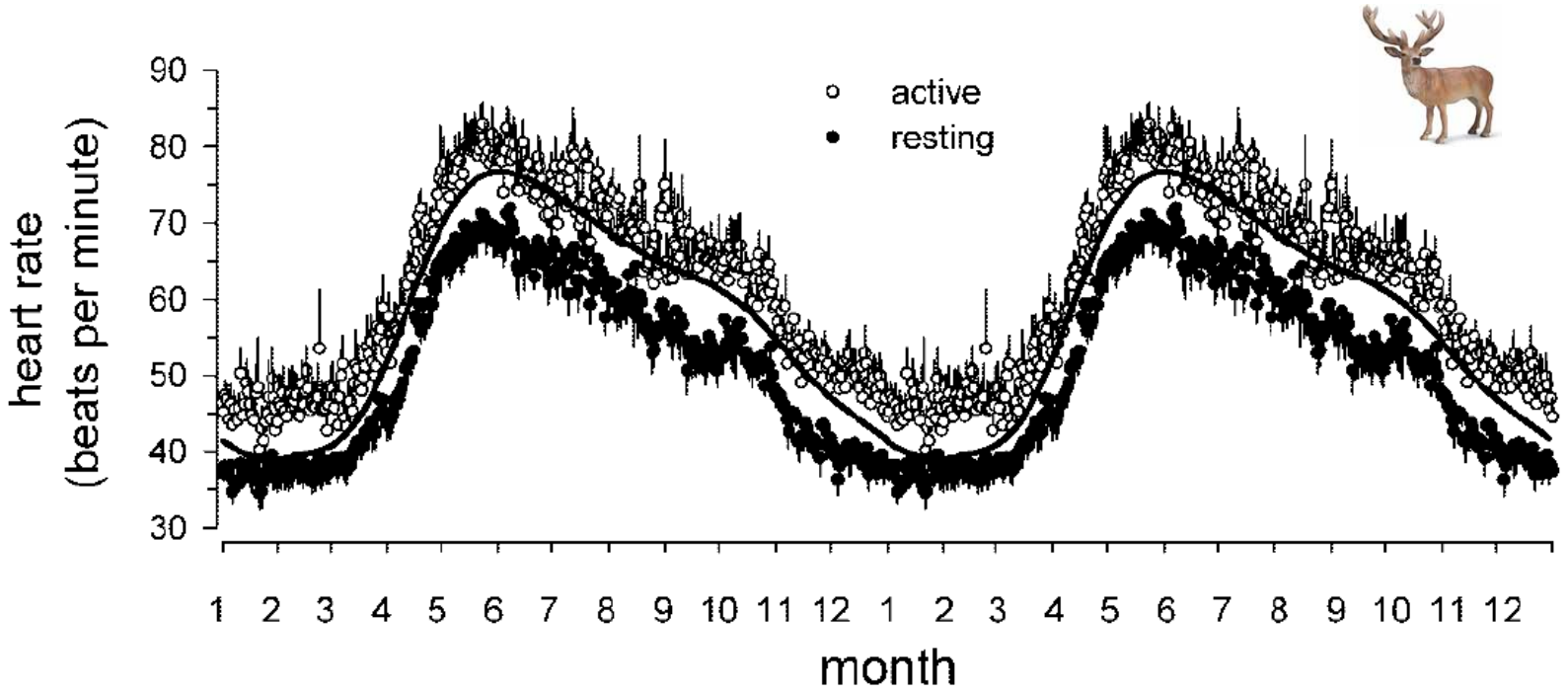
- Understanding adaptations by the comparative method



from Hofmann (1989)

Seasonality

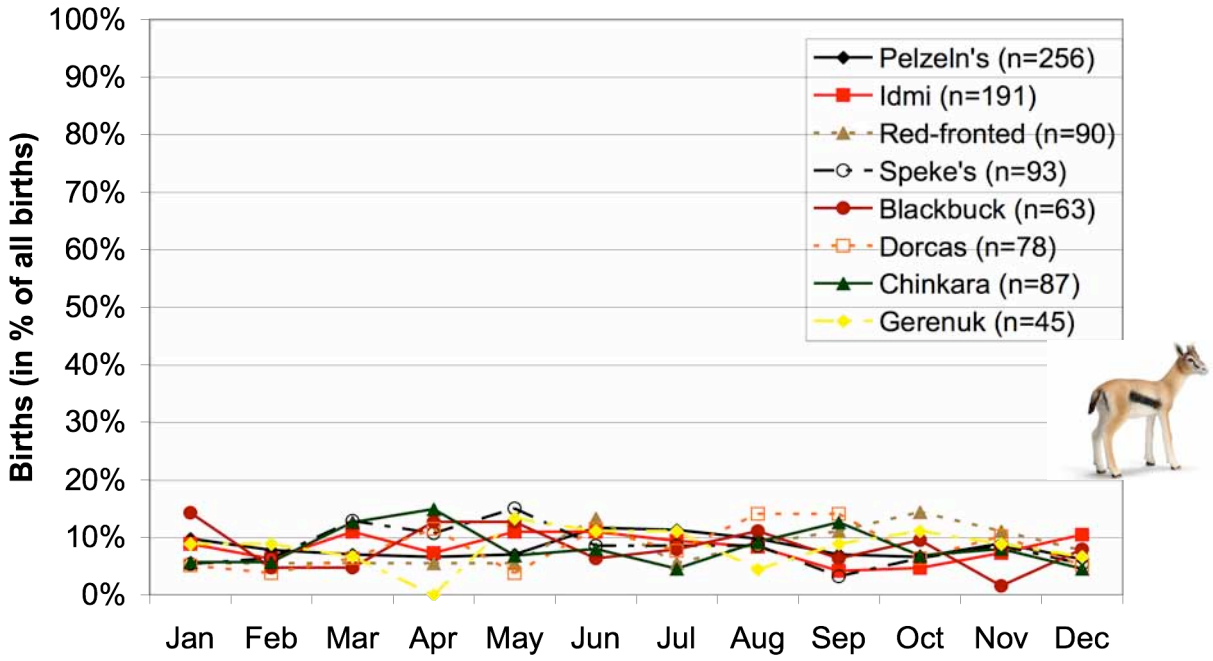
- Some wild ruminants undergo strong seasonal cycles of metabolism



from Arnold et al. (2004)

Seasonality

- Some wild ruminants undergo strong seasonal cycles of metabolism and reproduction



from Piening Schuler et al. (2009)

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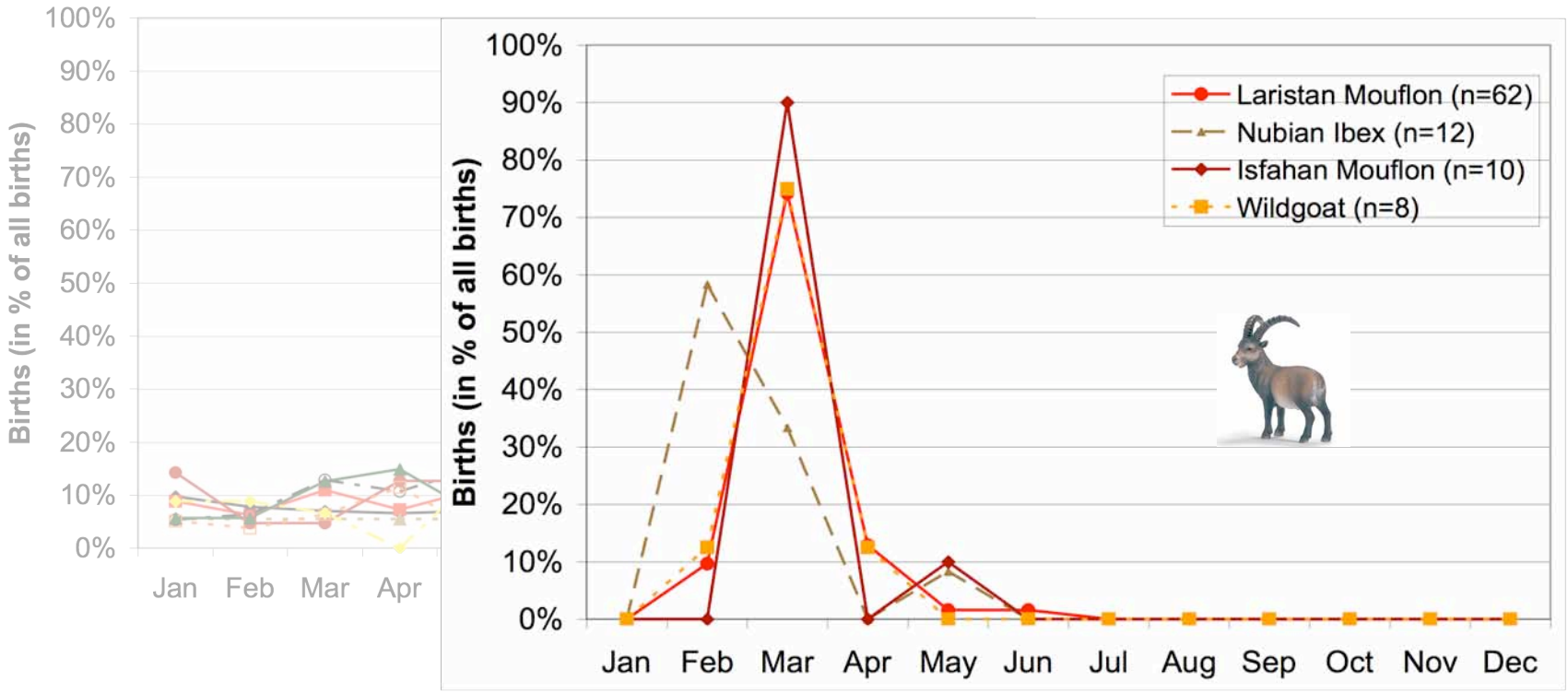
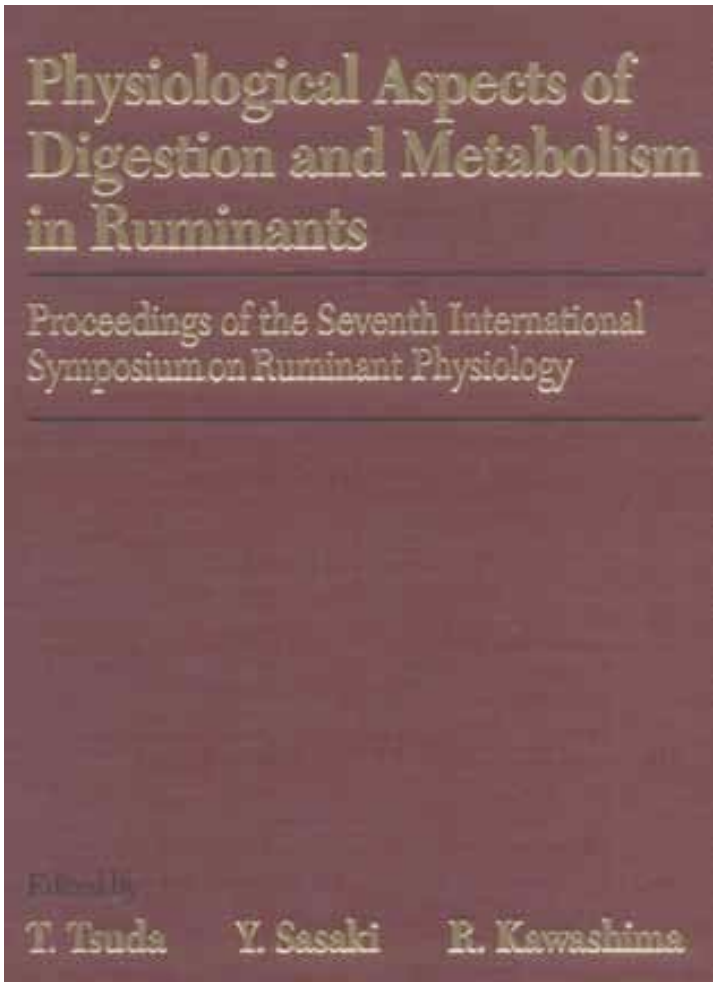


from Piening Schuler et al. (2009)

Adaptation to heat/drought

- Differences in rehydration between camels and ruminants

Digestive adaptations



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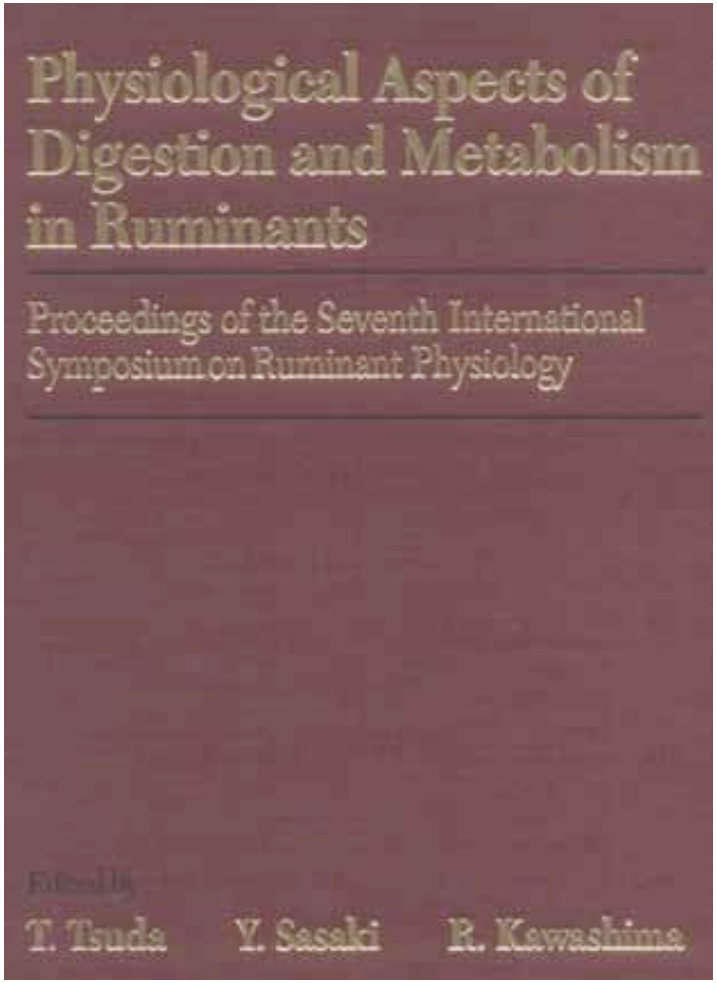

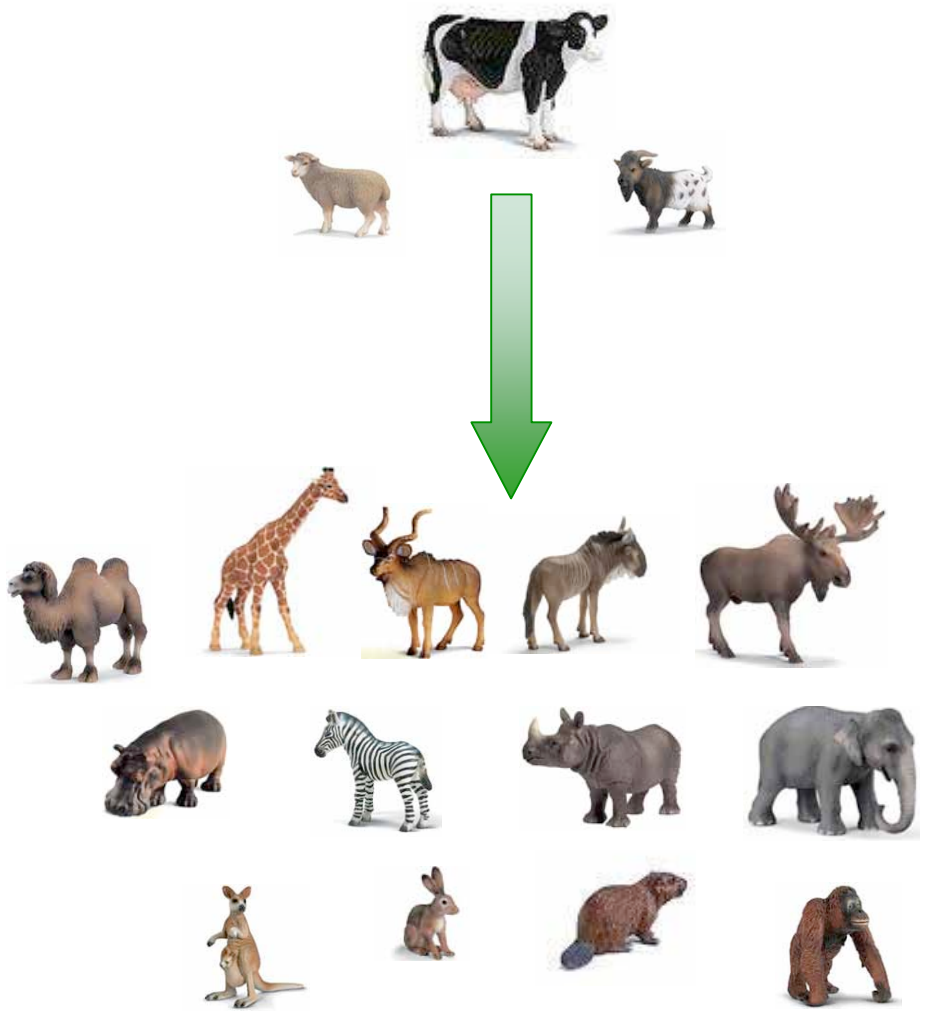

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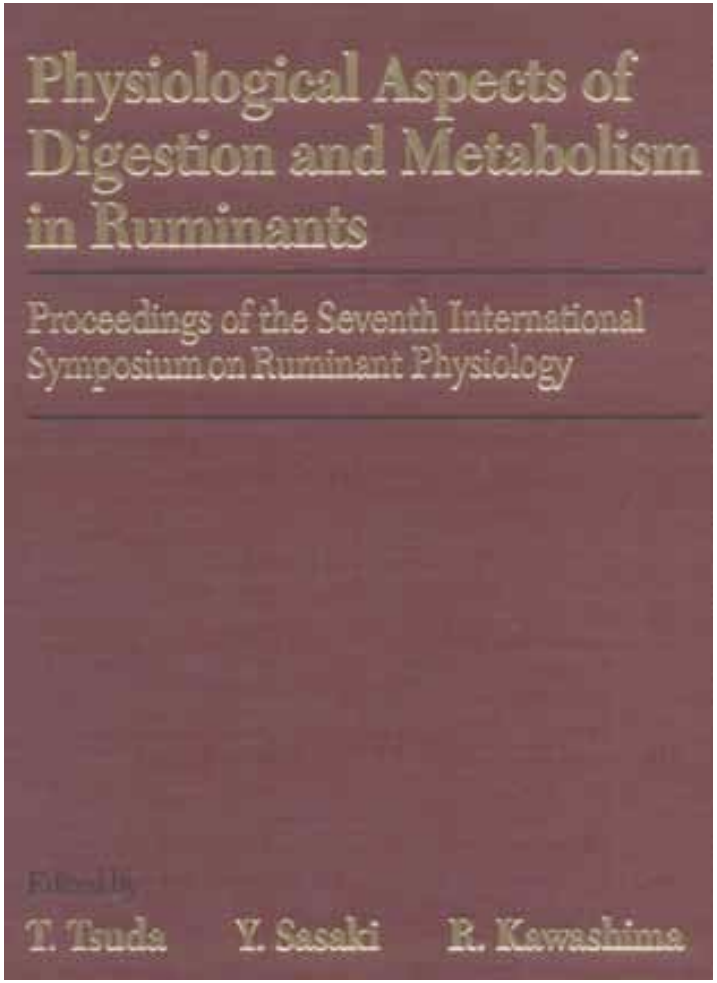

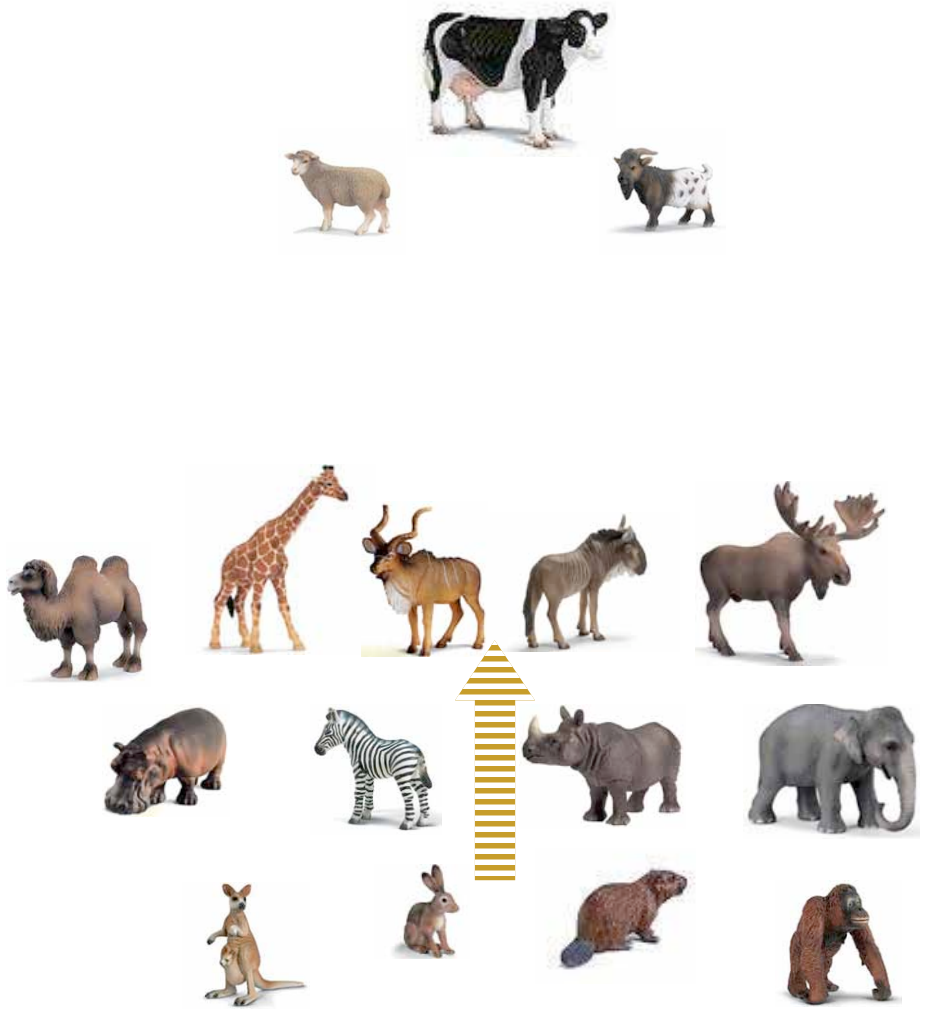

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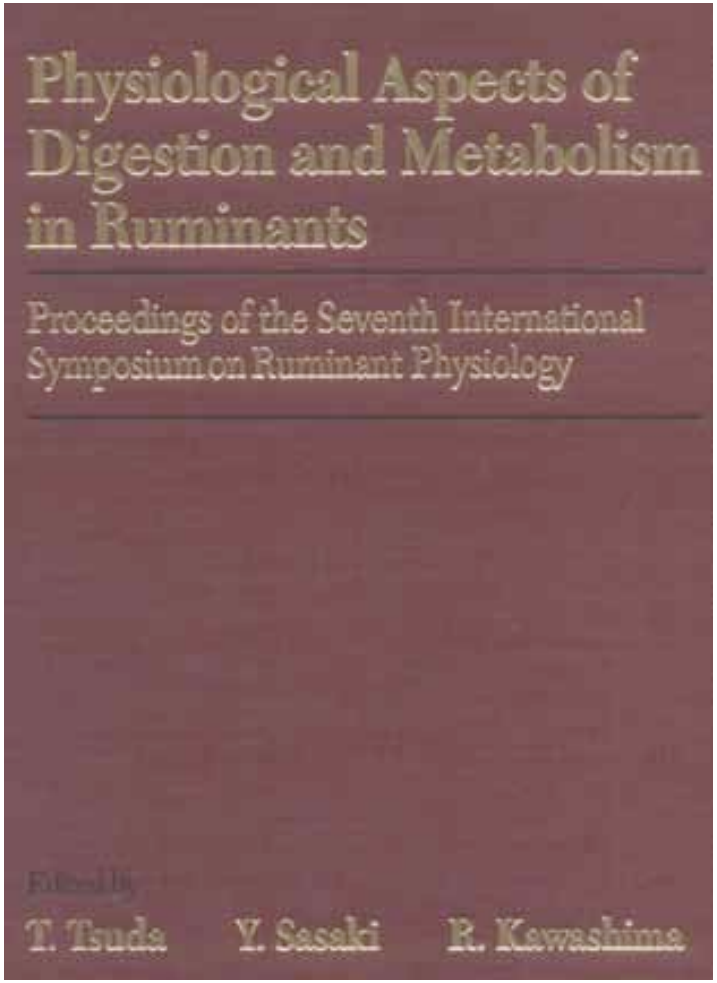
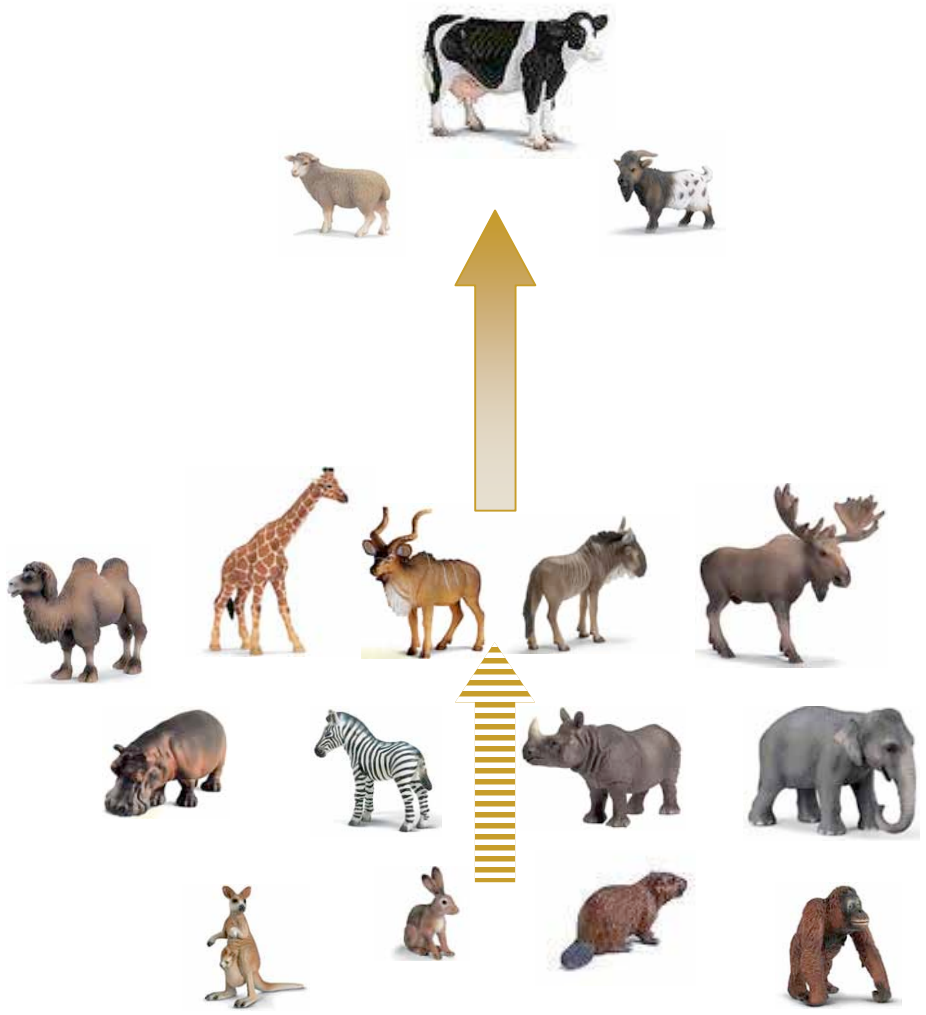
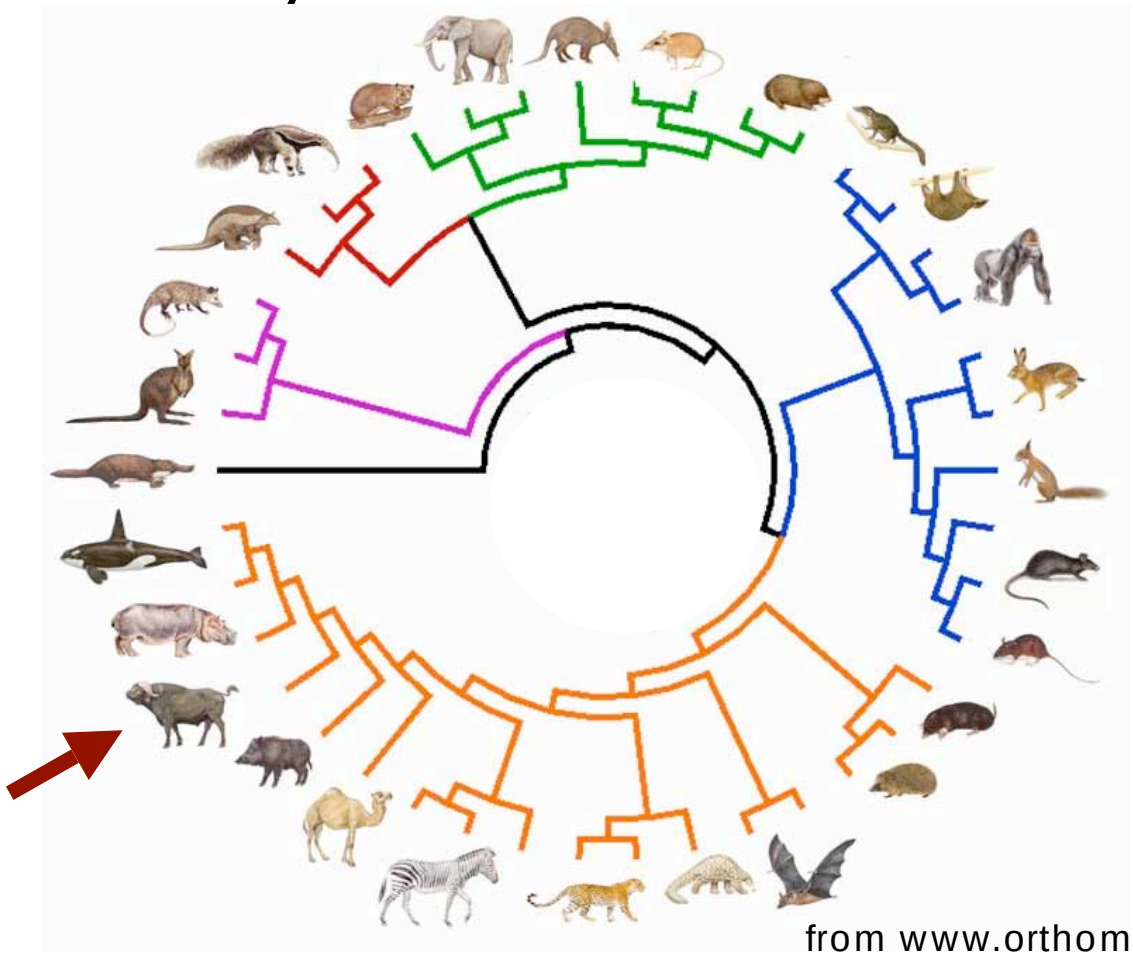




What comparative digestive physiology can offer to domestic ruminant research

- Understanding where ruminants ‘came from’ in evolutionary terms



from www.orthomam.univ-montp2.fr

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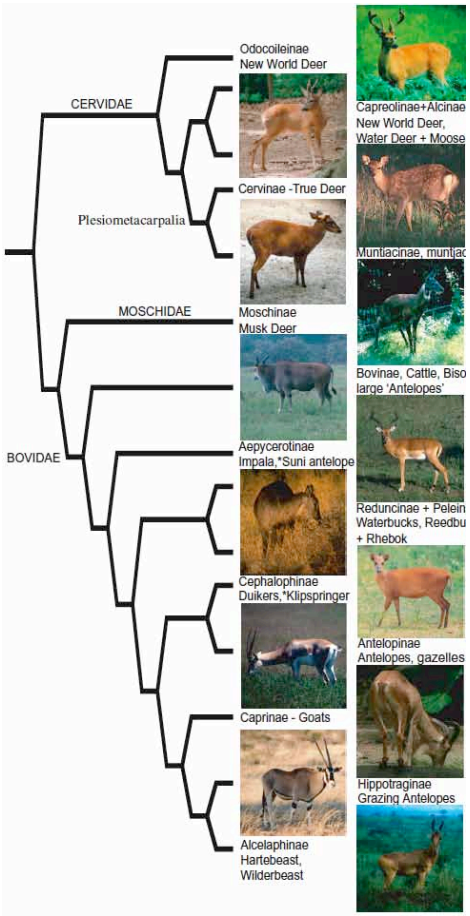
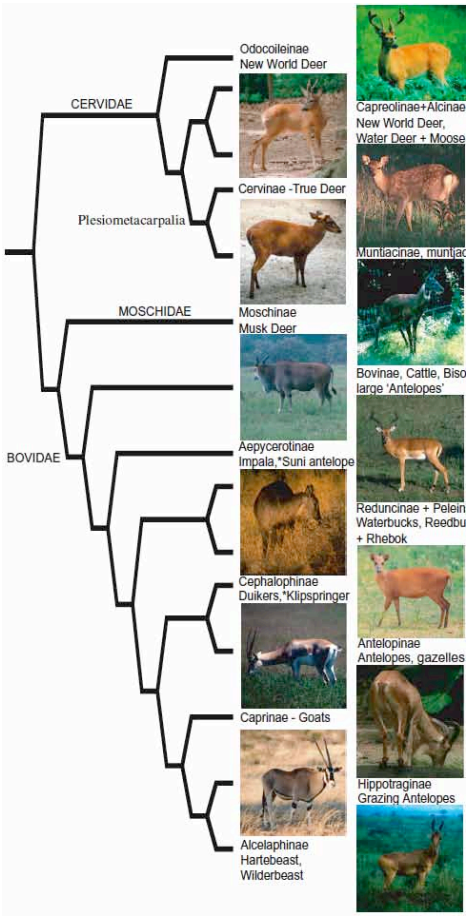


from Agnarsson et al. (2008)

What comparative digestive physiology can offer to domestic ruminant research

- Understanding where domestic ruminants ‘came from’ among the ruminants ...



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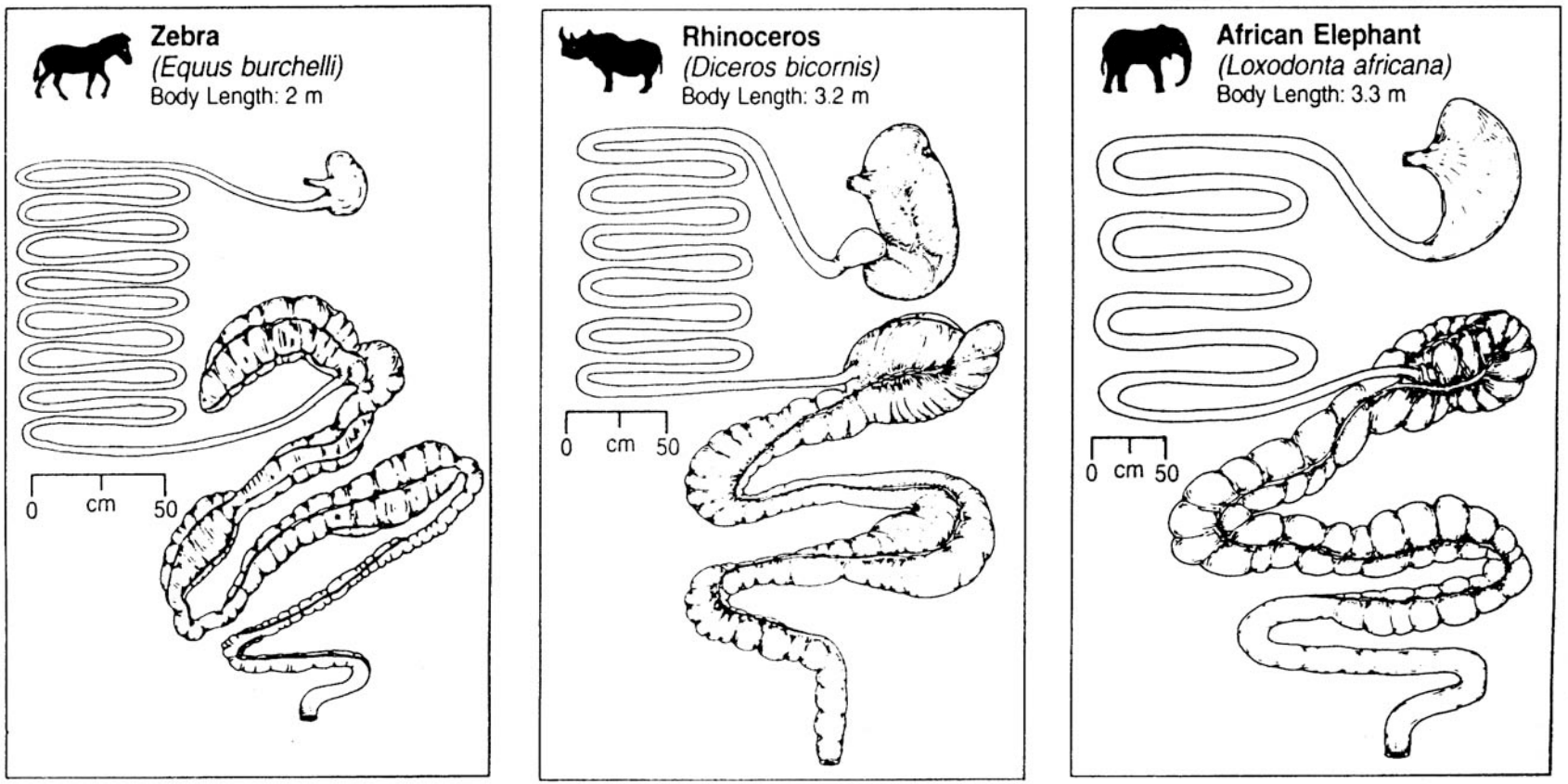
... and where they might be taken to in the future

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’).

Hindgut Fermentation - Colon



from Stevens & Hume (1995)

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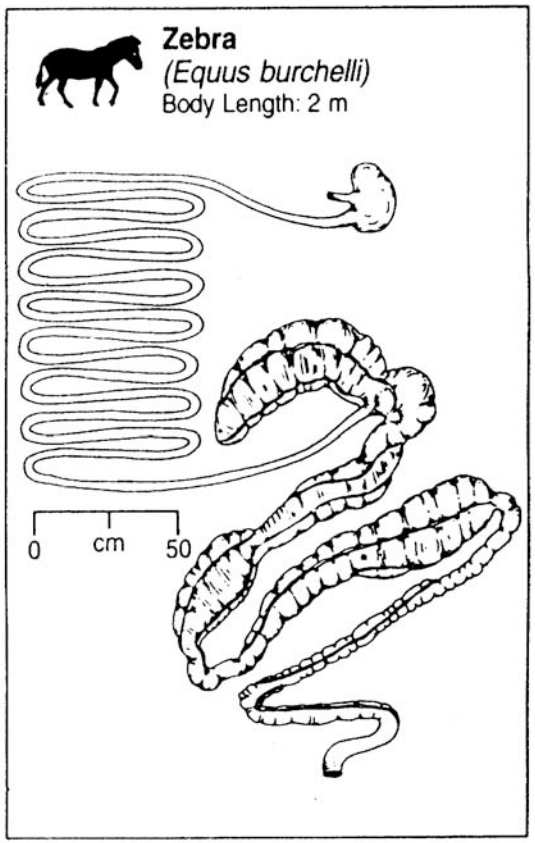

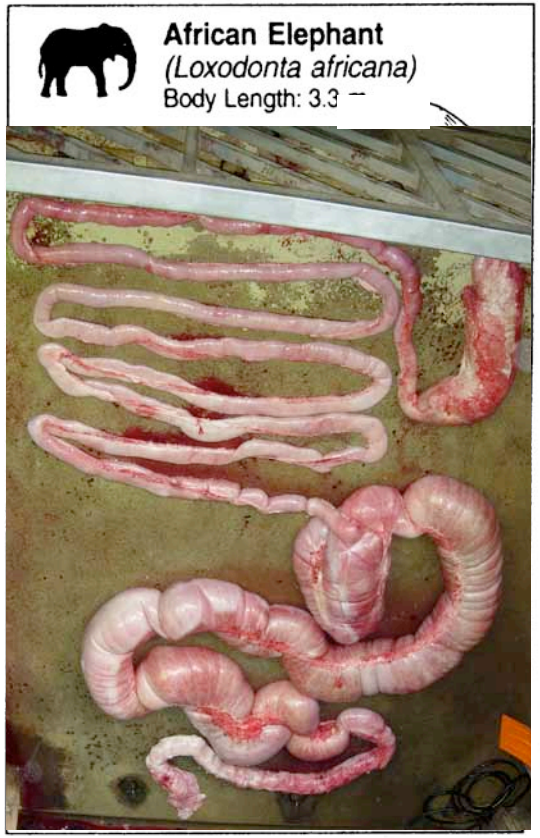

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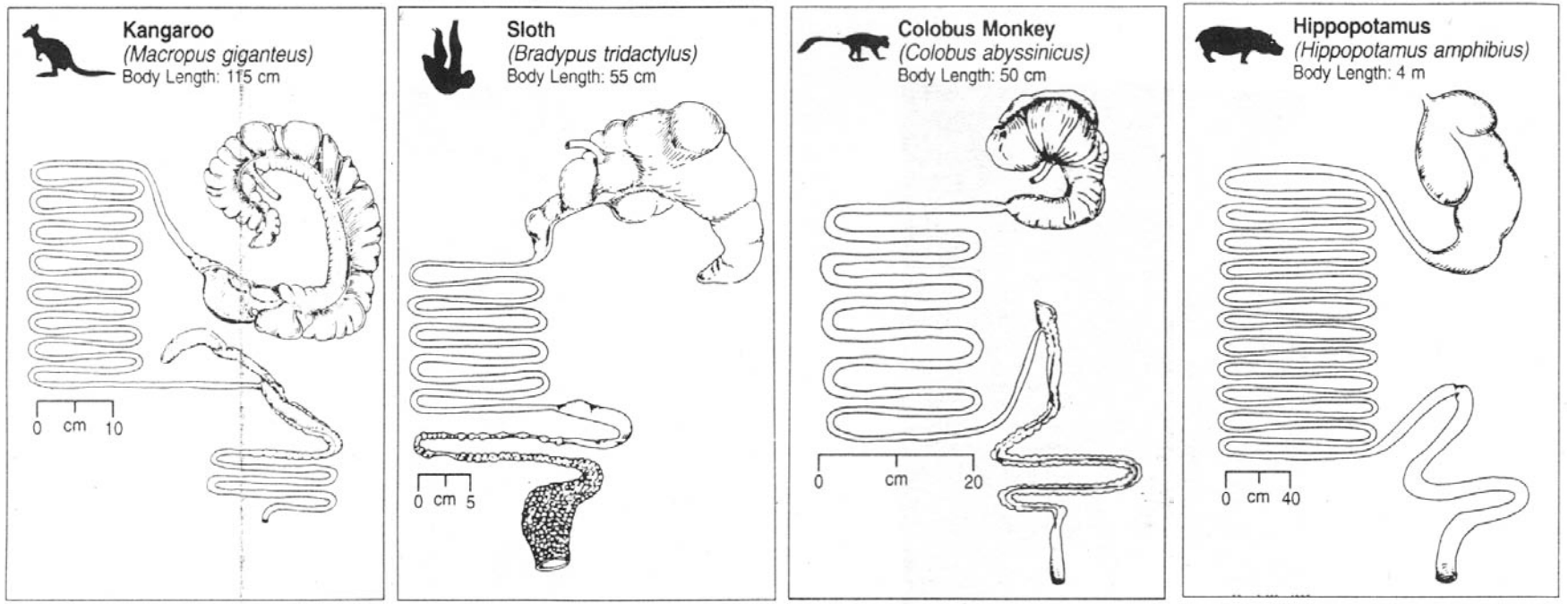
Foregut Fermentation



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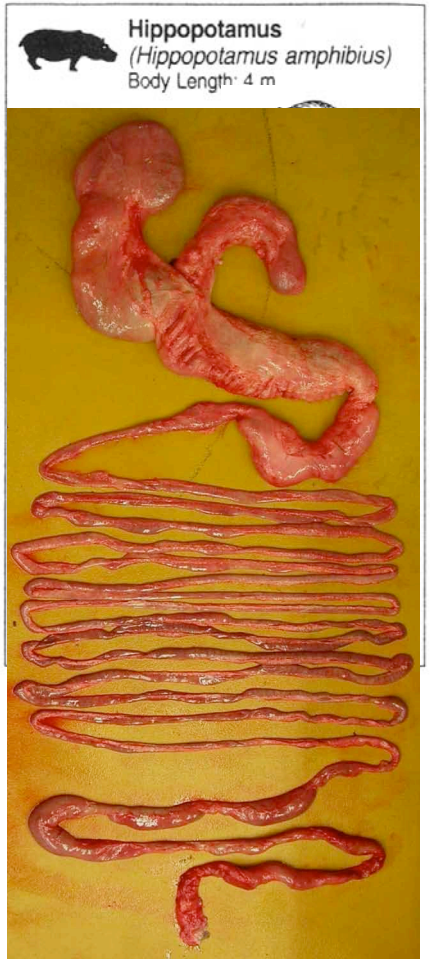
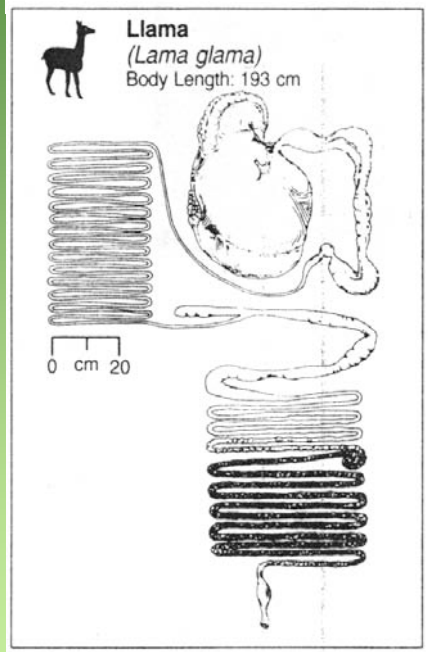
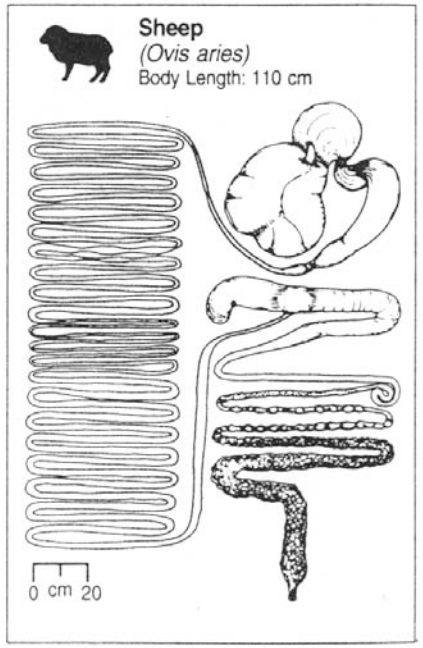


Photos A. Schwarm/
M. Clauss

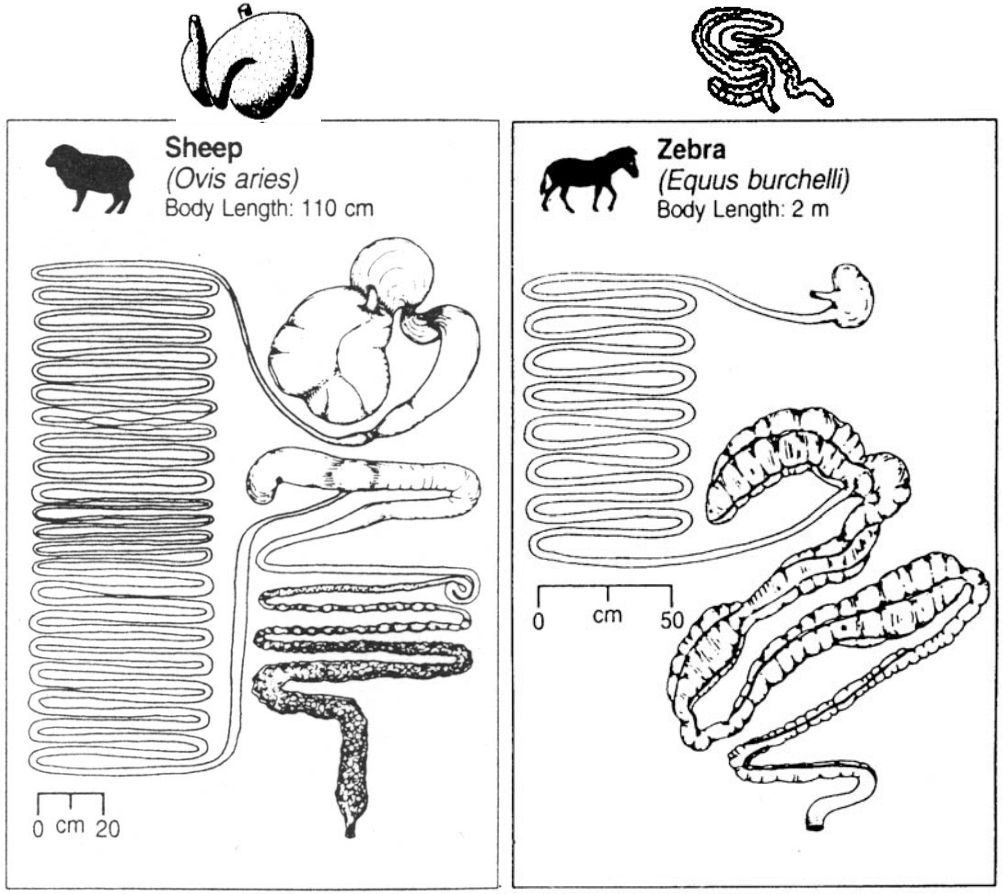
Foregut Fermentation - Ruminant





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

Foregut vs. Hindgut Fermentation



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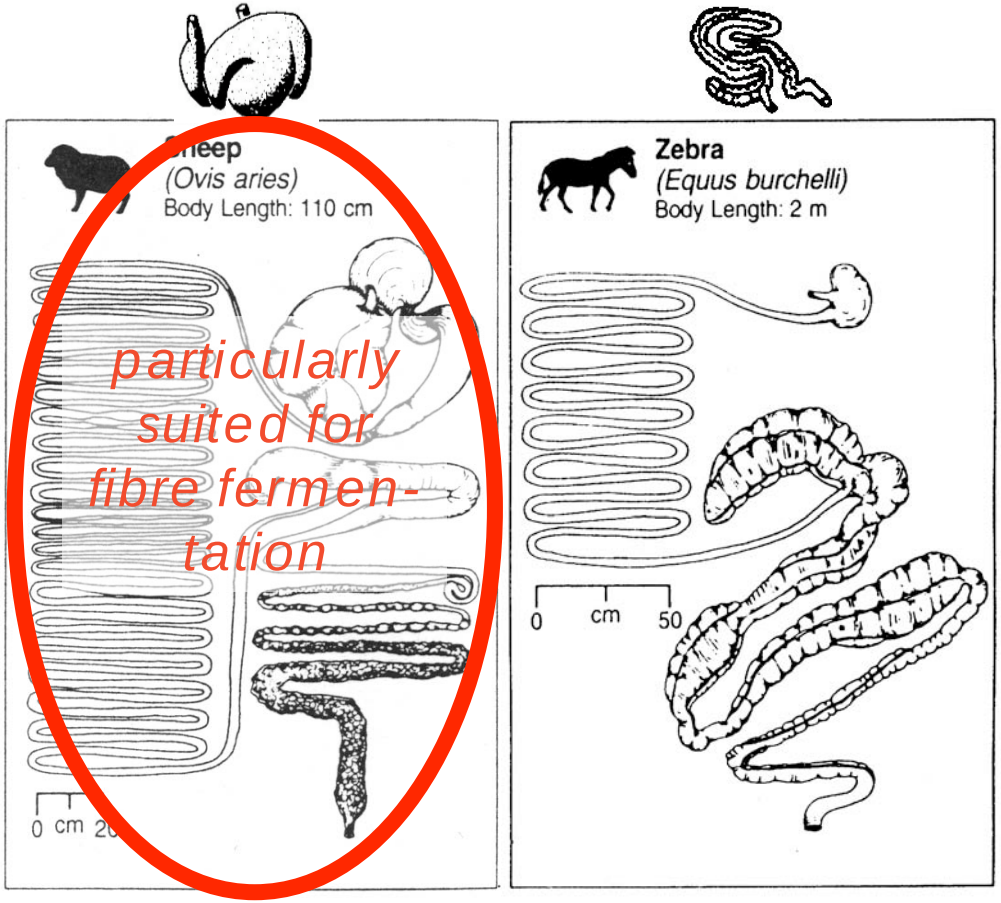

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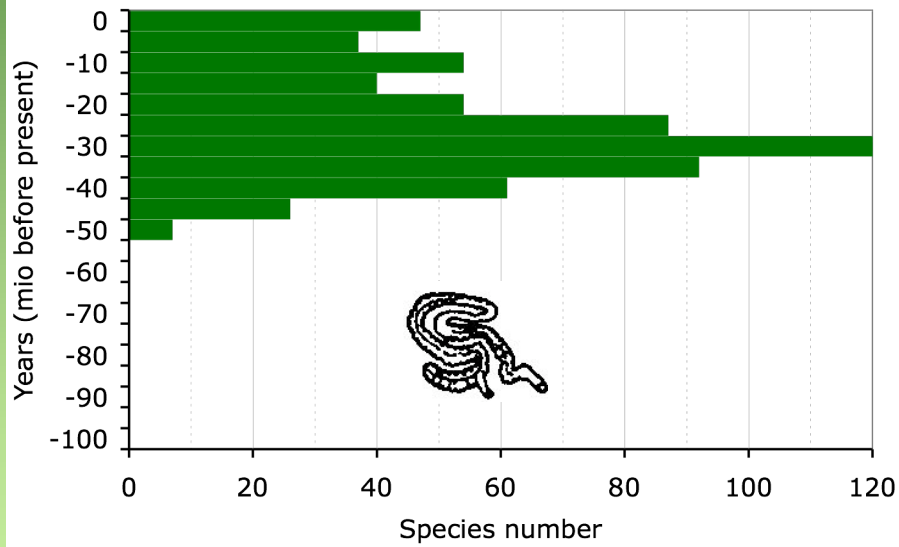
European Mammal Herbivores in Deep Time



from Langer (1991)

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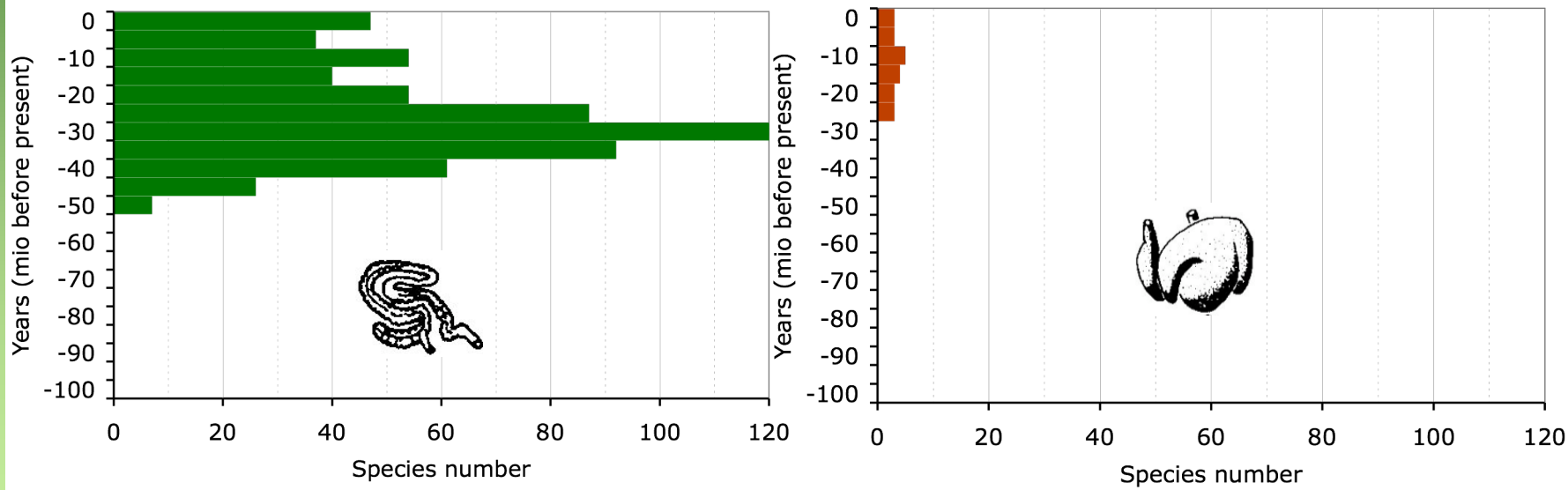
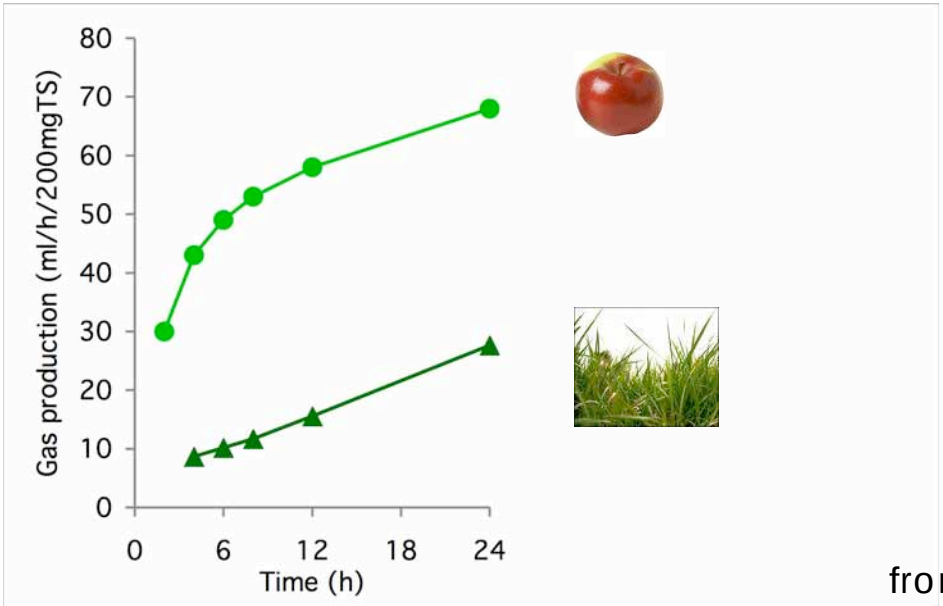


from Langer (1991)

Two Preconditions

1. It is energetically favourable to digest ‘auto-enzymatically digestible’ components auto-enzymatically, not by fermentative digestion.
2. Autoenzymatically digestible components are fermented ***at a drastically higher rate*** than plant fibre.



from Hummel et al. (2006ab)

Digestive Strategies

Low intake
⇒ long passage

High intake
⇒ short passage

Digestive Strategies

Low intake ⇒ long passage	Autoenzymatic digestion followed by thorough fermentative digestion ✓	
High intake ⇒ short passage		

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Digestive Strategies

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From Digestive to Metabolic Strategies

Low intake ⇒ long passage ⇒ ***low BMR***	✓	✓
High intake ⇒ short passage ⇒ ***high BMR***	✓	✗

How can you increase fermentative digestive efficiency?

- Digestion of plant fibre by bacteria is the more efficient ...
  - the more time is available for it
    = the longer the mean gastrointestinal retention time.
  - the finer the plant fibre particles are
    = the finer the ingesta is chewed.

How can you increase energy intake?

- higher food intake

- higher digestive efficiency

How can you increase energy intake?

- higher food intake
- longer retention
- finer chewing

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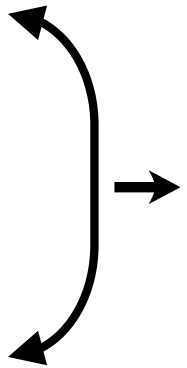

Keep only what can be further digested but pass on what already is.

- finer chewing

How can you increase energy intake?

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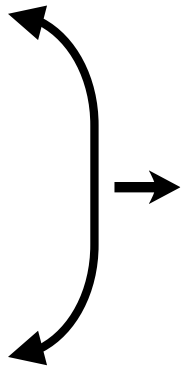

sorting !

- finer chewing

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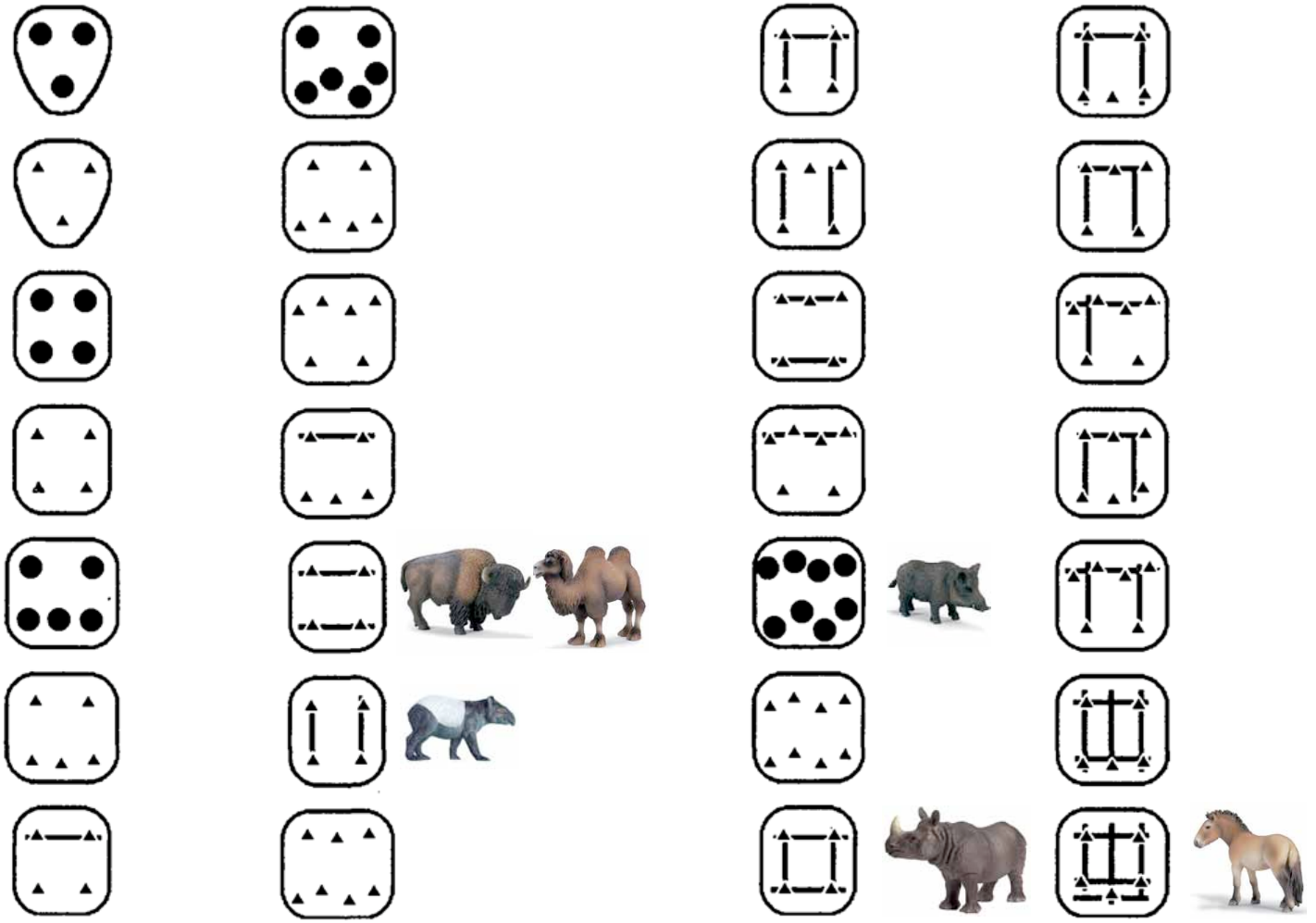
Herbivore molar occlusive surfaces



from Jernvall et al. (1996)

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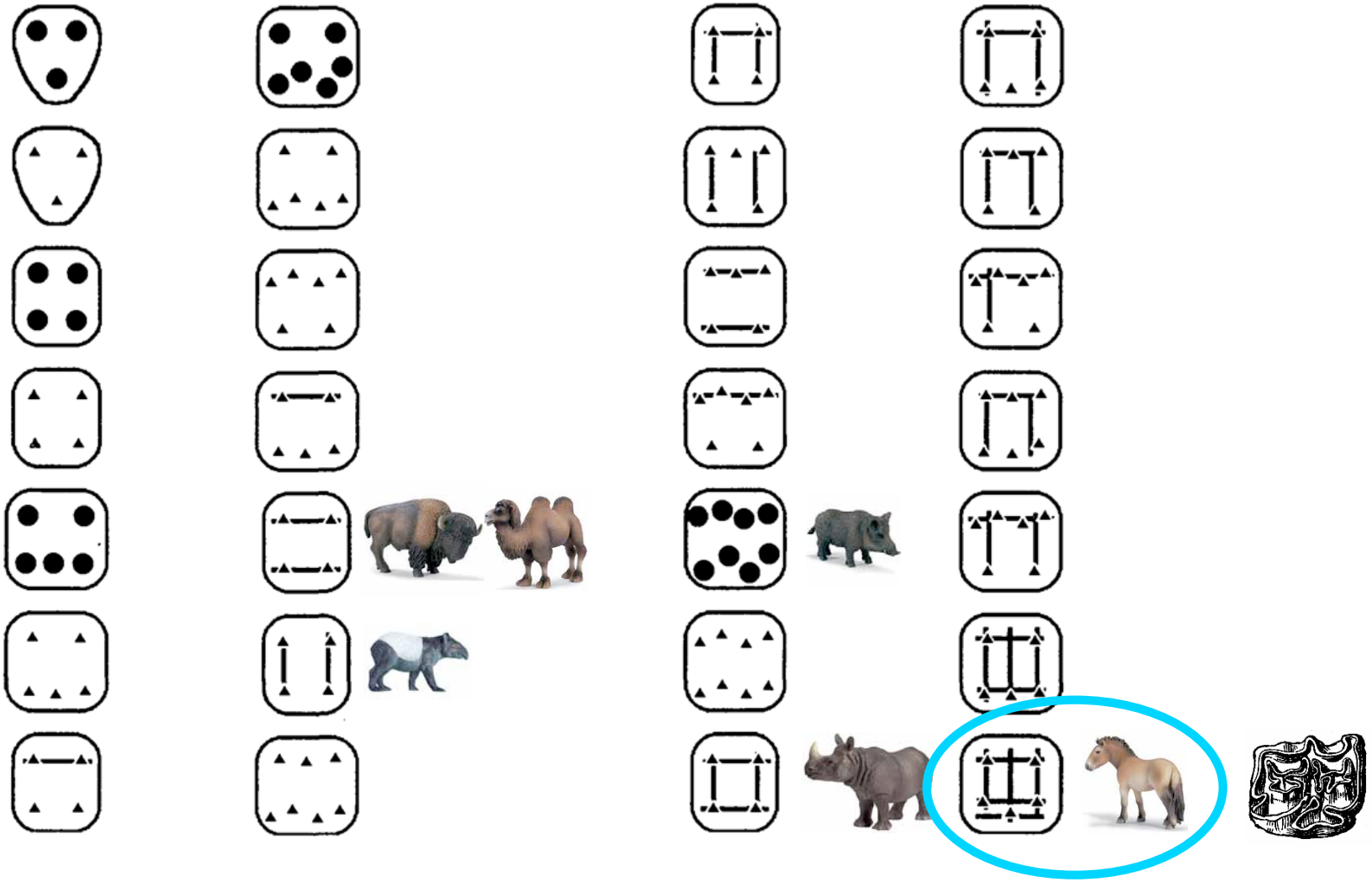

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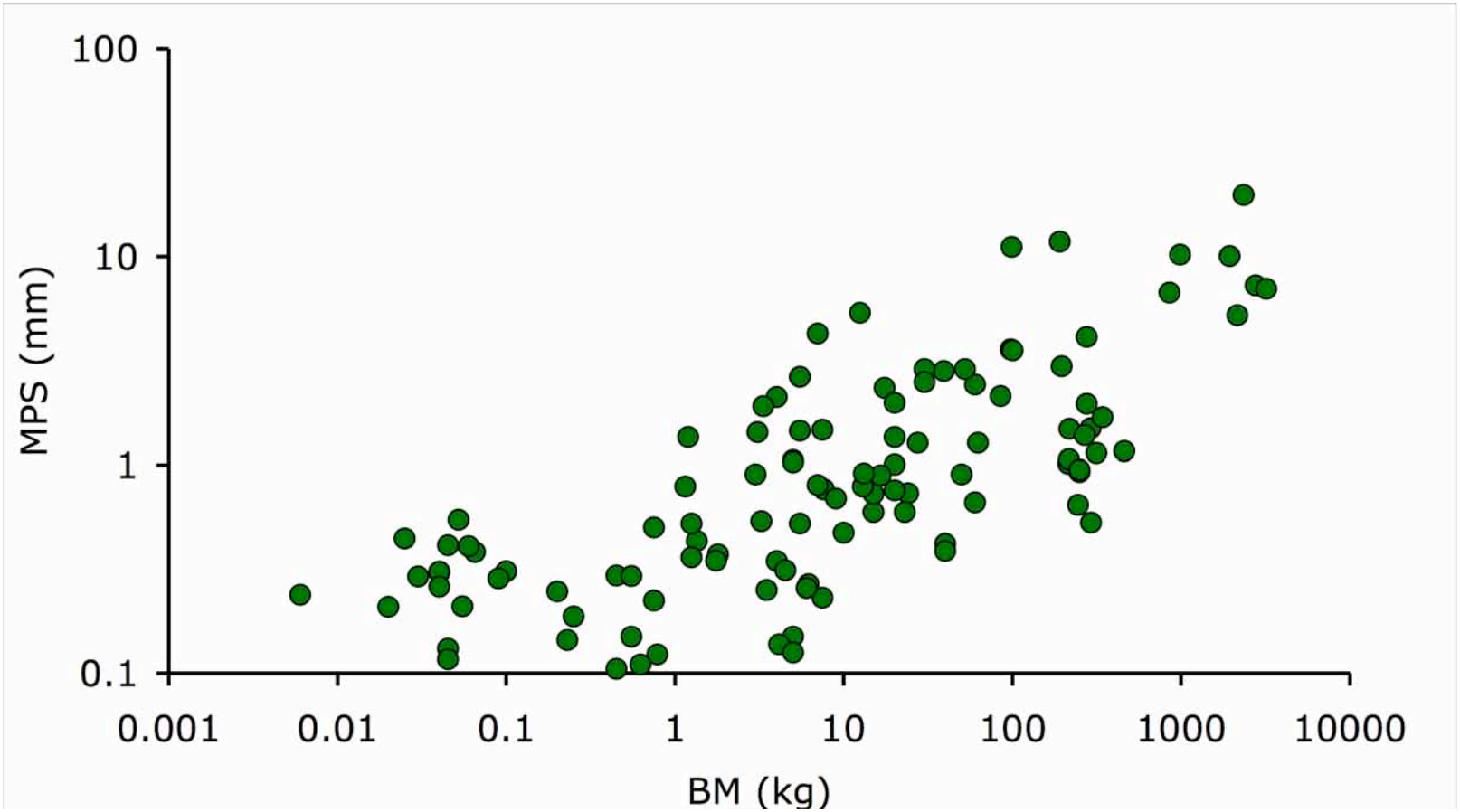
Faecal particle size (chewing efficiency)



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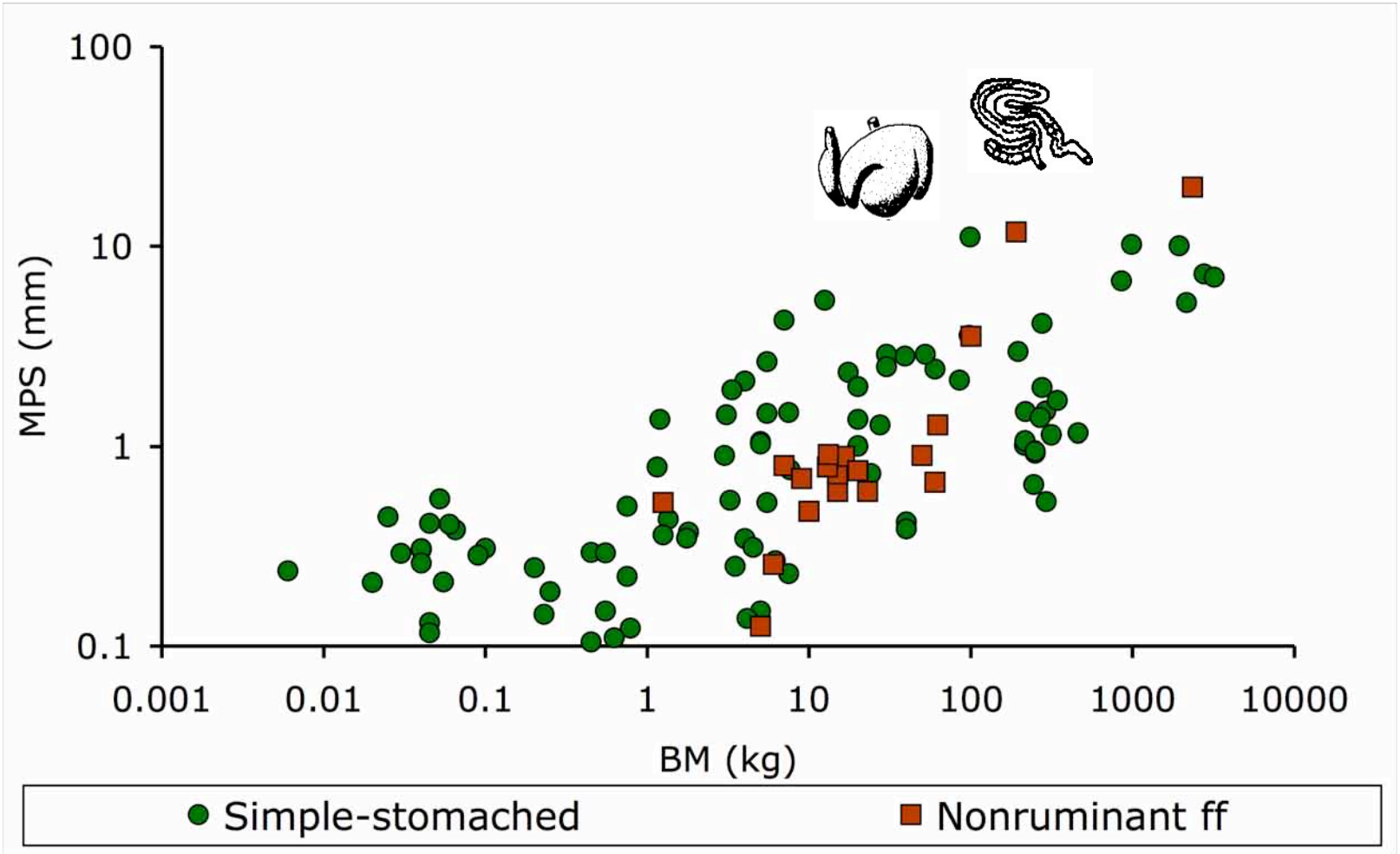

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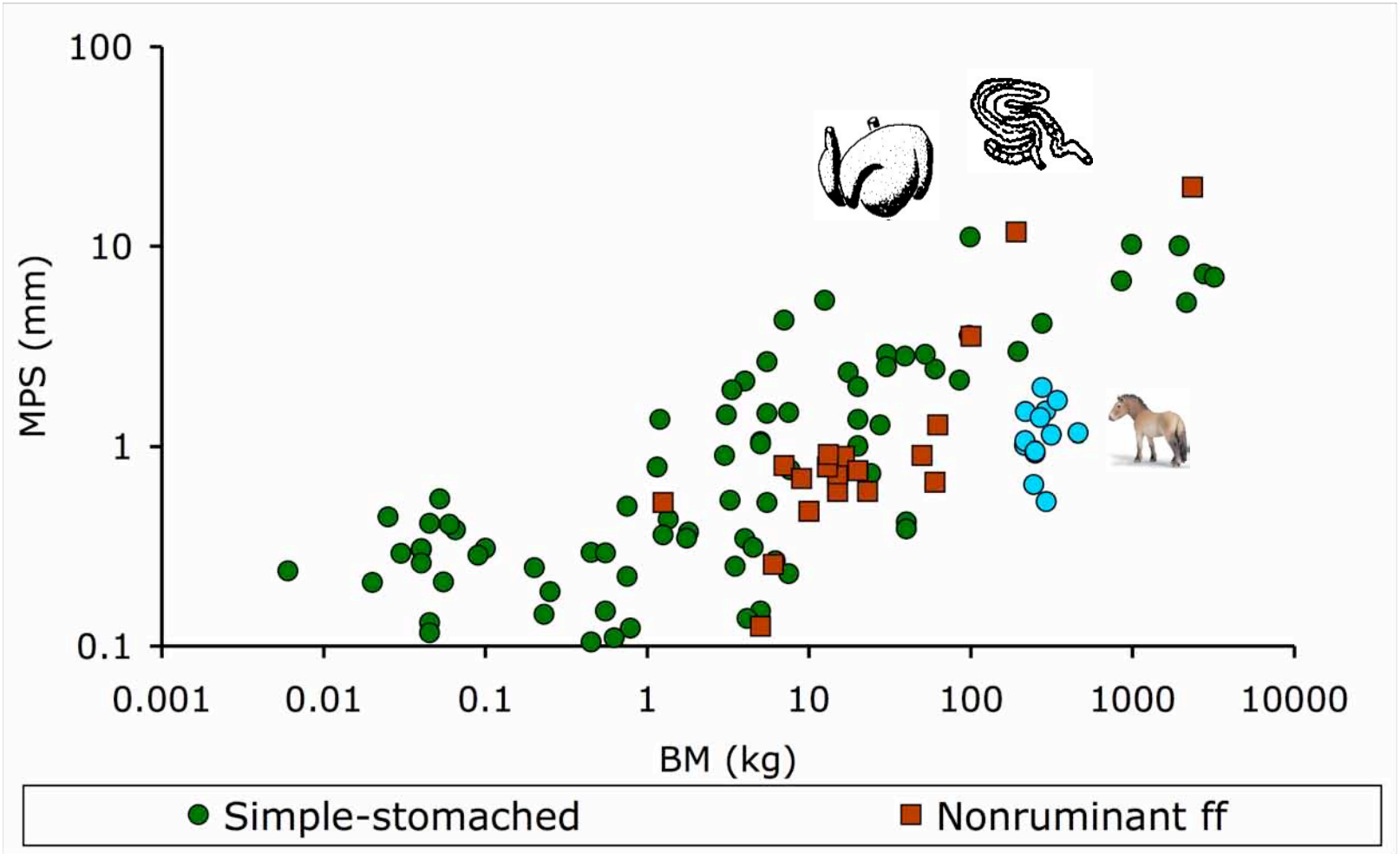

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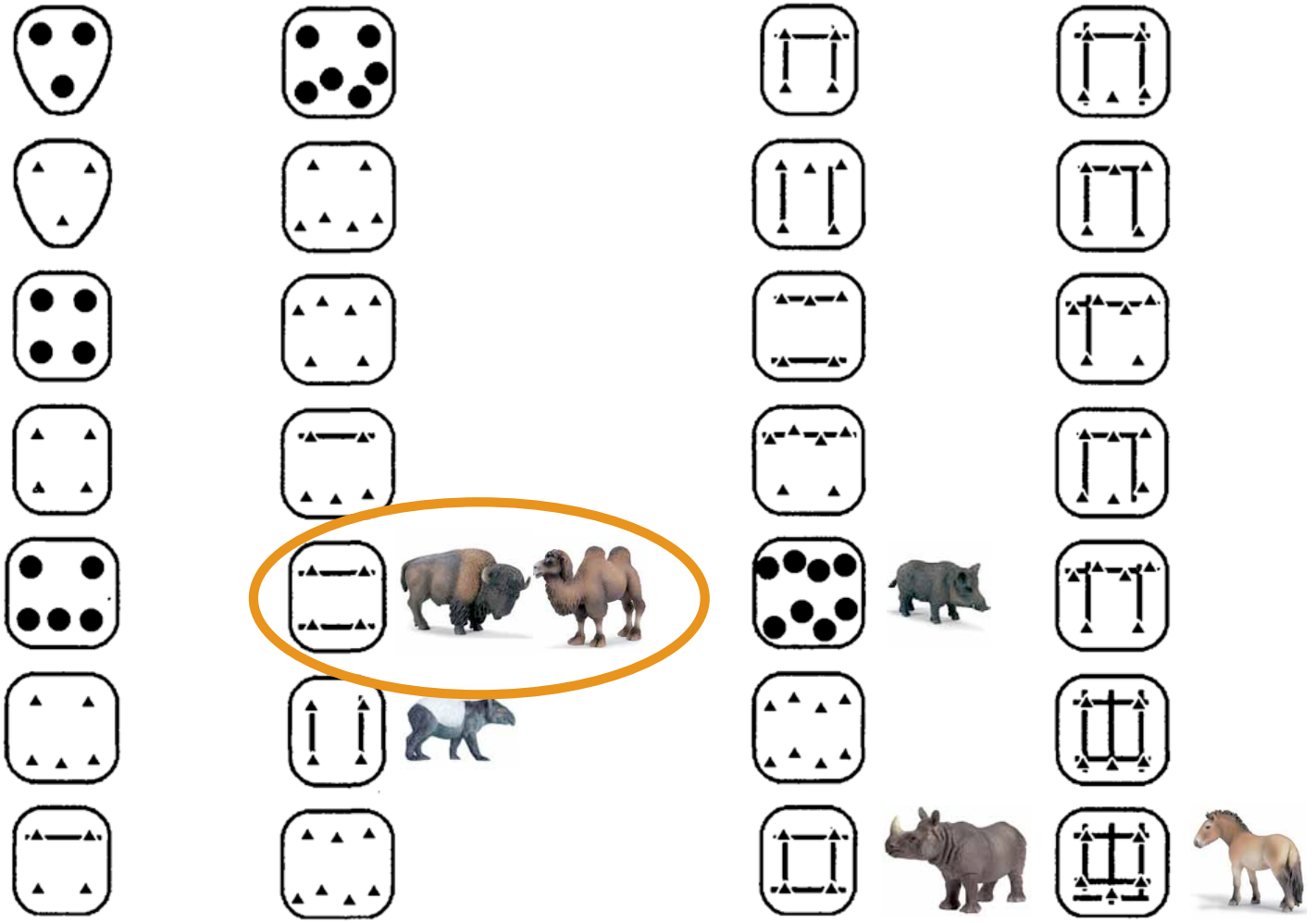

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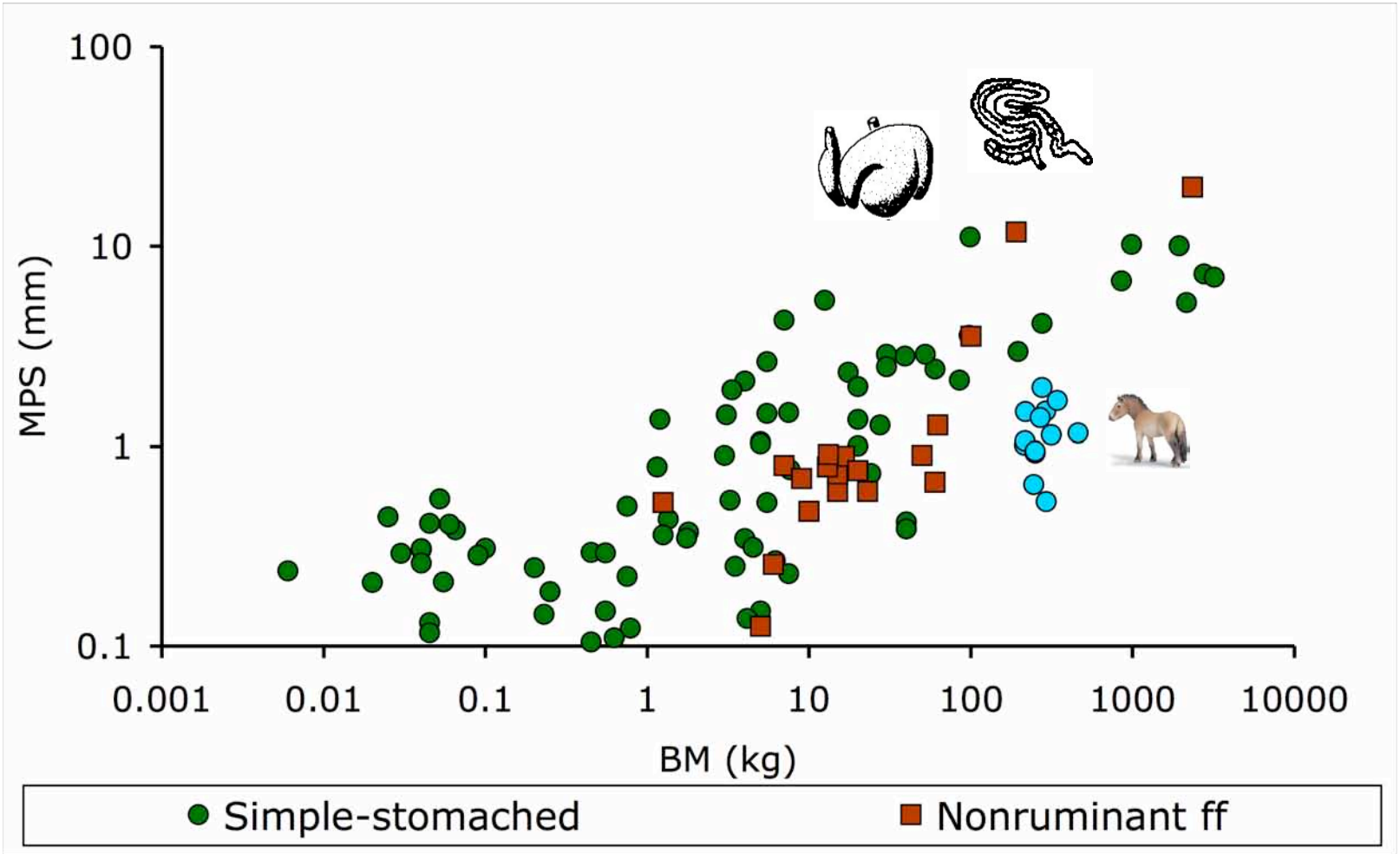

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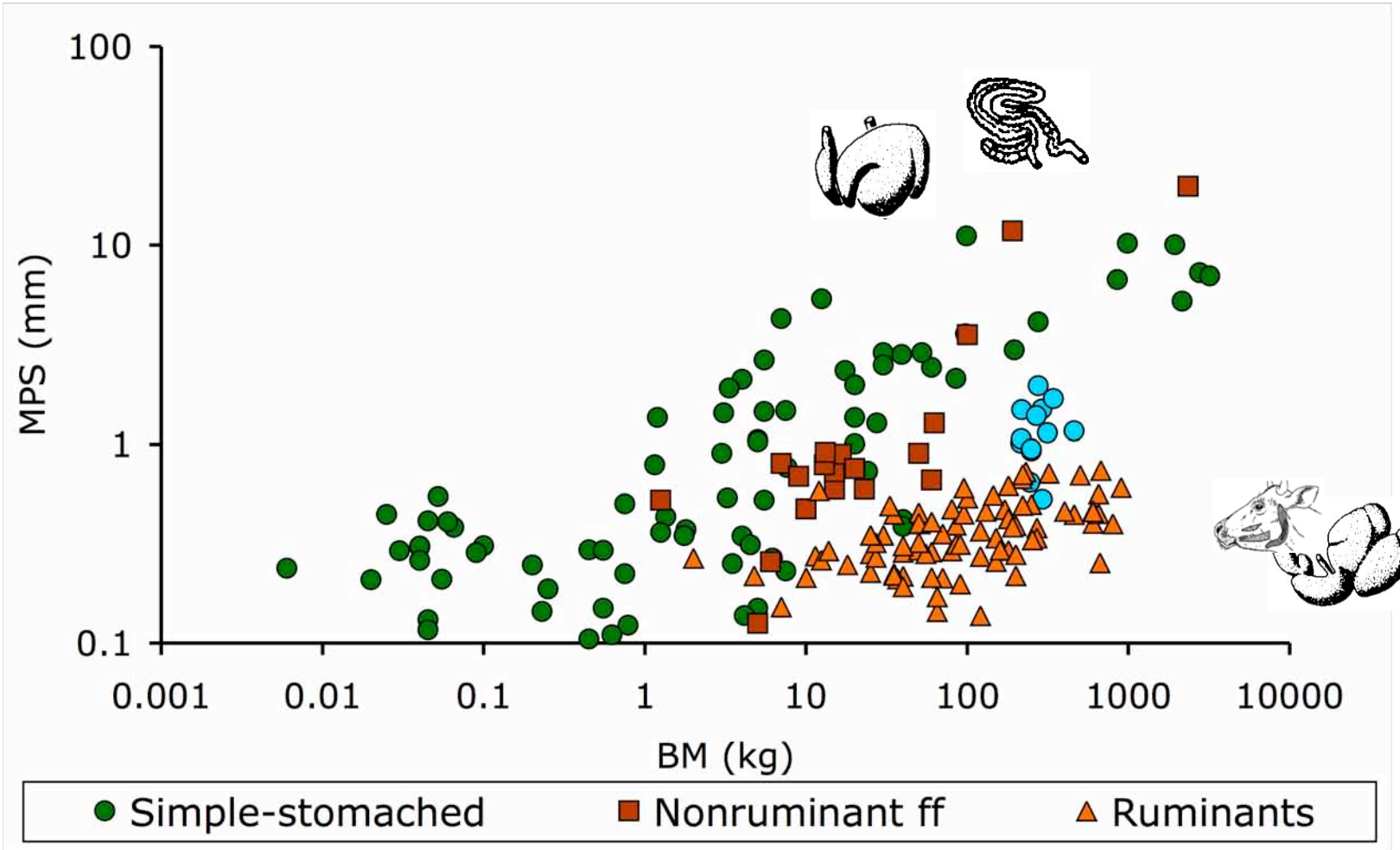

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Why can‘t everyone just chew more?

How can you increase energy intake?

- higher food intake
- longer retention

→ sorting !

- finer chewing

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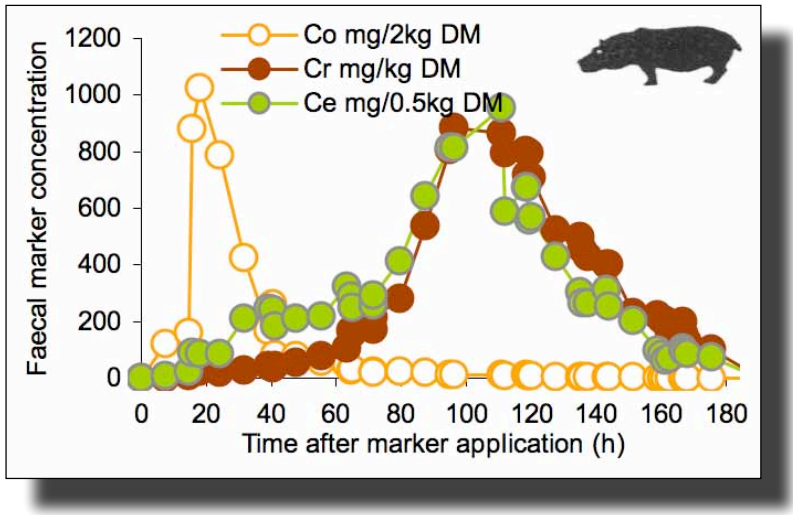
Ruminant vs. Nonruminant Foregut Fermentation



Schwarm et al. (2008)

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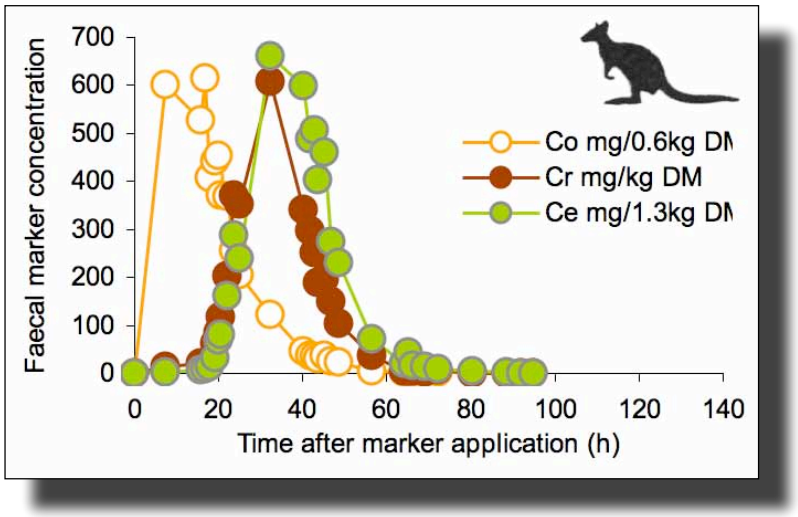

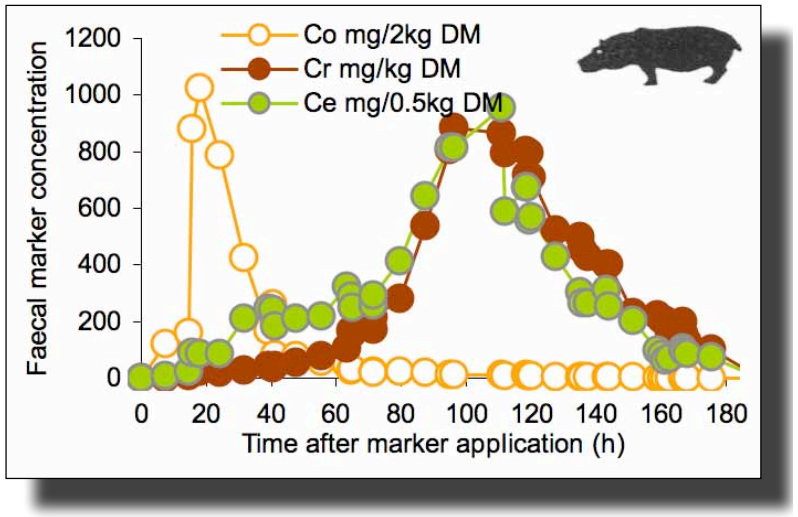

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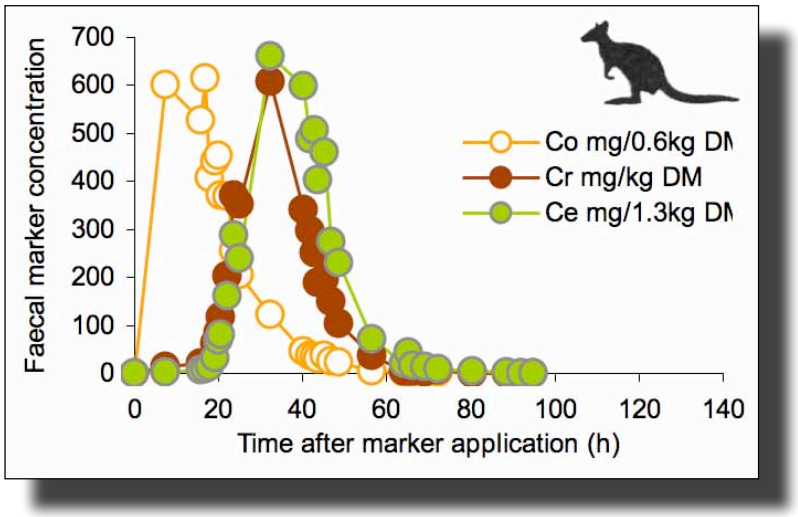

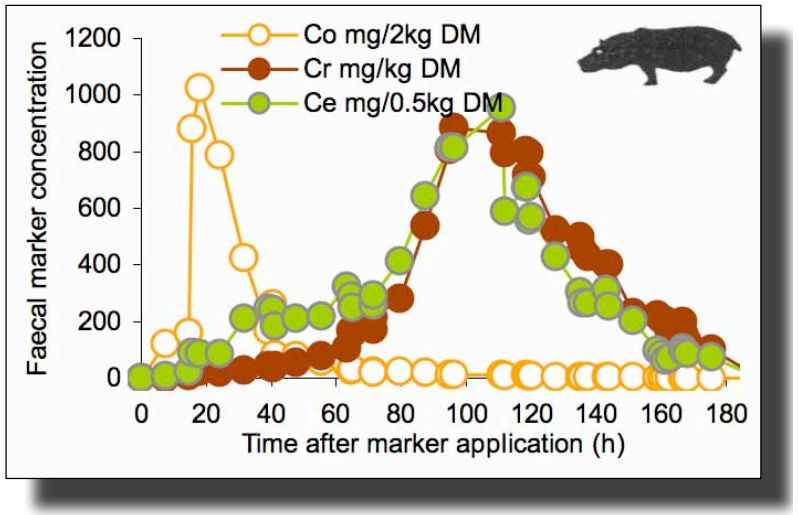

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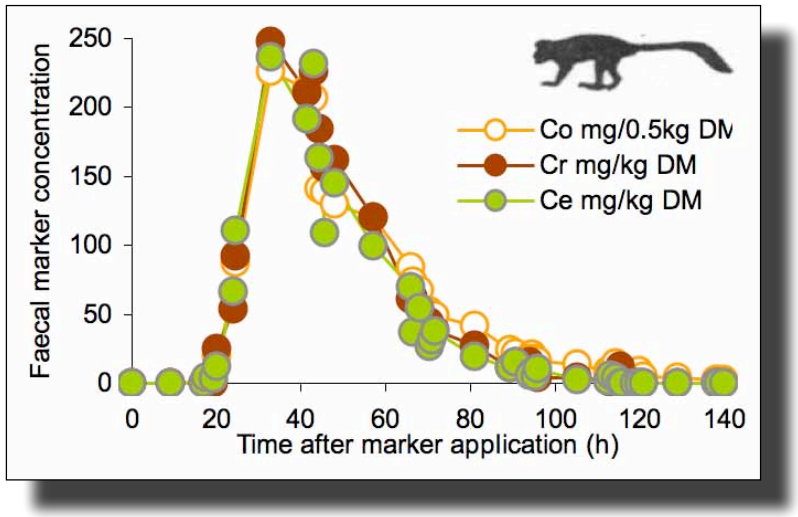

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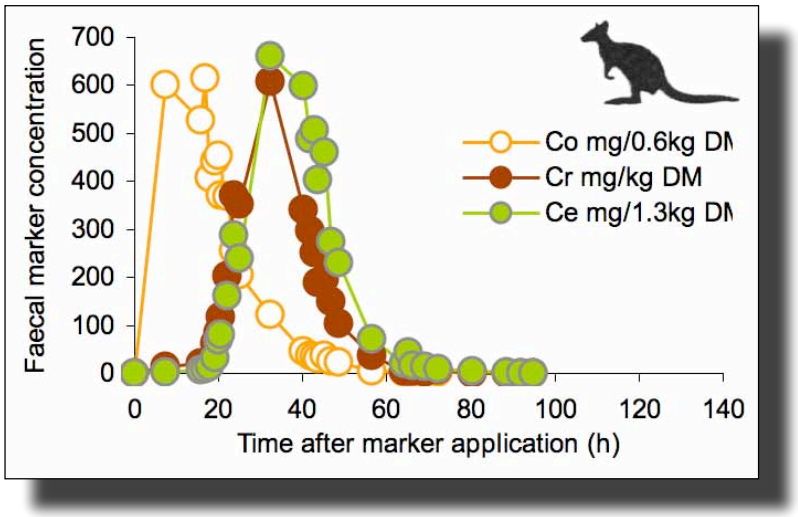

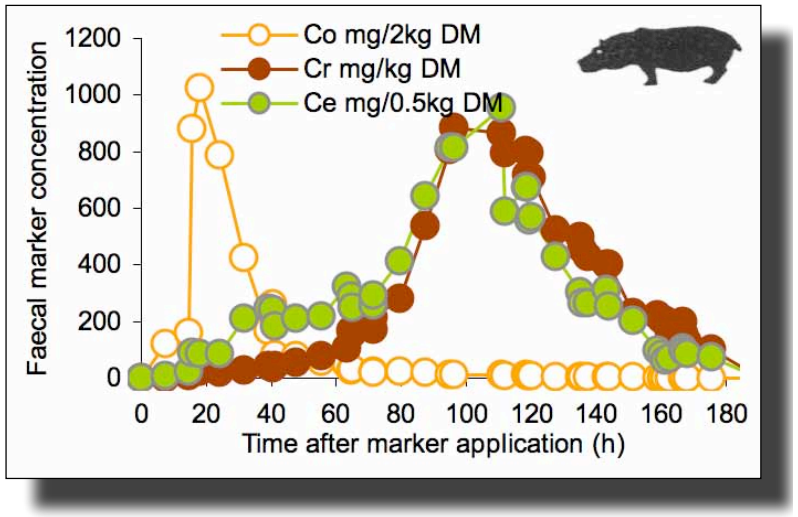

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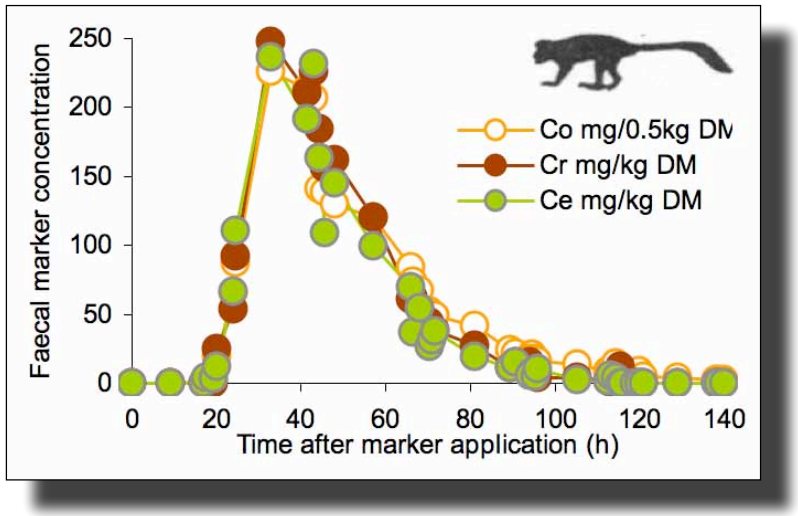

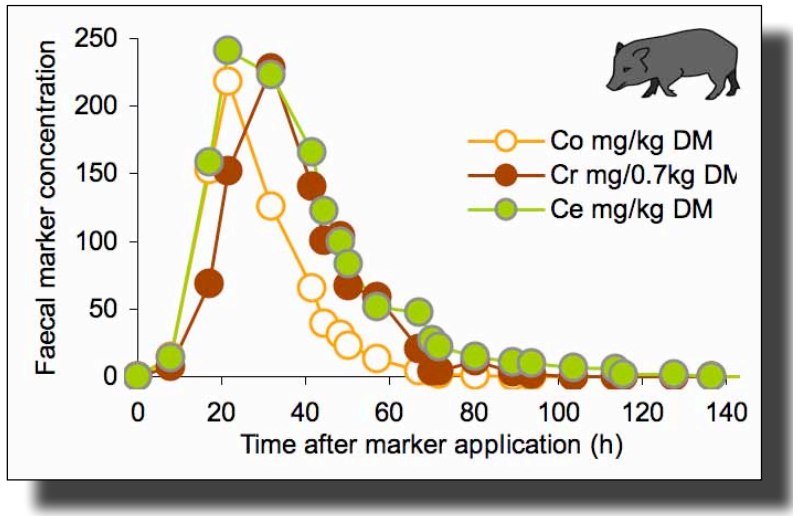

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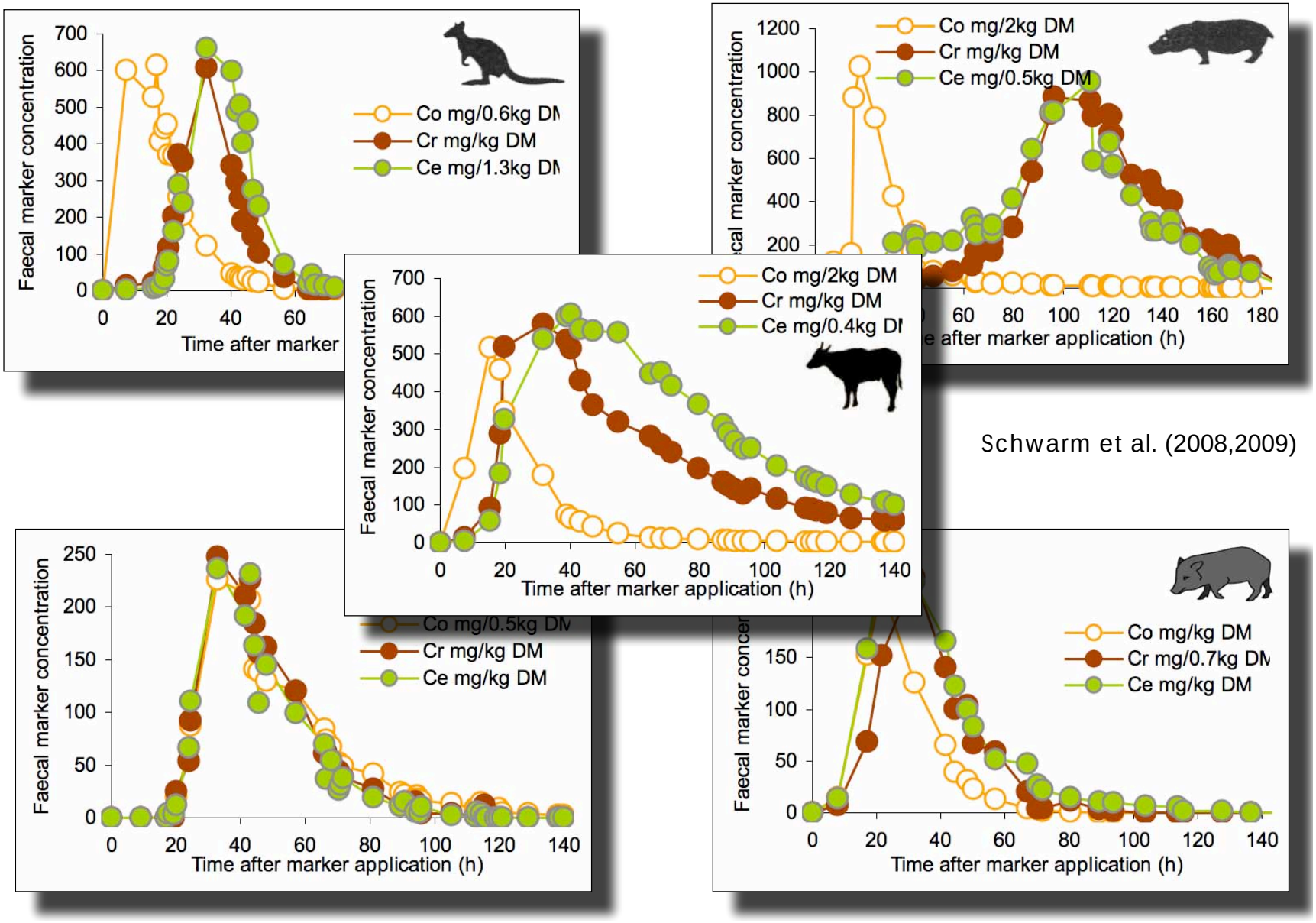

Schwarm et al. (2008,2009)

Digestive and Metabolic Strategies



Low intake ⇒ long passage ⇒ ***low BMR***	✓	✓	
High intake ⇒ differentiated passage ⇒ ***high BMR***	✓	✗	

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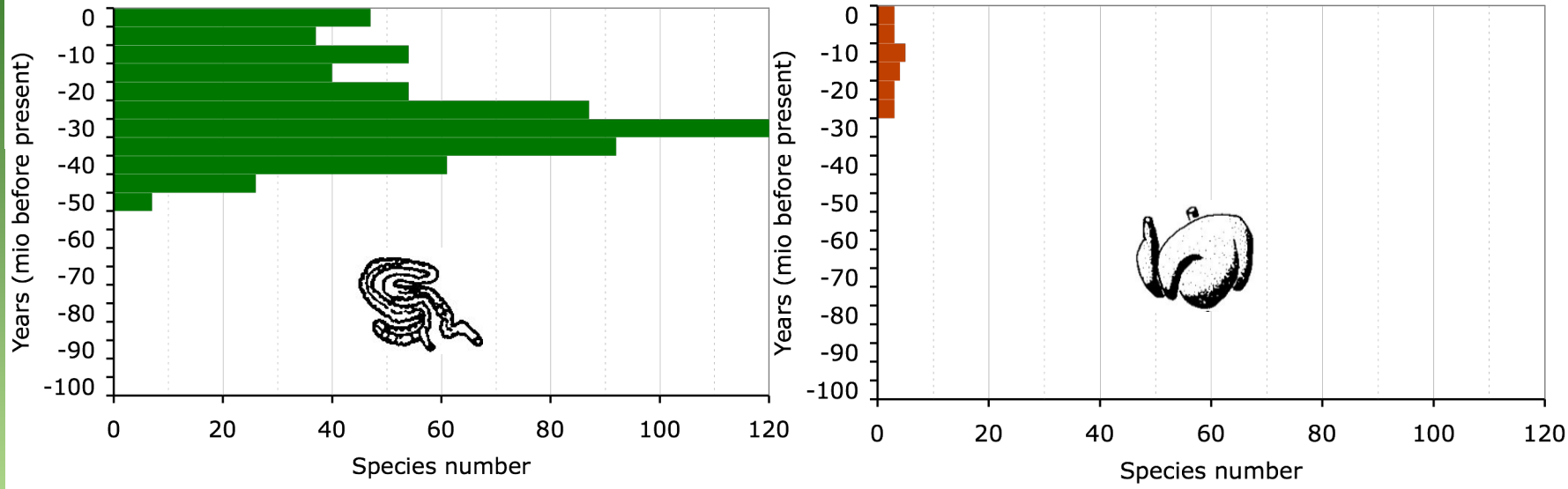
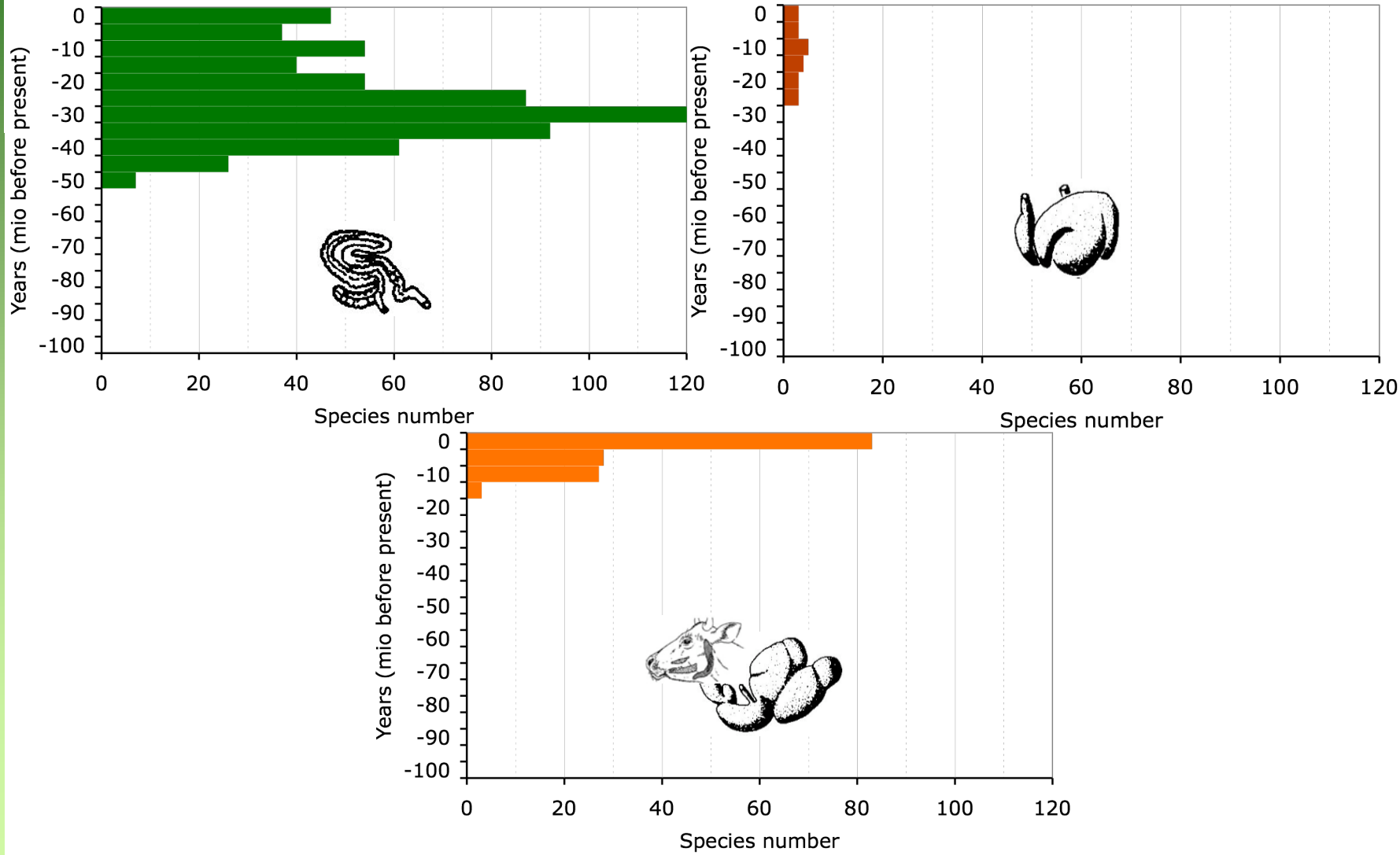
High intake ⇒ differentiated passage ⇒ ***high BMR***	✓	✗	✓ 

European Mammal Herbivores in Deep Time



from Langer (1991)

European Mammal Herbivores in Deep Time

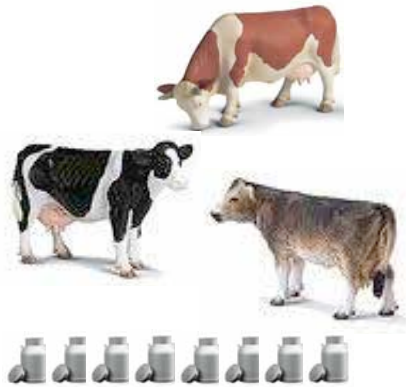


from Langer (1991)

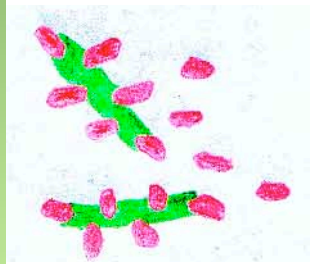
Digestive and Metabolic Strategies

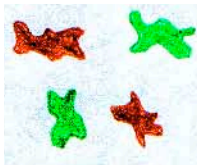


Low intake ⇒ long passage ⇒ ***low BMR***	✓	✓	✓
High intake ⇒ differentiated passage ⇒ ***high BMR***	✓	✗	✓



Sorting by density

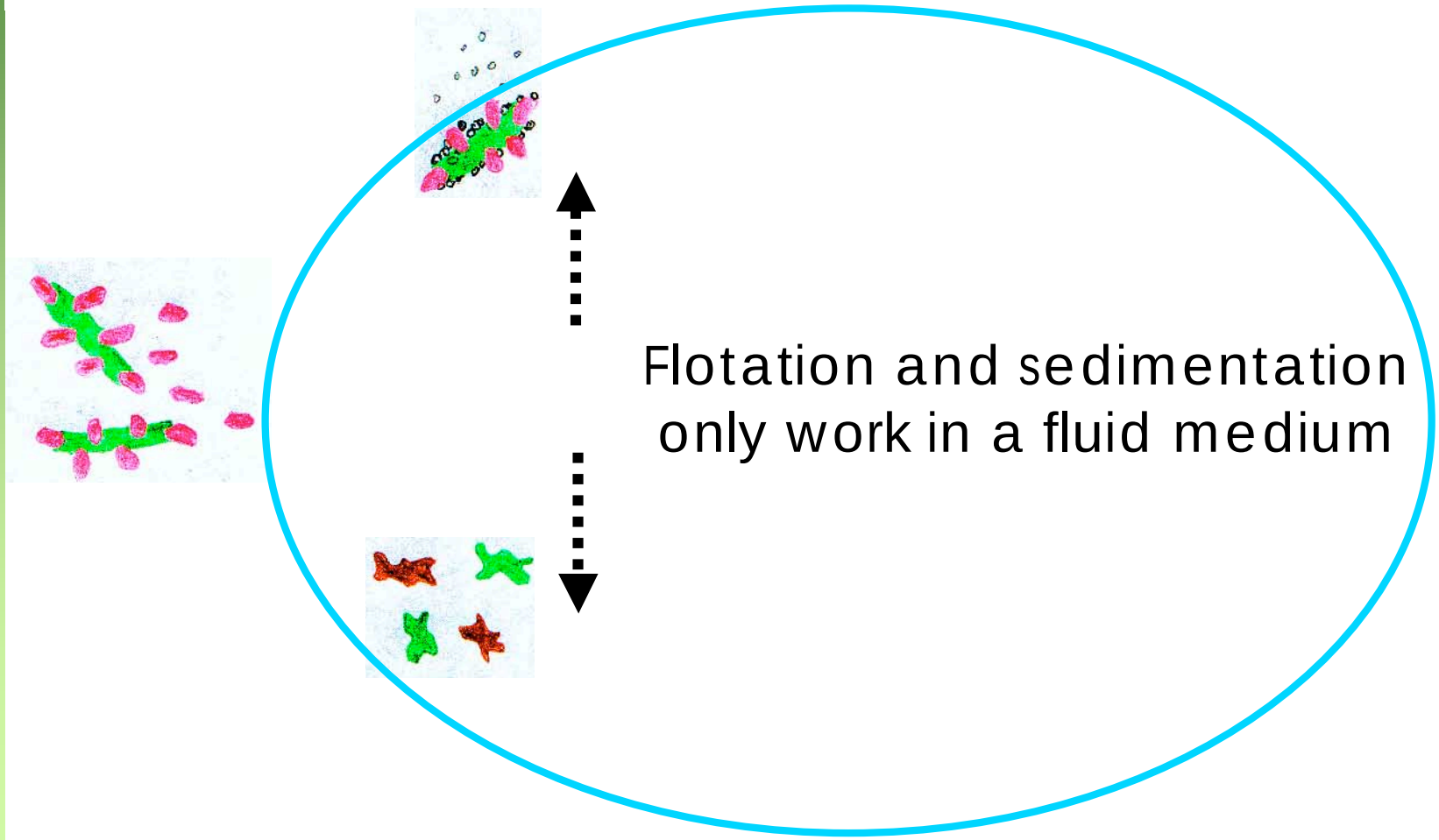




fermentation = gas production
gas bubbles = updrift

fermented particles
no gas bubbles = high density

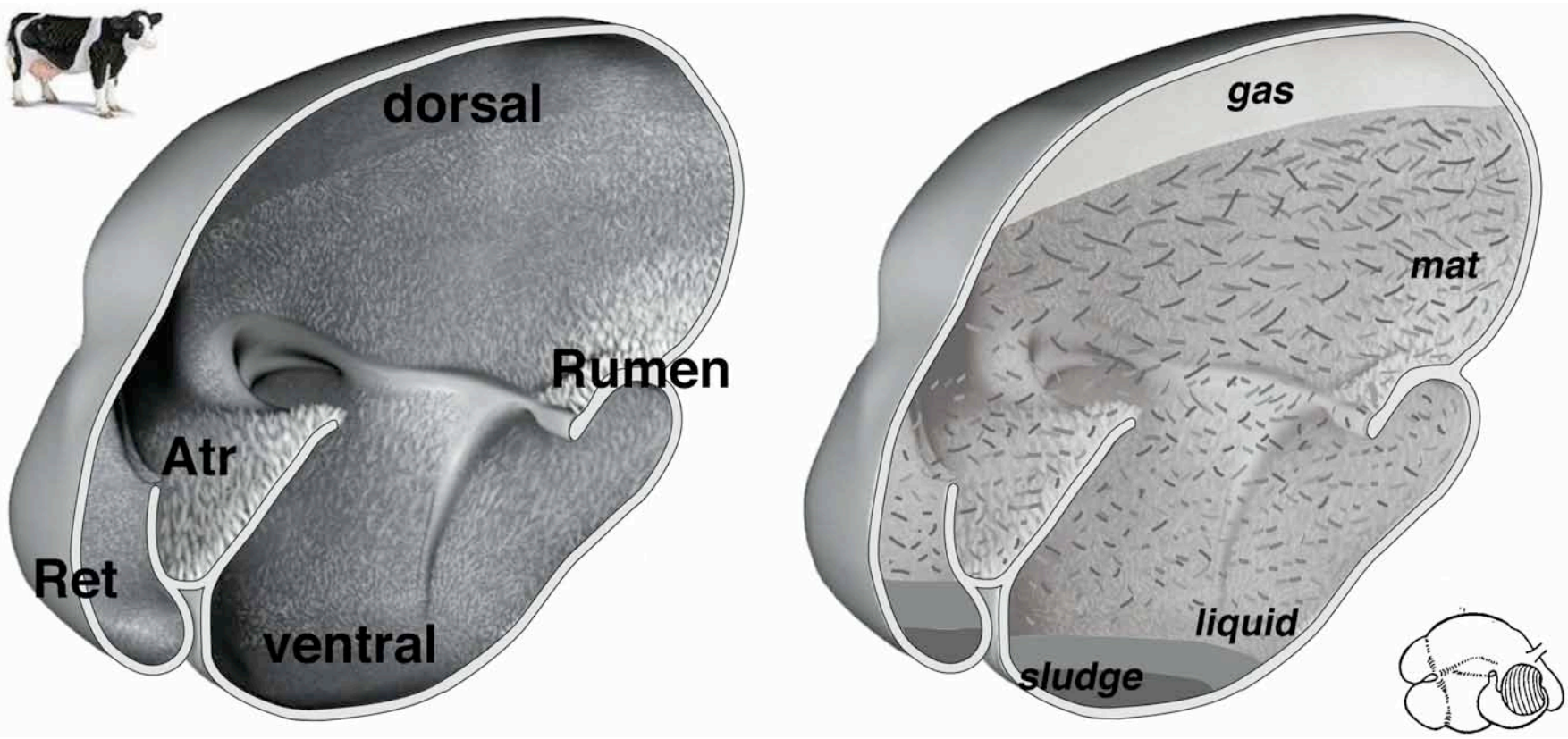
Sorting by density



Ruminants have moist forestomach contents

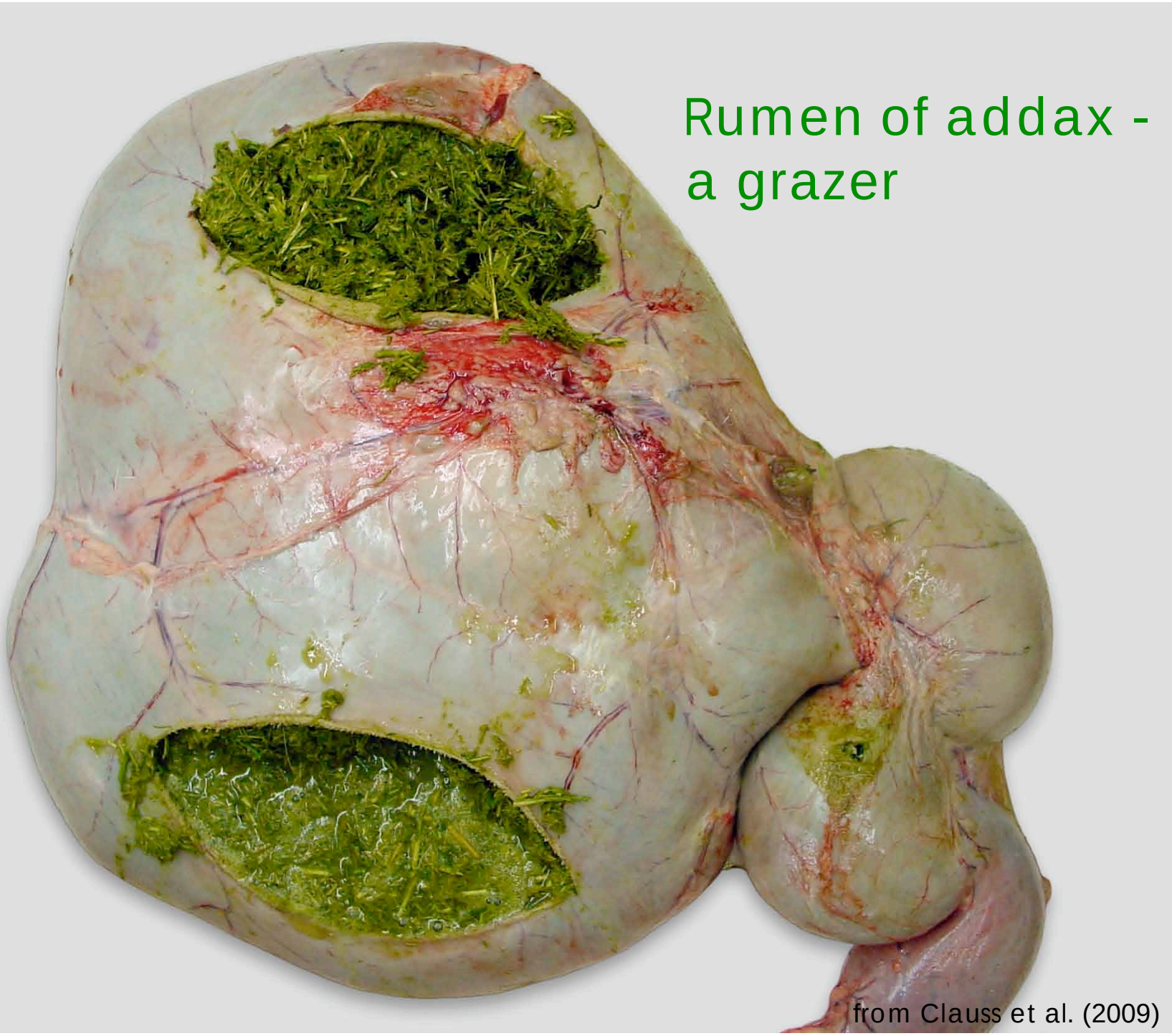
Photos A. Schwarm &
M. Lechner-Doll

Stratification of rumen contents: ‘cattle-type’



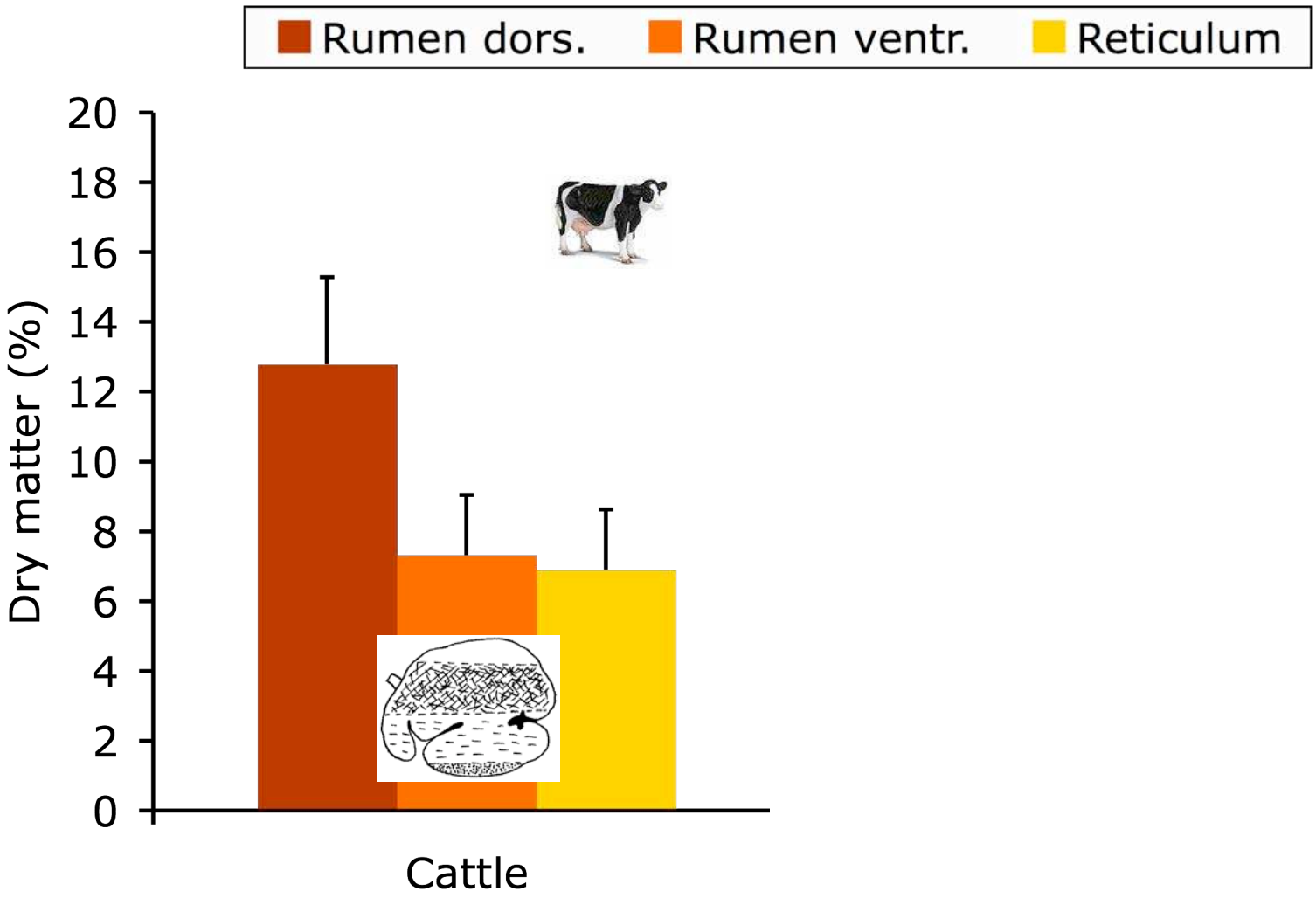
from Clauss et al. (2010)

Rumen of addax - a grazer



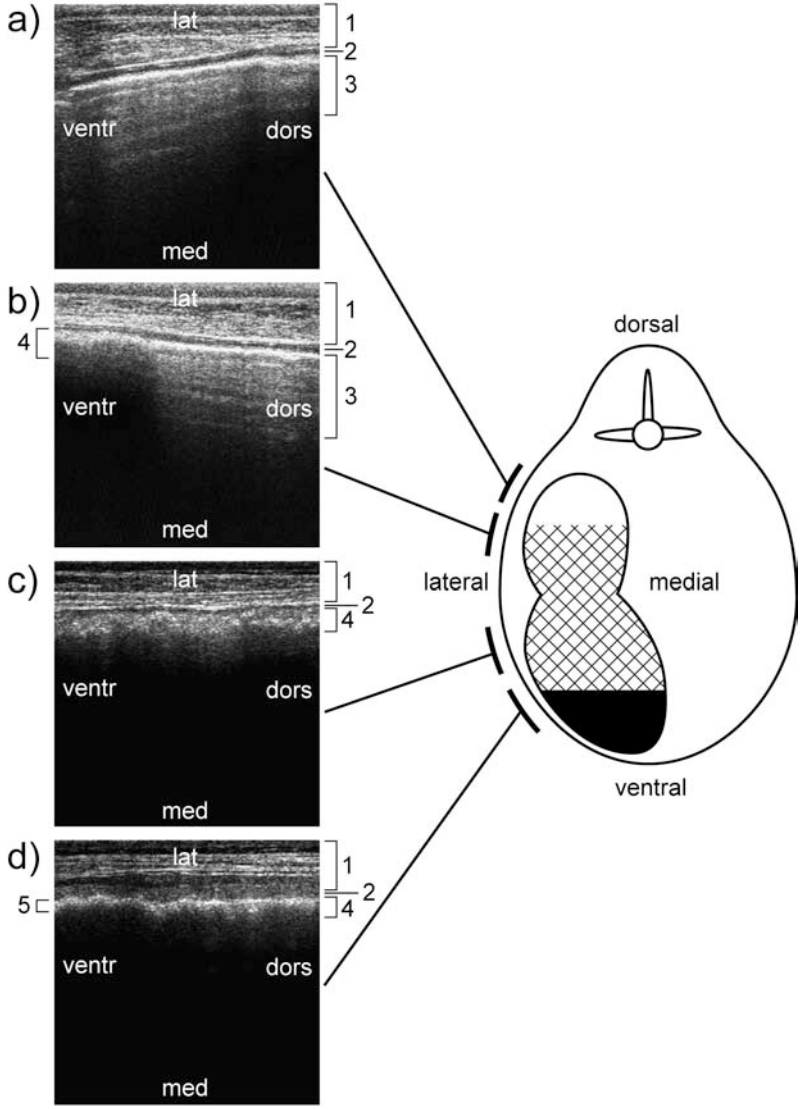
from Clauss et al. (2009)

Stratification of rumen contents



from Clauss et al. (2010)

Testing stratification by ultrasound - cattle

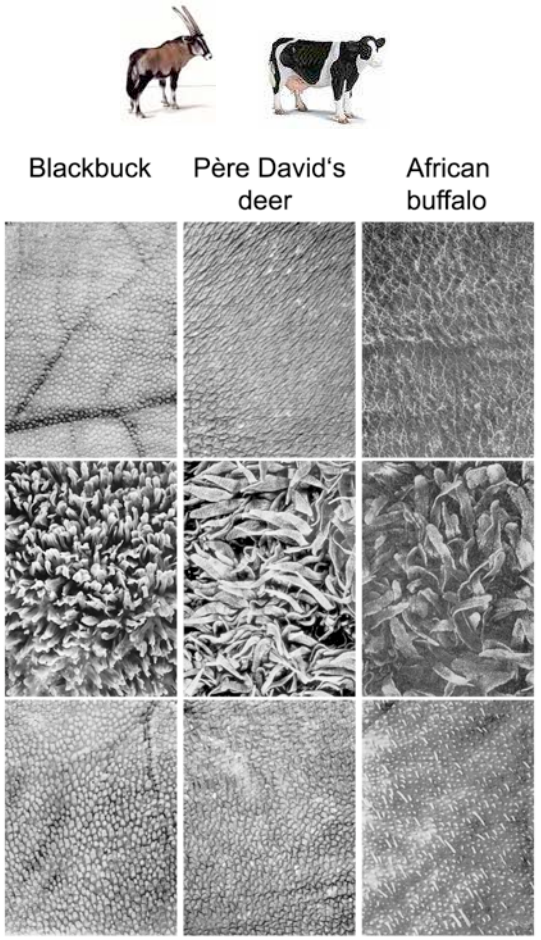


from Tschuor & Clauss (2008)

Stratification and rumen papillation

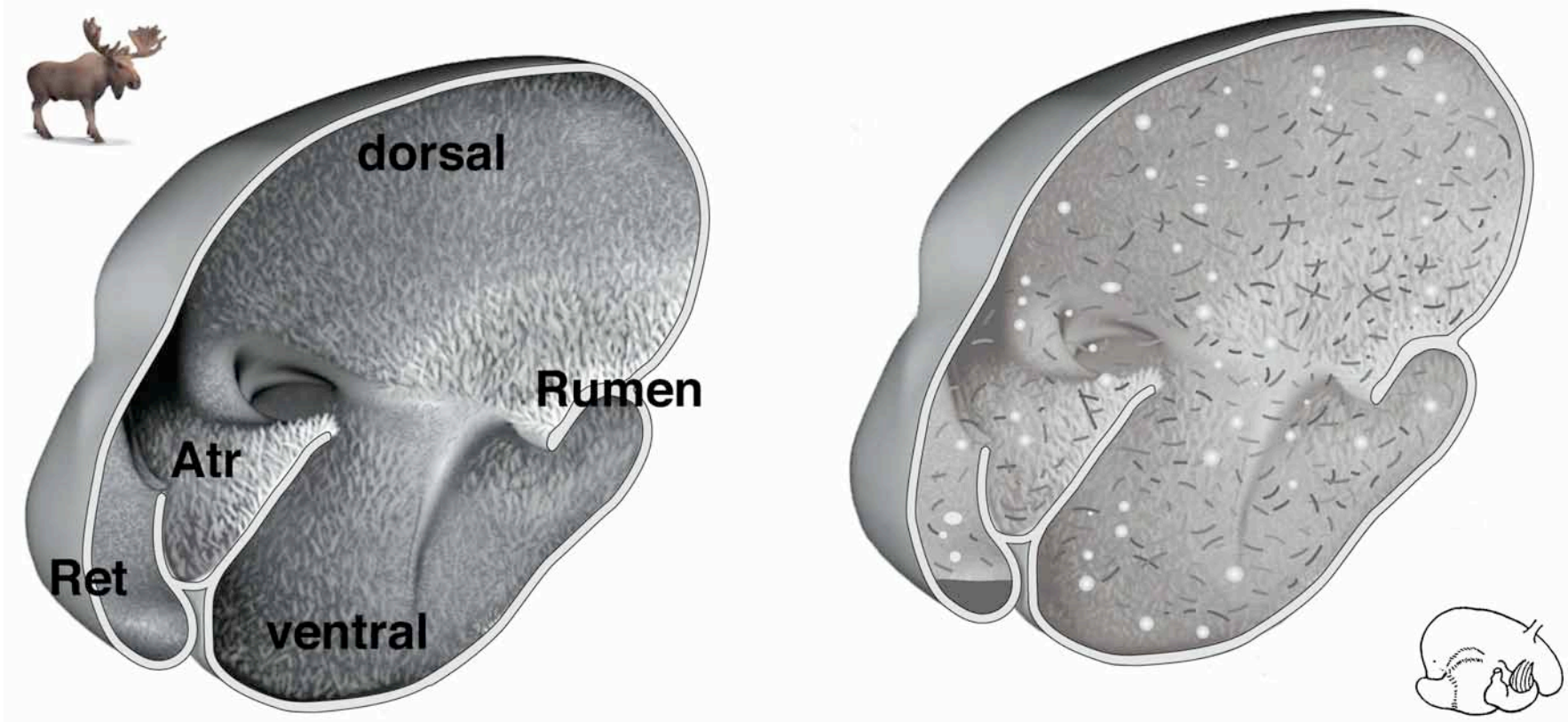
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



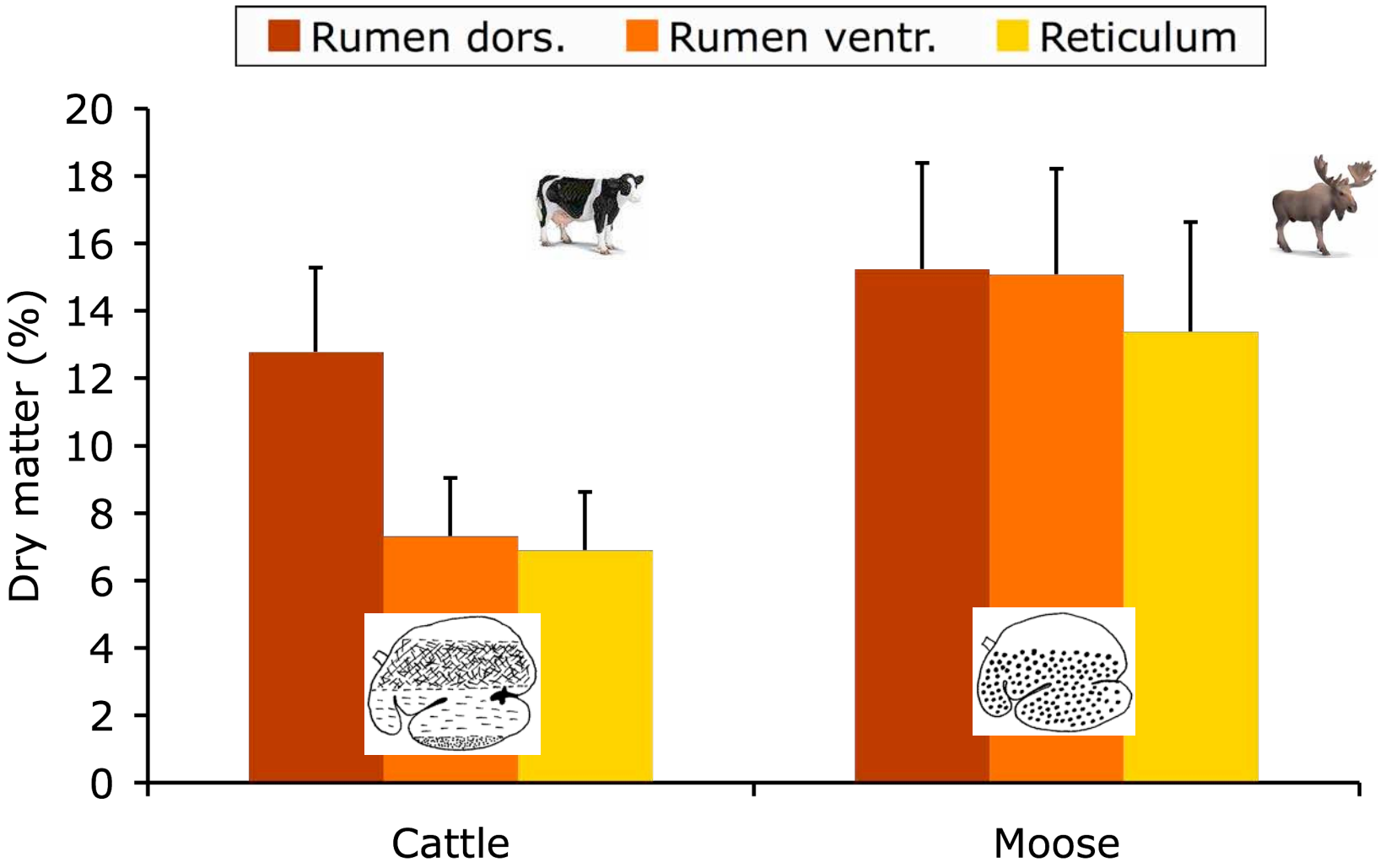
from Clauss, Hofmann et al. (2009)

No stratification of rumen contents: ‘moose-type’



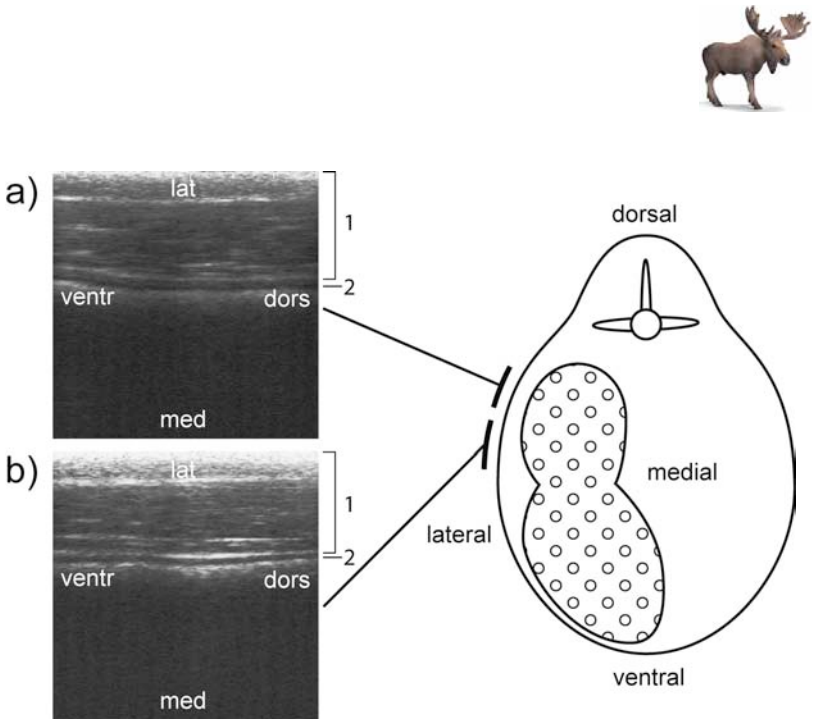
from Clauss et al. (2010)

Stratification of rumen contents



from Clauss et al. (2010)

Testing stratification by ultrasound - moose

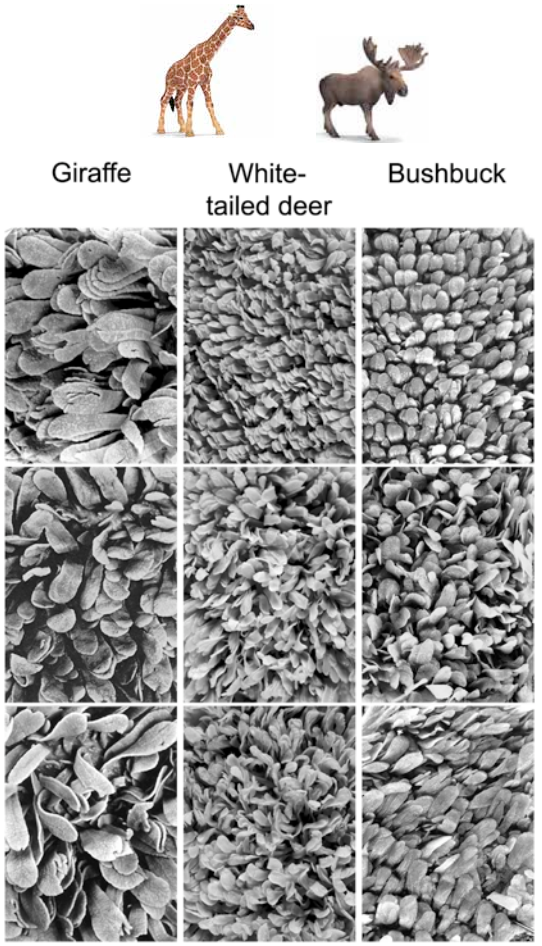


from Tschuor & Clauss (2008)

No stratification - even rumen papillation

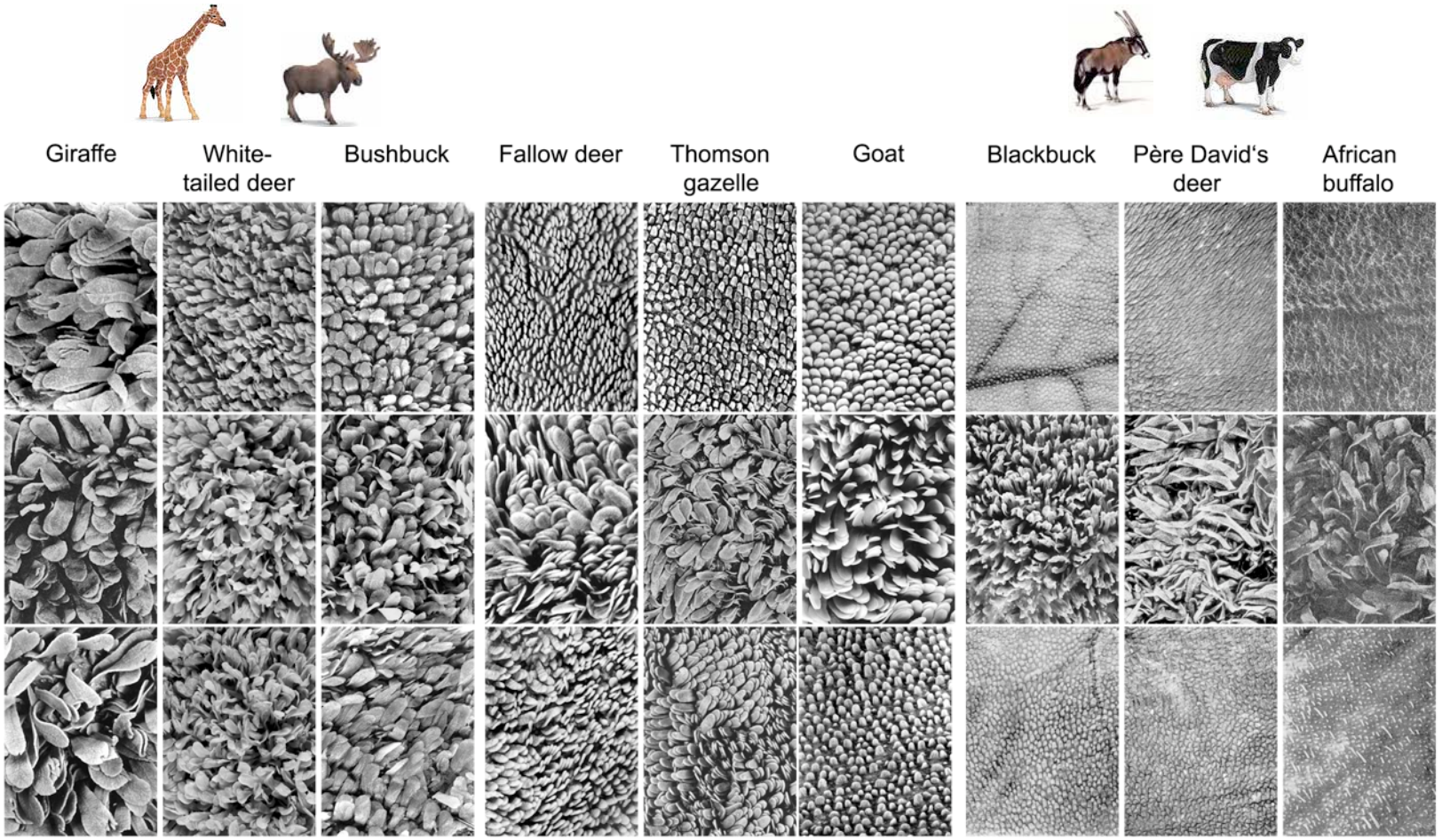
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



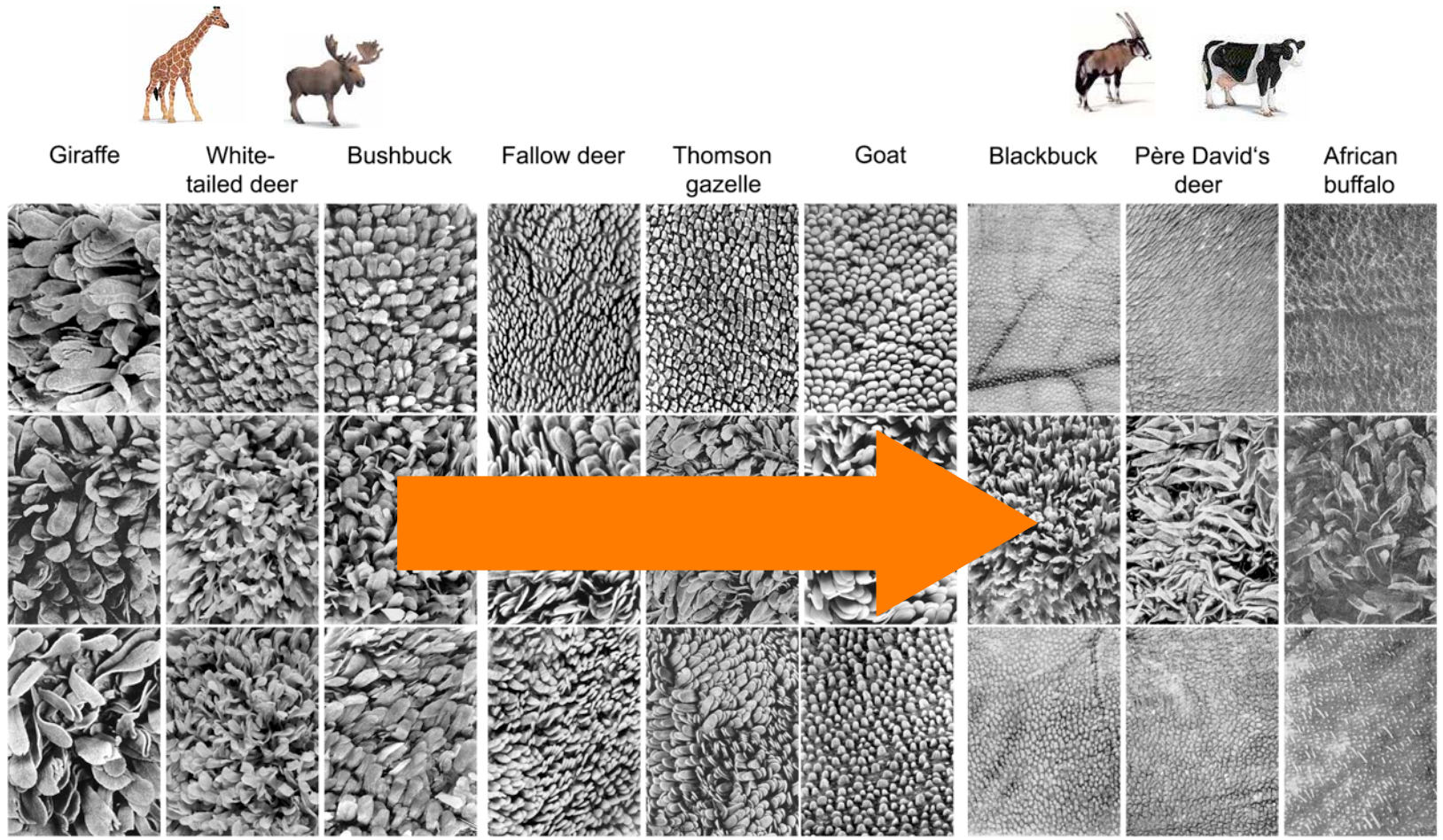
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



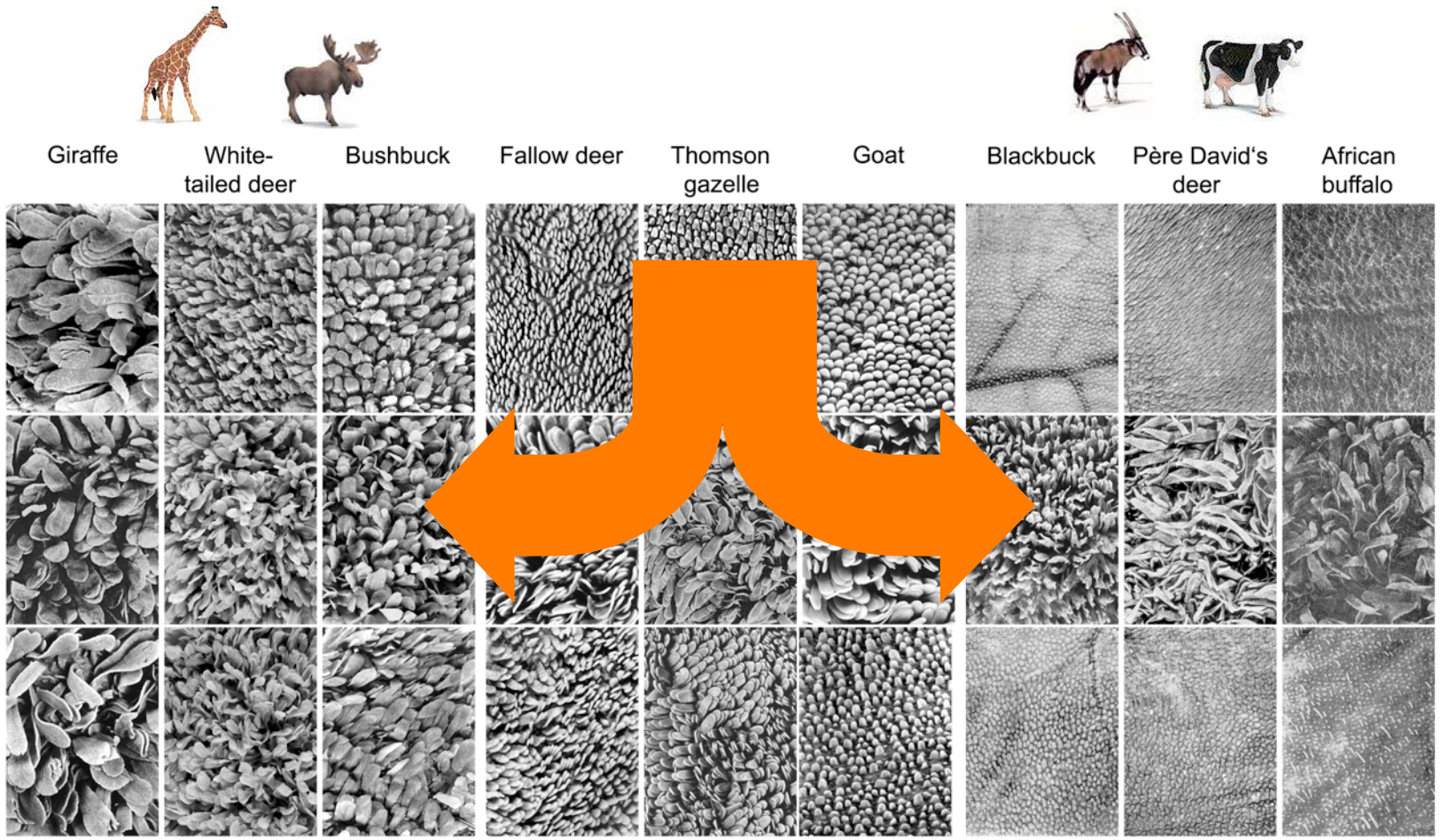
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



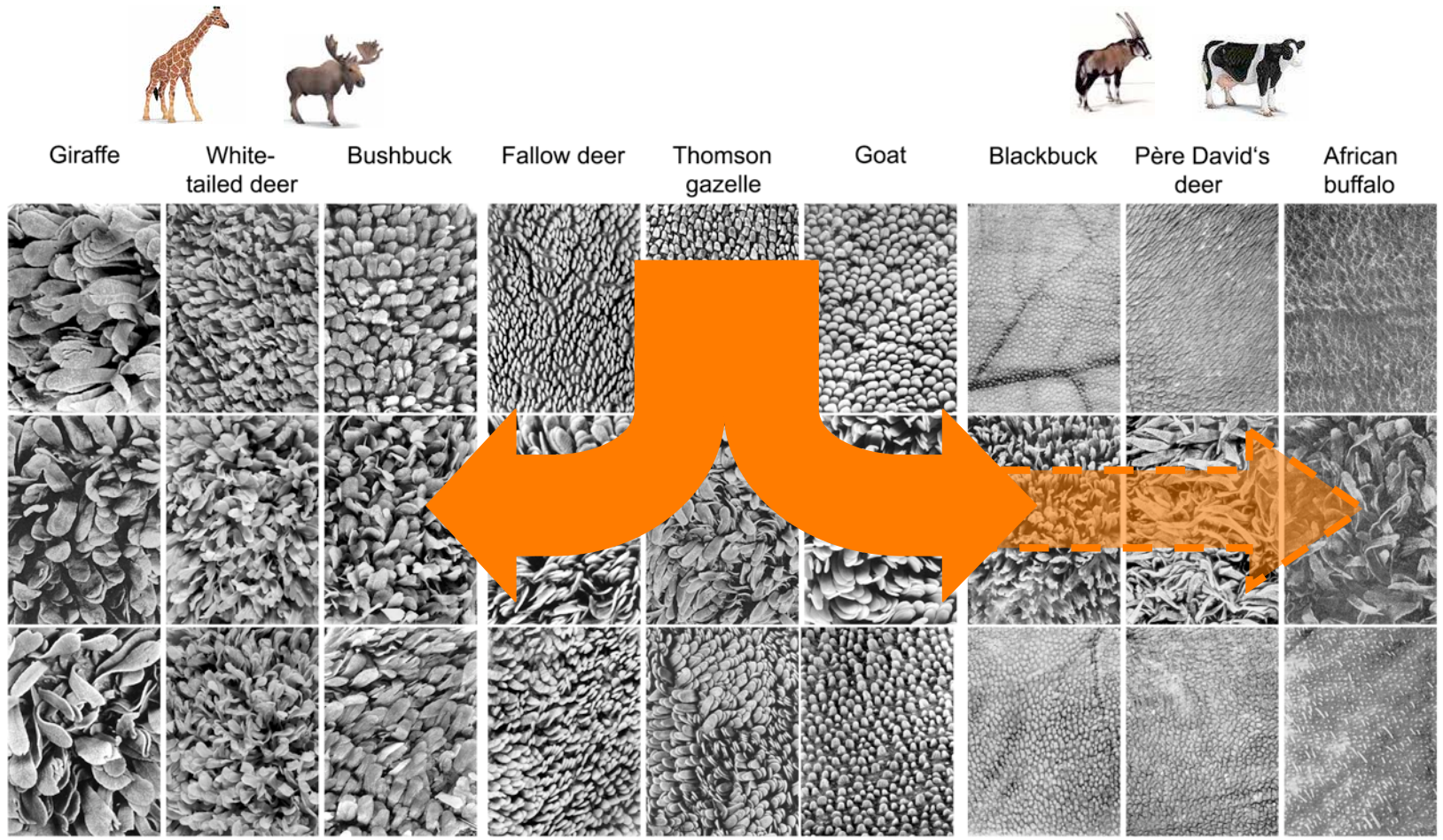
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



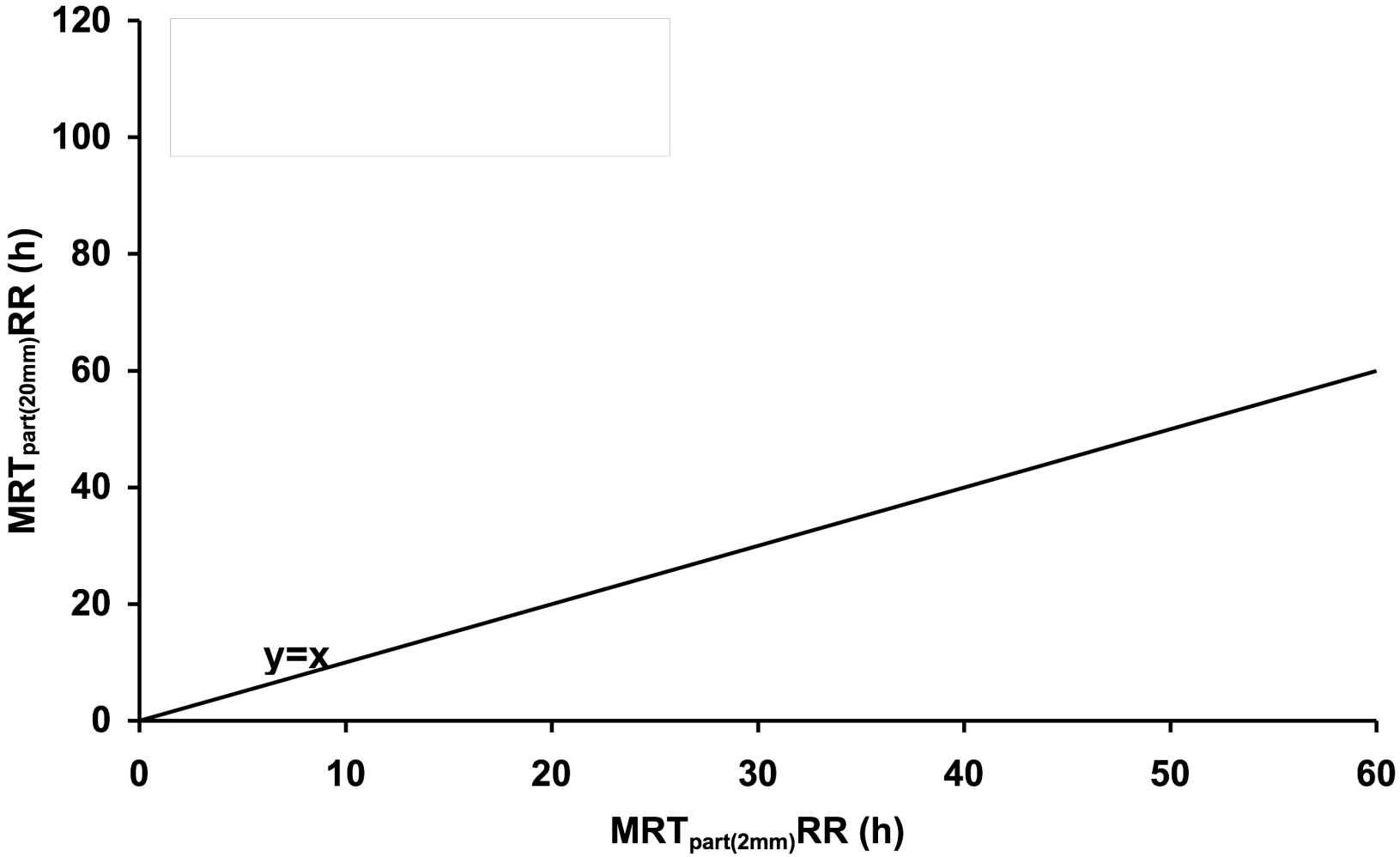
from Clauss, Hofmann et al. (2009)

Stratification and rumen papillation



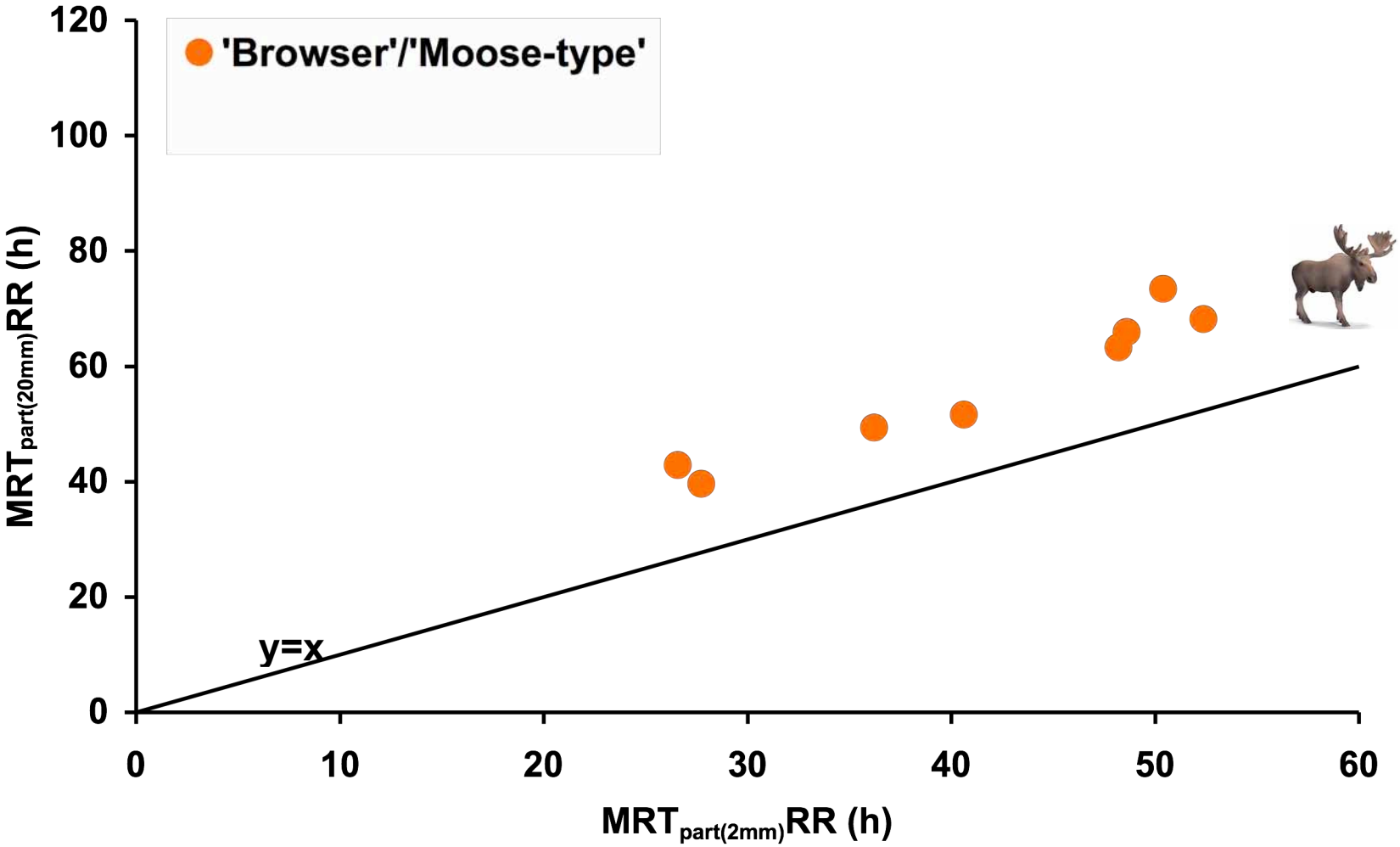
from Clauss, Hofmann et al. (2009)

No difference in sorting mechanism



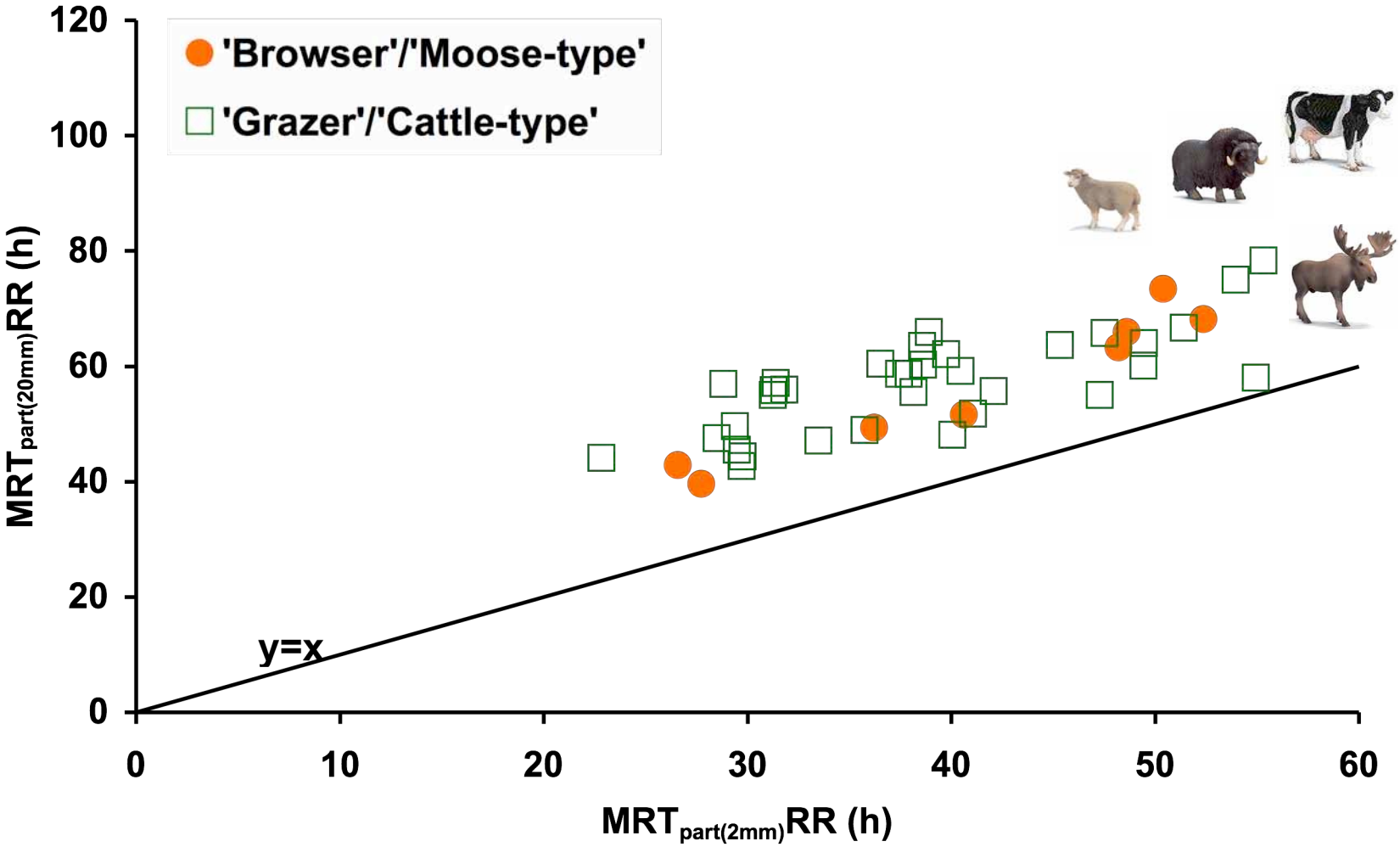
from Clauss et al. (2010)

No difference in sorting mechanism



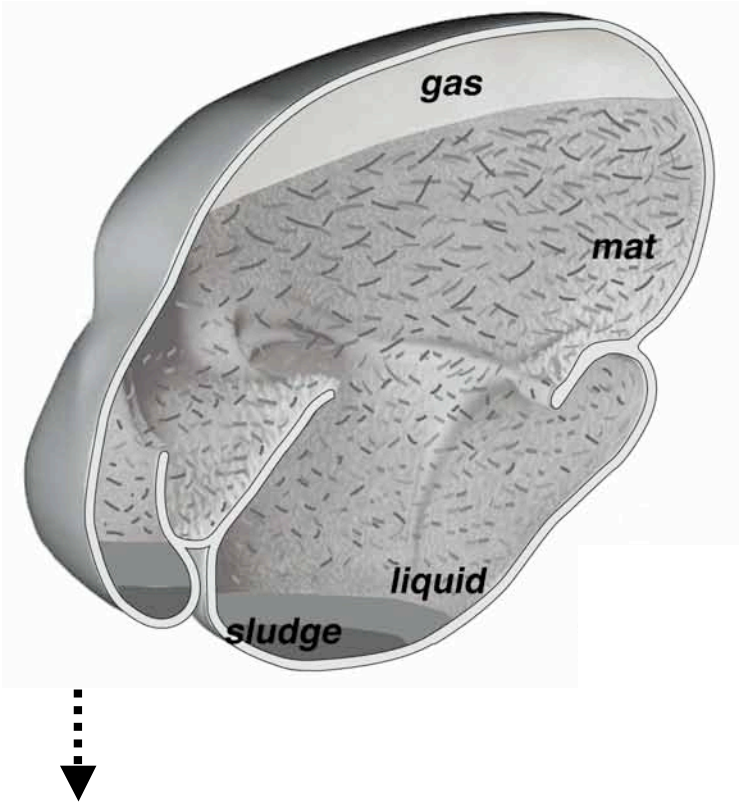
from Clauss et al. (2010)

No difference in sorting mechanism

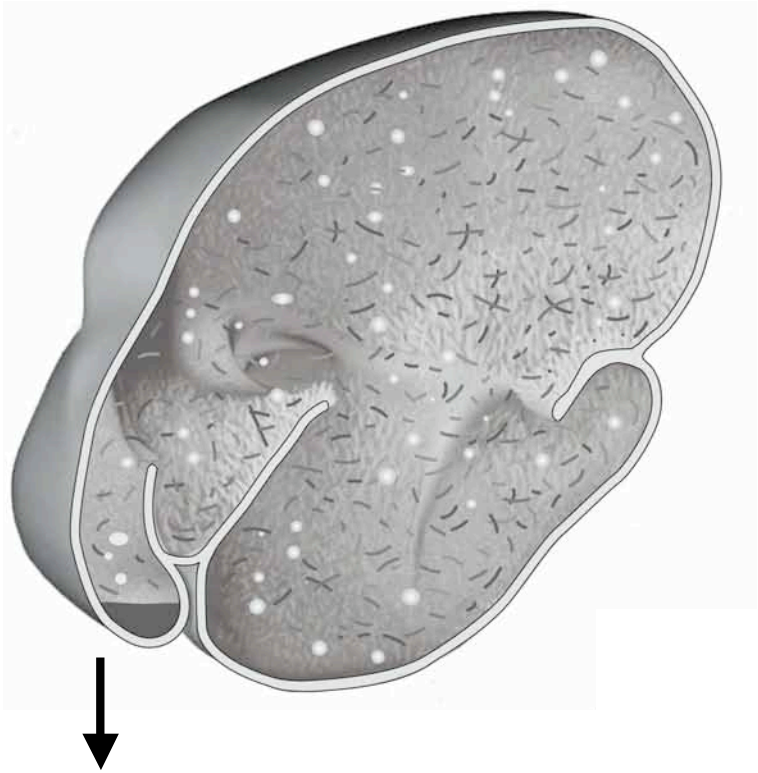


from Clauss et al. (2010)

Difference in fluid retention

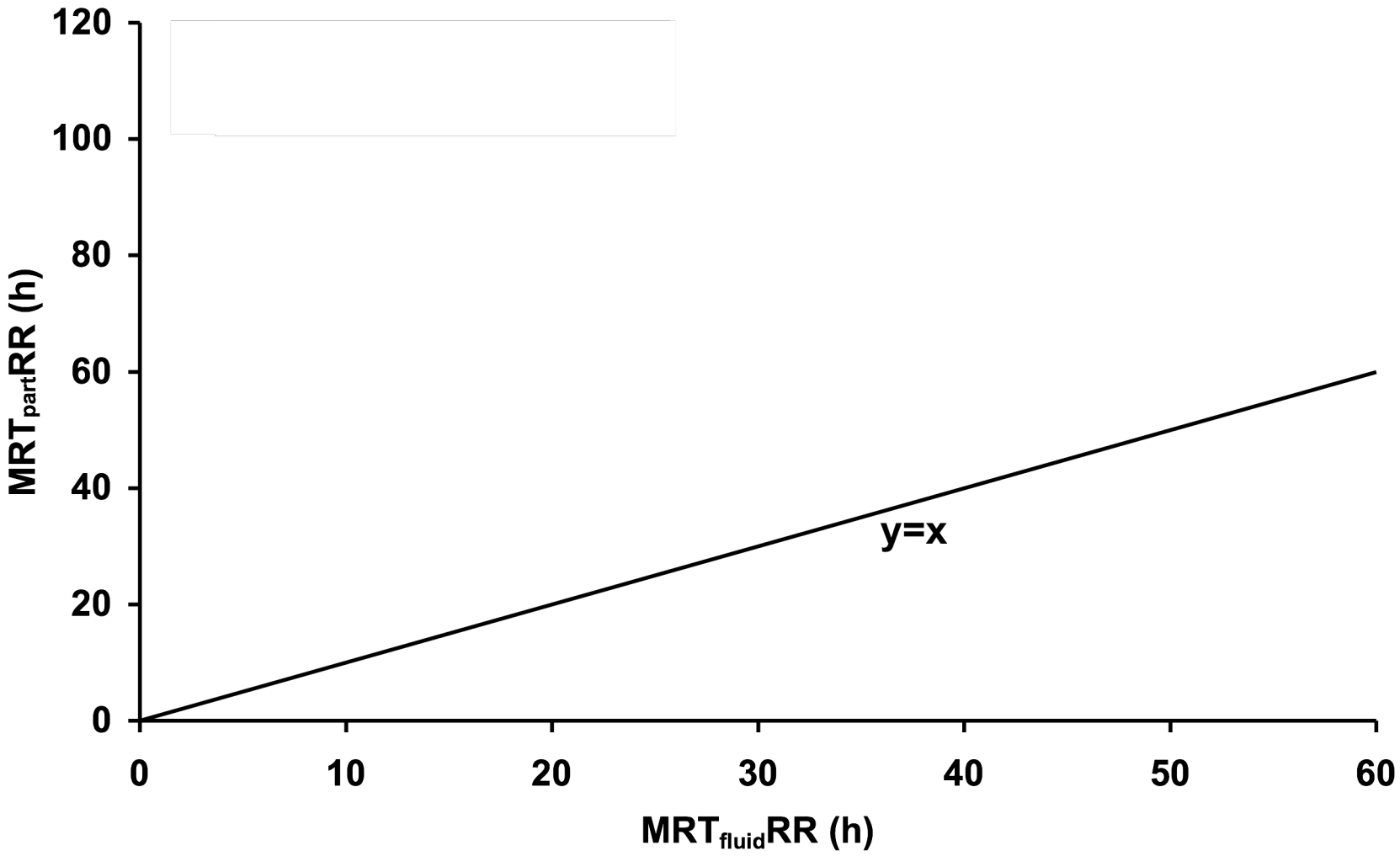


large difference between fluid and particle passage



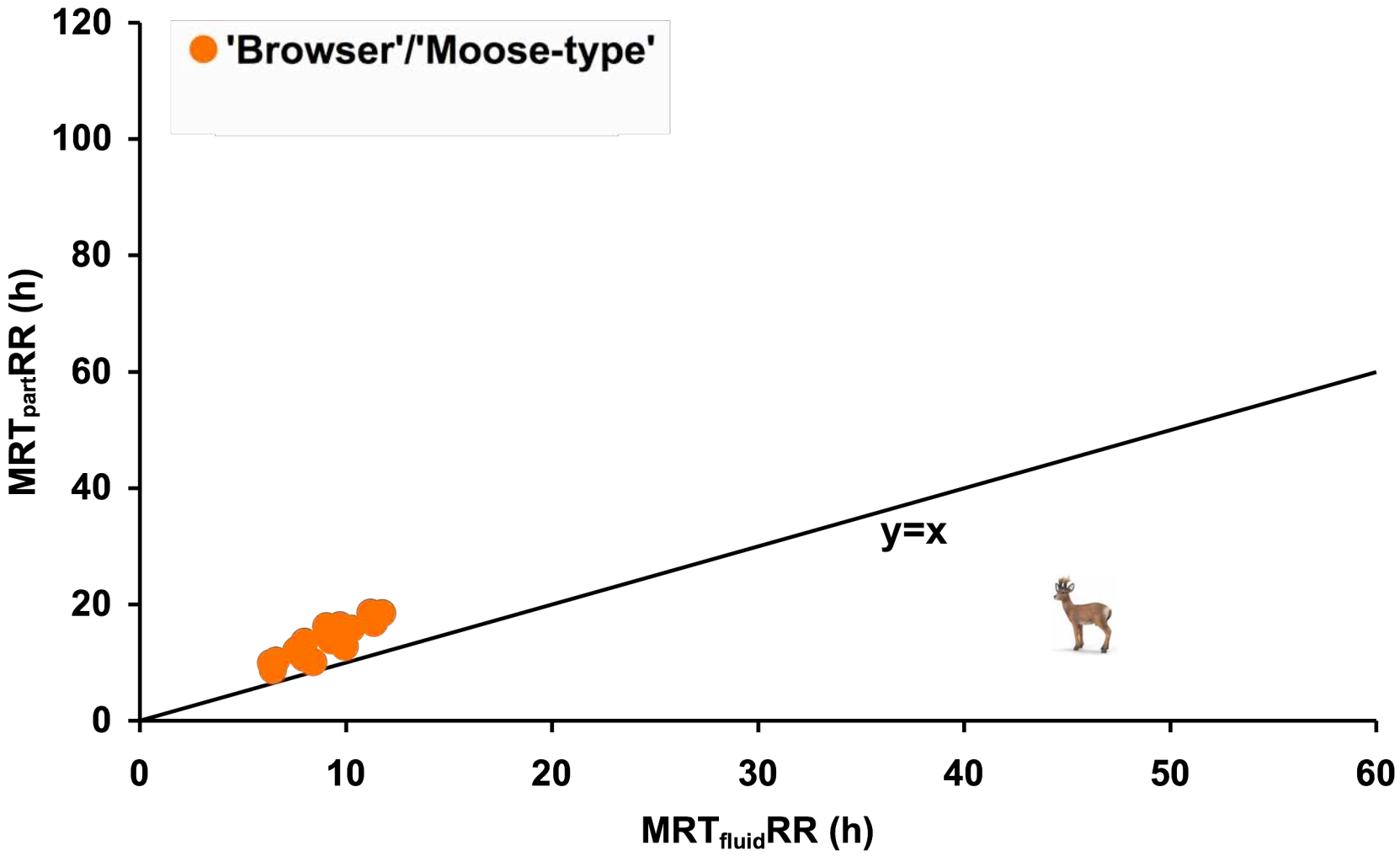
small difference between fluid and particle passage

Fluid and particle retention



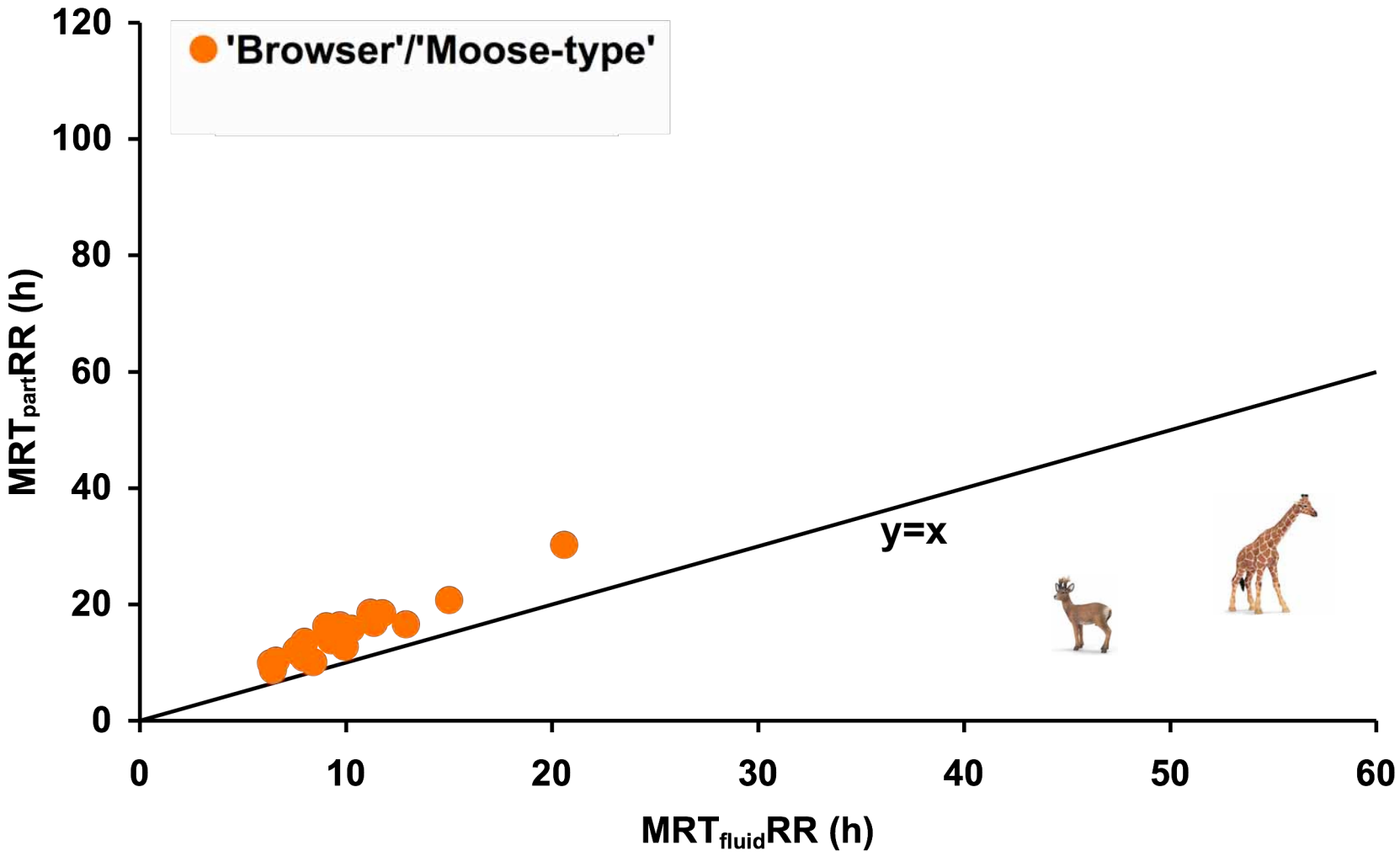
from Clauss et al. (2010)

Fluid and particle retention



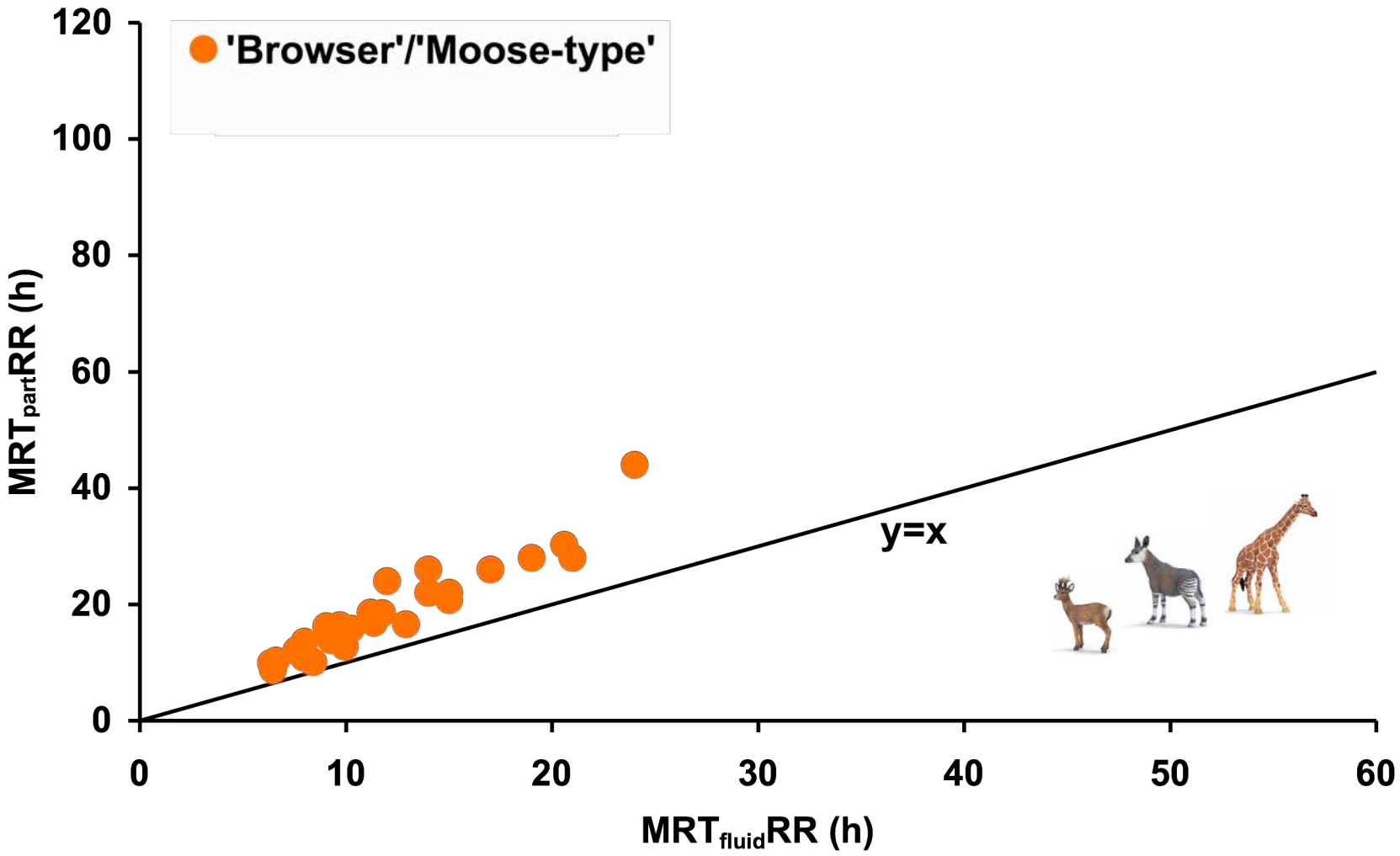
from Clauss et al. (2010)

Fluid and particle retention



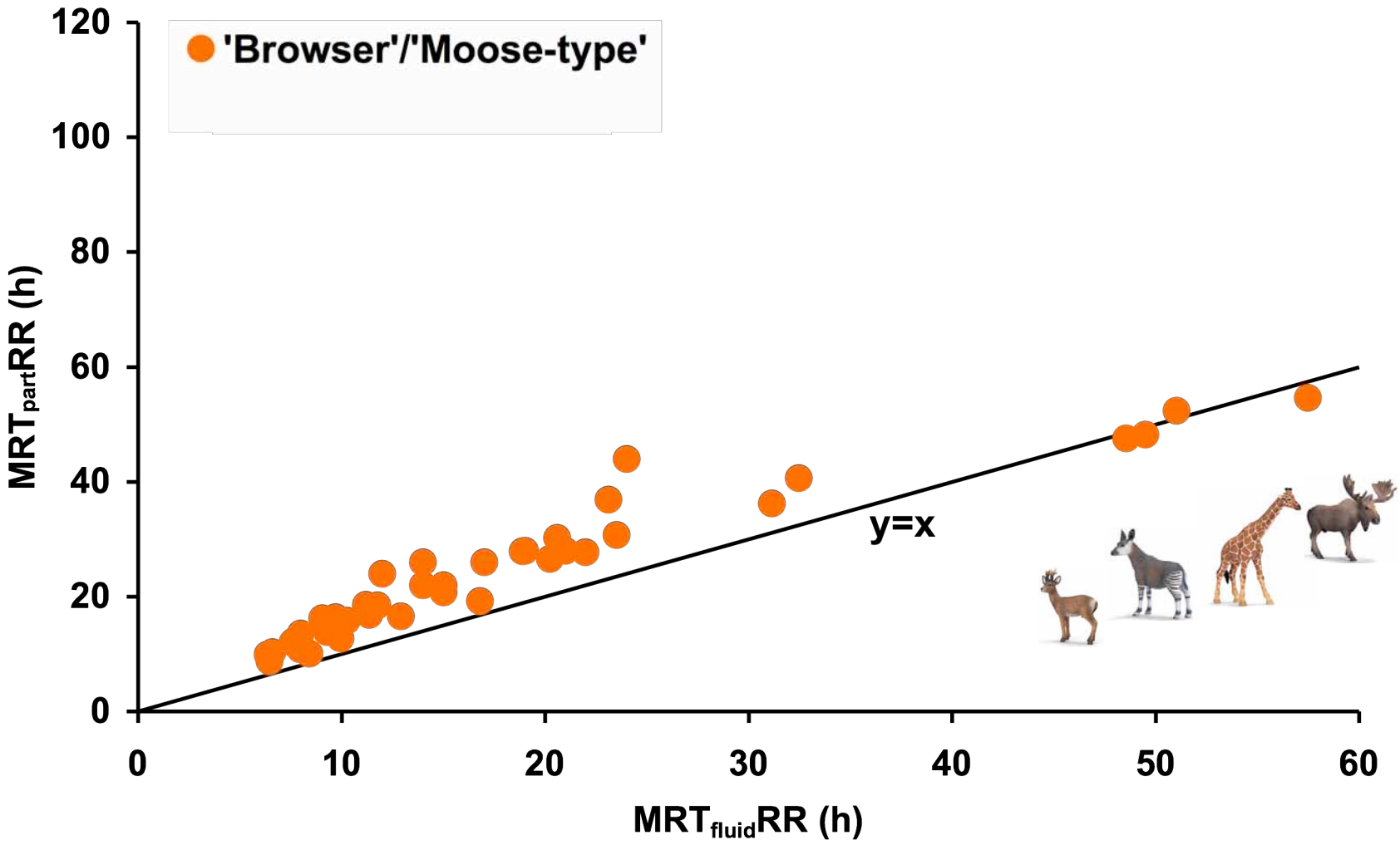
from Clauss et al. (2010)

Fluid and particle retention



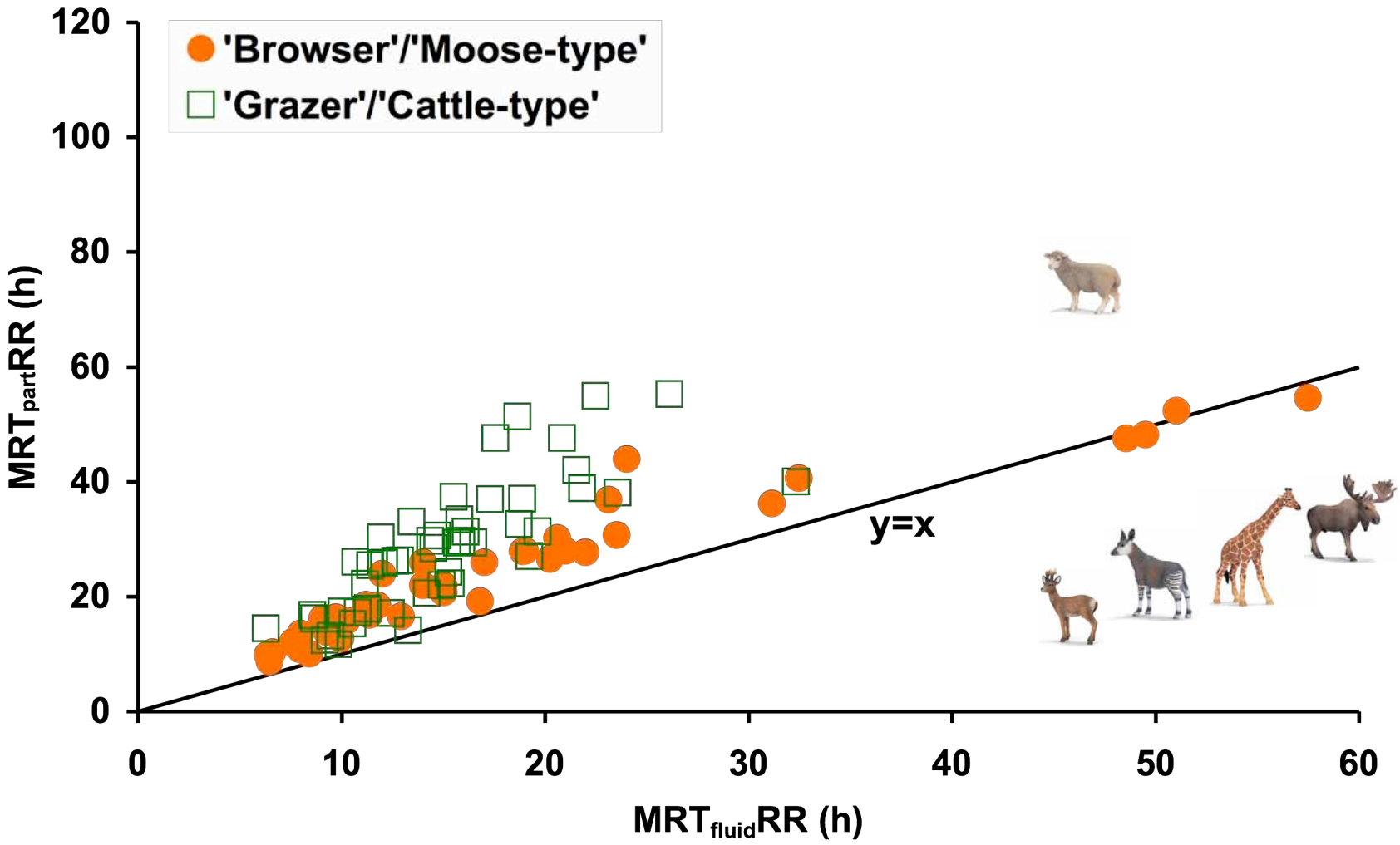
from Clauss et al. (2010)

Fluid and particle retention



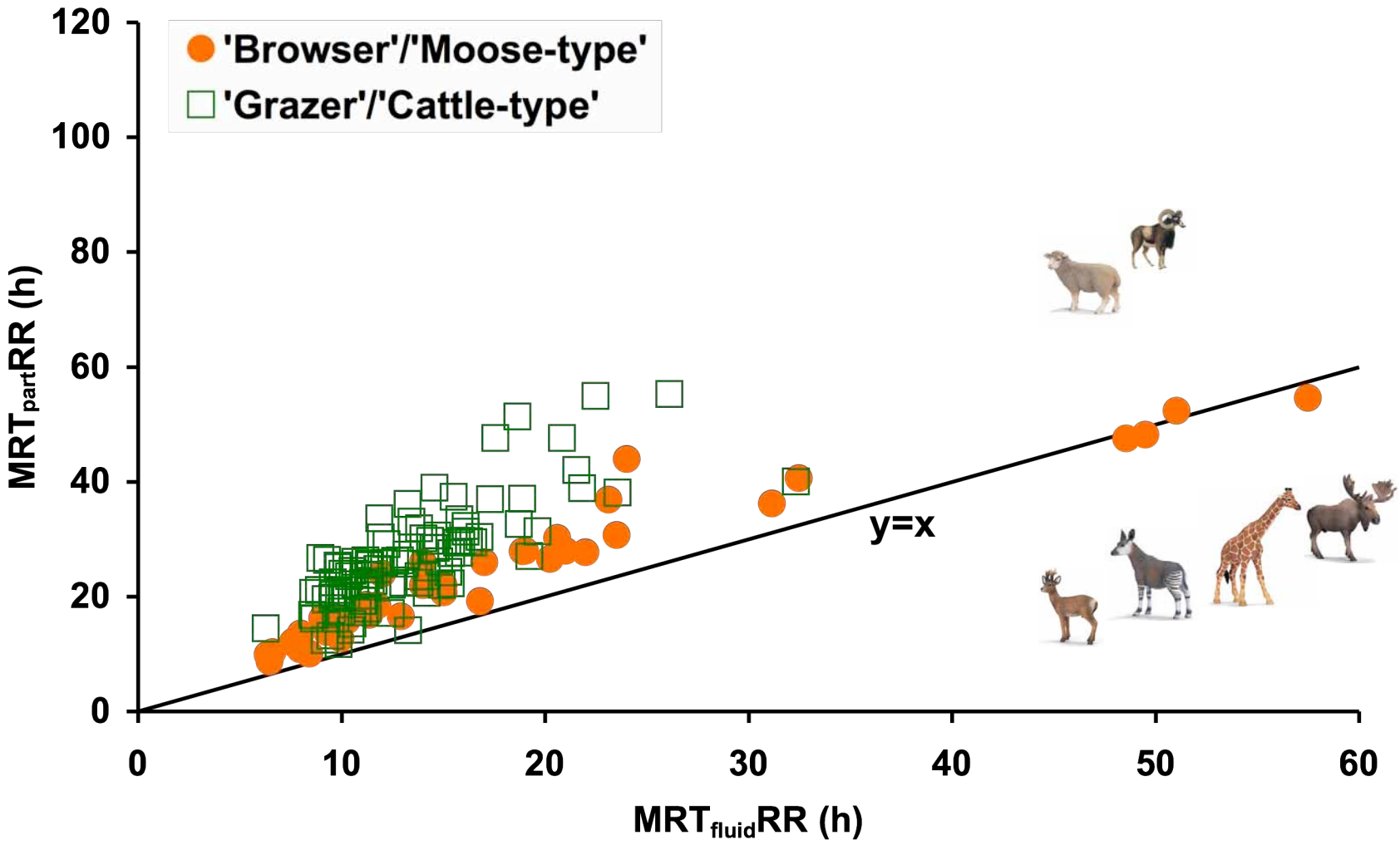
from Clauss et al. (2010)

Fluid and particle retention



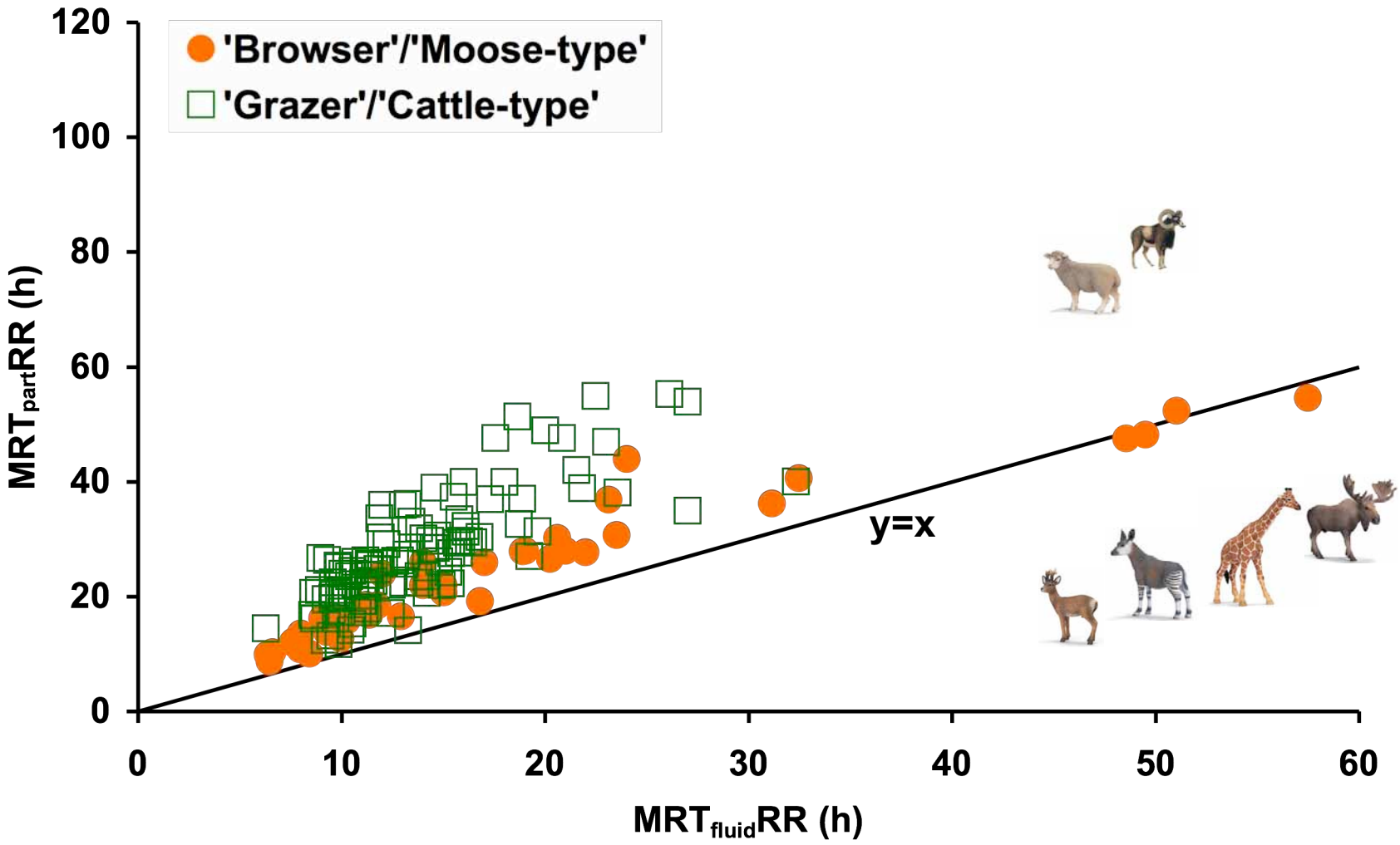
from Clauss et al. (2010)

Fluid and particle retention



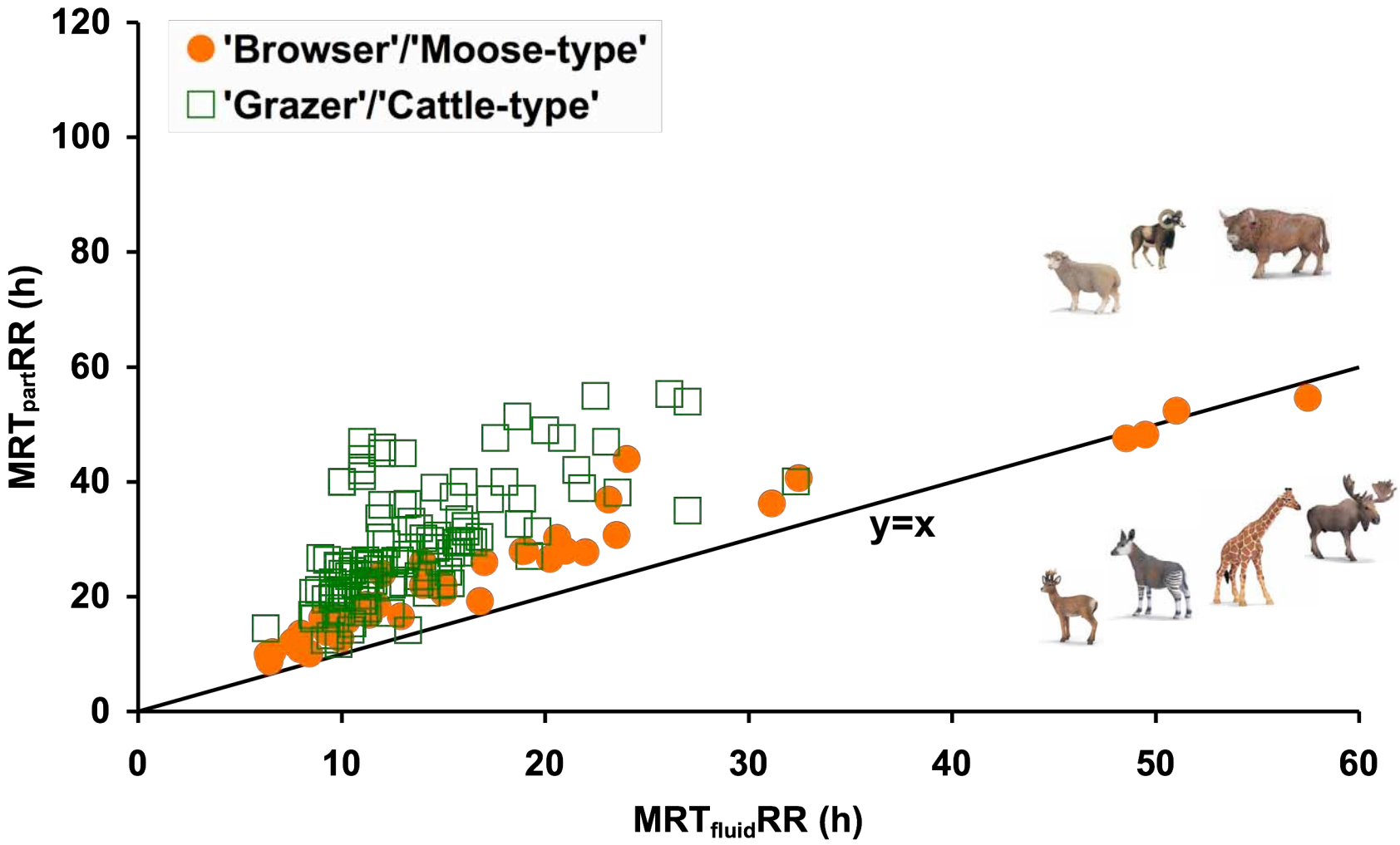
from Clauss et al. (2010)

Fluid and particle retention



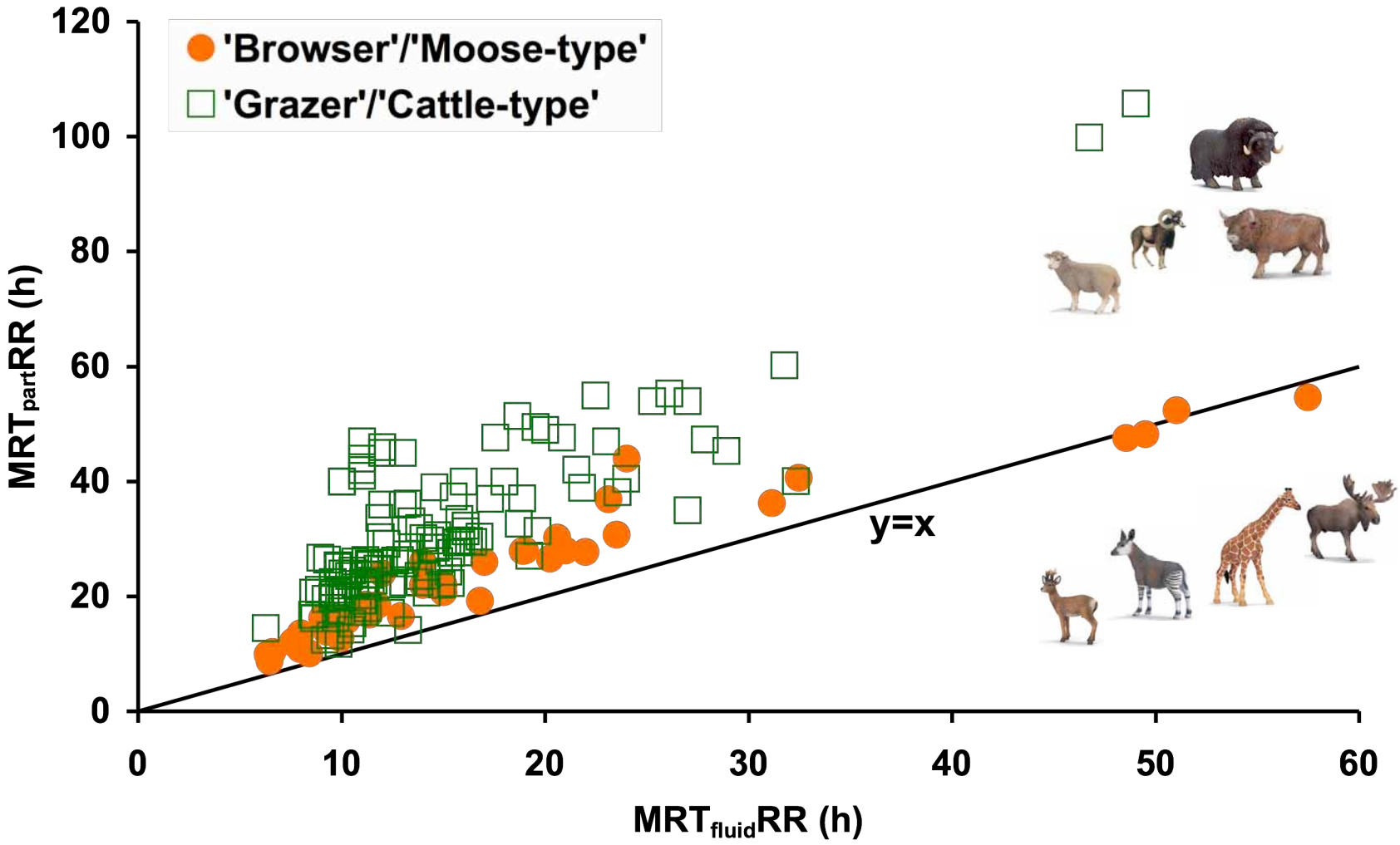
from Clauss et al. (2010)

Fluid and particle retention



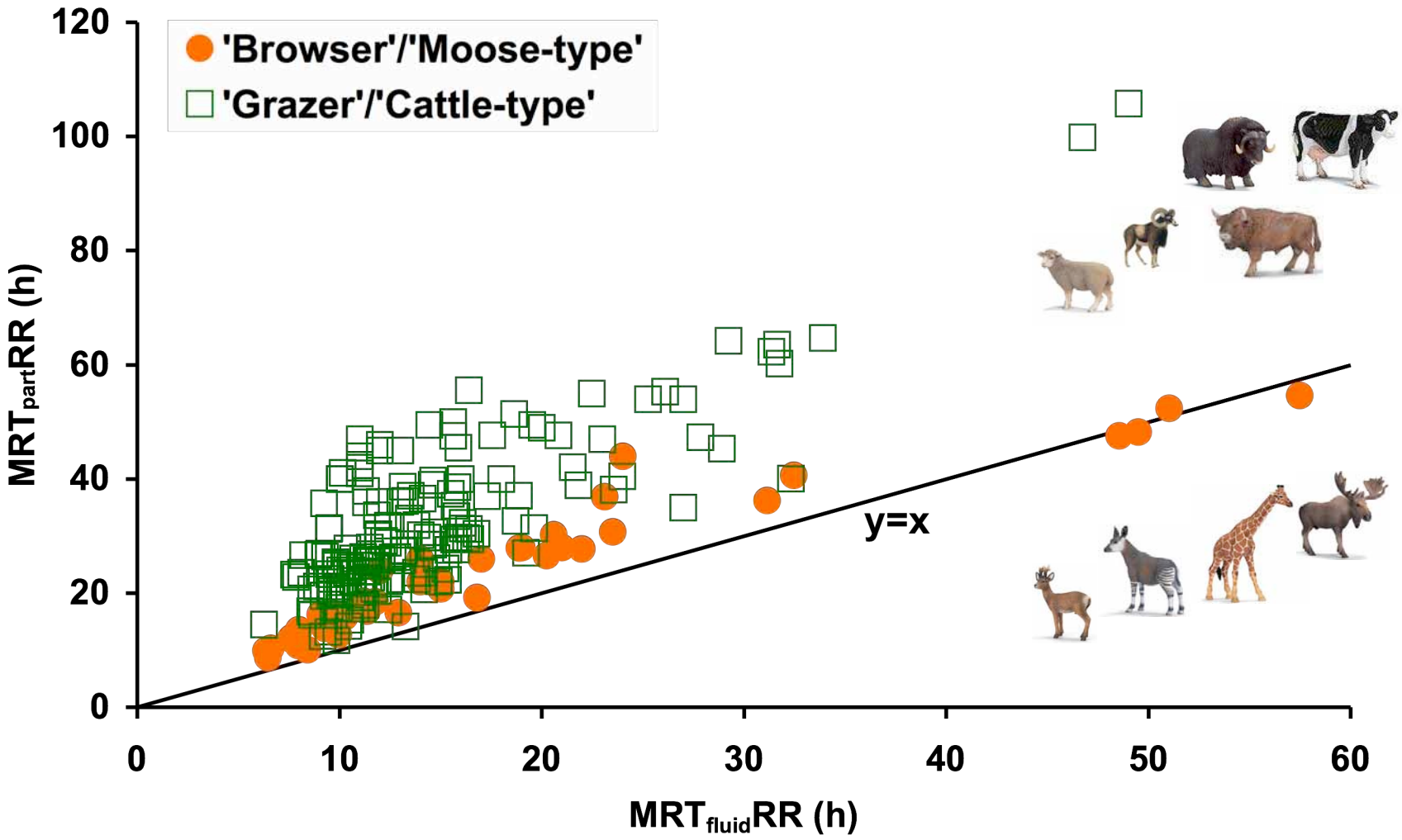
from Clauss et al. (2010)

Fluid and particle retention



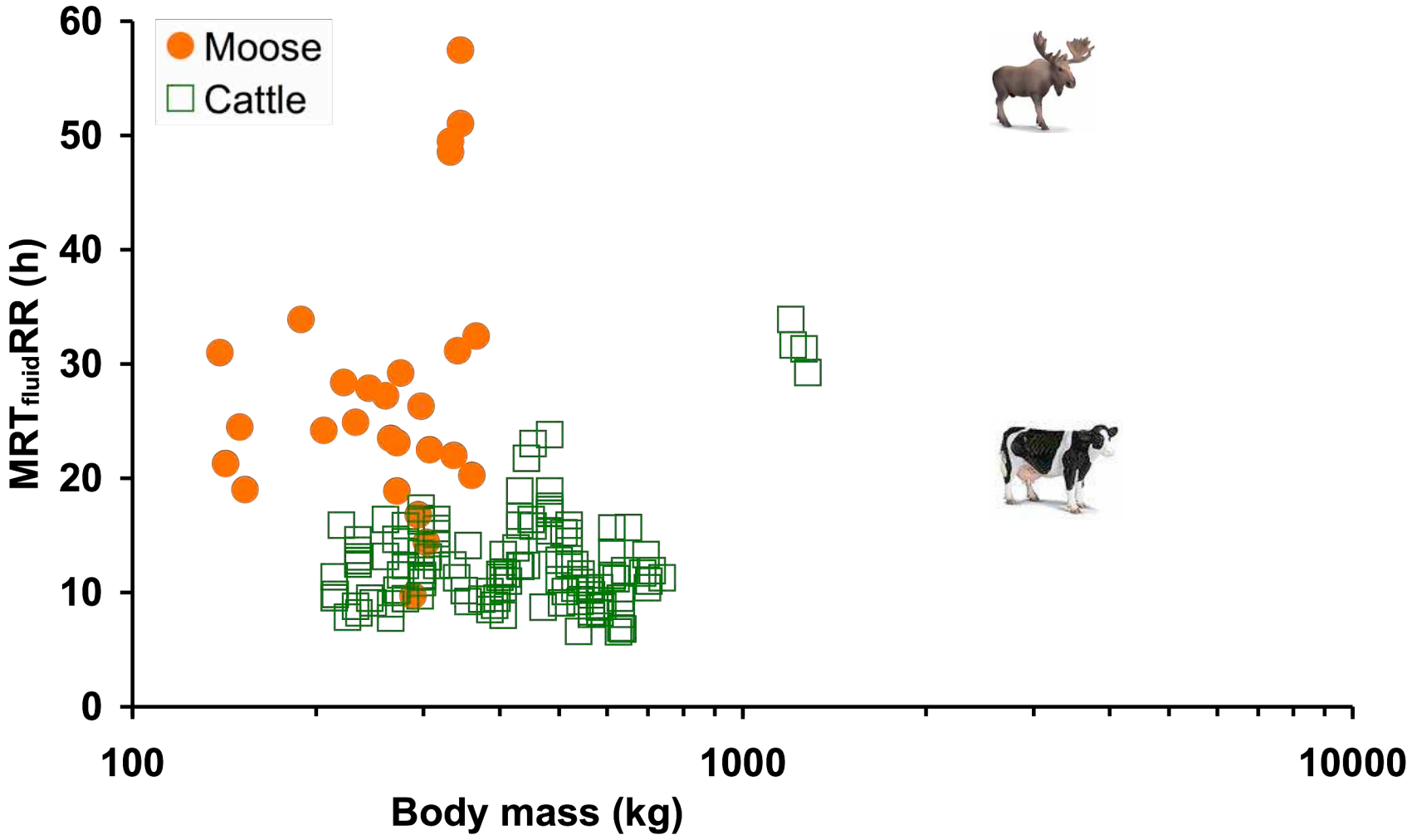
from Clauss et al. (2010)

Fluid and particle retention

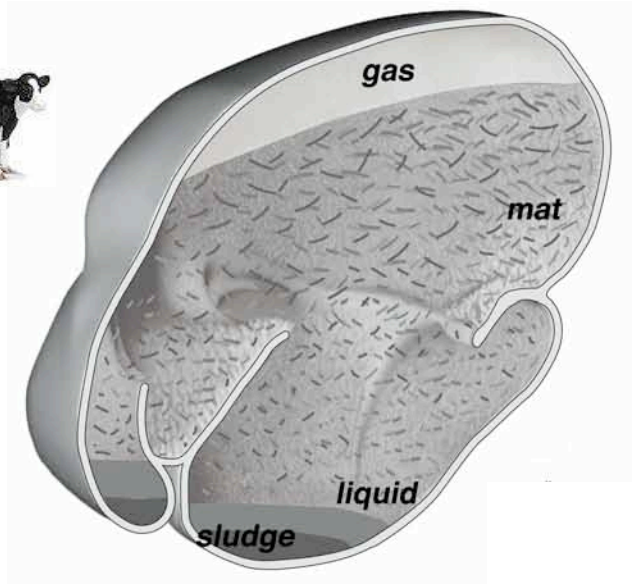


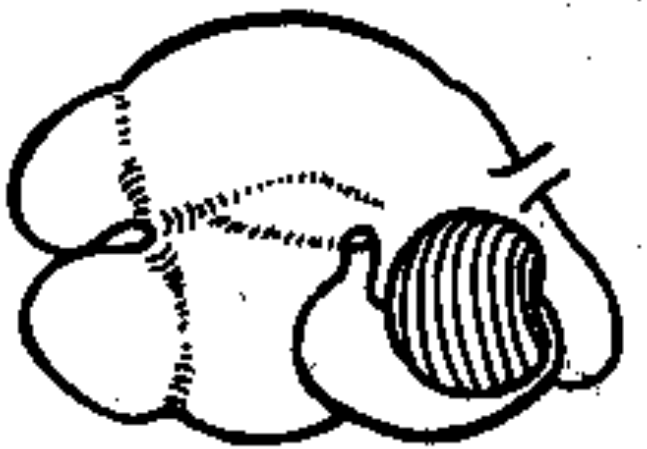
from Clauss et al. (2010)

Absolute fluid retention - moose vs. cattle

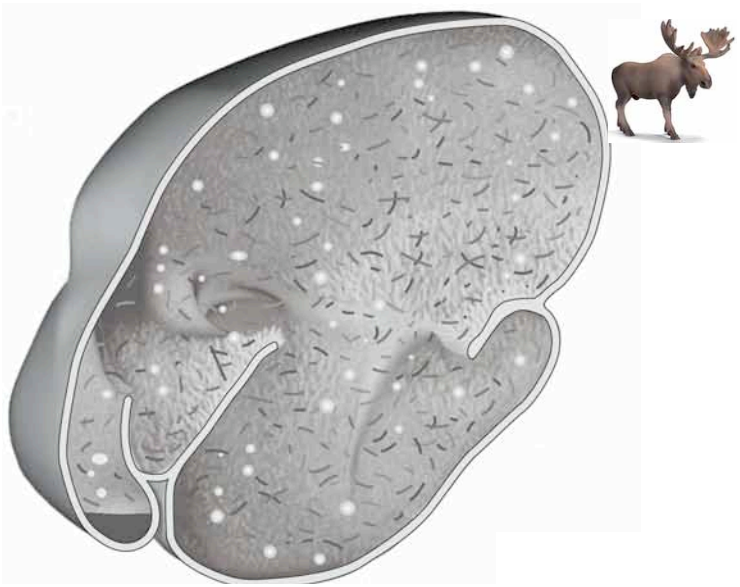


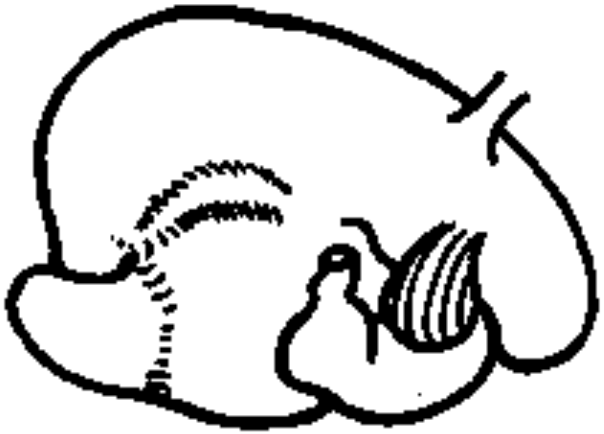
from Clauss et al. (2010)





large omasum – high water absorption capacity





small omasum – lower water absorption capacity

from Hofmann (1973, 1992)

Why a higher fluid throughput?

- A high fluid throughput ensures a fluid, low viscosity medium in the rumen - stratification, building of a mat, ‘filter-bed effect’

- A high fluid throughput increases microbial harvest from the forestomach - microbes are washed out faster, more energy used for microbial growth than microbial maintenance

Attempts to increase rumen fluid throughput

- Continuous infusion of artificial saliva in fistulated animals
- Feeding of mineral salts
- Offering of isotonic fluids instead of drinking water?

Chalupa (1977) Manipulating rumen fermentation. J Anim Sci 46, 585
Harrison & McAllan (1980) Factors affecting microbial growth yields in the reticulo-rumen. In Digestive physiology and metabolism in ruminants (eds. Ruckebush & Thivend), p 205, MTP Press, Lancaster
Croom et al. (1993) Manipulation of gastrointestinal nutrient delivery in livestock. J Dairy Sci 76, 2112

Attempts to increase rumen fluid throughput

EFFECTS OF A SALIVARY STIMULANT, SLAFRAMINE, ON RUMINAL FERMENTATION, BACTERIAL PROTEIN SYNTHESIS AND DIGESTION IN FREQUENTLY FED STEERS[1]

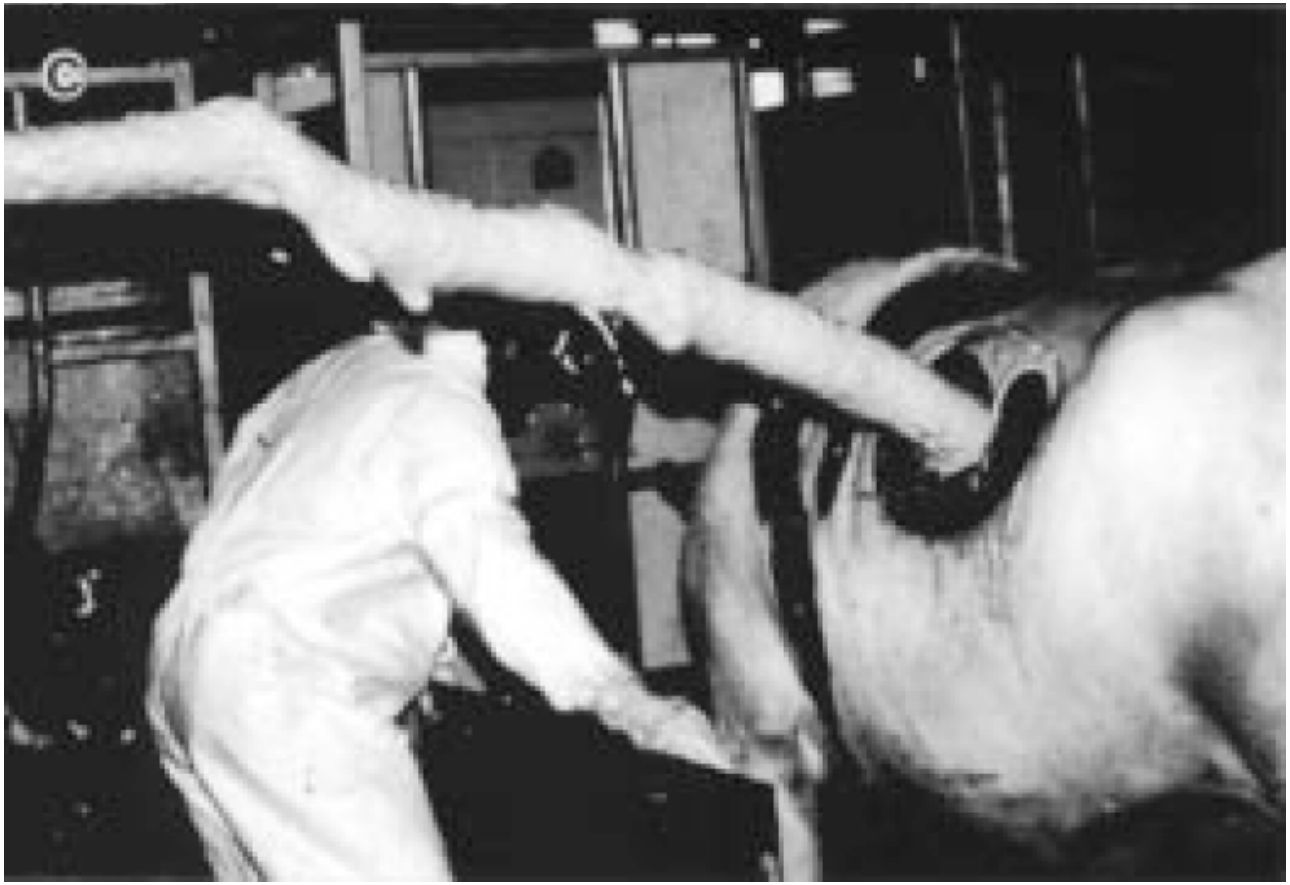
M. A. Froetschel[2], H. E. Amos[2], J. J. Evans[3], W. J. Croom, Jr.[4] and W. M. Hagler, Jr.[5]

J. Anim. Sci. 1989. 67:827–834

With SF administration, as much as 13% more bacterial protein exited the rumen, resulting in a 16.5% linear improvement ($P < .1$) in the efficiency of ruminal bacterial protein production per 100 g of OM fermented.

These results demonstrate a positive relationship between salivation and ruminal bacterial protein synthesis and suggest that feed utilization by ruminants may be improved by pharmacological stimulation of salivary secretions.

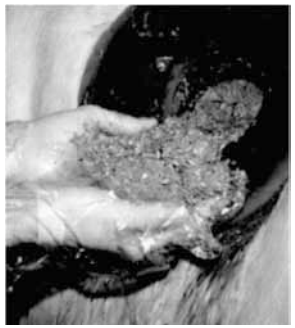
Frothy bloat



from Cheng et al. (1998)

Frothy bloat

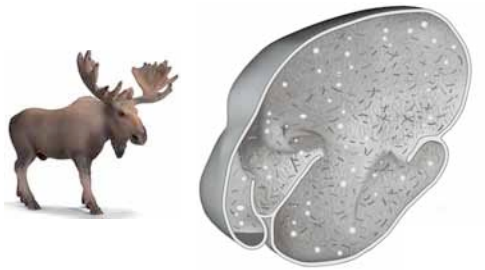
frothy rumen contents

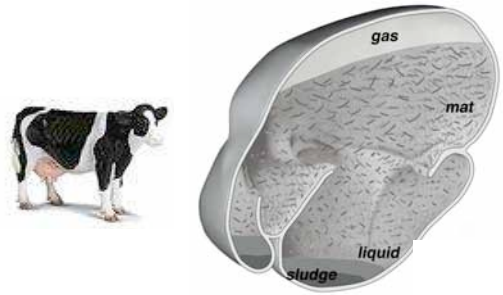


'dry' rumen contents

from Cheng et al. (1998)

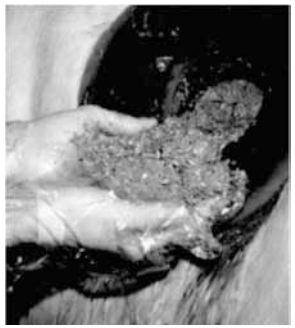
Frothy bloat





frothy rumen contents

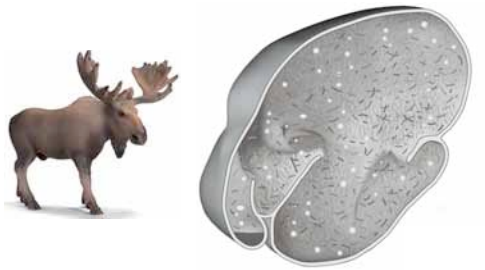
low saliva production
low RR fluid throughput



'dry' rumen contents

from Cheng et al. (1998)

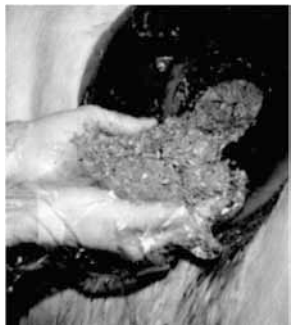
Frothy bloat



frothy rumen contents

low saliva production
low RR fluid throughput

selective breeding against bloat susceptibility possible

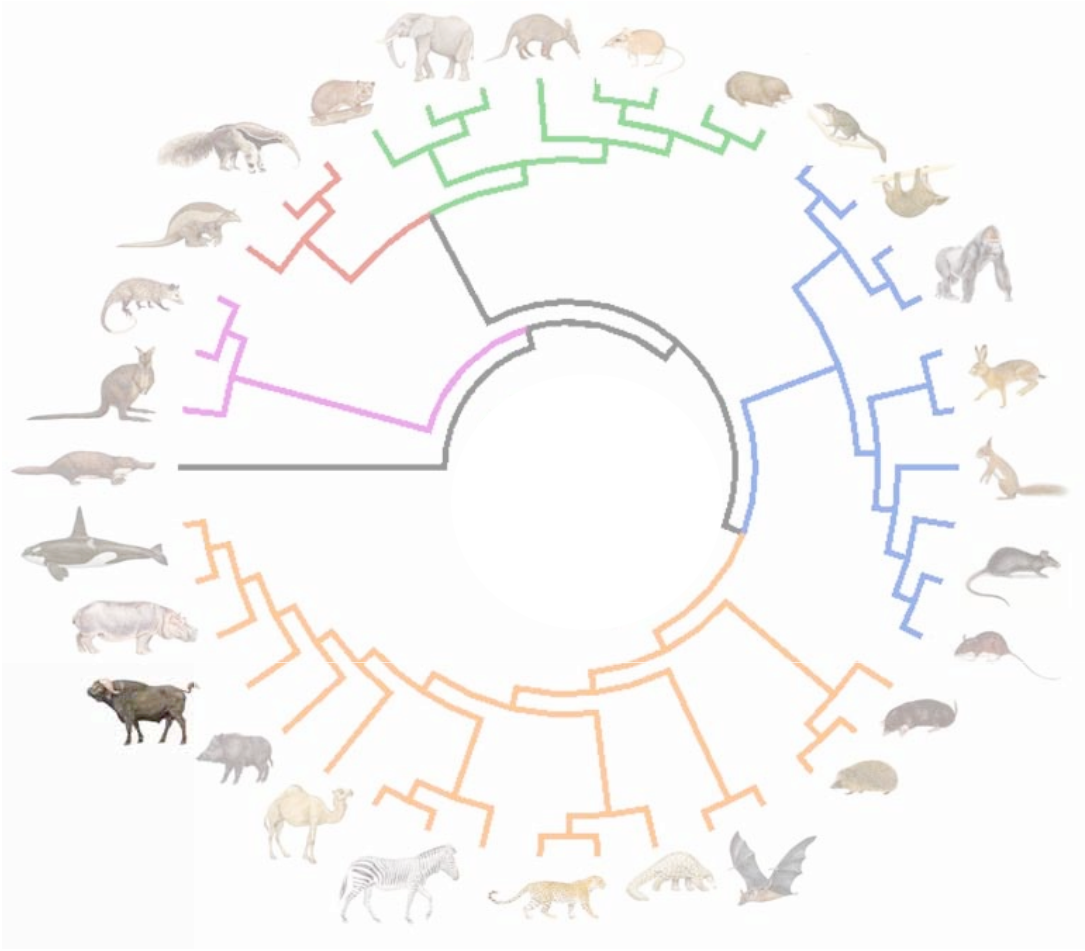


'dry' rumen contents

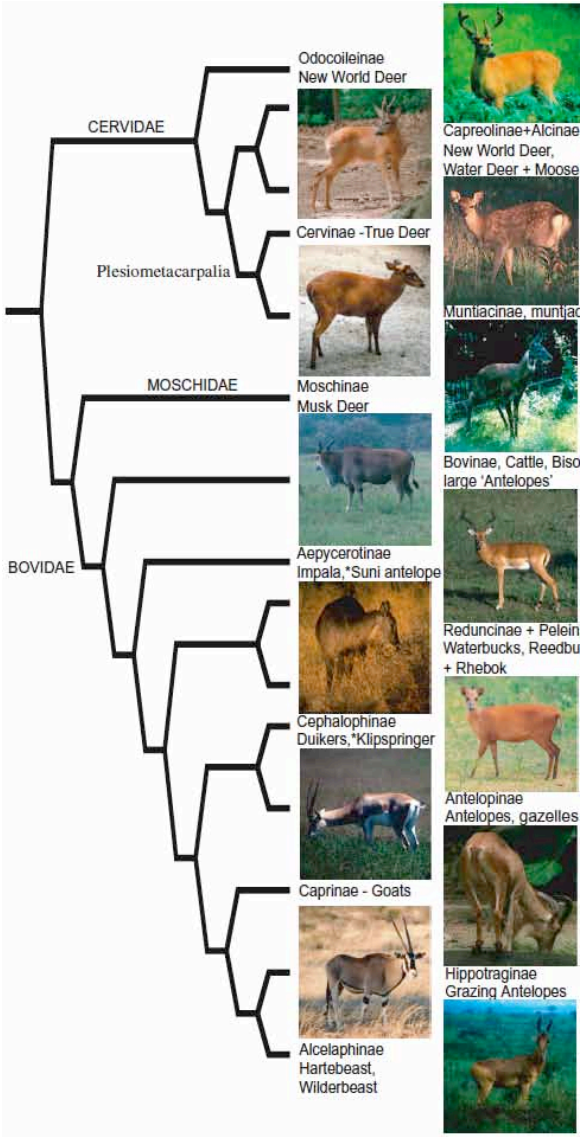
Morris et al. (1997) Genetic studies of bloat susceptibility in cattle. Proc N Z Soc Anim Prod 57, 19

Conclusion: ruminants and fluids

- Ruminants increase energy uptake by means of a sorting mechanism (that requires a fluid medium)



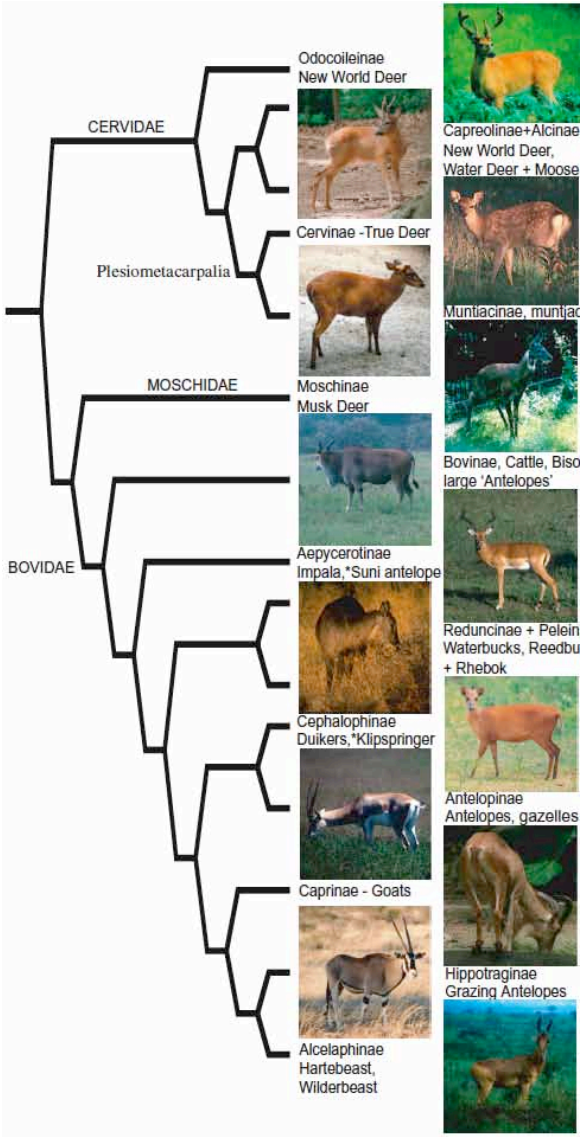
Conclusion: ruminants and fluids



from Agnarsson et al. (2008)

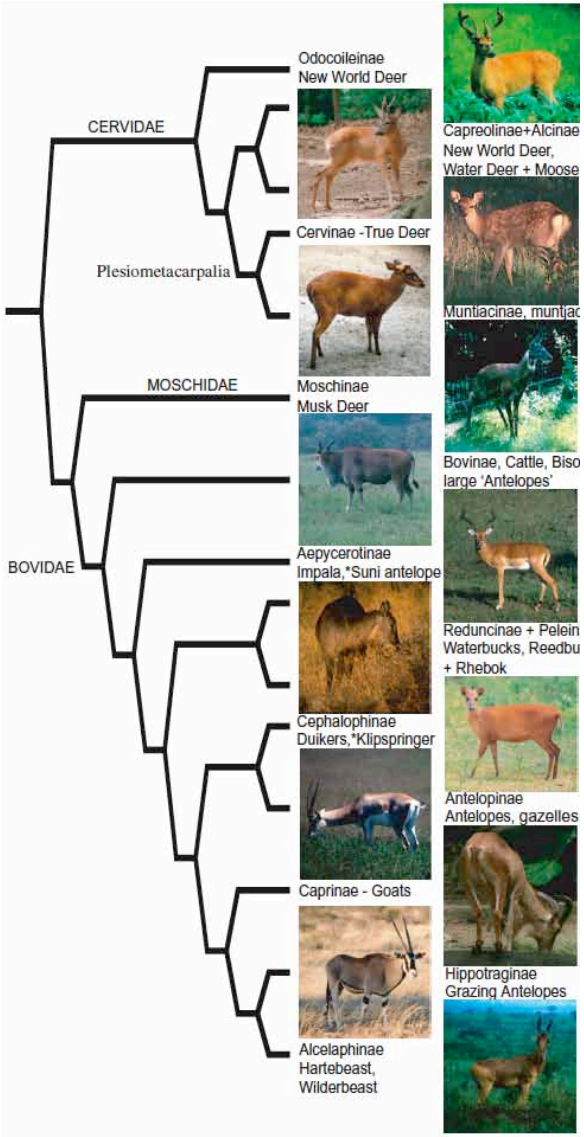
Evidence for convergent evolution of high fluid throughput in ruminant lineages suggests that benefits are substantial.

Conclusion: ruminants and fluids



from Agnarsson et al. (2008)

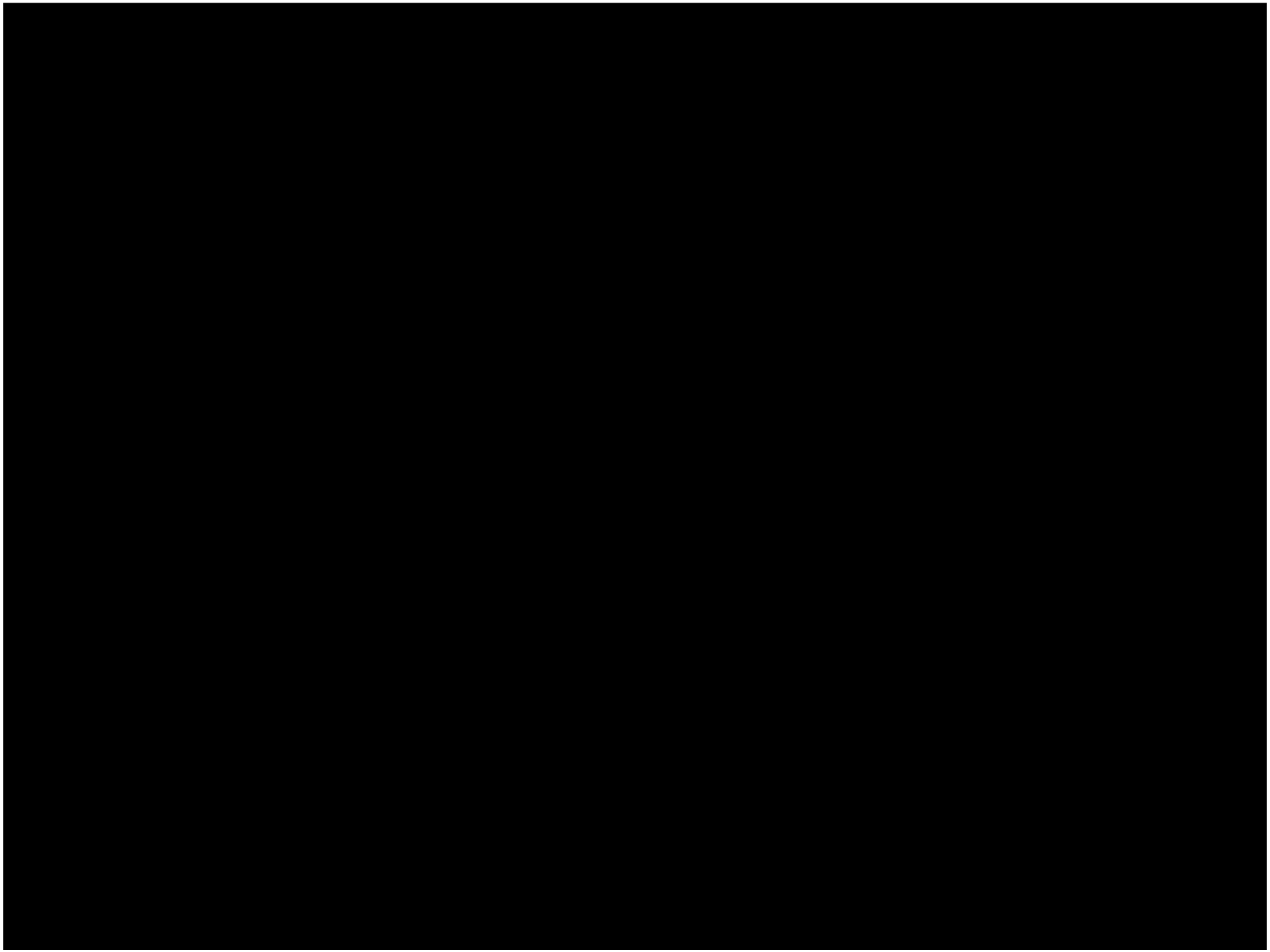
Conclusion: ruminants and fluids



from Agnarsson et al. (2008)

Further increase of RR fluid throughput by selective breeding could

- increase microbial yield from RR
- increase buffering capacity (capacity to deal with concentrate diets)
- increase capacity for particle retention/fibre digestion?
- increase proportion of autoenzymatic digestion in small intestine?



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