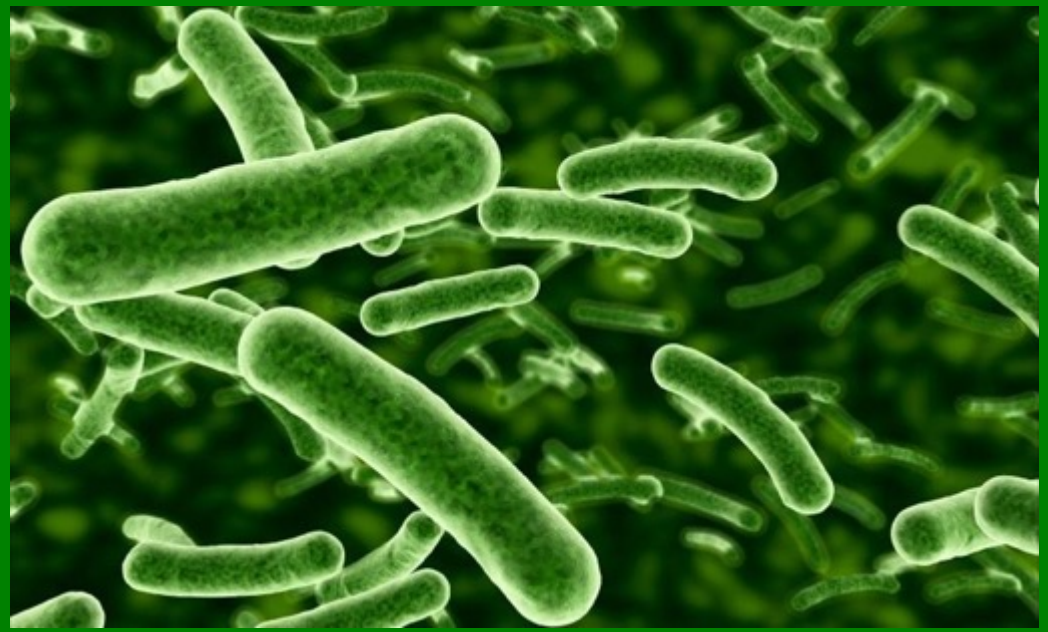
Vertebrates as microbe farmers



Marcus Clauss

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

ETH Special Seminar August 2020

University of Zurich[UZH]

Clinic of Zoo Animals, Exotic Pets and Wildlife

Structure

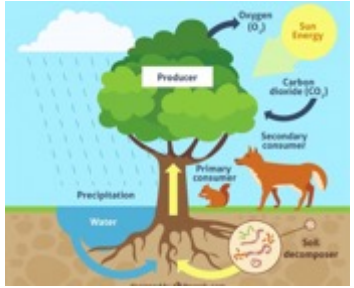
1. Ecology: Food chains and shortcuts

2. Microbes in digestive tracts: service providers or prey?

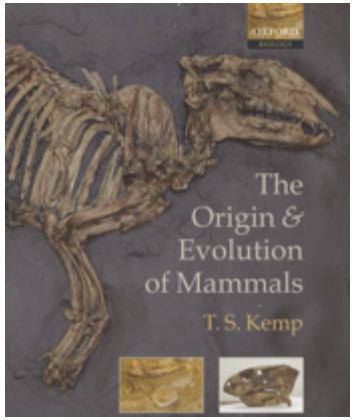
3. Vertebrates as microbe farmers
   - ecological logic
   - farming: nurture and harvest
     Hindgut fermentation – Colonic separation
     Foregut fermentation – Digesta washing

4. Ruminant production and a patent on an evolutionary pattern

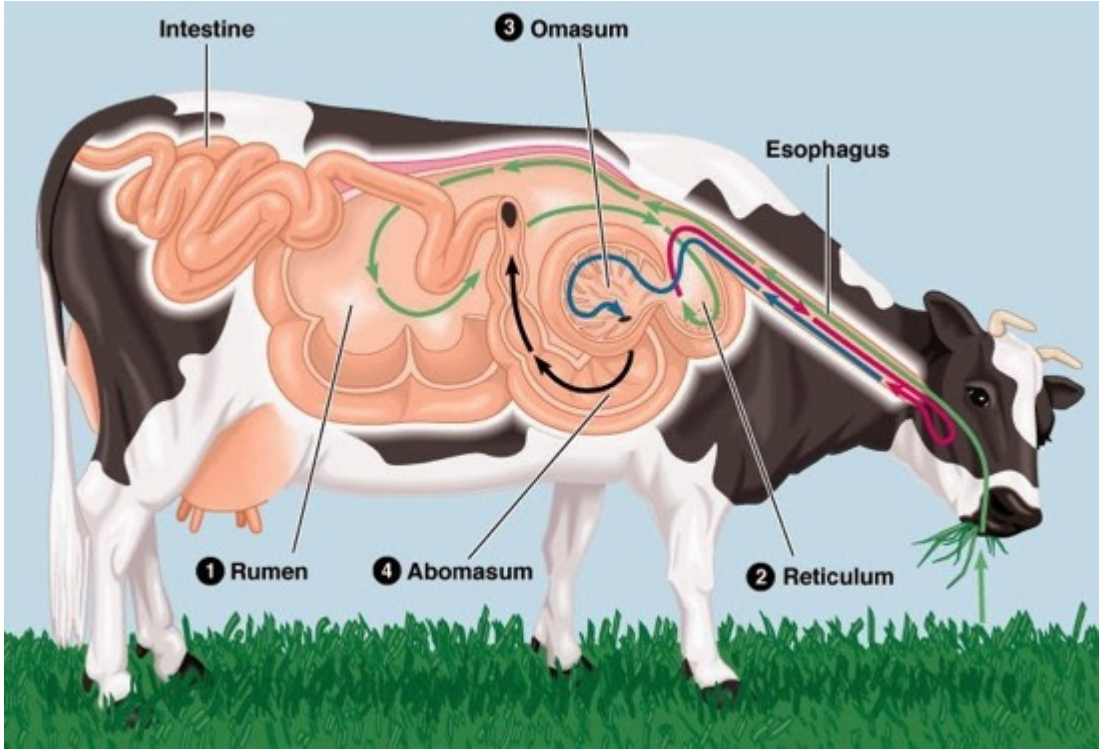
Physiology-centric view



Ecology

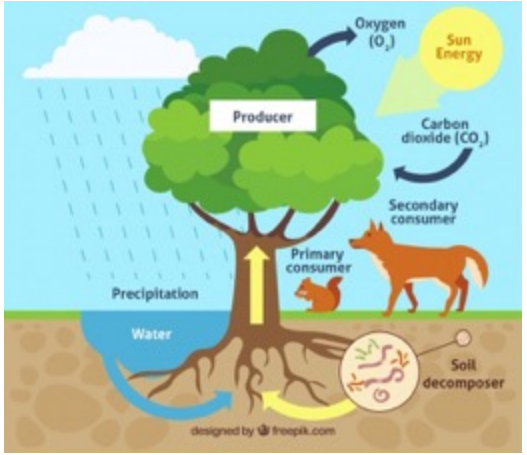


Evolution

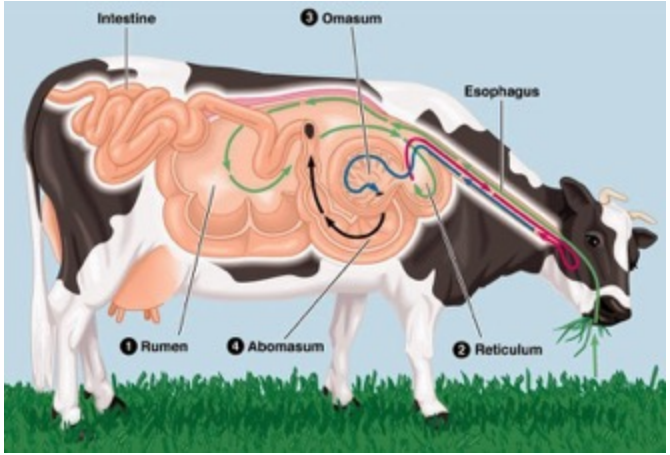


Physiology

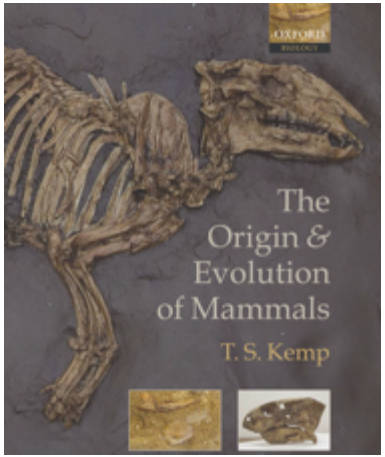
Balanced views



Ecology



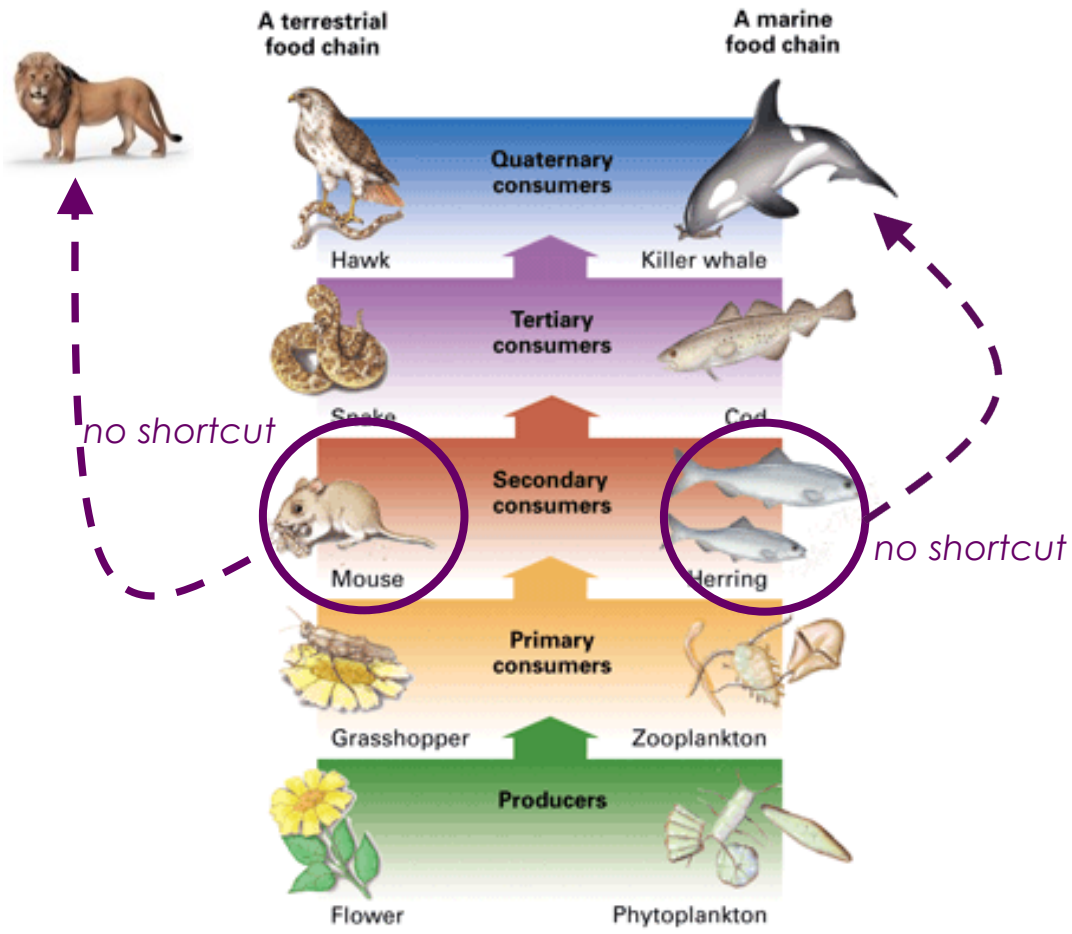
Physiology



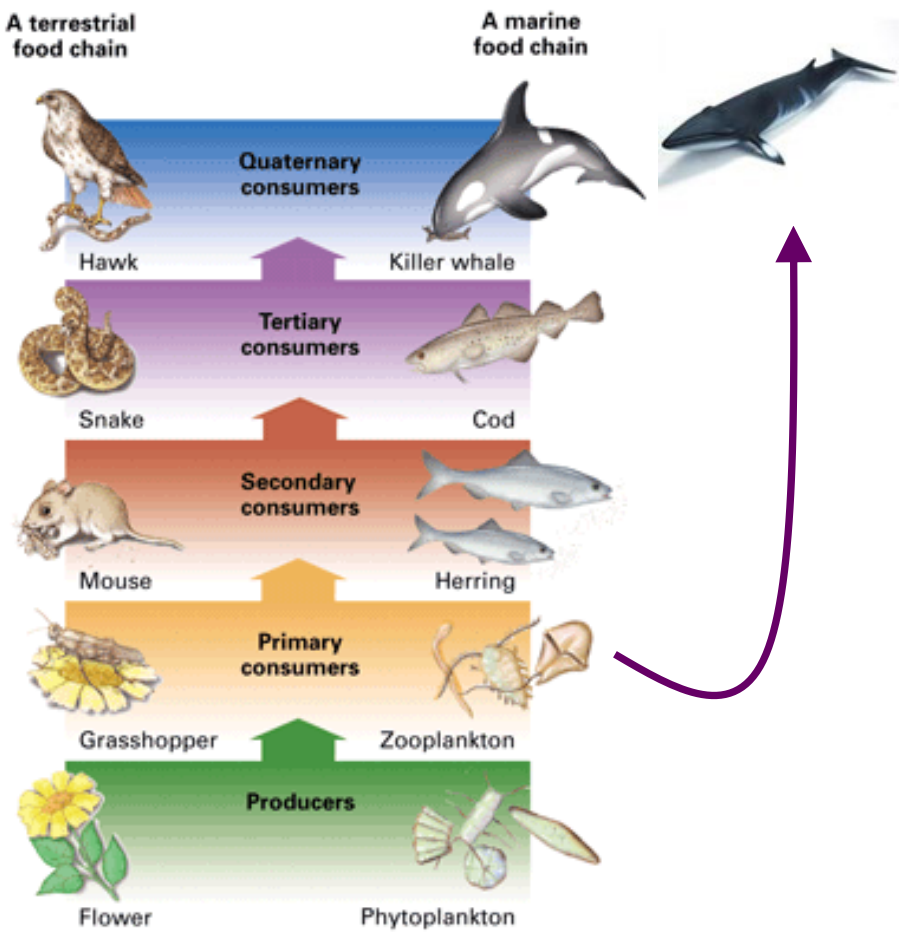
Evolution

'Nutrition' is just an observational science.

Food chains – and shortcuts

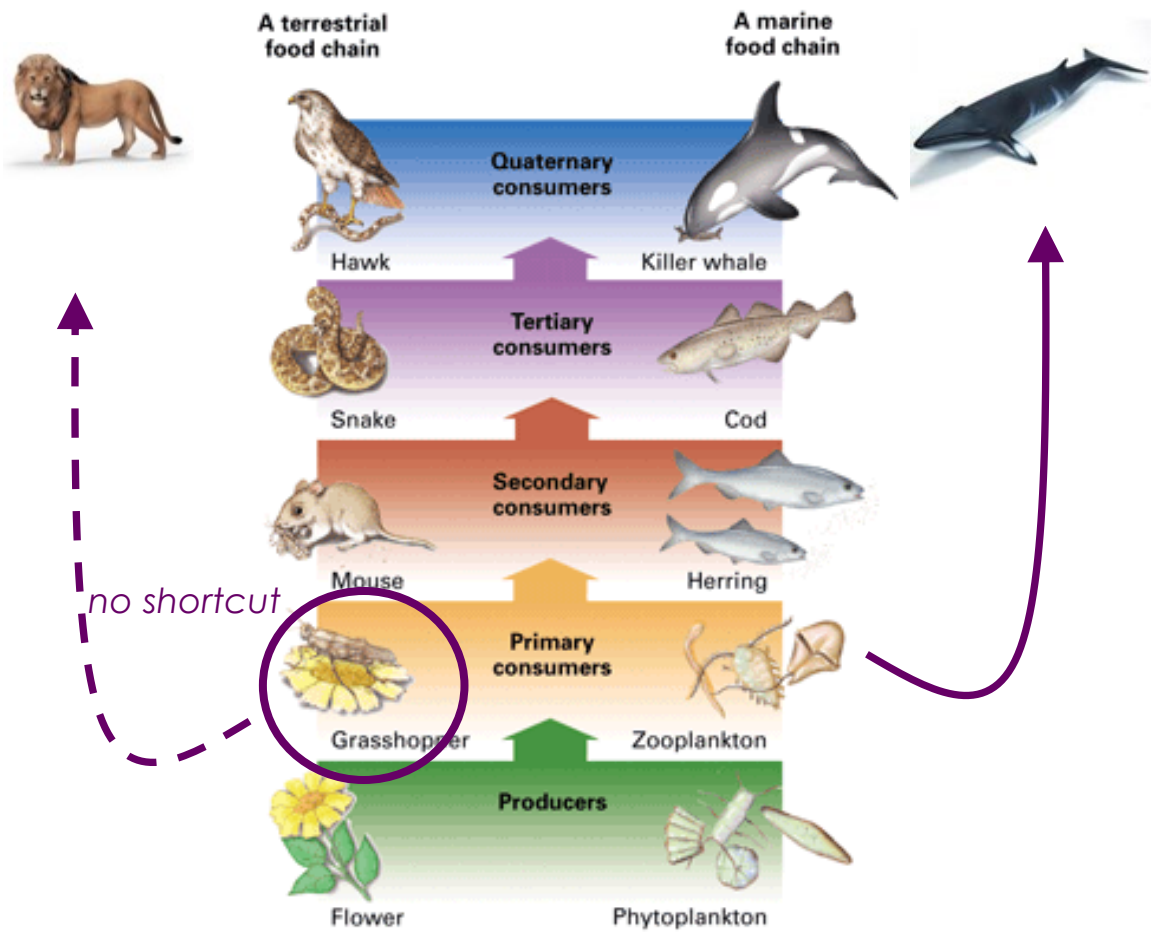


Food chains – and shortcuts



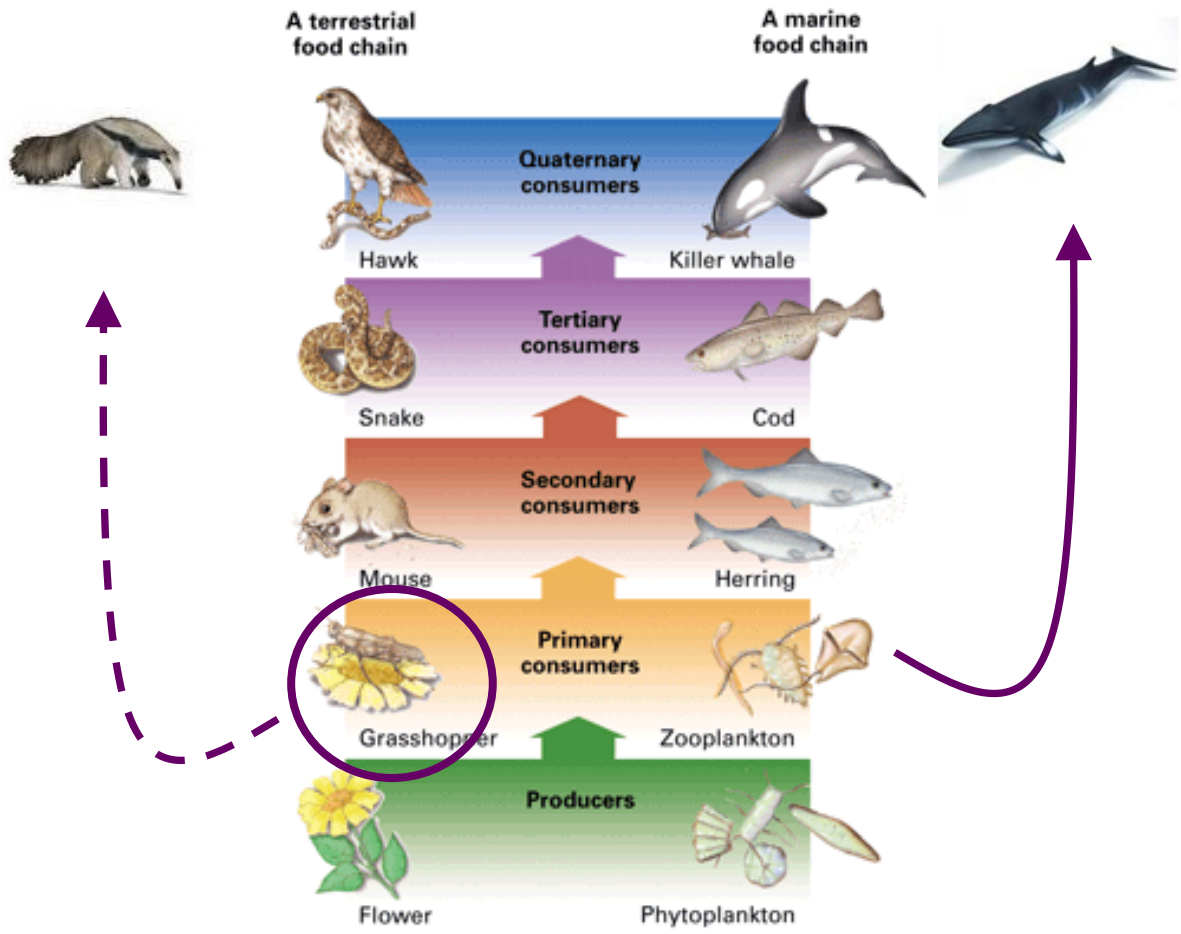
Easy-to-harvest packages of tiny invertebrates – krill clouds

Food chains – and shortcuts

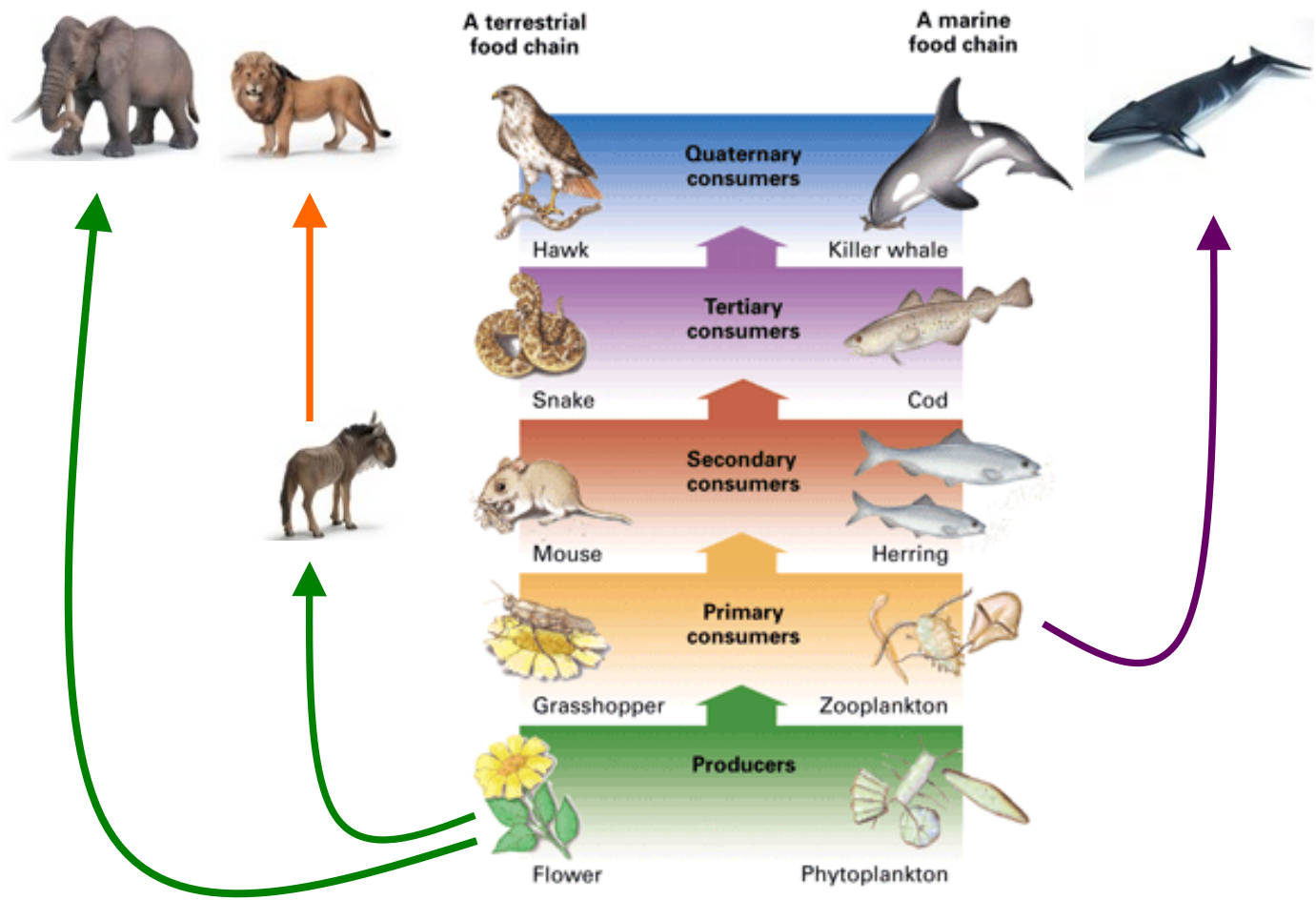


No easy-to-harvest packages of tiny invertebrates

Food chains – and shortcuts

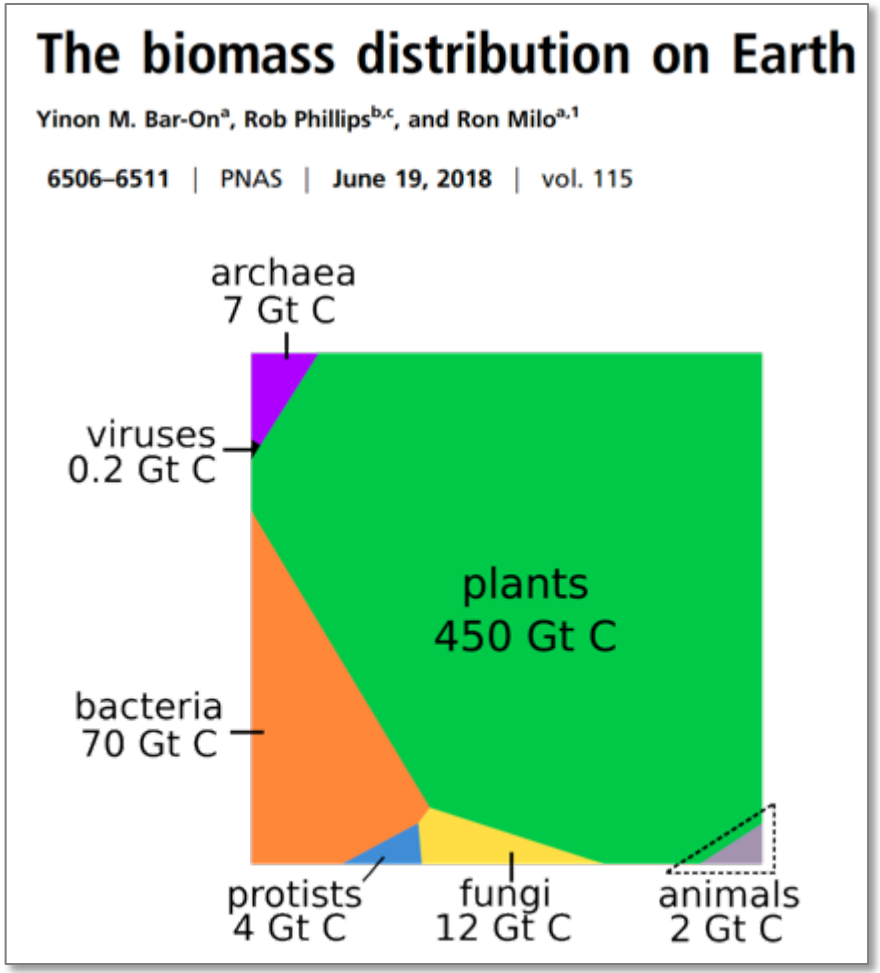


Food chains – and shortcuts

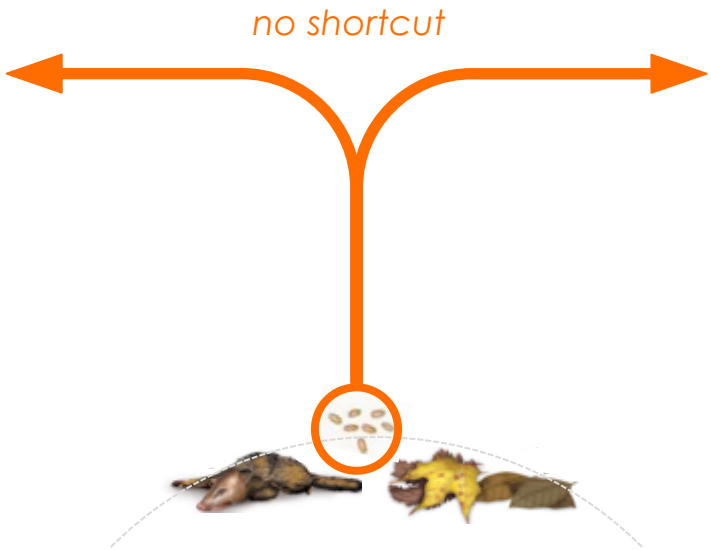


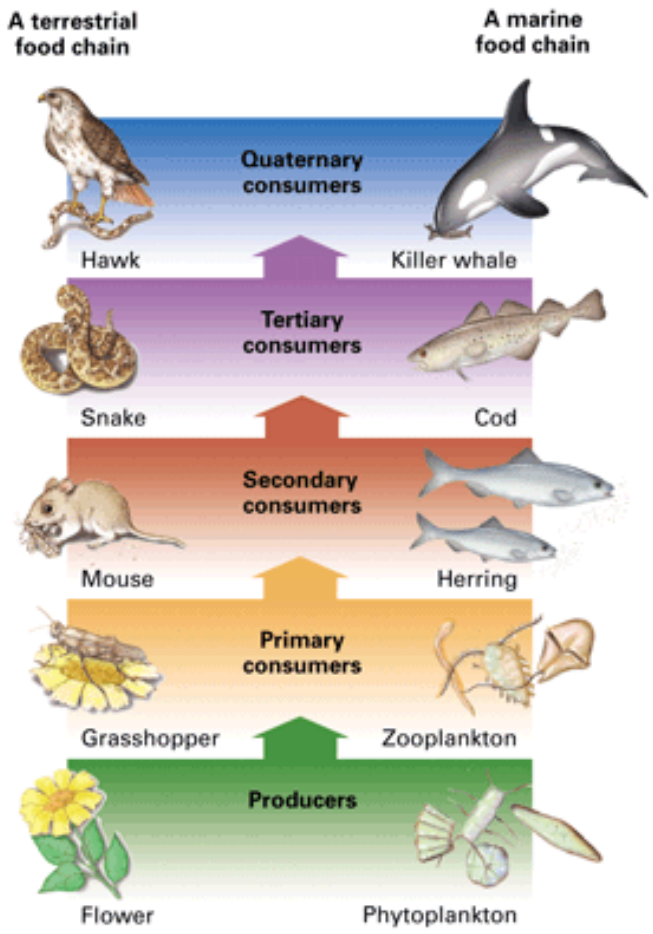
Ubiquitous dense large packages of plant food in terrestrial systems

Food chains – and shortcuts

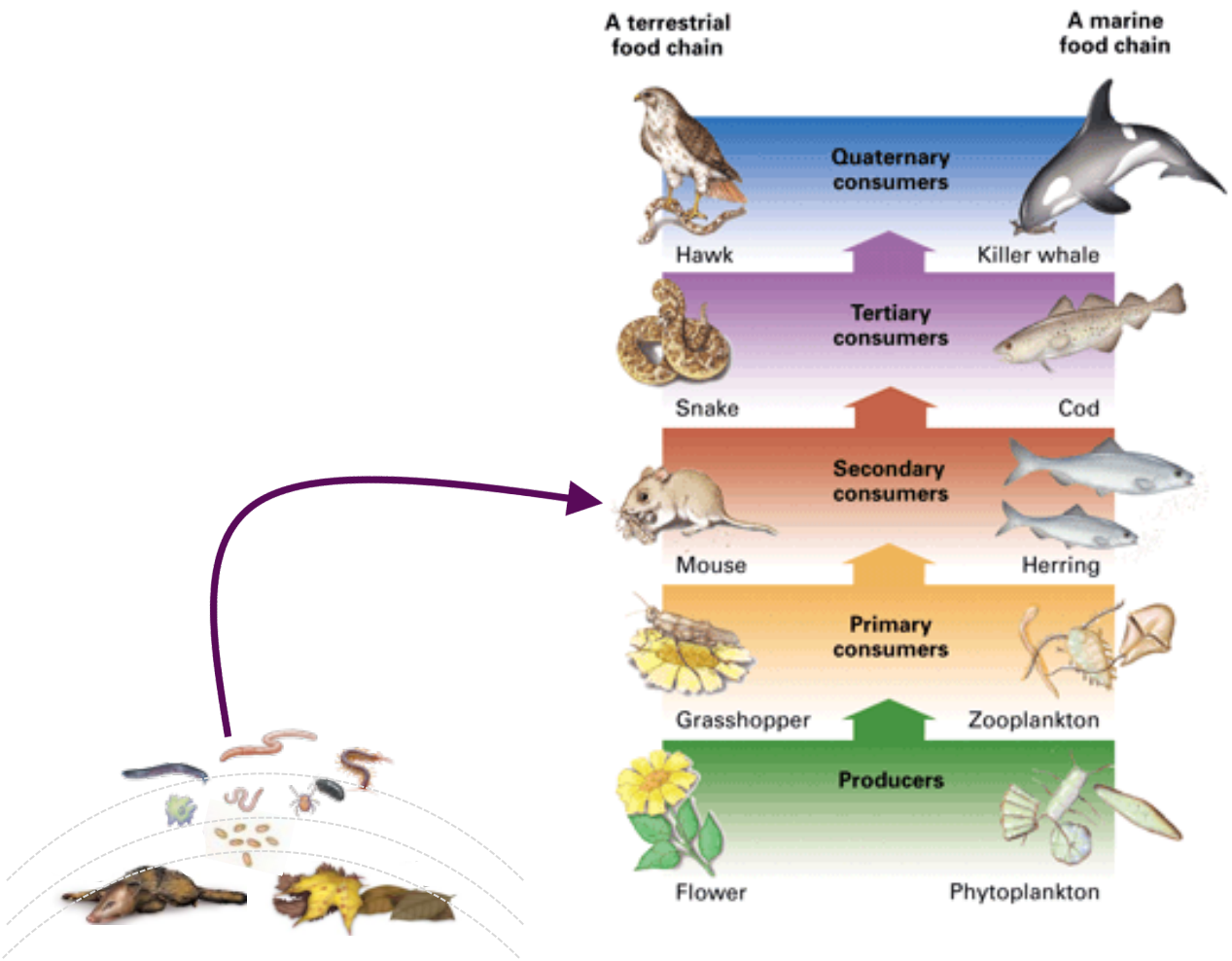


Food chains – and shortcuts





Food chains – and shortcuts



Microbes in the digestive tract

Microbes in the digestive tract

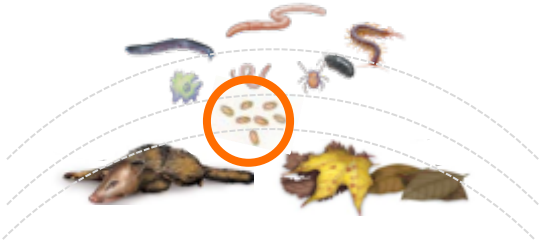
… "*provide a service*":

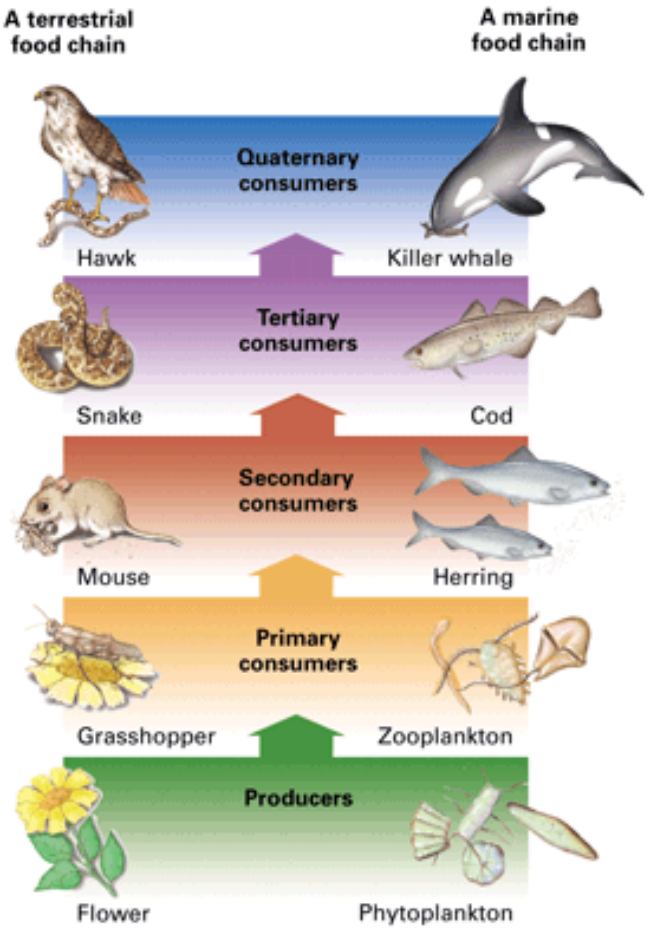
- they 'ferment' carbohydrates and produce volatile fatty acids
- they may detoxify certain substances
- they produce vitamins
- they '*produce microbial protein*'

= microbes are (potential) prey in a trophic chain

Food chains – and shortcuts

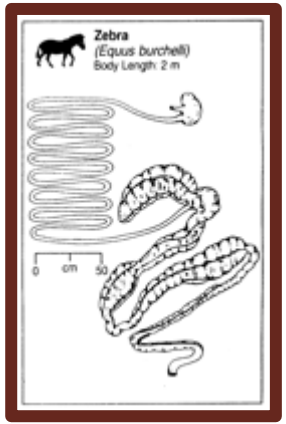
but there is microbe farming



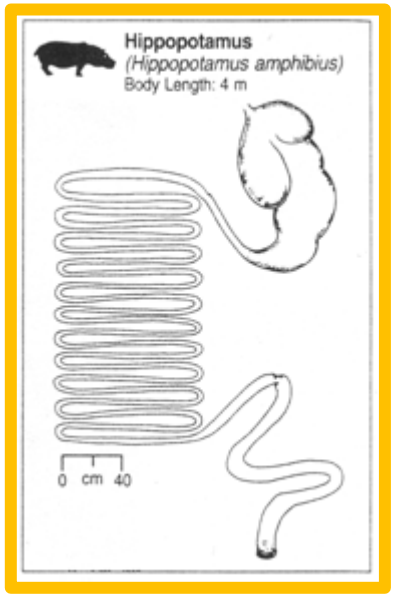


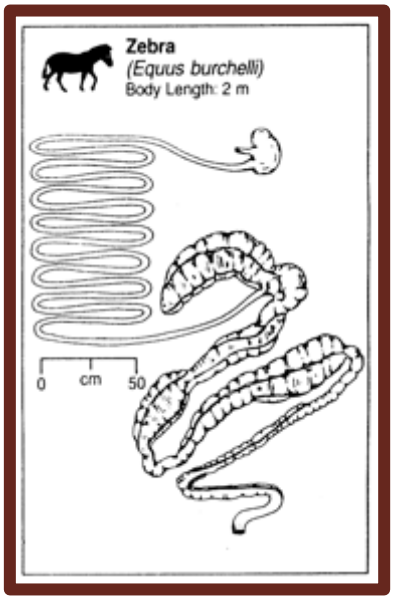
Farming: contain, nurture, harvest

Farming: contain, nurture, harvest



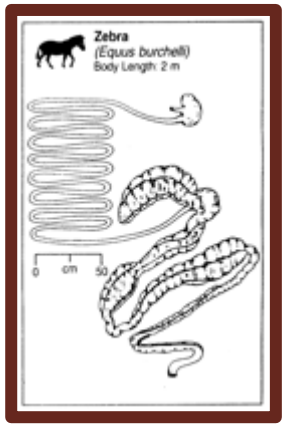
Foregut and hindgut fermenters



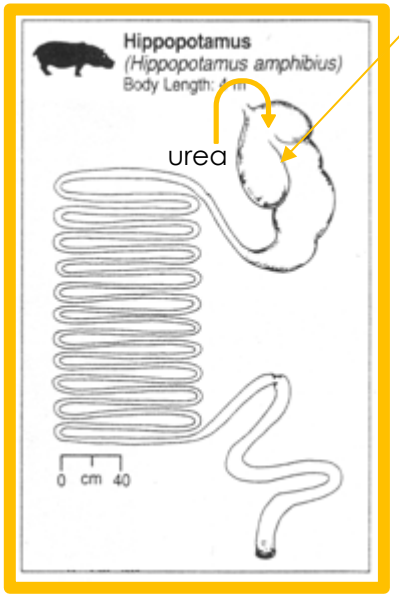


(from Stevens & Hume 1995)

Farming: contain, nurture, harvest

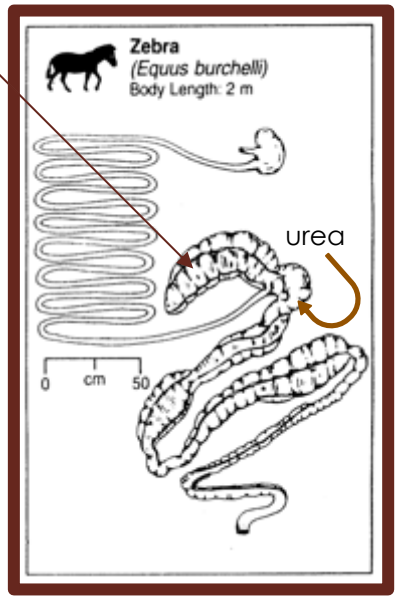


Foregut and hindgut fermenters



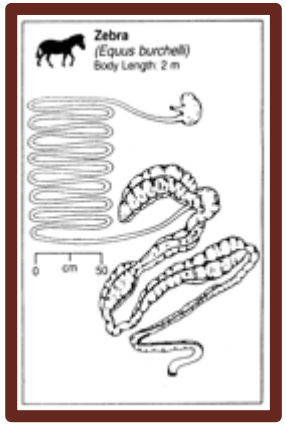
Microbes live and grow by fermenting the diet (rest) ...
... and produce volatile fatty acids

... and are supplied with urea via saliva / blood



(from Stevens & Hume 1995)

Farming: contain, nurture, harvest

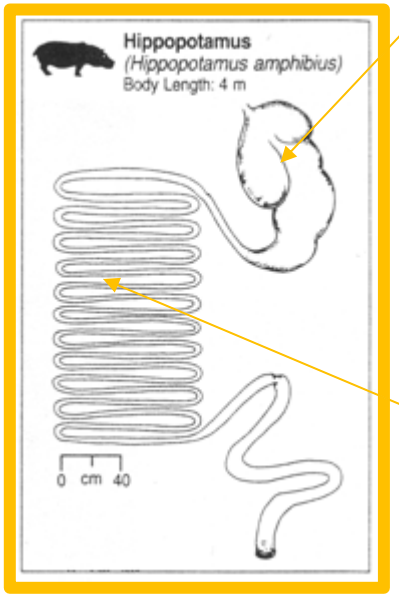


+ supplemental (endogenous) nitrogen

?

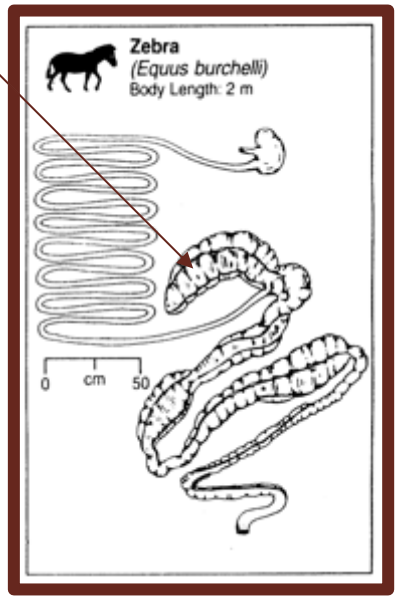
Foregut and hindgut fermenters

Bacteria ferment the diet (rest) ...



... **prior to** small intestine

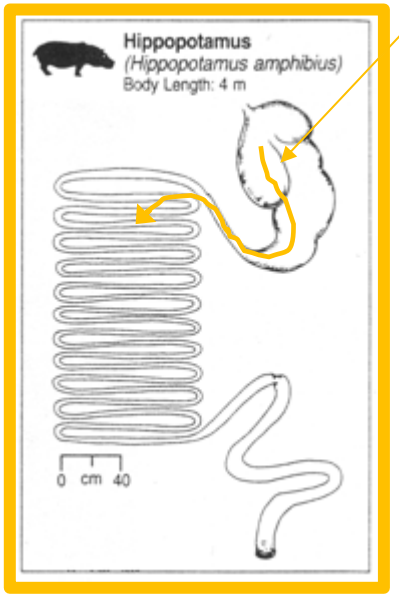
enzymatic digestion of processed material



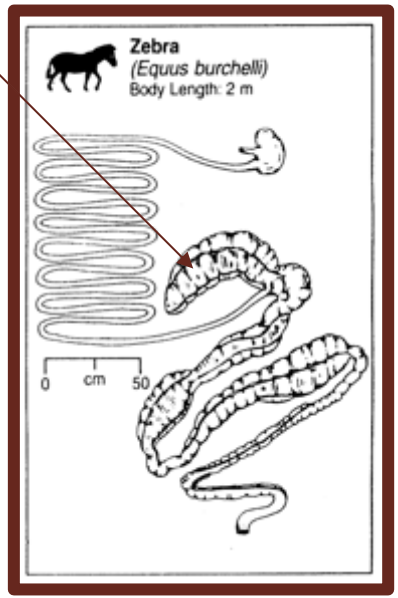
(from Stevens & Hume 1995)

Foregut and hindgut fermenters

Bacteria ferment the diet (rest) ...

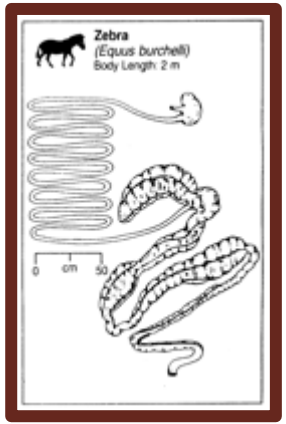


... flow out and are digested



(from Stevens & Hume 1995)

Farming: contain, nurture, harvest

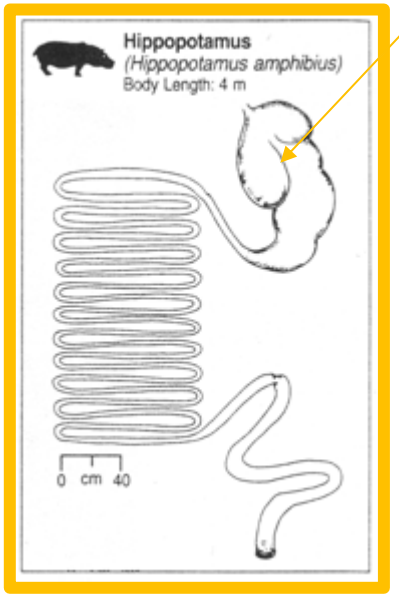


+ supplemental (endogenous) nitrogen

no effort required ?

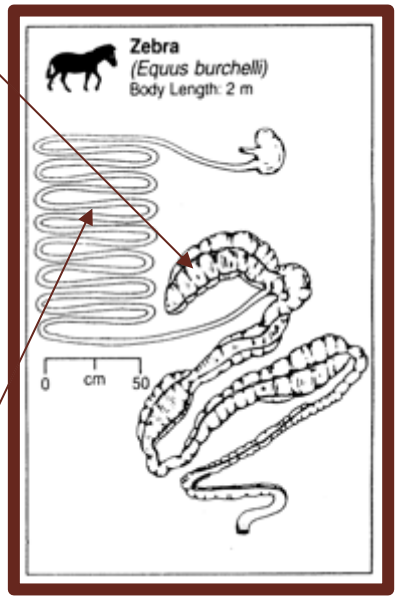
Foregut and hindgut fermenters

Bacteria ferment the diet (rest) ...



... **after** small intestine

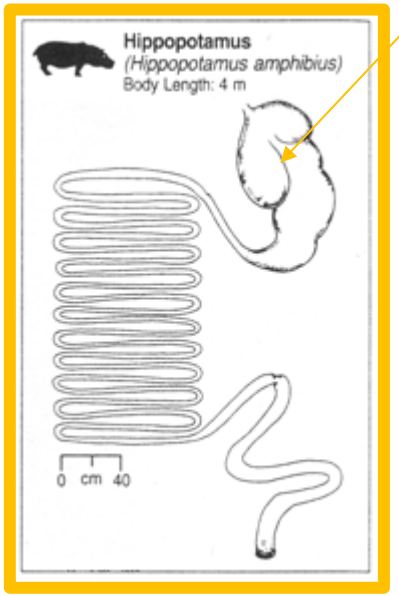
enzymatic digestion of diet

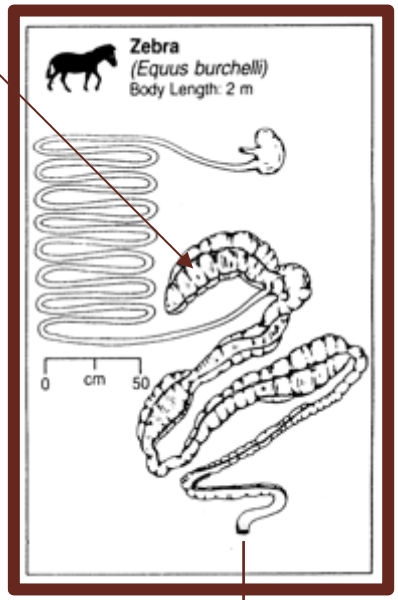


(from Stevens & Hume 1995)

Foregut and hindgut fermenters

Bacteria ferment the diet (rest) ...

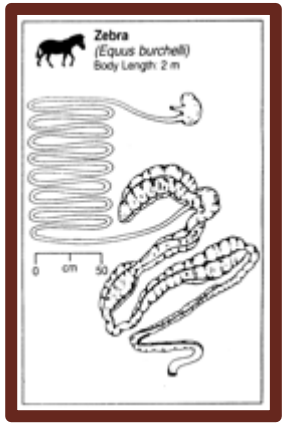




... and are excreted

(from Stevens & Hume 1995)

Farming: contain, nurture, harvest

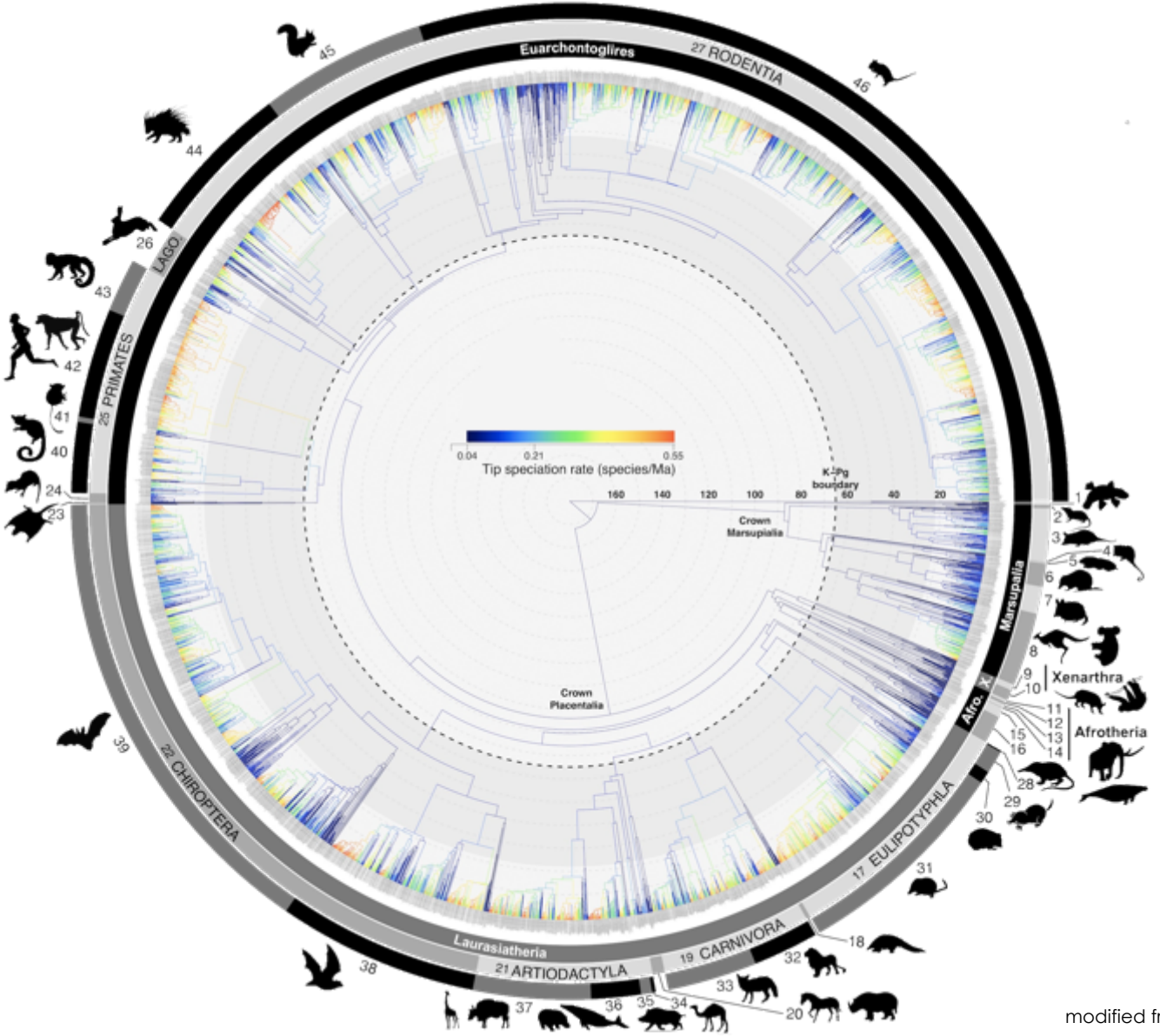


+ supplemental (endogenous) nitrogen

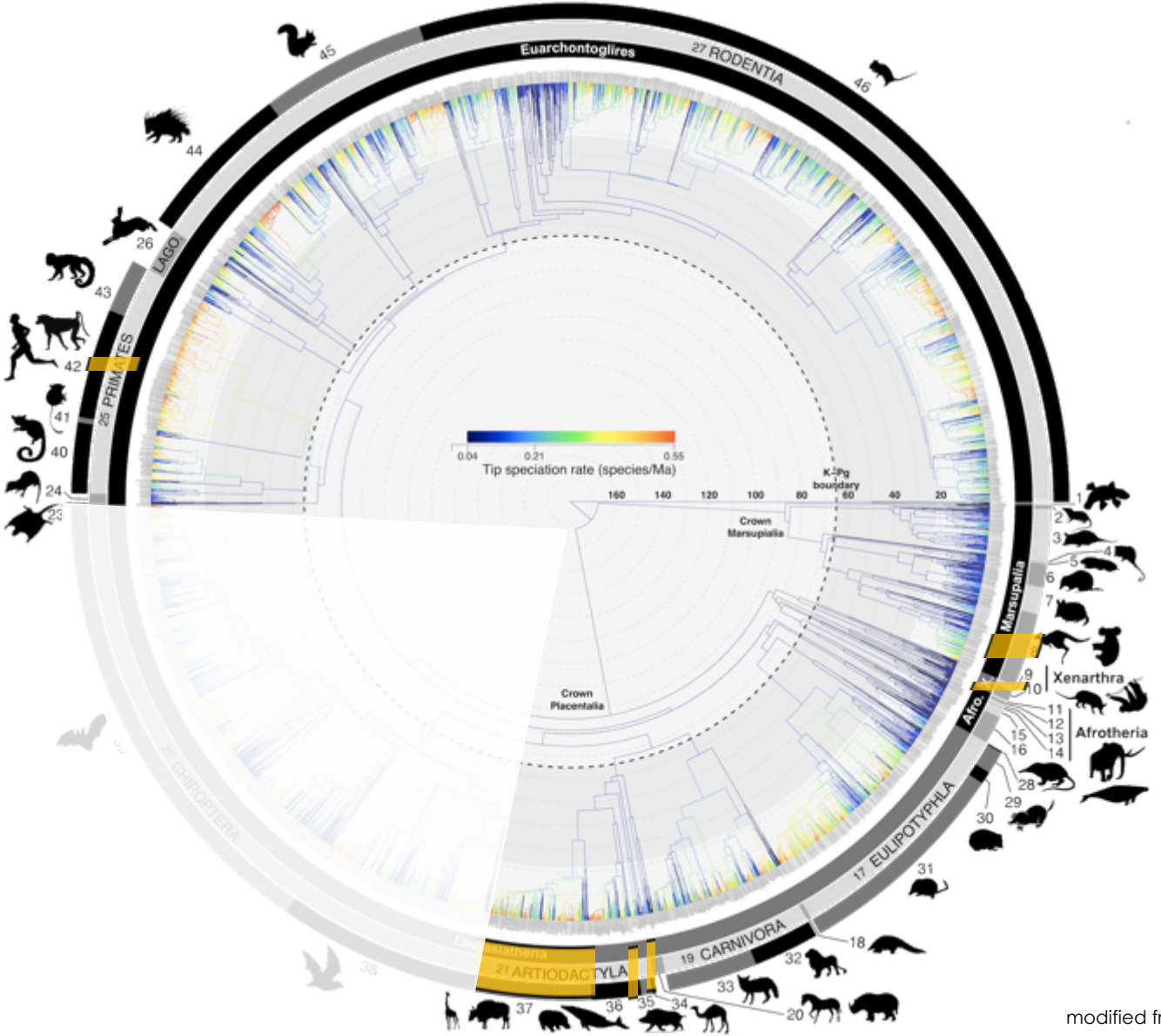
no effort required ?

not possible ?

Extraction not possible

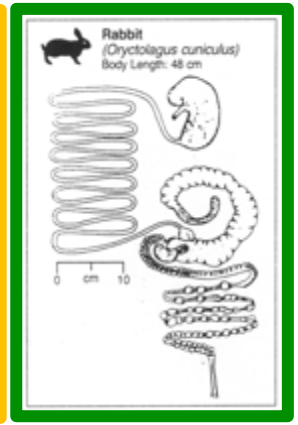


modified from Upham et al. (2019)



modified from Upham et al. (2019)

Farming: contain, nurture, harvest



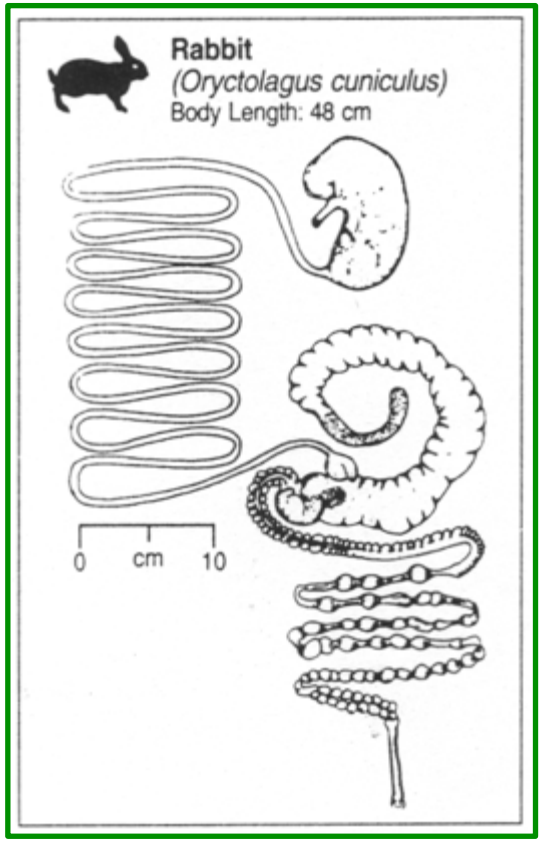
+ supplemental (endogenous) nitrogen

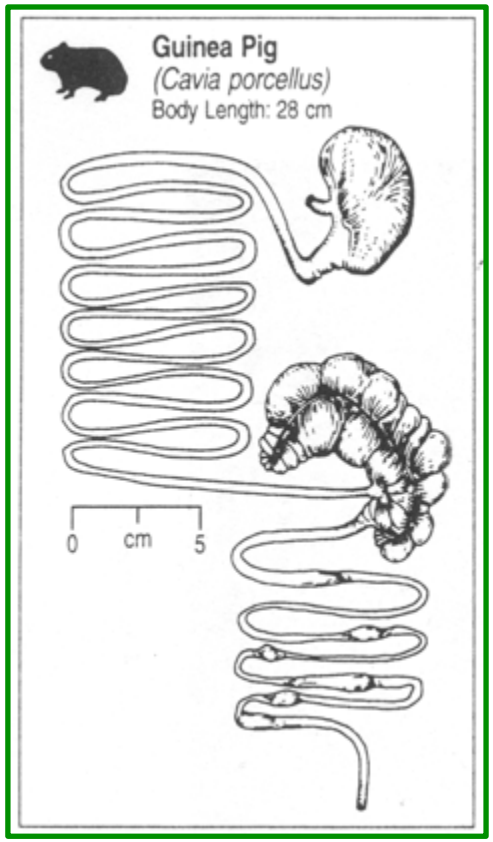
no effort required ?

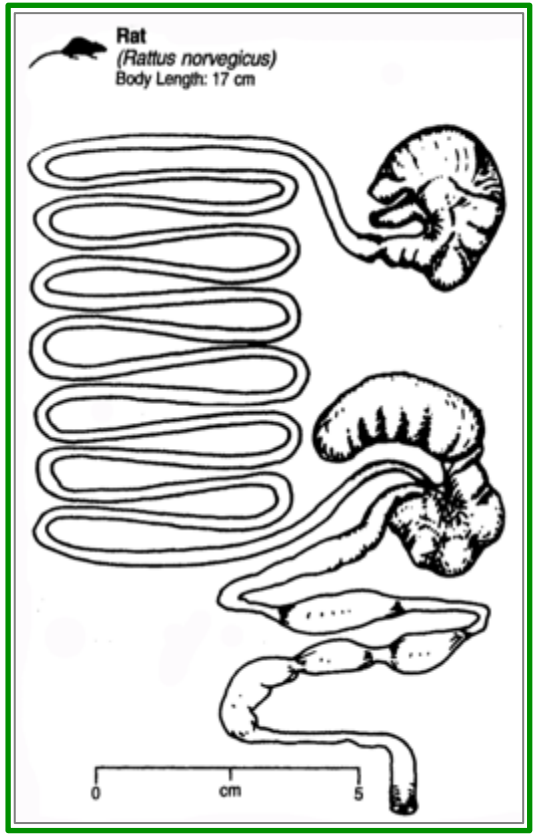
really not possible ?

Extraction not possible ?

Small hindgut fermenters







from Stevens und Hume (1995)

Separating ‘soft’ and ‘hard’ faeces

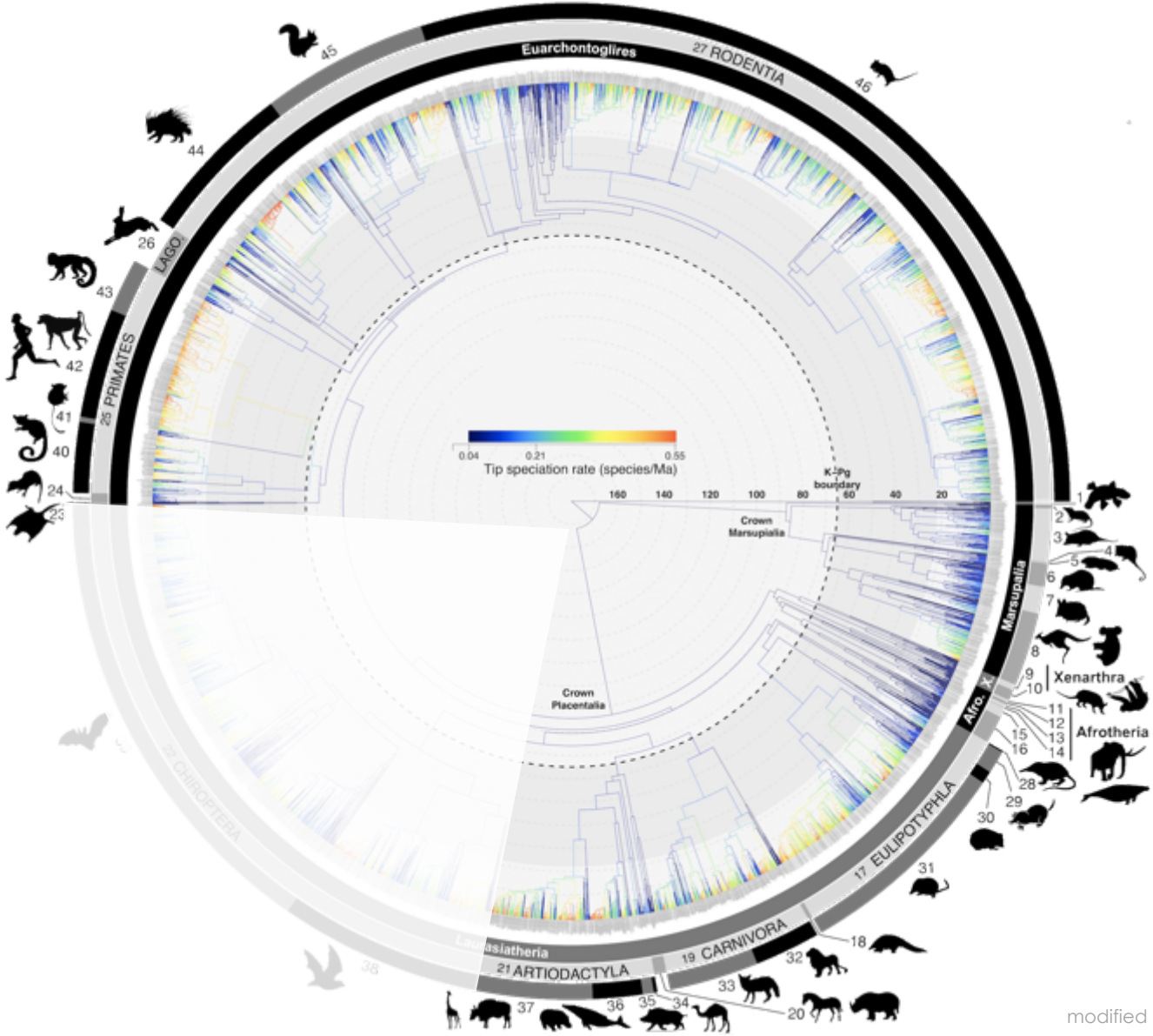
“Colonic separation mechanism”

more microbial matter,
measurable as protein

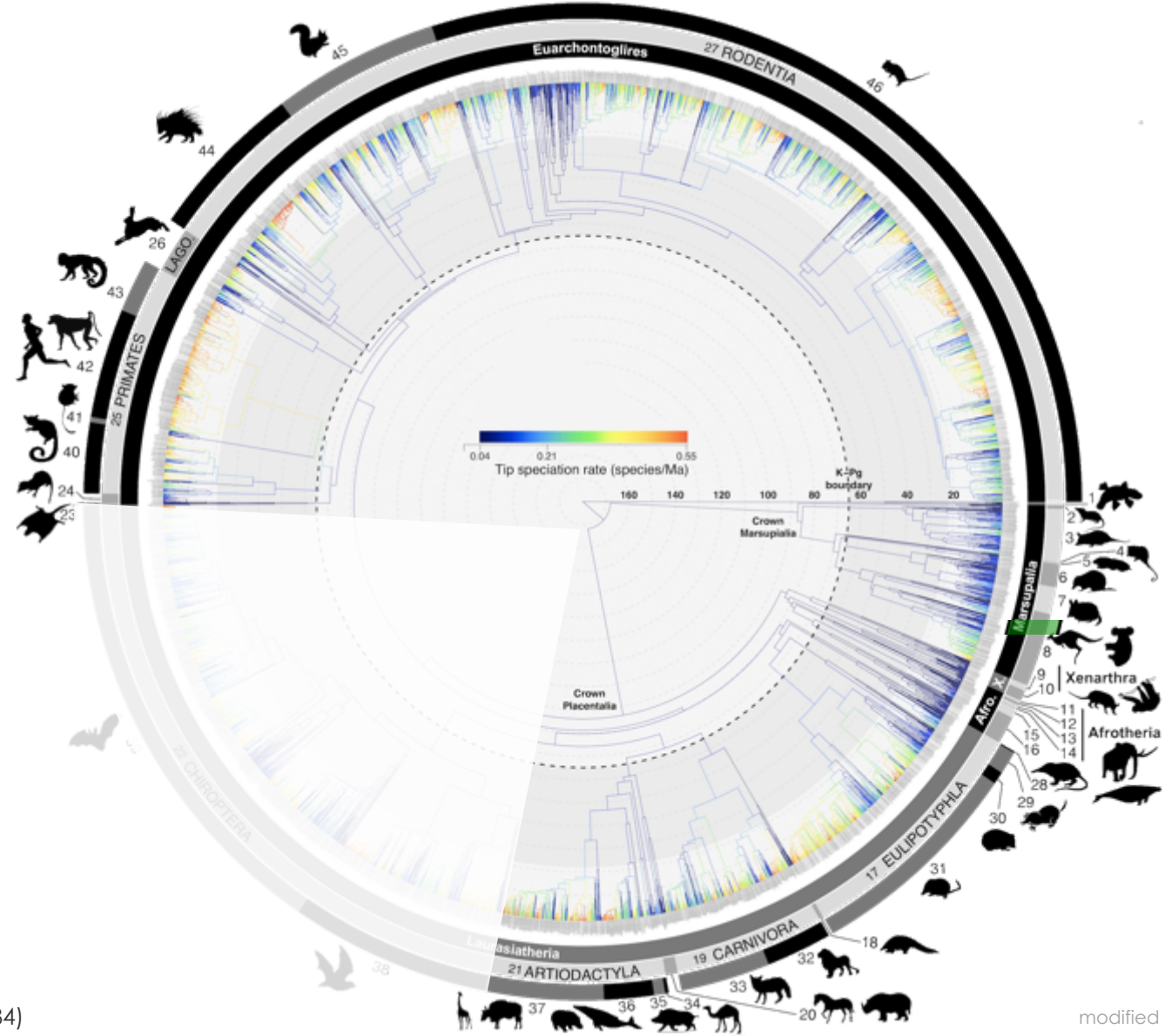
more indigestible material,
especially fibre

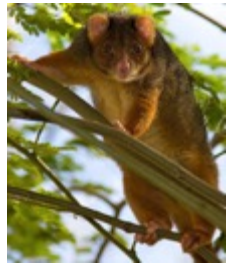
Separating ‘soft’ and ‘hard’ faeces

Chilcott (1984), Takahashi & Sakaguchi (1998), Martino et al. (2007), Mendes and Nogueira-Filho (2013), Aldrigui et al. (2018)



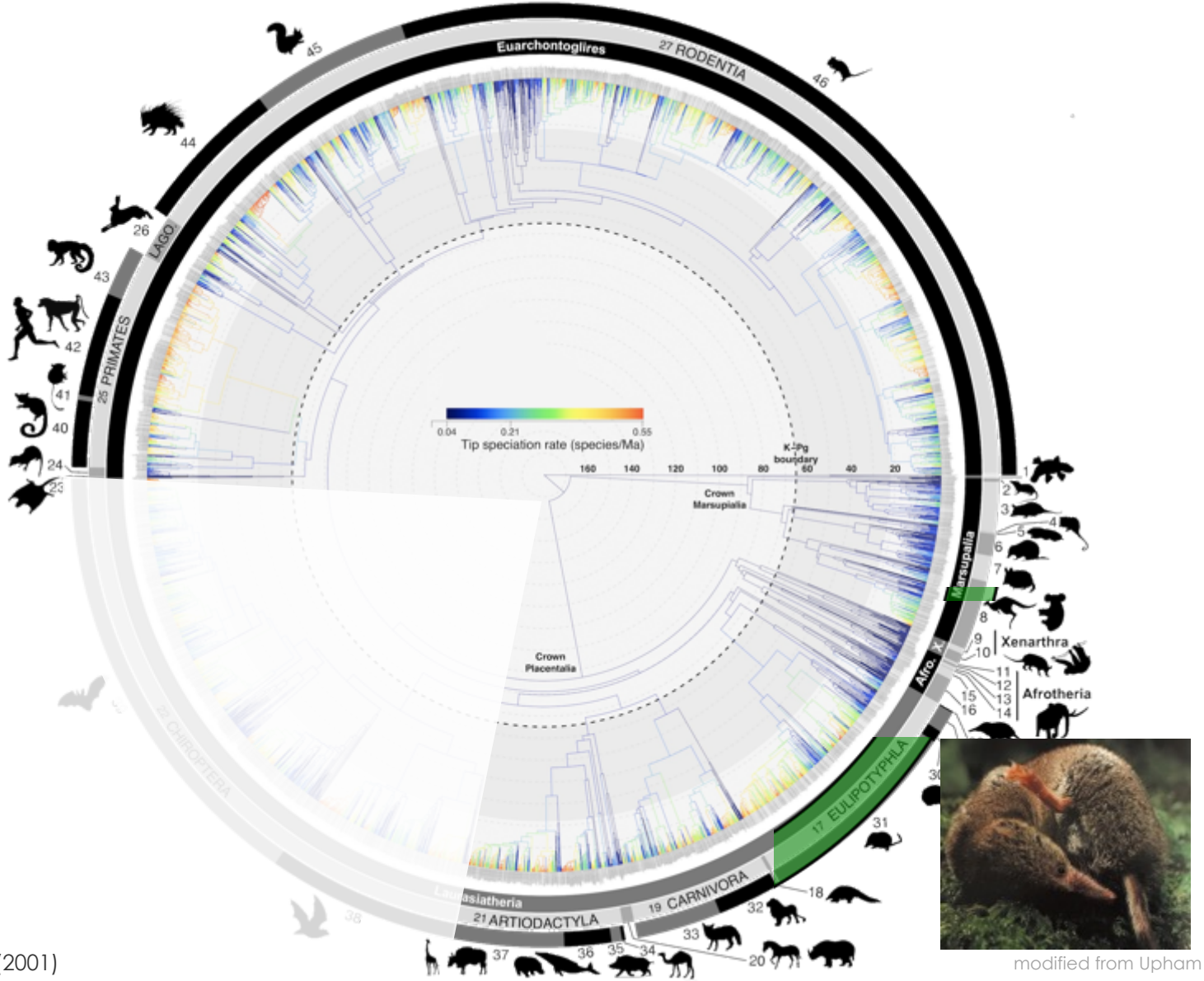
modified from Upham et al. (2019)





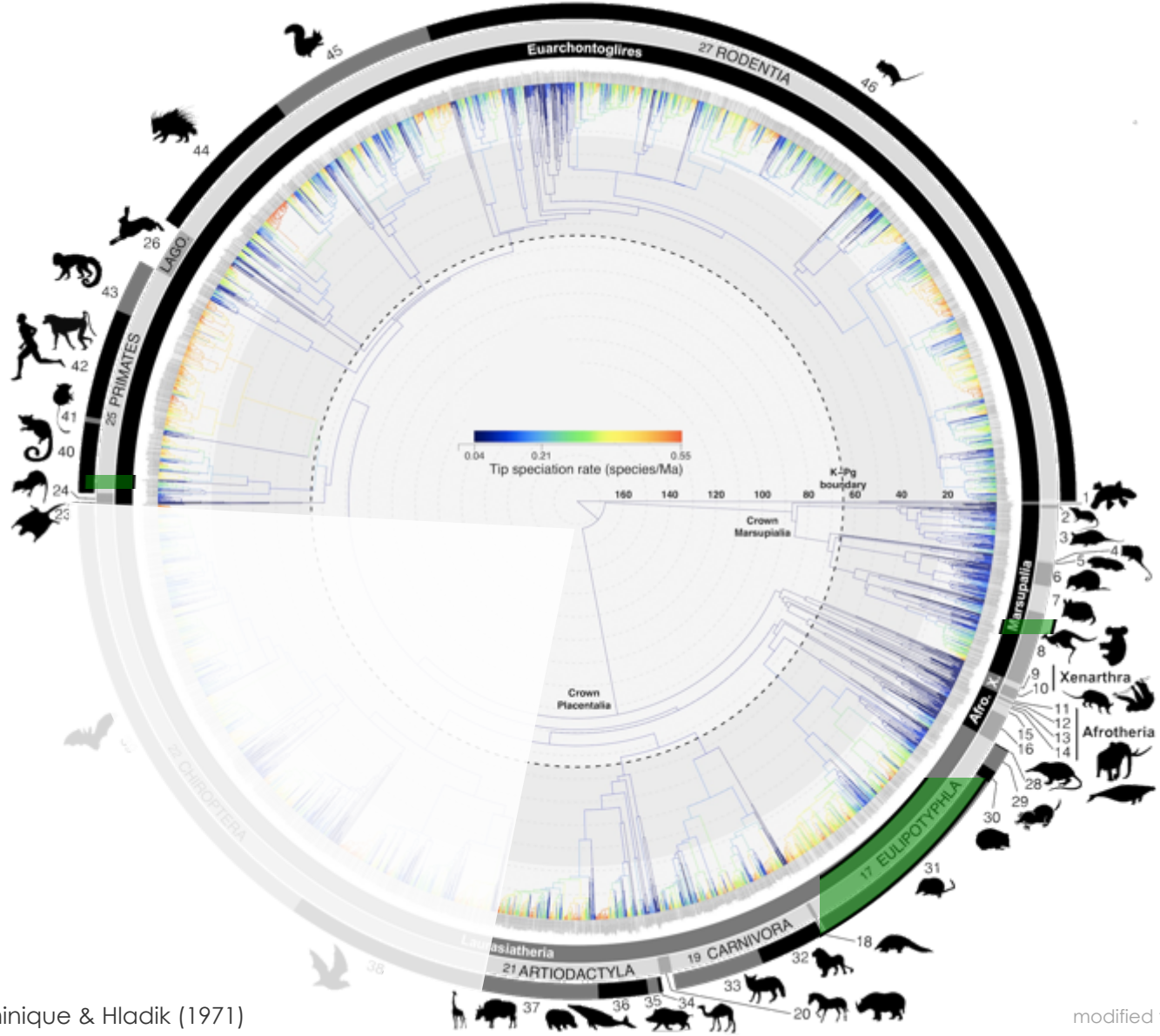
Chilcott (1984)

modified from Upham et al. (2019)



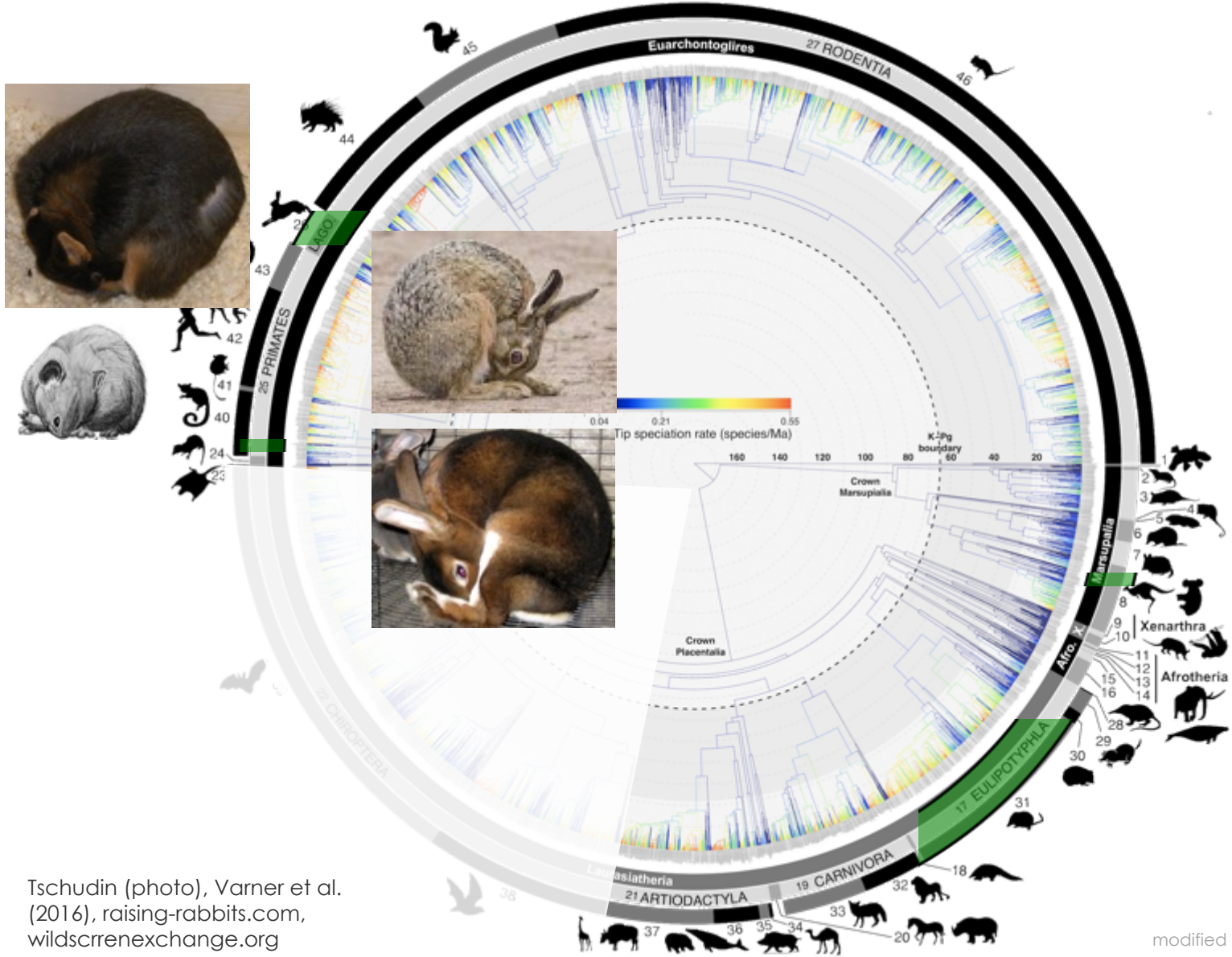
Macdonald (2001)

modified from Upham et al. (2019)



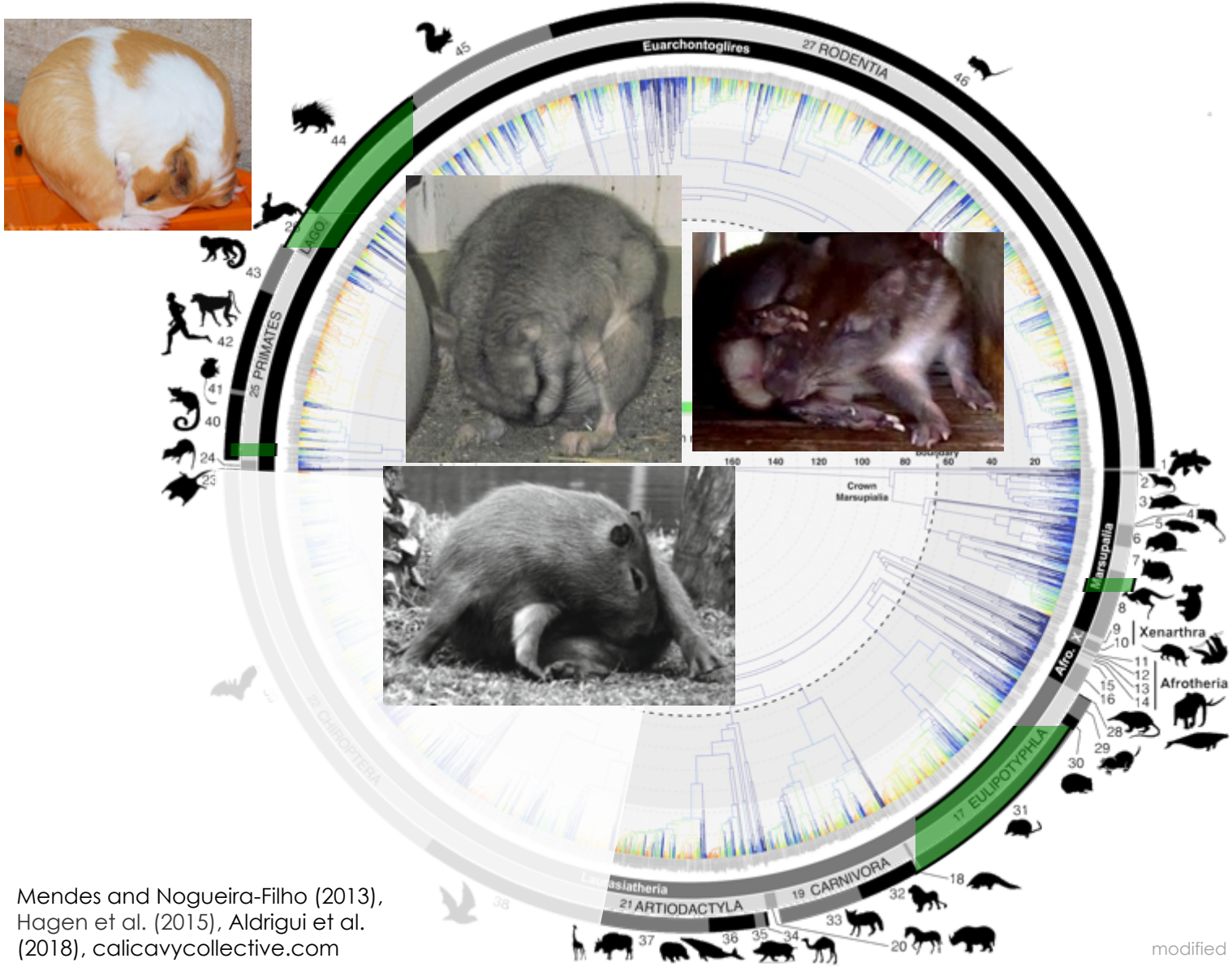
Charles-Dominique & Hladik (1971)

modified from Upham et al. (2019)



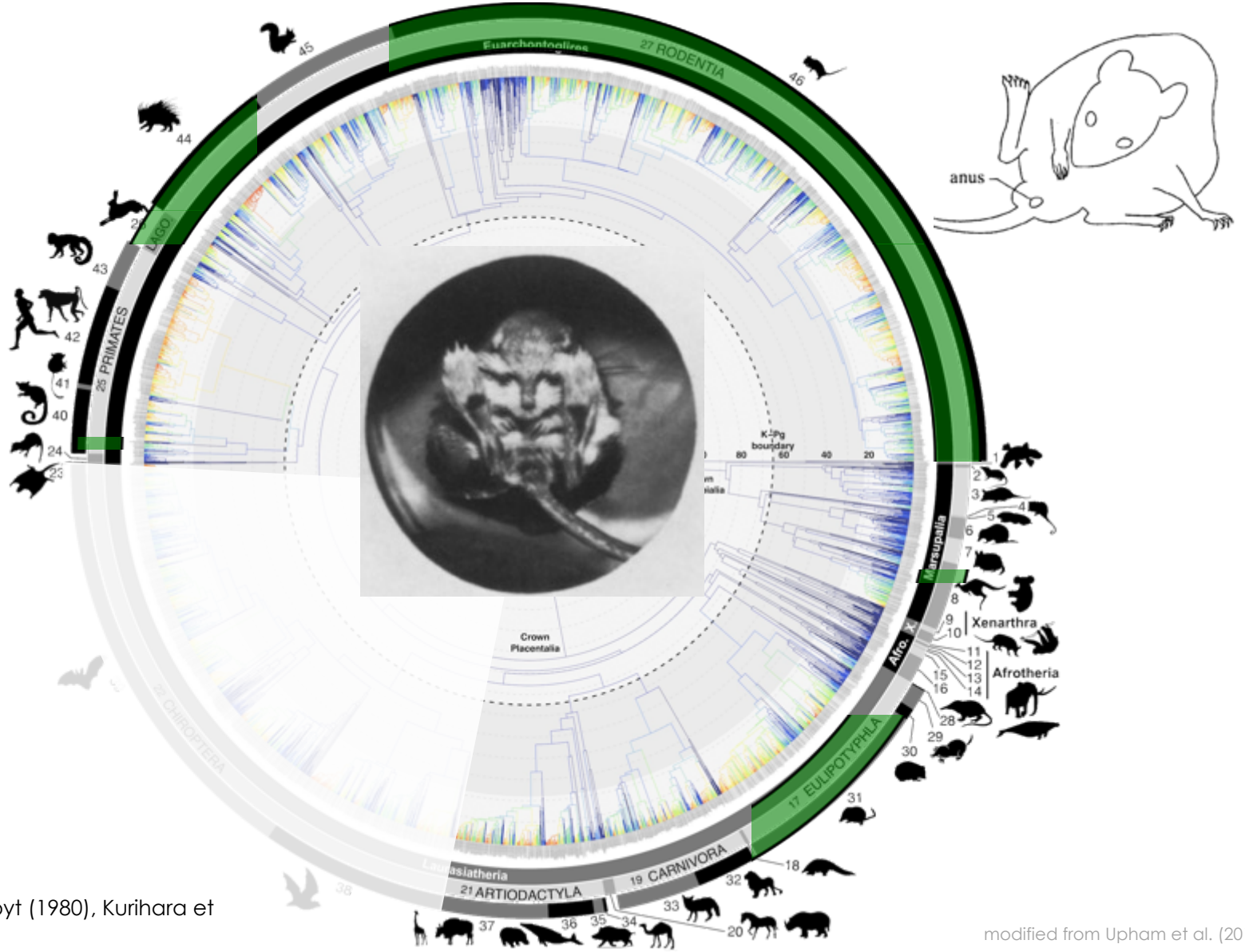
Tschudin (photo), Varner et al. (2016), raising-rabbits.com, wildscrrenexchange.org

modified from Upham et al. (2019)



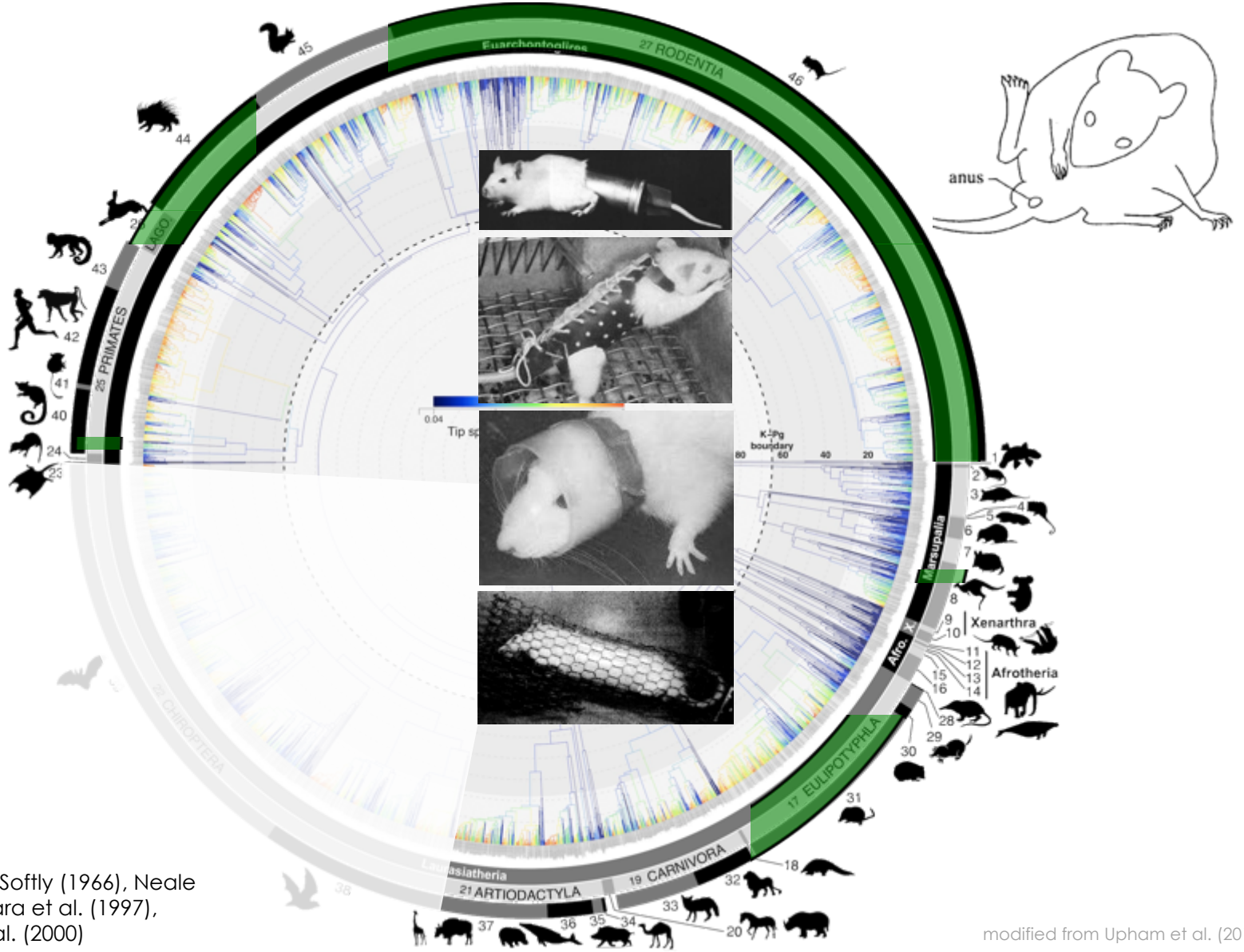
Mendes and Nogueira-Filho (2013), Hagen et al. (2015), Aldrigui et al. (2018), calicavycollective.com

modified from Upham et al. (2019)



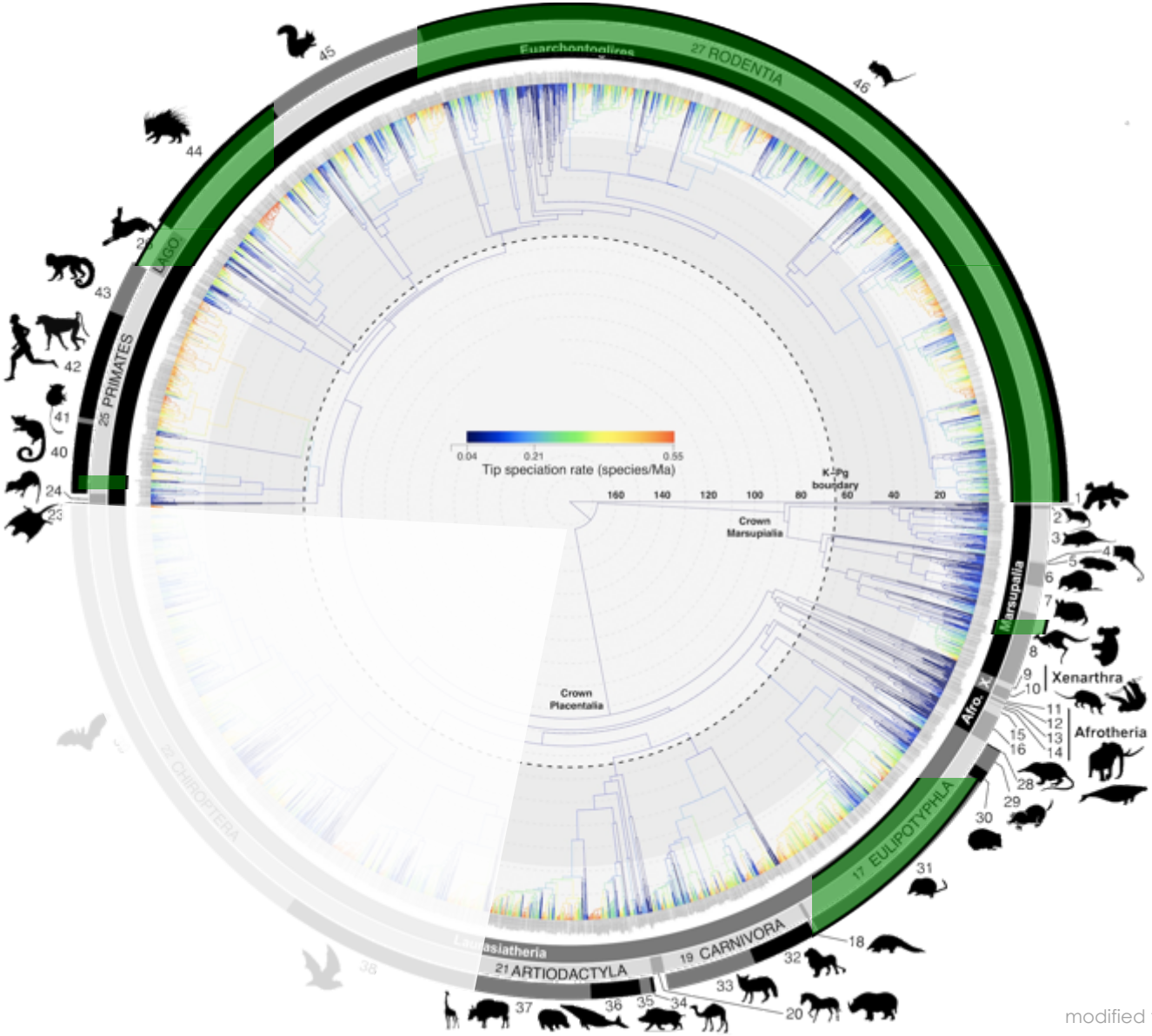
Kenagy & Hoyt (1980), Kurihara et al. (1997)

modified from Upham et al. (2019)



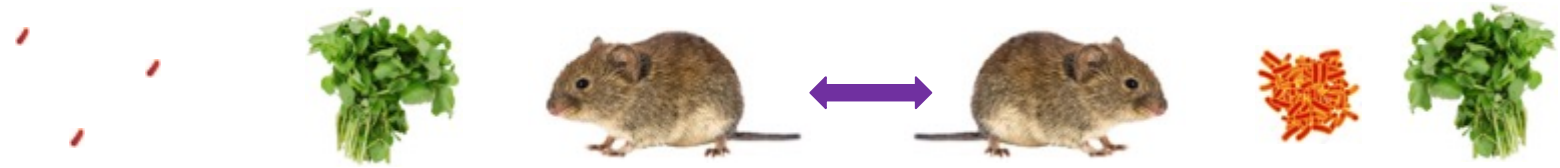
Armstrong & Softly (1966), Neale (1994), Kurihara et al. (1997), Sukemori et al. (2000)

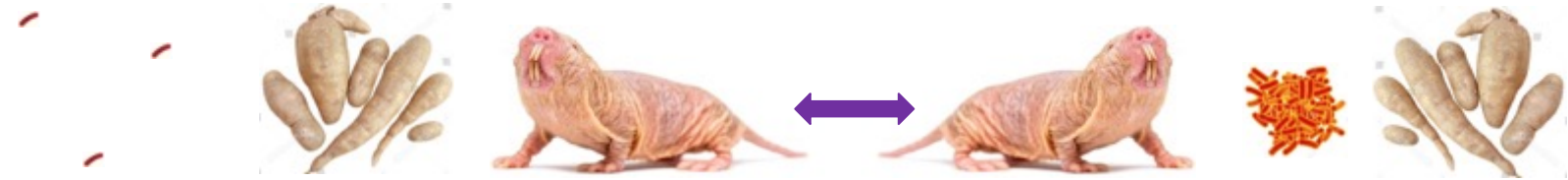
modified from Upham et al. (2019)

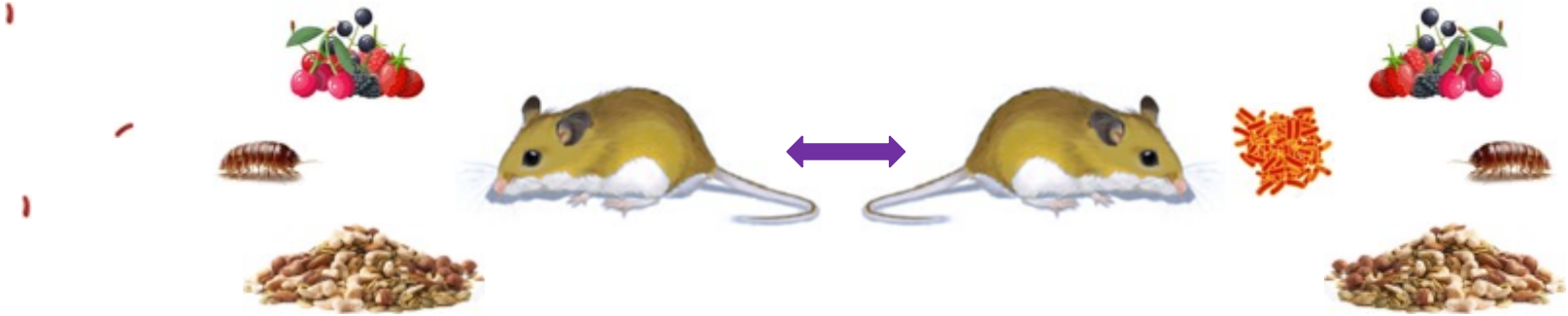


modified from Upham et al. (2019)

Expanded menus: an ecological opportunity

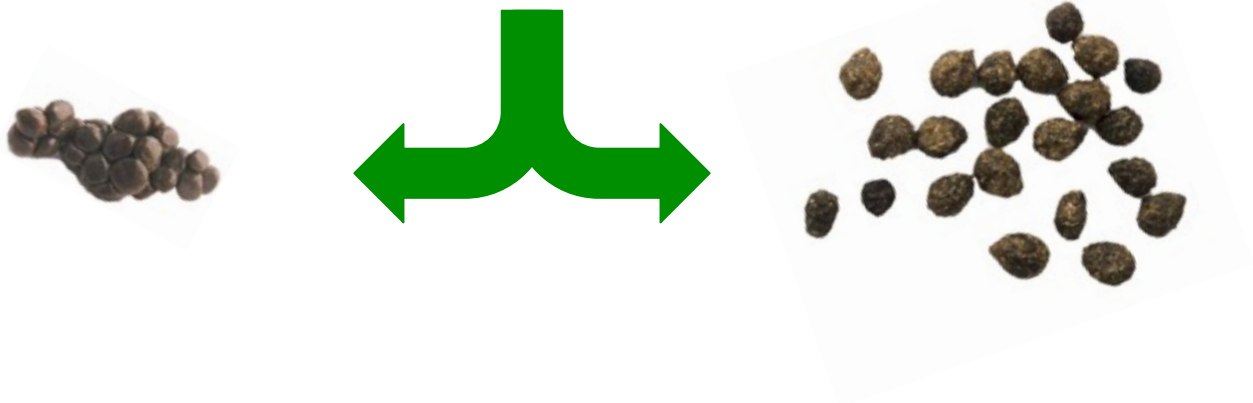


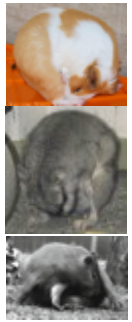


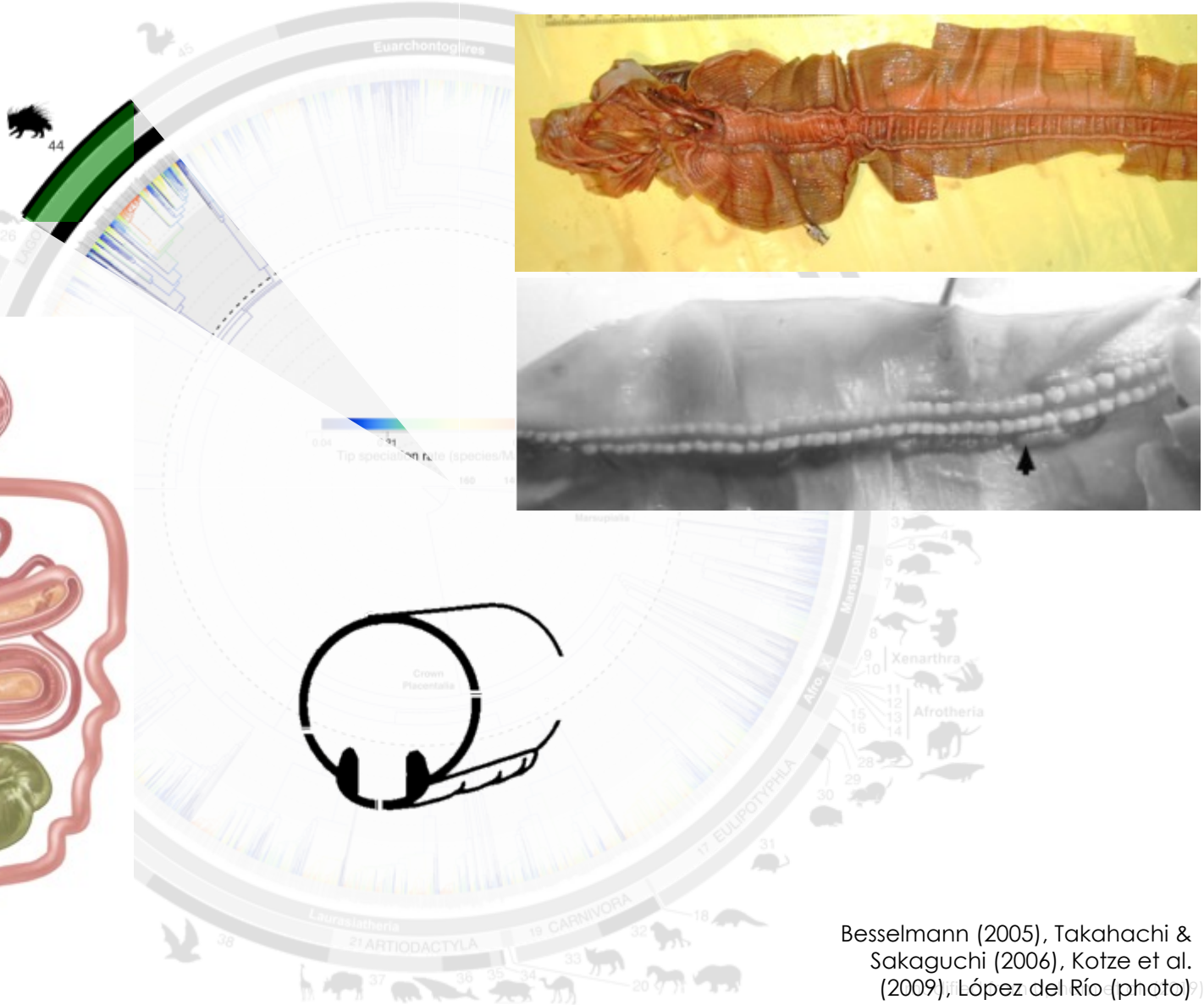


How is the separation achieved ?

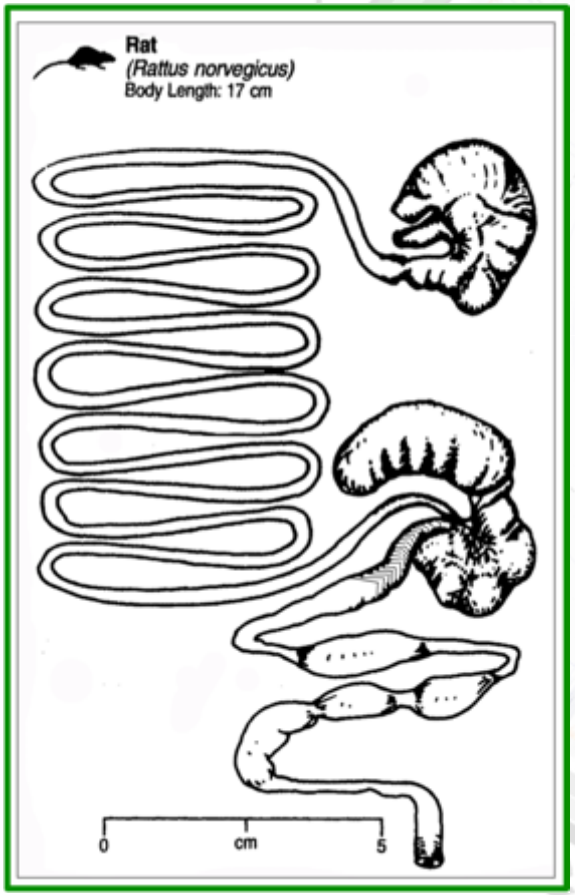
"Colonic separation mechanism"

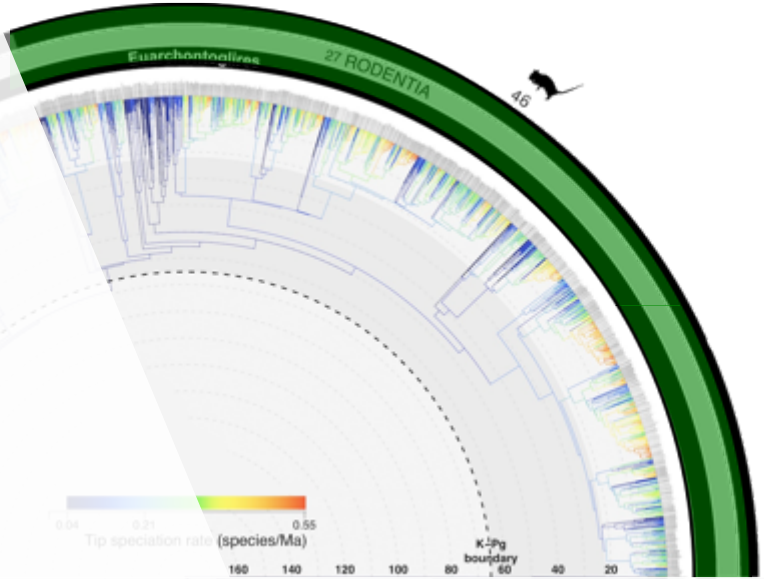


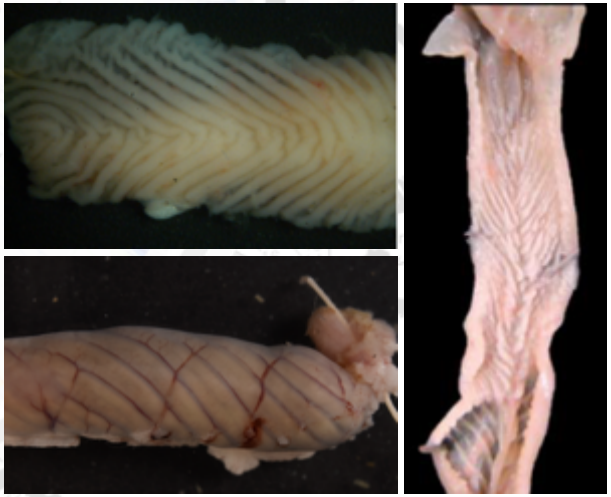




Besselmann (2005), Takahachi & Sakaguchi (2006), Kotze et al. (2009), López del Río (photo)



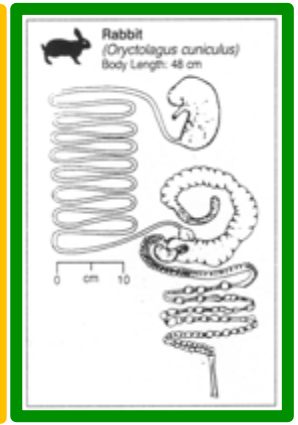




Stevens & Hume (1995), Sahd et al. (2017), Martin (photo)

Ehrlein et al. (1983), Stevens & Hume (1995)

Farming: contain, nurture, harvest



+ supplemental (endogenous) nitrogen

no effort required ?

feasible at small body size

(and few extant small species do ***not*** do it)

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+ supplemental (endogenous) nitrogen

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How do you increase the yield of a growing system ?

How do you increase the yield of a growing system ?

How do you increase the yield of a growing system ?

How do you increase the yield of a growing system ?

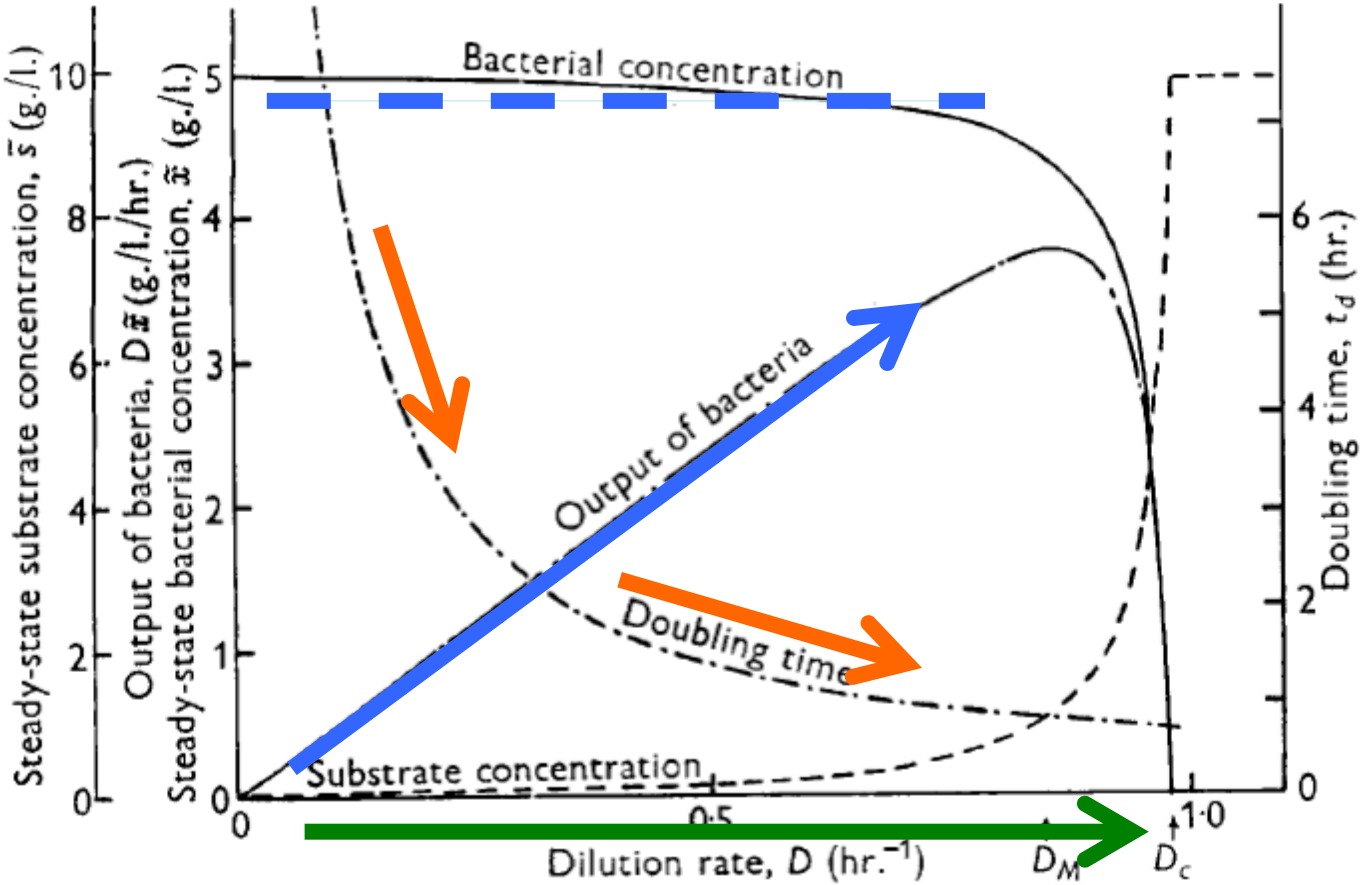
frequent harvest to keep the population in the growth stage

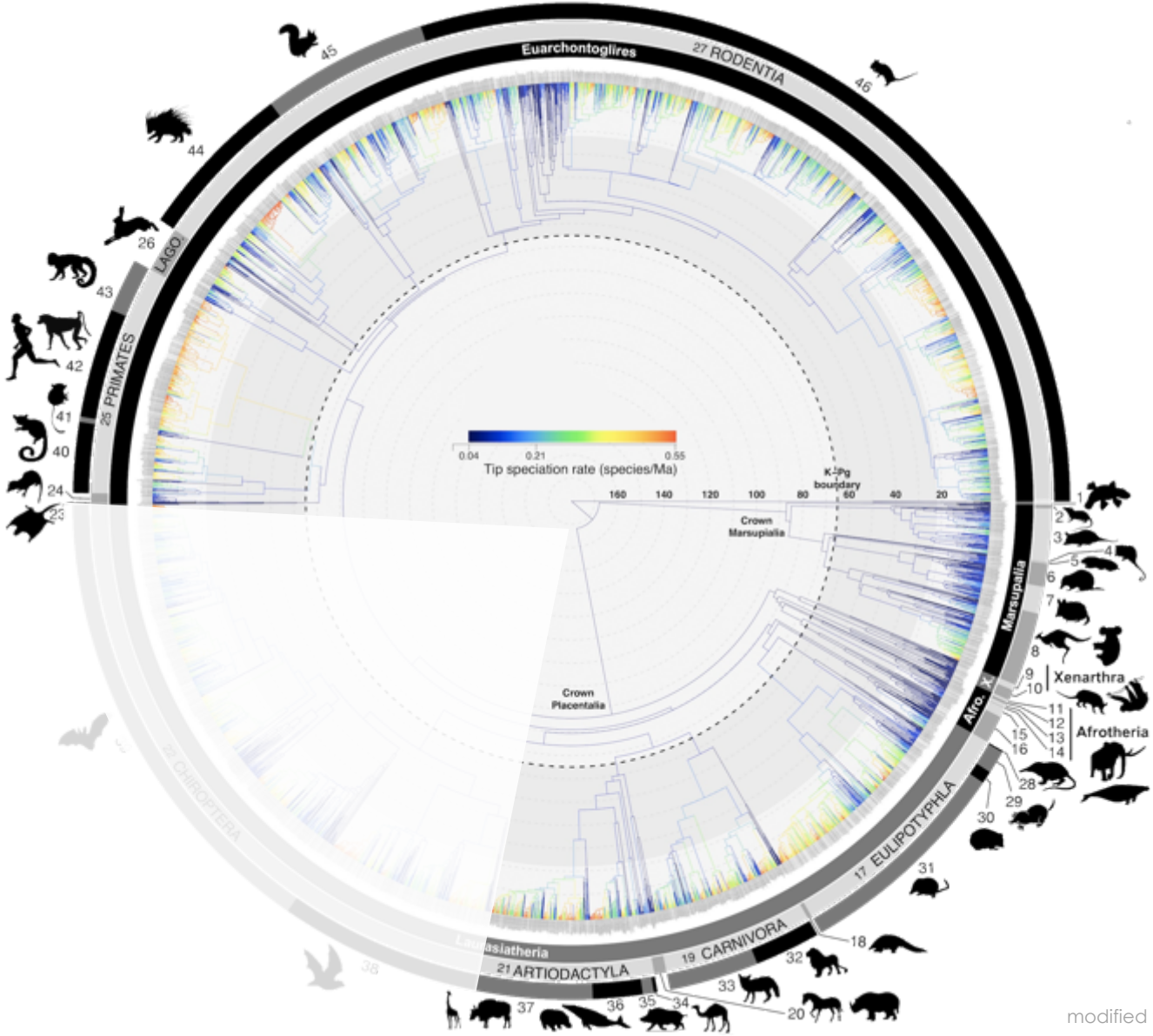
How do you harvest microbes ?

by flushing them out of the fermenter
while retaining the substrate

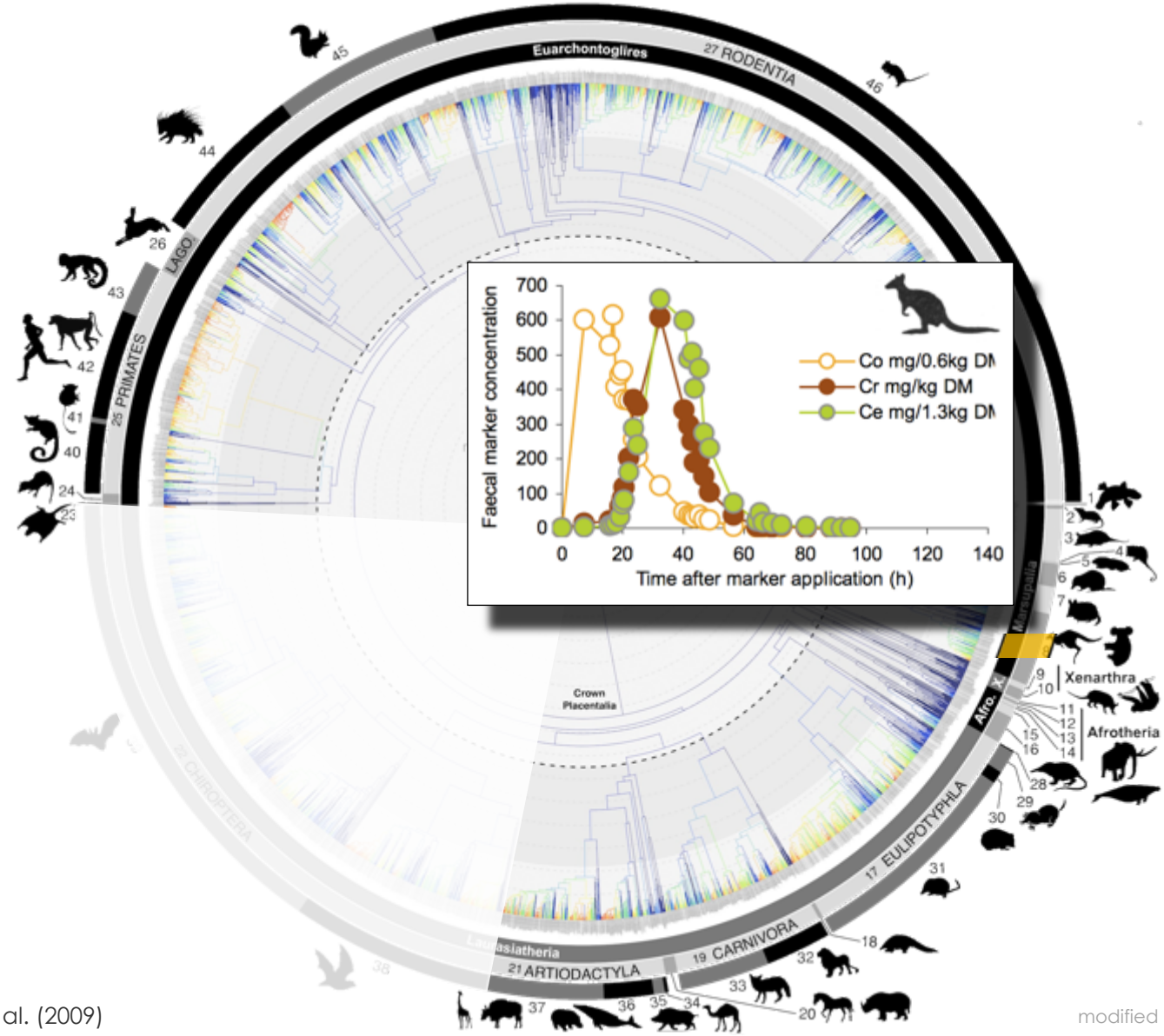
Herbert, D., Elsworth, R. & Telling, R. C. (1956). *J. gen. Microbiol.* **14**, 601–622

The Continuous Culture of Bacteria; a Theoretical and Experimental Study



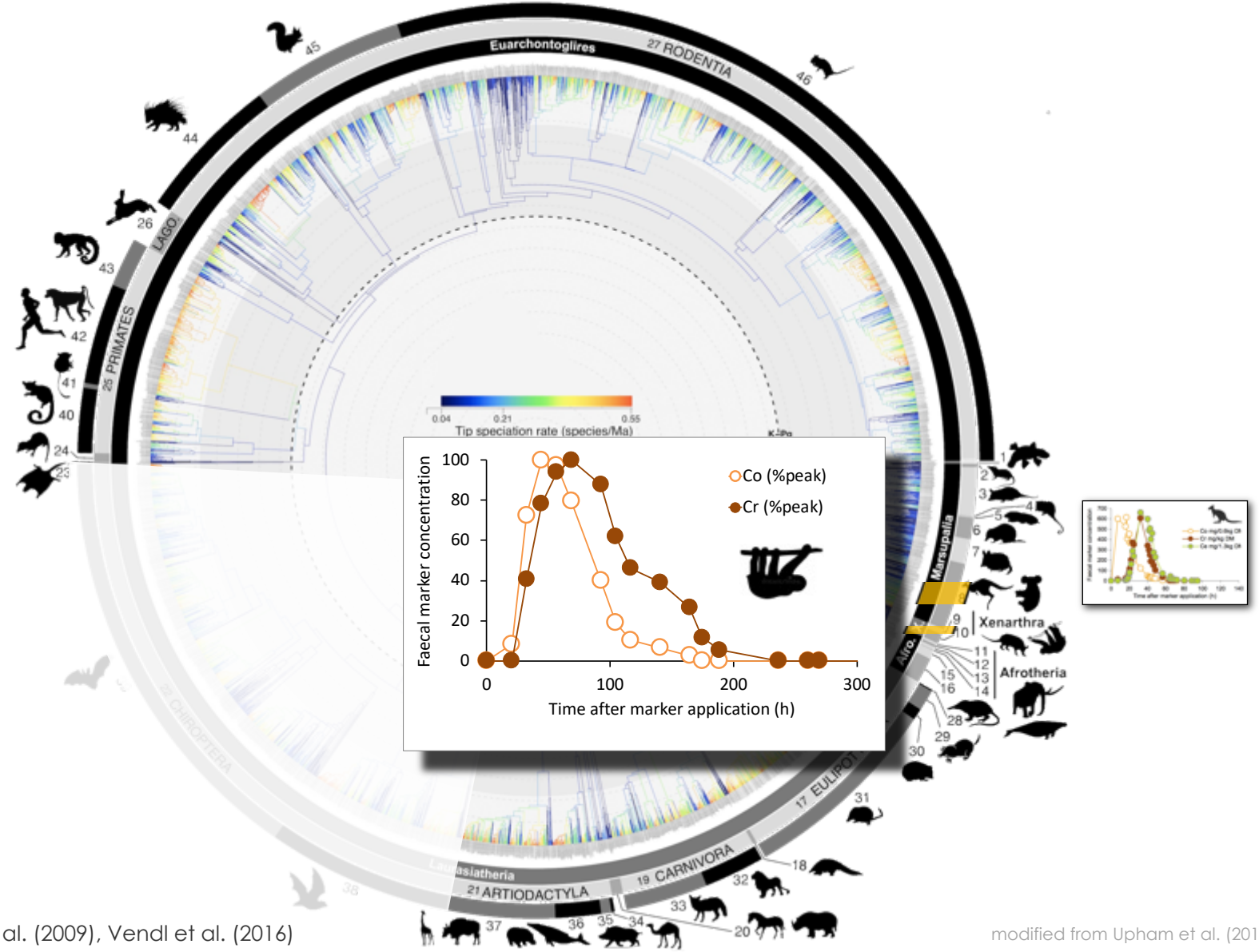


modified from Upham et al. (2019)



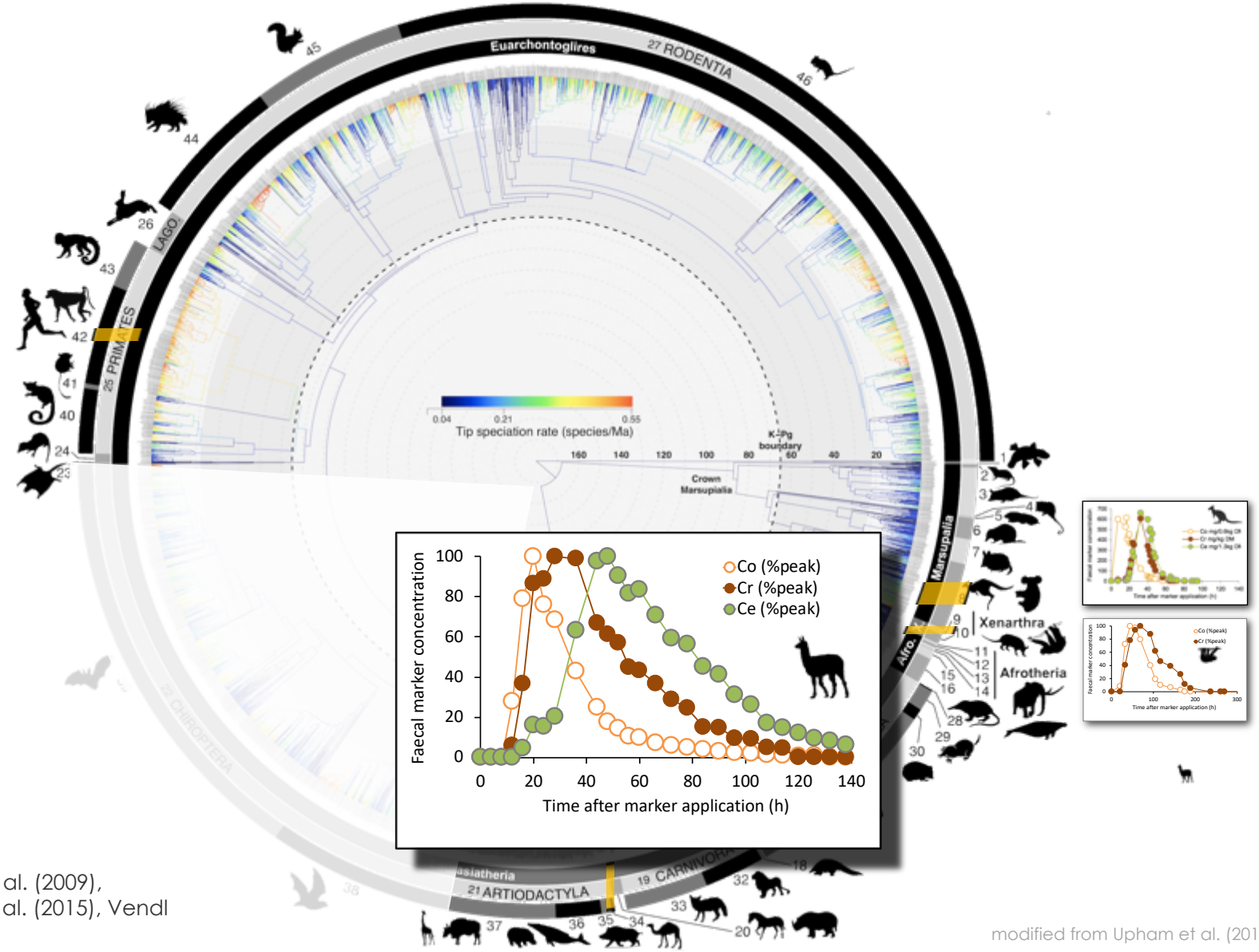
Schwarm et al. (2009)

modified from Upham et al. (2019)



Schwarm et al. (2009), Vendl et al. (2016)

modified from Upham et al. (2019)



Schwarm et al. (2009), Dittmann et al. (2015), Vendl et al. (2016)

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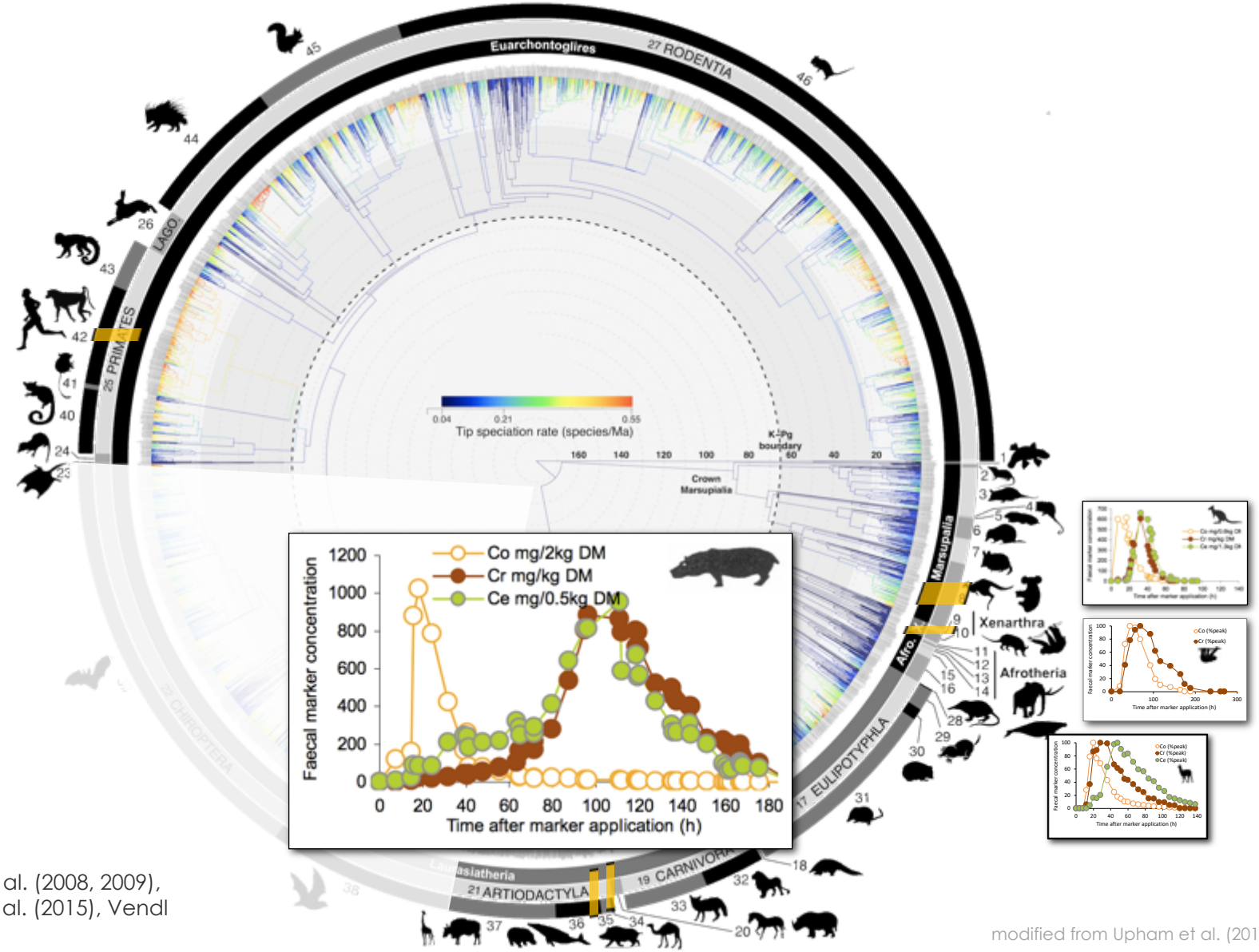

Schwarm et al. (2008, 2009), Dittmann et al. (2015), Vendl et al. (2016)

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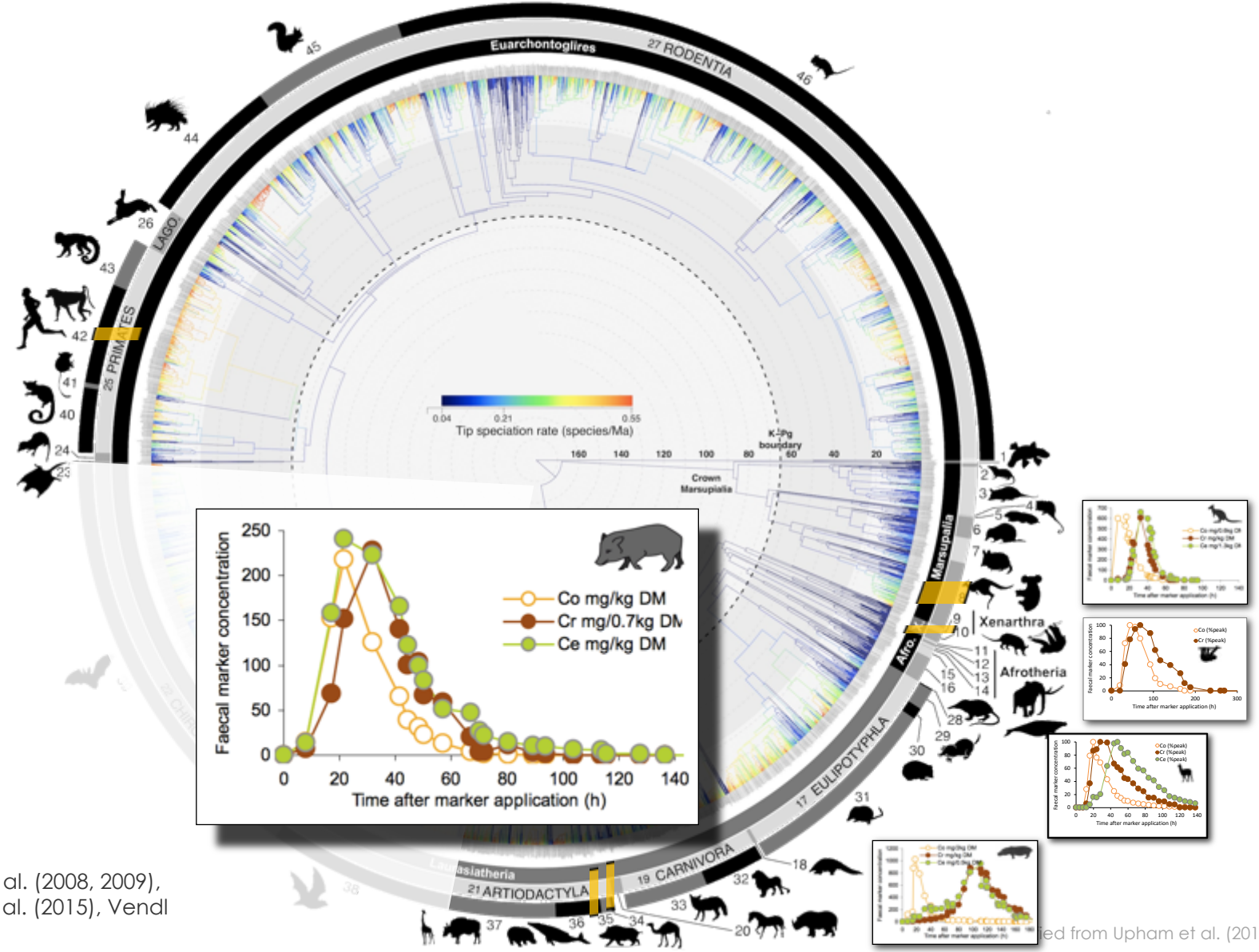

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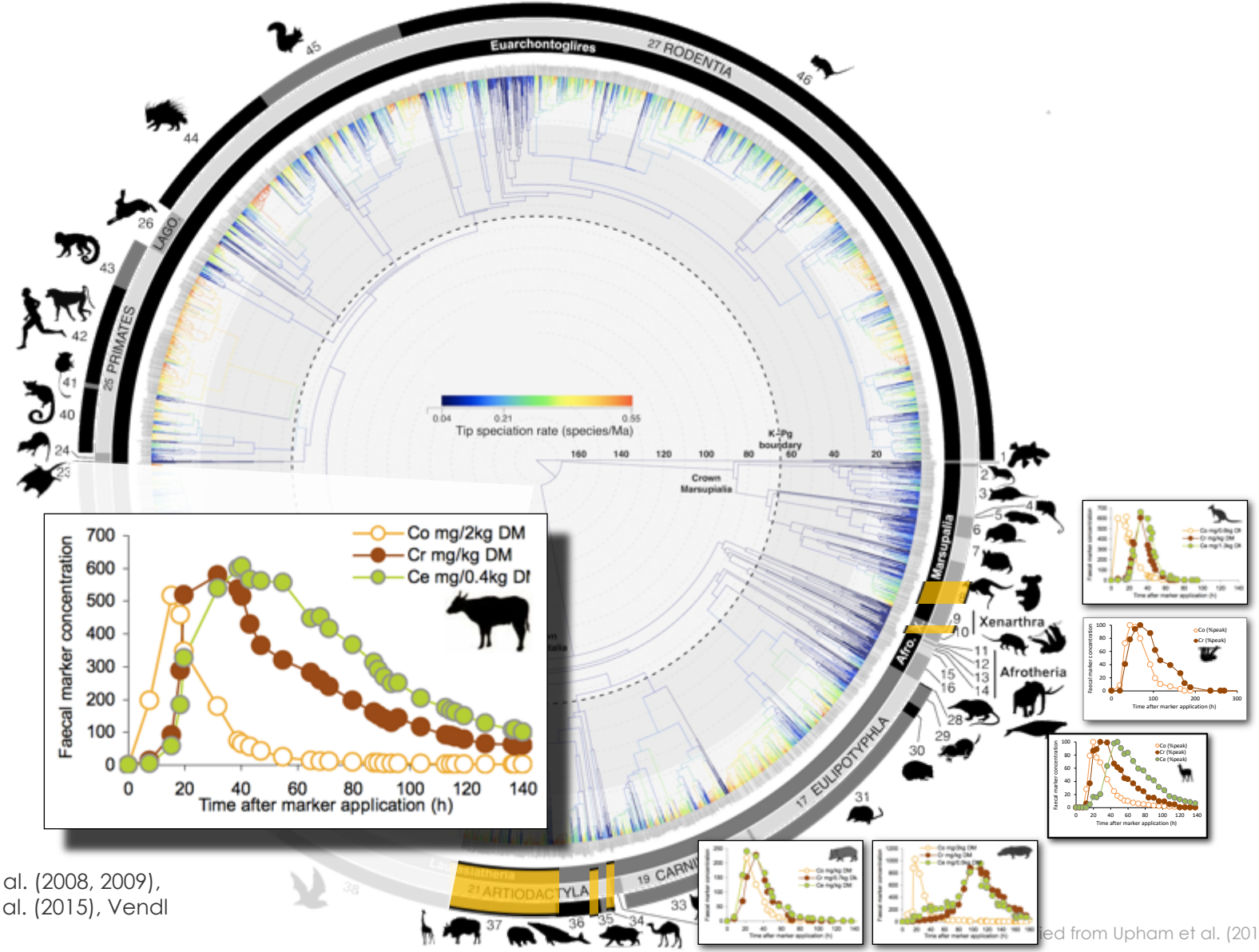

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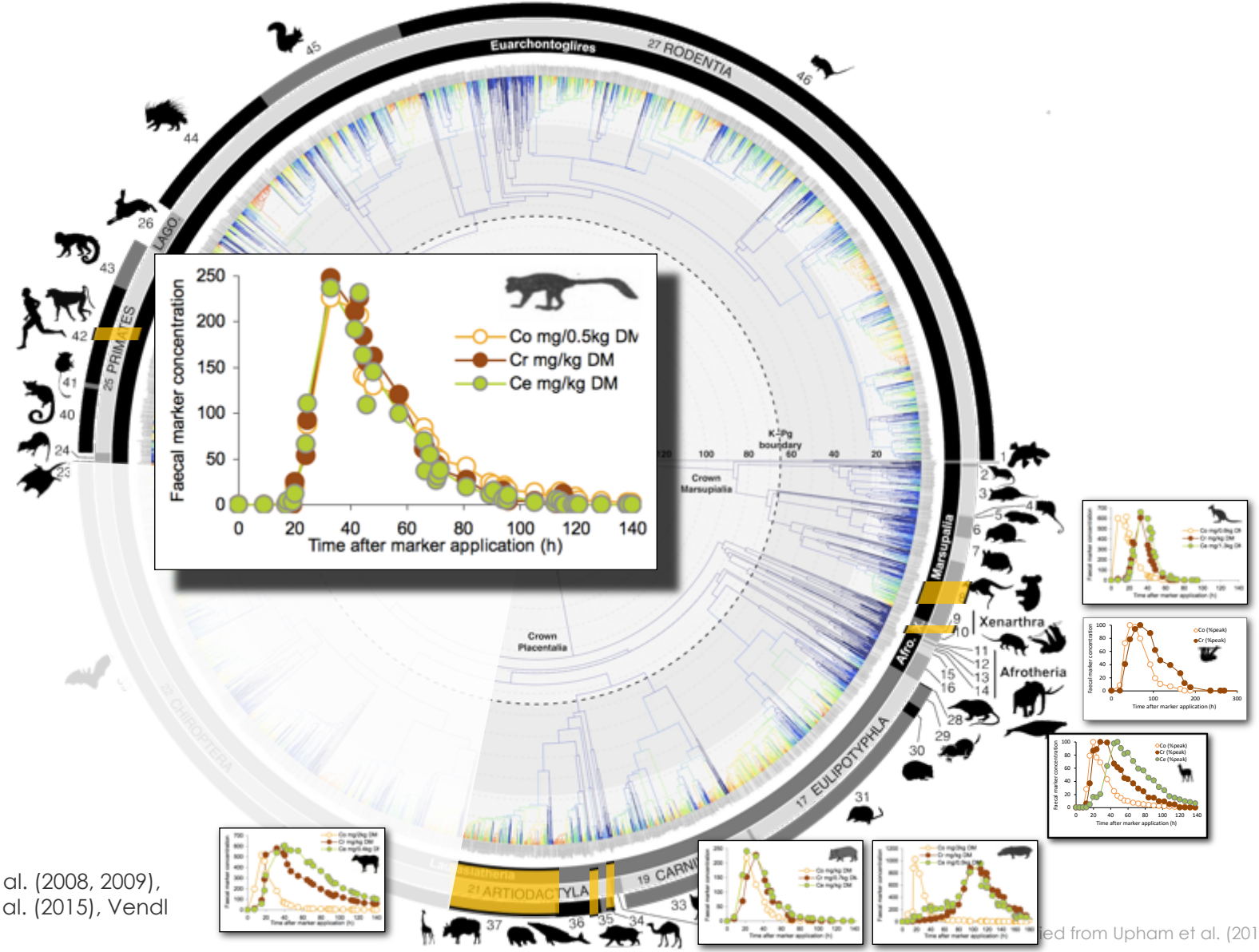

Schwarm et al. (2008, 2009), Dittmann et al. (2015), Vendl et al. (2016)

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Farming: contain, nurture, harvest

+ supplemental (endogenous) nitrogen

optimise via 'flushing' - *saliva*

feasible at small body size

(and few extant small species do not do it)

A patent on an evolutionary pattern !

United States Patent [19]
Croom, Jr. et al.

[11] **Patent Number: 4,857,534**
[45] **Date of Patent: * Aug. 15, 1989**

METHOD OF MAINTAINING RUMINANTS ON HIGH ENERGY LOW FIBER DIET

Inventors: **Warren J. Croom, Jr.**, Cary; **Winston M. Hagler, Jr.**, Raleigh, both of N.C.

Assignee: **North Carolina State University**, Raleigh, N.C.

ABSTRACT

This invention relates to the use of parasympathomimetic compounds, their precursors, salts and metabolites, to alter the digestive process in livestock so as to increase the efficiency of food utilization while simultaneously reducing the risk of certain disorders frequently associated with high energy diets. Specifically, the invention comprises administration to ruminants and other livestock of low level dosages of a parasympathomimetic compound to increase salivation during feeding and rumination, thereby increasing rumen digesta turnover rates and efficiency of food utilization while reducing the risk of certain digestive tract disorders such as acidosis and displaced abomasum.

Effect of Orally Administered Pilocarpine on Ruminal Characteristics and Nutrient Digestibility in Cattle

1987 J Dairy Sci 70:284–289

R. D. WIEDMEIER, M. J. ARAMBEL, and J. L. WALTERS

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]

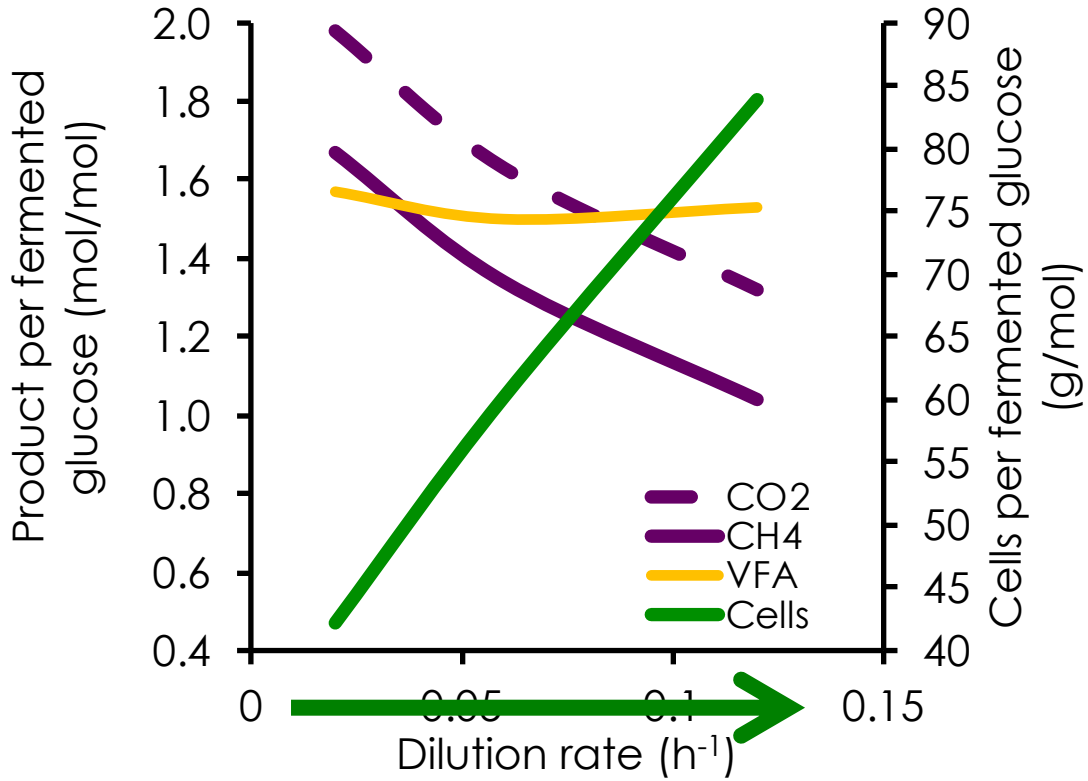
J. Anim. Sci. 1989. 67:827–834

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.

Efficiency of Energy Utilization by Mixed Rumen Bacteria in Continuous Culture

H. R. ISAACSON, F. C. HINDS, M. P. BRYANT, and F. N. OWENS[1]

Journal of Dairy Science Vol. 58, No. 11 1975



Proceedings of the Society of Nutrition Physiology (2019) 28

98.
Fermentation characteristics of feeds with different carbohydrate composition incubated at low and high dilution rate in the RUSITEC
Fermentationscharakteristika von Futtermitteln mit unterschiedlicher Kohlenhydratzusammensetzung inkubiert mit niedriger und hoher Verdünnungsrate im RUSITEC

*Pfau F., Hünerberg M., Zhang X., Hummel J. – Göttingen

The amount of CH_4 was lower ($p<0.001$) for fermenters with high (58 mmol/d) compared to low dilution rate (35 mmol/d). Substrate source had no effect on the CH_4 amount.

"Microbial cells act as H_2 sinks." *Huhtanen et al. (2015)*

$C_{16}H_2O_8N_2$

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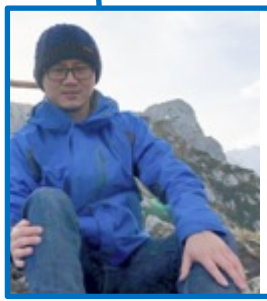

can we demonstrate a CH_4-sparing effect of increased saliva production in vivo ?

Proceedings of the Society of Nutrition Physiology (2019) 28

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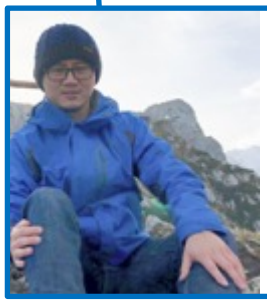
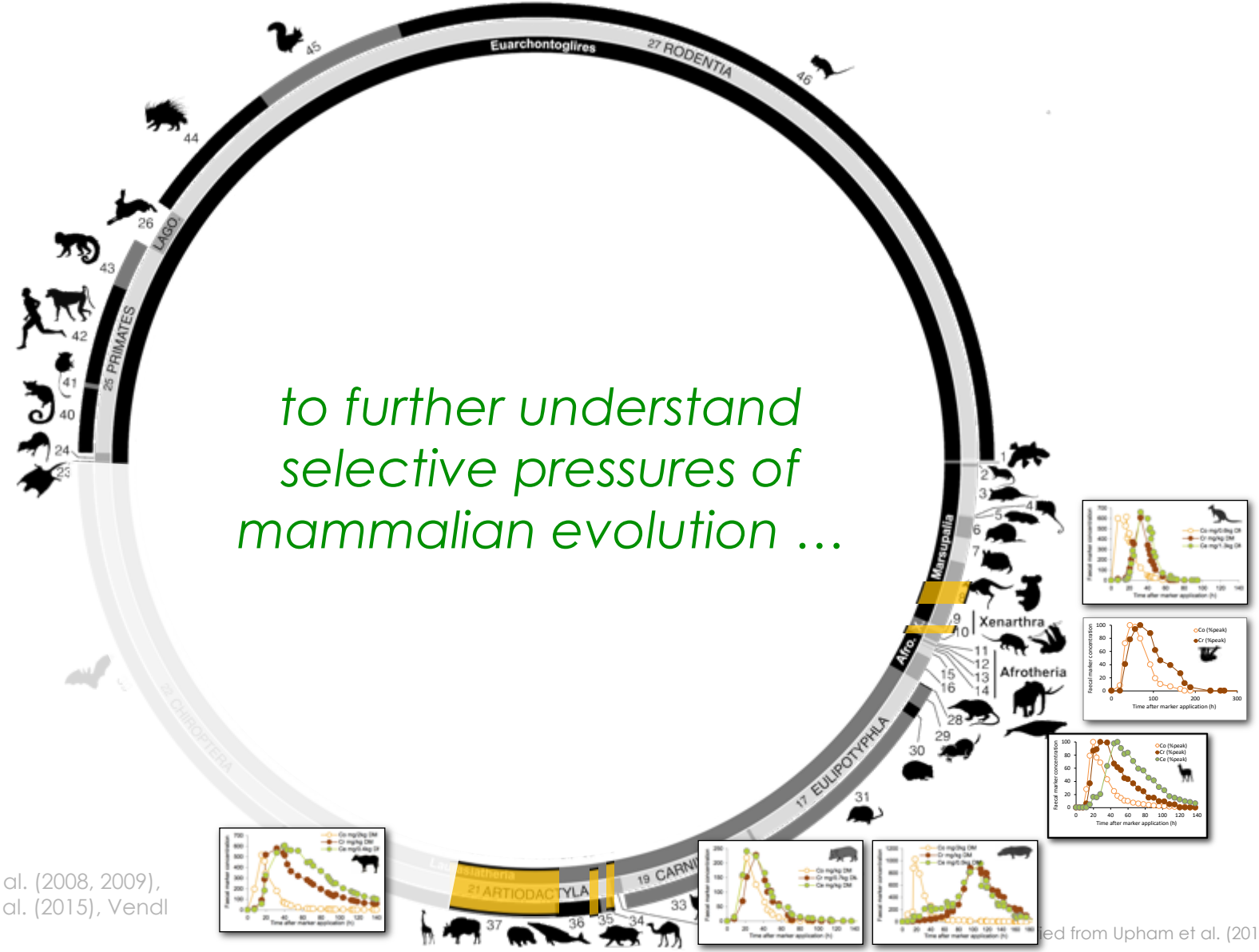


can we demonstrate differences in rumen microbiome?

(functional/molecular)



to further understand selective pressures of mammalian evolution …

Schwarm et al. (2008, 2009), Dittmann et al. (2015), Vendl et al. (2016)

ied from Upham et al. (2019)

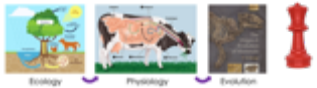
… and possibly define goals for domestic ruminant breeding selection

Schwarm et al. (2008, 2009), Dittmann et al. (2015), Vendl et al. (2016)

modified from Upham et al. (2019)

Summary

1. Comprehensive view of ecology, physiology and evolution

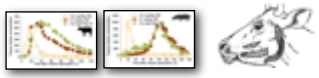


2. Trophic chains that include microbes

3. Harvesting microbes from the digestive tract

Hindgut fermentation – Colonic separation

Foregut fermentation – Digesta washing



thanks to

Jürgen Hummel (JLU Göttingen) & Michael Kreuzer (ETH Zurich)

Sylvia Ortmann (IZW Berlin)

Angela Schwarm, Anja Tschudin, Marie Dittmann, Catharina Vendl, Katharina Hagen, Letícia Guerra Aldrigui, Louise Martin, Xiaoyu Zhang

numerous public and private zoological collections
the teams of
the Clinic for Zoo Animals, Exotic Pets and Wildlife
AgroVet Strickhof

funding at various stages by DFG, SNF, BLV, FU Berlin, CAPES

thank you for your attention

Microbes in the digestive tract