Zähne und Kauen von Pferden
im Vergleich zu anderen Pflanzenfressern

Marcus Clauss

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

Deutscher Tierärztetag Leipzig 2018

University of Zurich[UZH]

Clinic of Zoo Animals, Exotic Pets and Wildlife

Gliederung

Verdauung und Partikelgrösse

Zerkleinerung bei Landwirbeltieren

Zahnoptimierung: Lebensdauer
Zahnoptimierung: Kauleistenverlängerung
Zahnoptimierung: Schmelzfalten
Kauoptimierung: Rhythmisches Kauen

Zahn- vs. Kauoptimierung: Wiederkäuen

Zahnoptimierung: Lebensdauer II

Verdauung und Partikelgrösse

Verdauung braucht ... Zeit?

Tierische Zelle – Pflanzenzelle

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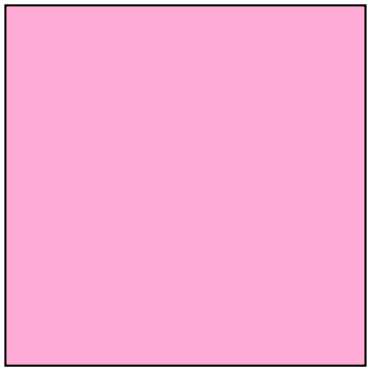

Zellmembran

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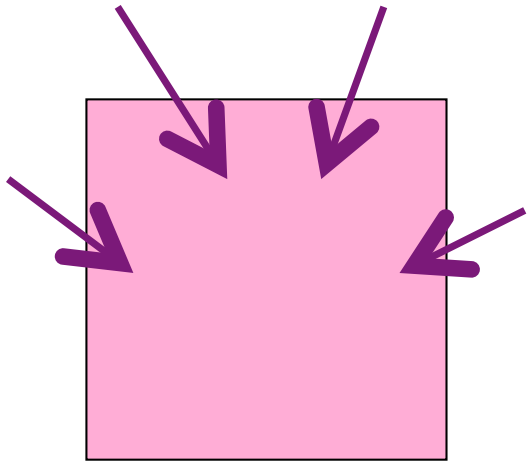

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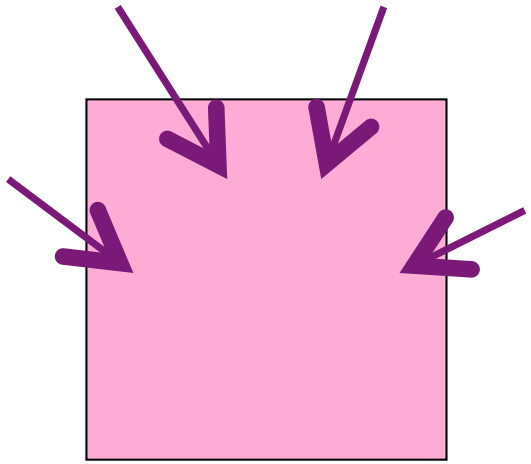

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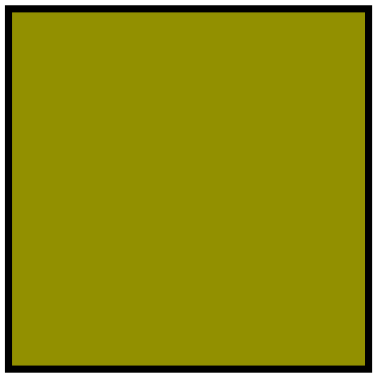

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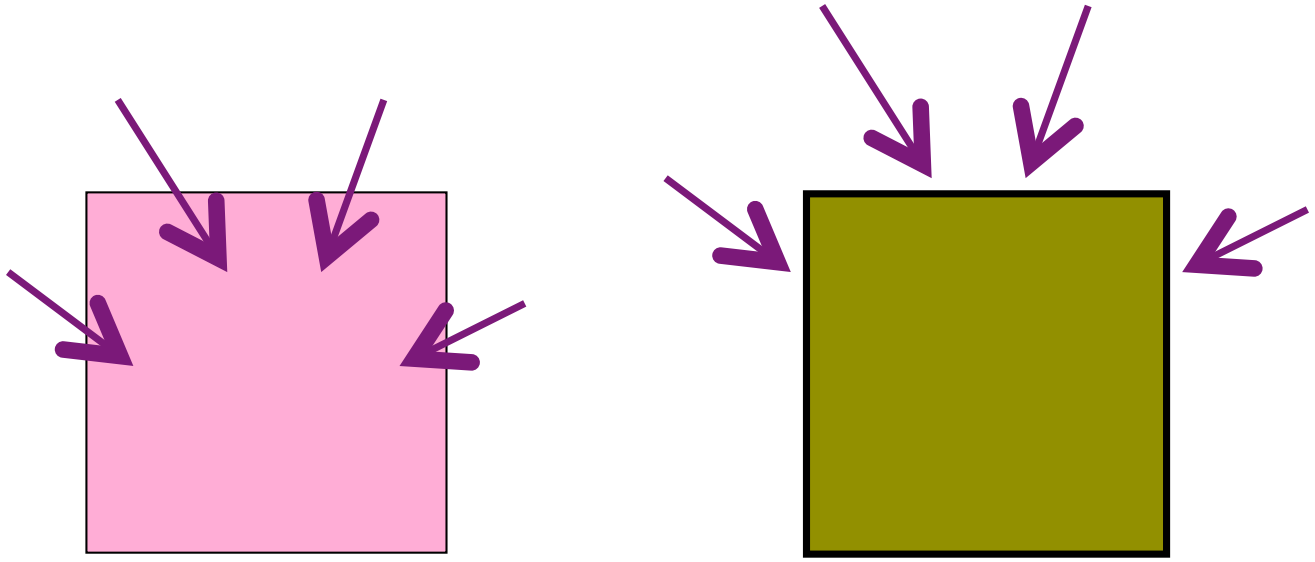

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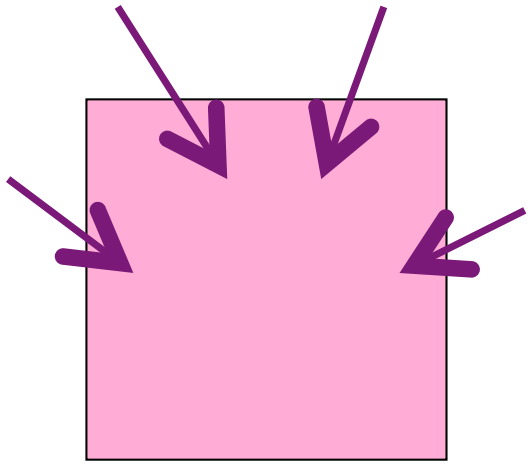

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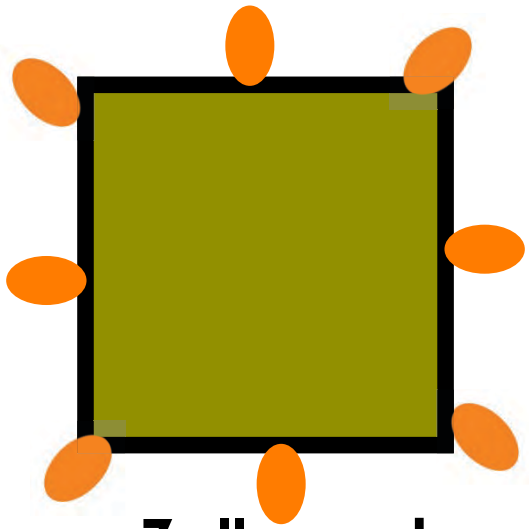

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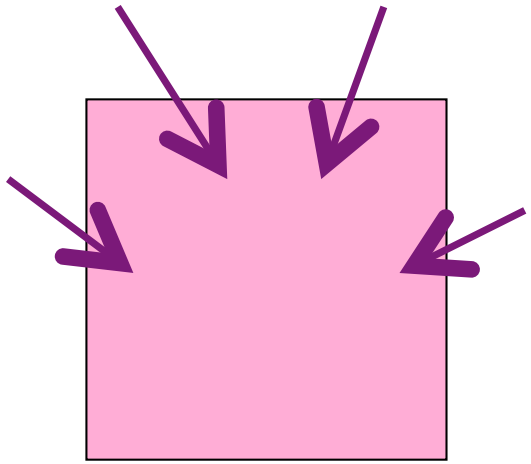

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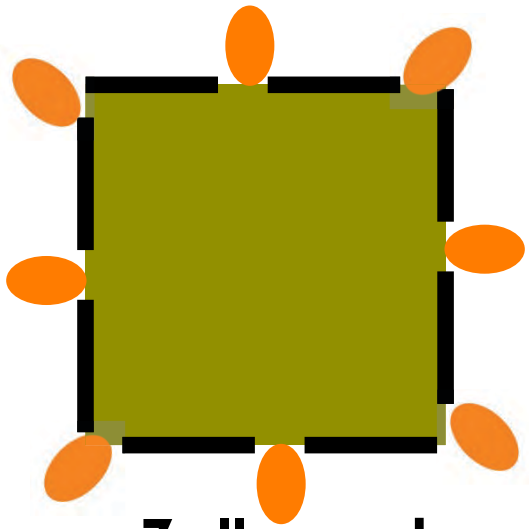

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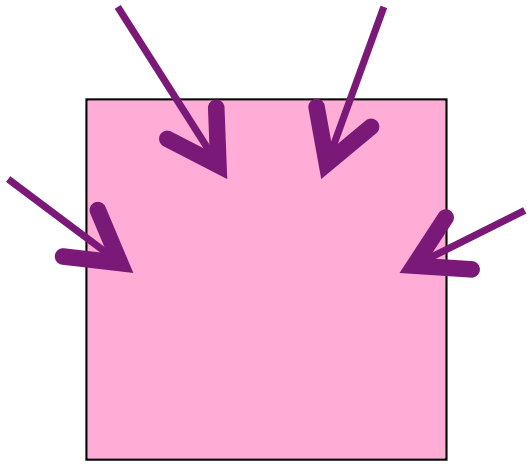

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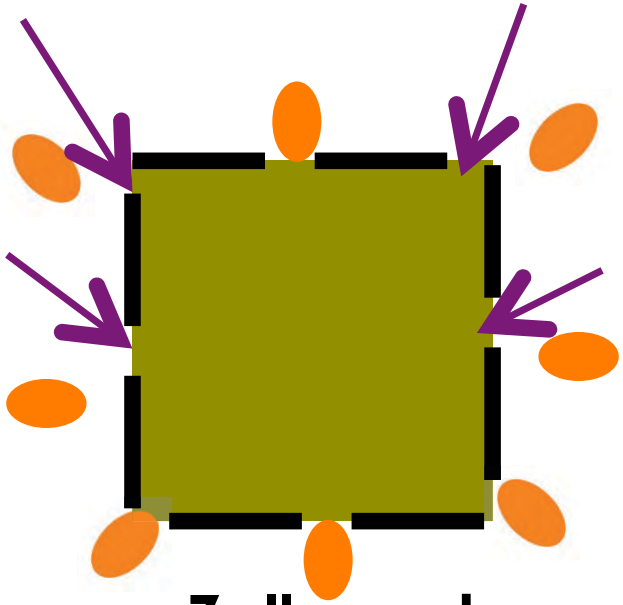

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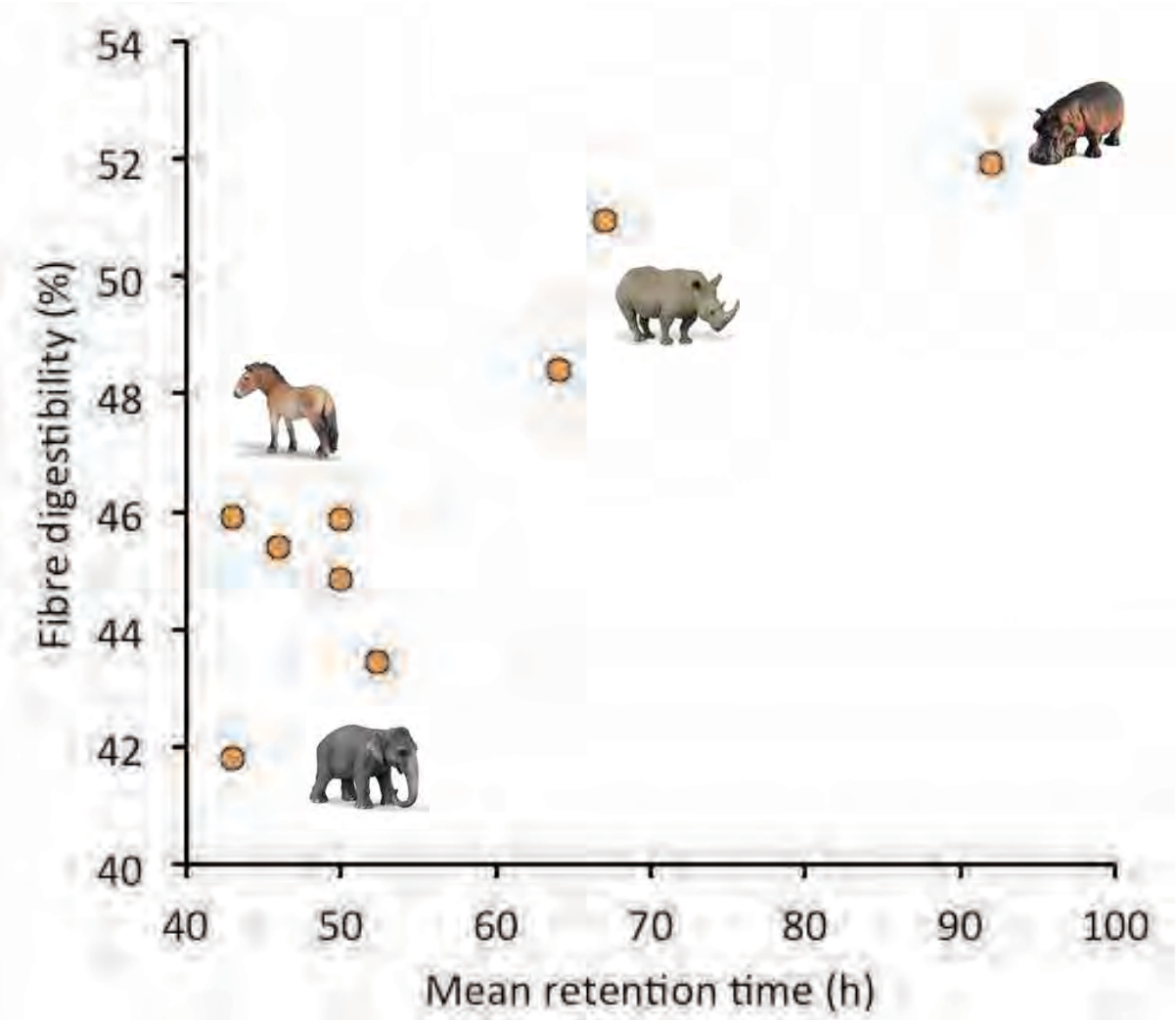
Comparative Biochemistry and Physiology, Part A 154 (2009) 376–382



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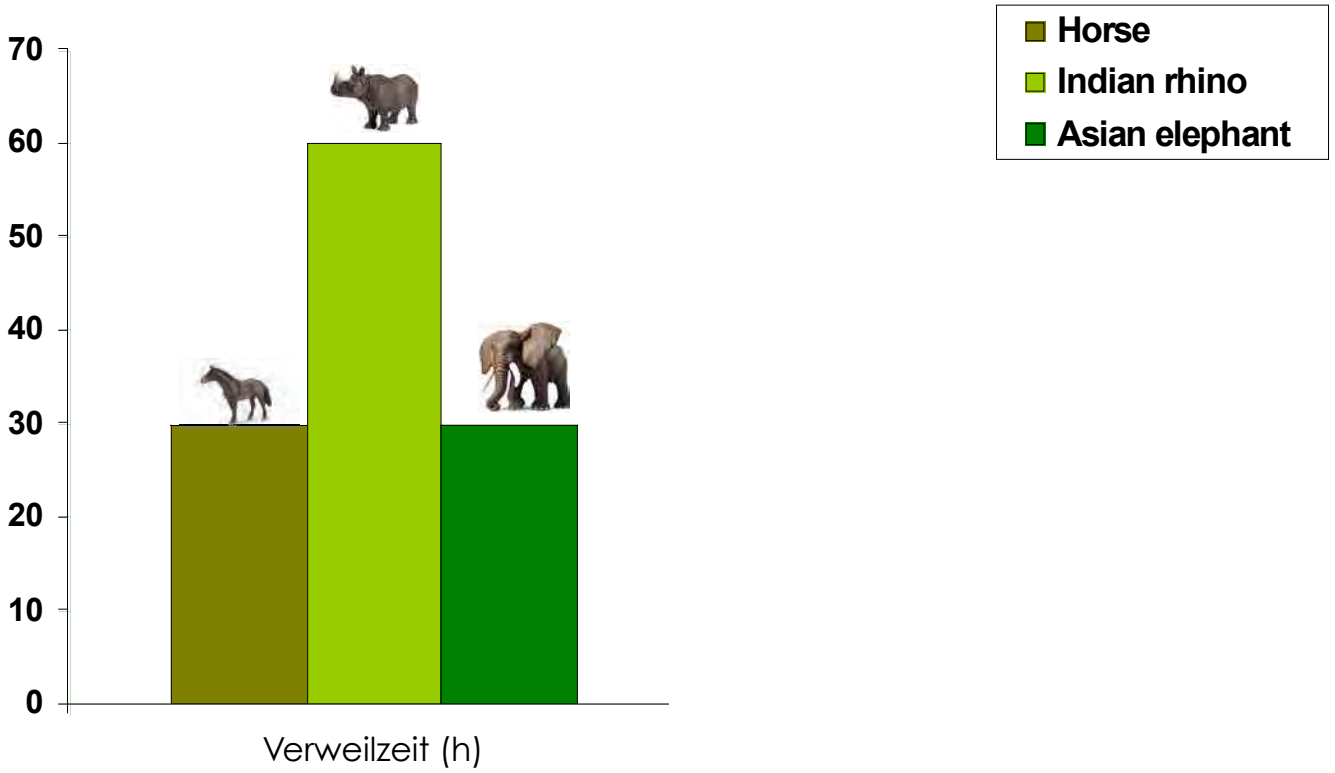
Journal of Animal Physiology and Animal Nutrition **89** (2005) 229–237



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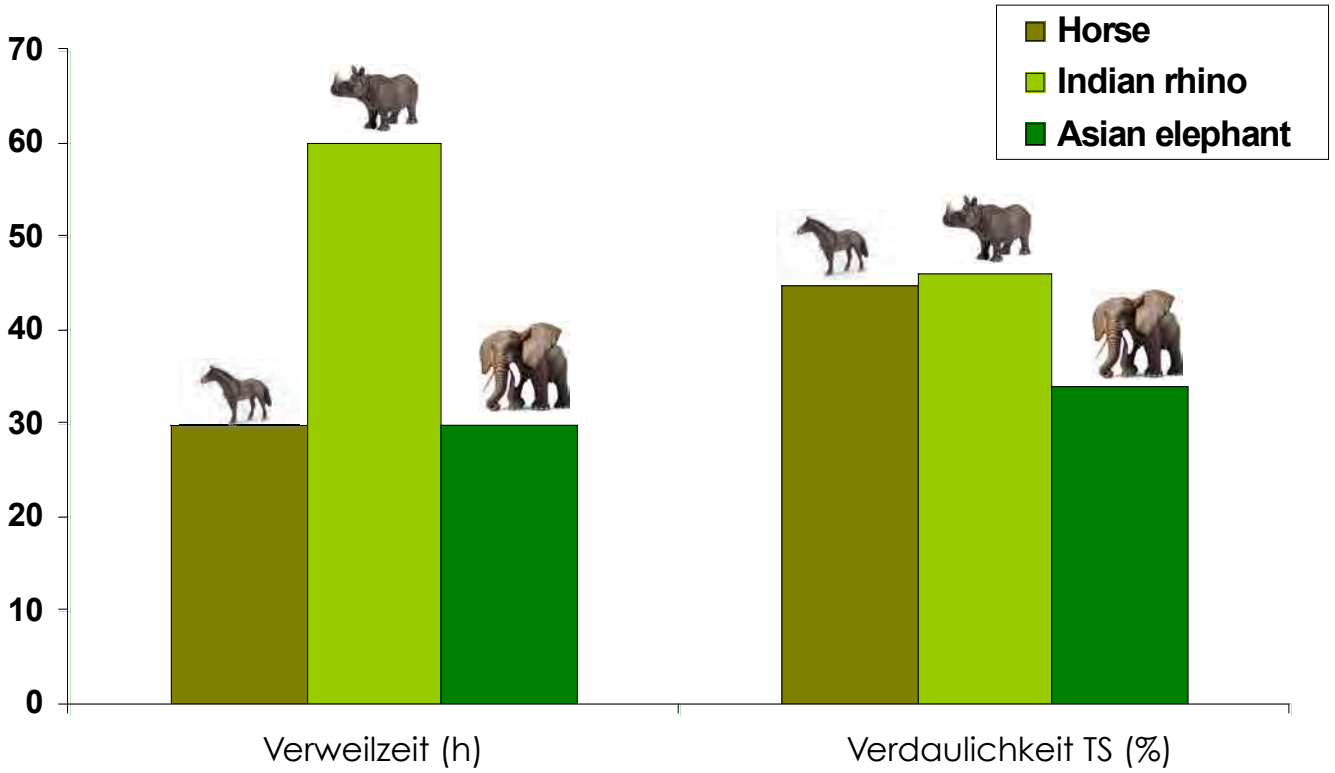

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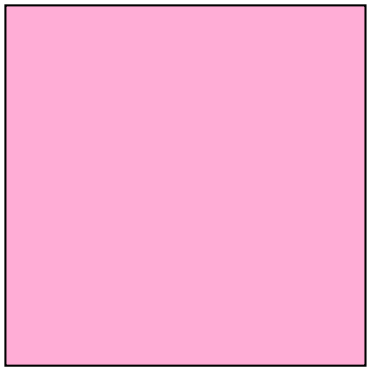

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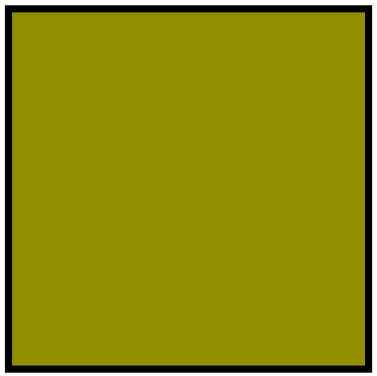

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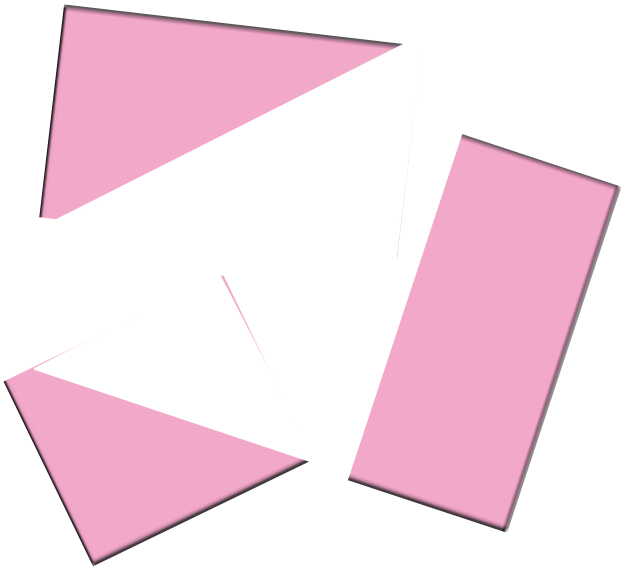

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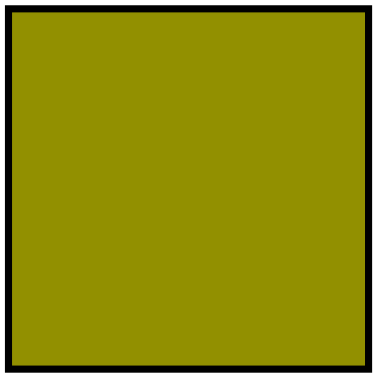

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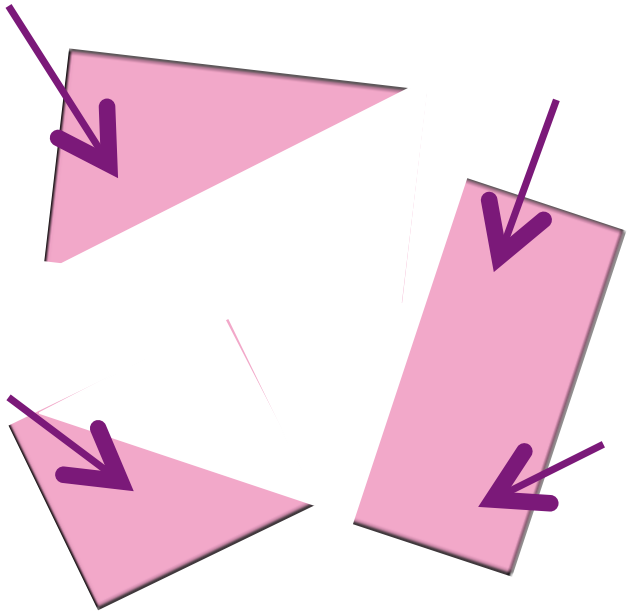

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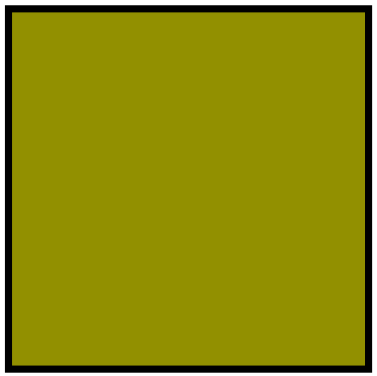

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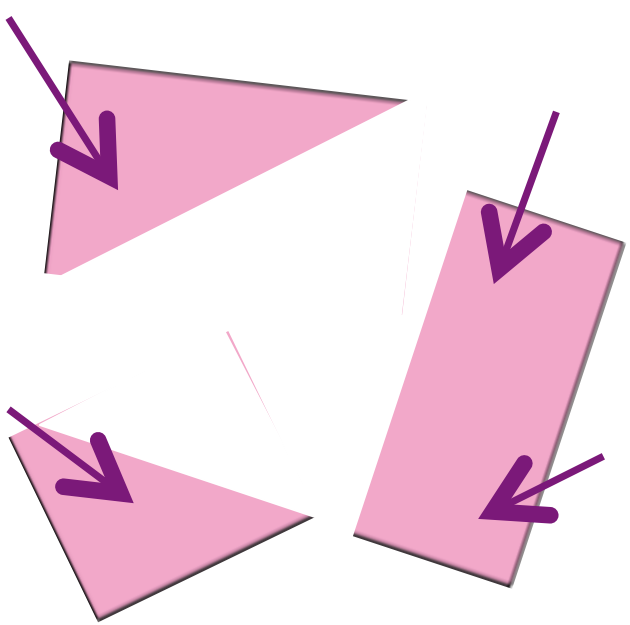

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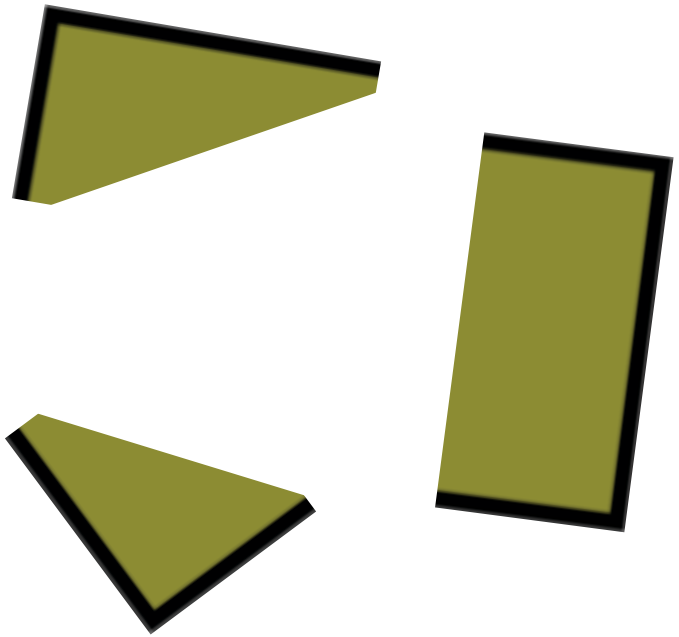

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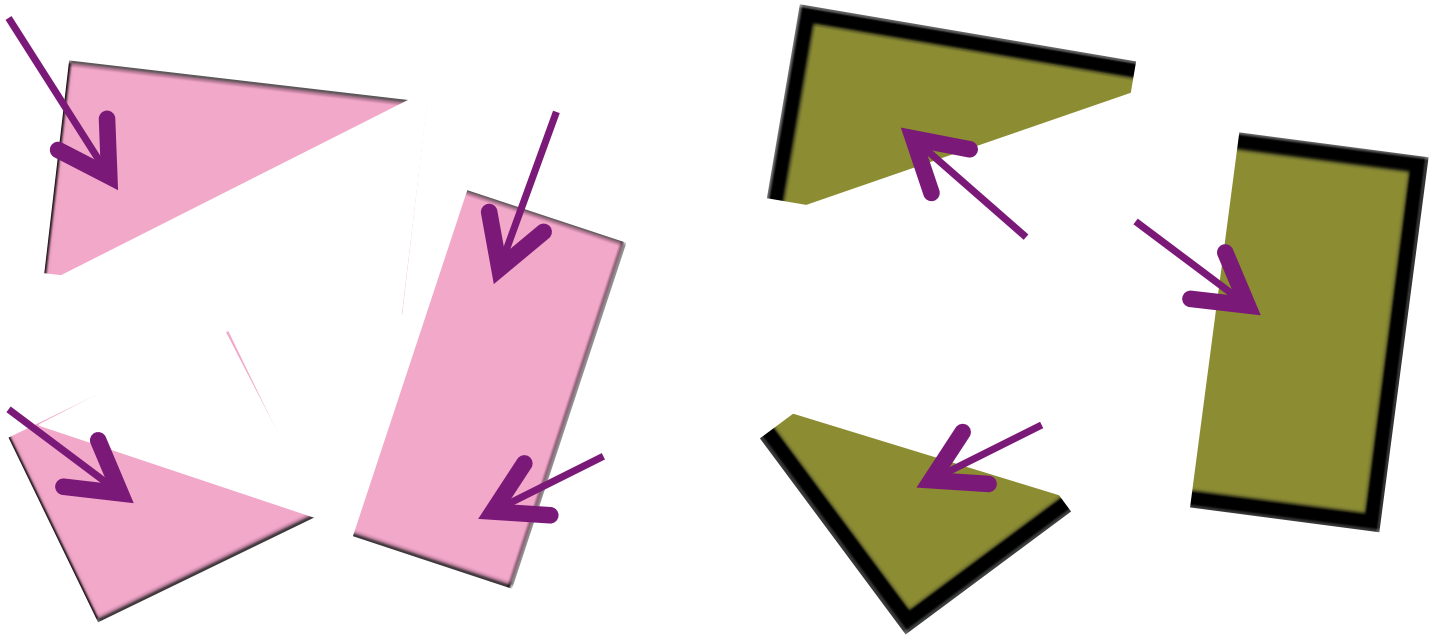

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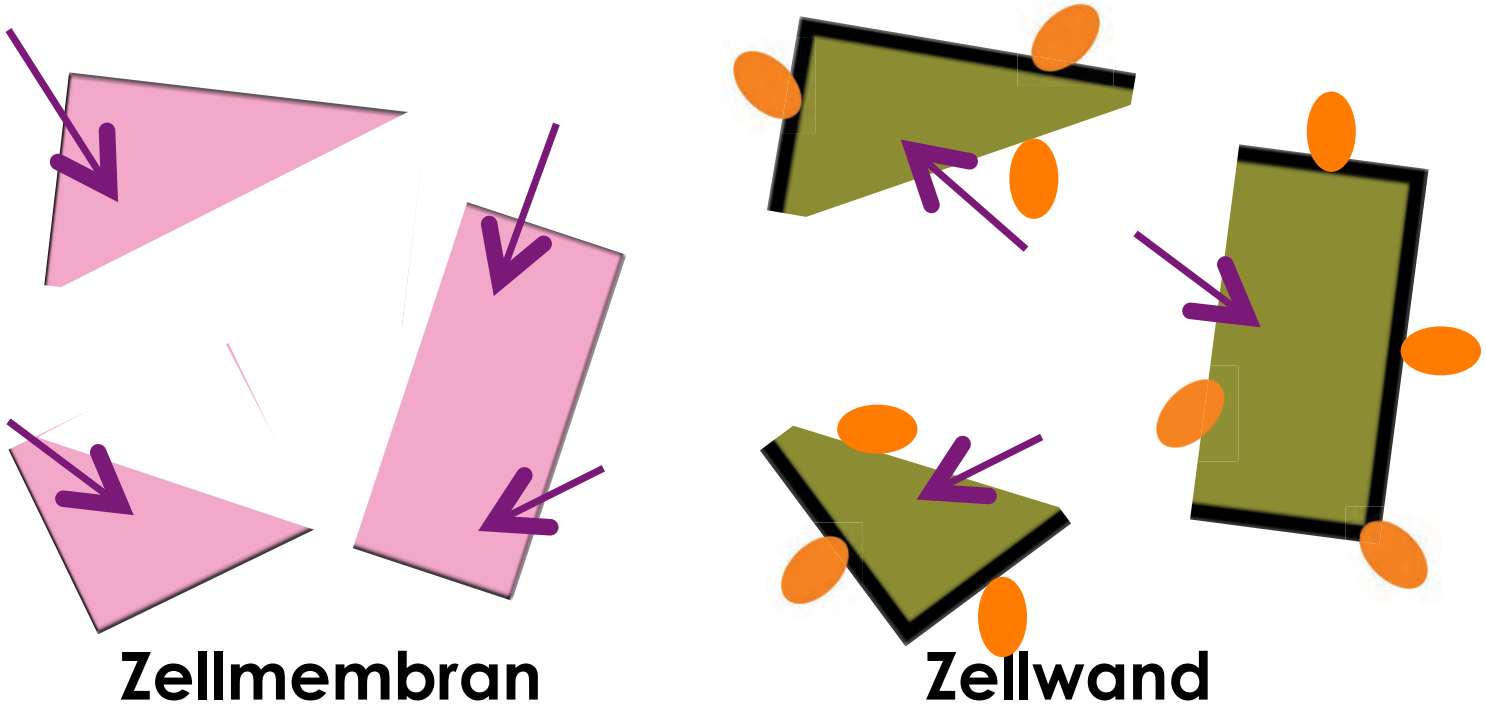

Digestive Fermentation in Herbivores: Effect of Food Particle Size

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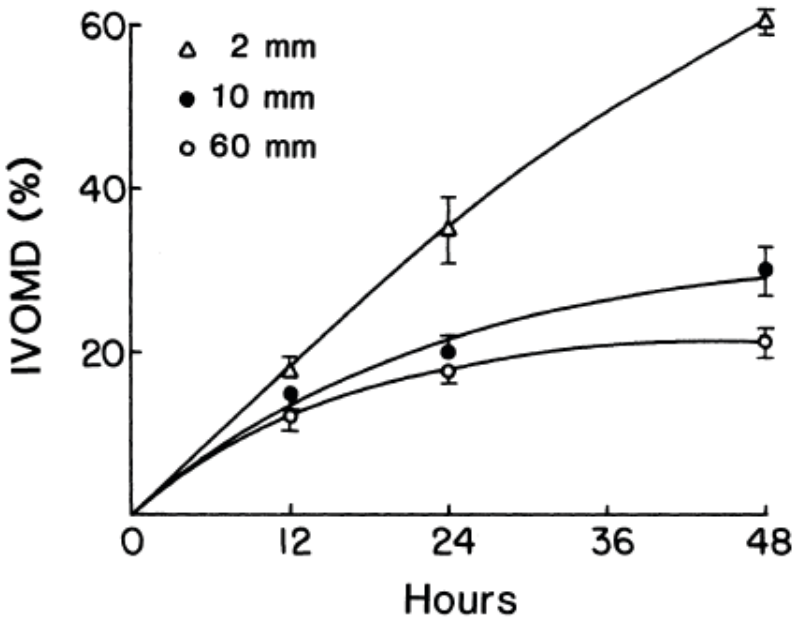
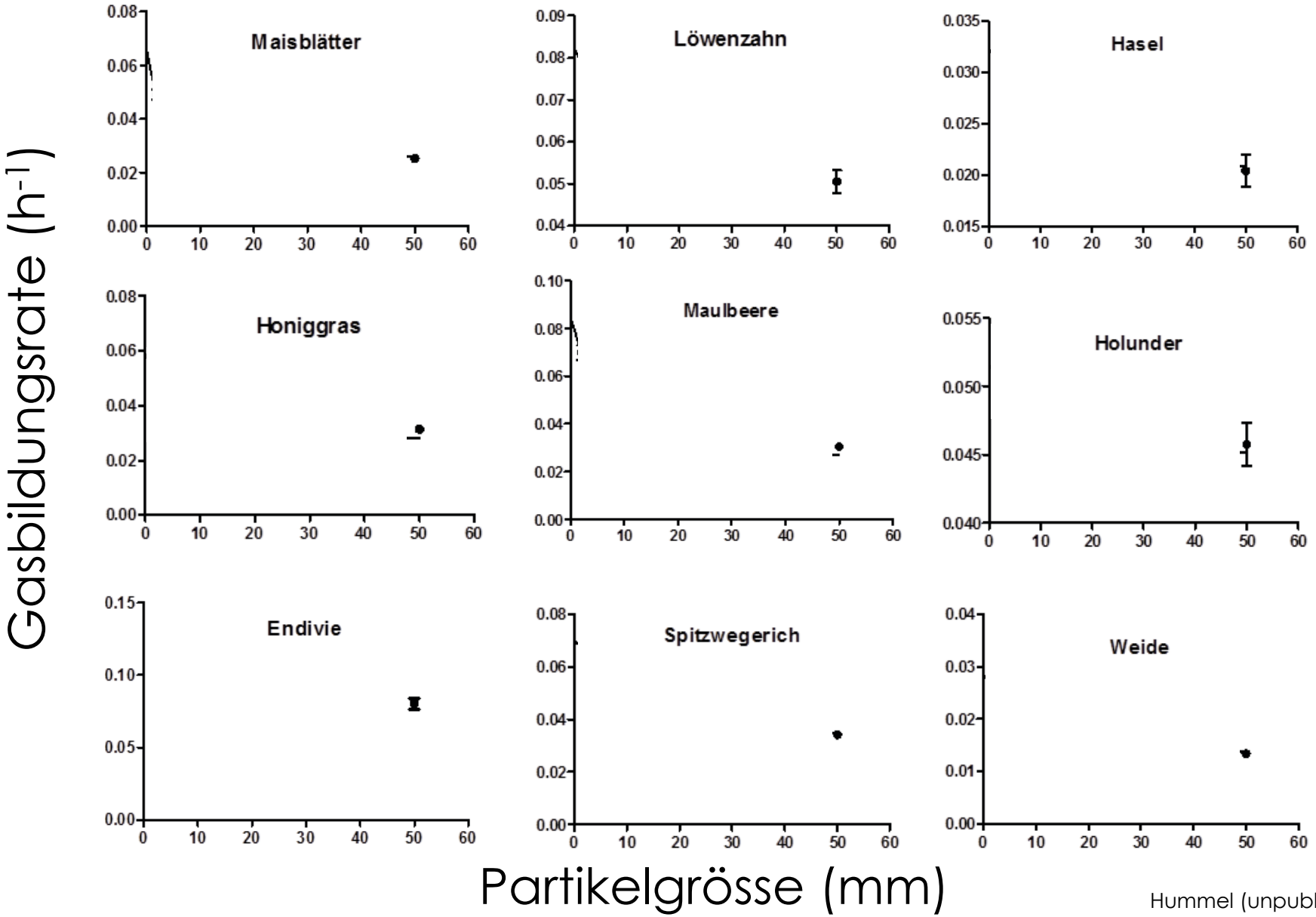


In vitro Fermentation und Partikelgrösse



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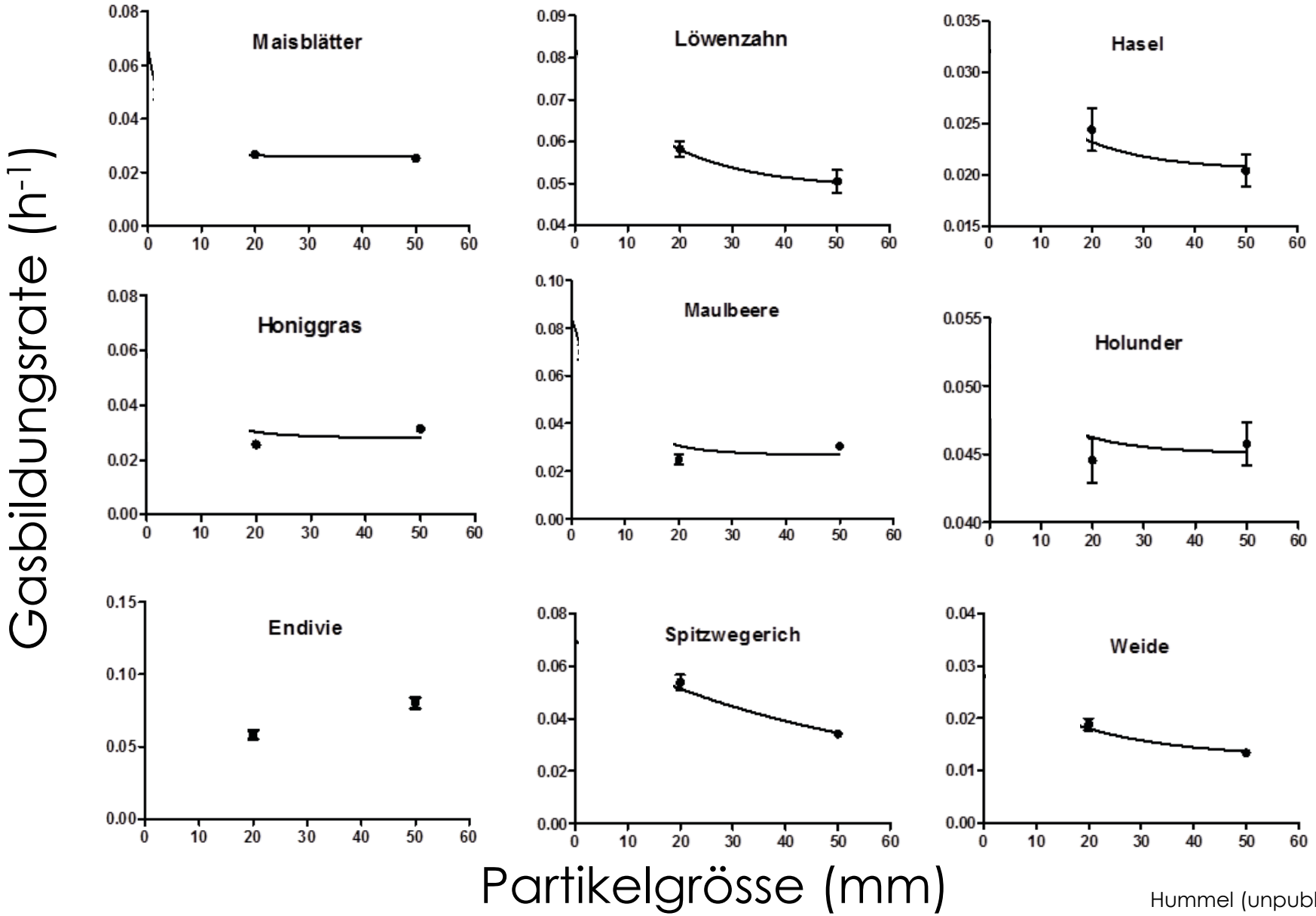

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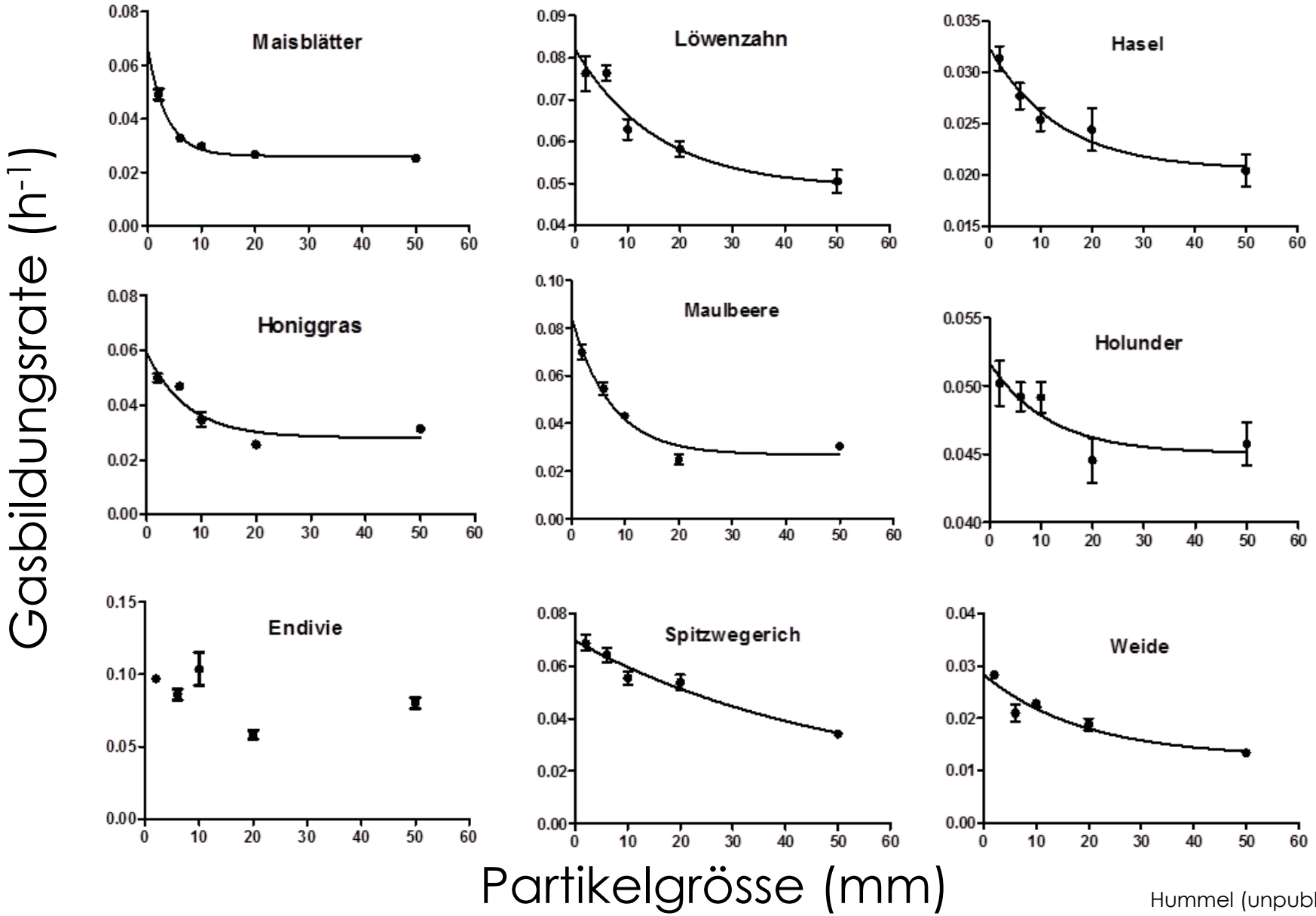

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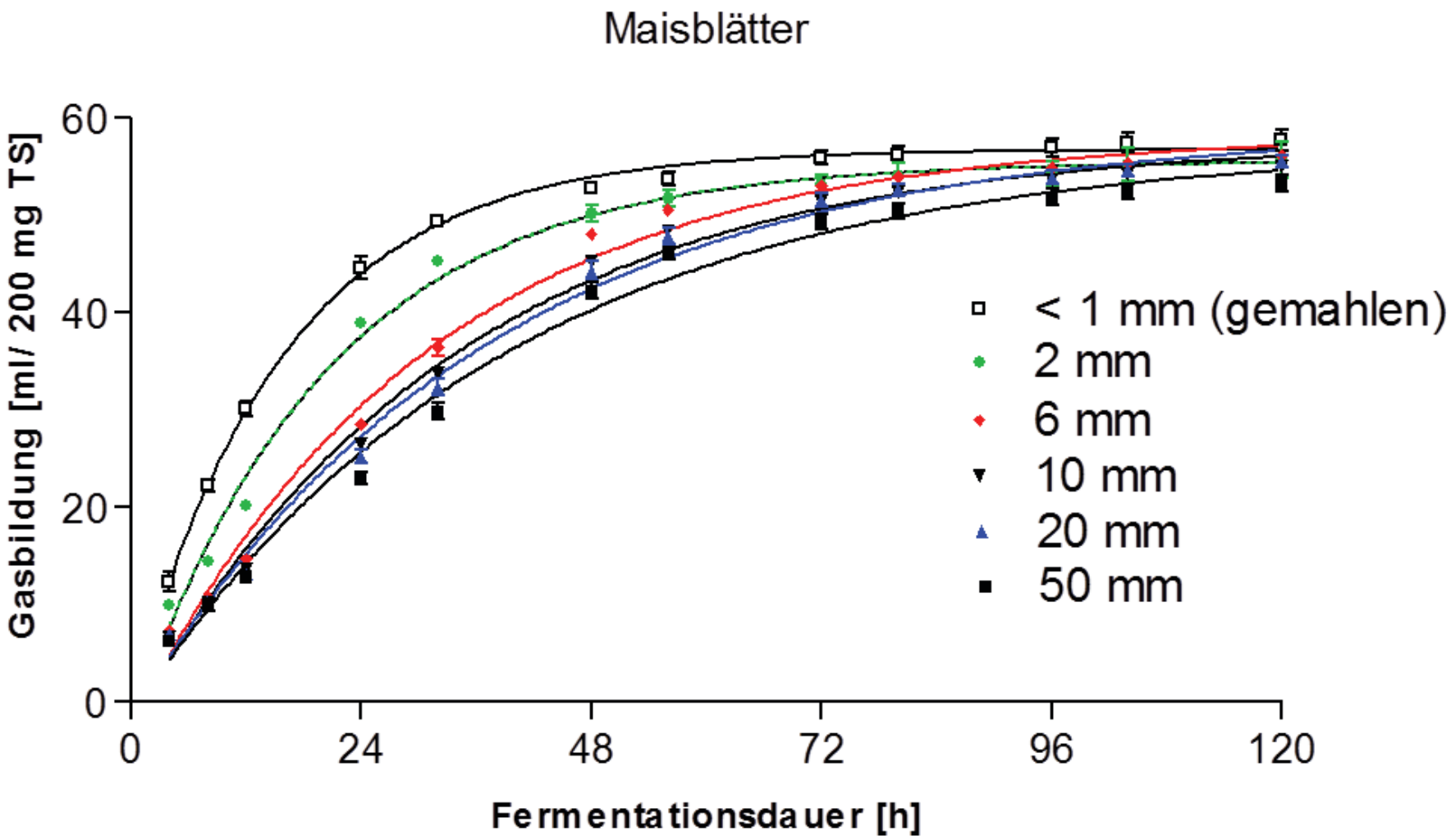

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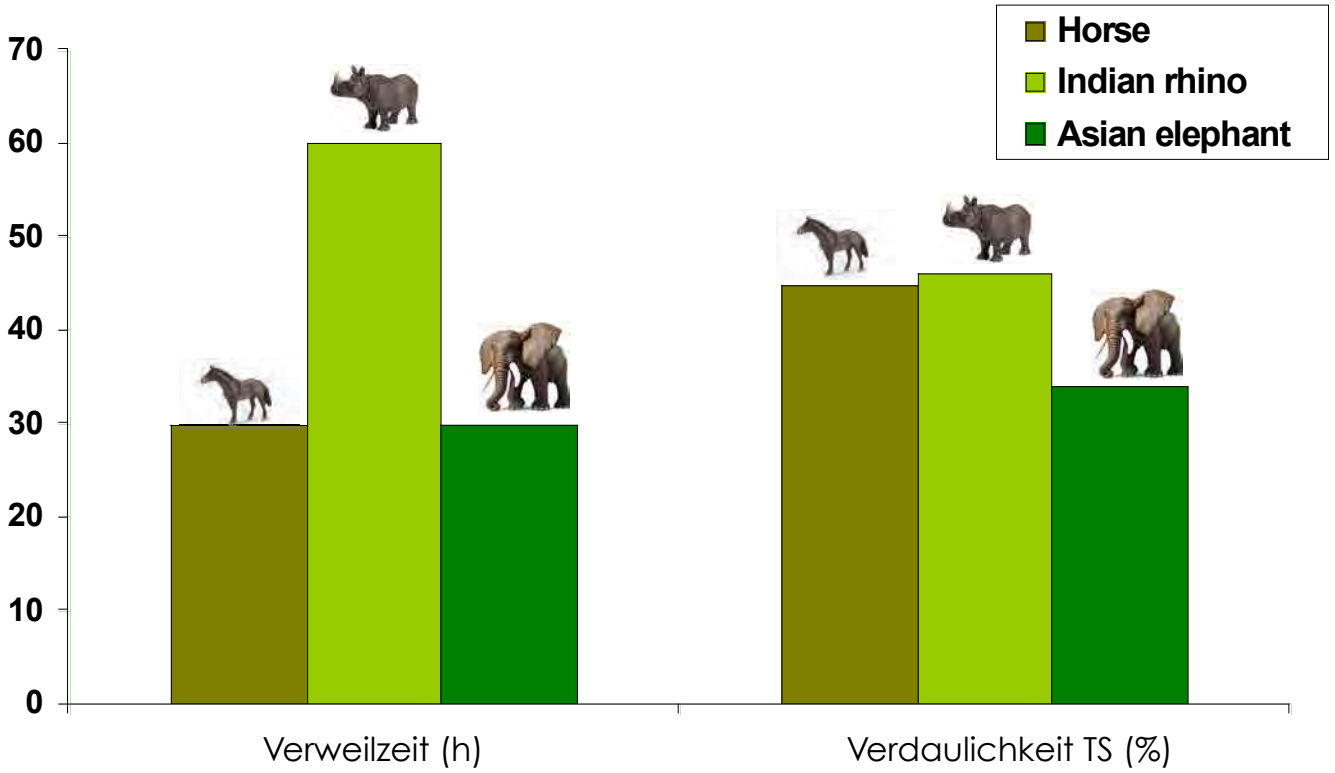

Zerkleinerung bei Landwirbeltieren

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Comparative chewing efficiency in mammalian herbivores

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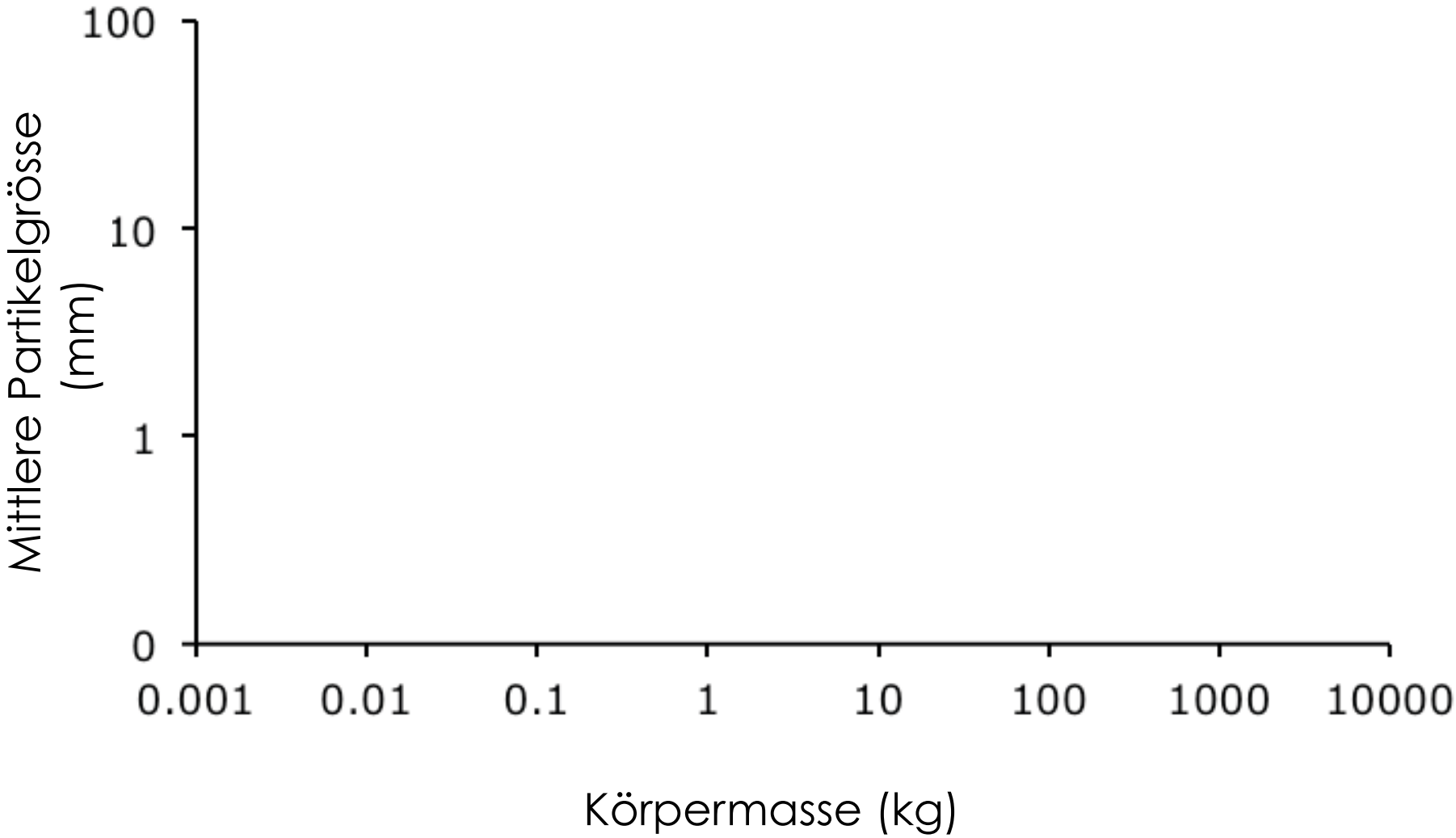

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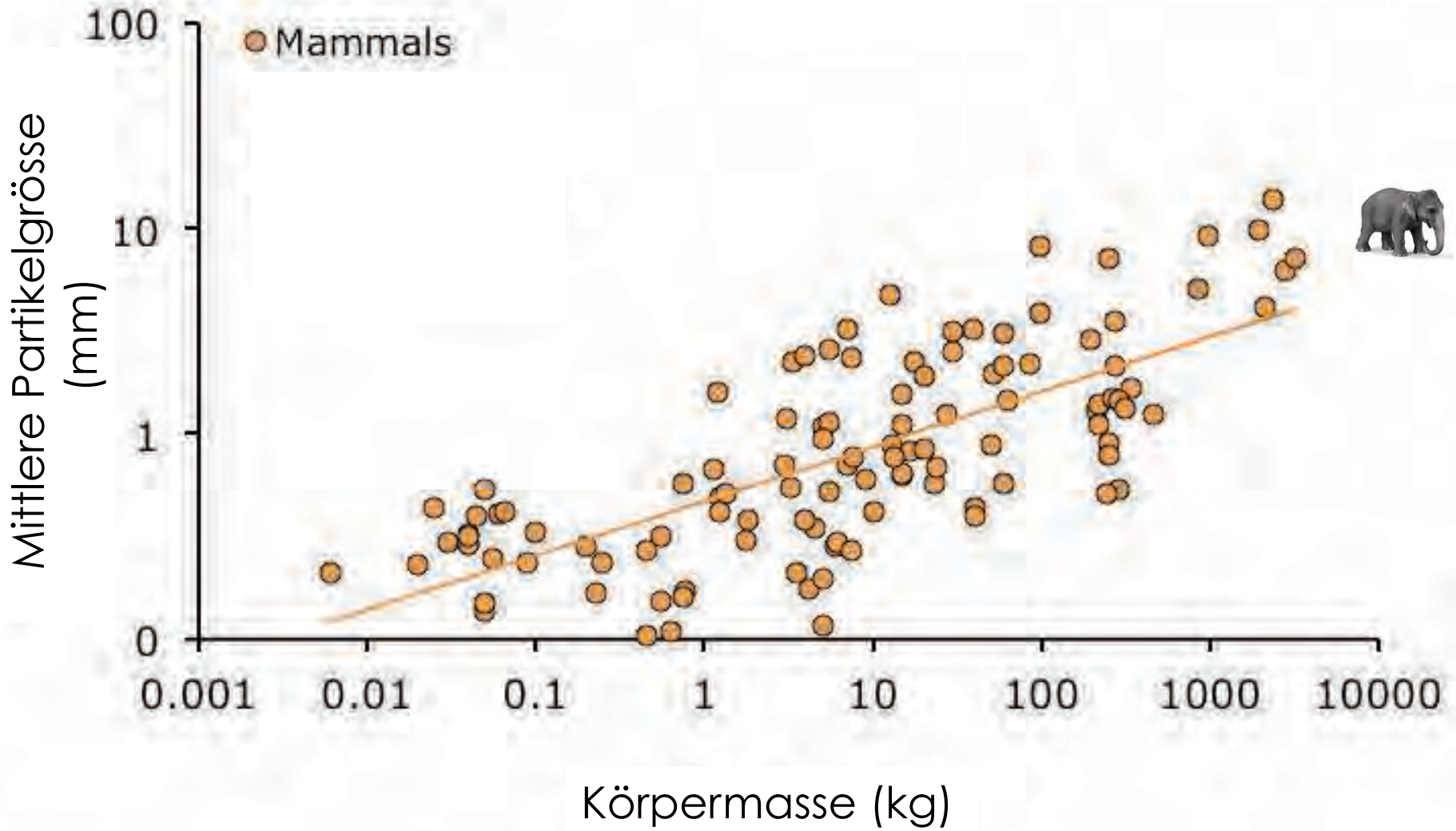

To Chew

To Chew or Not to Chew

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J. Exp. Zool. 313A:579–586, 2010

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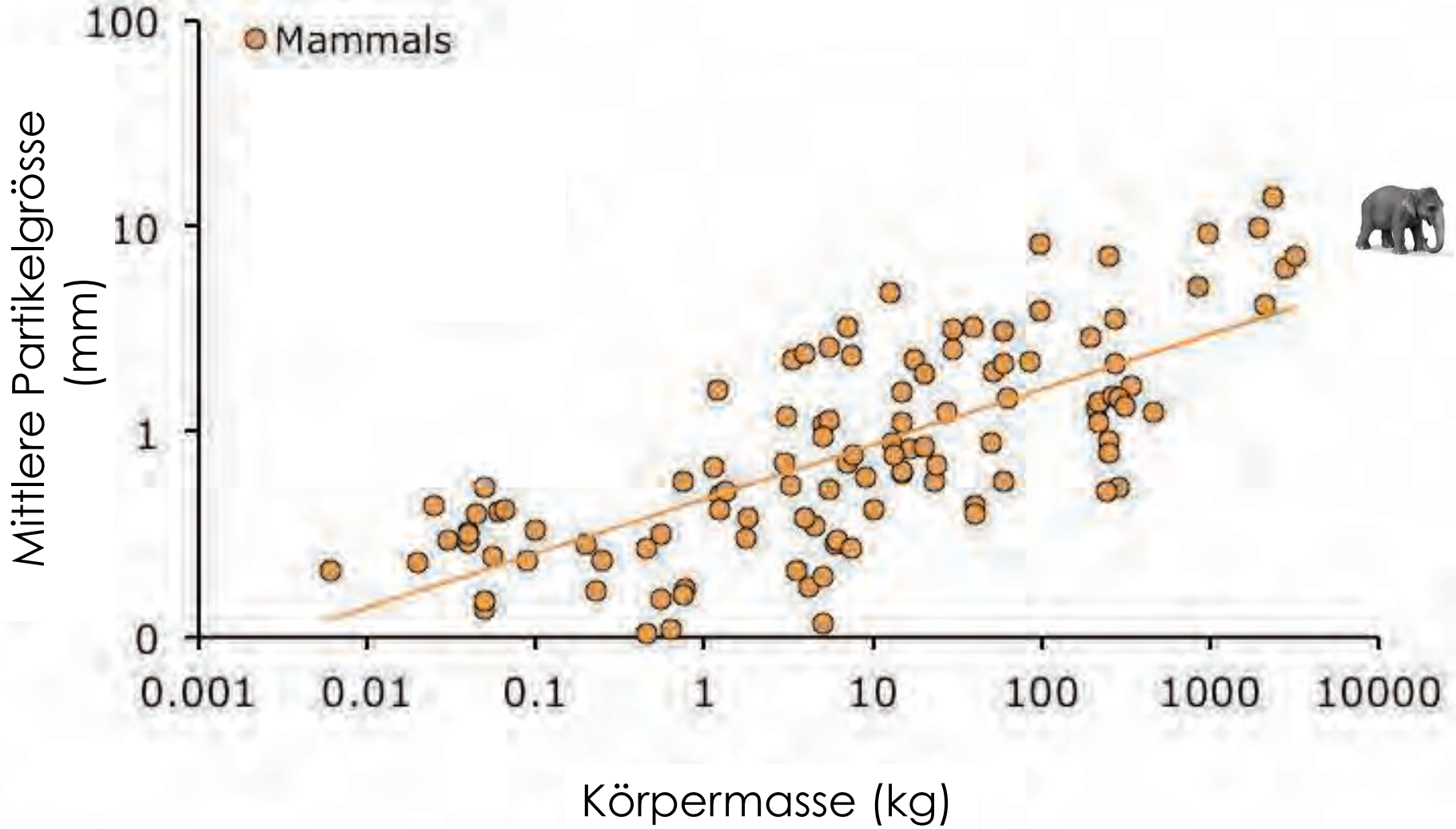

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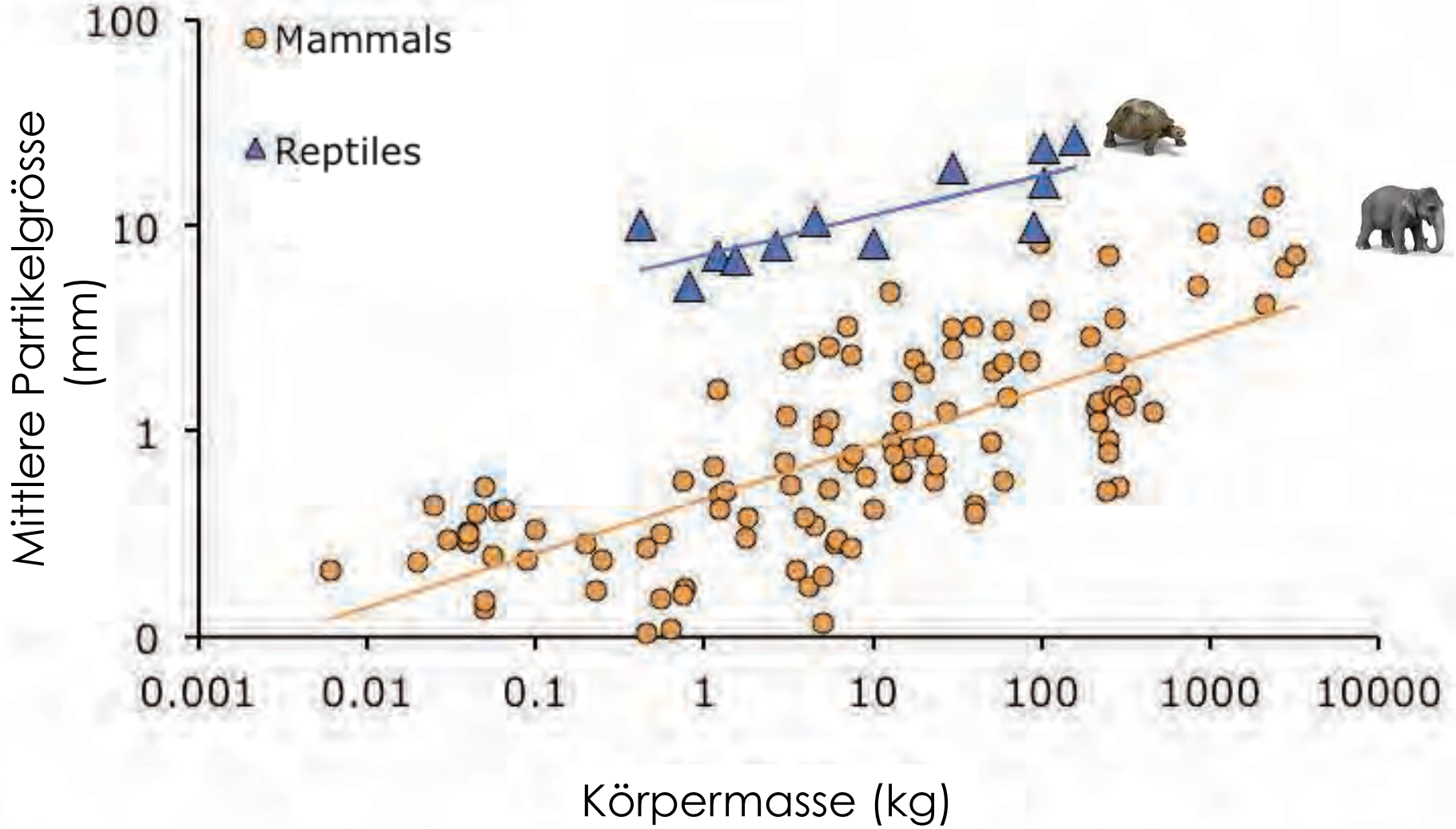

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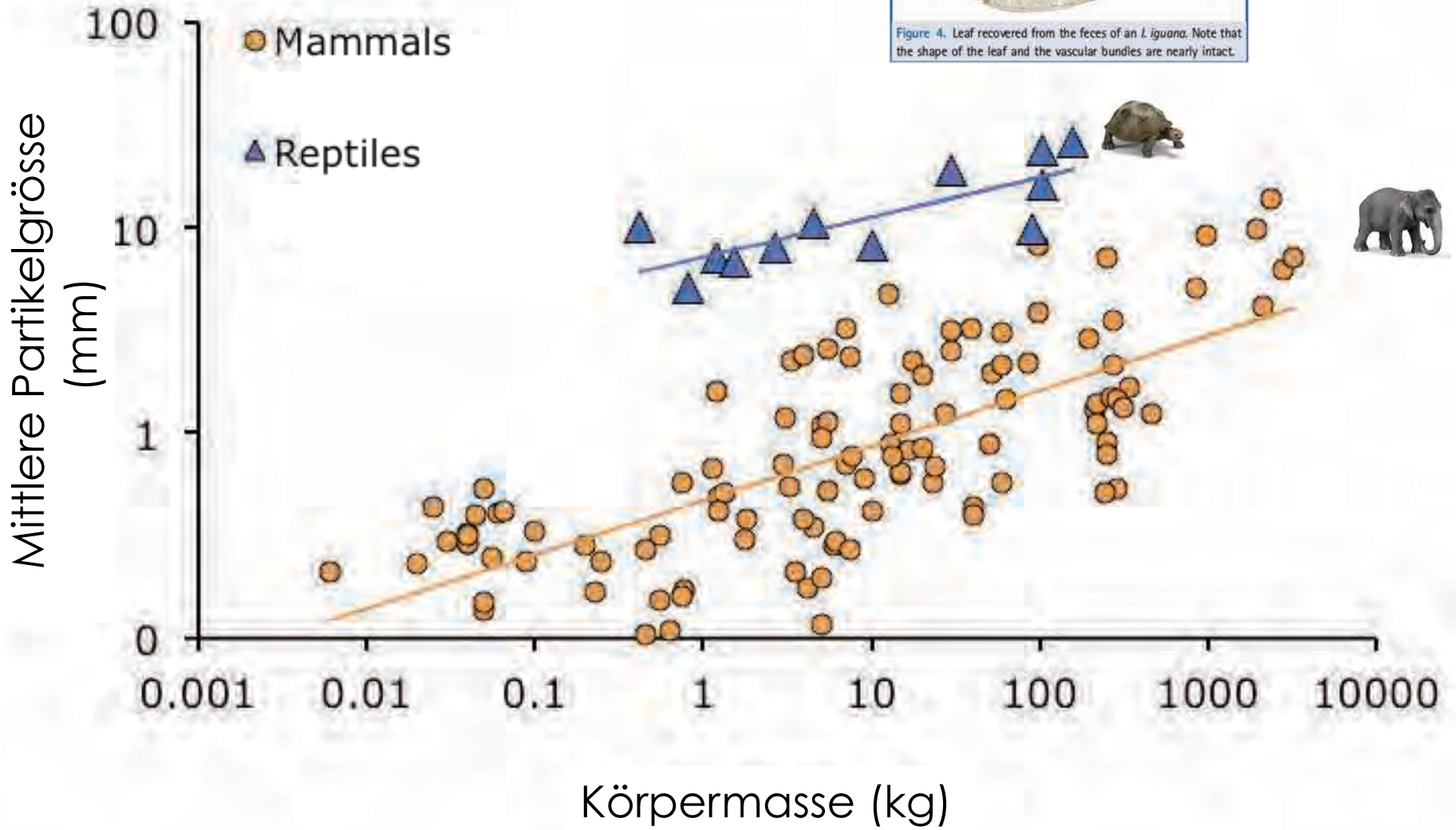
Figure 4. Leaf recovered from the feces of an *I. iguana*. Note that the shape of the leaf and the vascular bundles are nearly intact.



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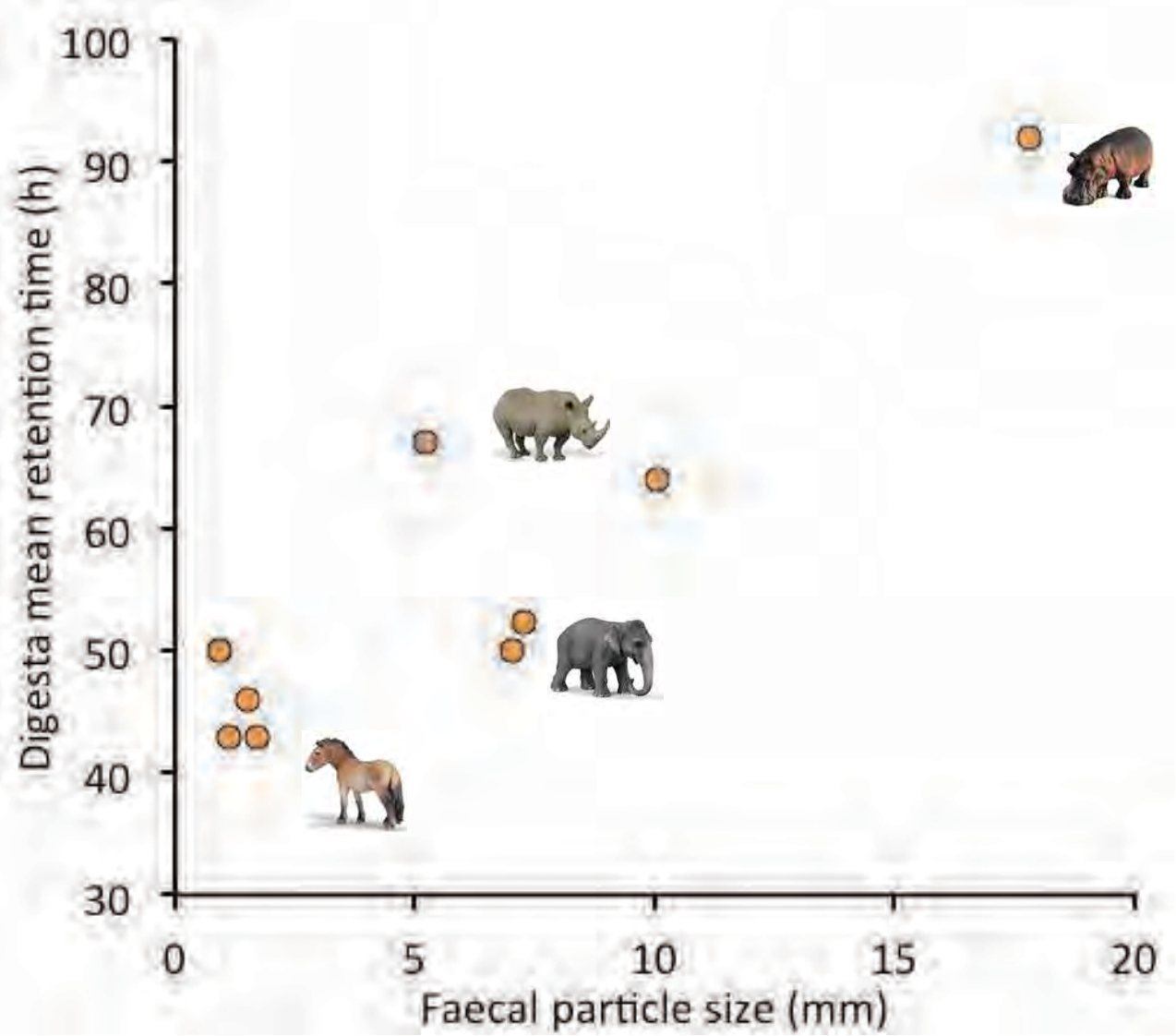

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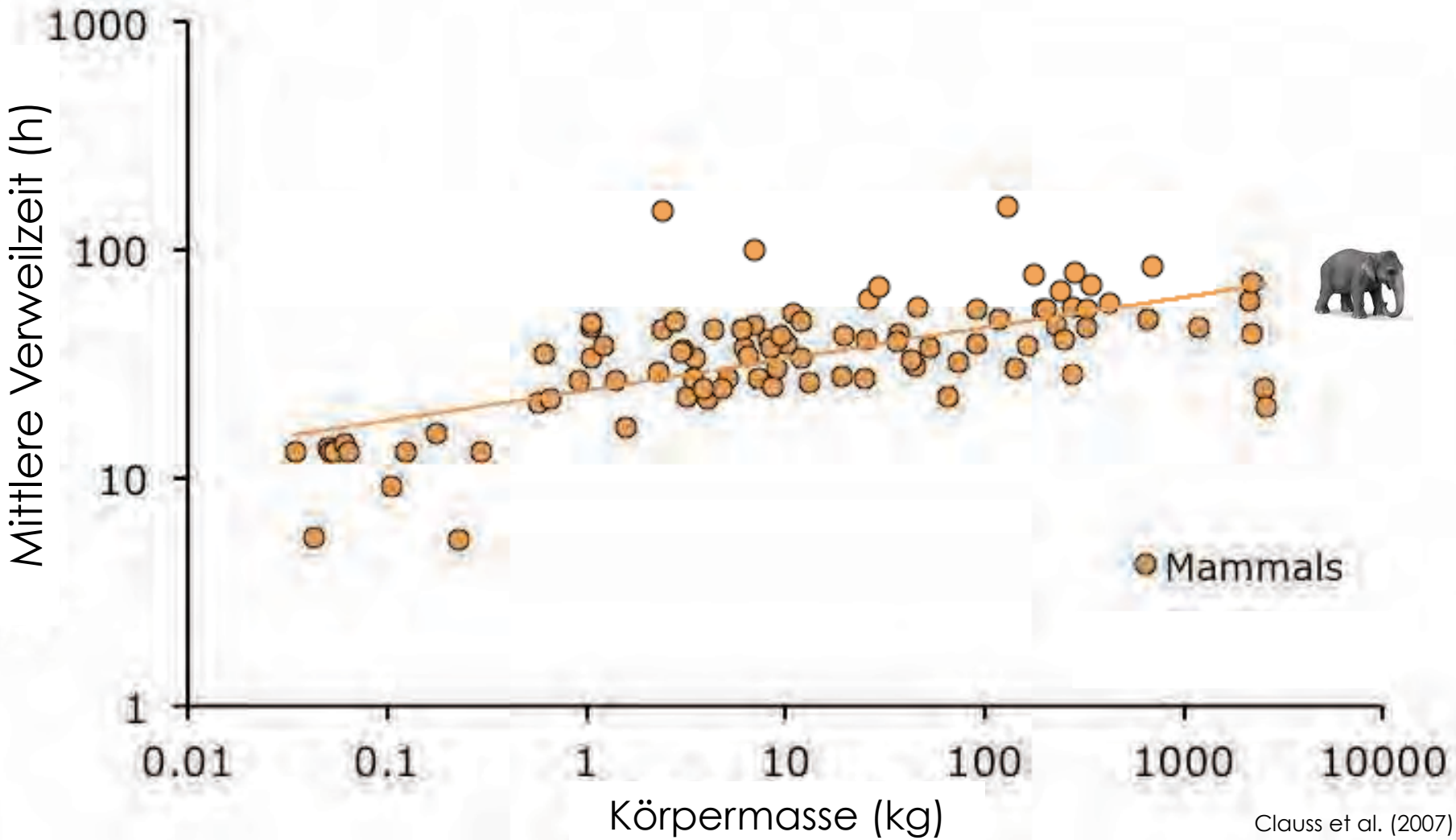

Clauss et al. (2007)

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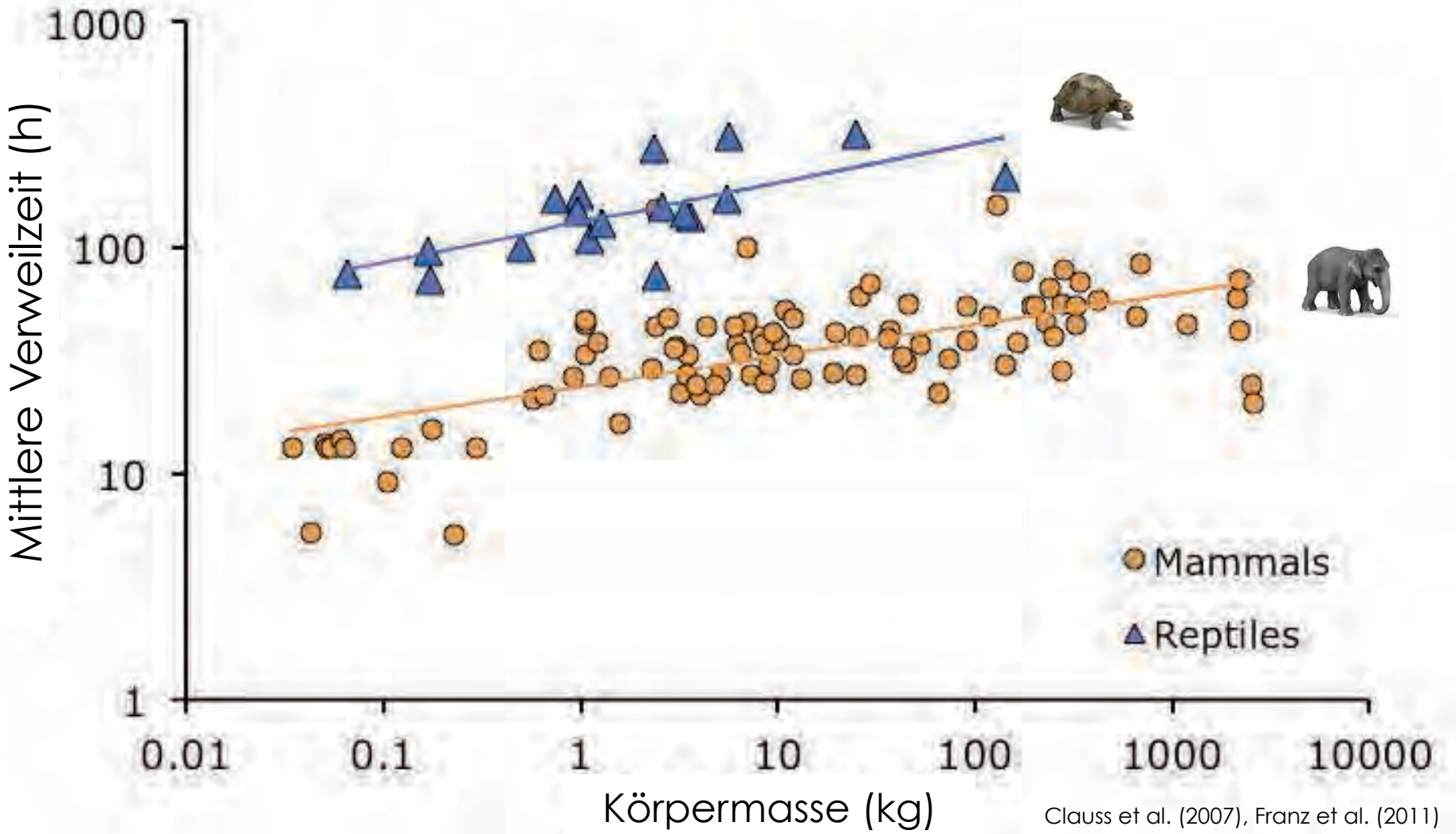

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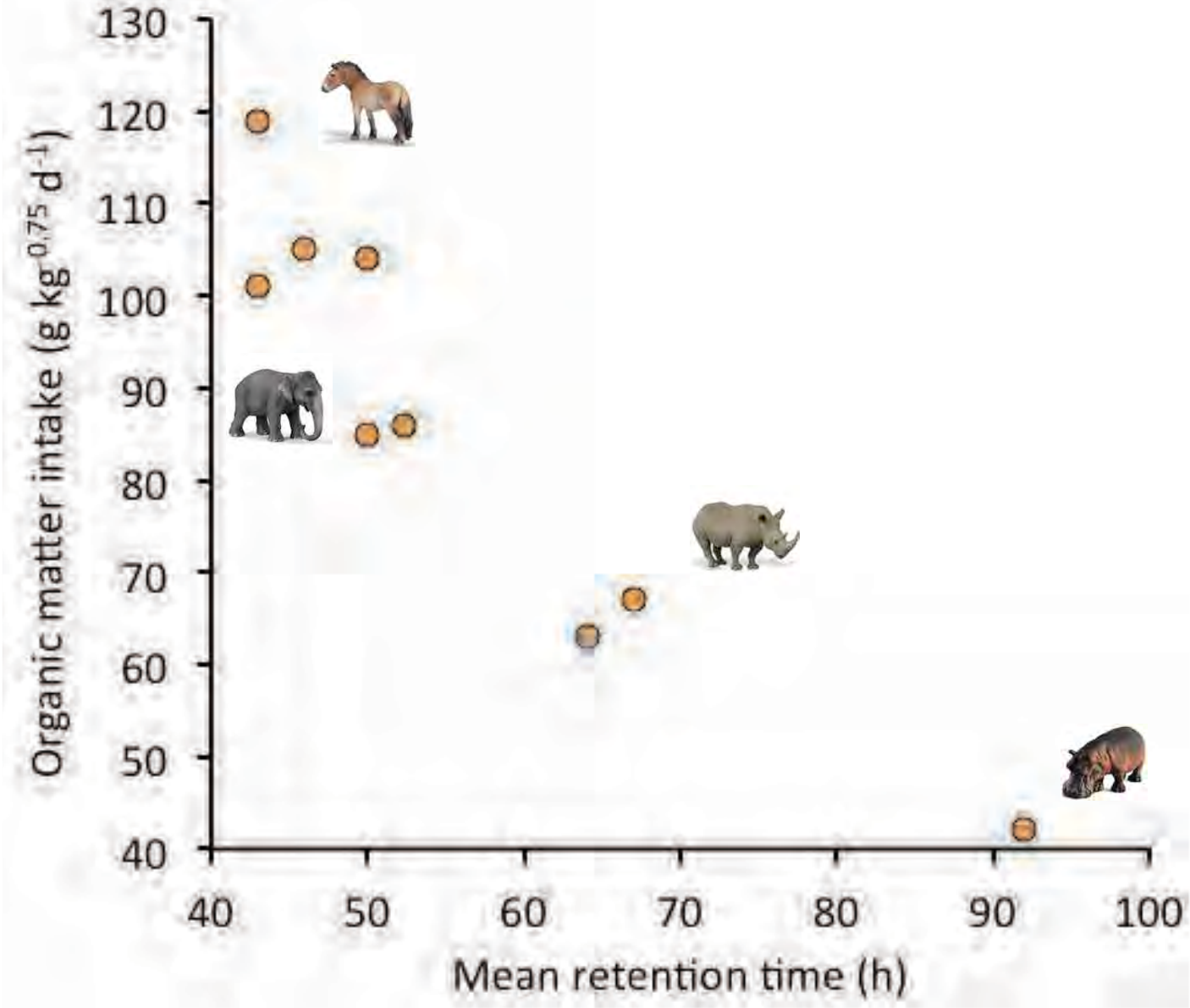

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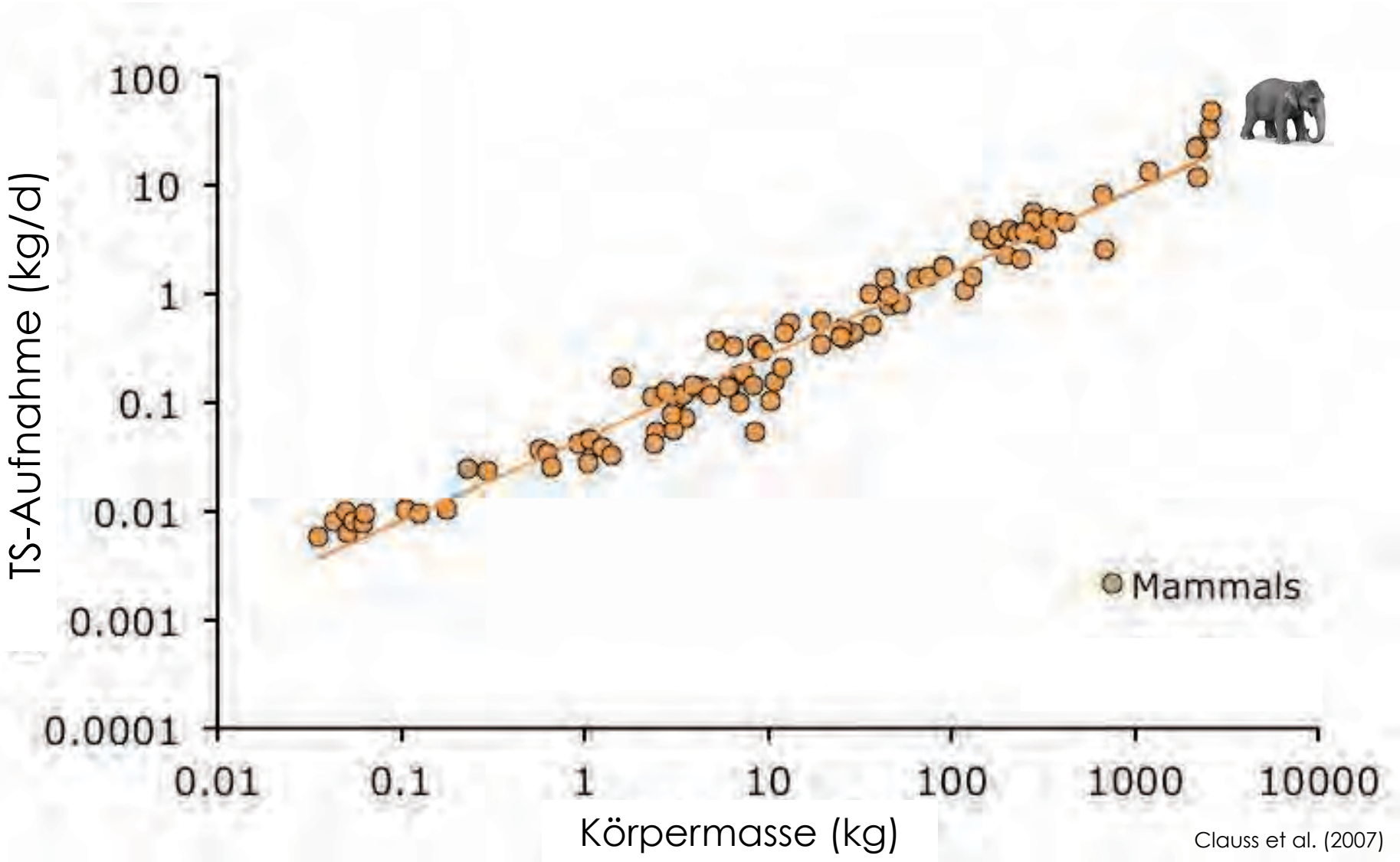

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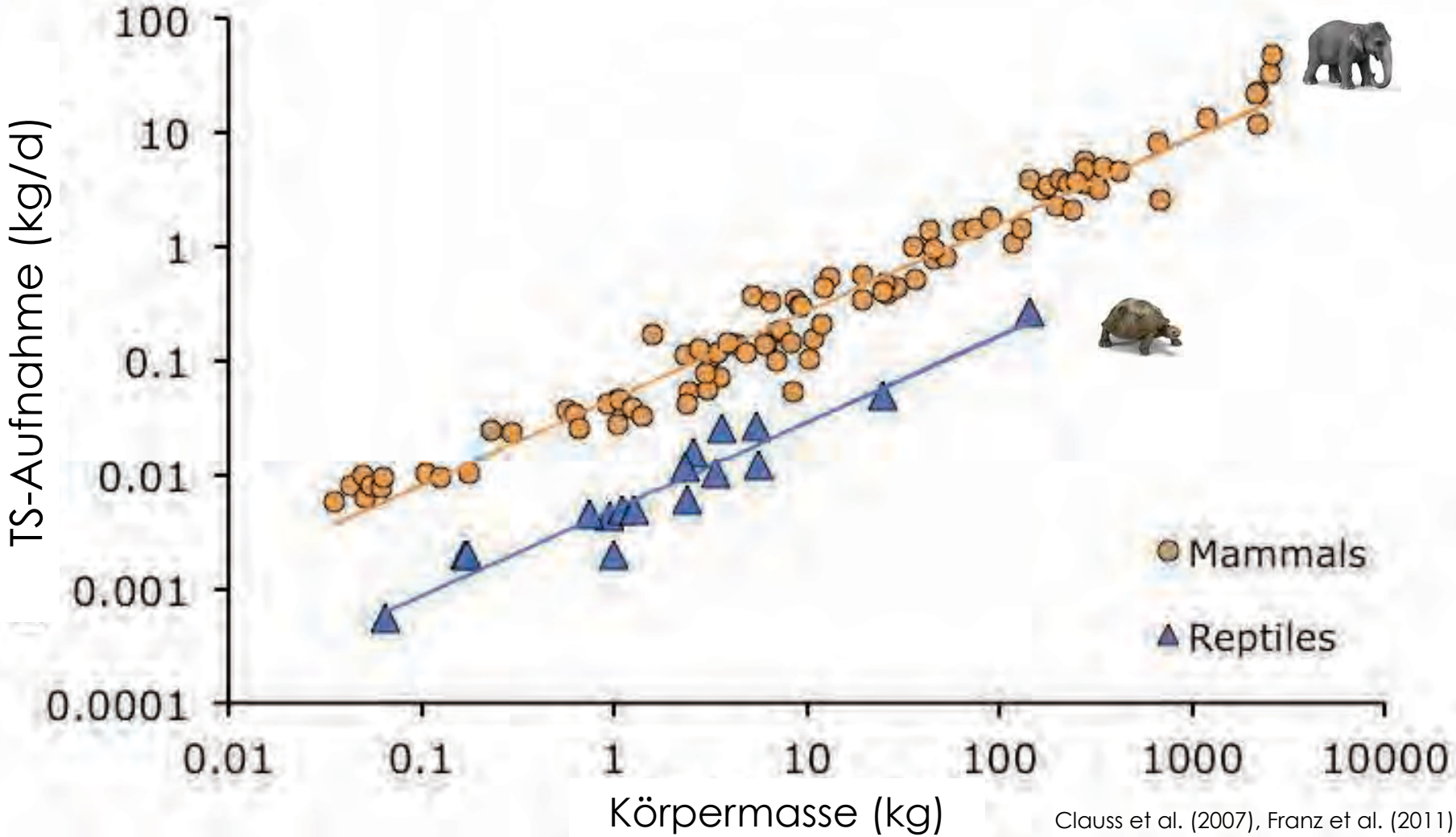

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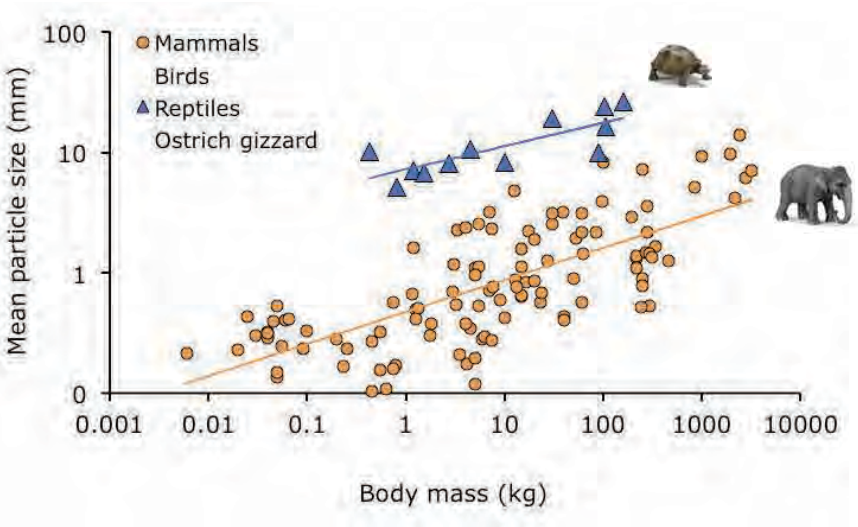
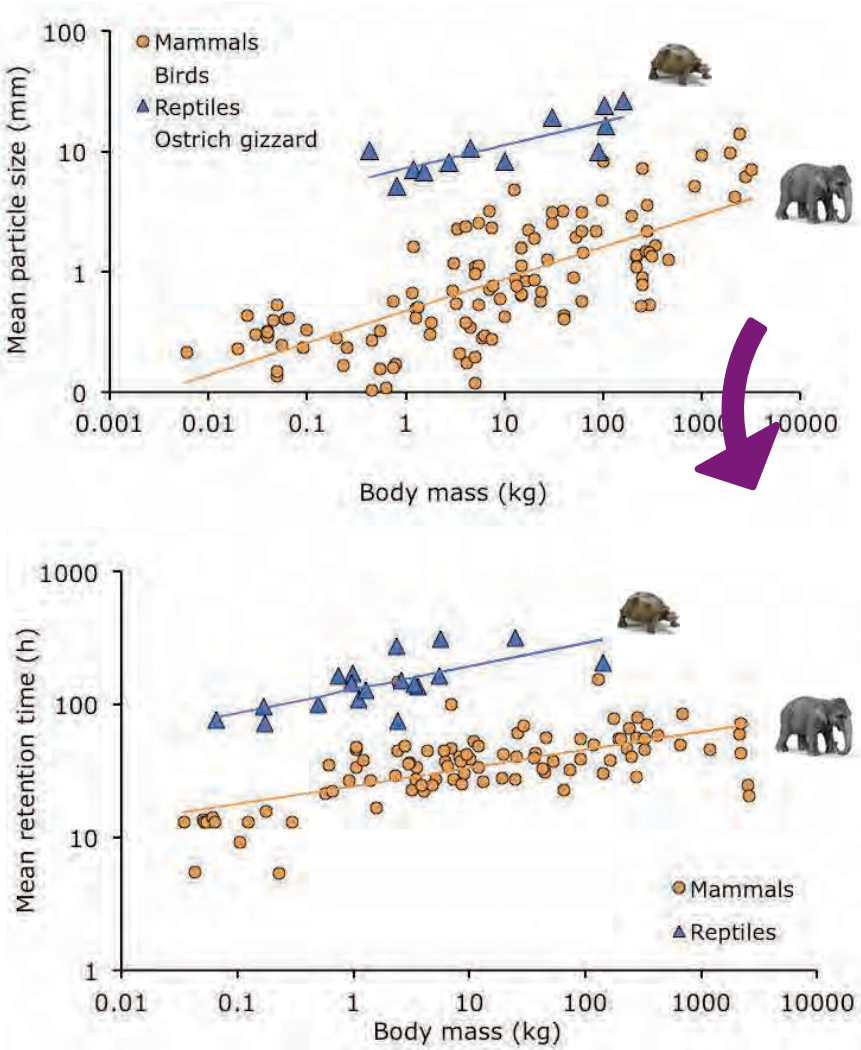
Kauen ...



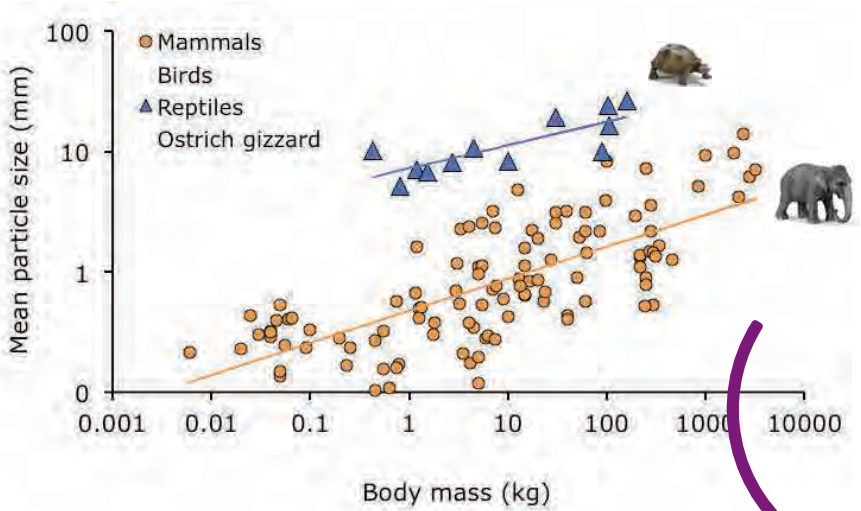
Fritz et al. (2009, 2010)

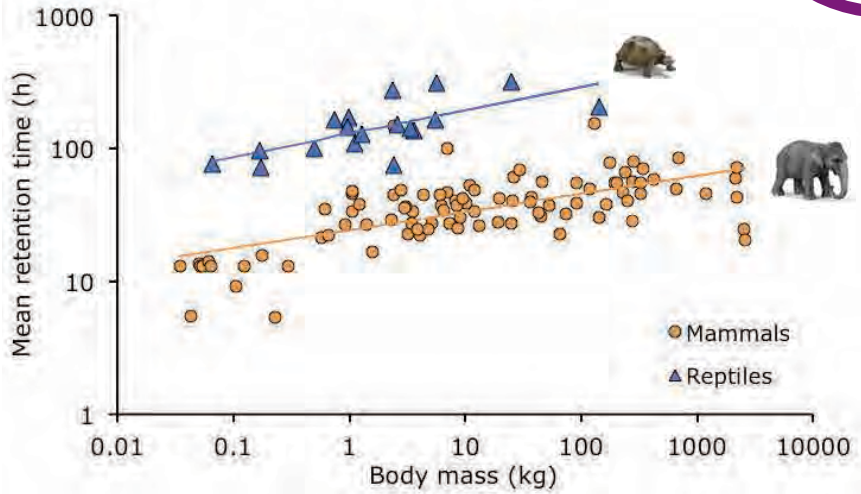
Kauen ... ermöglicht kurze Verweildauer

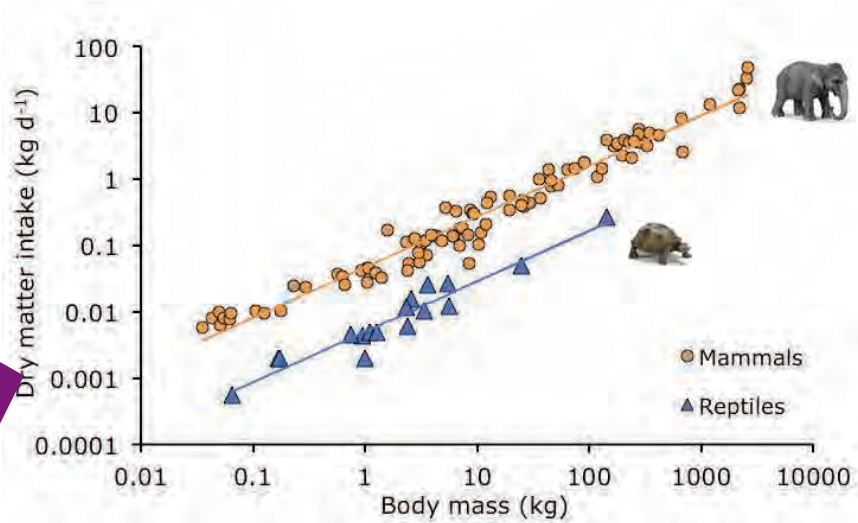


Clauss et al. (2007), Fritz et al. (2009, 2010), Franz et al. (2011)

Kauen ... ermöglicht hohe Futteraufnahme



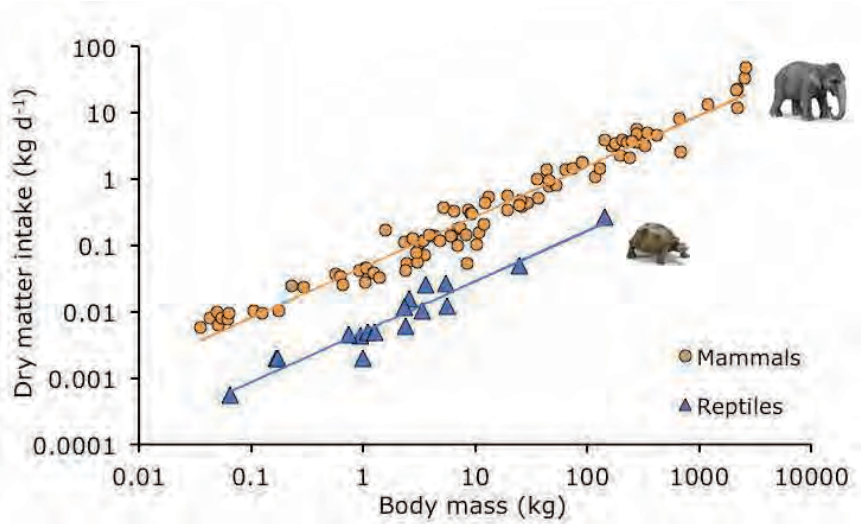




Clauss et al. (2007), Fritz et al. (2009, 2010), Franz et al. (2011)

Zerkleinern .. ermöglicht hohe Futteraufnahme

für Pflanzenfresser ist Futterzerkleinerung die Voraussetzung für Endothermie !



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

Zahnoptimierung:

Langlebigkeit I

Wodurch werden Zähne abgerieben ?

- ‘Härte’ der Nahrung (typische Vorstellung: Zweige, trockenes Brot)

- Abrasiva in/auf der Nahrung

- Zahn-Zahn-Kontakt => Kauen !

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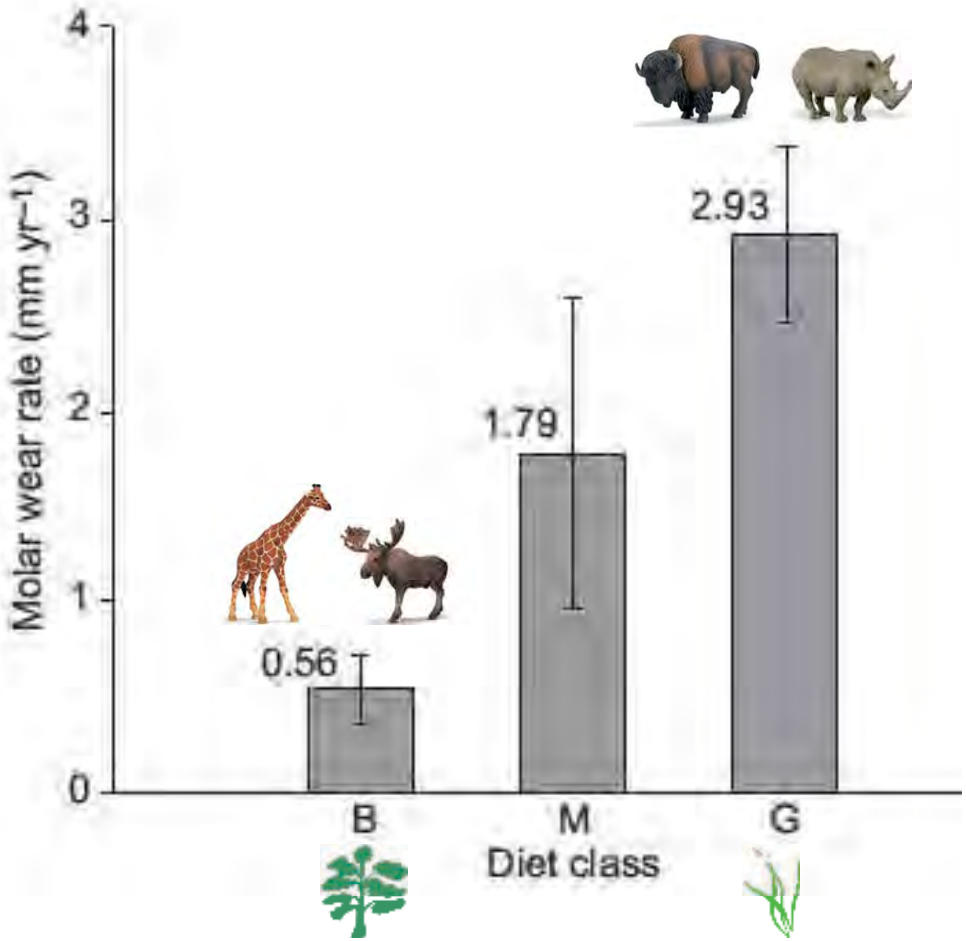
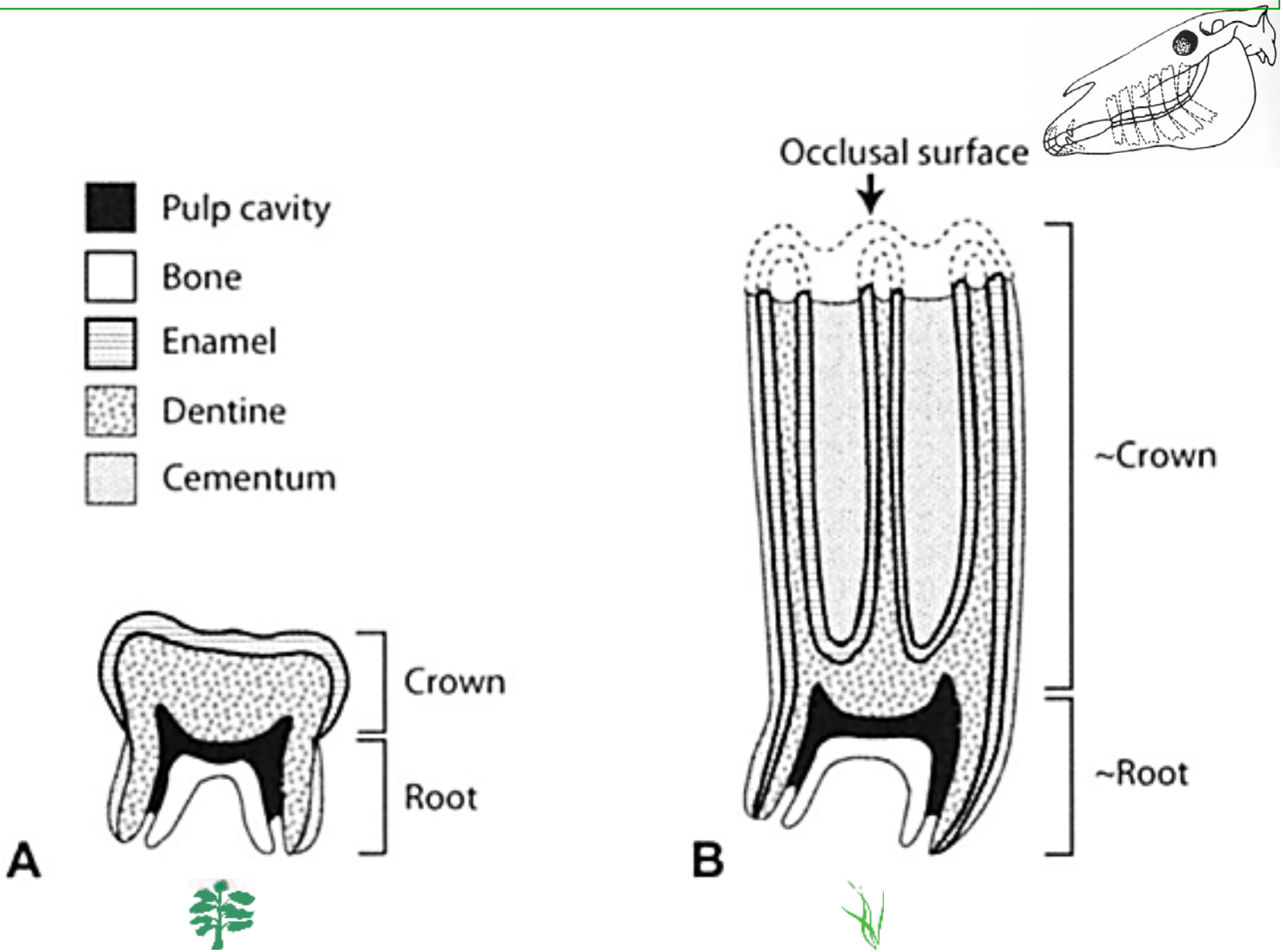
A comparison of observed molar wear rates in extant herbivorous mammals

John Damuth[1] & Christine M. Janis[2]

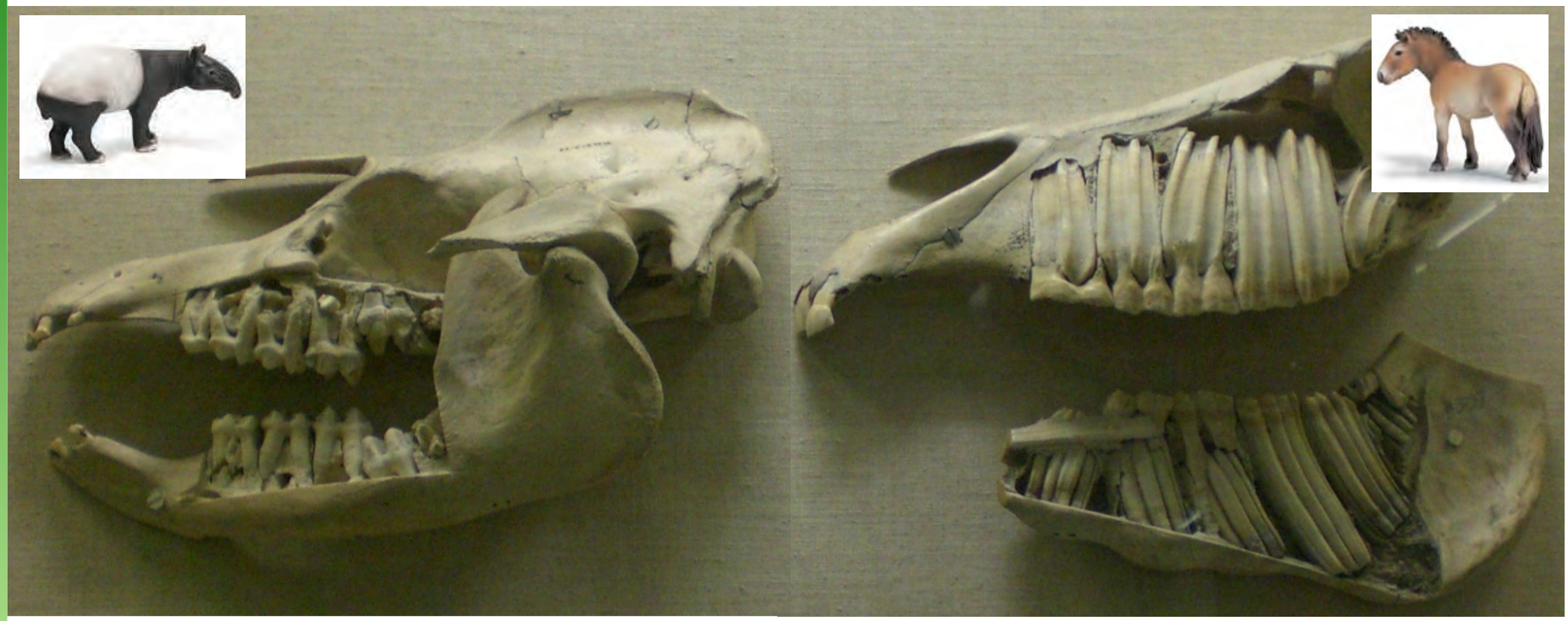
Ann. Zool. Fennici 51: 188–200
Helsinki 7 April 2014

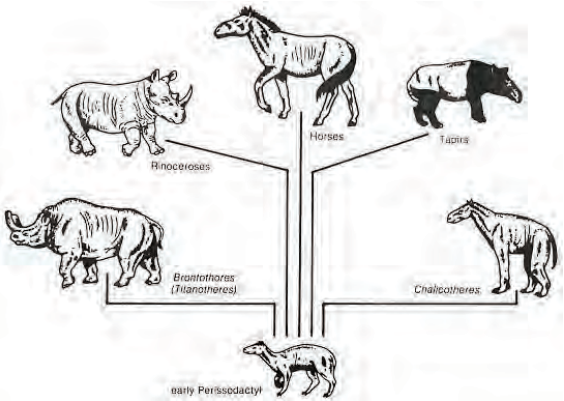


Hypsodontie



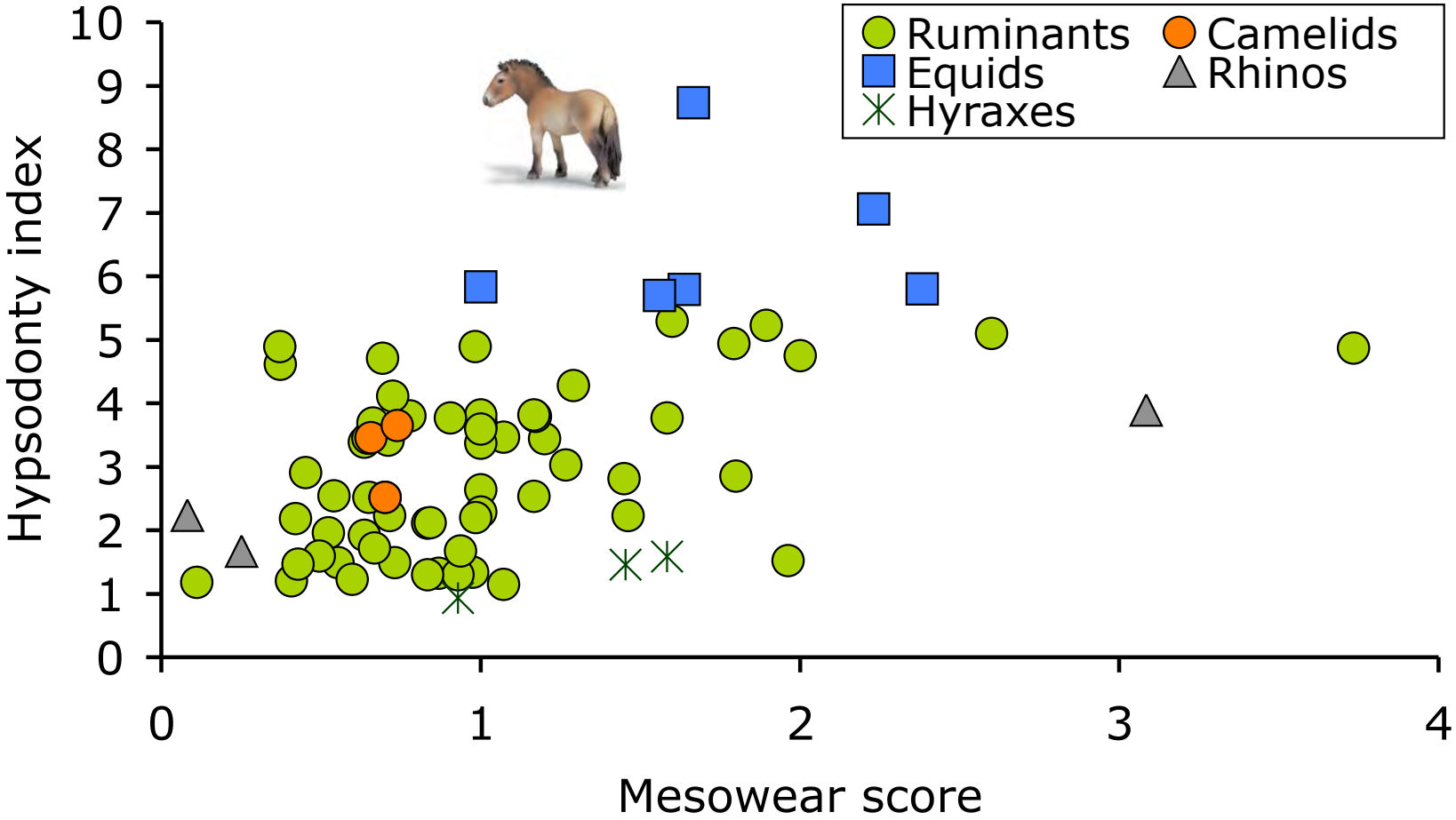
Hypsodontie





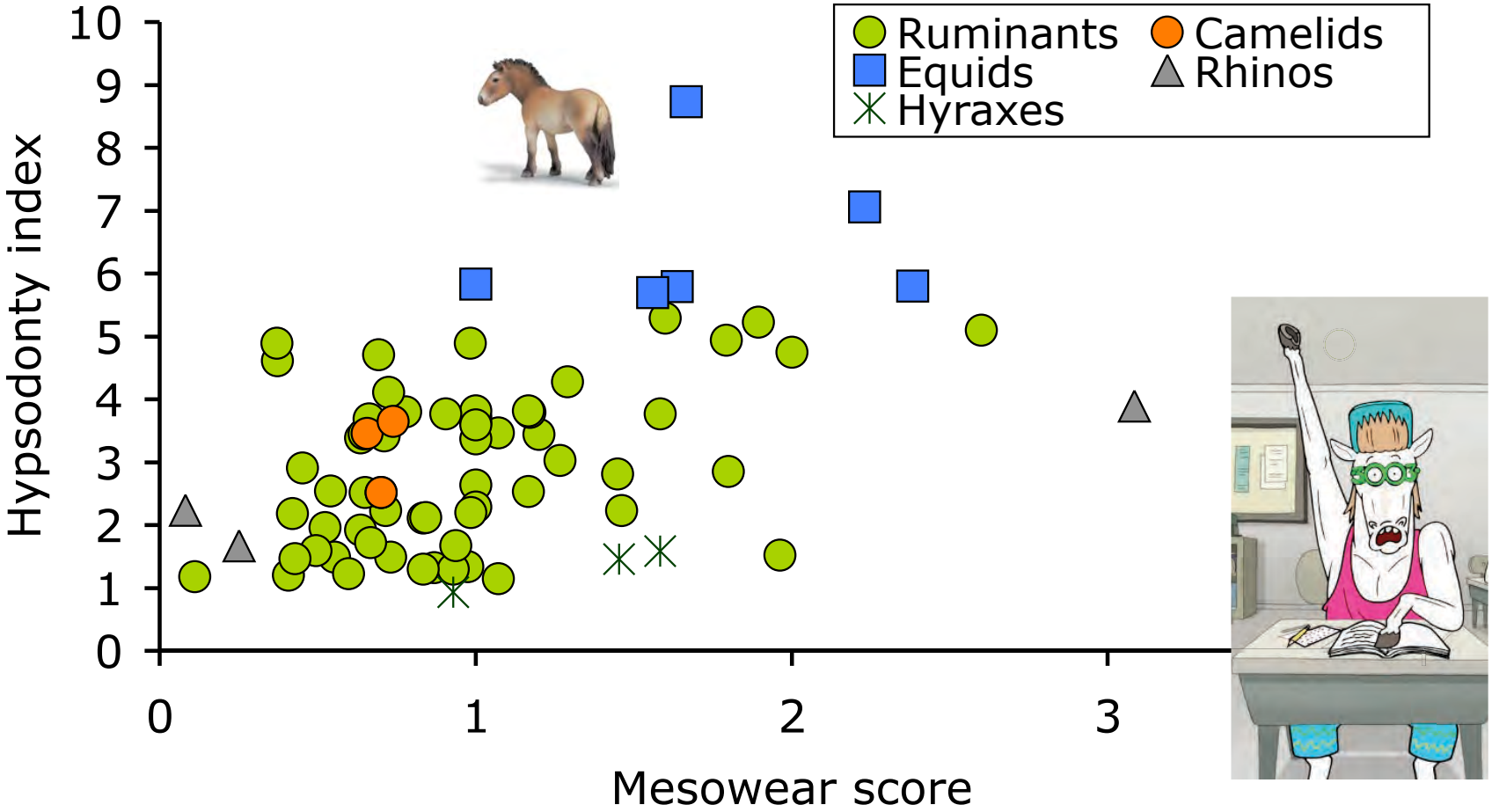
Hummel (unpubl.)

Hypsodontie



Kaiser et al. (2013)

Hypsodontie

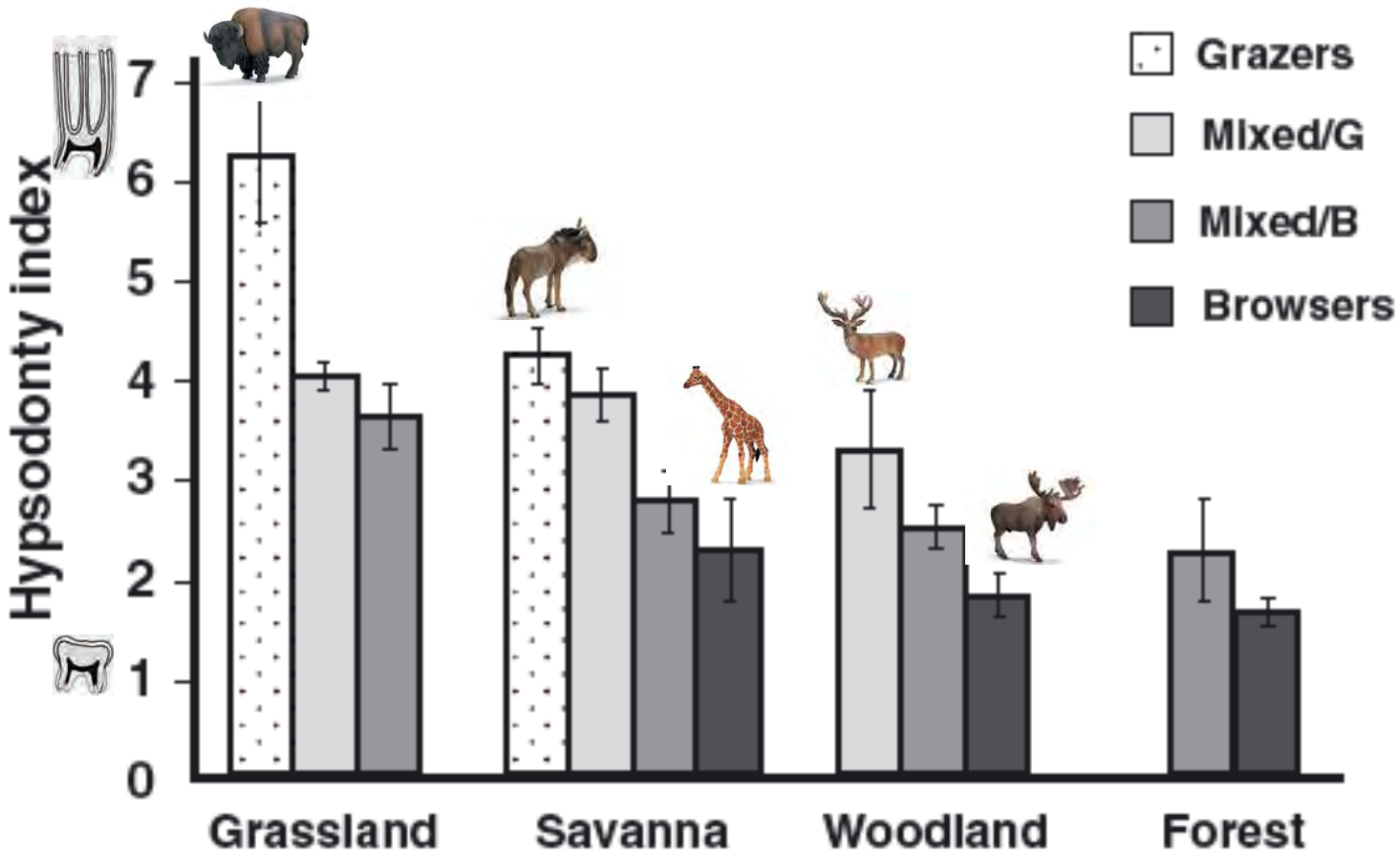


Kaiser et al. (2013)

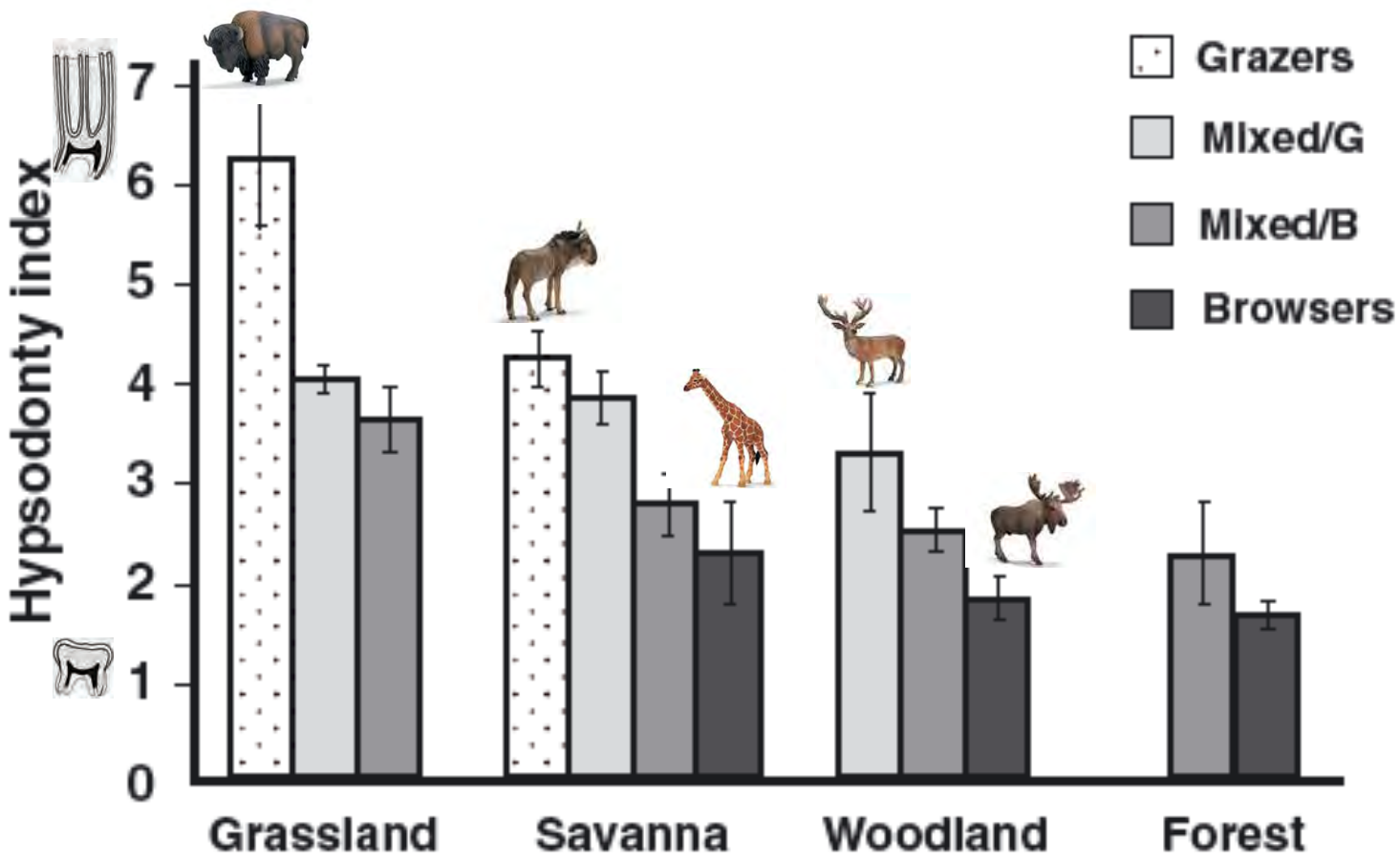
On the relationship between hypsodonty and feeding ecology in ungulate mammals, and its utility in palaeoecology

John Damuth[1]* and Christine M. Janis[2]

Biol. Rev. (2011).



Womit korreliert Hypsodontie ?



Another one bites the dust: faecal silica levels in large herbivores correlate with high-crowned teeth

Jürgen Hummel[1,*], Eva Findeisen[1], Karl-Heinz Südekum[1], Irina Ruf[2], Thomas M. Kaiser[3], Martin Bucher[4], Marcus Clauss[5] and Daryl Codron[5]

Proc. R. Soc. B (2011) 278, 1742–1747

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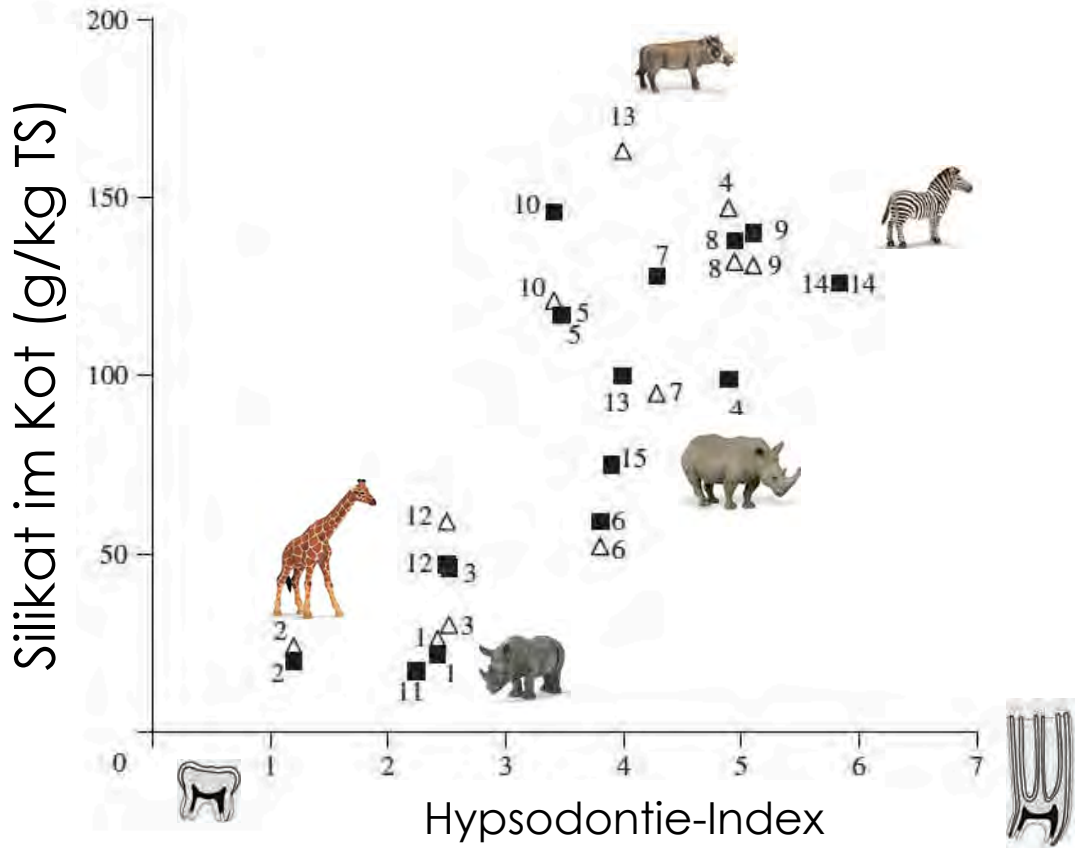
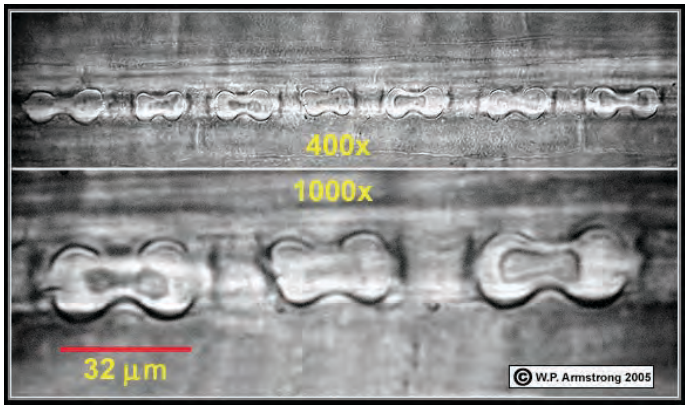


Woher das Silikat ?

- Staub/Schmutz
  (externe Abrasiva)?

- Phytolithe
  (interne Abrasiva)?



Sind Phytolithe abrasiv ?

Do silica phytoliths really wear mammalian teeth?

Gordon D. Sanson [a,*], Stuart A. Kerr [a], Karlis A. Gross [b]

Journal of Archaeological Science 34 (2007) 526–531

JOURNAL OF THE ROYAL SOCIETY Interface

2013

rsif.royalsocietypublishing.org

J R Soc Interface 10: 20120923.

Mechanisms and causes of wear in tooth enamel: implications for hominin diets

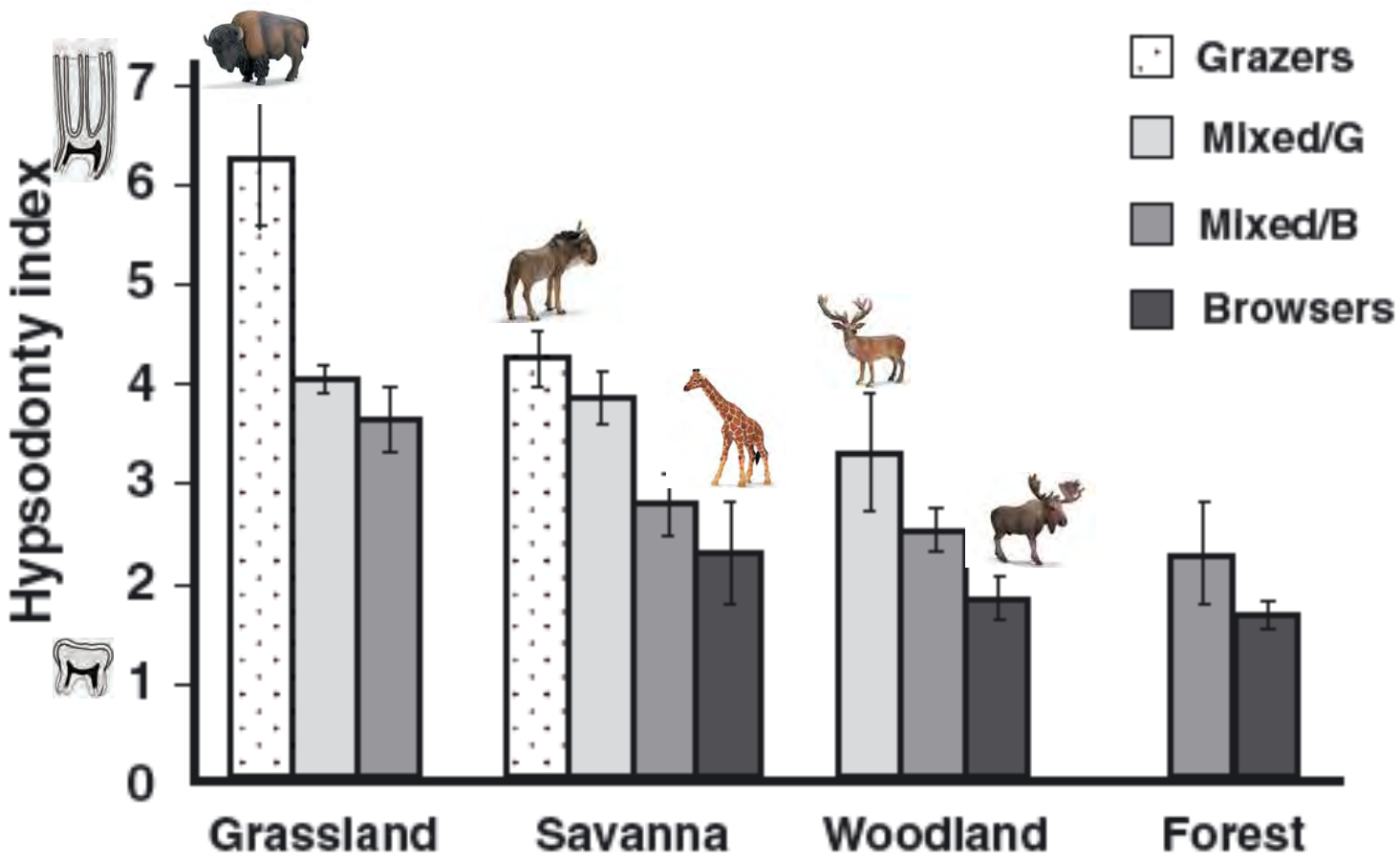
Peter W. Lucas[1], Ridwaan Omar[2], Khaled Al-Fadhalah[3], Abdulwahab S. Almusallam[4], Amanda G. Henry[6], Shaji Michael[5], Lidia Arockia Thai[5], Jörg Watzke[6], David S. Strait[7] and Anthony G. Atkins[8]

Untangling the environmental from the dietary: dust does not matter

Proc. R. Soc. B
283: 20161032.

Gildas Merceron[1], Anusha Ramdarshan[1], Cécile Blondel[1], Jean-Renaud Boisserie[1,2], Noël Brunetiere[3], Arthur Francisco[3], Denis Gautier[4,5], Xavier Milhet[3], Alice Novello[6] and Dimitri Pret[7]

Womit korreliert Hypsodontie ?



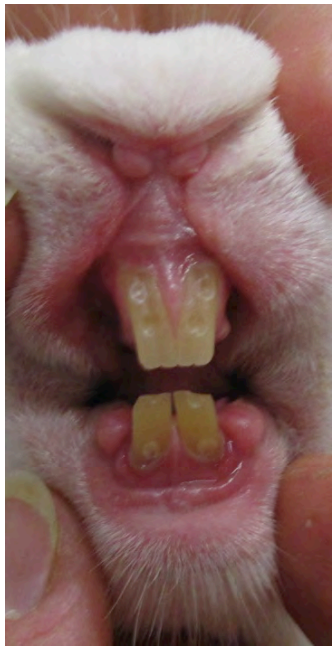
RESEARCH ARTICLE

Growth and Wear of Incisor and Cheek Teeth in Domestic Rabbits (*Oryctolagus cuniculus*) Fed Diets of Different Abrasiveness

JOURNAL OF EXPERIMENTAL ZOOLOGY
PART A
ECOLOGICAL GENETICS AND PHYSIOLOGY
A Journal of Integrative Biology

JACQUELINE MÜLLER[1], MARCUS CLAUSS[1]*, DARYL CODRON[1,2], ELLEN SCHULZ[3], JÜRGEN HUMMEL[4], MIKAEL FORTELIUS[5], PATRICK KIRCHER[6], AND JEAN-MICHEL HATT[1]

J. Exp. Zool. 321A:283–298, 2014



Experimentelle Futtermischungen

Table 1. Composition of different complete pelleted diets (lucerne L, grass G, grass and rice hulls GR, grass and rice hulls and sands GRS) and grass hay (H).

	L	G	GR	GRS	H
Ingredients					
Lucerne meal (%)	60.0	–	–	–	–
Grass meal (%)	–	60.0	64.8	64.8	–
Rice hulls (%)	–	–	20.0	20.0	–
Sand[a] (%)	–	–	–	5.0	–
Pure lignocellulose (%)	33.8	27.4	5.0	–	–
Soybean meal (%)	–	7.0	5.0	5.0	–
Molasses (%)	3.0	3.0	3.0	3.0	–
Lignobond (%)	2.0	2.0	2.0	2.0	–
Soy oil (%)	1.0	0.4	–	–	–
Mineral/vitamin premix (%)	0.2	0.2	0.2	0.2	–
Dry matter (% as fed)	91.4	91.9	91.8	92.2	90.8
Nutrient composition (g/kg DM)					
Total ash	79	64	75	130	104
Crude protein	102	90	97	85	109
aNDFom[b]	578	600	487	459	579
ADFom[c]	434	403	322	299	354
ADL[d]	131	110	74	65	52
Dry matter digestibility (%)	39.7 ± 9.3	34.3 ± 8.1	41.2 ± 5.7	40.7 ± 11.1	45.1 ± 4.1

[a]Sand for playgrounds, grain size 0–1 mm, REDSUN garden products B.V., Heijen, Denmark; mean particle size measured by sieve analysis as dMEAN (Fritz et al., 2012) of 0.233 mm.
[b]aNDFom neutral detergent fiber, determined using amylase and ash corrected.
[c]ADFom acid detergent fiber, ash corrected.
[d]ADL acid detergent lignin ash corrected.
[e]ADIA acid detergent insoluble ash (a measure for abrasives).

Experimentelle Futtermischungen

Unterschied in Abrasiva !

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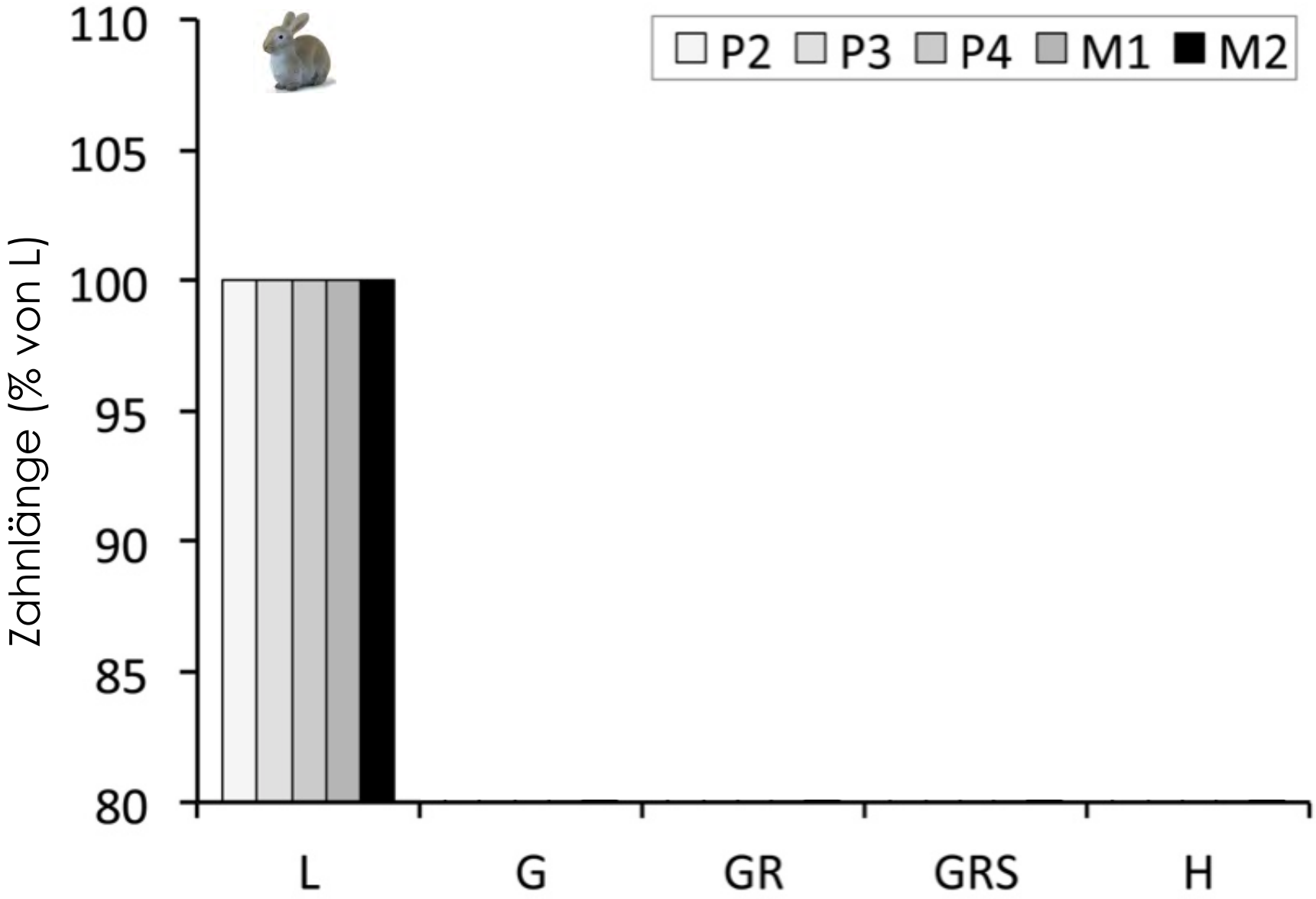
Relative Zahnlänge



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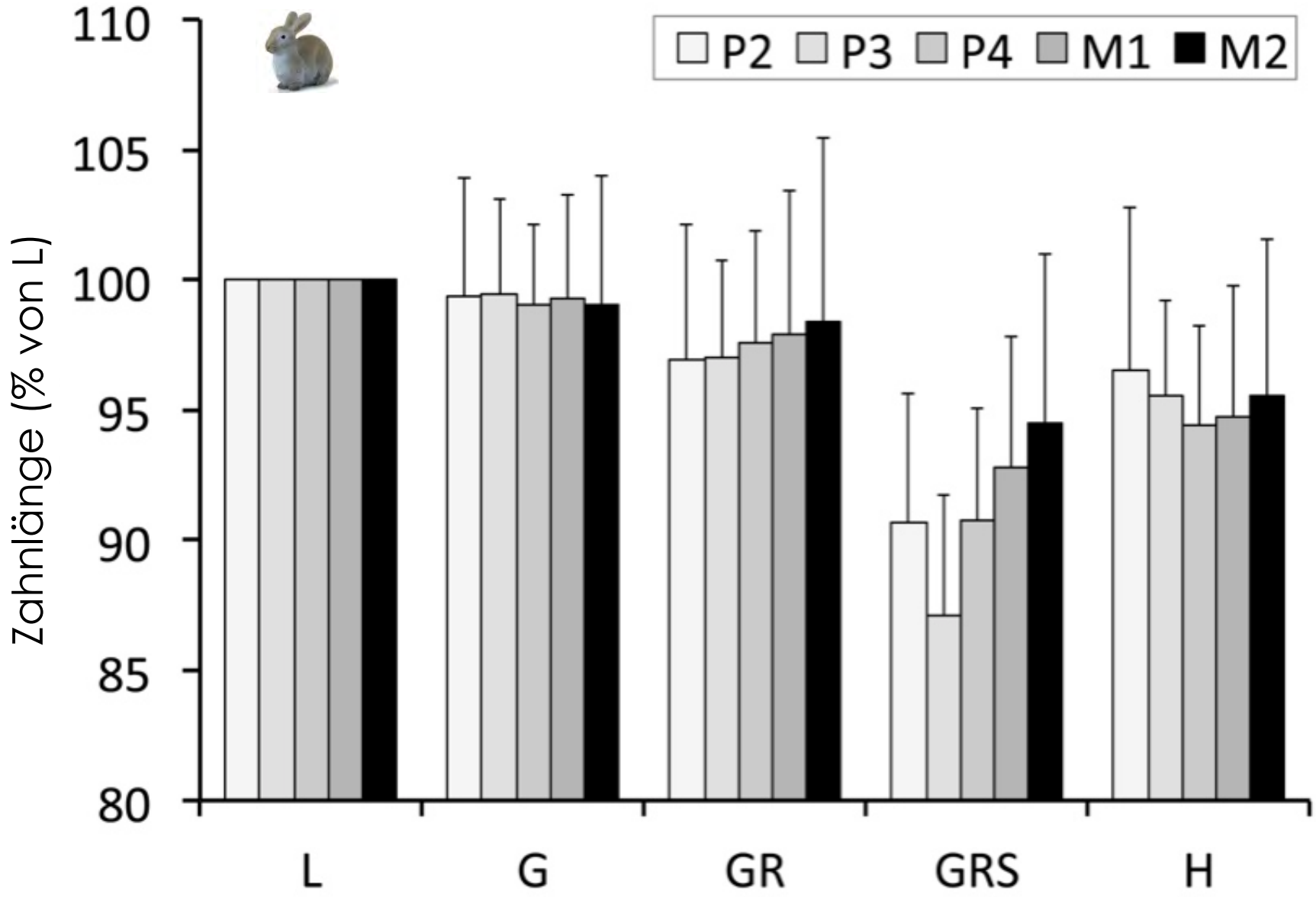

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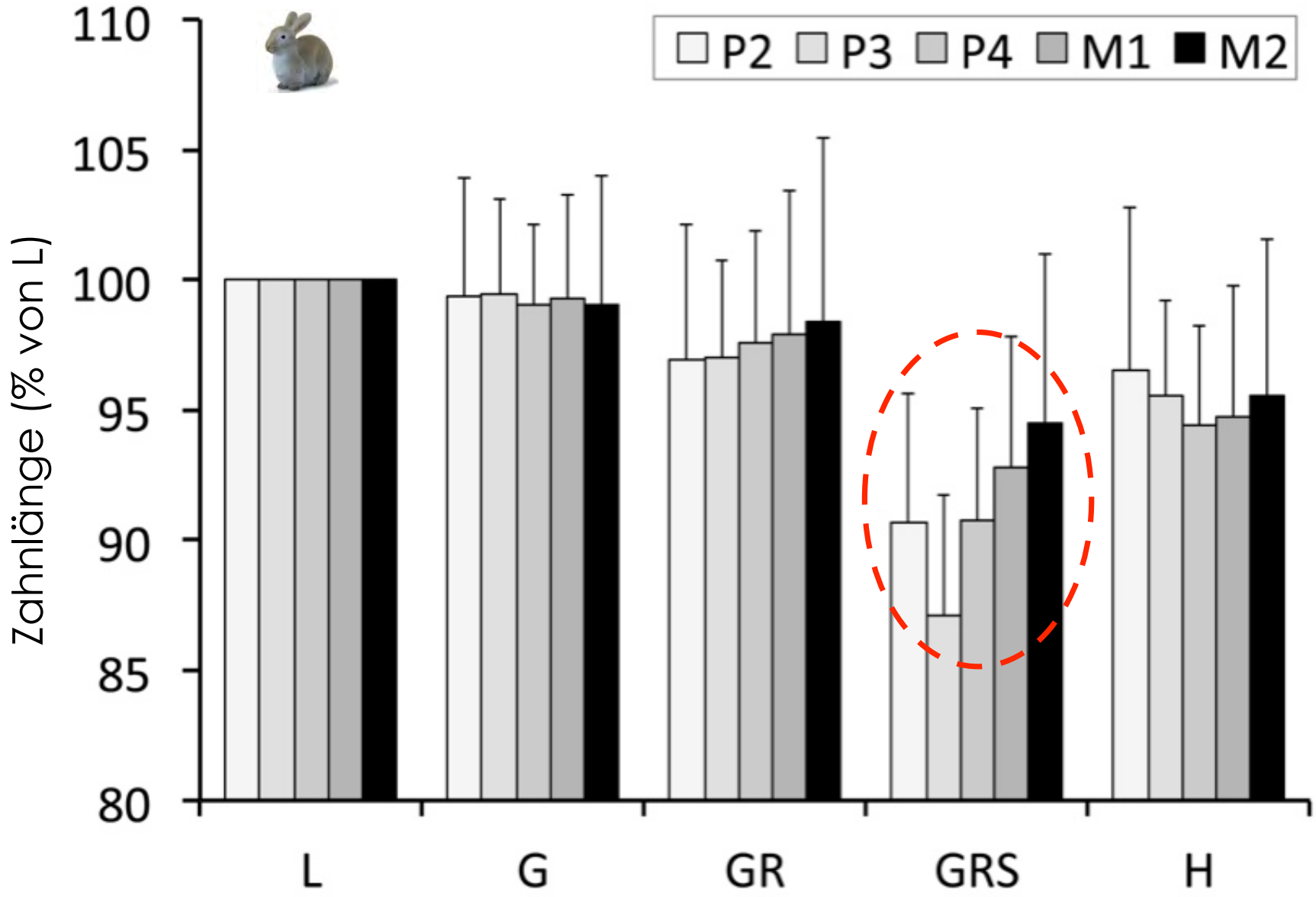

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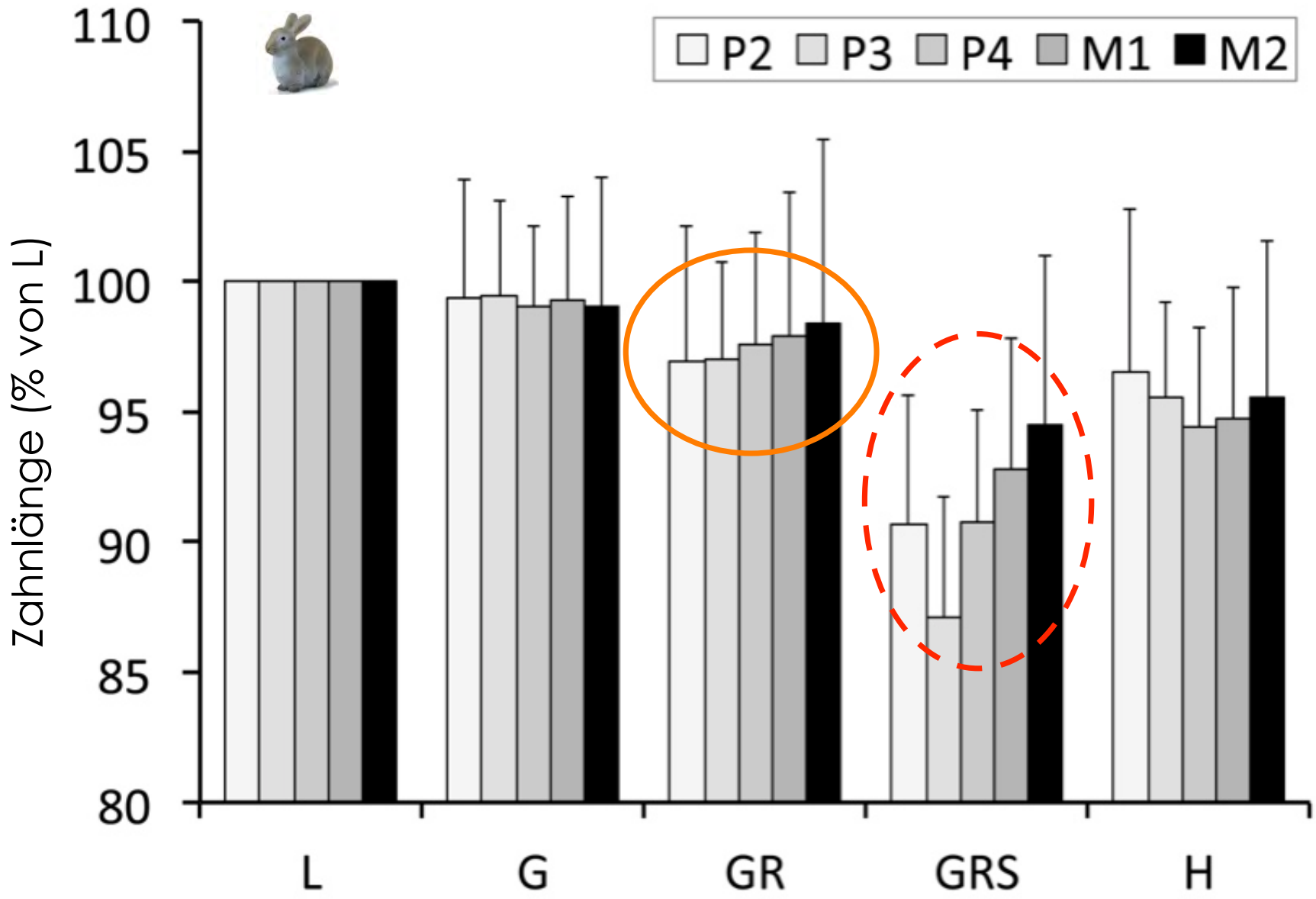
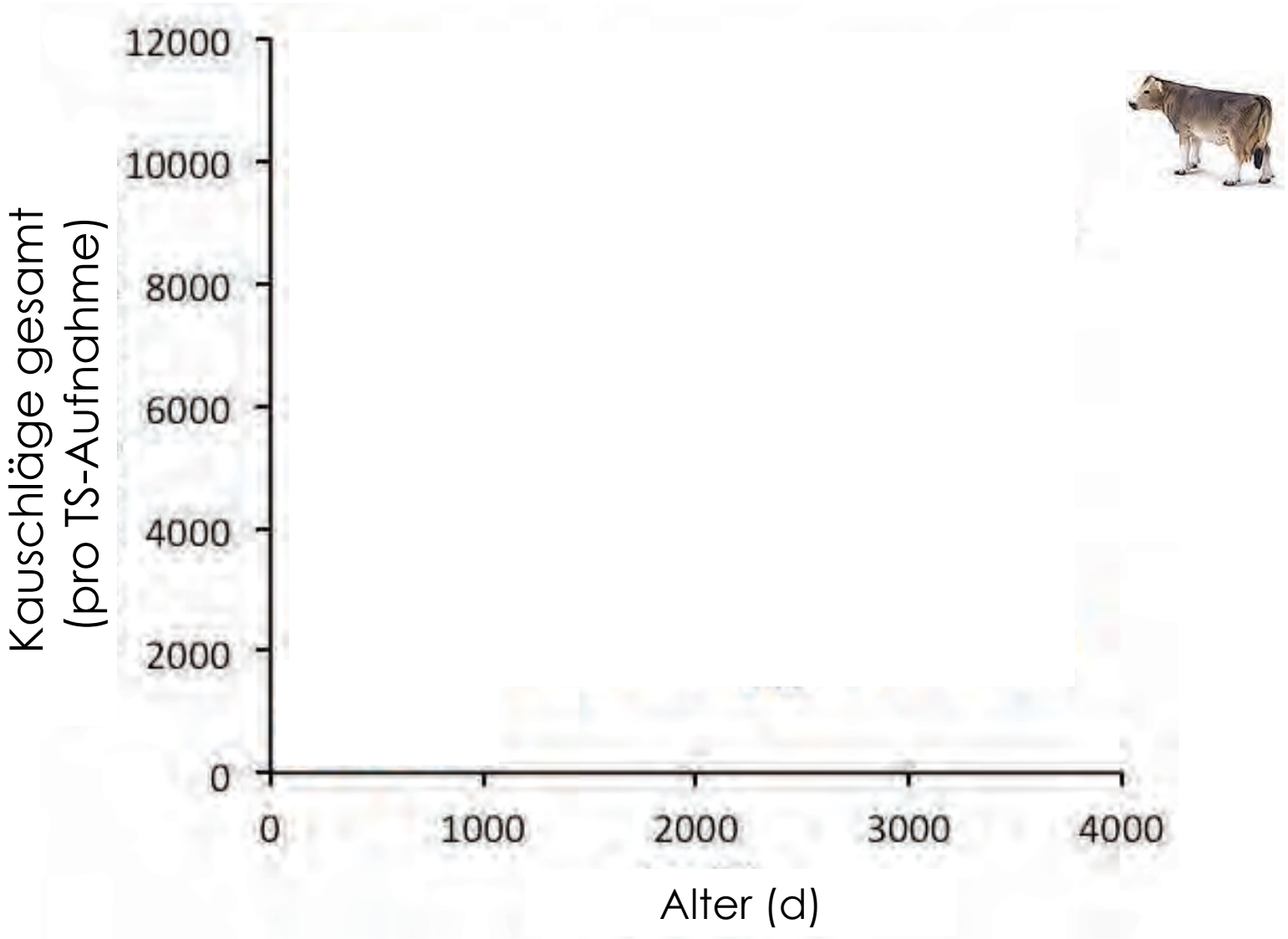


Zahnoptimierung:

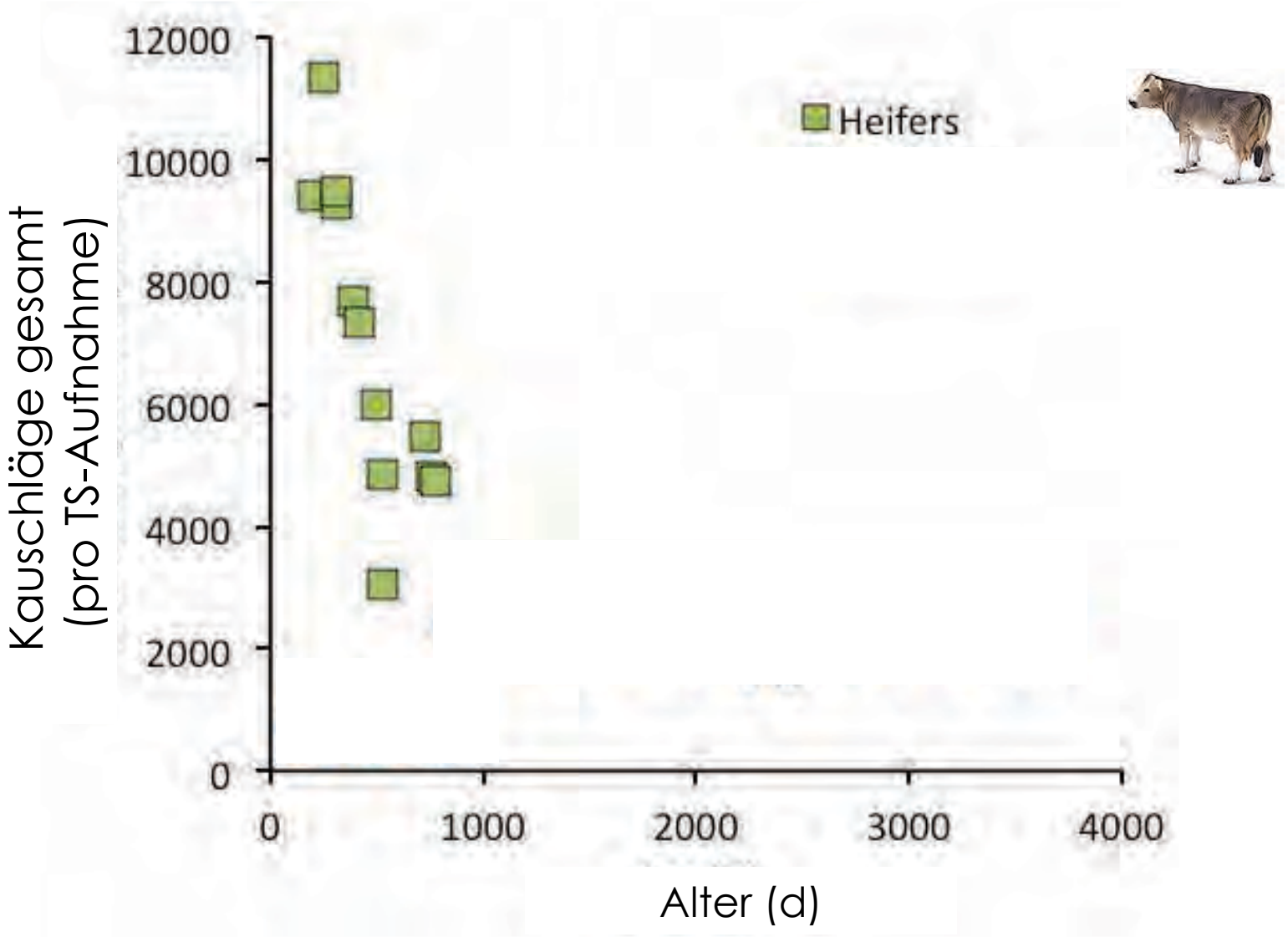
Verlängerung der Kauleiste

Kauschläge



Grandl et al. (2018)

Kauschläge



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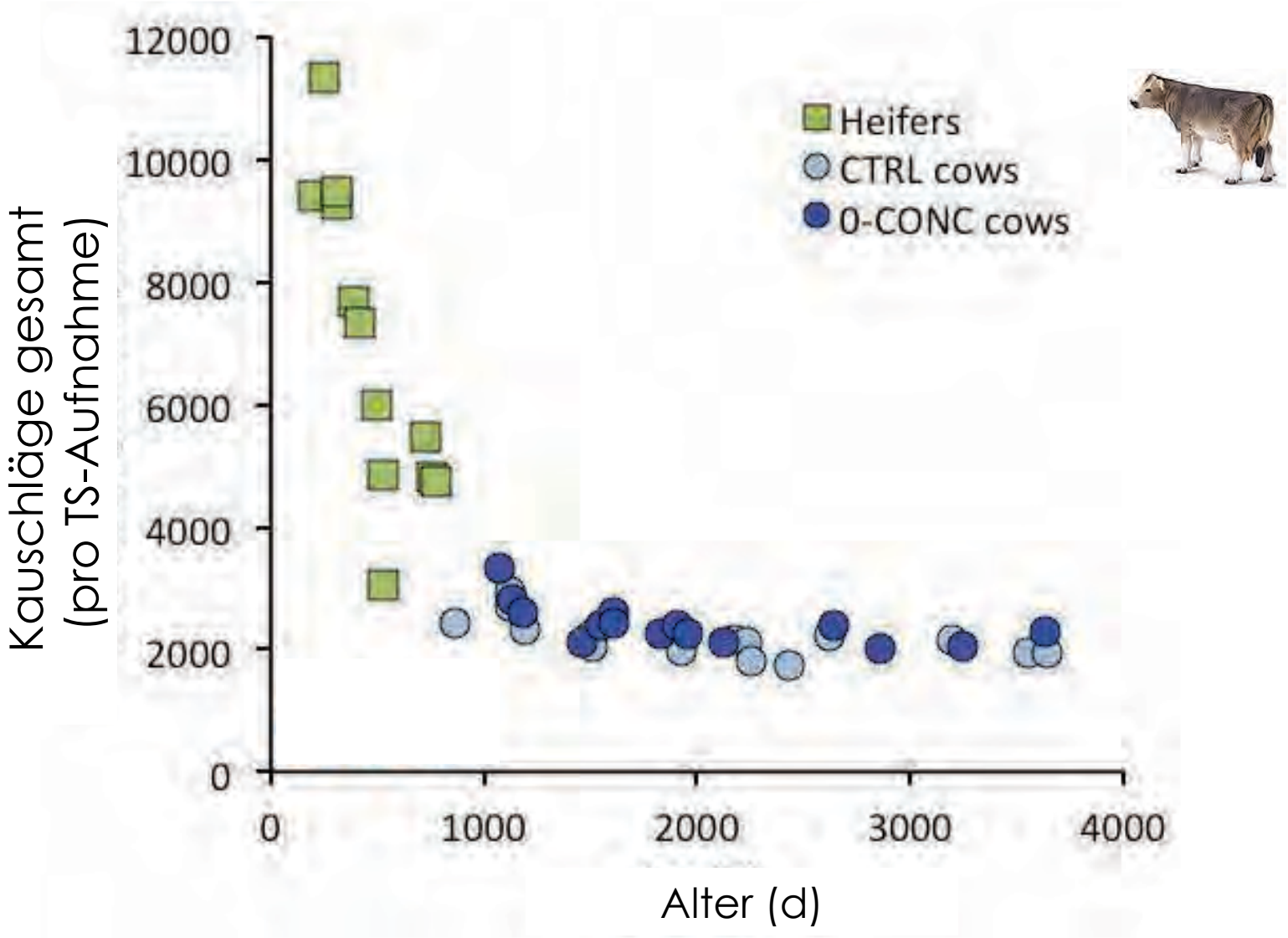

Grandl et al. (2018)

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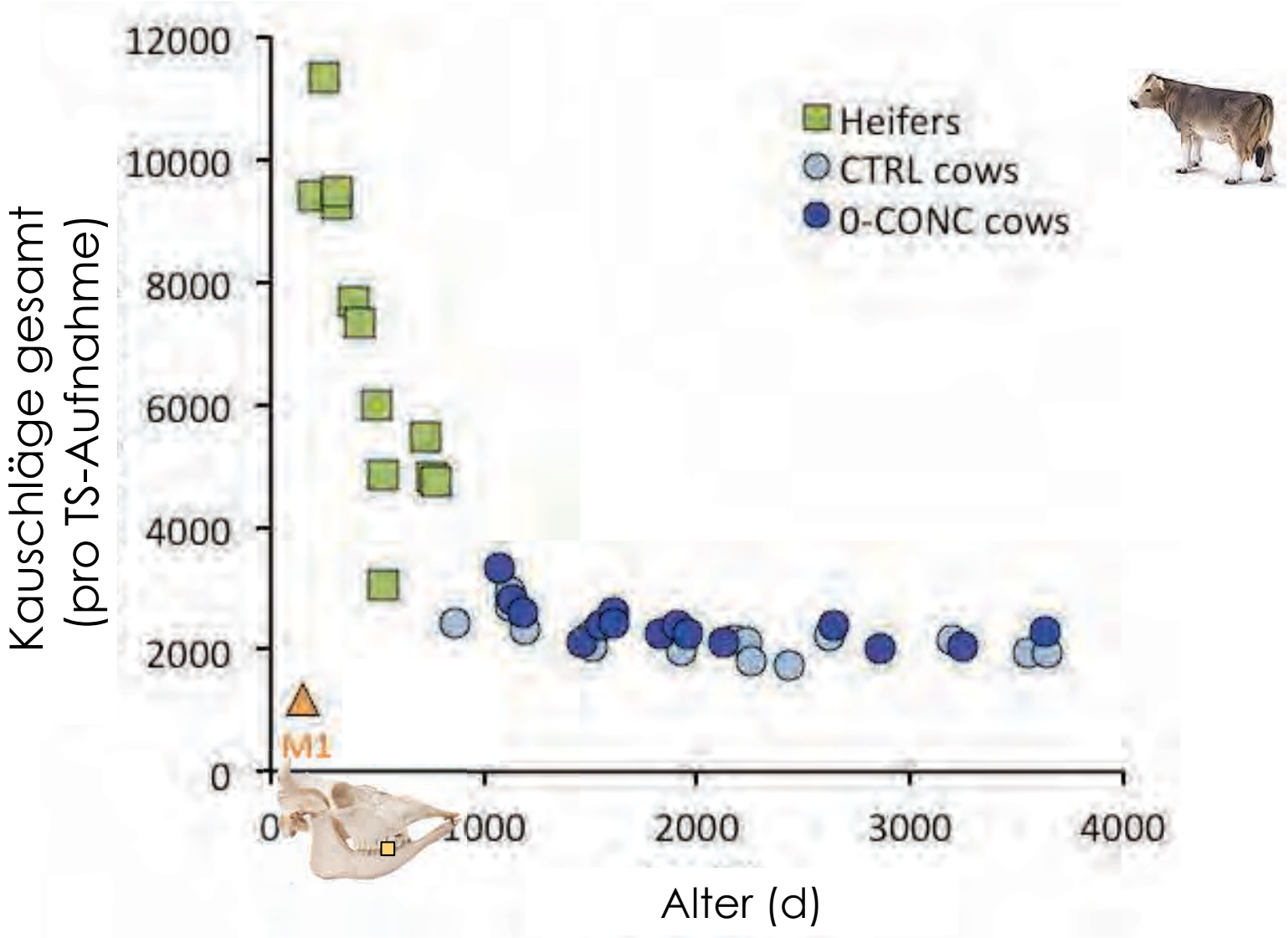

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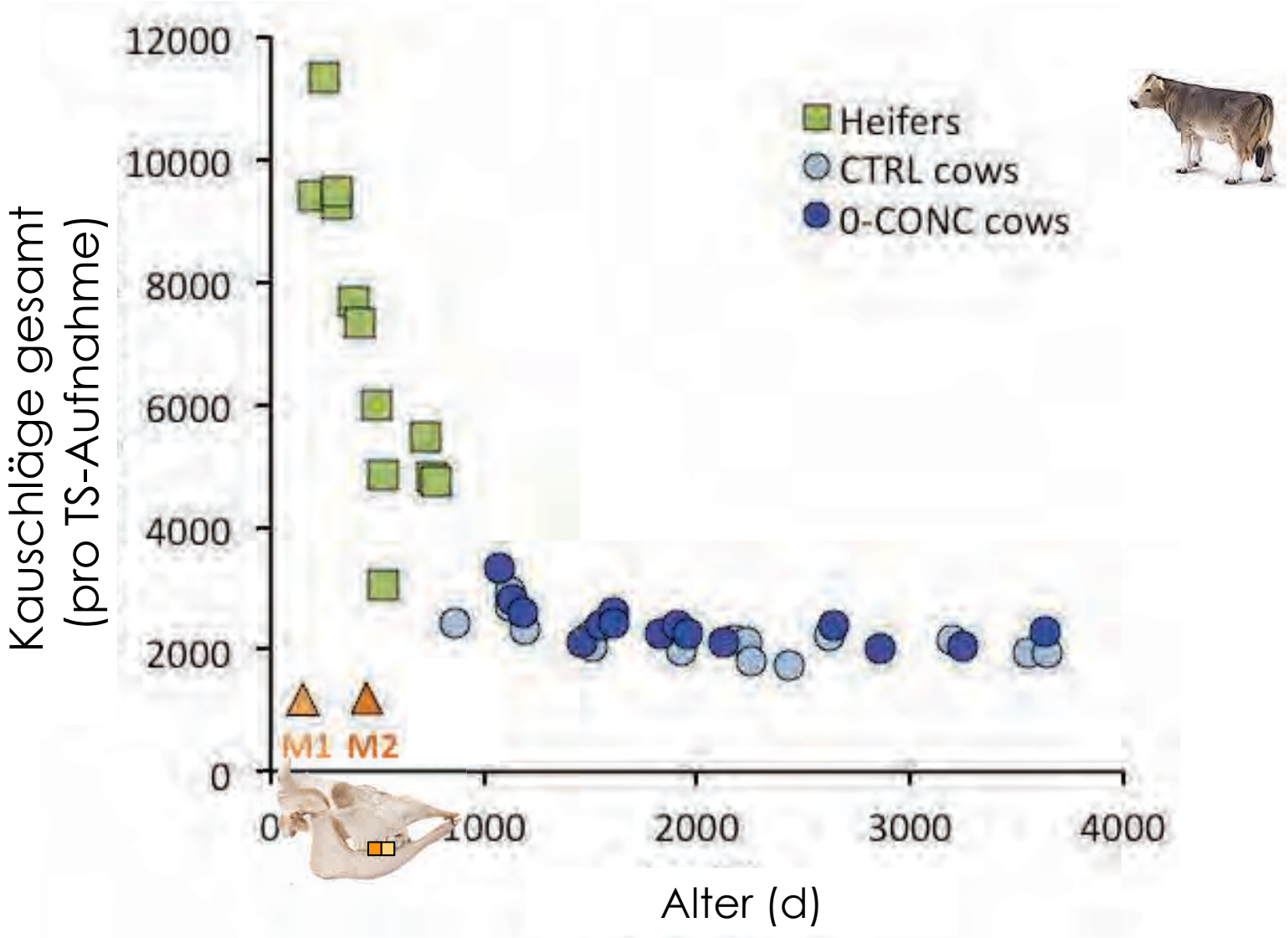

Grandl et al. (2018)

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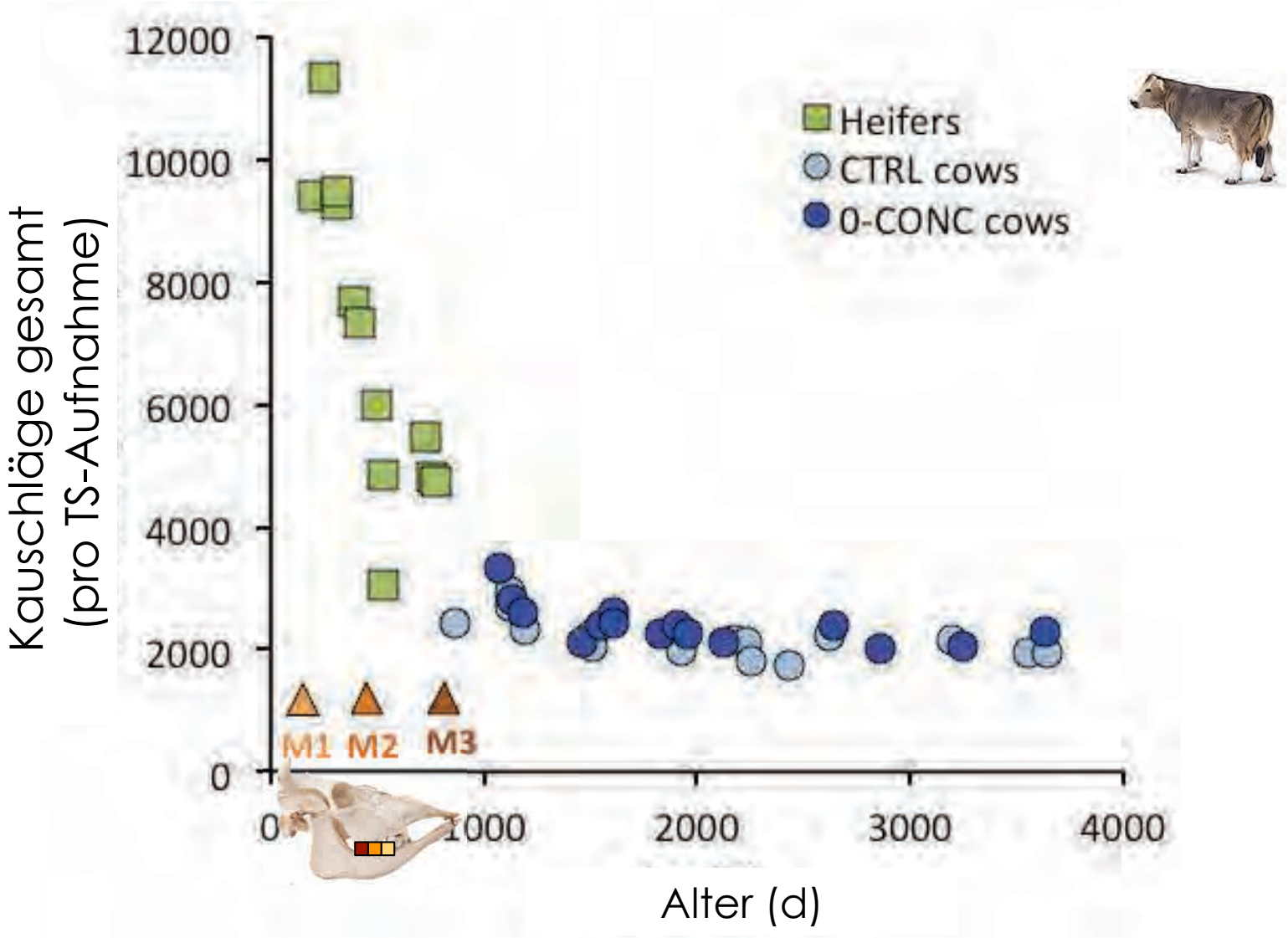
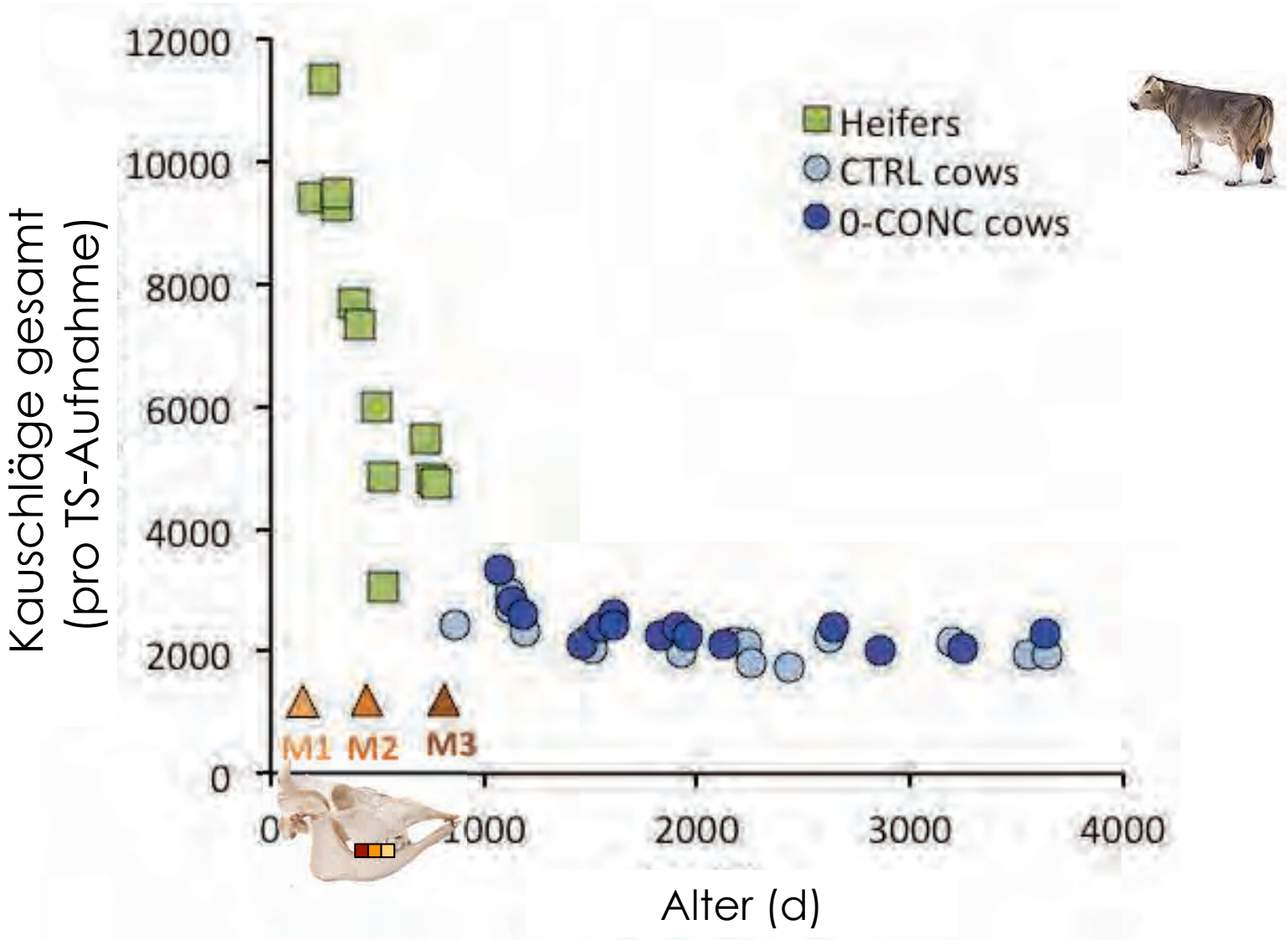


Grandl et al. (2018)

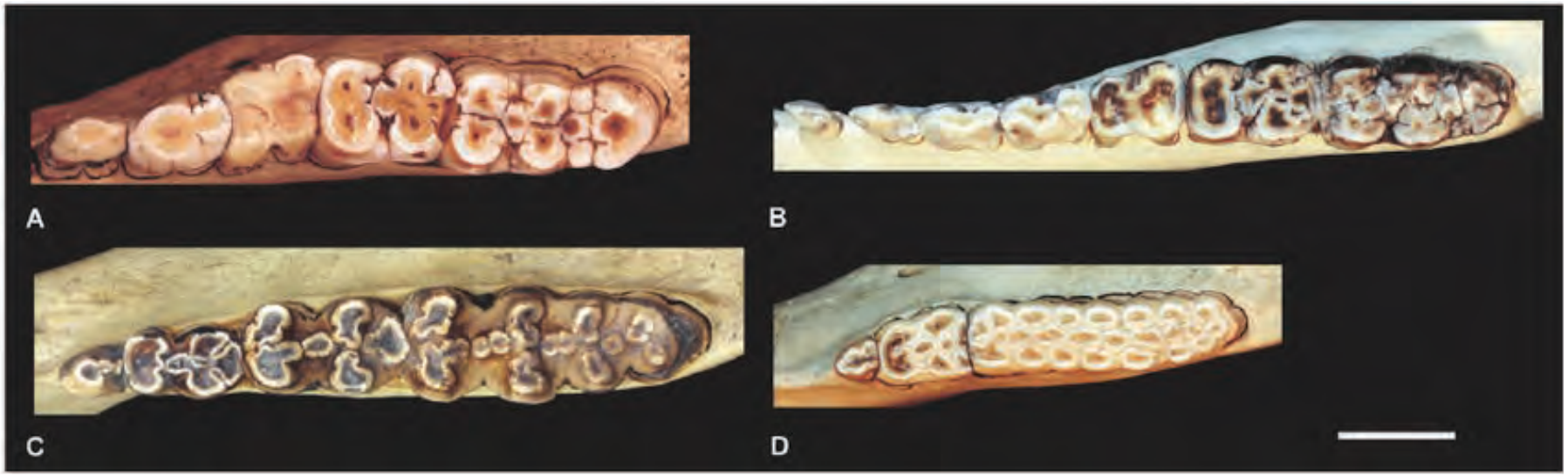
Kauschläge



Alterseffekt auf Kauintensität
(aufgrund Molaren-Eruption)

Grandl et al. (2018)

Verlängerung des 3. Molaren bei Schweinen



from Souron et al. (2014)

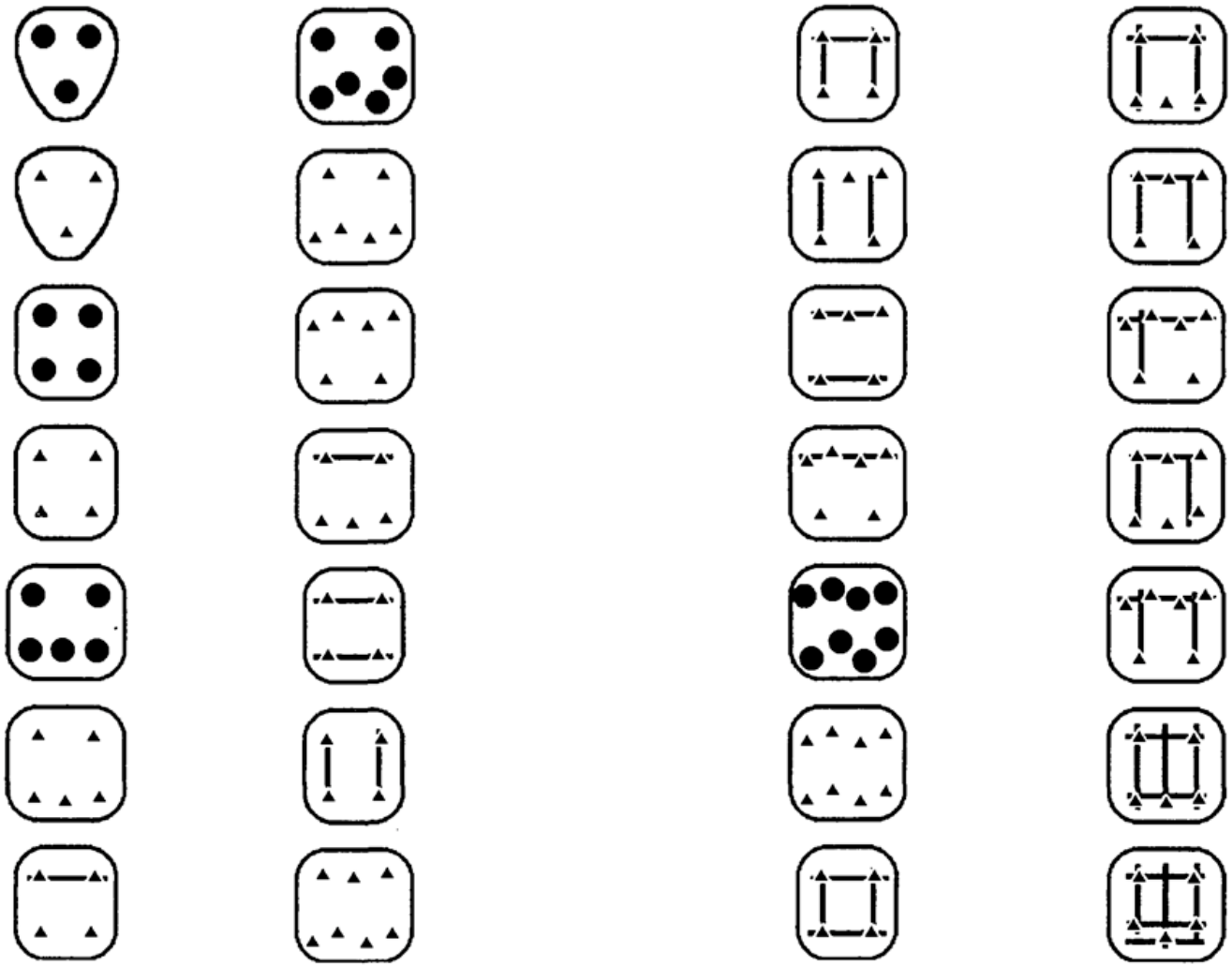
Molarisierung der Prämolaren bei Equiden

Molarisierung der Prämolaren bei Equiden

Zahnoptimierung:

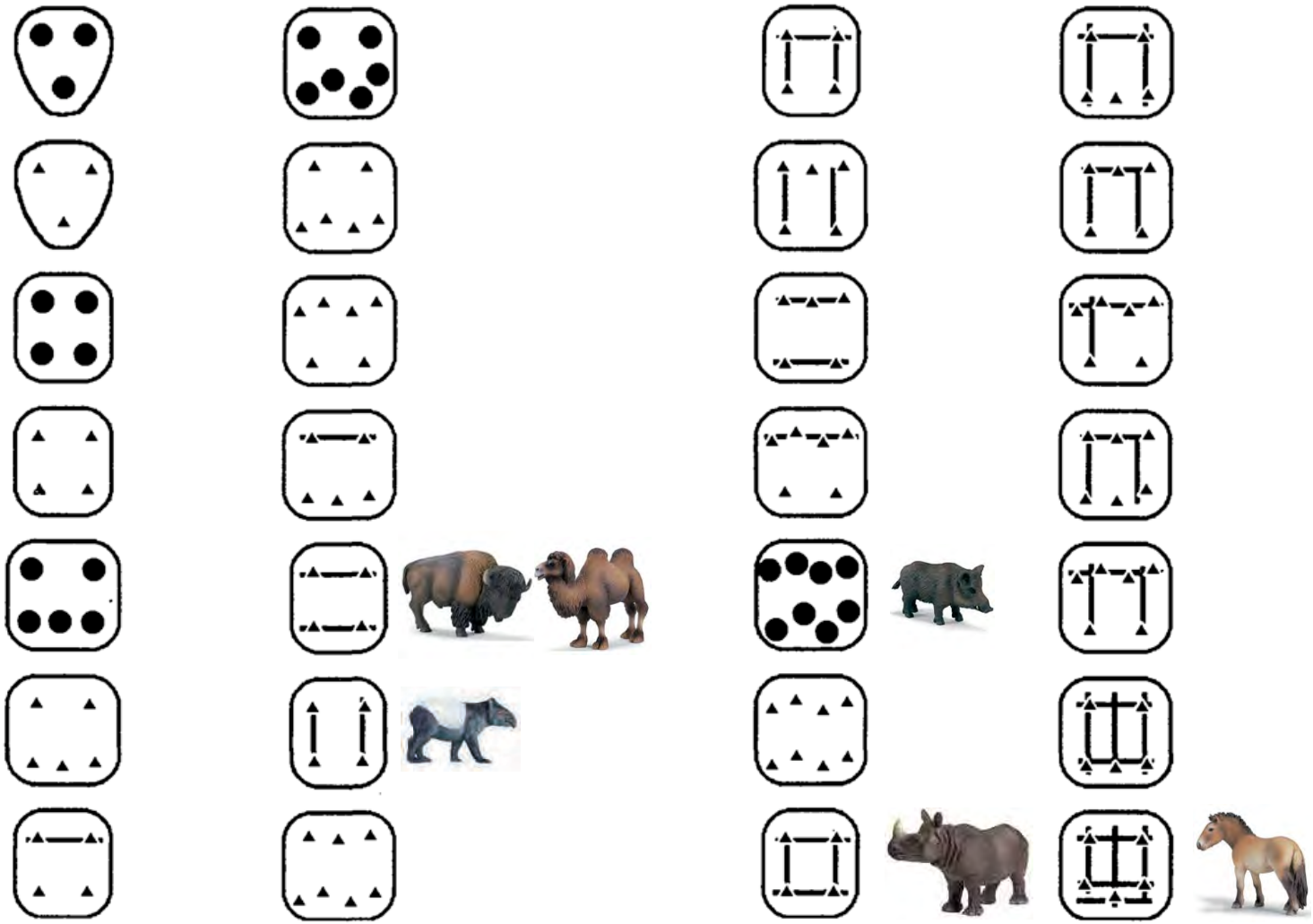
Schmelzfalten

Backenzahn-Oberflächen



aus Jernvall et al. (1996)

Backenzahn-Oberflächen



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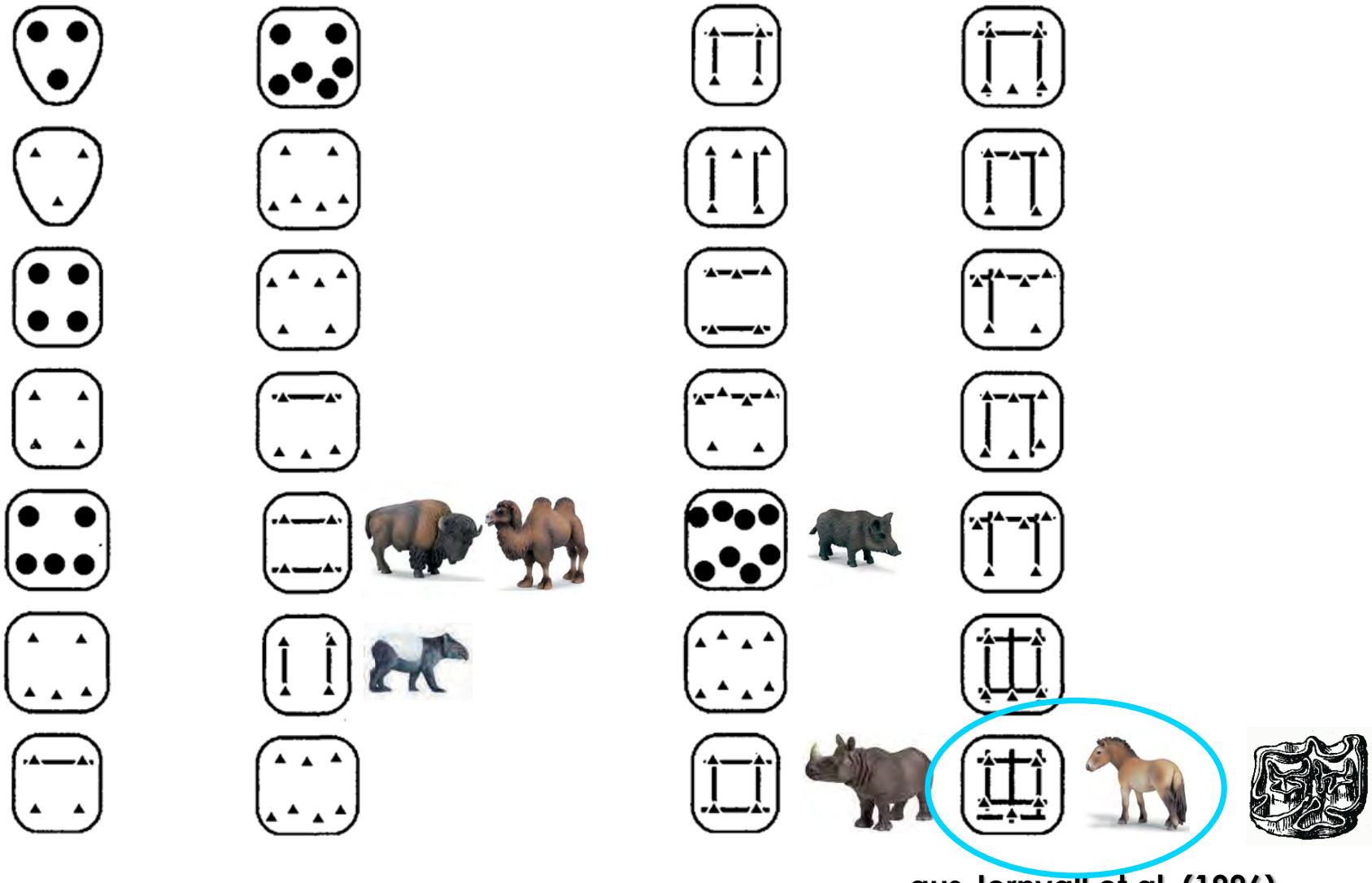

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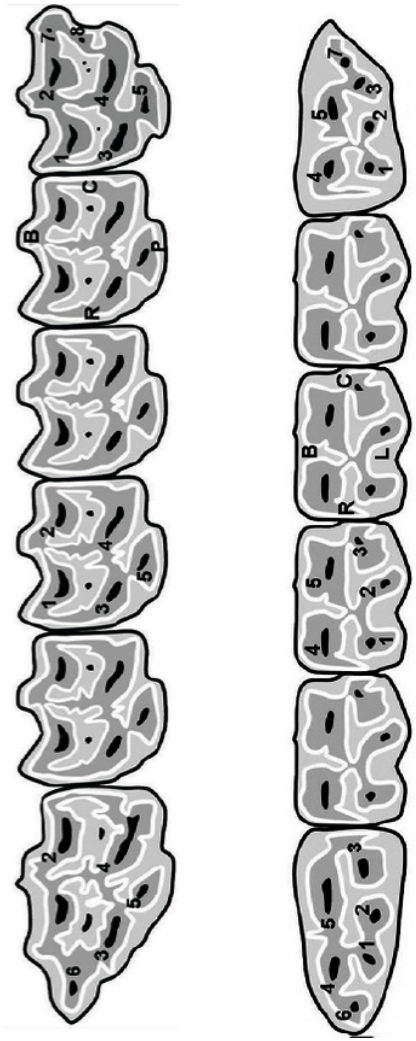
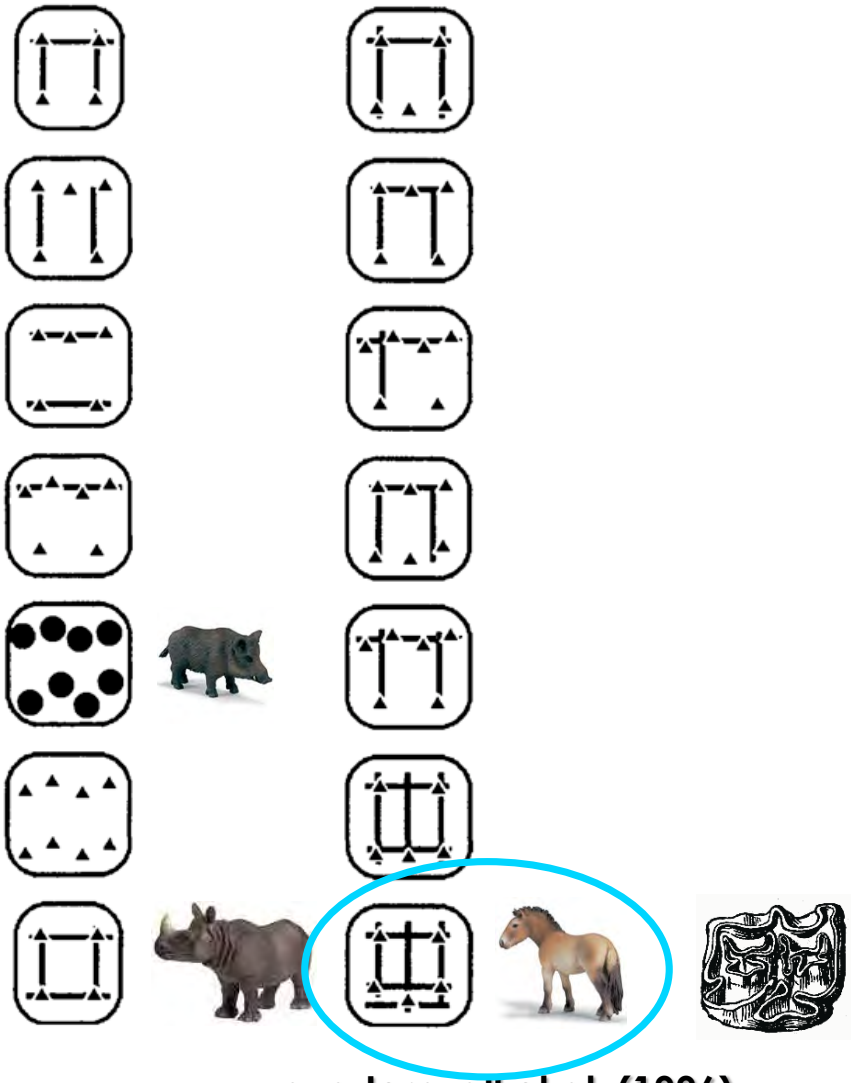
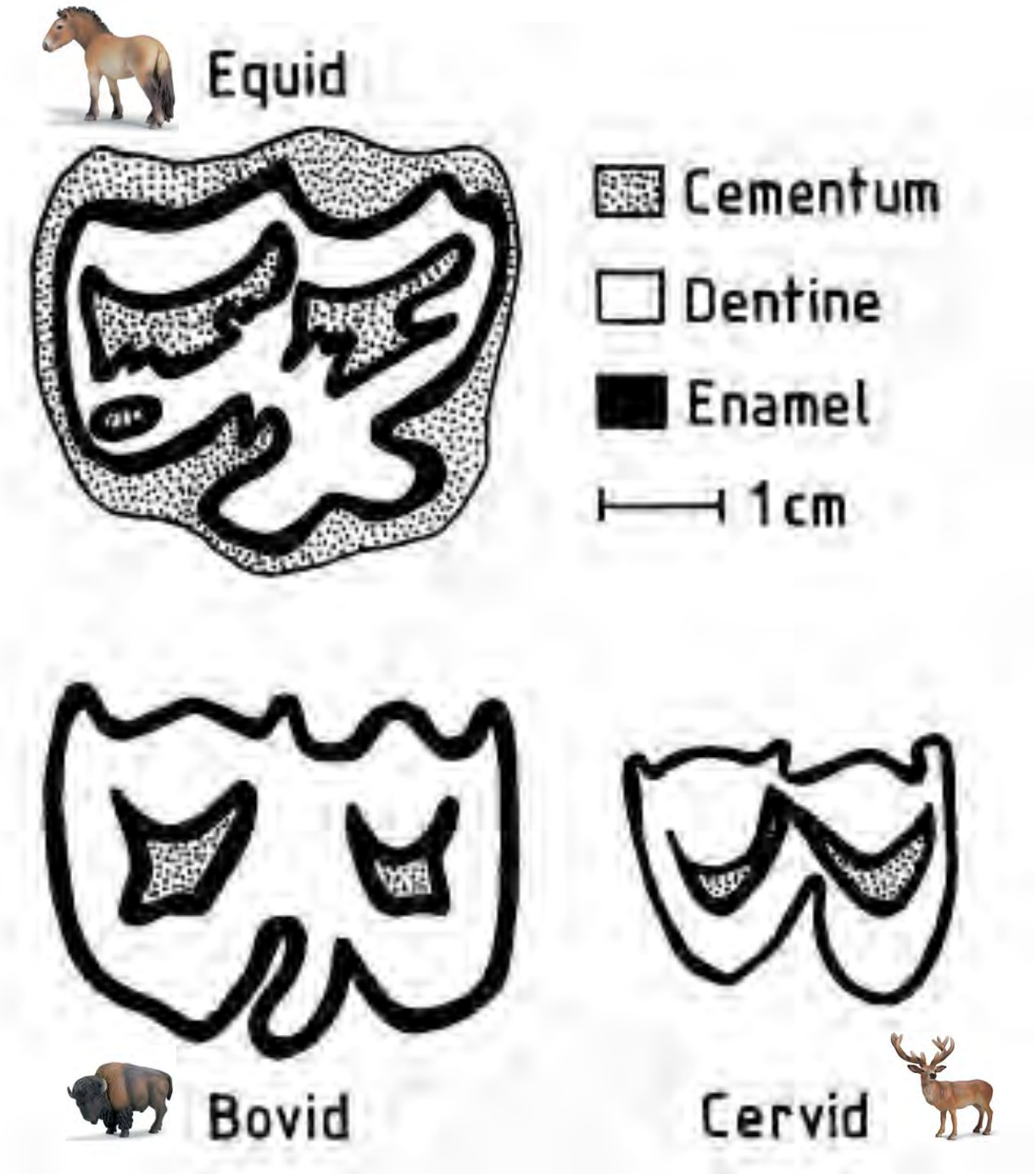
Backenzahn-Oberflächen





aus Jernvall et al. (1996)



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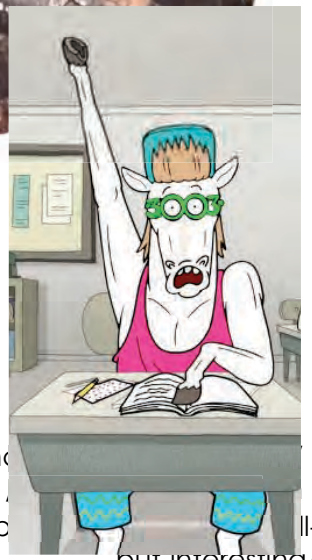

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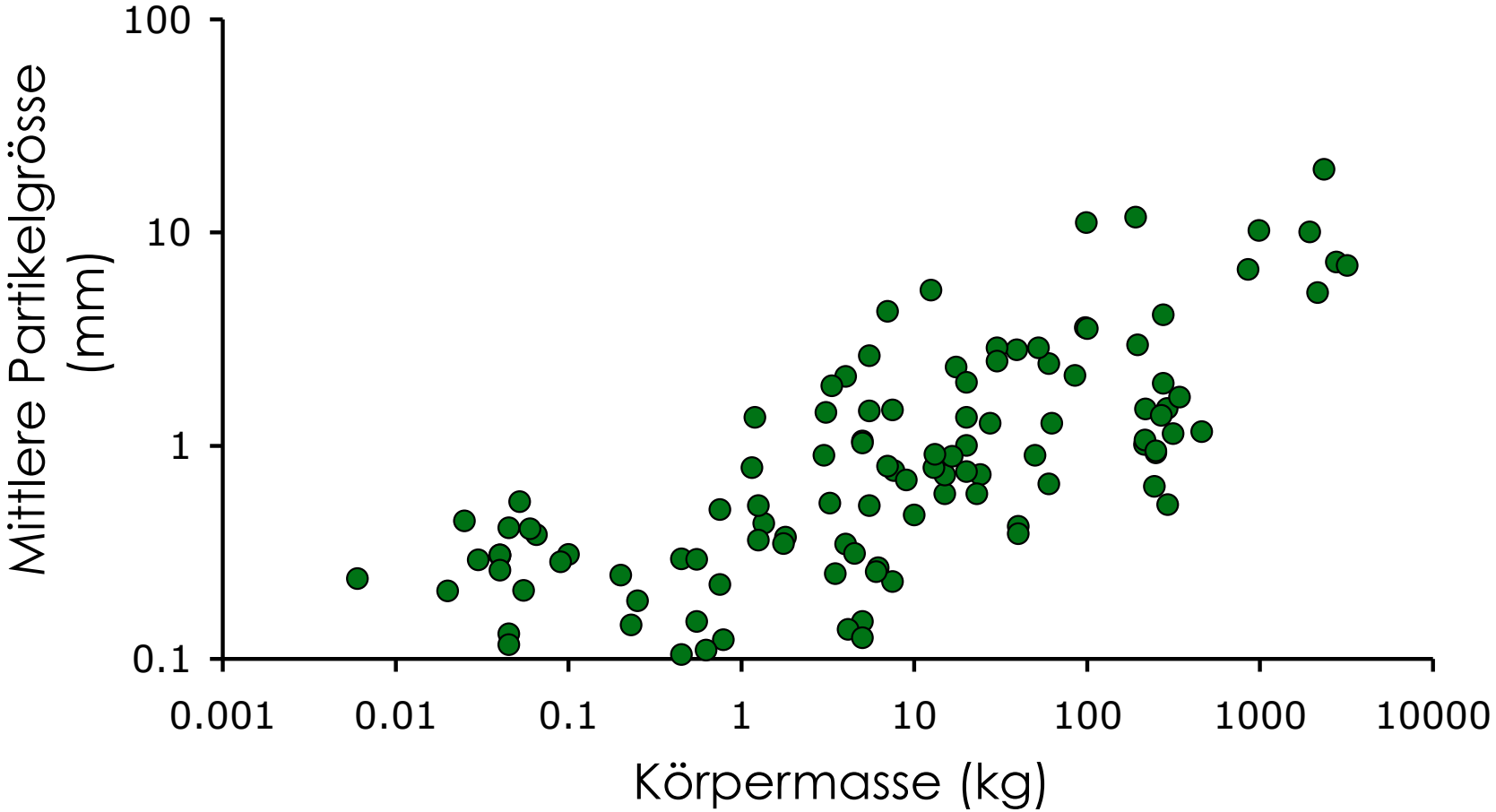
but-interesting/

Comparative chewing efficiency in mammalian herbivores

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

Oikos 118: 1623–1632, 2009



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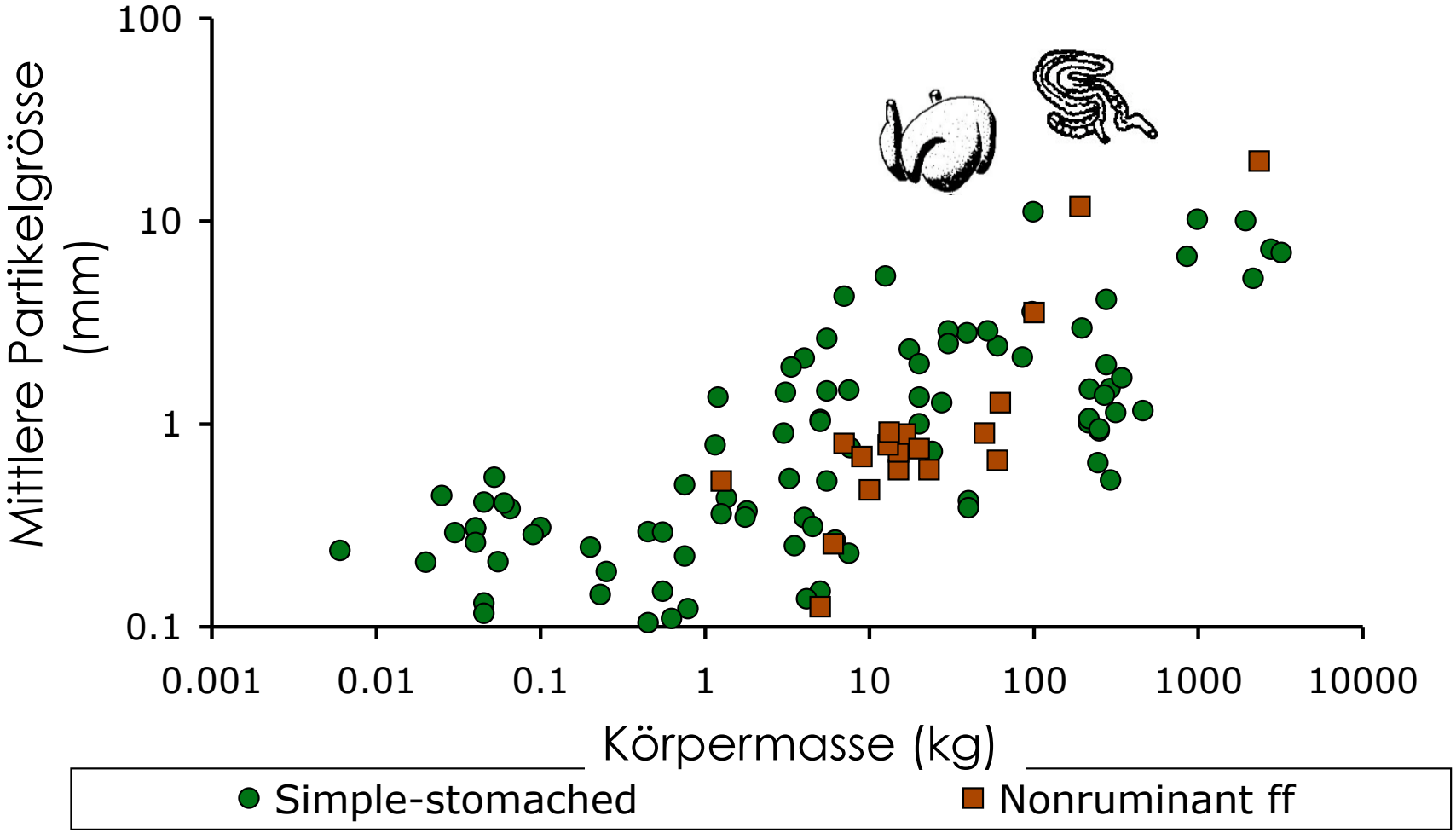

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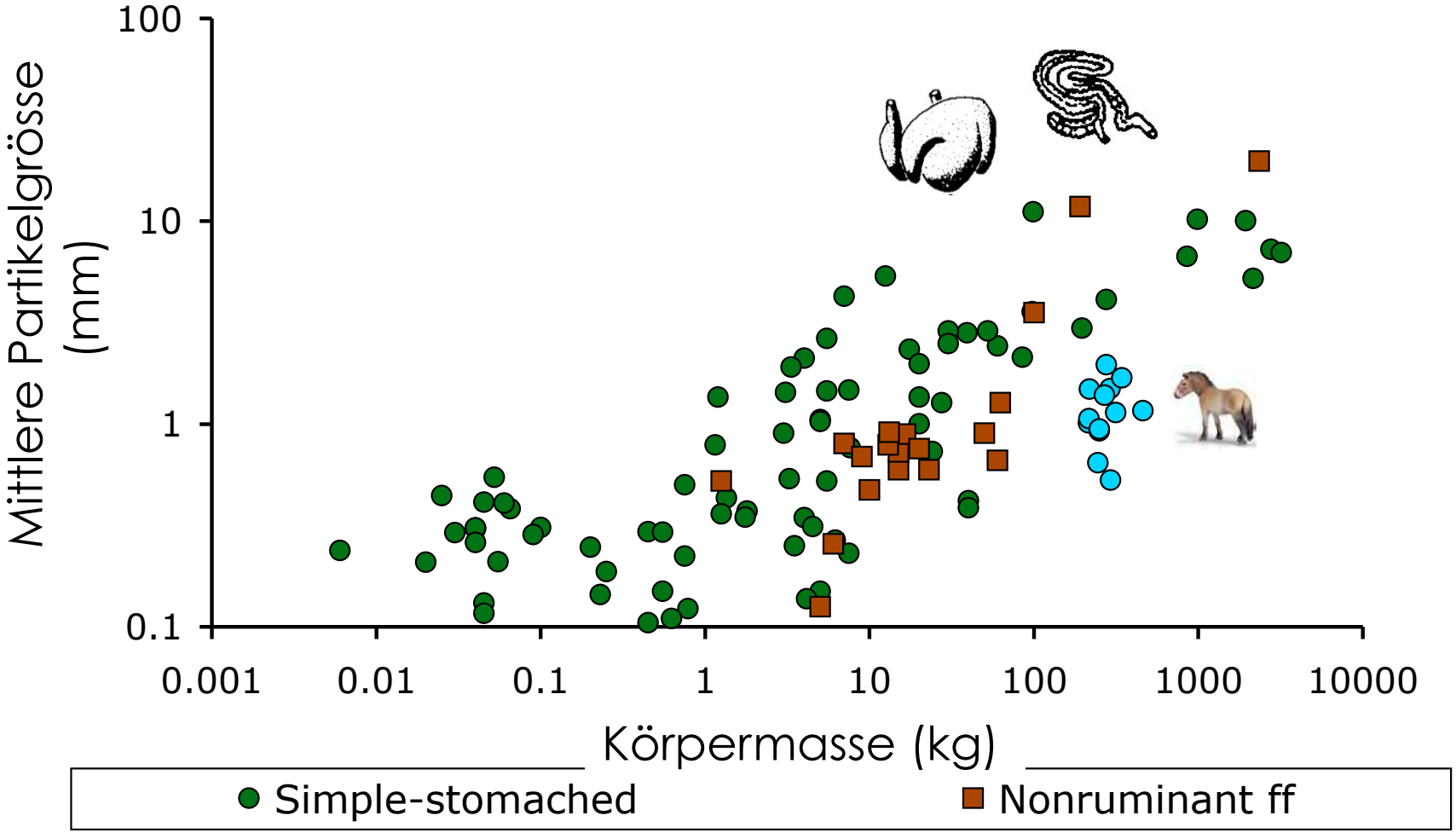

Comparative chewing efficiency in mammalian herbivores

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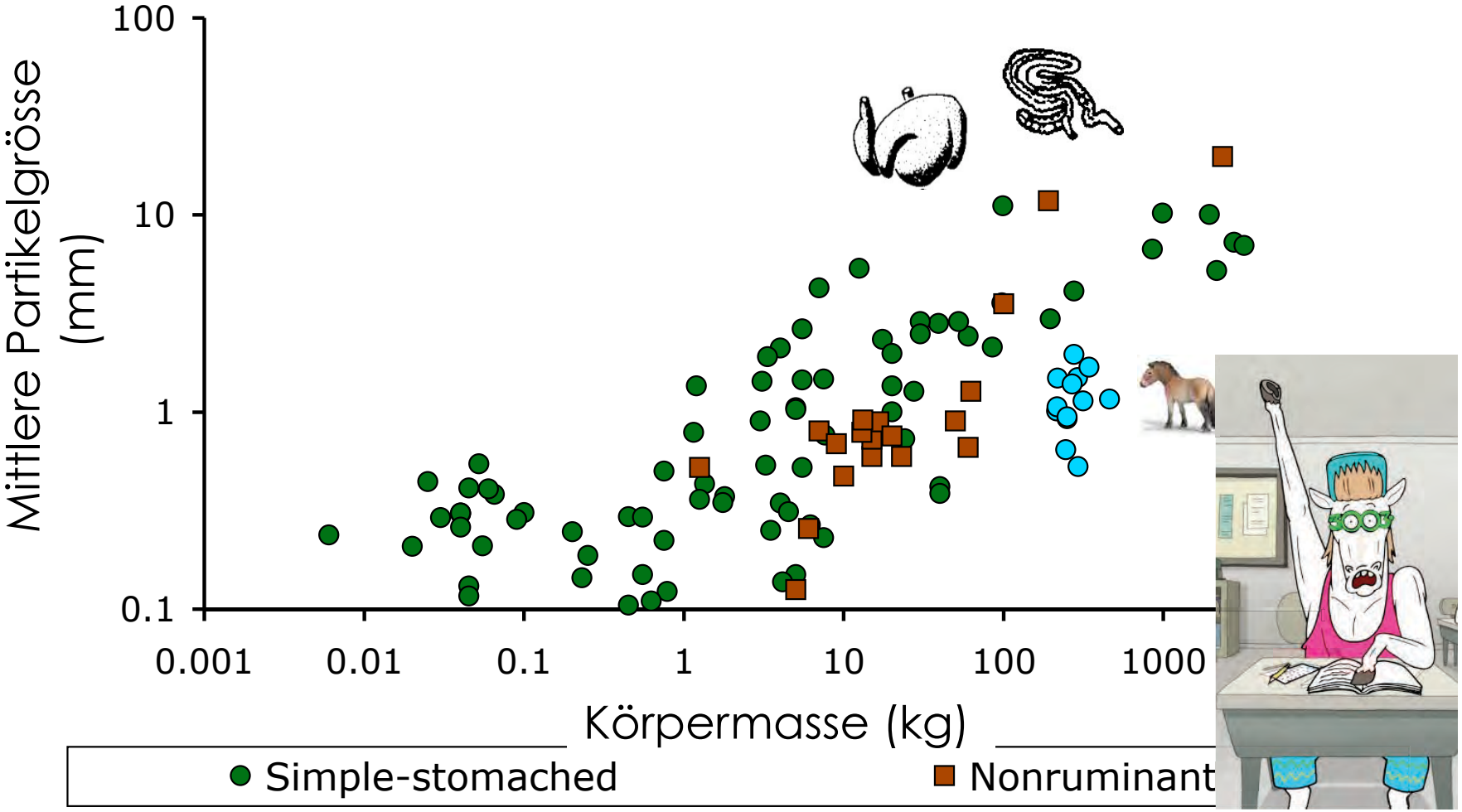
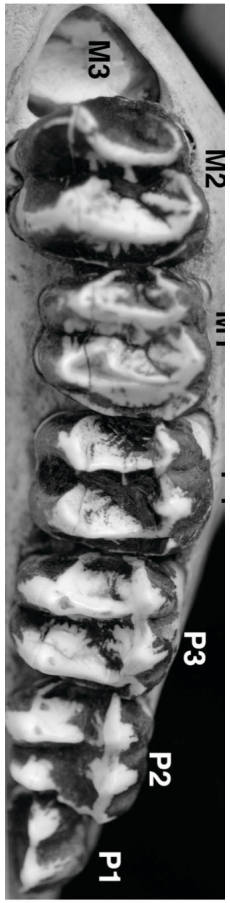
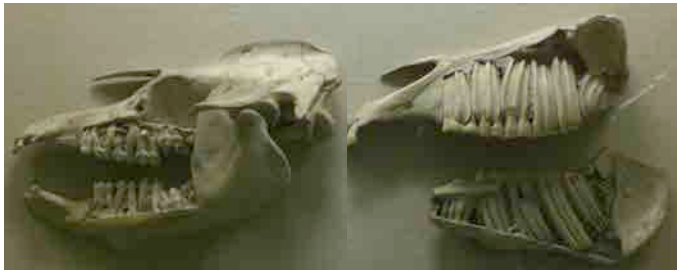
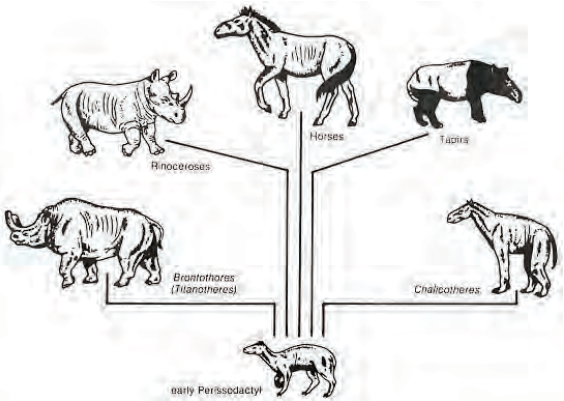


Backenzahn-Oberflächen

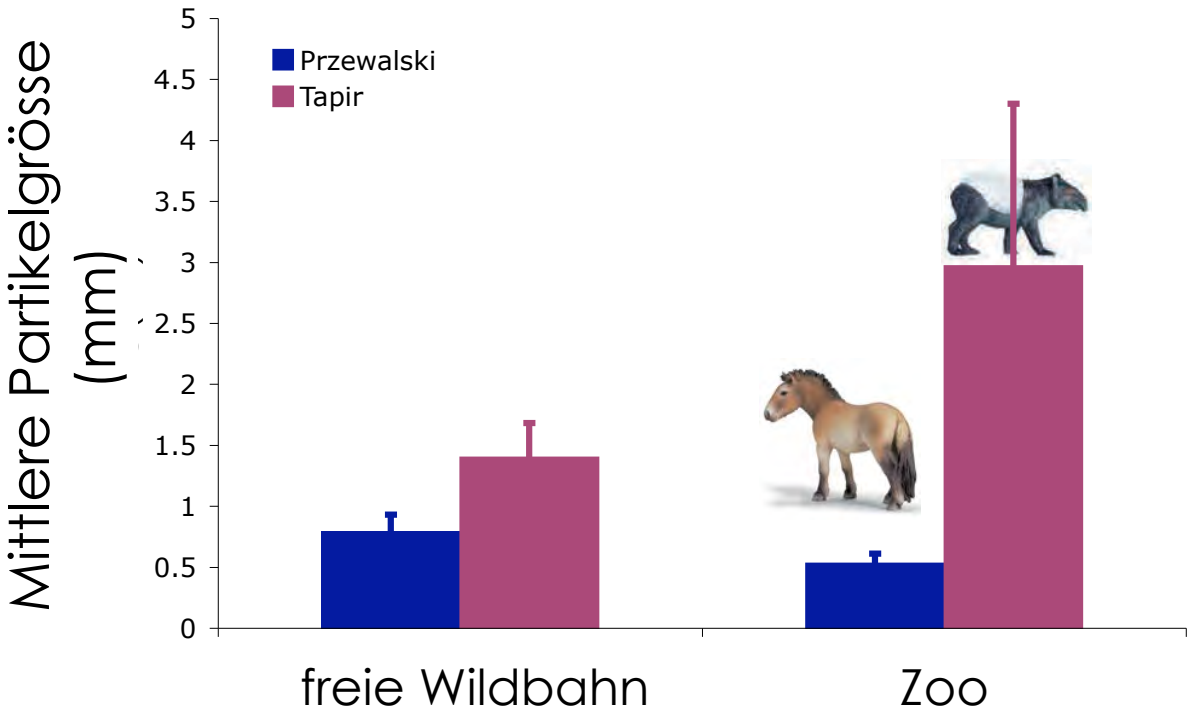






Kotpartikelgrösse bei Huftieren

- Wir erwarten, dass Zootiere feinere Kotpartikel haben als Tiere in freier Wildbahn (wegen teilweiser Pelletfütterung)
- Das bestätigt sich bei Przewalski-Pferden aber nicht bei Tapiren!
- Tapirzähne sind weniger flexibel, was konstante Effizienz bei verschiedenen Futterrationen betrifft.



from Hummel et al. (2008)

Kau-Optimierung:

Rhythmisches Kauen

Kauhaltermessungen

Kauhaltermessungen

Applied Animal Behaviour Science 174 (2016) 19–23

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/applanim

Validation of a pressure sensor-based system for measuring eating, rumination and drinking behaviour of dairy cattle

Salla Ruuska[a,b,*,1], Sari Kajava[b,**,1], Mikaela Mughal[a], Nils Zehner[c], Jaakko Mononen[a,b]

[a] University of Eastern Finland, Department of Biology, Kuopio, Finland
[b] Natural Resources Institute Finland (Luke), Green Technology, Mauninkia, Finland
[c] Swiss Federal Department of Economic Affairs, Education and Research EAER Agroscope, Institute for Sustainability Sciences ISS, Ettenhausen, Switzerland

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ABSTRACT

The main objective of our study was to validate, for dairy cows, a new pressure-based system (RumiWatch noseband sensor, Itin + Hoch GmbH, Liestal, Switzerland; RWS) that measures eating, rumination and drinking time. In experiment 1, eating, rumination and drinking time (RWS, min/h) measurements were compared with continuous behaviour recording (CR) of six dairy cows in tie-stalls (a total of 72 h). In addition, eating time measured by RWS was compared with the visiting time at automated feeders of a widely used type (Roughage Intake Control, RIC, Insentec BV, Marknesse, The Netherlands) to gain experience of the utility of RWS in a loose-housing system (experiment 2). A total of 403 h of RWS and RIC data from 18 cows was used for these two comparisons in experiment 2. In experiment 1, RWS and CR had a very dependable relationship (random coefficient regression model) for eating and rumination: eating, $y = 0.98$ (0.89–1.07)$x + 3.25$ (1.35) (the slope with the 95% confidence interval and the intercept with standard error of the mean) and rumination, $y = 0.88$ (0.73–1.02)$x + 1.77$ (1.00). The R^2 values were 0.94 and 0.93, respectively, i.e. random error was small. The 95% confidence intervals of the slopes included value 1, and the intercepts did not differ from 0; i.e. there was no significant systematic error. However, experiment 2 confirmed a tendency observed in experiment 1 that RWS overestimated eating, since RWS eating time (5.1 ± 2.7 h/24 h) exceeded significantly visiting time (RIC) (3.2 ± 1.1 h/24 h; paired t-test, $n = 18$) in the setup where, in principle, eating was possible only in the RIC feeders. In experiment 1, the relationship between drinking time (RWS) and CR was poor: $R^2 = 0.20$, and $y = 0.49$ (0.12–0.85)$x + 0.64$ (0.13). However, this may reflect more the challenges in measuring drinking in general than merely with RWS. In conclusion (i) the RWS results were relatively free from random errors for rumination and eating, but not for drinking, (ii) there was systematic error for eating and drinking, but not for rumination, and (iii) due to the relatively limited size of our data, further validation of RWS is recommended and RWS needs further development at least for eating and drinking measurements.

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1. Introduction

Eating, rumination and drinking are essential components of the nutritional behaviour of dairy cows (Phillips, 2002). In scientific studies, the feeding behaviour of loose-housed cattle has been measured traditionally by direct observation methods. Automated equipment for measuring feeding behaviour and feed intake of cattle is, however, used more and more widely, because of the very labour-intensive requirements for conducting visual observations of behaviour (Beauchemin et al., 1989; Elischer et al., 2013). These types of automated equipment could also be of great benefit in large commercial dairy herds because ingestive behaviour can also be regarded as an important parameter for predicting health issues (as reviewed by Weary et al., 2009).

Devices used for measuring the feeding behaviour of dairy cows can be classified into two categories: stationary systems and systems based on sensors attached to animals. Stationary feeding systems use transponder tags that identify the individual animals and measure either the duration of visits at a feed alley (DeVries et al., 2003) or the visit duration and feed intake at feed troughs

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E-mail addresses: salla.ruuska@uef.fi (S. Ruuska), sari.kajava@luke.fi (S. Kajava).
[1] These authors contributed equally to this work.

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Kauhaltermessungen

Computers and Electronics in Agriculture 136 (2017) 31–41

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Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

System specification and validation of a noseband pressure sensor for measurement of ruminating and eating behavior in stable-fed cows

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RumiWatch
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ABSTRACT

Rumination and eating behavior are important indicators for assessing health and well-being in cattle. The objective of this study was to develop and validate a novel scientific monitoring device for automated measurement of ruminating and eating behavior in stable-fed cows to provide research with a measuring instrument for automated health and activity monitoring. The RumiWatch noseband sensor (Itin+Hoch GmbH, Liestal, Switzerland) incorporates a noseband pressure sensor, a data logger with online data analysis, and software. Automated measurements of behavioral parameters are based on generic algorithms without animal-specific learning data. Thereby, the system records and classifies the duration of chewing activities and enables users to quantify individual ruminating and eating jaw movements performed by the animal. During the course of the development, two releases of the system-specific software RumiWatch Converter (RWC) were created and taken into account for the validation study. The results generated by the two software versions, RWC V0.7.2.0 and RWC V0.7.3.2, were compared with direct behavioral observations. Direct observations of cow behavior were conducted on 14 Swiss dairy farms with an observation time of 1 h per animal, resulting in a total sample of 60 dairy cows. Agreement of sensor measurement and direct observation was expressed as Spearman correlation coefficients (r_s) for the pooled sample. For consolidated classification of sensor data (1-h resolution), correlations for rumination time were $r_s = 0.91$ (RWC V0.7.2.0) and $r_s = 0.96$ (RWC 0.7.3.2), and for eating time $r_s = 0.86$ (RWC 0.7.2.0) and $r_s = 0.96$ (RWC V0.7.3.2). Both software versions provide a high standard of validity and measuring performance for ruminating and eating behavior. The high to very high correlations between direct observation and sensor data demonstrate that the RumiWatch noseband sensor was successfully developed and validated as a scientific monitoring device for automated measurement of ruminating and eating activity in stable-fed dairy cows.

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1. Introduction

Research in the field of Precision Livestock Farming has put a major effort on development and evaluation of technologies allowing early recognition of pathological and management-relevant behavioral changes and assessment of the individual health state in dairy cows (cf. review by Rutten et al., 2013). Hence, sensor devices for automated detection of health impairments in livestock are increasingly available and can provide effective management support in various types of farming systems. In dairy cattle nutrition, chewing activity has been identified as an important parameter to assess the adequate composition of a diet and the risk of ruminal acidosis (Yang and Beauchemin, 2007). Furthermore, ruminating activity may provide meaningful information on calving time and subclinical diseases or health disorders (Goff and Horst, 1997; Soriani et al., 2012). Accordingly, continuous measurements of cow feeding variables enable us to develop a more complete understanding of the dietary effects on digestive function and performance (Dado and Allen, 1993). The timeline and intensity of feeding activity provide information on the diurnal pattern of the behavior of ruminants, and identification of deviations may be used for detection of health impairments (Weary et al., 2009; Braun et al., 2014). Direct observation for measurement of ruminating and eating behavior is labor intensive, error-prone and hardly applicable for continuous observations on several animals simultaneously (Penning, 1983). For these reasons, several methods have been developed for automated, non-invasive measurement of chewing activity in ruminants. The working principle of

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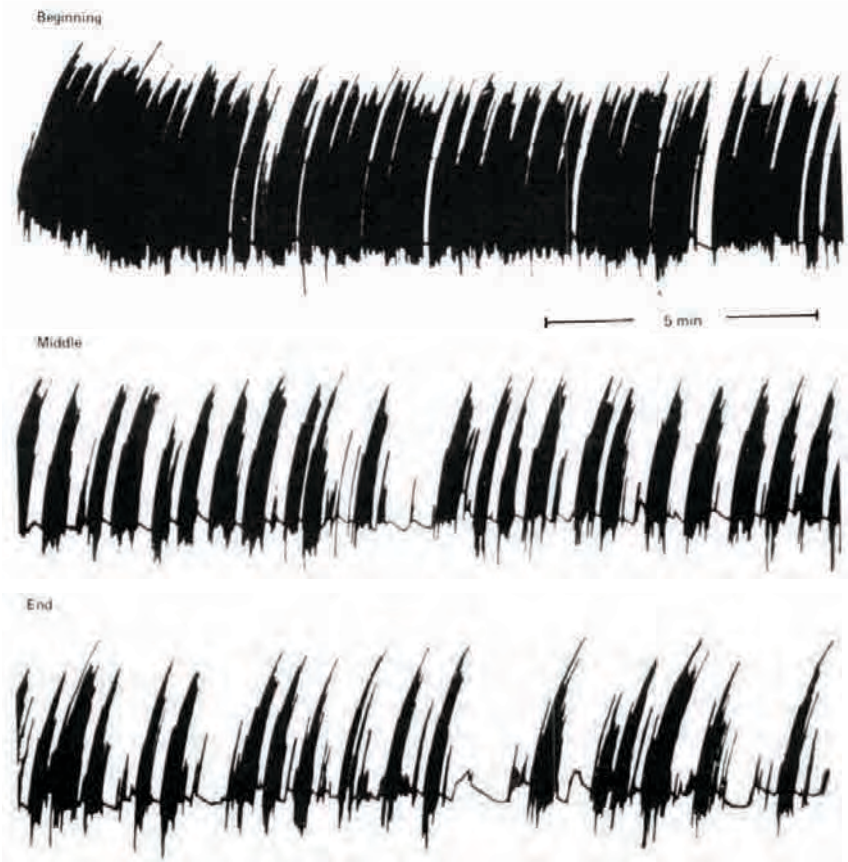
Silage intake, rumination and pseudo-rumination activity in sheep studied by radiography and jaw movement recordings

By A. G. DESWYSEN* and H. J. EHRLEIN

Br. J. Nutr. (*1981*), **46**, 327



Silage intake, rumination and pseudo-rumination activity in sheep studied by radiography and jaw movement recordings

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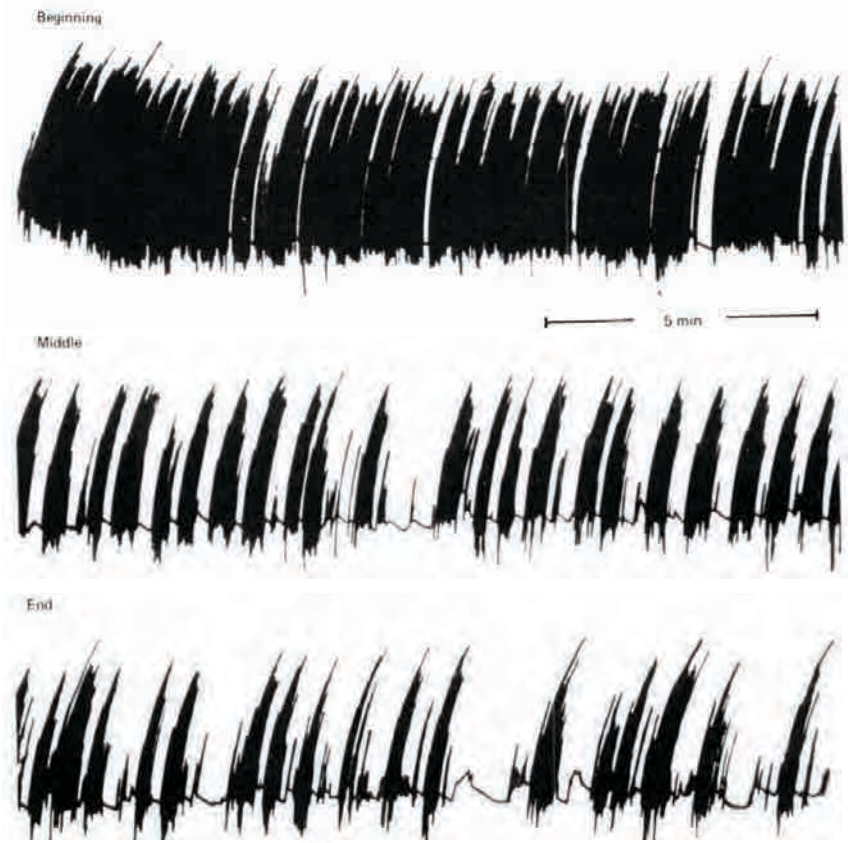

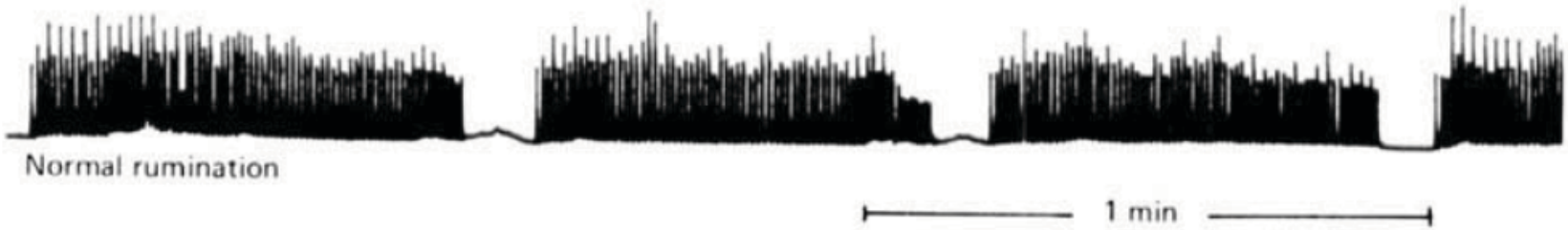

Kauhaltermessungen

Kauhaltermessungen

Livestock Science 186 (2016) 53–58

Contents lists available at ScienceDirect

Livestock Science

Journal homepage: www.elsevier.com/locate/livsci

Validation of a sensor-based automatic measurement system for monitoring chewing activity in horses

J. Werner [a,*], C. Umstatter [a], N. Zehner [a], J.J. Niederhauser [b], M. Schick [a]

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Stereotypies

ABSTRACT

The aim of this study was to determine the feasibility of using a jaw movement measuring system developed for cattle, the "RumWatchSystem", on horses. The system records the chewing activity and consists of a noseband pressure sensor, integrated into a halter, and a software package. In order to investigate the accuracy of the system, 10 horses (5 mares, 5 stallions) were equipped with the device. Additionally, they were observed visually as a reference method, while feeding three different feeds (hay, haylage and concentrate). To ensure similar conditions, the horses were stabled individually and fed twice daily with roughage and twice or three times with concentrate. The results of the visual observation were compared to the automatic measurement as an evaluation of the accuracy of the automatic measurement system.

The overall agreement of the observed and automatically measured data within all feedstuffs was 93%. The agreement of feeding roughage was even higher with 95%. However, for concentrate the visual observations and automatic measurements agreed only in 91.4%. The decreased agreement compared to the roughage is due to the high sensitivity of the automated system. Horses tend to display a high amount of lip movements towards the end of the concentrate intake. This is different compared to cattle behaviour and their feeding regime. However, the system was not specifically adapted to horses so far and can be optimized in order to improve accuracy. Consequently, the system has a high potential to become a reliable tool for research and practical use.

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1. Introduction

The chewing activity of horses can be a suitable parameter for health and welfare assessment as the prevalent housing and feeding conditions often leave horses unsatisfied. Evolutionary, horses adapted over a long period of time to their ecological niche (Janis, 1976). They used to live as grazers in steps with poor vegetation. Therefore, they are adjusted to a low energy and high fibre diet. The feed intake behaviour is defined by a long intake time of 12–16 h (Zeitler-Feicht, 2008; McGreevy, 2004) and travelling long distances of up to 28 km a day (Hampson et al., 2010). Because of the natural food resource, the gastric system is well adapted to small feeding bouts and a consistent filling of the stomach. With the help of microbial fermentation in the large caecum, it is possible to split high fibre feed (Frape, 2010). In modern housing systems, compared to the natural behaviour, horses are often fed roughage restrictive (twice daily) with an additional feeding of grains. This leads to a high amount of starch over a small period of time and can cause illness of the gastrointestinal system like gastric ulcerations (Hymøller et al., 2002). Even in pleasure horses the prevalence of gastric ulcer is 40–60% (Niedzwiedz et al., 2013). Additionally, horses are mostly individually stabled and there is often little or no possibility of social contact to other horses. In Northern Germany, 10% of stabled horses do not even have the possibility to observe their environment (Petersen et al., 2005). This deviation of natural behaviour may lead to abnormalities or stereotypies (Cooper and Albentosa 2005) and even to serious health problems. To evaluate and monitor the feed intake behaviour of a horse, it would be very valuable to measure the chewing activity automatically. The "RumWatchSystem" could provide us with an assessment tool for different feeding regimes and husbandry systems.

There are still a number of unanswered questions, e.g. why such a high number of stomach ulcers occur in horses. Analyzing the chewing behaviour linked to different feeding regimes would provide us with valuable information and might lead us to the solution how to reduce stomach ulcers. Another possibility to use

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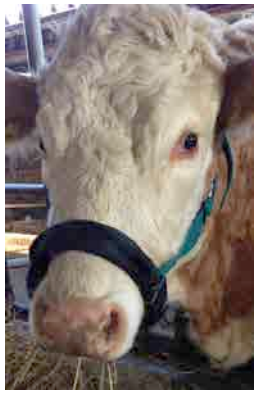
Methoden

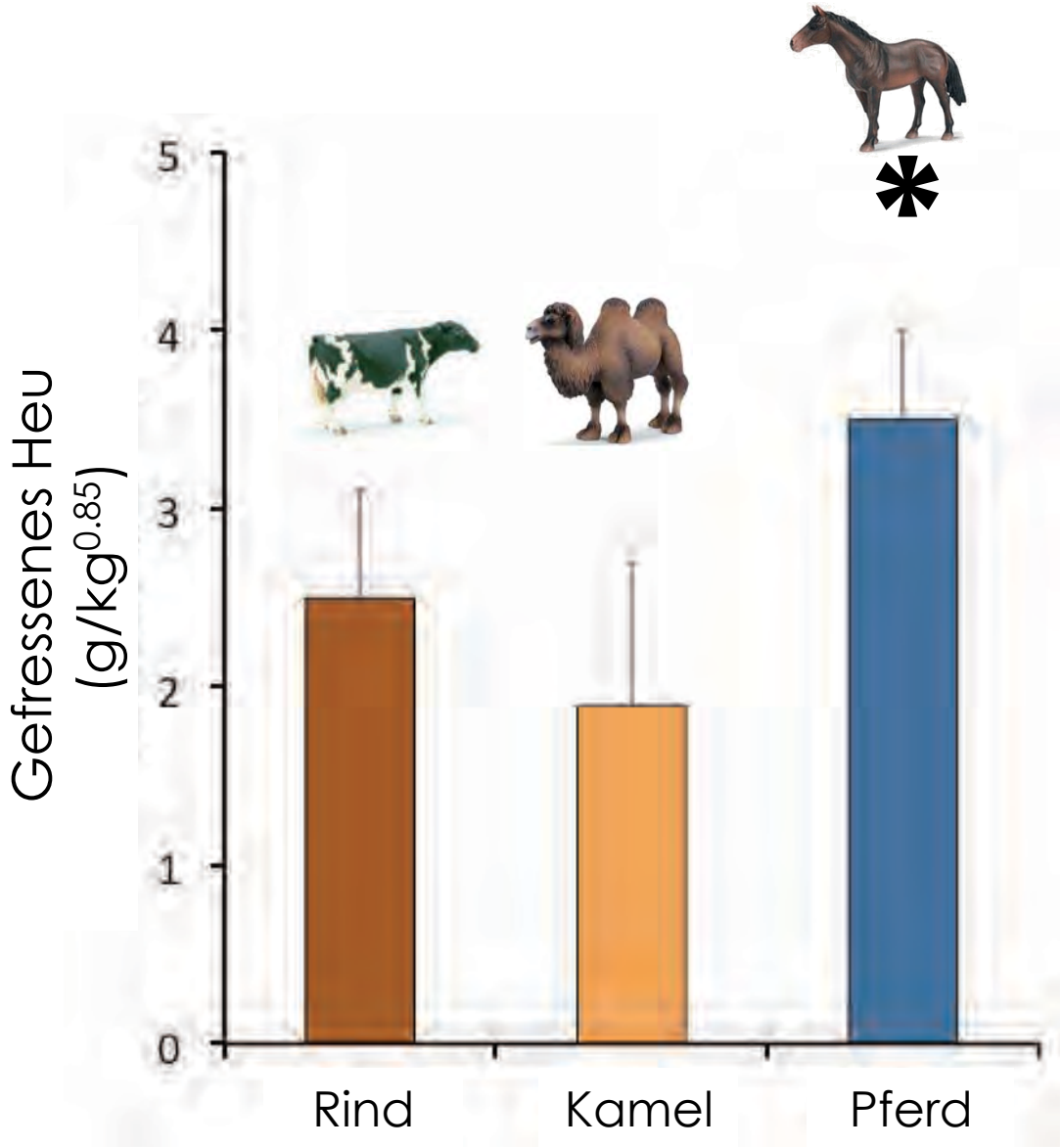
6 Simmental Färsen (*Bos taurus*, 459 ± 110 kg)
6 Trampeltiere (*Camelus bactrianus*, 645 ± 60 kg)
6 Warmblutpferde (*Equus caballus*, 563 ± 44 kg)

Rumiwatch Kauhalfter

Ganzes Heu (CP 74, NDF 607, ADF 324 g/kg DM)
für 15 Minuten (plus 2 h max. bis Wiederkäuen)
Futteraufnahme gemessen



Futteraufnahme



Methoden

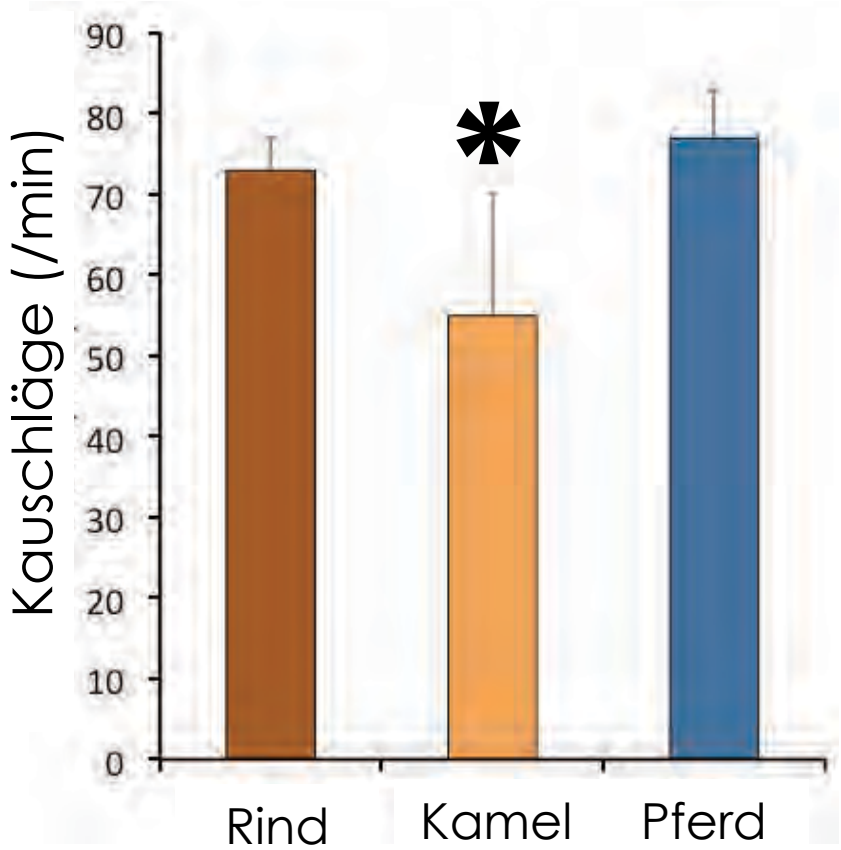
Rumiwatch Messungen:

1. Kauschläge

Kauschläge

Rumiwatch Messungen:

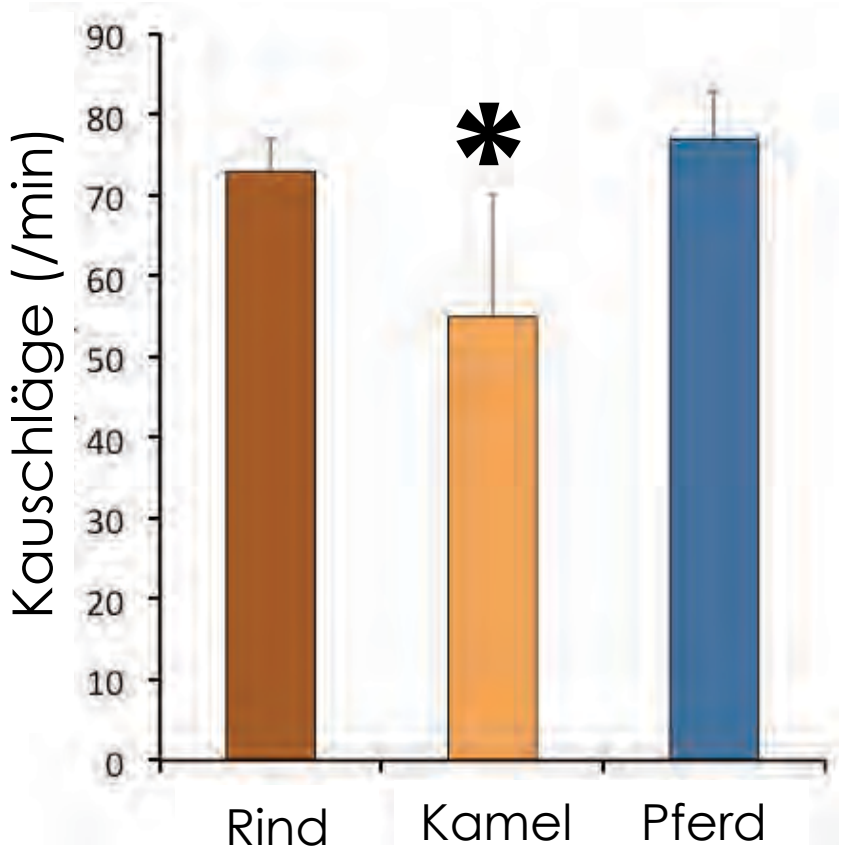
1. Kauschläge

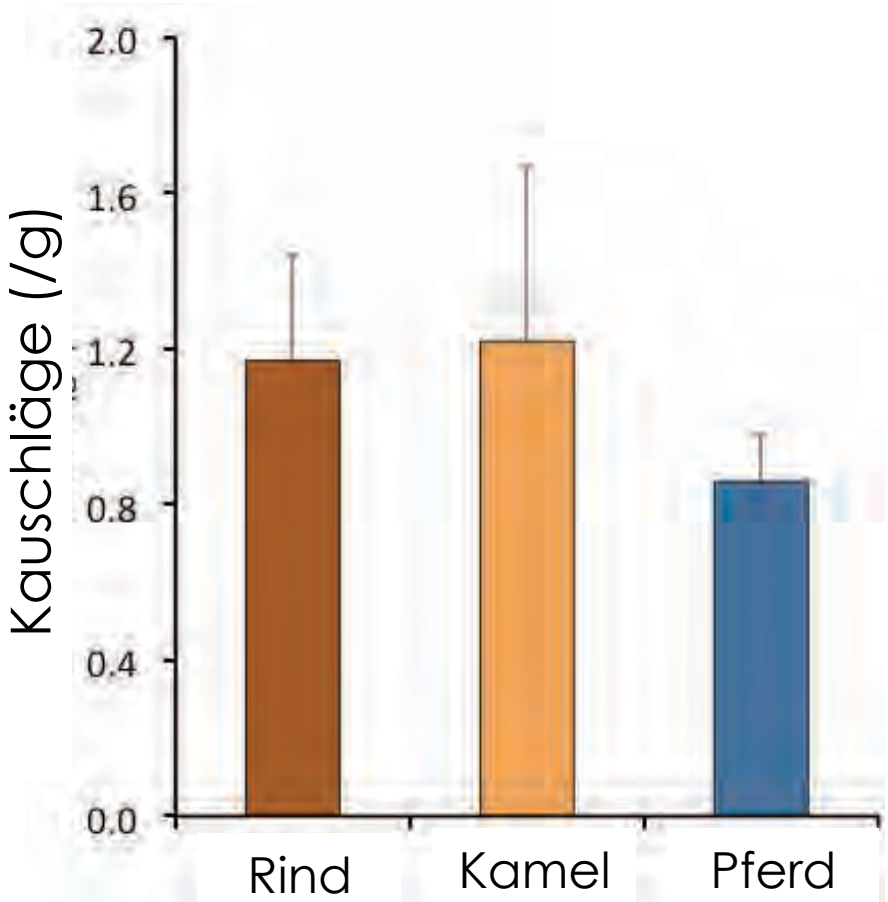


Kauschläge

Rumiwatch Messungen:

1. Kauschläge

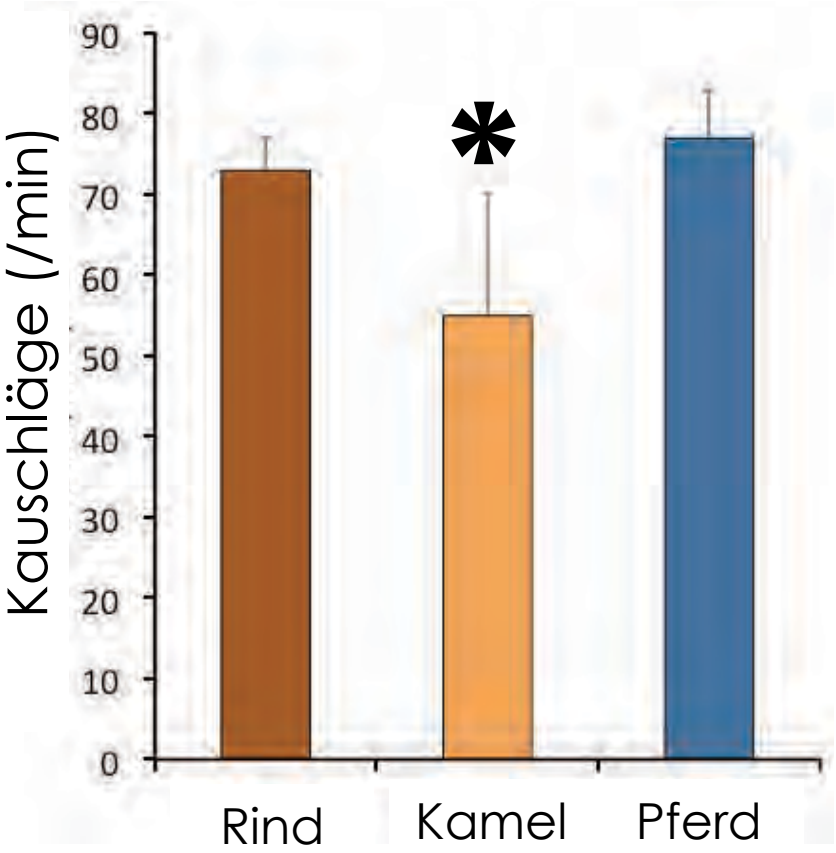


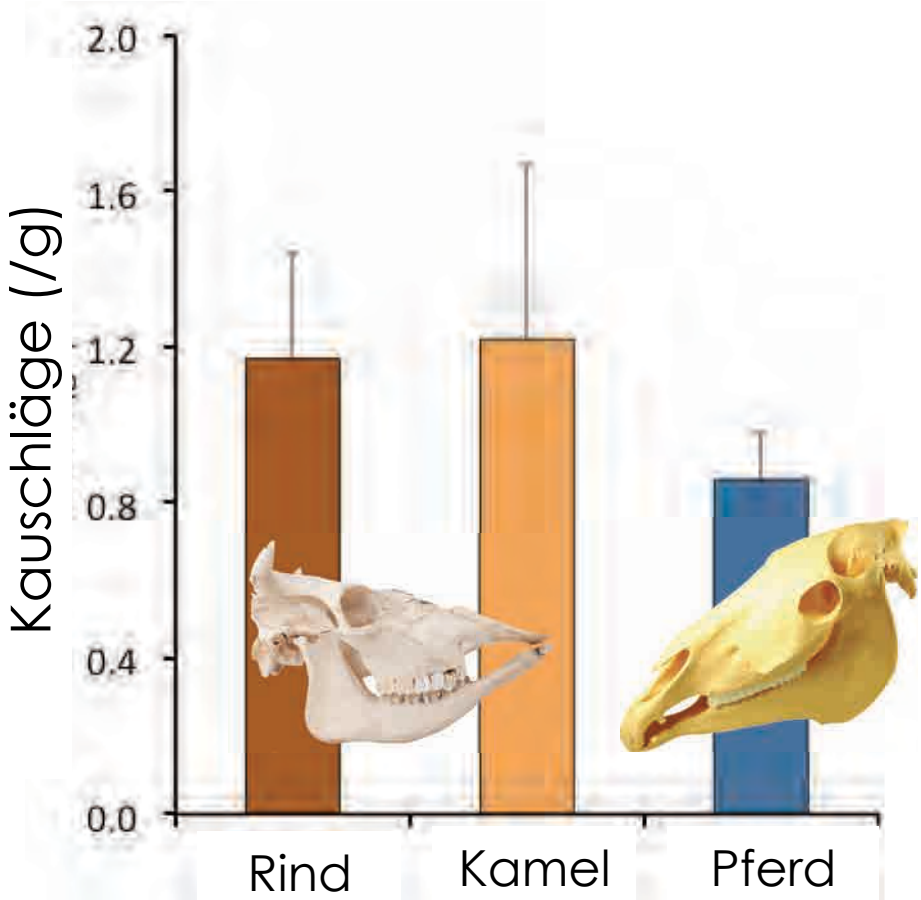


Kauschläge

Rumiwatch Messungen:

1. Kauschläge





Methoden

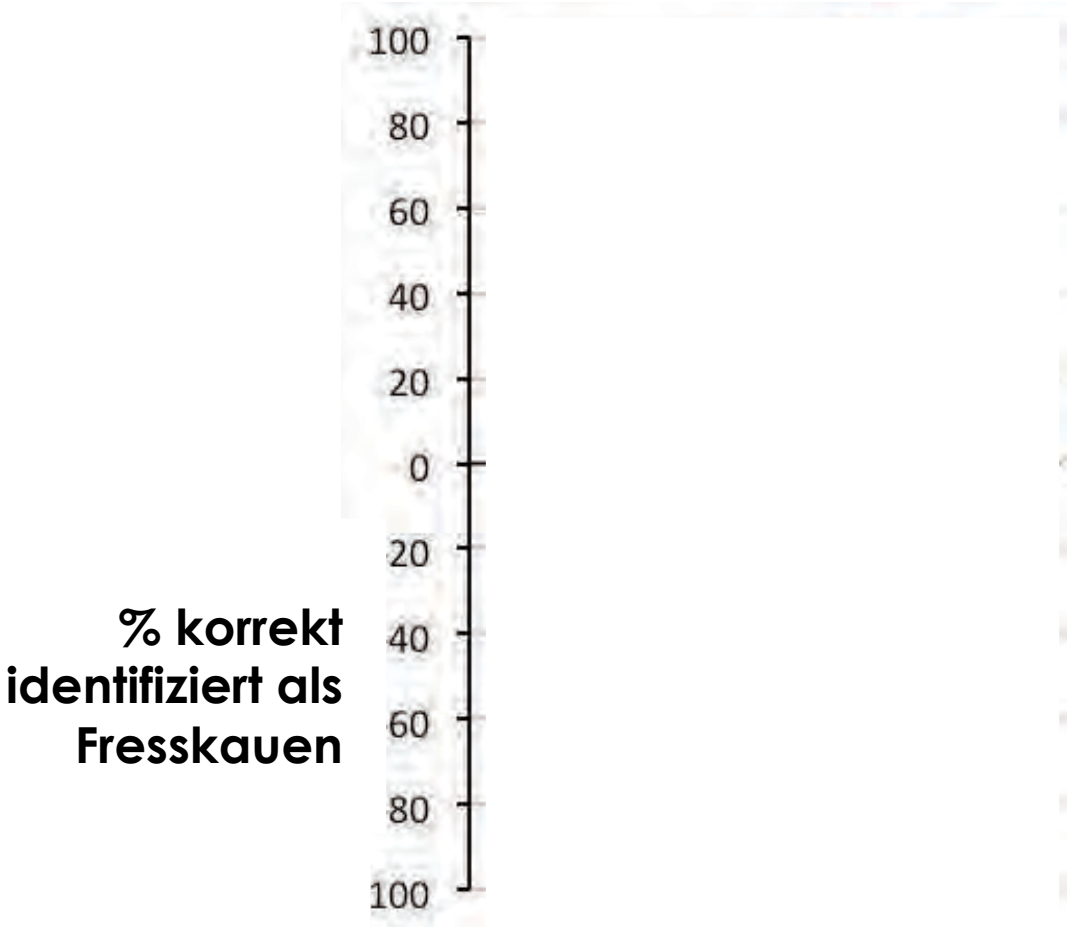
Rumiwatch Messungen:

2. Fresskauen / Wiederkäuen

Kau-Art Identifizierung

Rumiwatch Messungen:

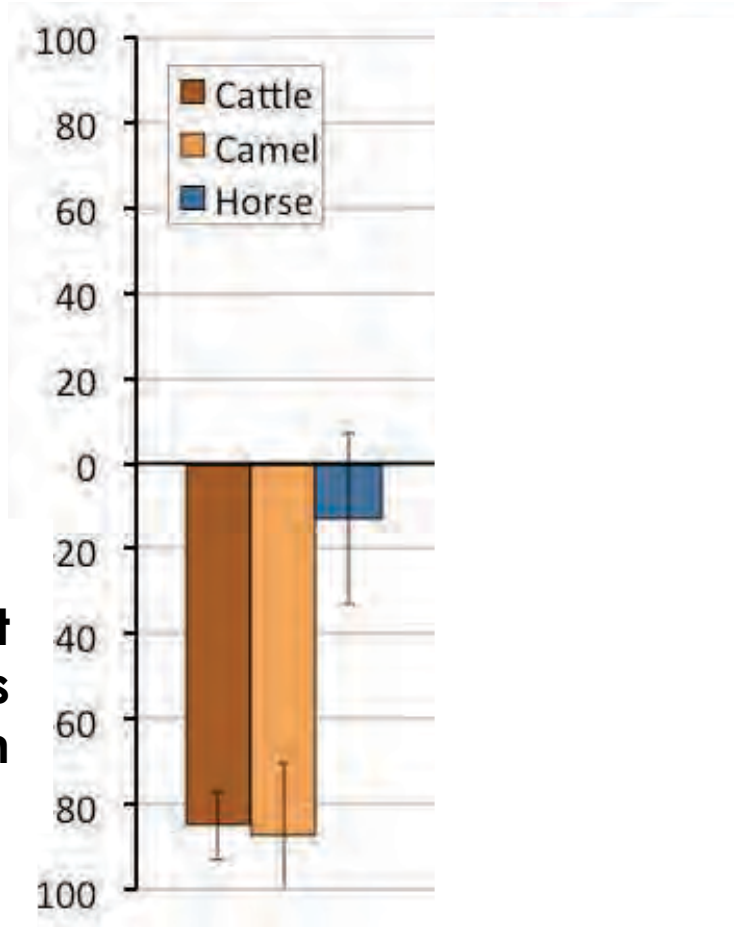
2. Fresskauen / Wiederkäuen



Kau-Art Identifizierung

Rumiwatch Messungen:

2. Fresskauen / Wiederkäuen



% korrekt identifiziert als Fresskauen

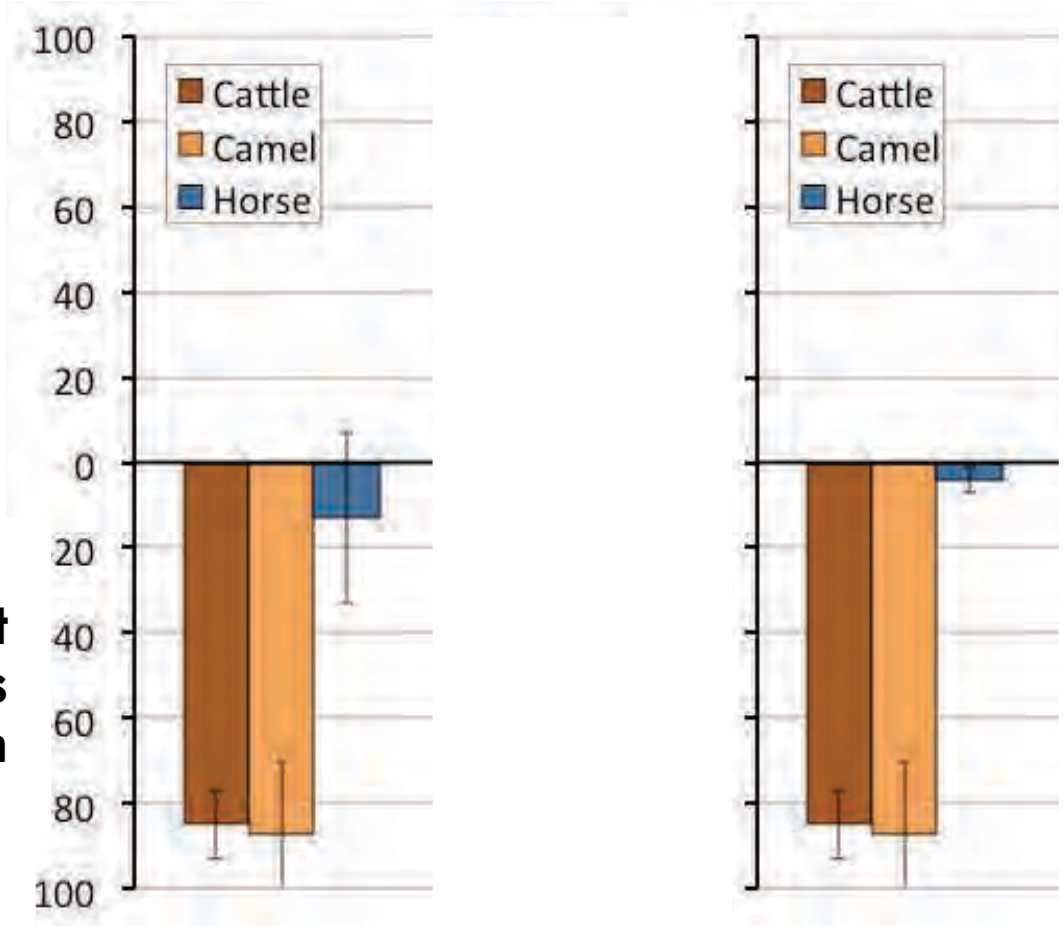
Kau-Art Identifizierung

Rumiwatch Messungen:

2. Fresskauen / Wiederkäuen

mit Outlier **ohne Outlier**

% korrekt identifiziert als Fresskauen



Kau-Art Identifizierung

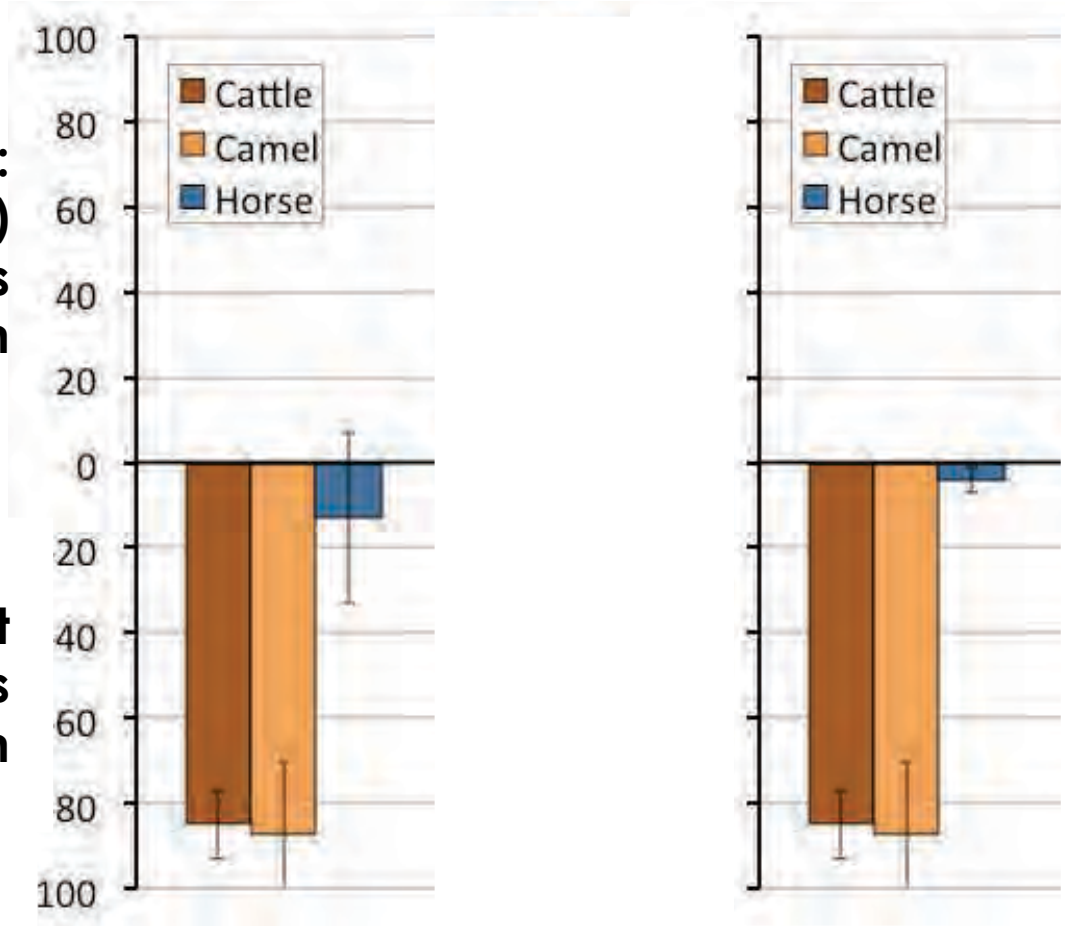
Rumiwatch Messungen:

2. Fresskauen / Wiederkäuen

mit Outlier **ohne Outlier**

% (bei Wdk.: korrekt) identifiziert als Wiederkäuen

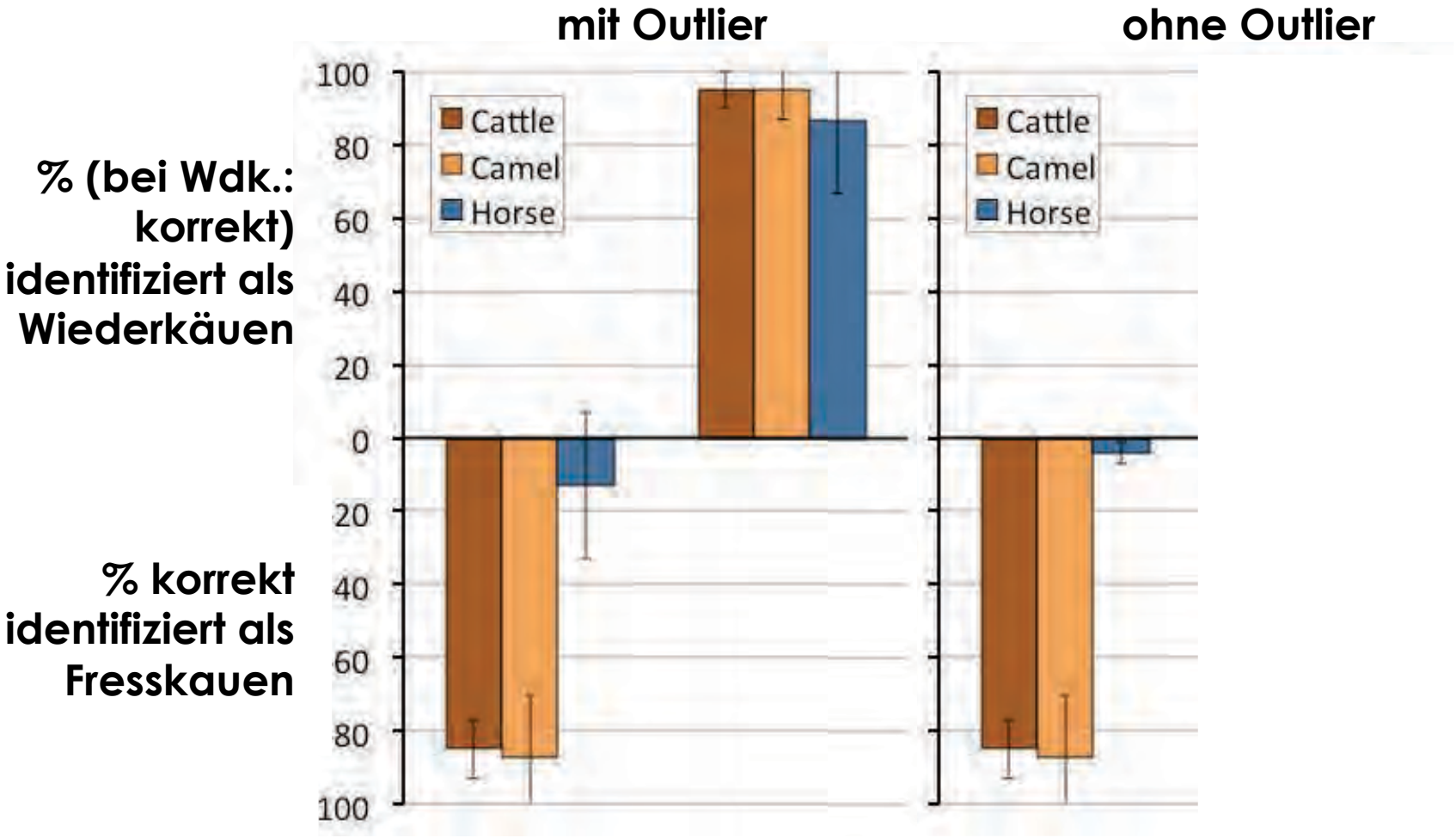
% korrekt identifiziert als Fresskauen



Kau-Art Identifizierung

Rumiwatch Messungen:

2. Fresskauen / Wiederkäuen



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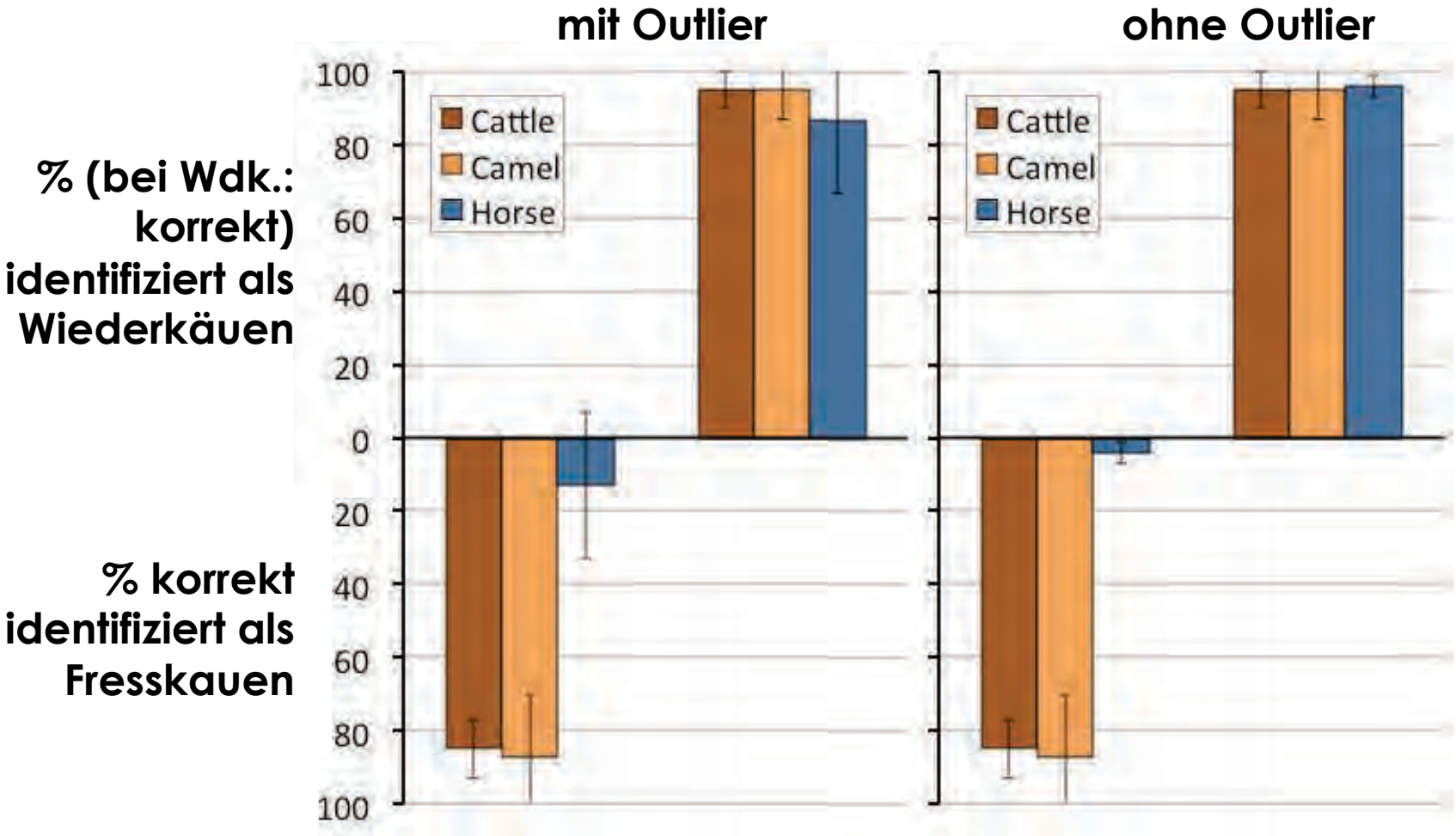

Methoden

Rumiwatch Messungen (zusätzl. Software):

3. Visualisierung der Rohdaten

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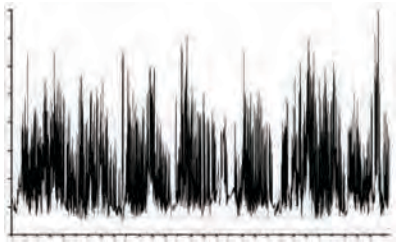

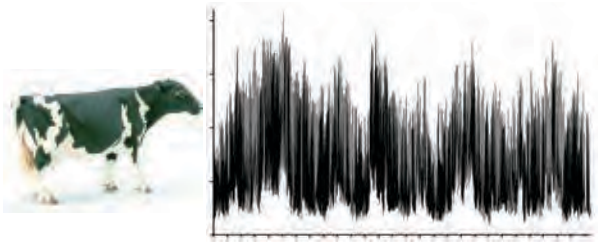

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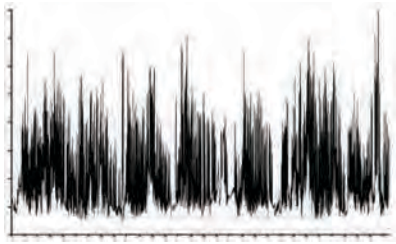

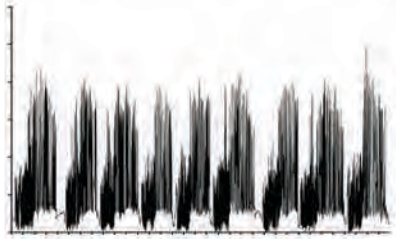

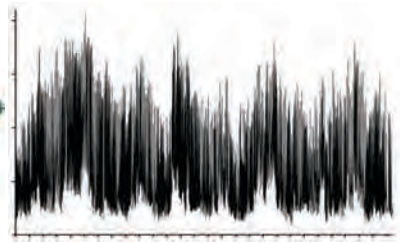

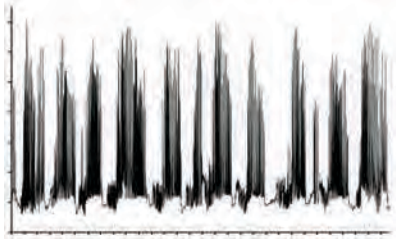

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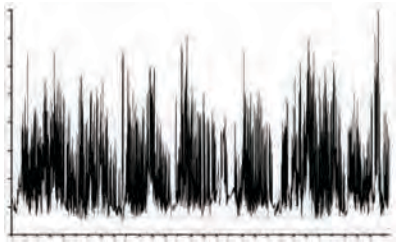
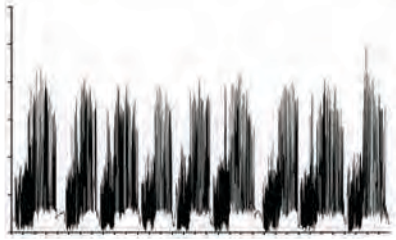
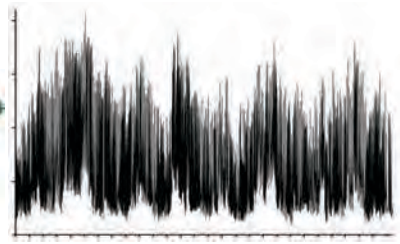
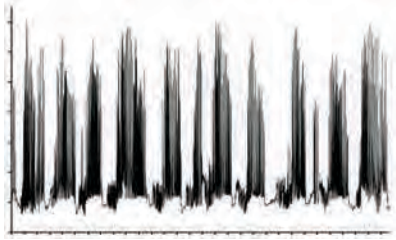
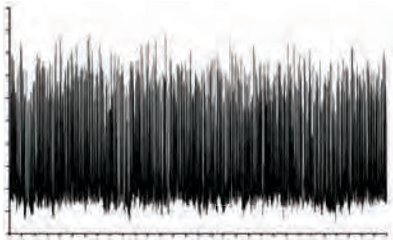
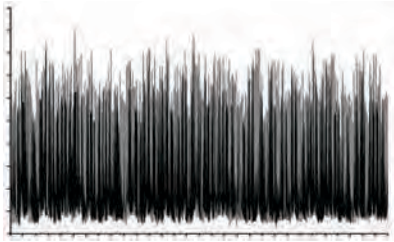








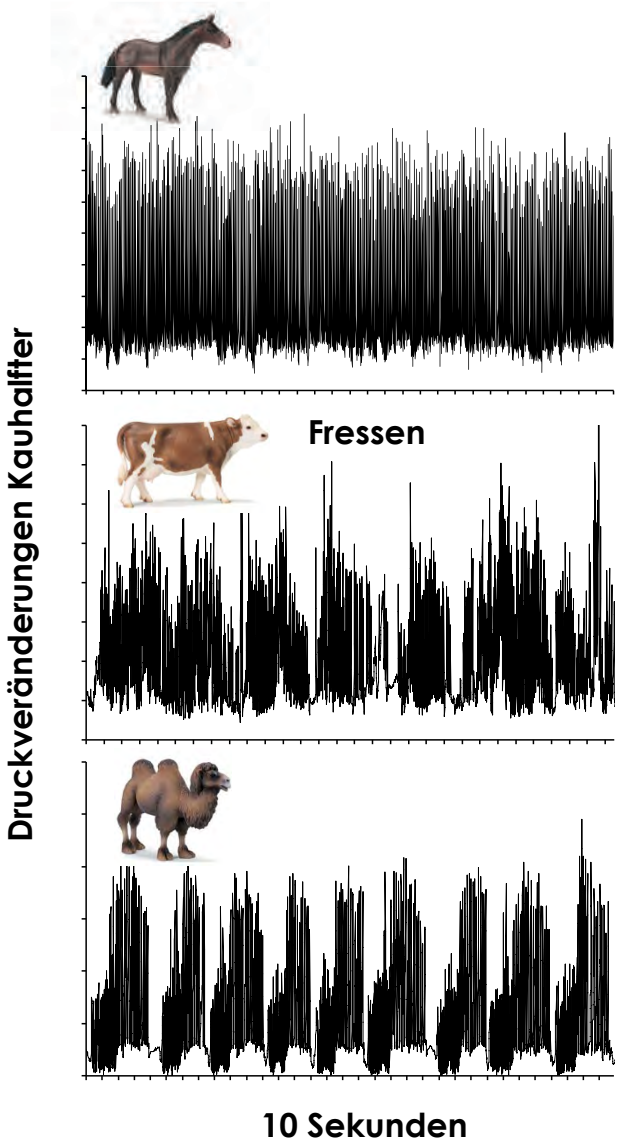




Ingestive mastication in horses resembles rumination but not ingestive mastication in cattle and camels

J. Exp. Zool. 2017;**327**:98–109.

Marie T. Dittmann[1,2,3] | Michael Kreuzer[2] | Ullrich Runge[4] | Marcus Clauss[3]



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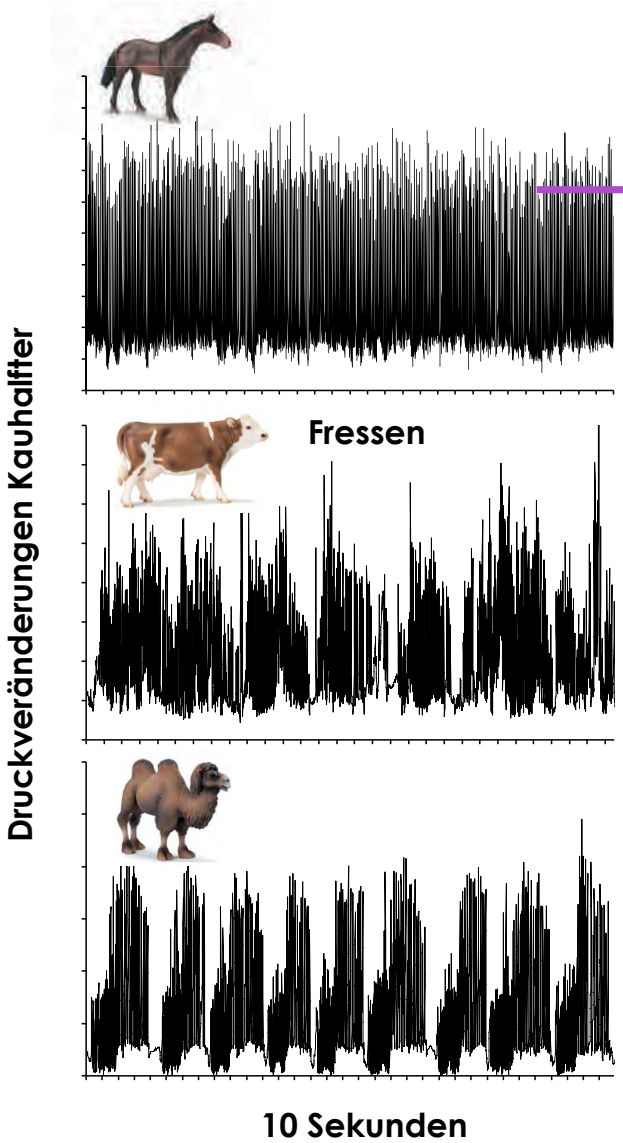

intensive **Partikel-Zerkleinerung**

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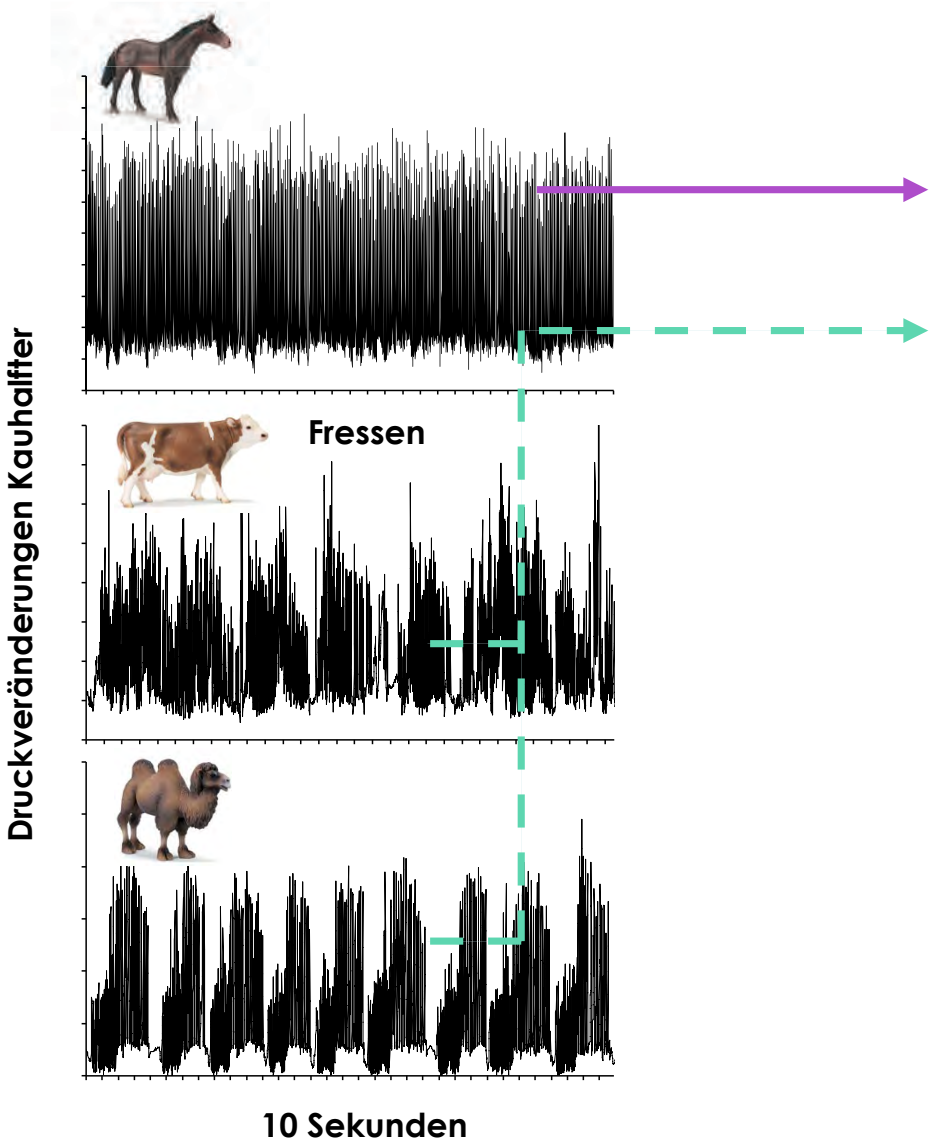

intensive

geringe

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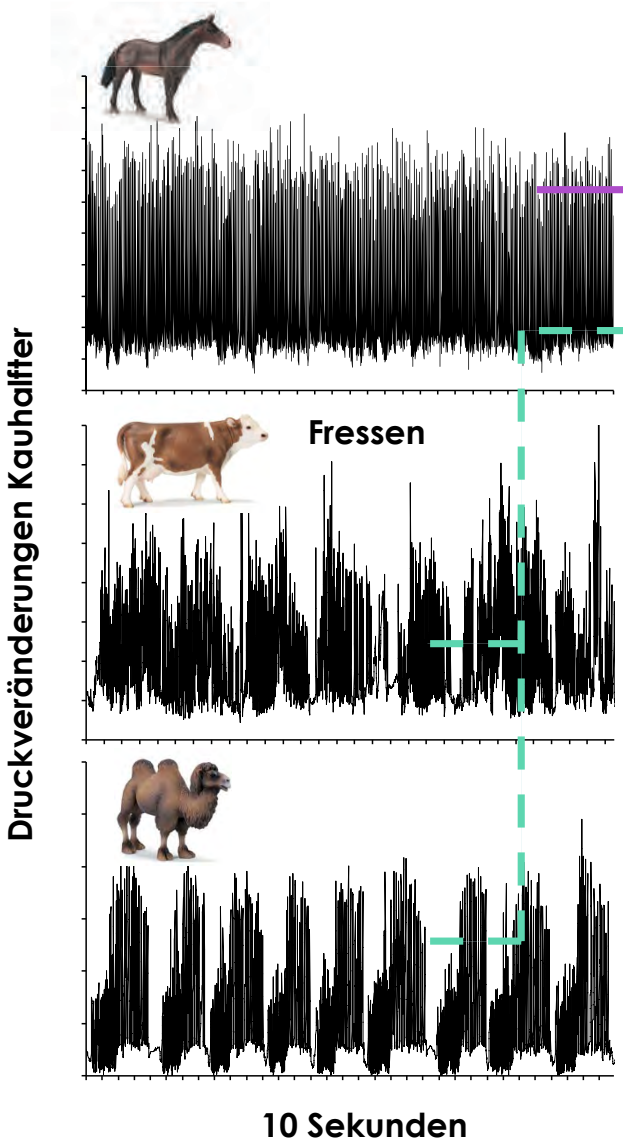

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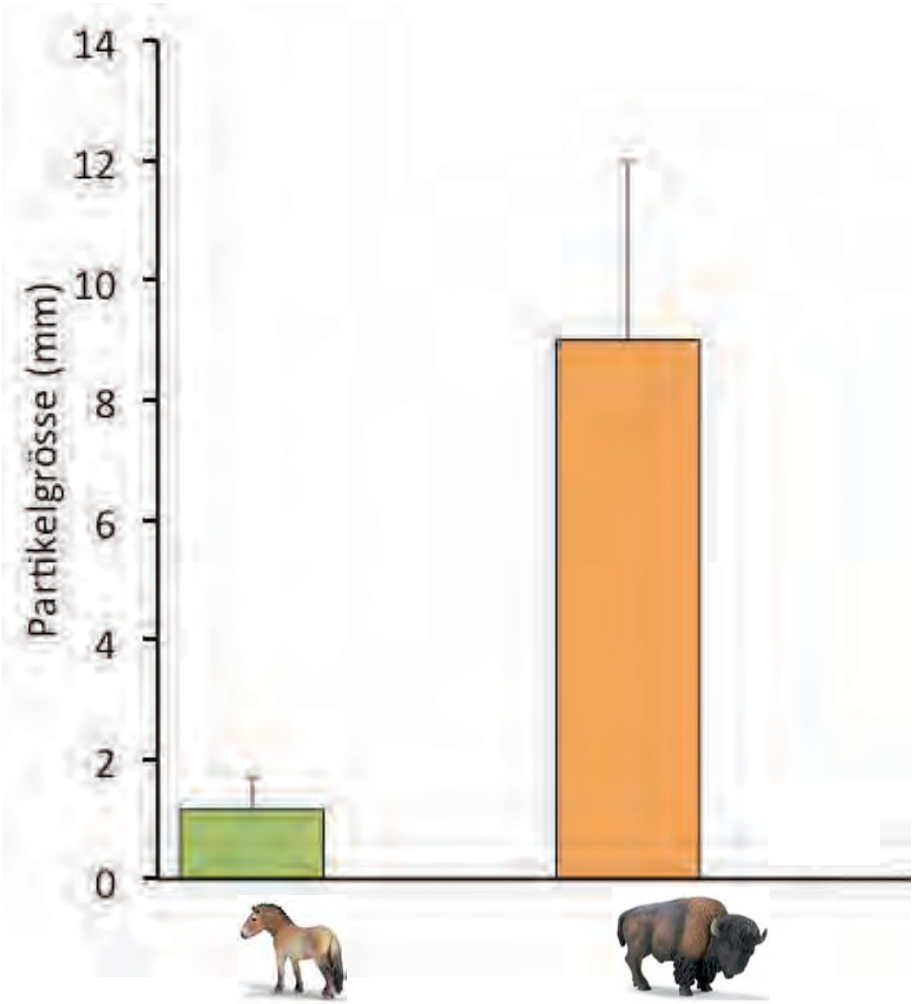
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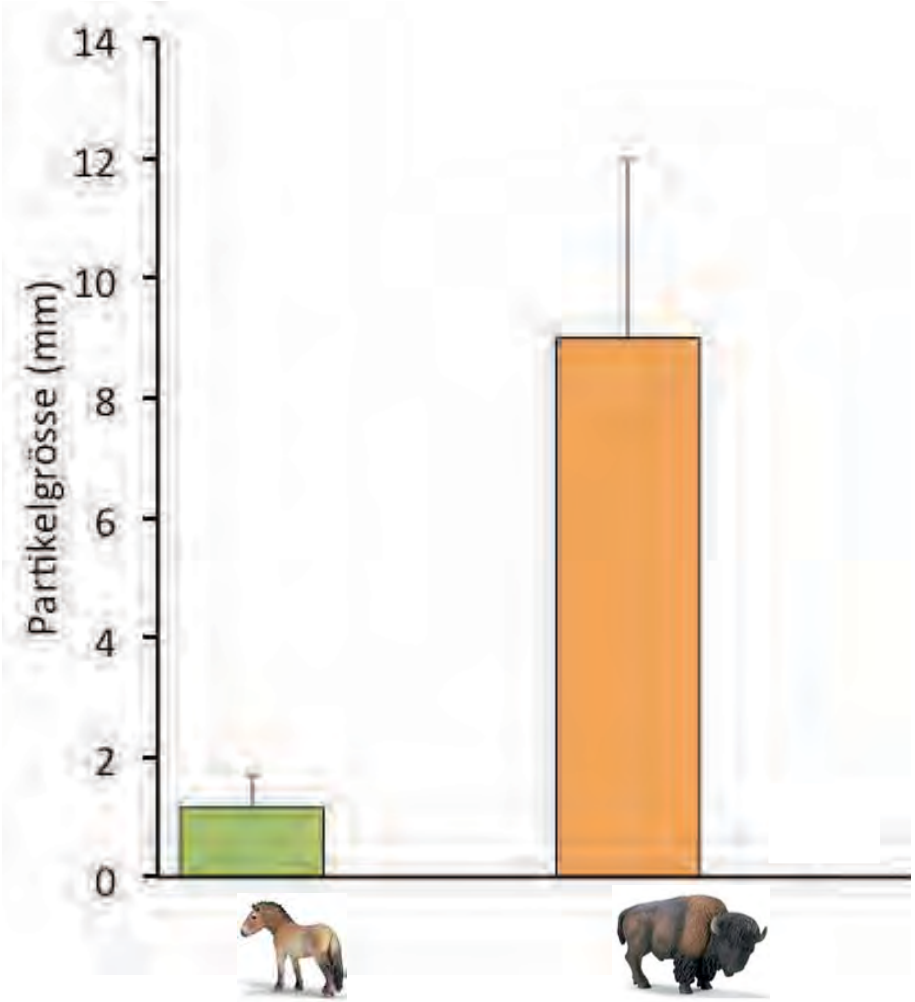
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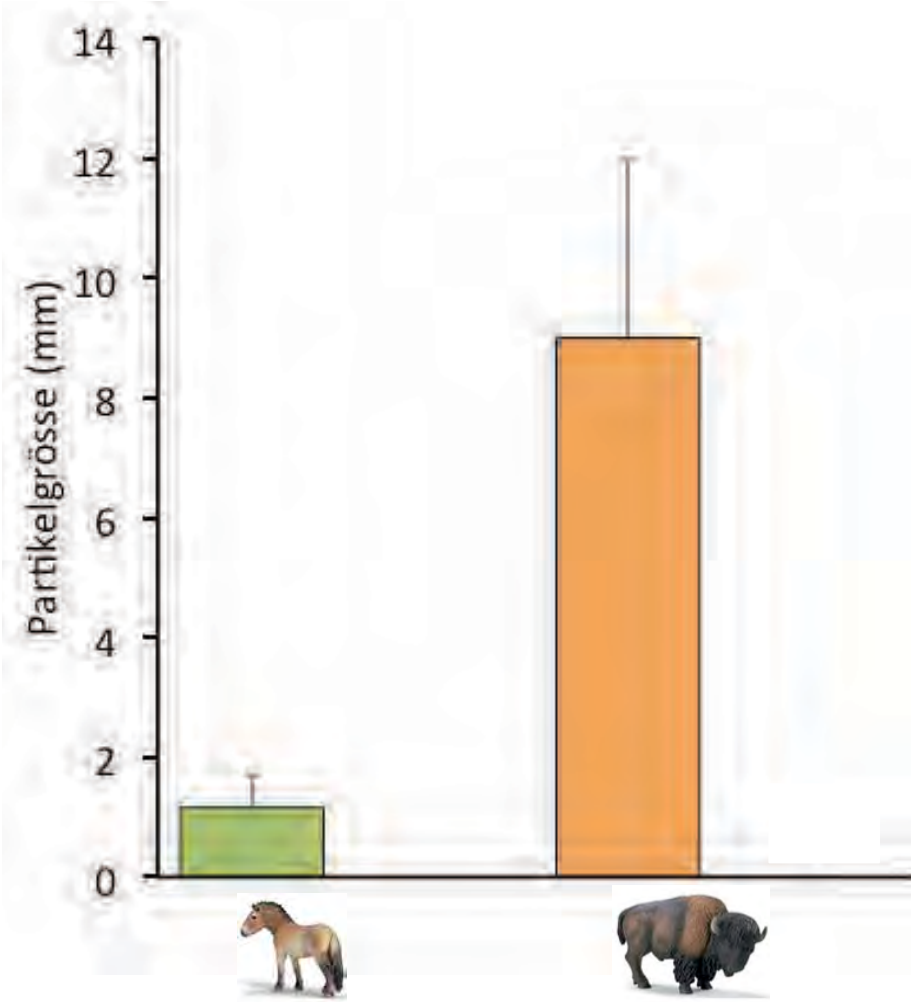
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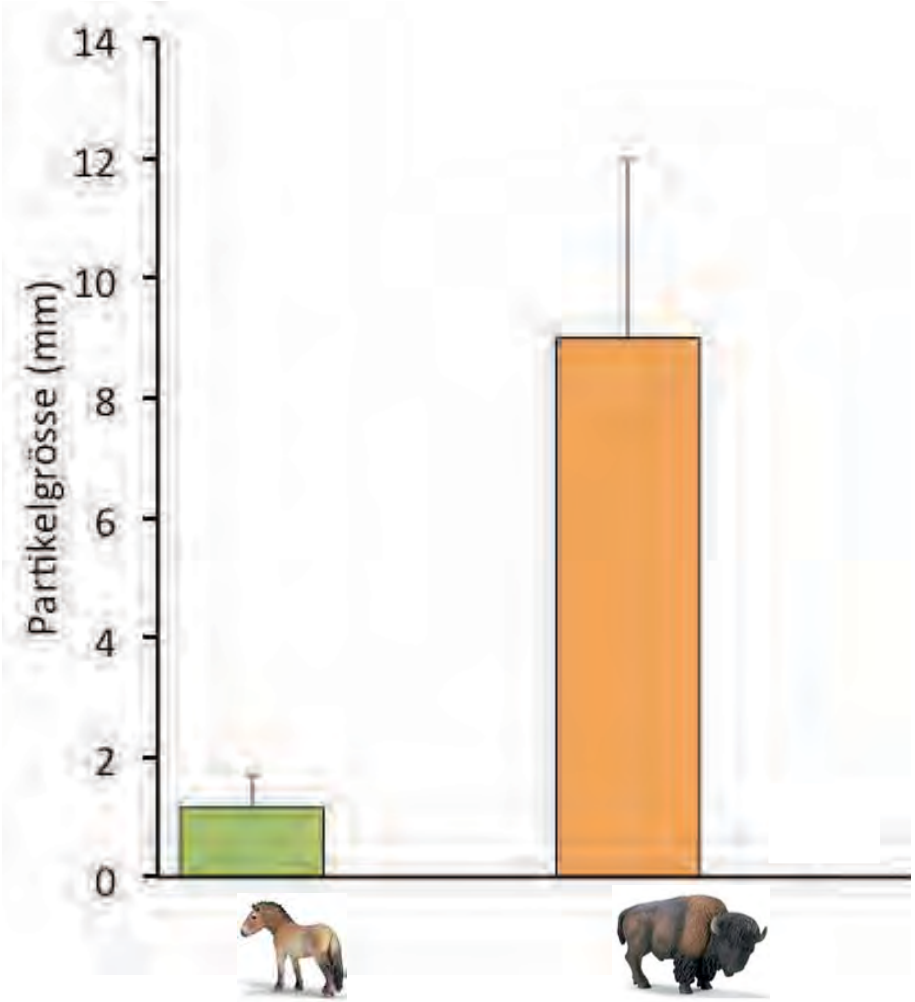
Partikelgrösse (mm)
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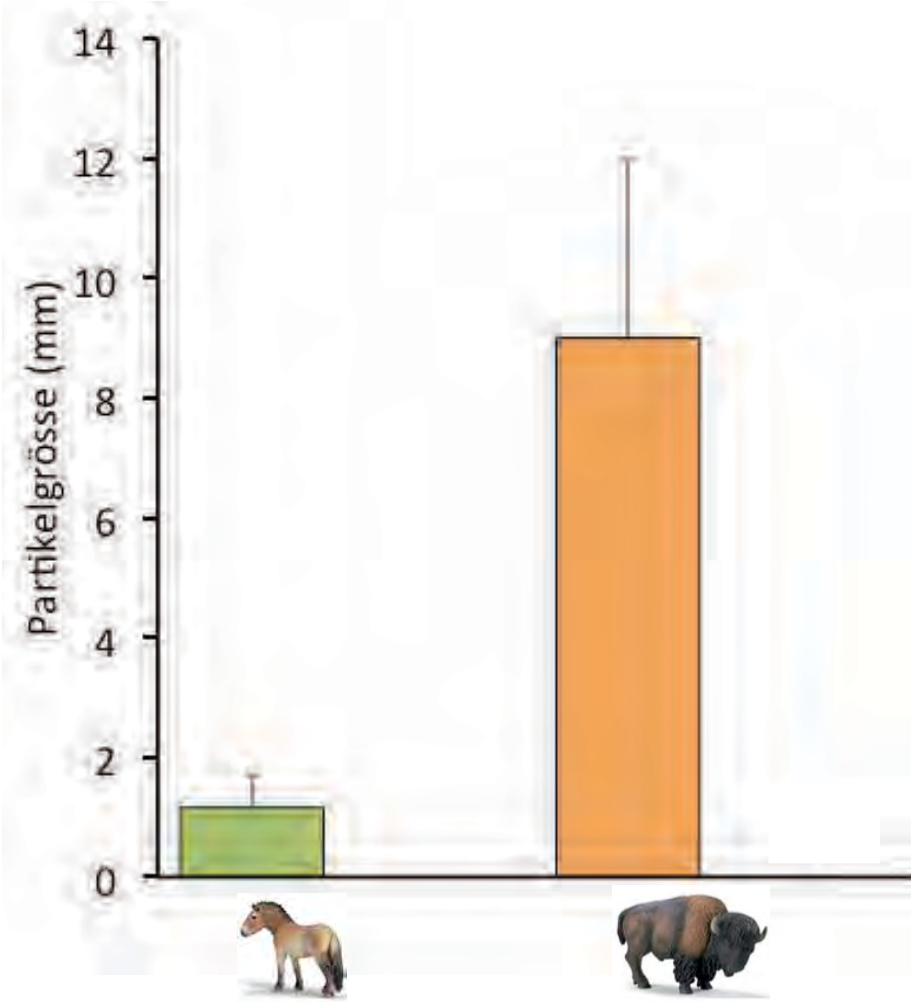
Zahnoptimierung vs. Kau-Optimierung:

Sortieren und Wiederkäuen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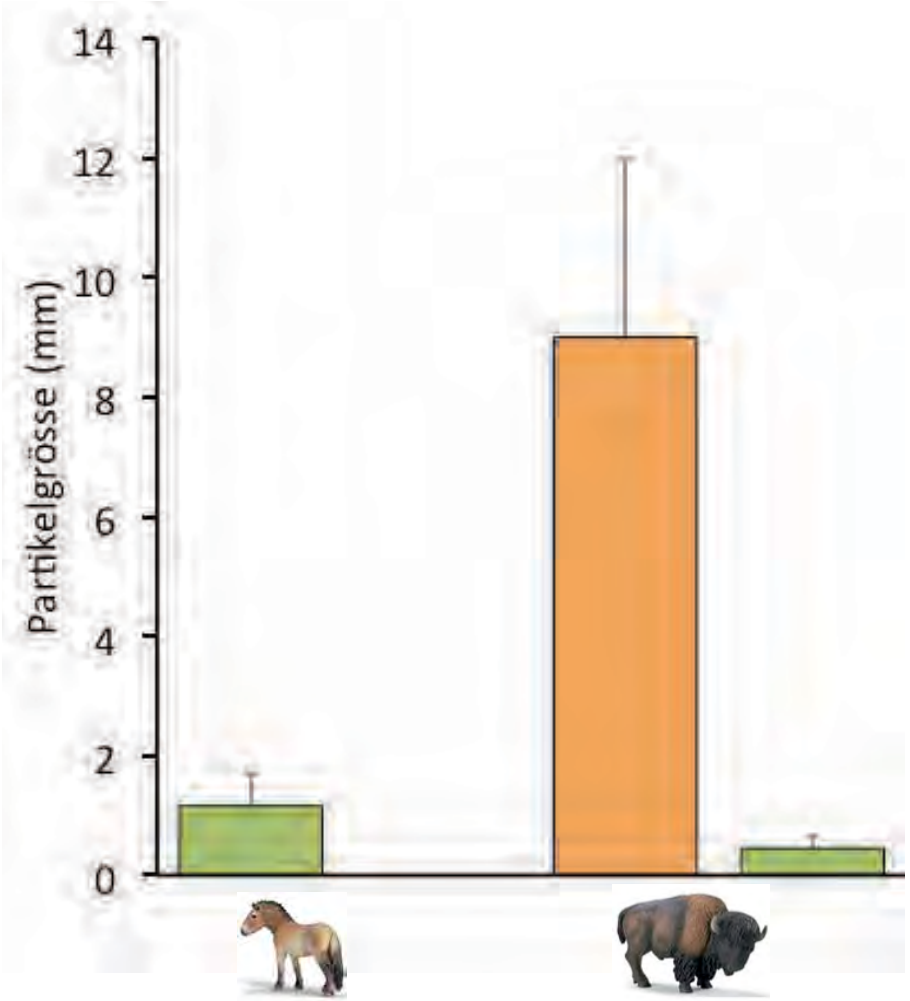
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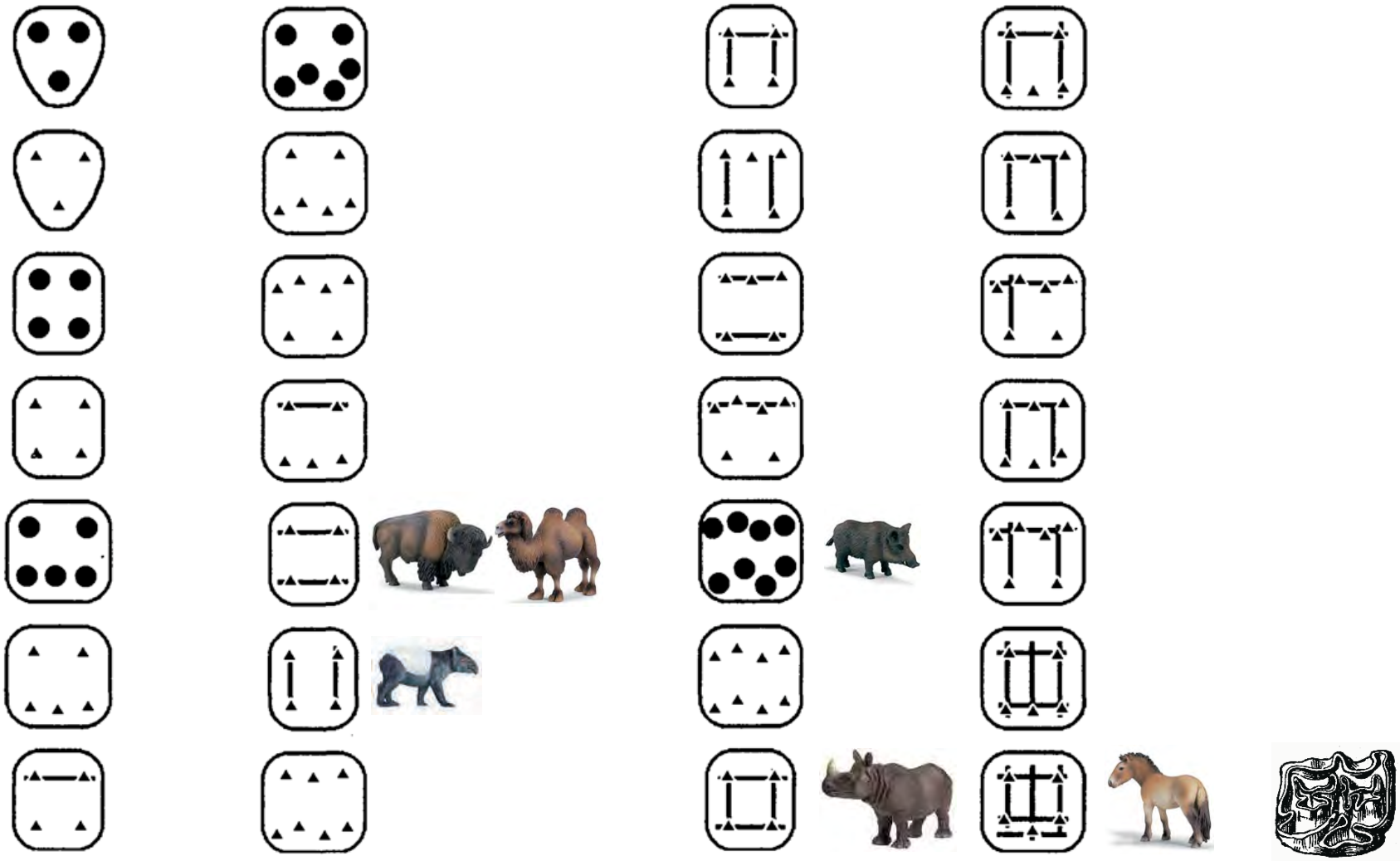
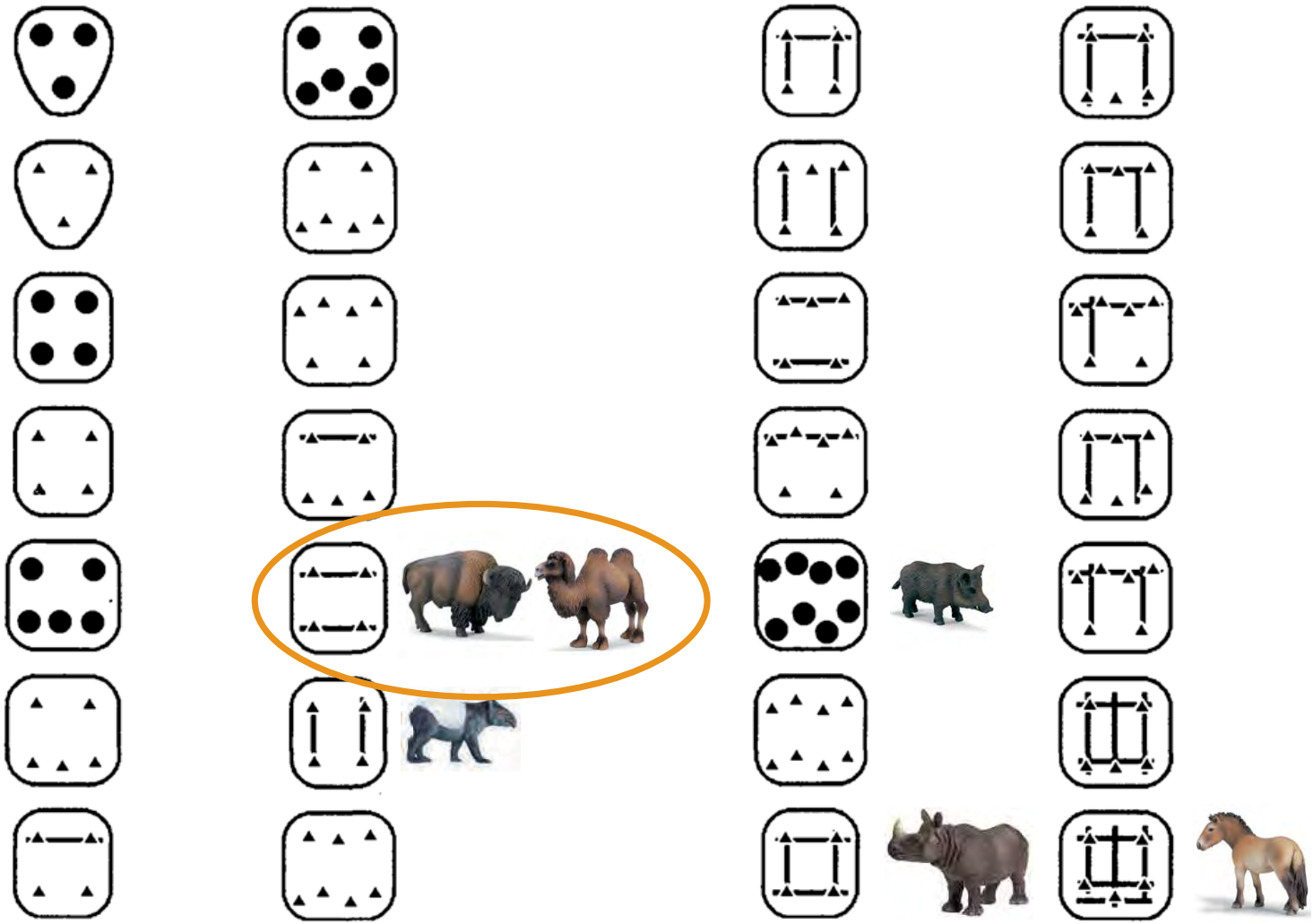
Backenzahn-Oberflächen



aus Jernvall et al. (1996)

Backenzahn-Oberflächen



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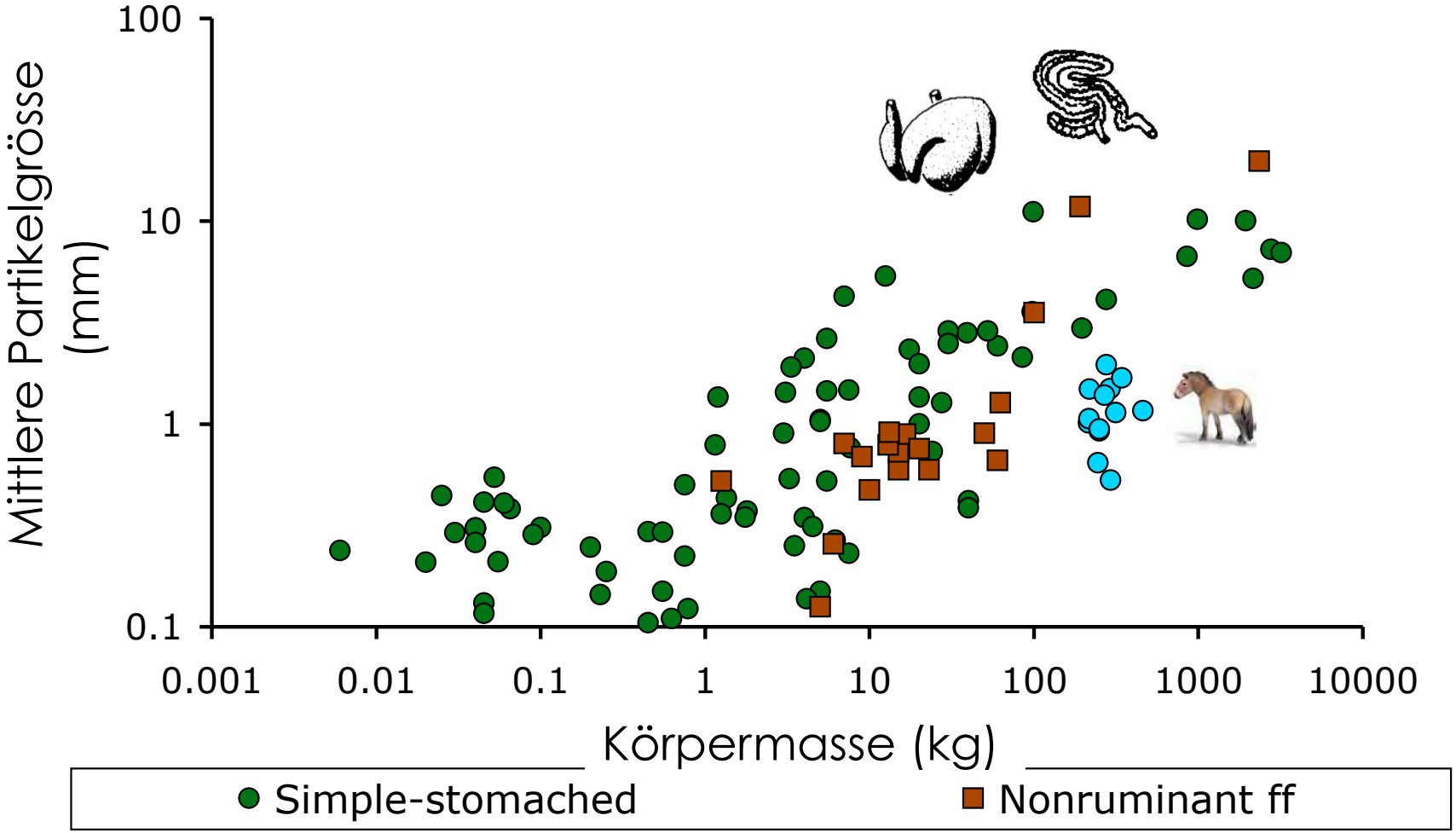
Comparative chewing efficiency in mammalian herbivores

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

Oikos 118: 1623–1632, 2009



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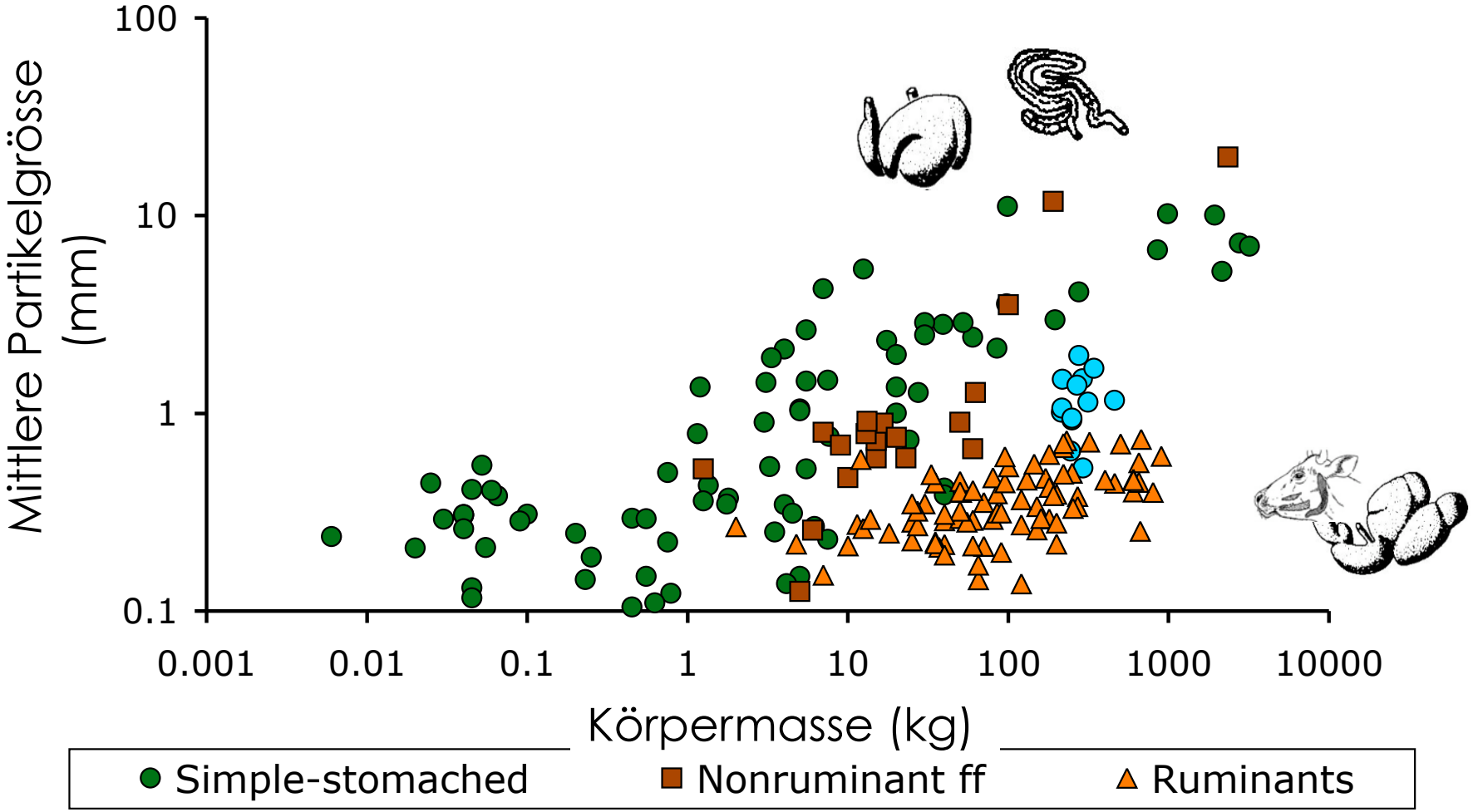


Kotpartikel bei Wiederkäuer und Nicht-Wiederkäuer

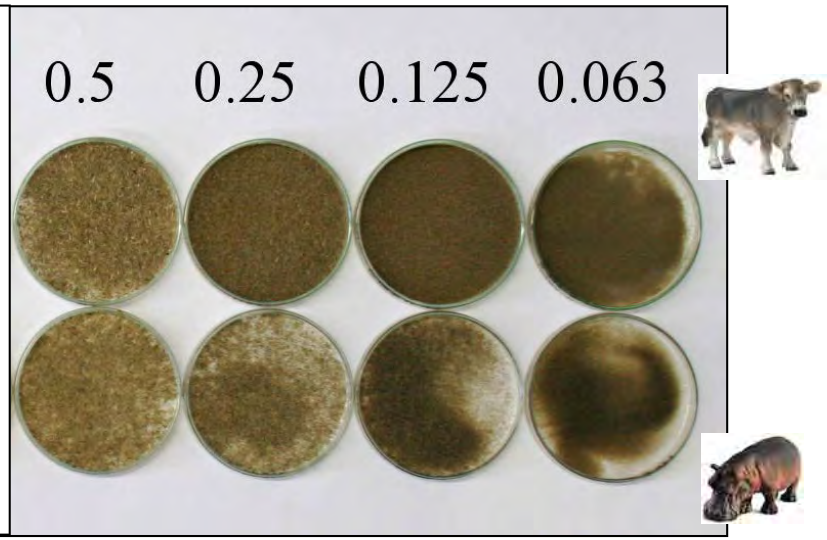
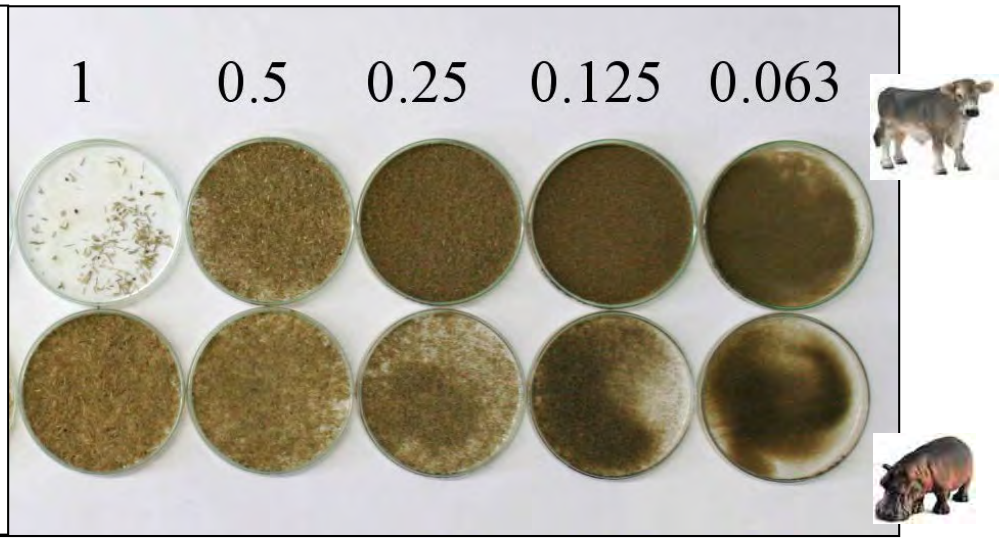


Photo A. Schwarm

Kotpartikel bei Wiederkäuer und Nicht-Wiederkäuer



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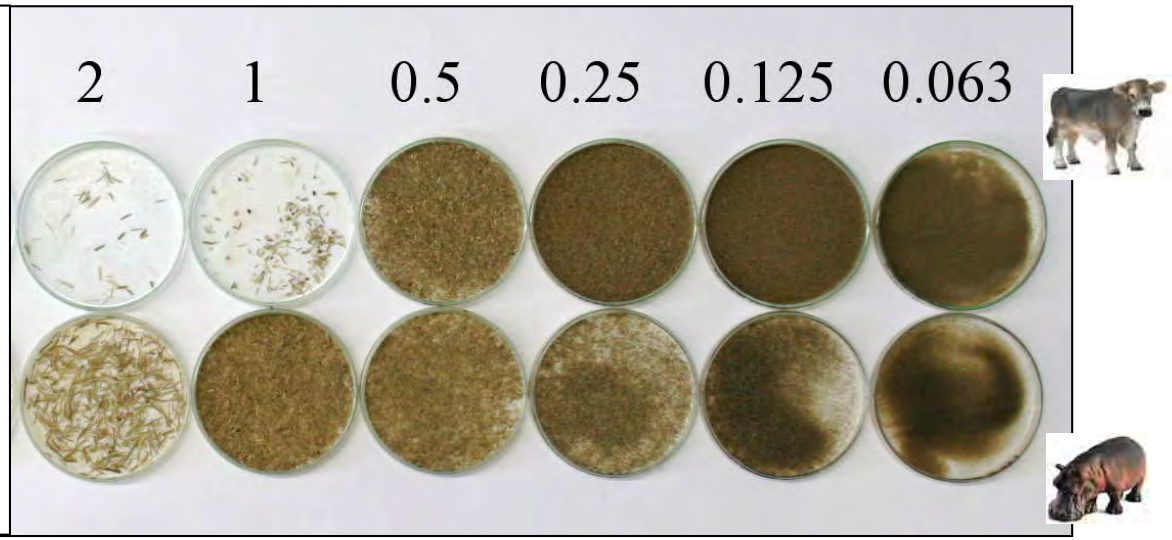

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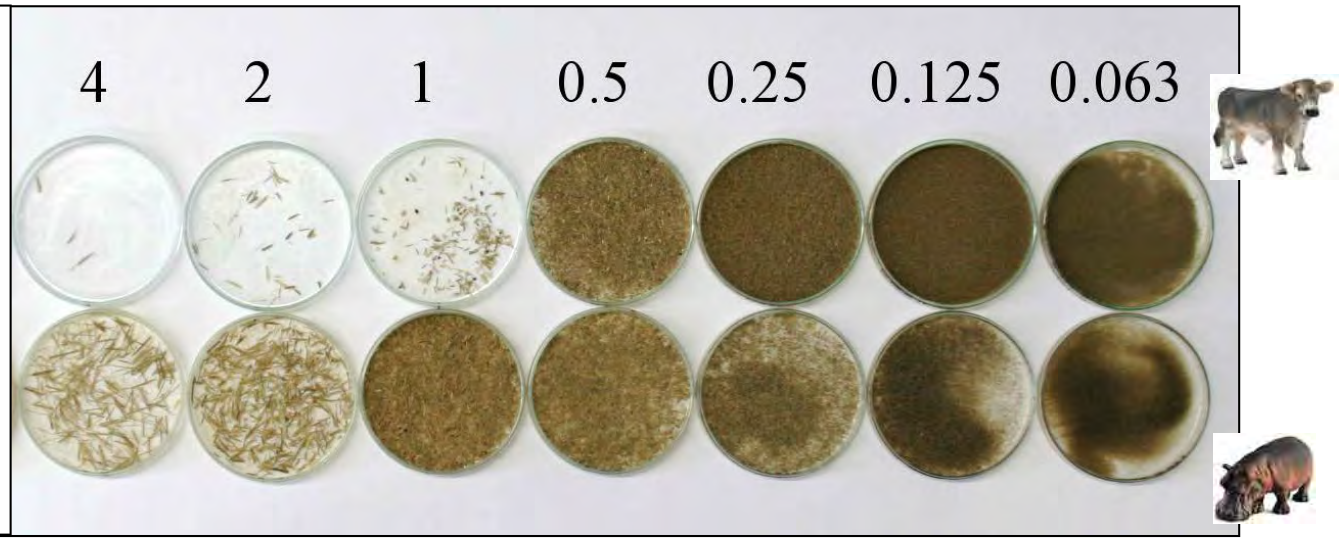

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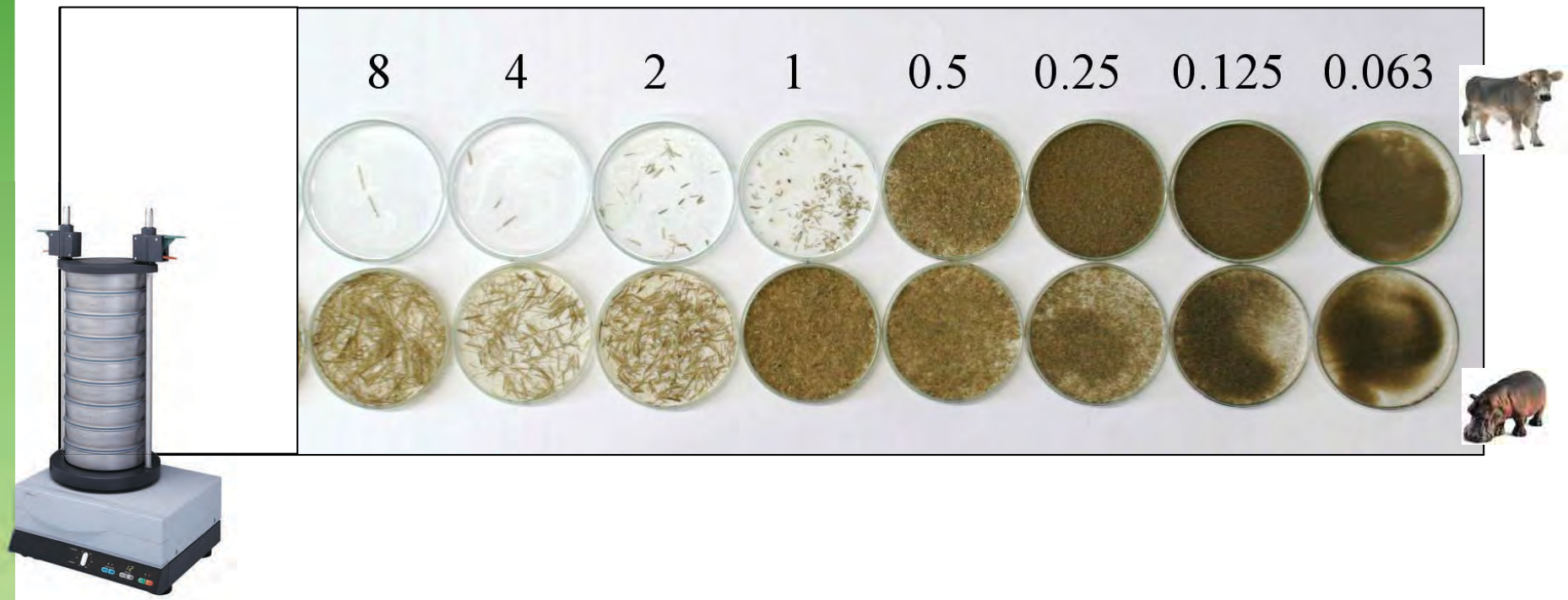

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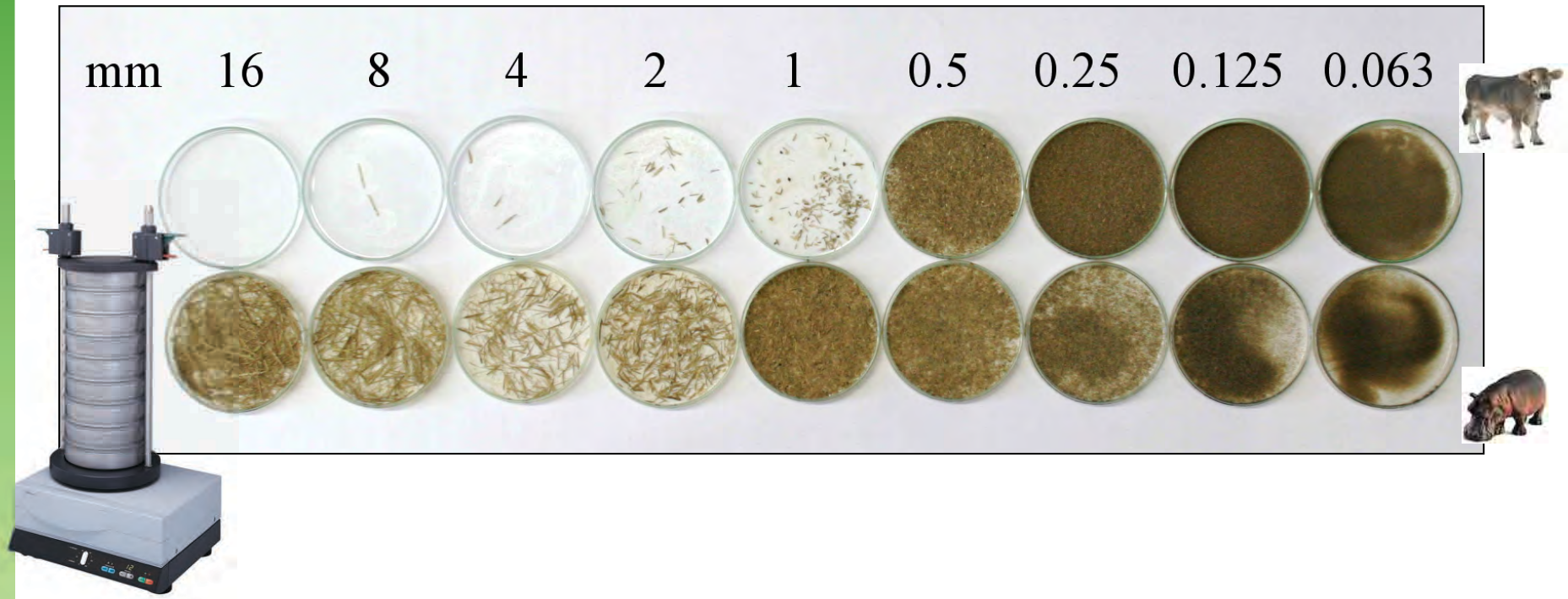

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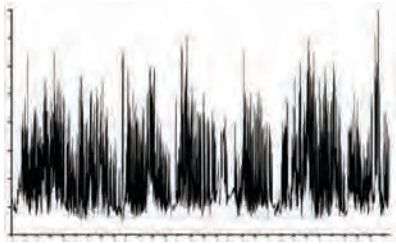

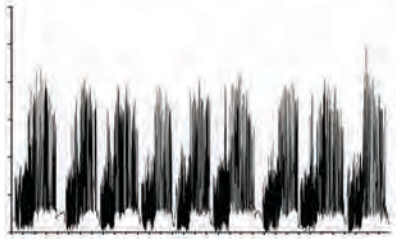

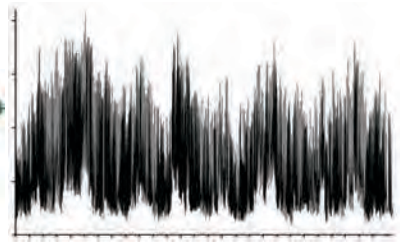

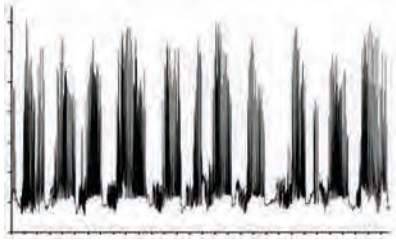

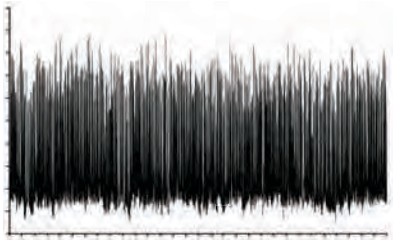

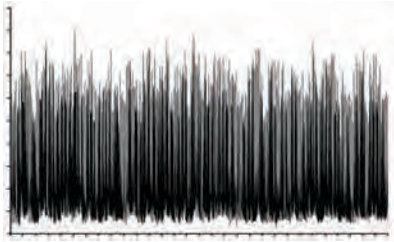

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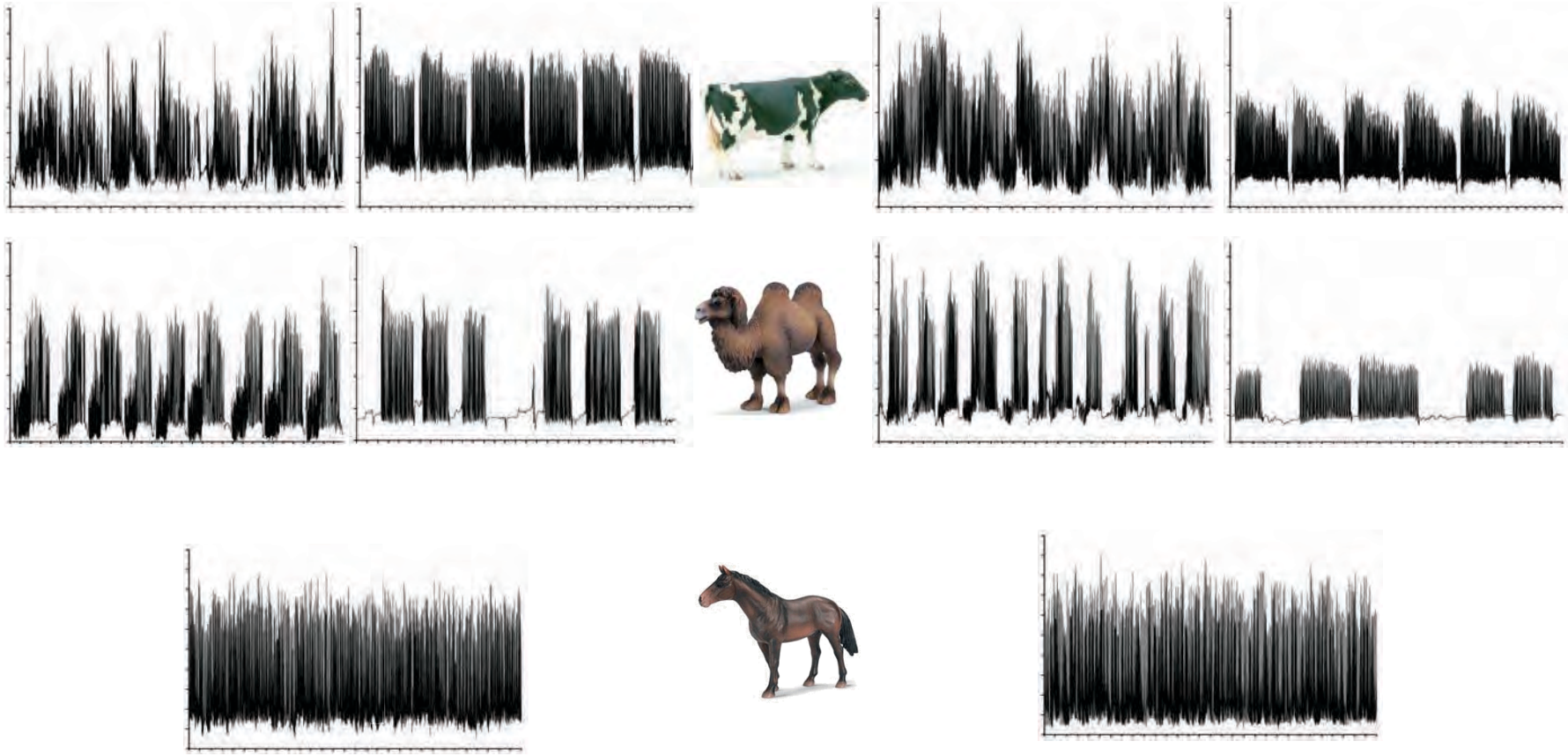
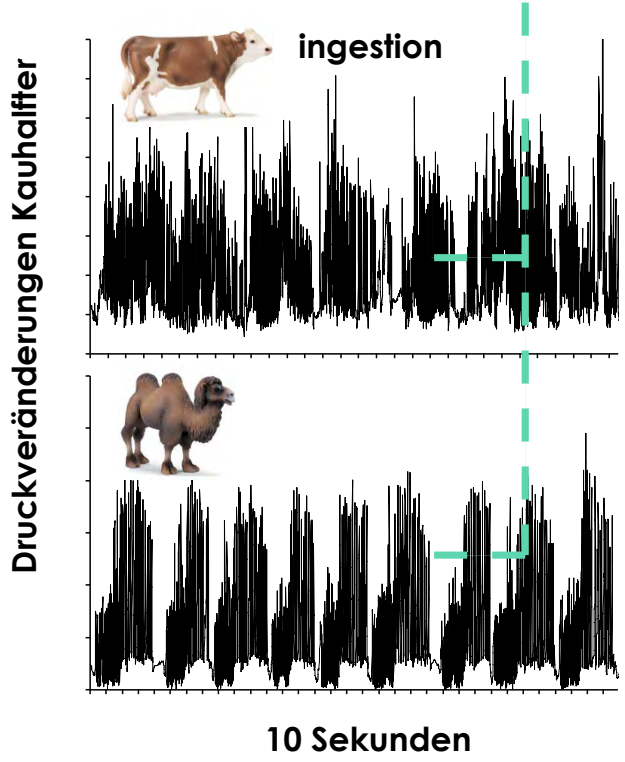


Die wirklich spannende Frage ist ...

... warum kauen Wiederkäuer so 'nachlässig' beim Fressen ?

Partikel-Zerkleinerung

geringe



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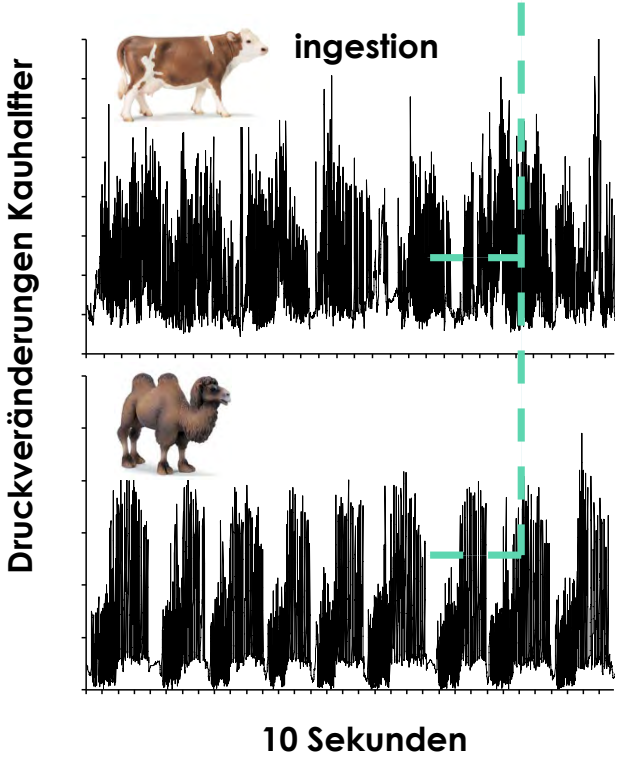
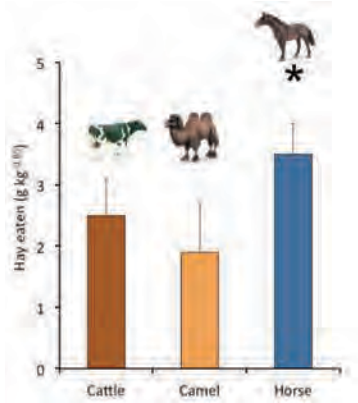


... wenn es nicht um die Futteraufnahme geht ?



Die wirklich spannende Frage ist ...

Wenn es um eine Optimierung der Partikelzerkleinerung ginge, sollten Wiederkäuer schon beim Fressen den rhythmischen/gleichmässigen Kauschlag verwenden.

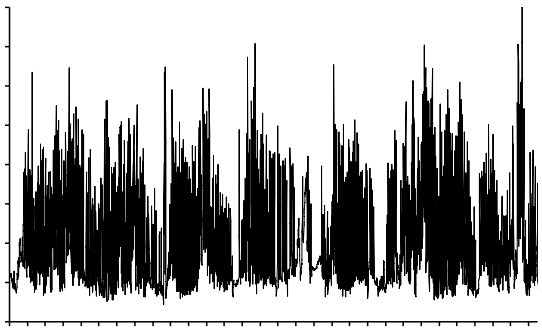
Zahnoptimierung:

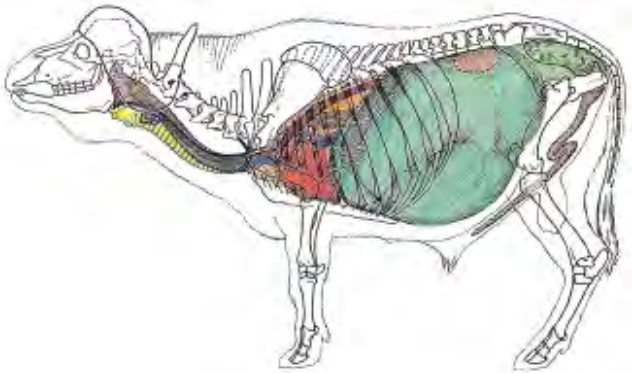
Langlebigkeit II

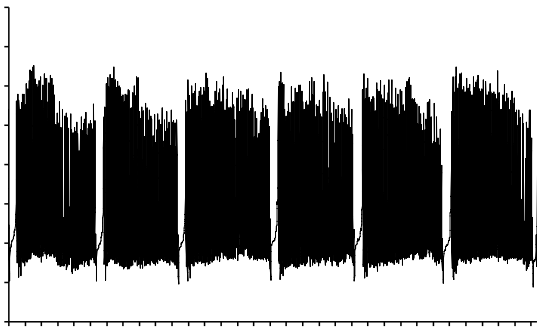
Ein zusätzlicher Vorteil für Wiederkäuer ?

Wiederkäuer-Kau-Strategie:

Die Abriebs-intensiven gleichmässigen Kauschläge erst anwenden, wenn der Nahrungsbrei im Vormagen von Staub/ Erde freigewaschen wurde ?





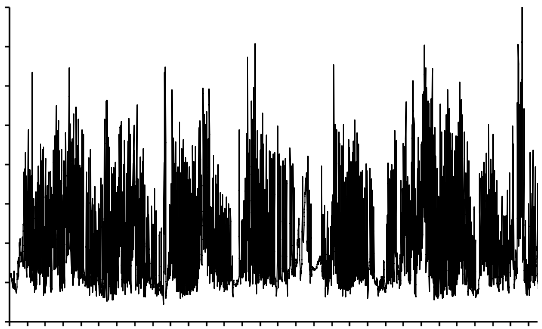


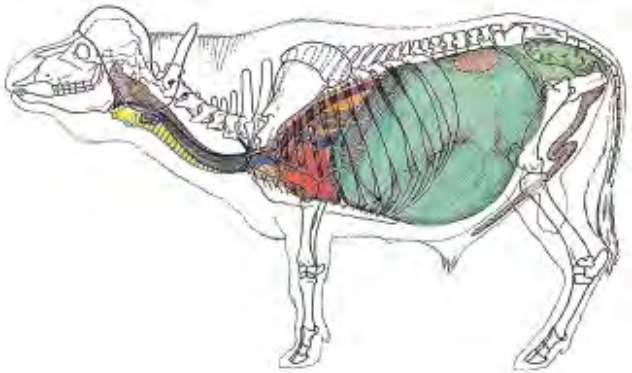
Ein zusätzlicher Vorteil für Wiederkäuer ?

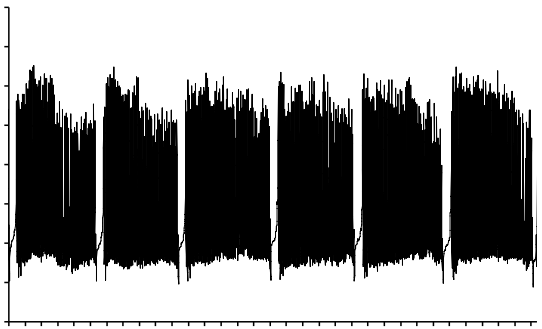
Untangling the environmental from the dietary: dust does not matter

Proc. R. Soc. B **283**: 20161032.

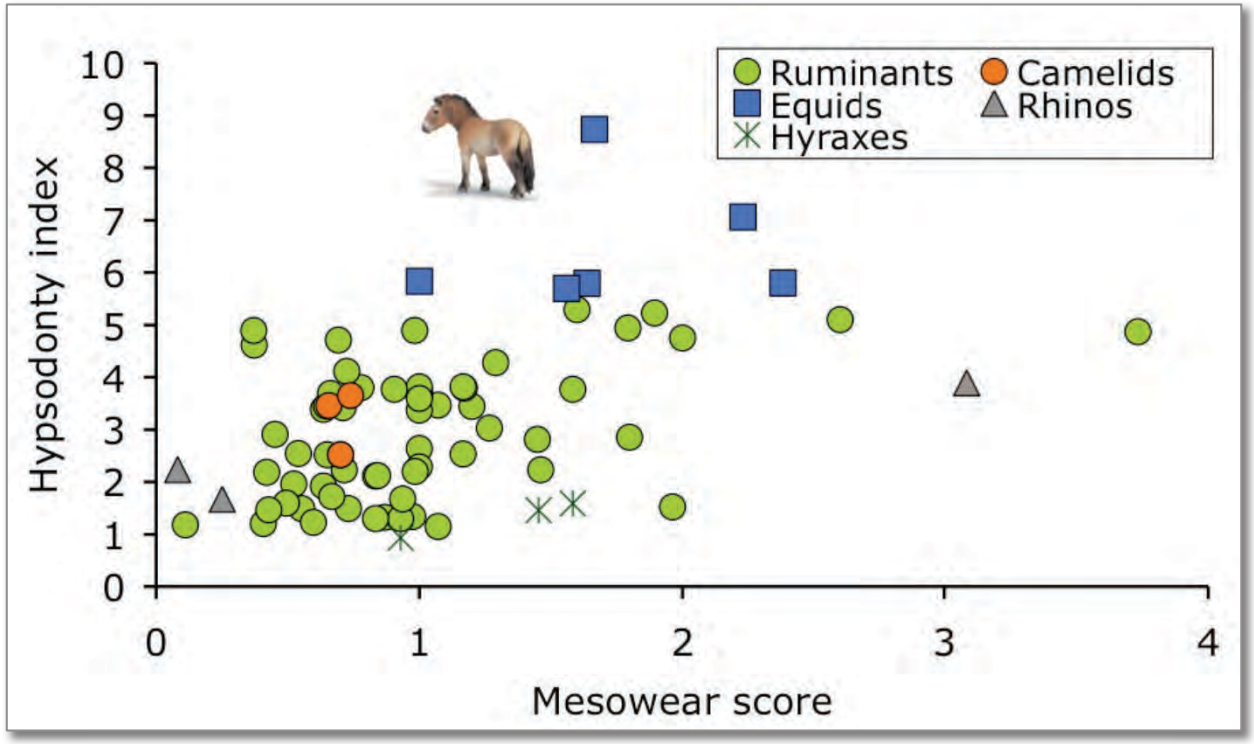
Gildas Merceron[1], Anusha Ramdarshan[1], Cécile Blondel[1], Jean-Renaud Boisserie[1,2], Noël Brunetiere[3], Arthur Francisco[3], Denis Gautier[4,5], Xavier Milhet[3], Alice Novello[6] and Dimitri Pret[7]

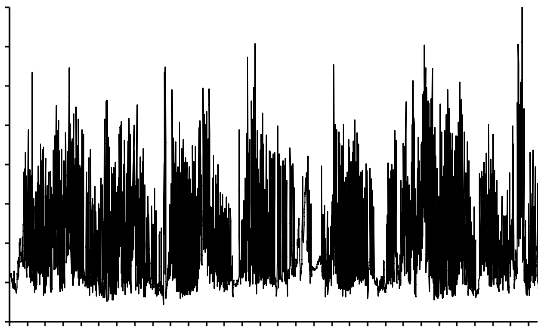


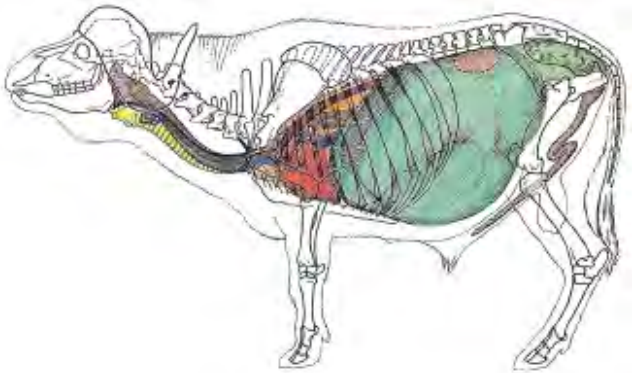


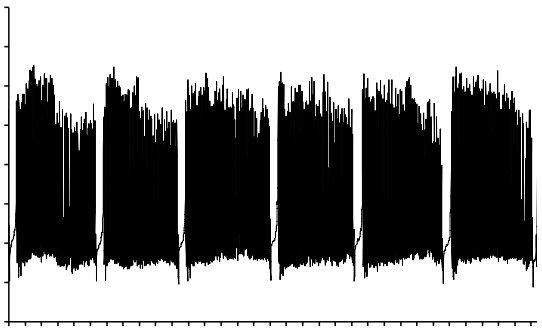


Ein zusätzlicher Vorteil für Wiederkäuer ?









Gliederung

Verdauung und Partikelgrösse

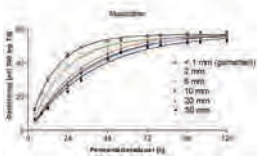
Zerkleinerung bei Landwirbeltieren

Zahnoptimierung: Lebensdauer
Zahnoptimierung: Kauleistenverlängerung
Zahnoptimierung: Schmelzfalten
Kauoptimierung: Rhythmisches Kauen

Zahn- vs. Kauoptimierung: Wiederkäuen

Zahnoptimierung: Lebensdauer II

Gliederung

Verdauung und Partikelgrösse 

Zerkleinerung bei Landwirbeltieren

Zahnoptimierung: Lebensdauer
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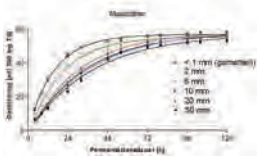
Gliederung

Verdauung und Partikelgrösse



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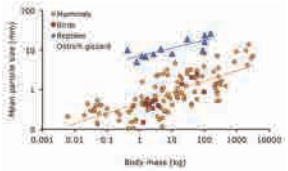

Zahnoptimierung: Lebensdauer
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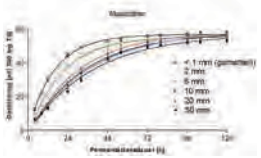

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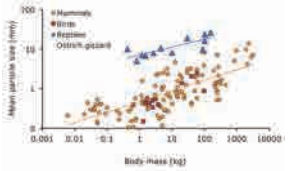
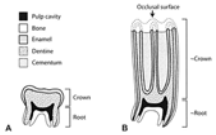


Zahnoptimierung: Lebensdauer



Zahnoptimierung: Kauleistenverlängerung
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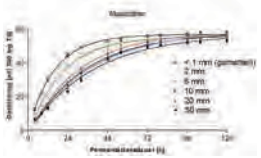
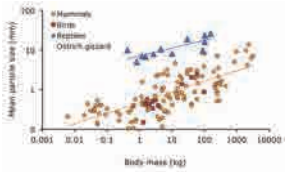
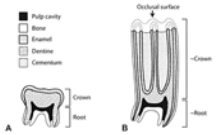
Verdauung und Partikelgrösse 

Zerkleinerung bei Landwirbeltieren 

Zahnoptimierung: Lebensdauer 

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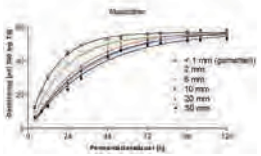
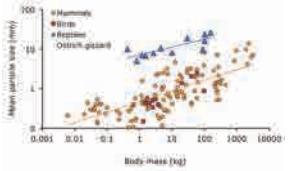
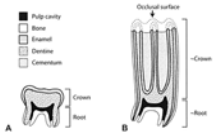
Verdauung und Partikelgrösse 

Zerkleinerung bei Landwirbeltieren 

Zahnoptimierung: Lebensdauer 

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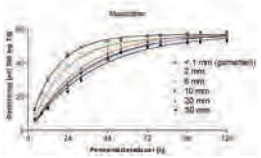
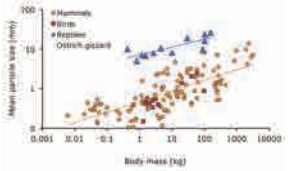
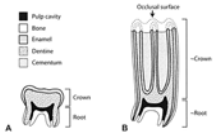
Verdauung und Partikelgrösse 

Zerkleinerung bei Landwirbeltieren 

Zahnoptimierung: Lebensdauer 

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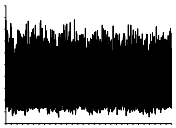
Zahnoptimierung: Schmelzfalten

Kauoptimierung: Rhythmisches Kauen 

Zahn- vs. Kauoptimierung: Wiederkäuen

Zahnoptimierung: Lebensdauer II

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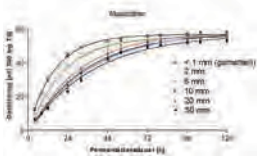
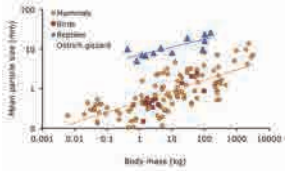
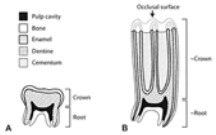


Zerkleinerung bei Landwirbeltieren



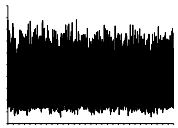
Zahnoptimierung: Lebensdauer



Zahnoptimierung: Kau[illegible]enverlängerung

Zahnoptimierung: Sch[illegible]zfalten

Kauoptimierung: Rhyt[illegible]sches Kauen



Zahn- vs. Kauoptimierung: Wiederkäuen

Zahnoptimierung: Lebensdauer II

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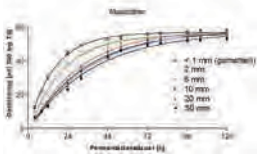
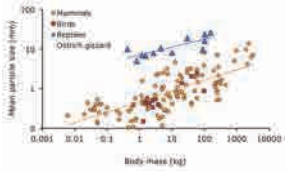
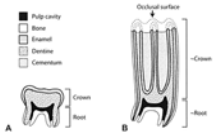
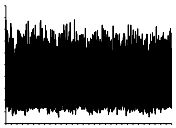
Verdauung und Partikelgrösse 

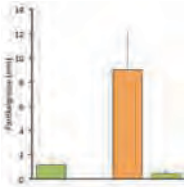
Zerkleinerung bei Landwirbeltieren 

Zahnoptimierung: Lebensdauer 

Zahnoptimierung: Kauleistenverlängerung

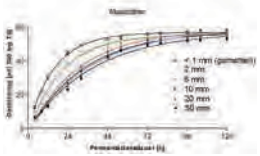
Zahnoptimierung: Schmelzfalten

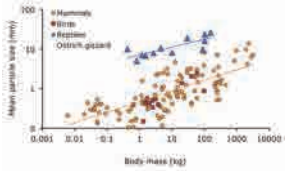
Kauoptimierung: Rhythmisches Kauen 

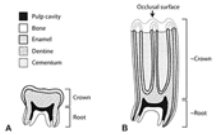
Zahn- vs. Kauoptimierung: Wiederkäuen 

Zahnoptimierung: Lebensdauer II

Gliederung

Verdauung und Partikelgrösse 

Zerkleinerung bei Landwirbeltieren 

Zahnoptimierung: Lebensdauer 

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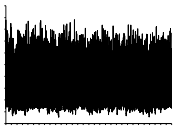
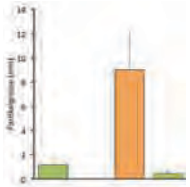
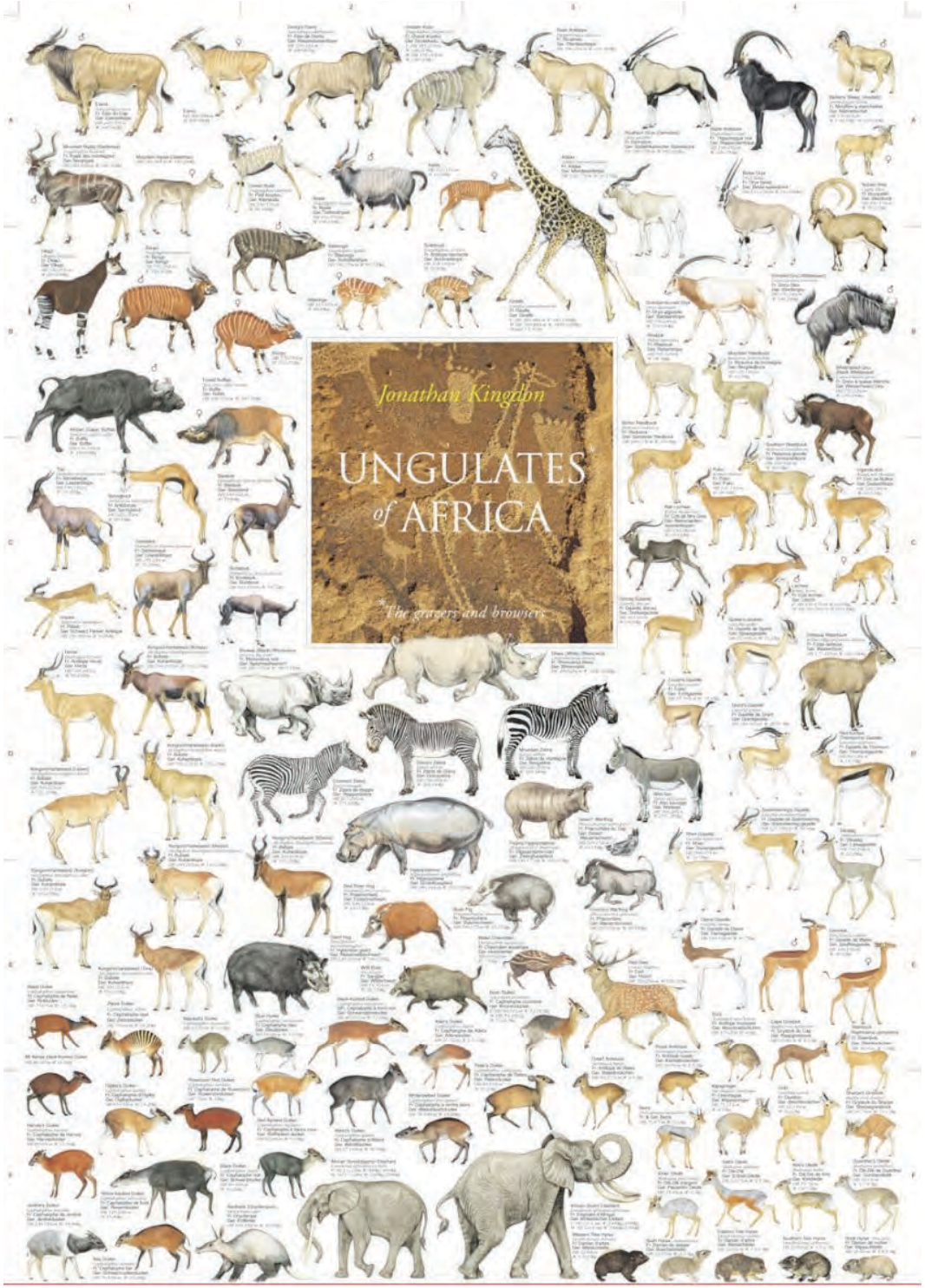
Kauoptimierung: Rhythmisches Kauen 

Zahn- vs. Kauoptimierung: Wiederkäuen 

Zahnoptimierung: Lebensdauer II


Jonathan Kingdon
UNGULATES
of AFRICA
The grazers and browsers

vielen Dank für Ihre Aufmerksamkeit