

Linking energetics with population responses to prey abundance: implications for carnivore conservation

Chris Carbone



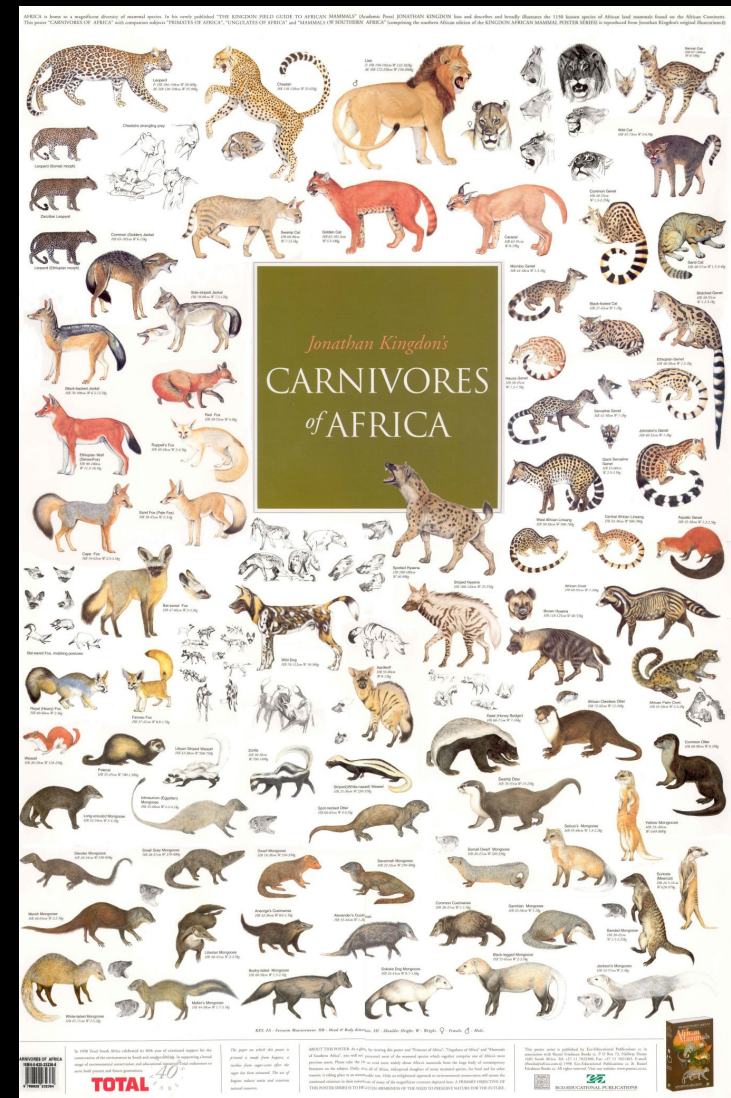
Institute of Zoology

LIVING CONSERVATION

Topics



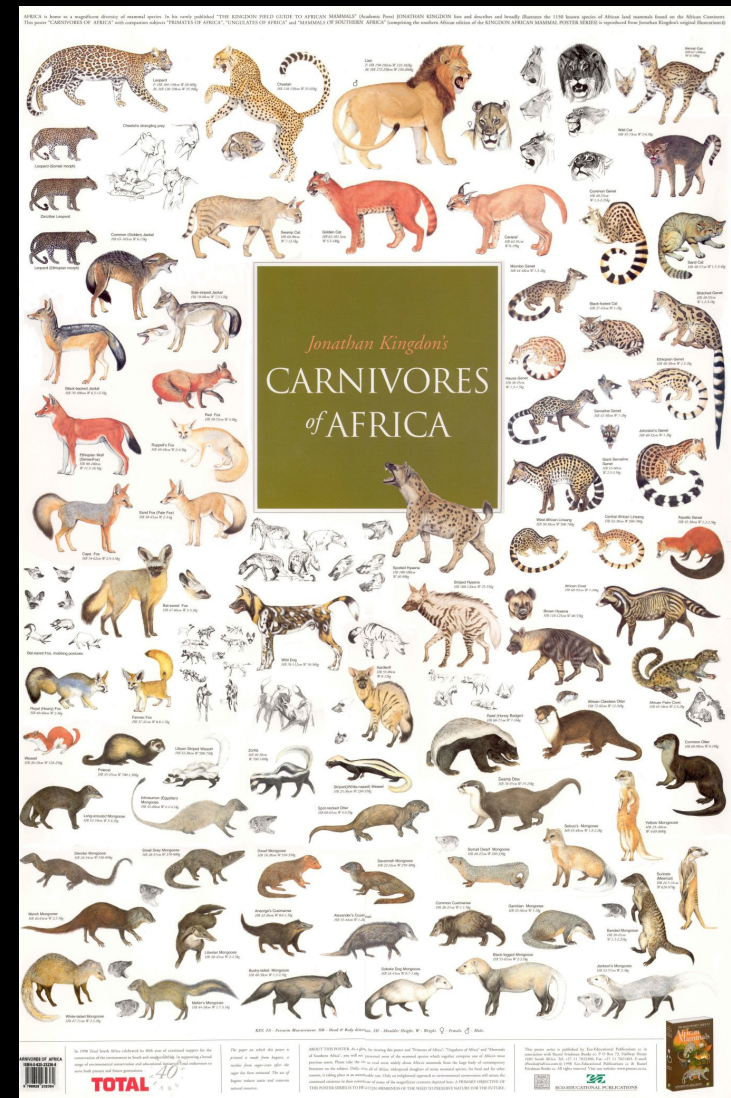
- Size & Abundance
 - Energy use and resources
- Size & Diet
 - Energy, morphology
- Population Responses
 - Linking behaviour & population responses
- Field Studies
 - Conservation Implications



Why Work on Carnivores?



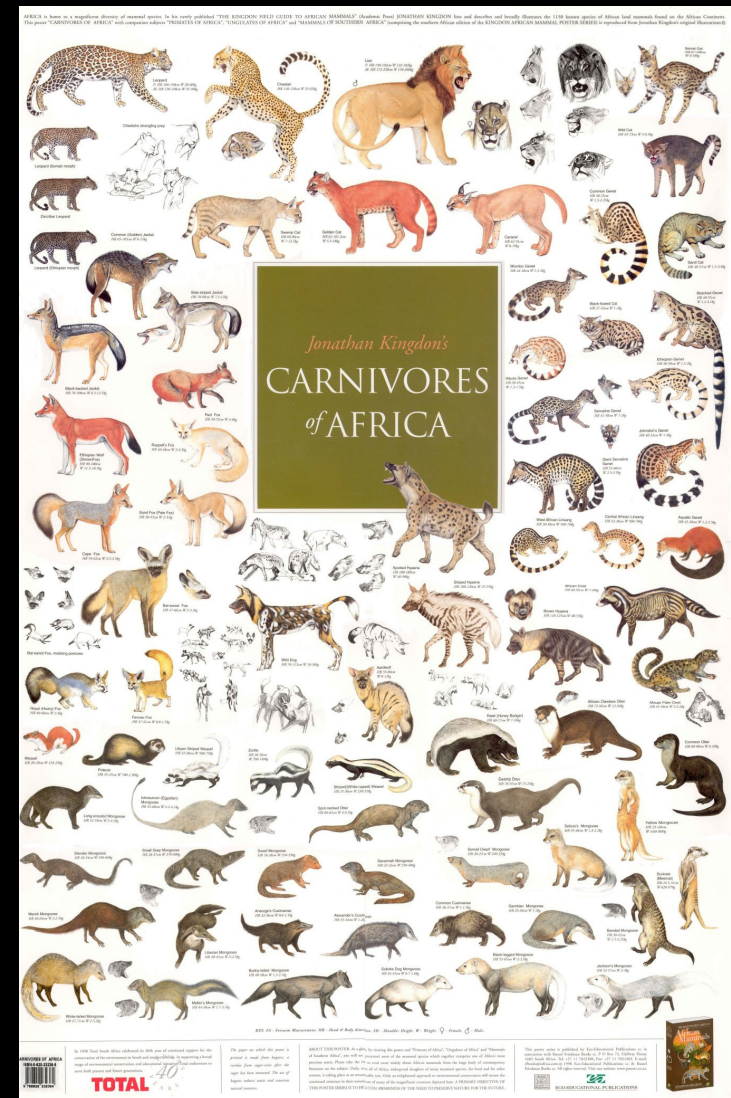
- Diverse, in body size and species richness
- Well studied
- Information on predator and diets
- Prey size and abundance
- Ideal for studying consumer - resource relationships
- Relatively simple systems



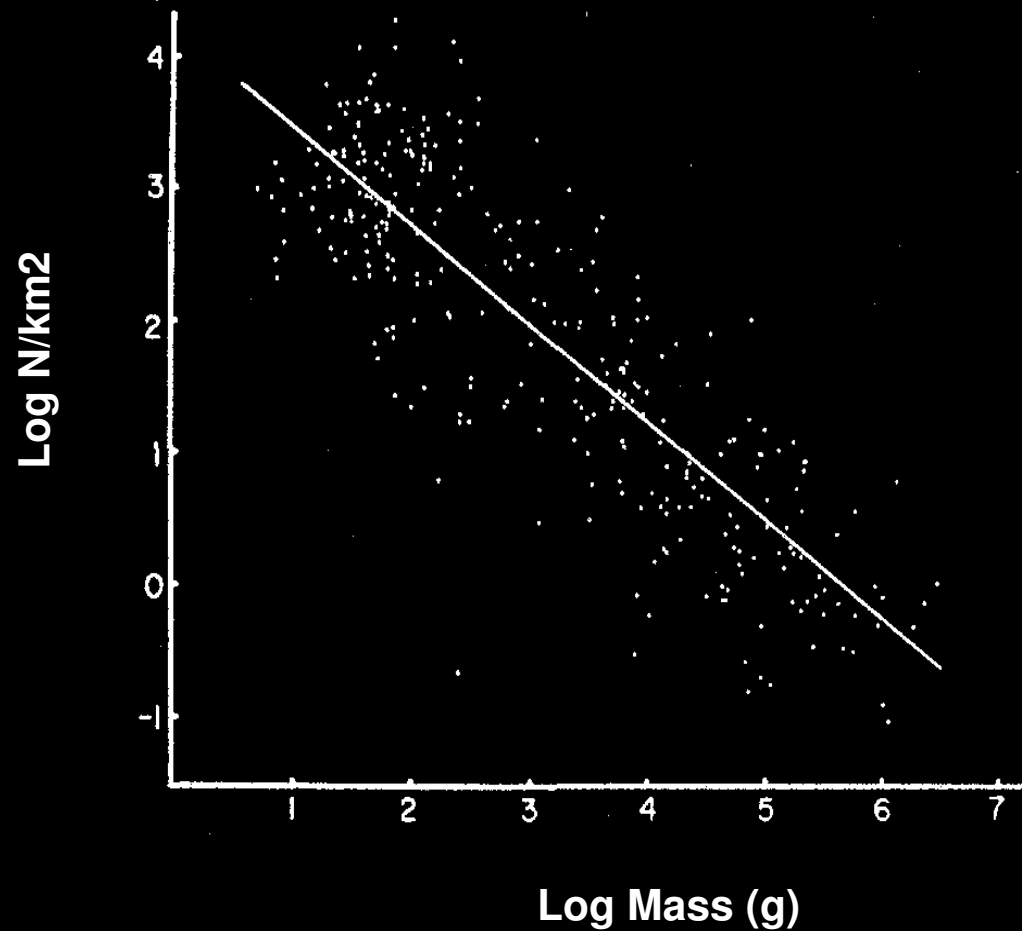
Topics



- Size & Abundance
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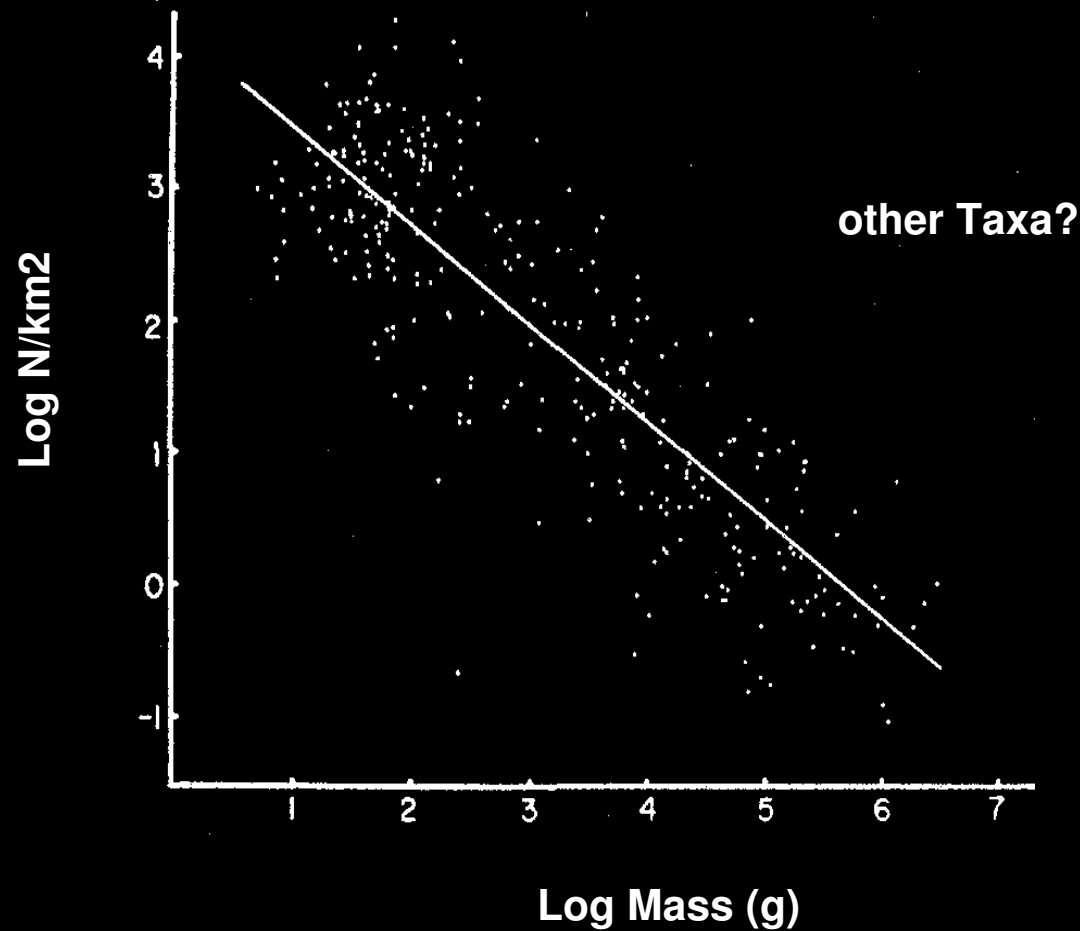


Size and Population Density



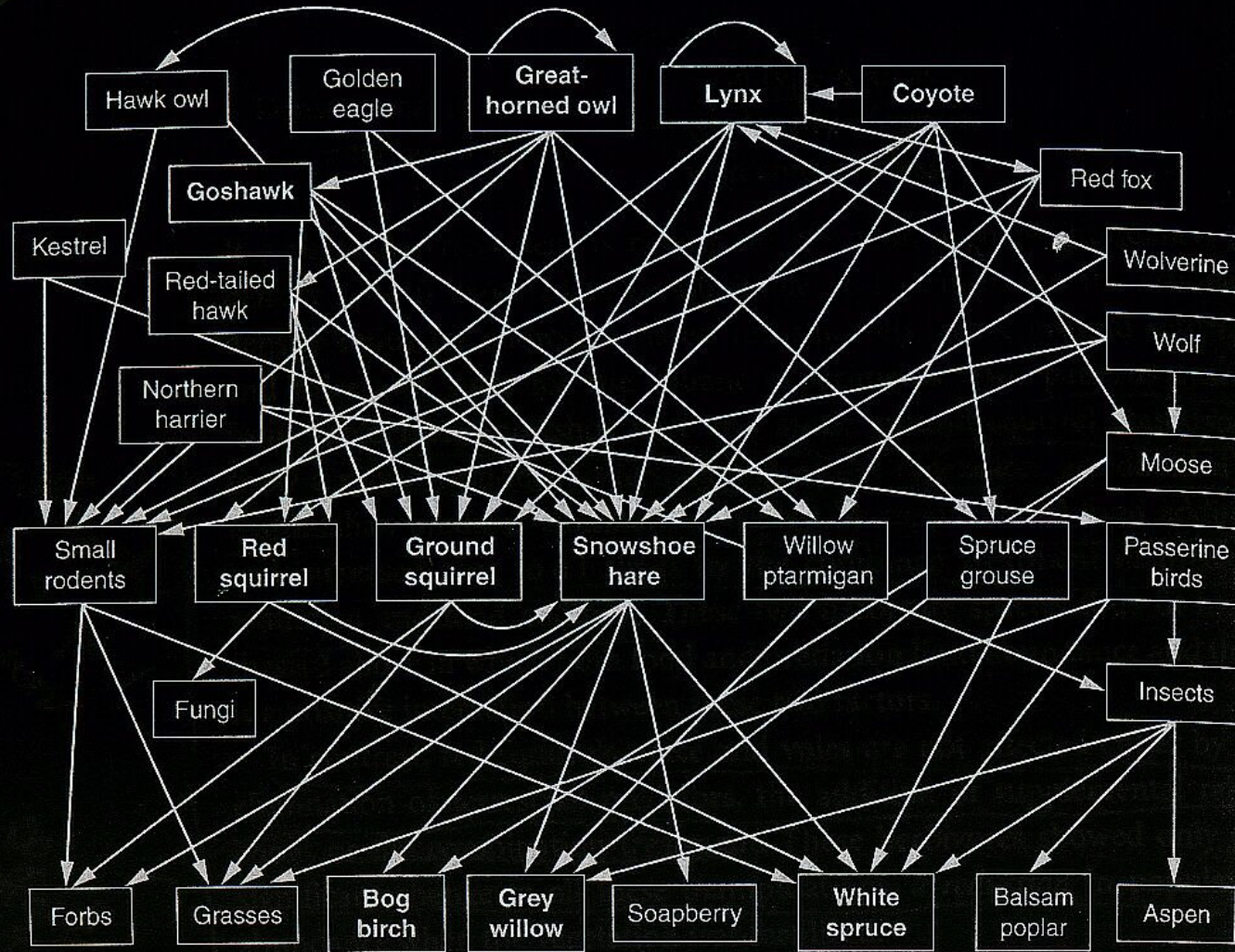
Damuth J 1981. Population-Density and Body Size in Mammals.
Nature 290: 699-700.

Size and Population Density



Damuth J 1981. Population-Density and Body Size in Mammals.
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Food Webs

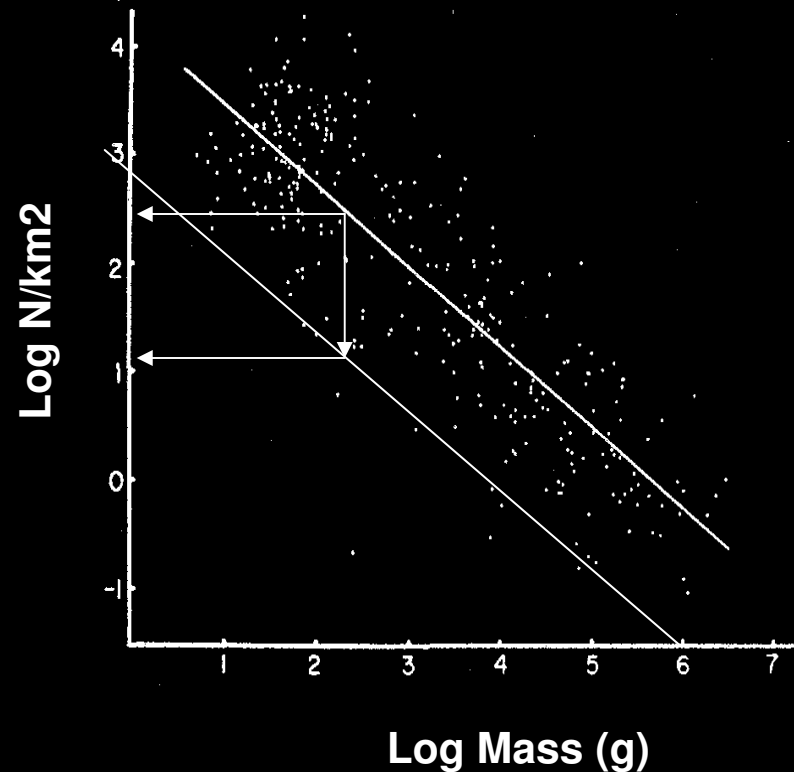


Krebs et al. 1999. Community Dynamics of vertebrate herbivores: how can we untangle the web? In *Herbivores: Between Plants and Predators*, eds. Olf, H. Brown, V.K. & Drent R Blackwell.

Size, Populations and Prey



- 2-3 Orders magnitude variation
- Account for variation in food abundance

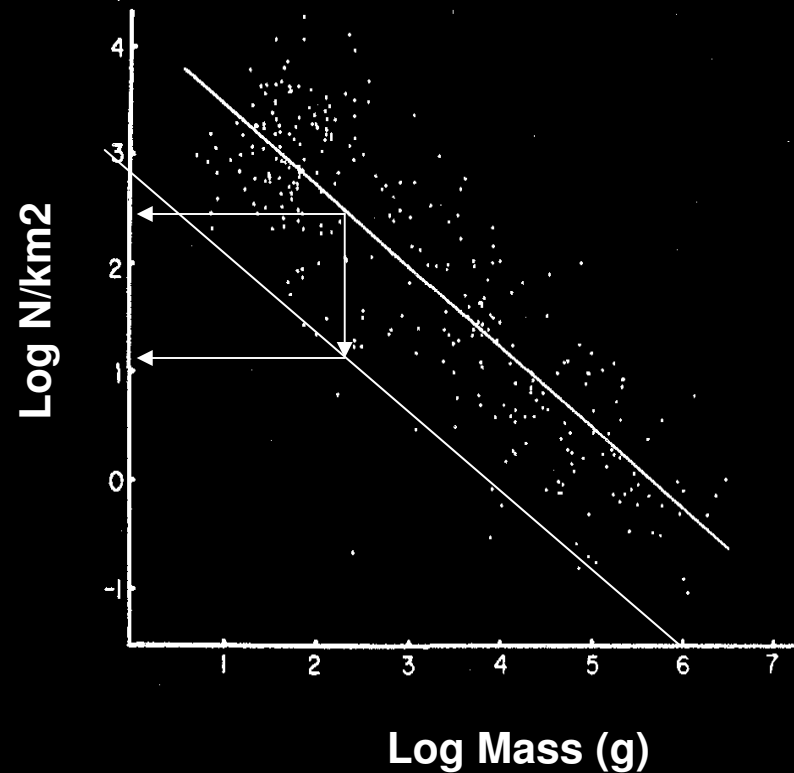


Damuth J 1981. Population-Density and Body Size in Mammals. **Nature** 290: 699-700.

Size, Populations and Prey



- Carnivores!
- Predator & prey density

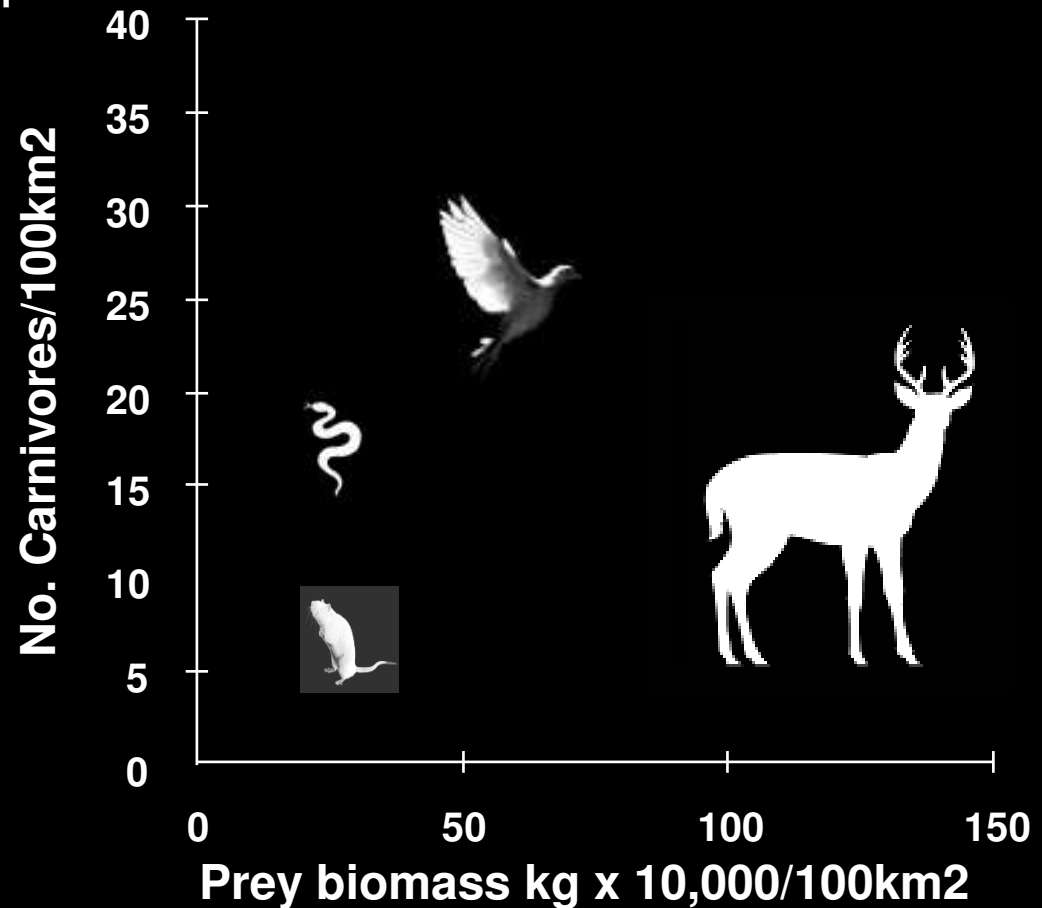


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Size, Populations and Prey



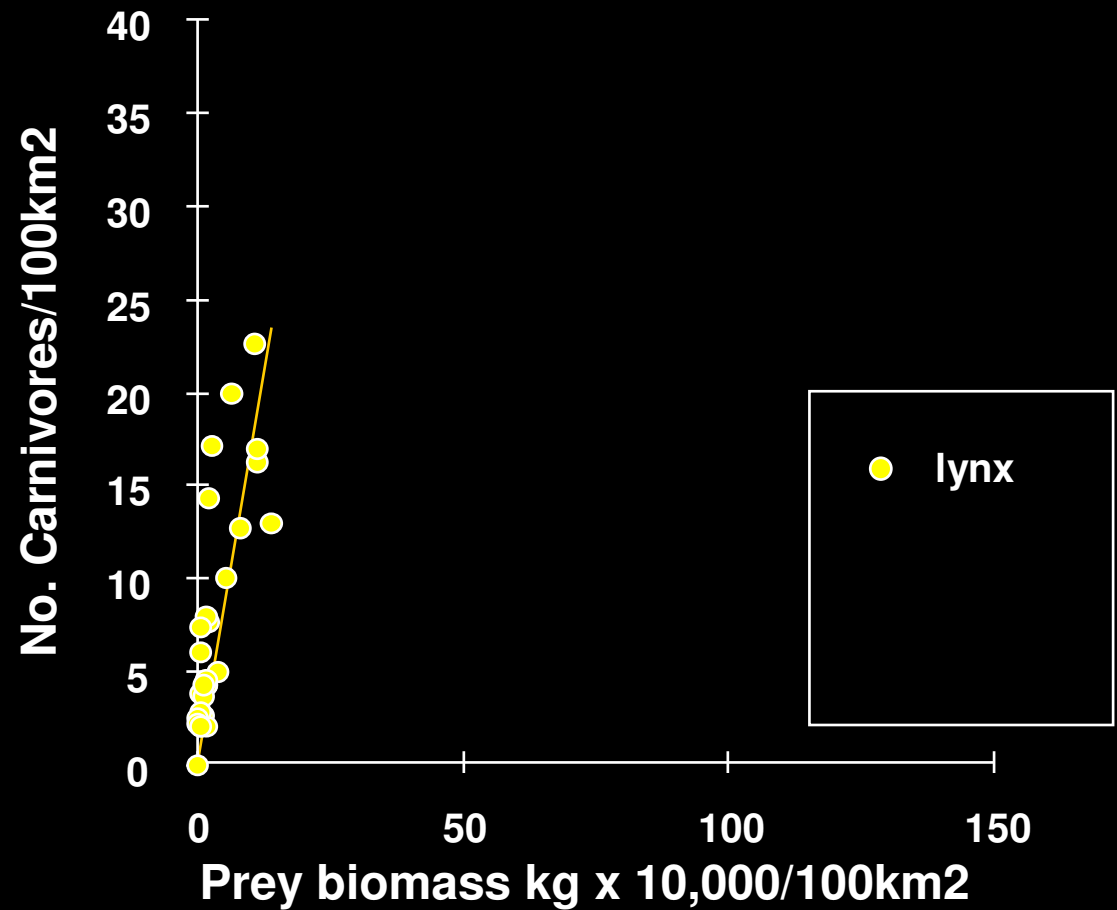
- Common measure of prey abundance?
- Prey biomass
- Look at predator abundance
 - within
 - between



Size, Populations and Prey



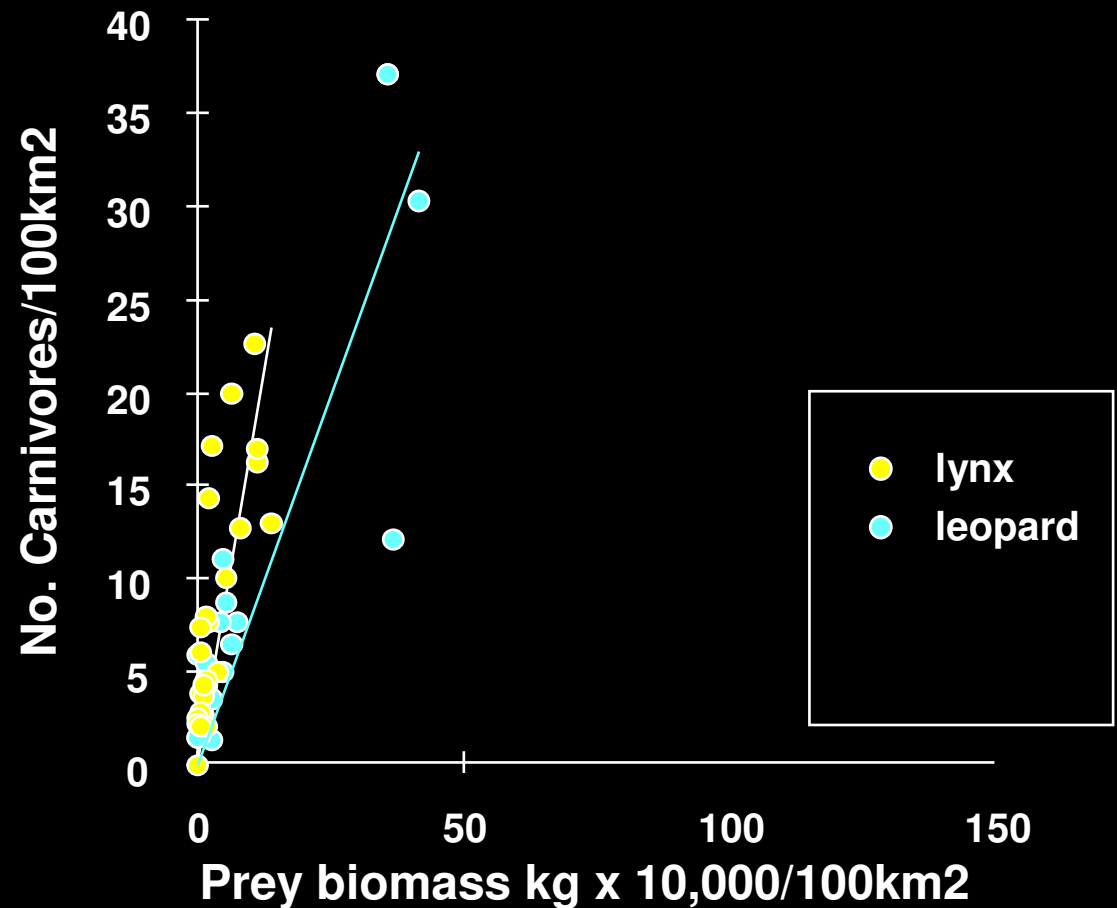
- Within species relationship



Size, Populations and Prey



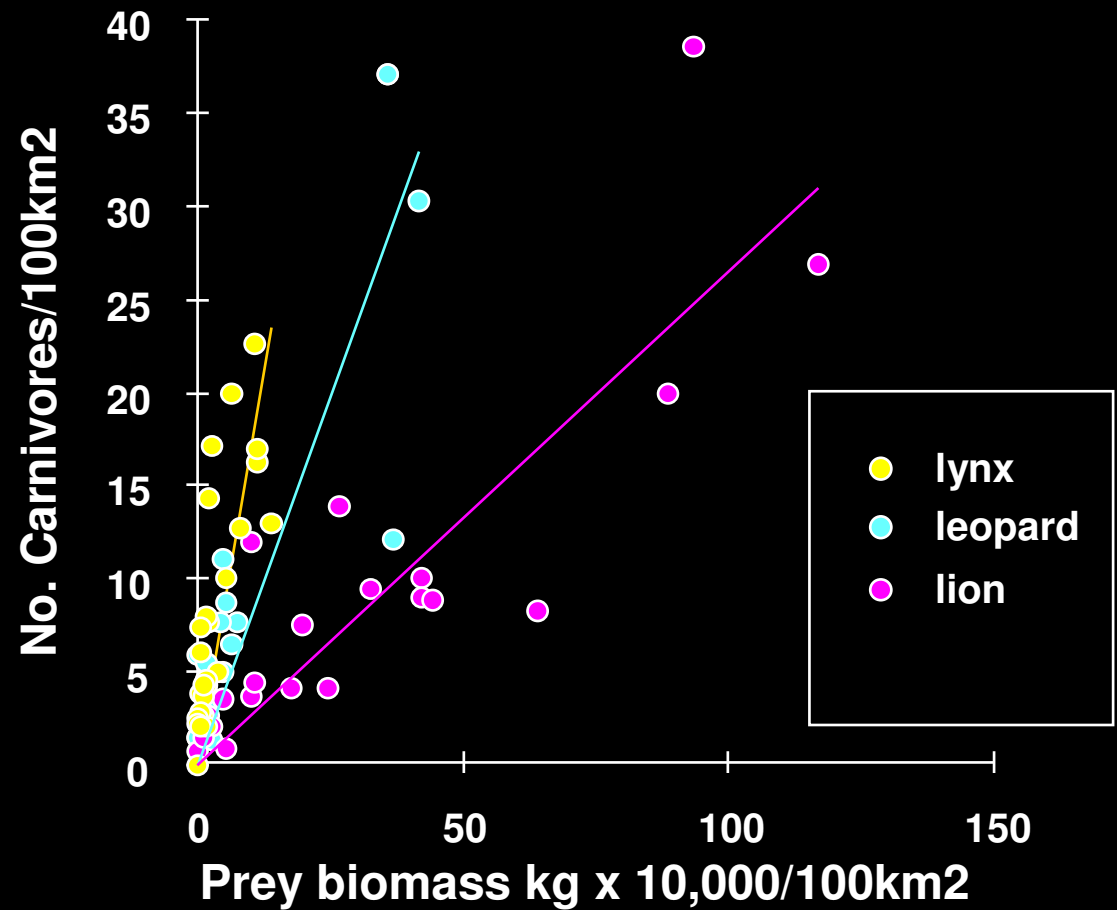
- Larger species - slower population response



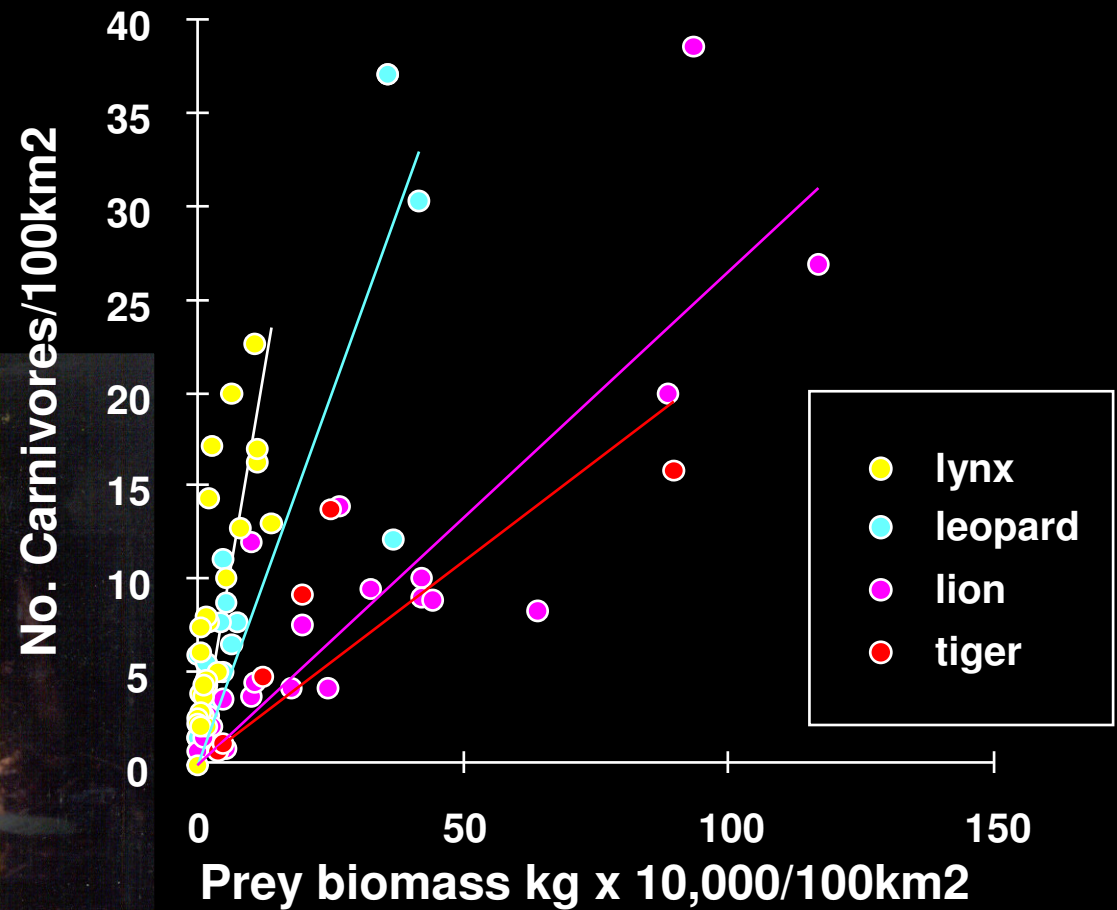
Size, Populations and Prey



- Larger species - slower population response

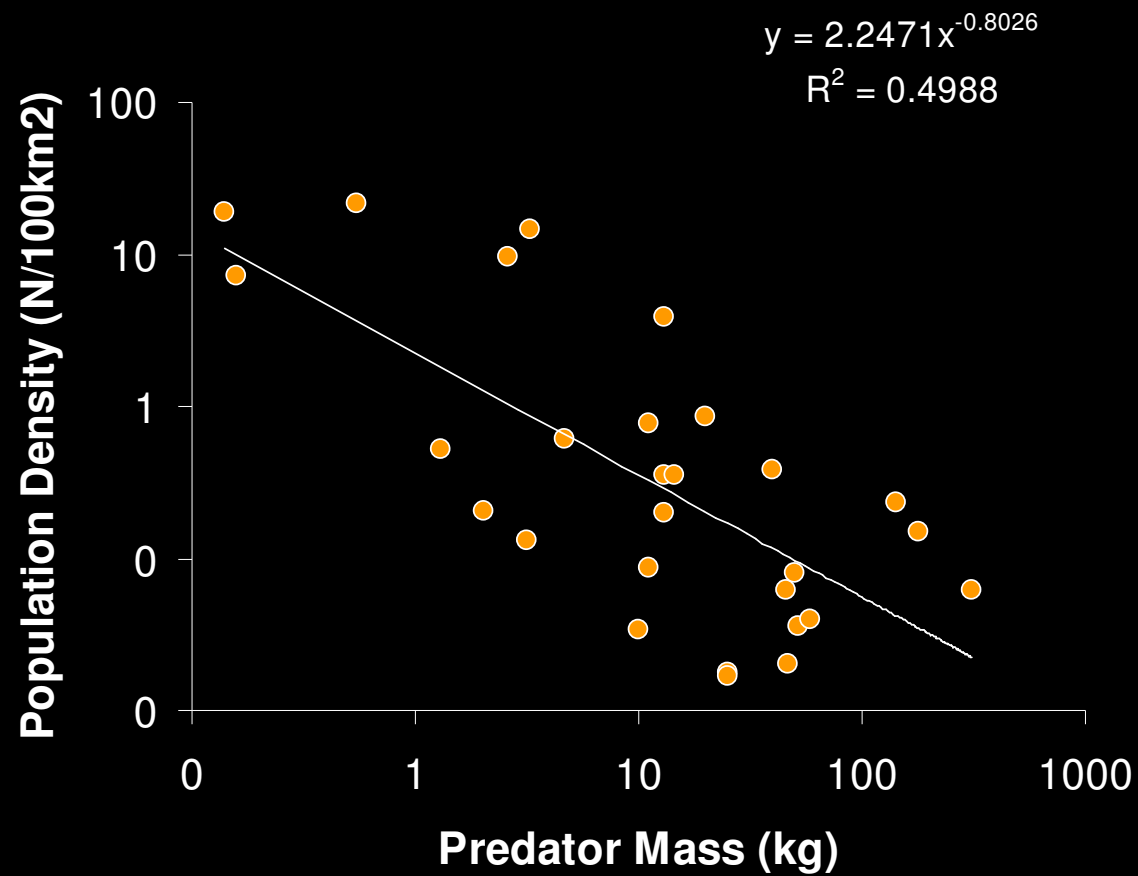


Size, Populations and Prey

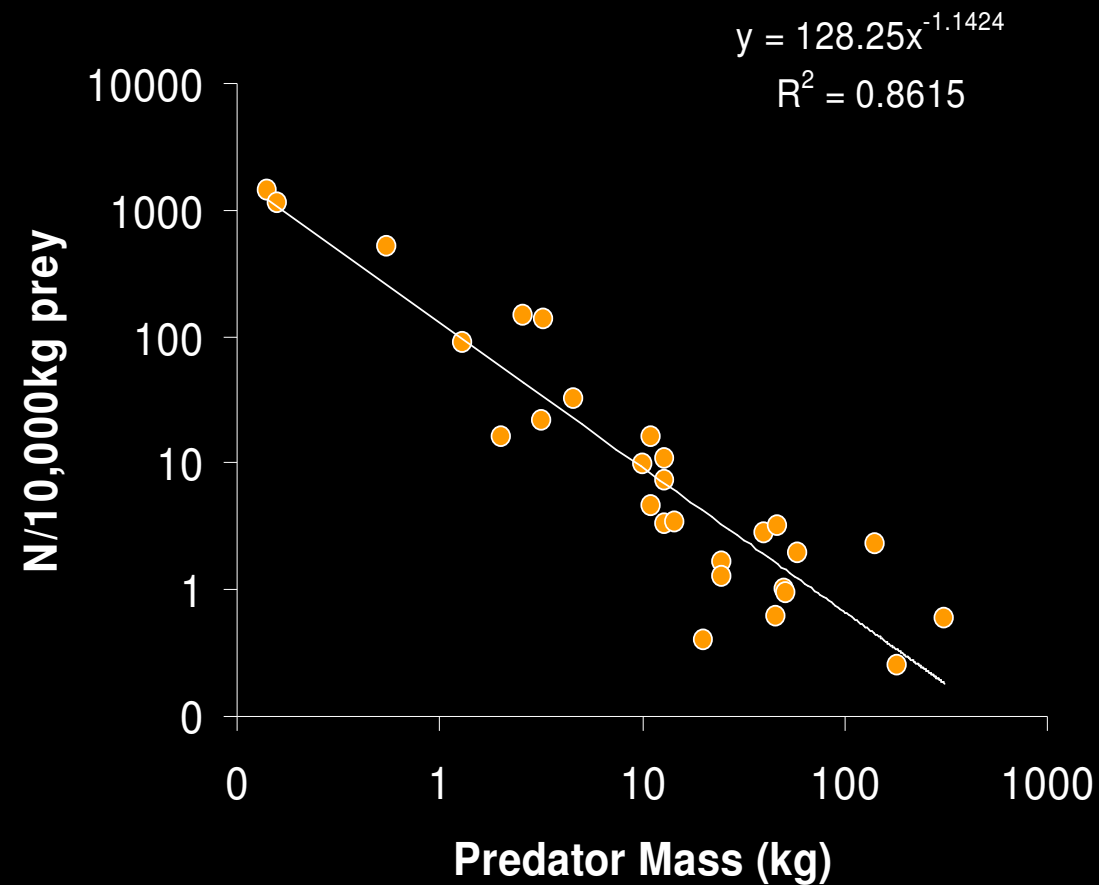


Carbone & Gittleman 2002. A common rule for the scaling of carnivore density. *Science* 295 2273

Size, Populations and Prey

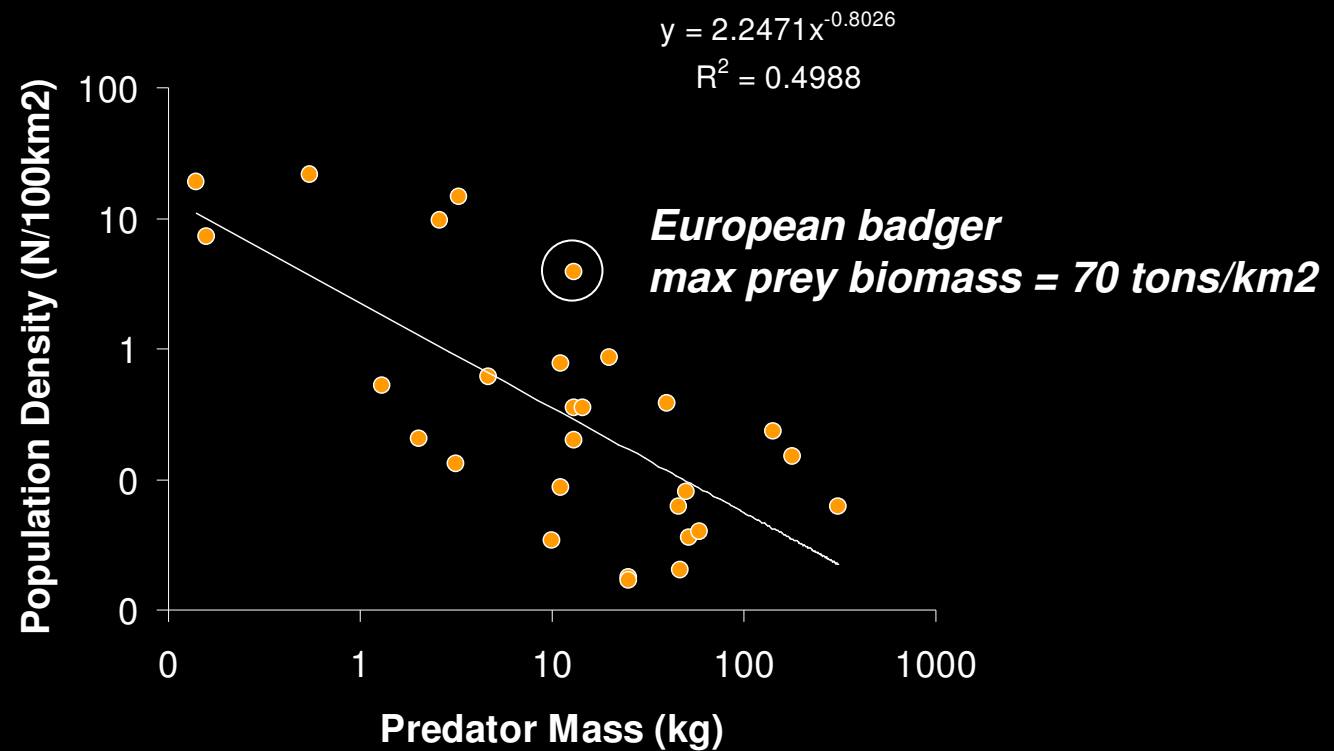


Size, Populations and Prey



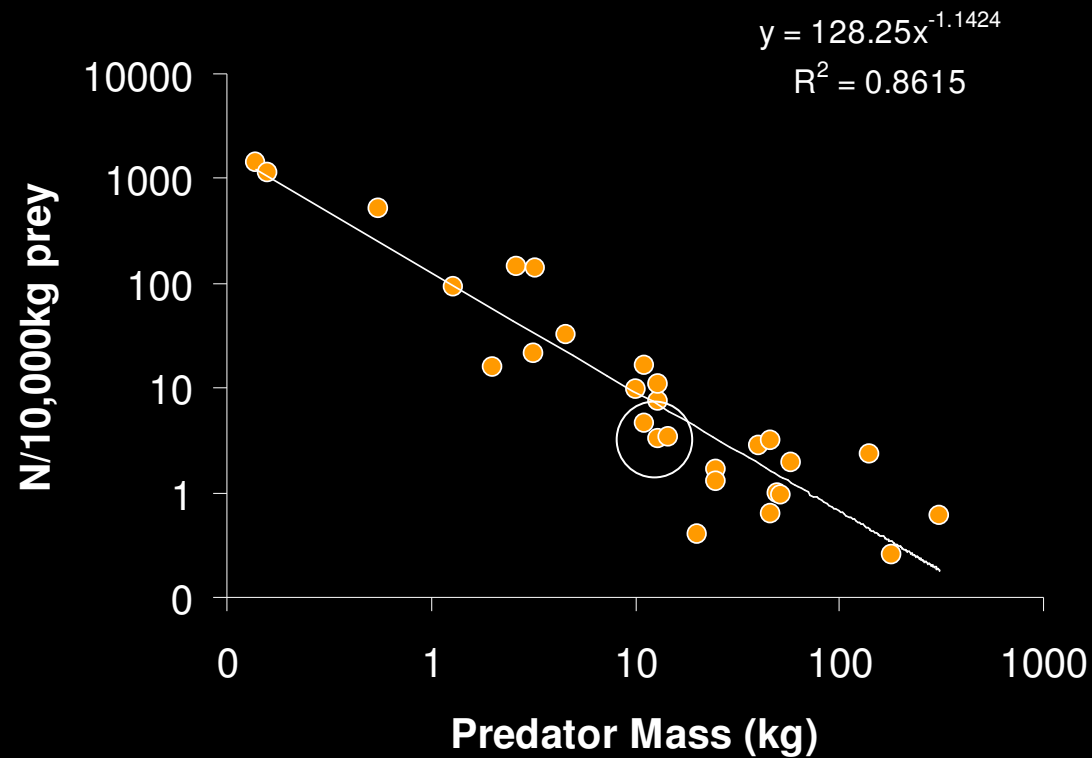
Following: Carbone & Gittleman 2002. A common rule for the scaling of carnivore density. **Science** 295 2273

Size, Populations and Prey



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Size, Populations and Prey



Following: Carbone & Gittleman 2002. A common rule for the scaling of carnivore density. **Science** 295 2273

Size, Populations and Prey (conclusions)



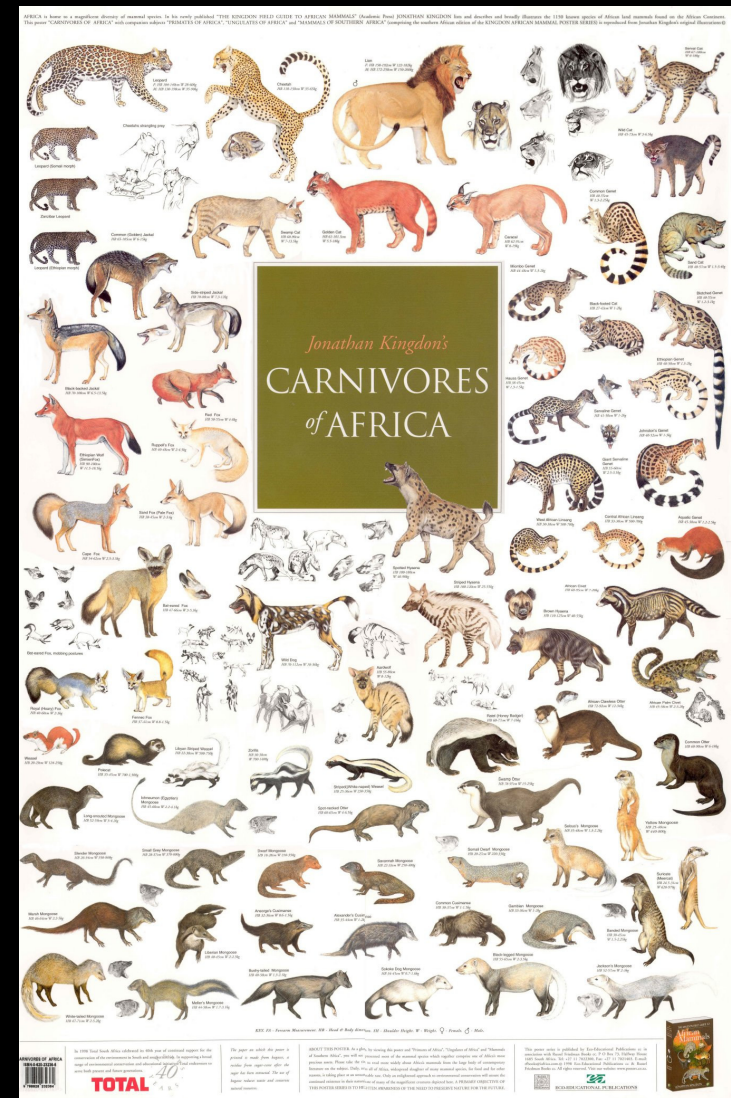
- Size affects carnivore abundance and the carnivores' absolute population response to prey abundance
- But across species there is a consistent predator-prey biomass ratio
- Rule of thumb – typically 100kg of prey support 1kg of carnivore



Topics

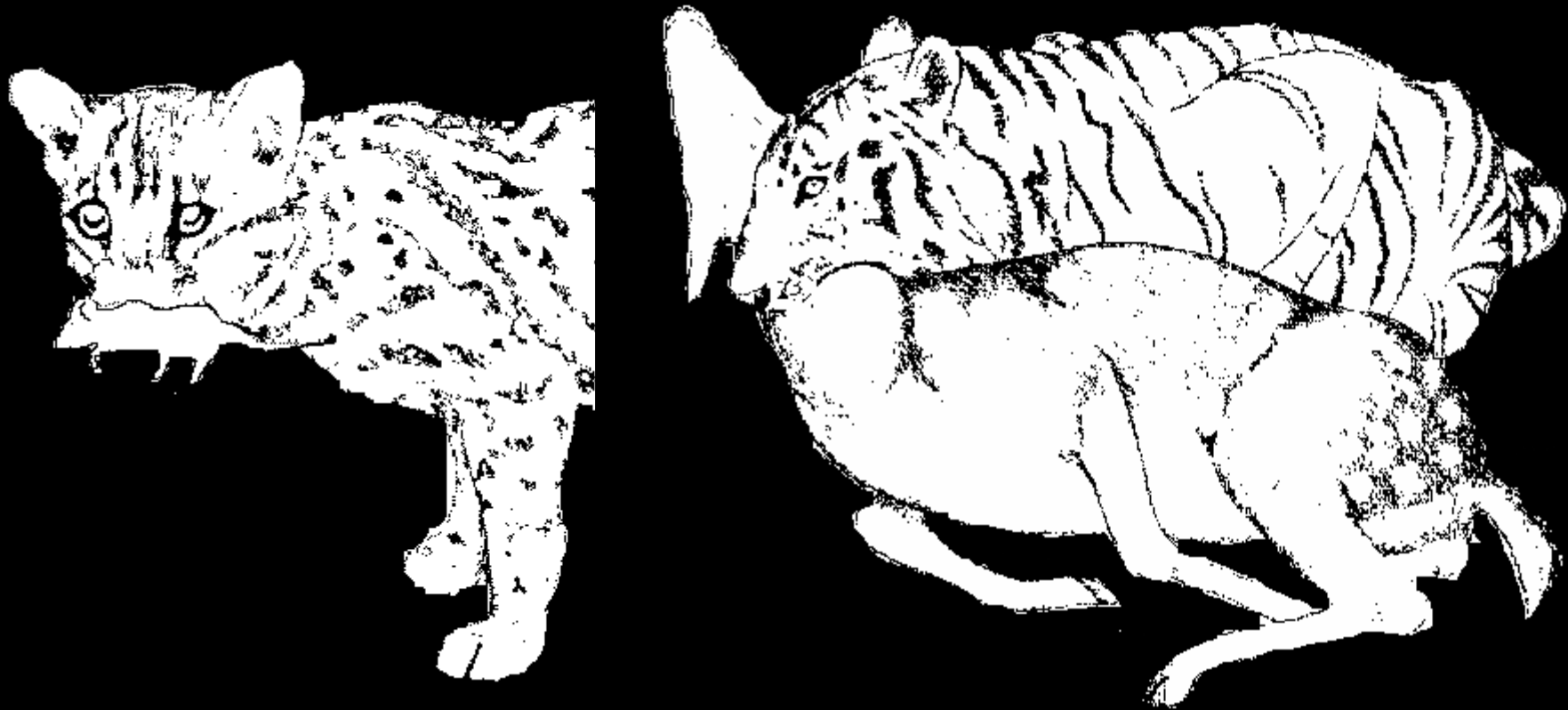


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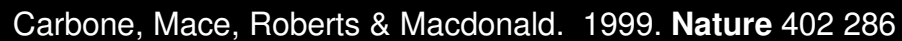


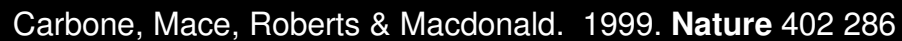
Prey Size

ZSL

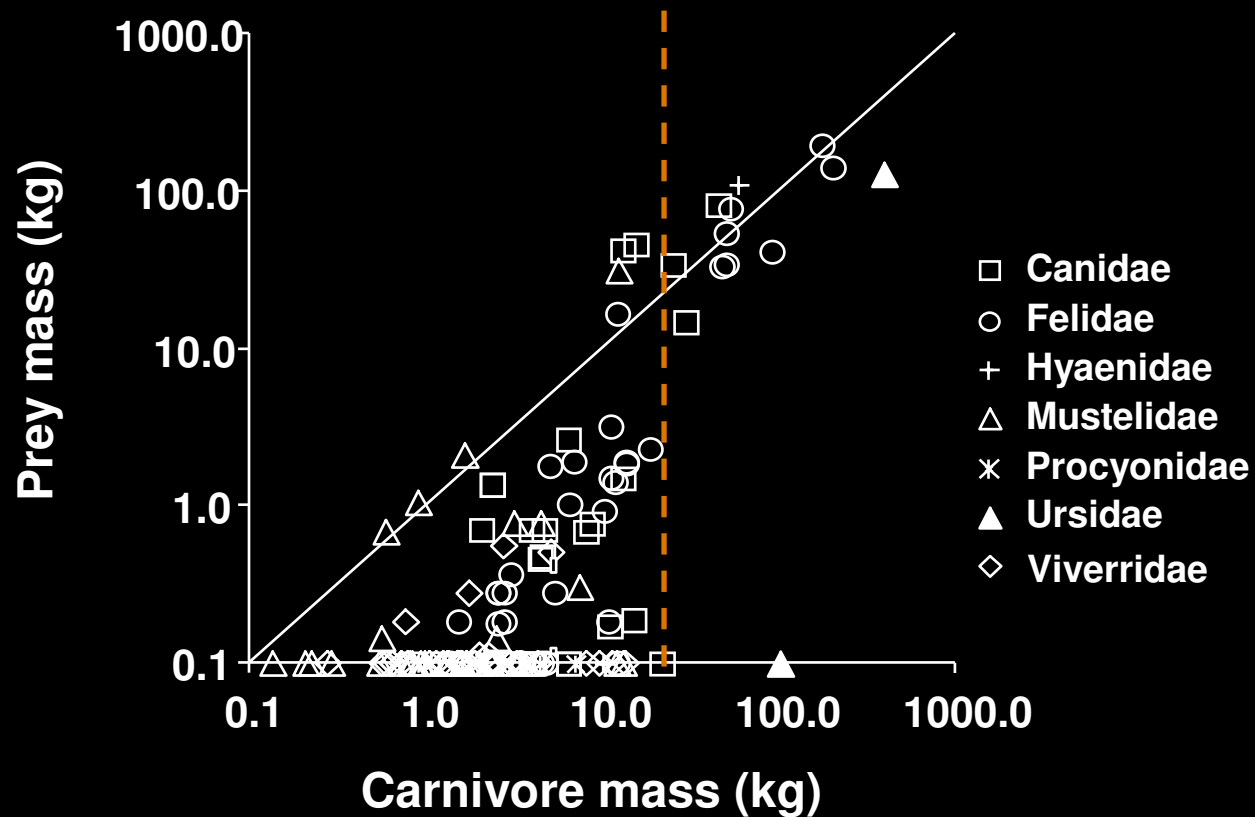


From: Kitchner. The Natural History of Wild Cats, 1991. *Cornell University Press*





Prey Size (predators & prey)



Prey Size (predators & prey)



Size class	Carnivore mass	Prey mass (% carnivore mass)
‘Small’	≤ 21 kg	$< 45\%$
‘Large’	> 21 kg	$> 45\%$

holds 92% of 139 species

Prey Size (Behaviour & Energetics)



Carnivore size & prey size

- Small prey are diverse and abundant
- But intake rates are lower
- Large prey offer high energy gain
- But are rare and difficult to hunt



Prey Size (Behaviour & Energetics)



small



Prey Type	Foraging Time (hr)	Travel Speed (km/hr)	Intake Rate (kJ/hr)
Invertebrates	9.8	1.2	915
Small Vertebrates	9.8	1.2	1500



Prey Size (Behaviour & Energetics)



large



Prey Type	Foraging Time (hr)	Travel Speed (km/hr)	Intake Rate (kJ/hr)
Large Vertebrates	3.5	26	22,250 max



Gorman *et al.* 1998 High hunting costs make African wild dogs vulnerable to kleptoparasitism by hyaenas. **Nature** 391: 479-481.

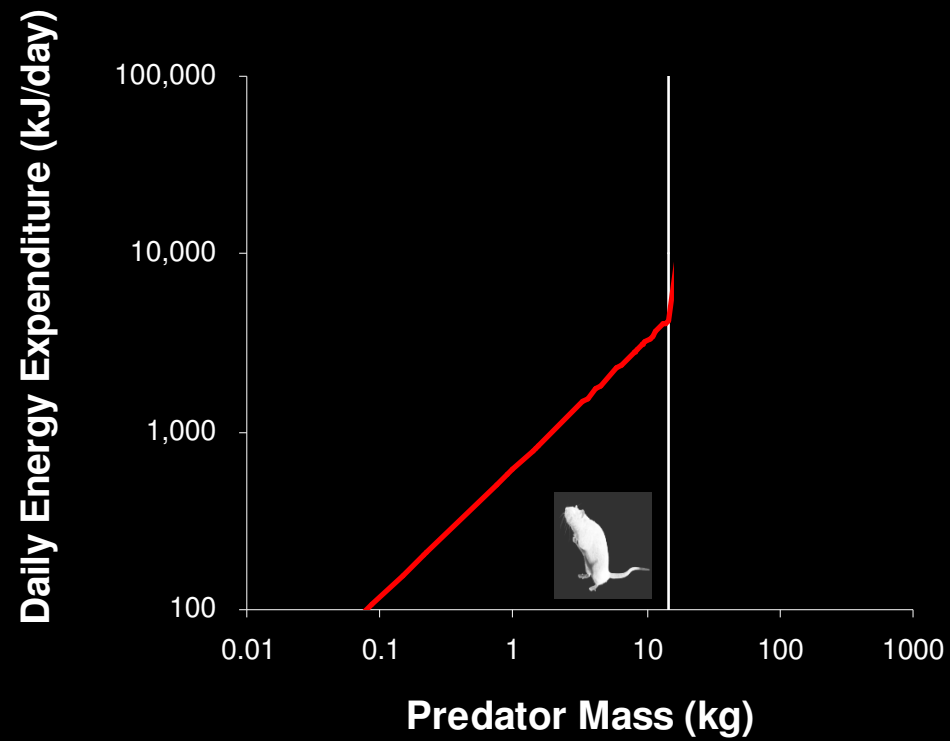
Prey Size (Behaviour & Energetics)



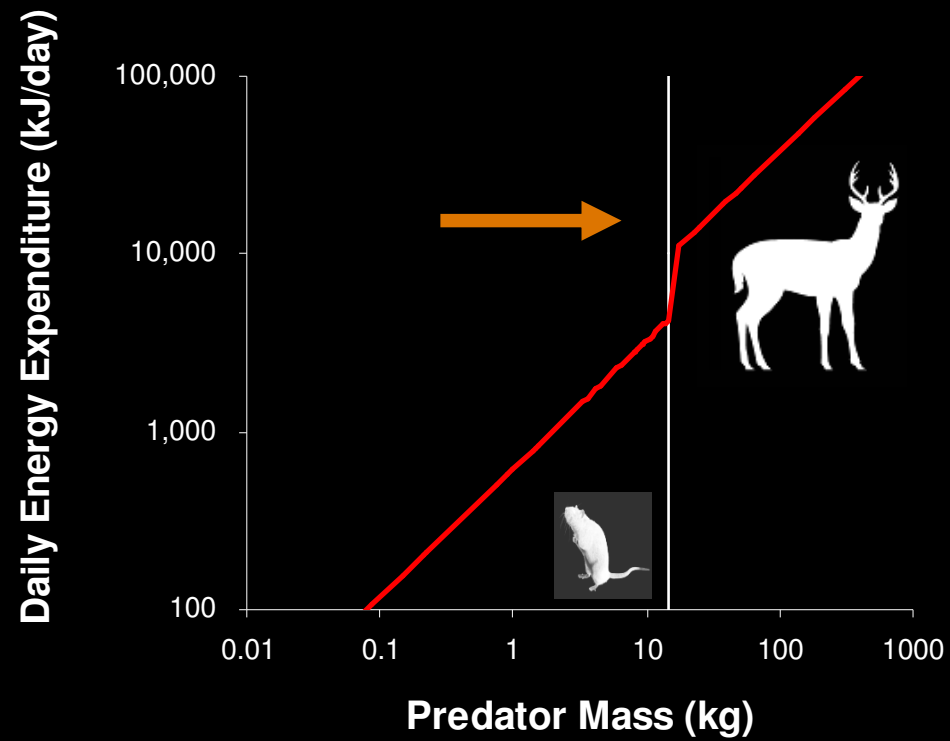
		Prey Type	Foraging Time (hr)	Travel Speed (km/hr)	Intake Rate (kJ/hr)
small	{	Invertebrates	9.8	1.2	915
		Small Vertebrates	9.8	1.2	1500
large	{	Large Vertebrates	3.5	26	22,250 max

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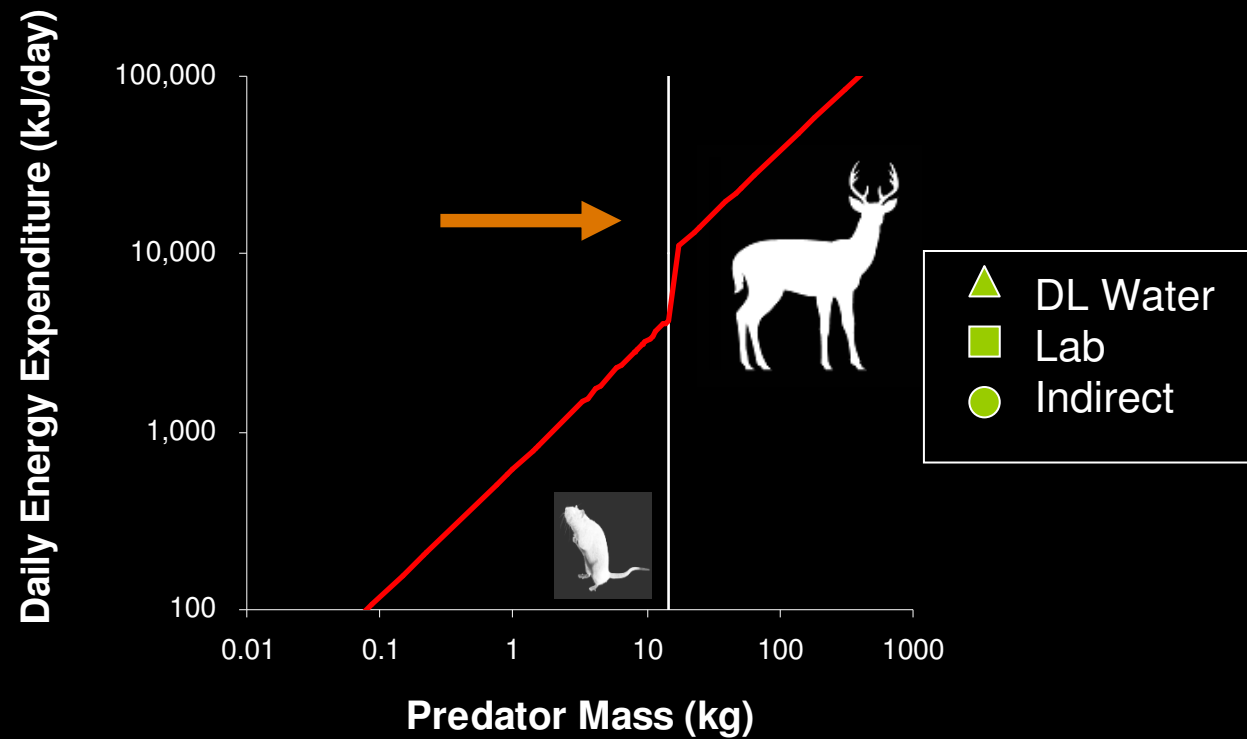
Behaviour & Energetics - DEE (kJ/day)



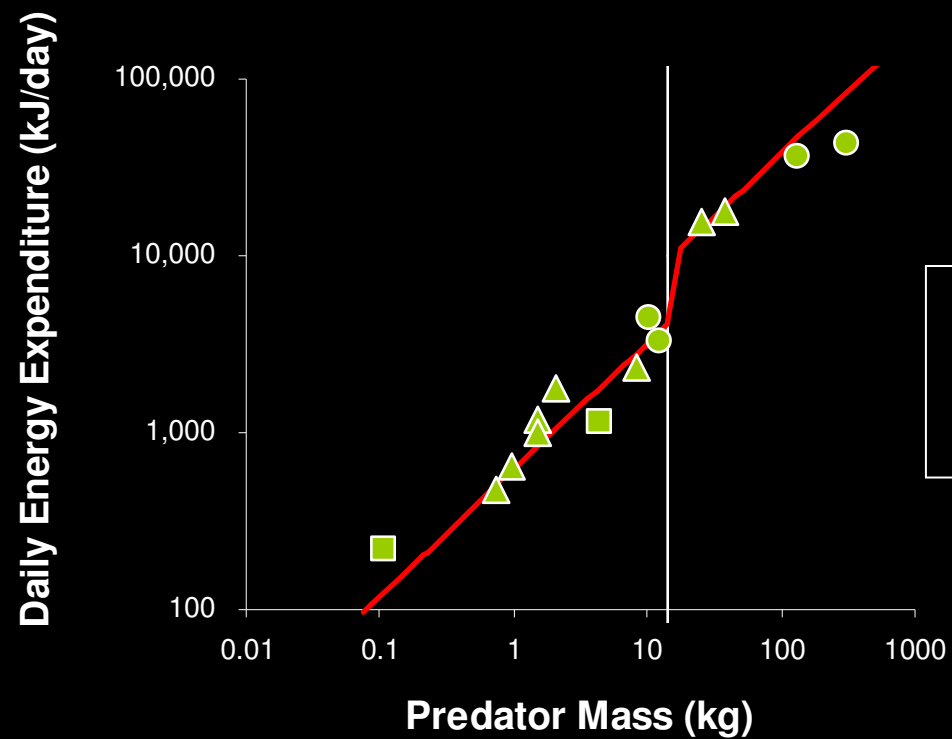
Behaviour & Energetics - DEE (kJ/day)



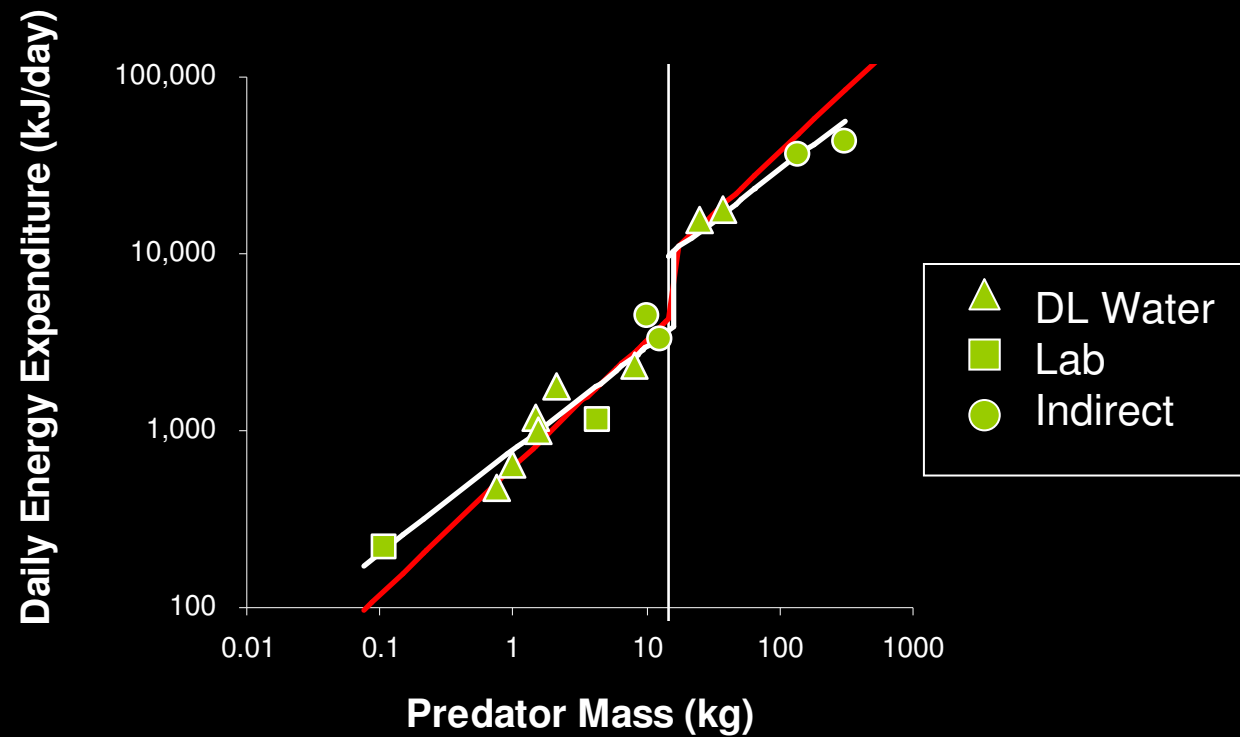
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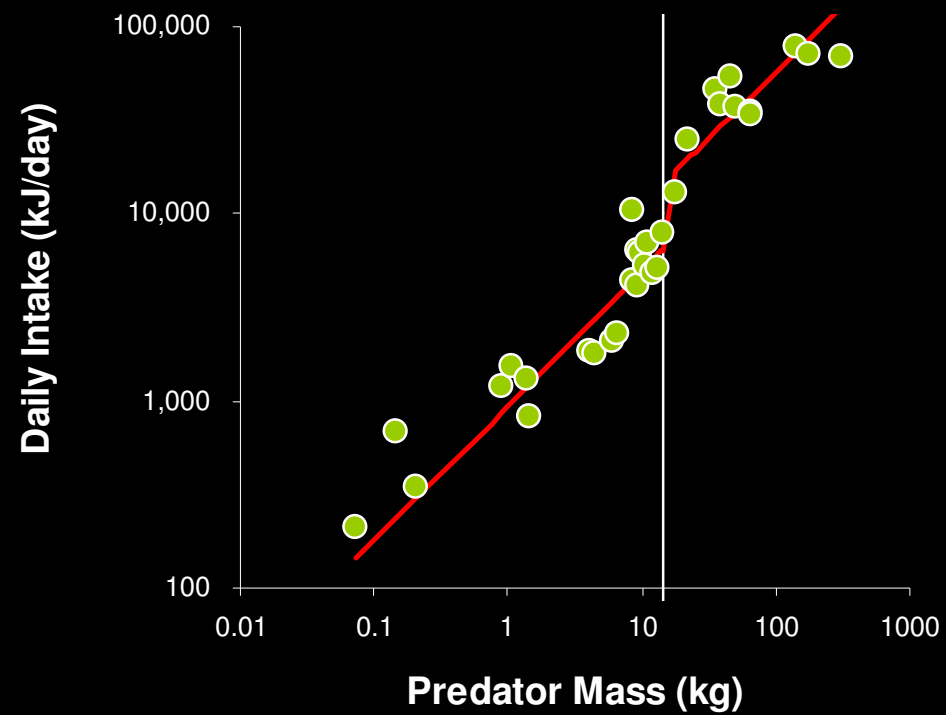


Behaviour & Energetics - DEE (kJ/day)

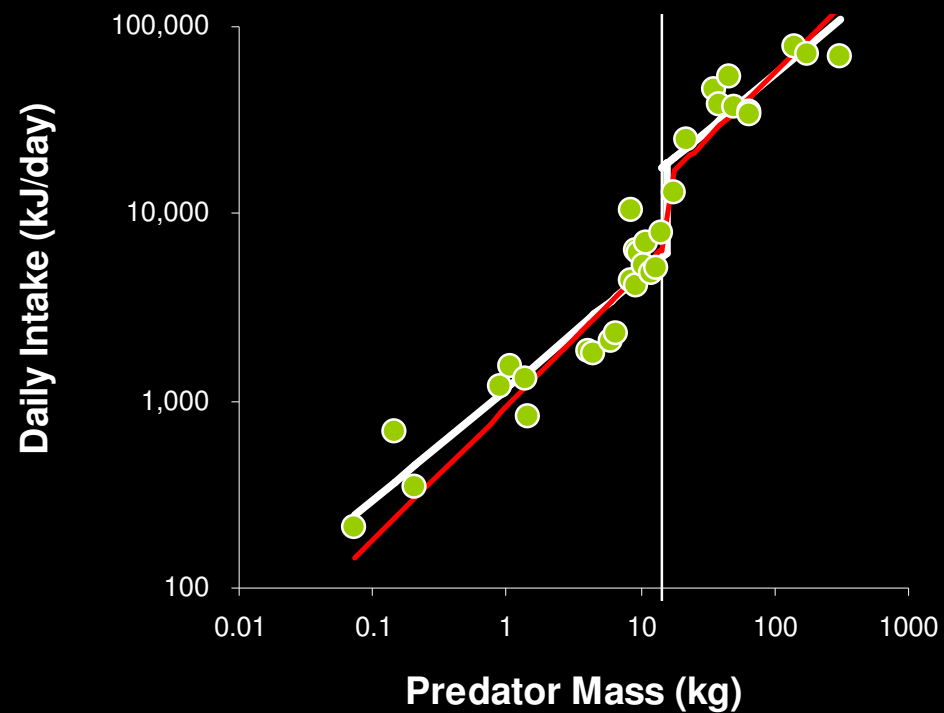


Carbone C *et al.* 2007 The costs of carnivory. **PloS Biology** 5: 363-368.

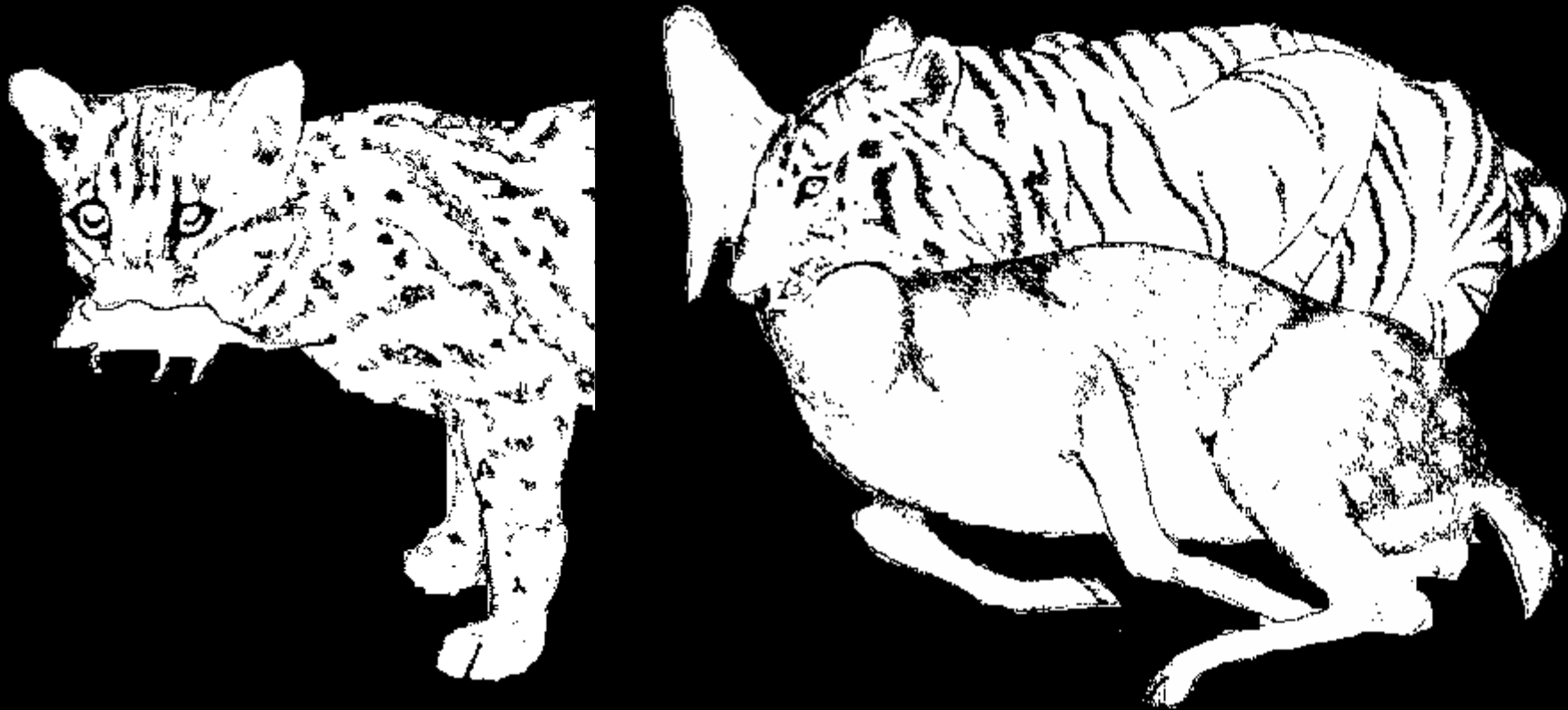
Behaviour & Energetics – Food Intake (kJ/day)



Behaviour & Energetics – Food Intake (kJ/day)



Prey Size – Morphology



From: Kitchner. *The Natural History of Wild Cats*, 1991. *Cornell University Press*

Prey Size – Morphology, Skull



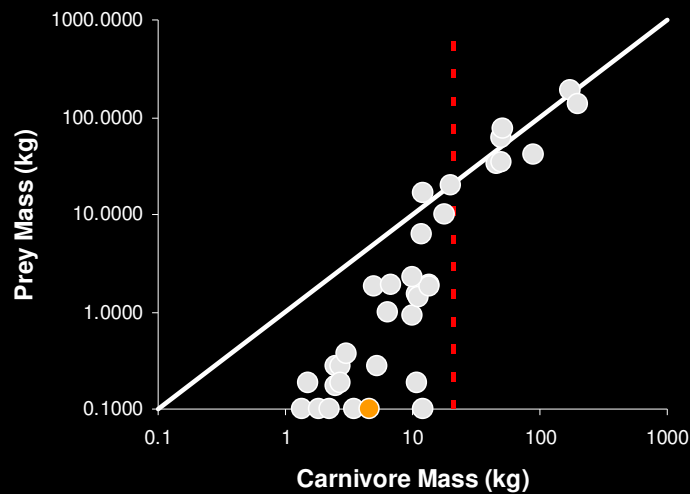
From: Kitchner. *The Natural History of Wild Cats*, 1991. *Cornell University Press*

Prey Size – Morphology, Skull

ZSL



Domestic cat 4kg



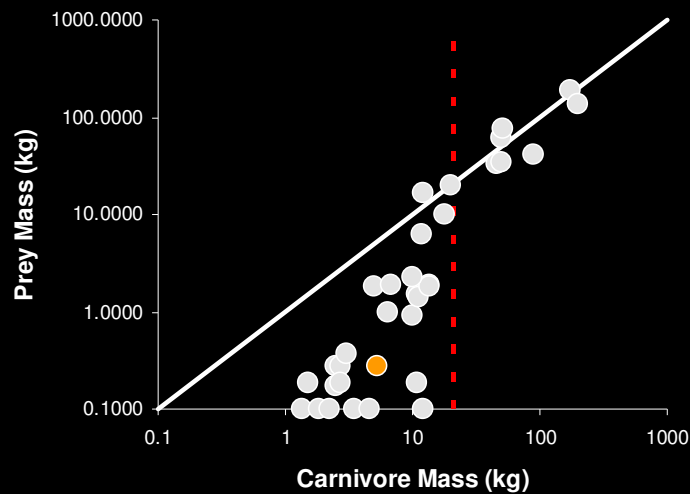
<http://www.digimorph.org/navcommon.phtml>

Prey Size – Morphology, Skull

ZSL



African wild cat 6kg



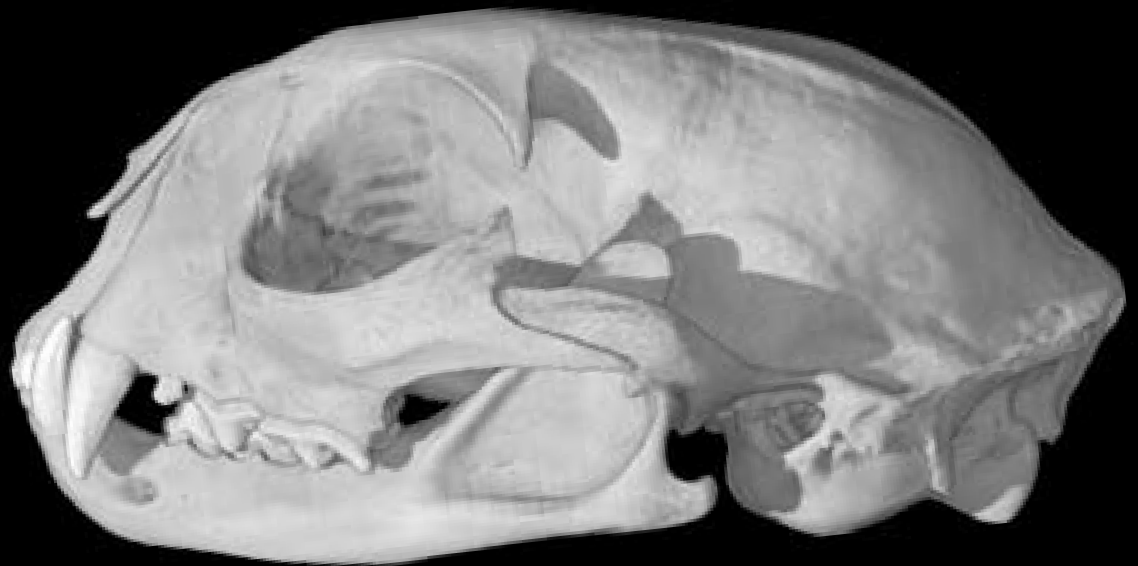
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Prey Size – Morphology, Skull

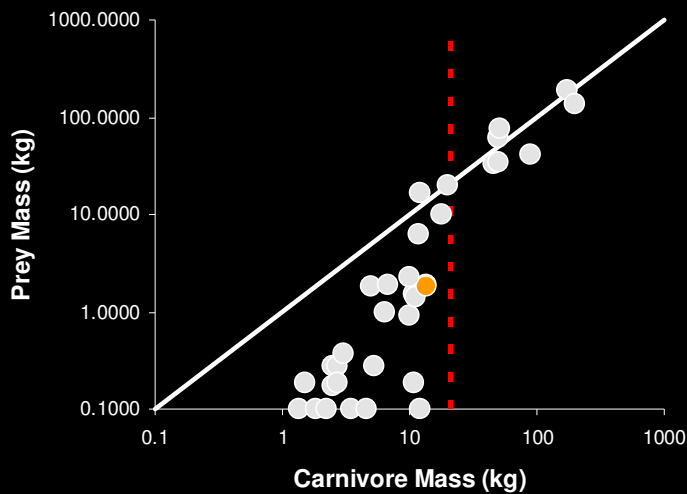
ZSL



Ocelot 12kg

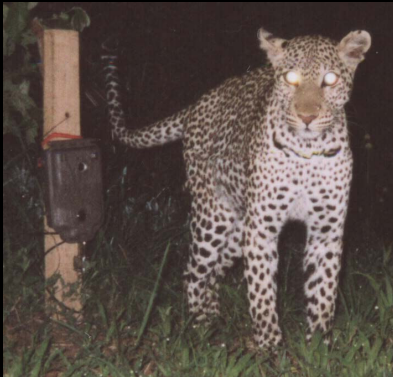


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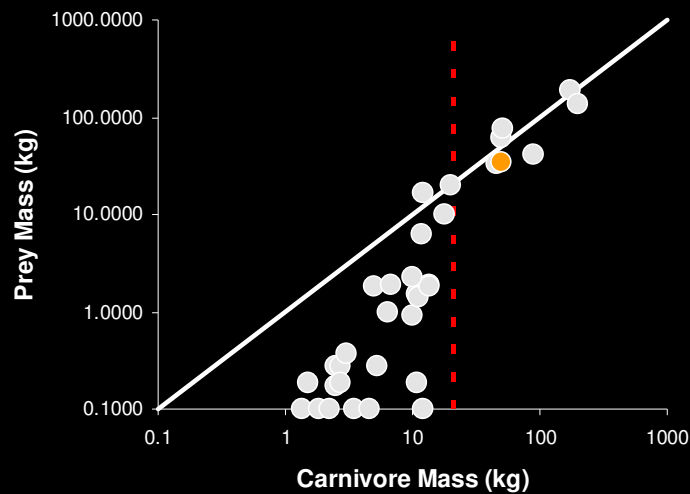


Prey Size – Morphology, Skull

ZSL



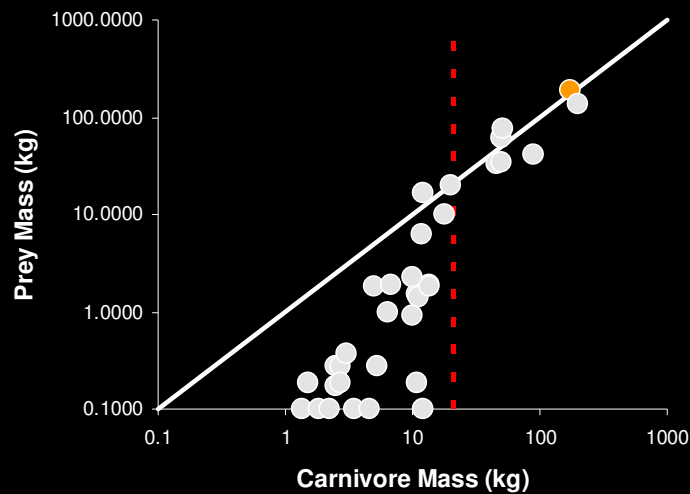
Leopard 46kg



Prey Size – Morphology, Skull



Lion 152kg



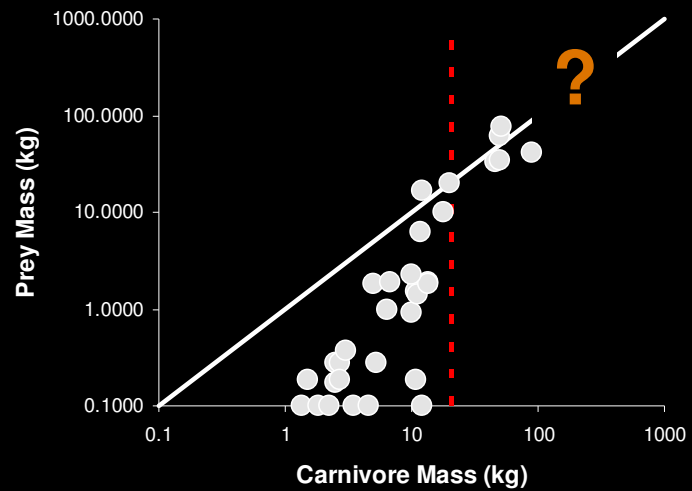
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Prey Size – Morphology, Skull

ZSL



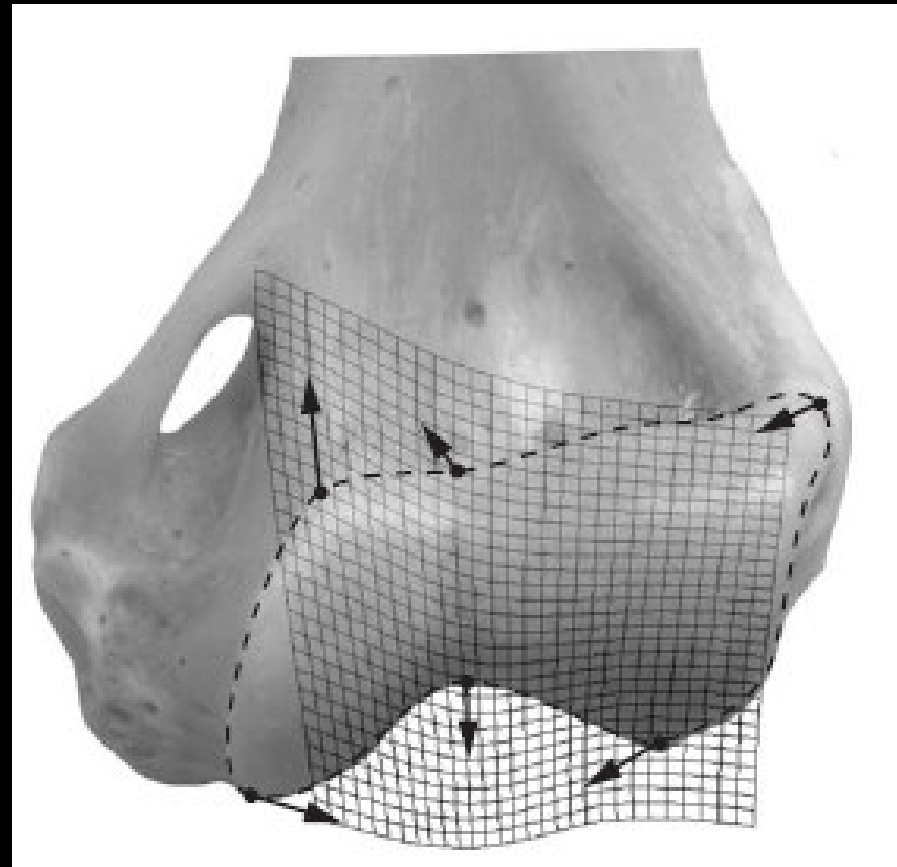
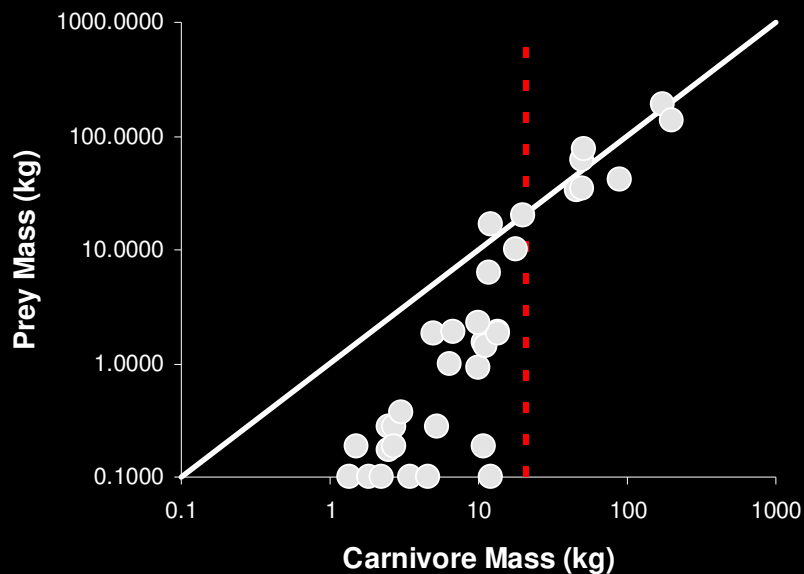
Smilodon 250kg



Prey Size – Morphology, Joints



- Morphology – function
- Motion
 - forward – back
 - grappling

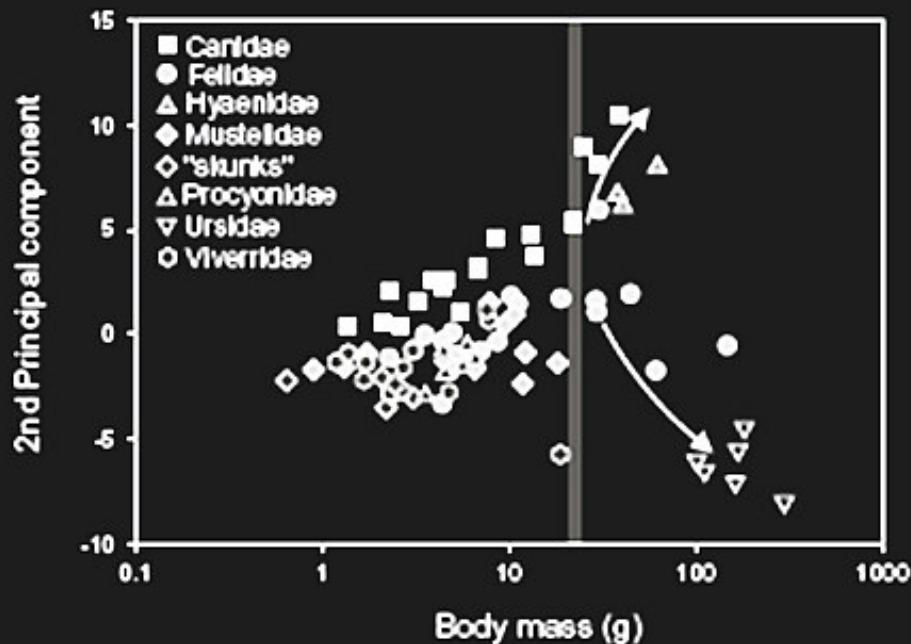


Andersson K 2004. Elbow-joint morphology as a guide to forearm function and foraging behaviour in mammalian carnivores. **Zoological Journal of the Linnean Society** 142: 91-104.

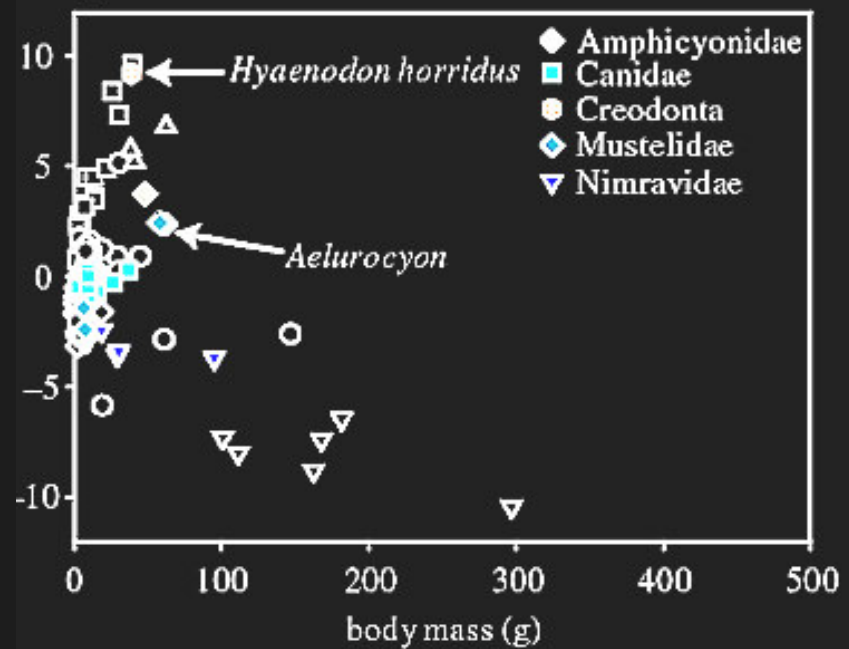
Prey Size – Morphology, Joints



a) Extant Carnivores



a) Carnivores from the Oligocene and Miocene



Andersson K 2004. Elbow-joint morphology as a guide to forearm function and foraging behaviour in mammalian carnivores. **Zoological Journal of the Linnean Society** 142: 91-104.

Andersson K, Werdelin L 2003. The evolution of cursorial carnivores in the Tertiary: implications of elbow-joint morphology. **Proc.Roy. Soc. B.** 270: S163-S165

Size, Morphology, Behaviour & Energetics

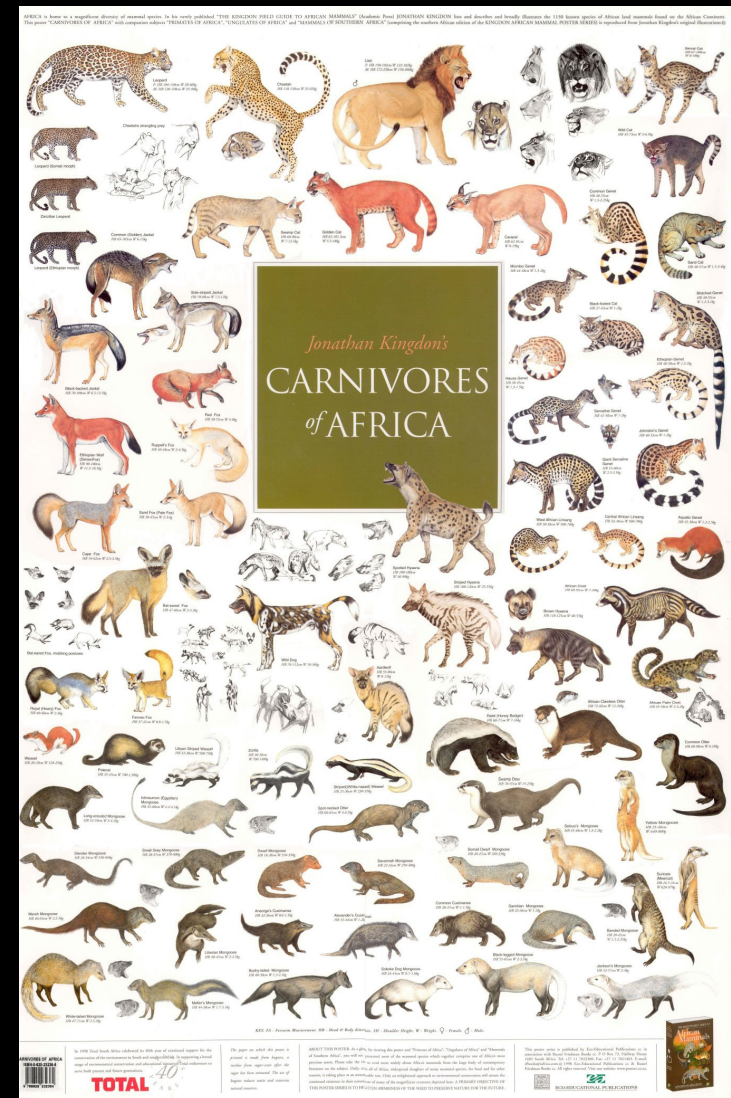


- Size affects many aspects of predator ecology
- Two distinct groups – small & large prey feeders
- Related shifts in morphology & behaviour
- Energetics – evolution and may limit maximum sizes of different predatory types

Topics



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Energetic Constraints & Population Responses



letters to nature

High hunting costs make African wild dogs vulnerable to kleptoparasitism by hyaenas

Martyn L. Gorman*, Michael G. Mills†, Jacobus P. Raath† & John R. Speakman*

* Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen AB24 2TZ, UK

† National Parks Board, Kruger National Park, Box X402, Skukuza 1350, Republic of South Africa



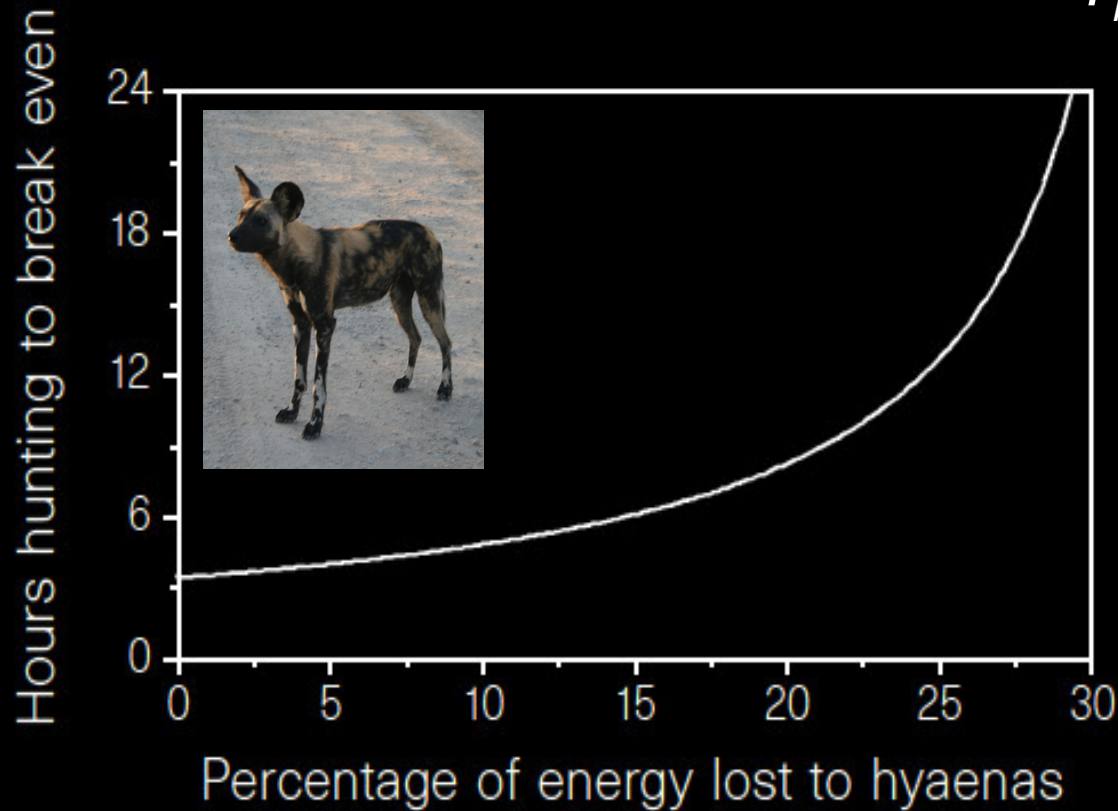
Gorman, M. L., M. G. Mills, J. P. Raath, and J. R. Speakman. 1998. High hunting costs make African wild dogs vulnerable to kleptoparasitism by hyaenas. *Nature* 391:479-481.

Energetic Constraints & Population Responses



$$T_h = 24 E_r / (I_h + E_r - E_h)$$

T_h = time hunting
 E_r , E_h = energetic rates
resting & foraging
 I_h = foraging intake rates

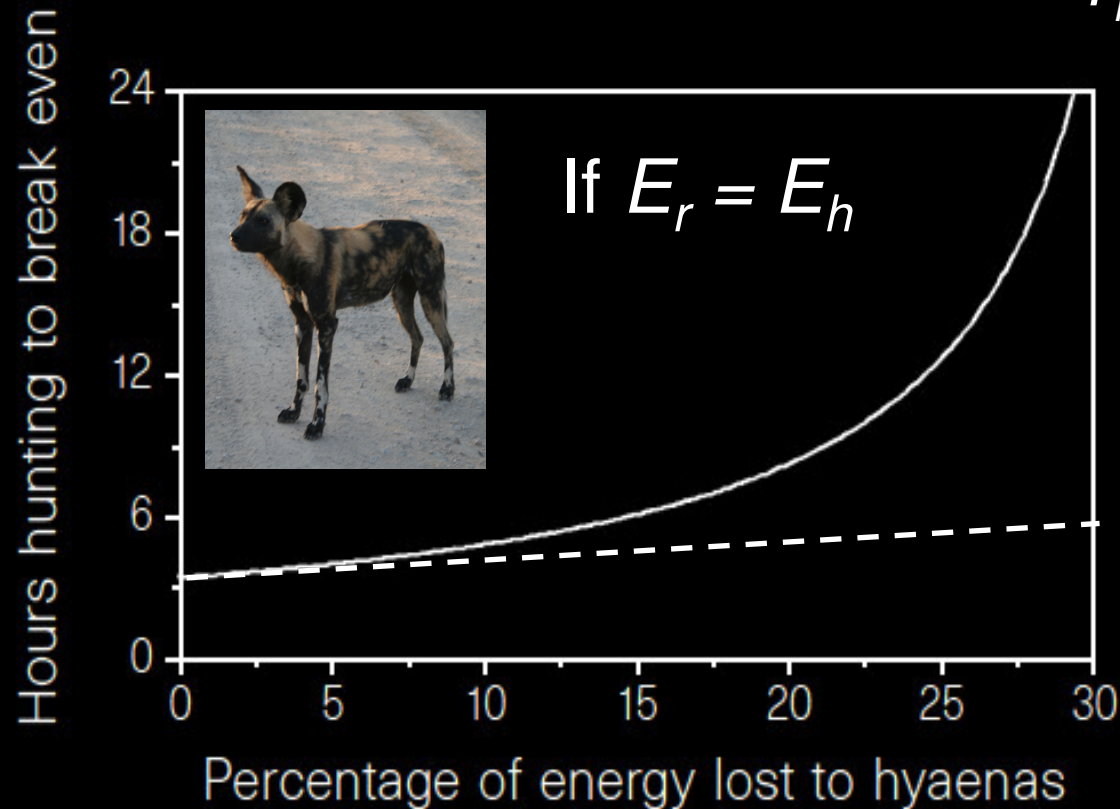


Gorman, M. L., M. G. Mills, J. P. Raath, and J. R. Speakman. 1998. High hunting costs make African wild dogs vulnerable to kleptoparasitism by hyaenas. *Nature* 391:479-481.

Energetic Constraints & Population Responses



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Energetic Constraints & Population Responses



**Energy Rates
in relation to
body mass?**

$$T_h = 24 E_r / (I_h + E_r - E_h)$$

**Intake Rates in
relation to prey
abundance**

Allometric Equations for Running



- Expenditure depends on mammal mass (kg) and travel speed (m/s)

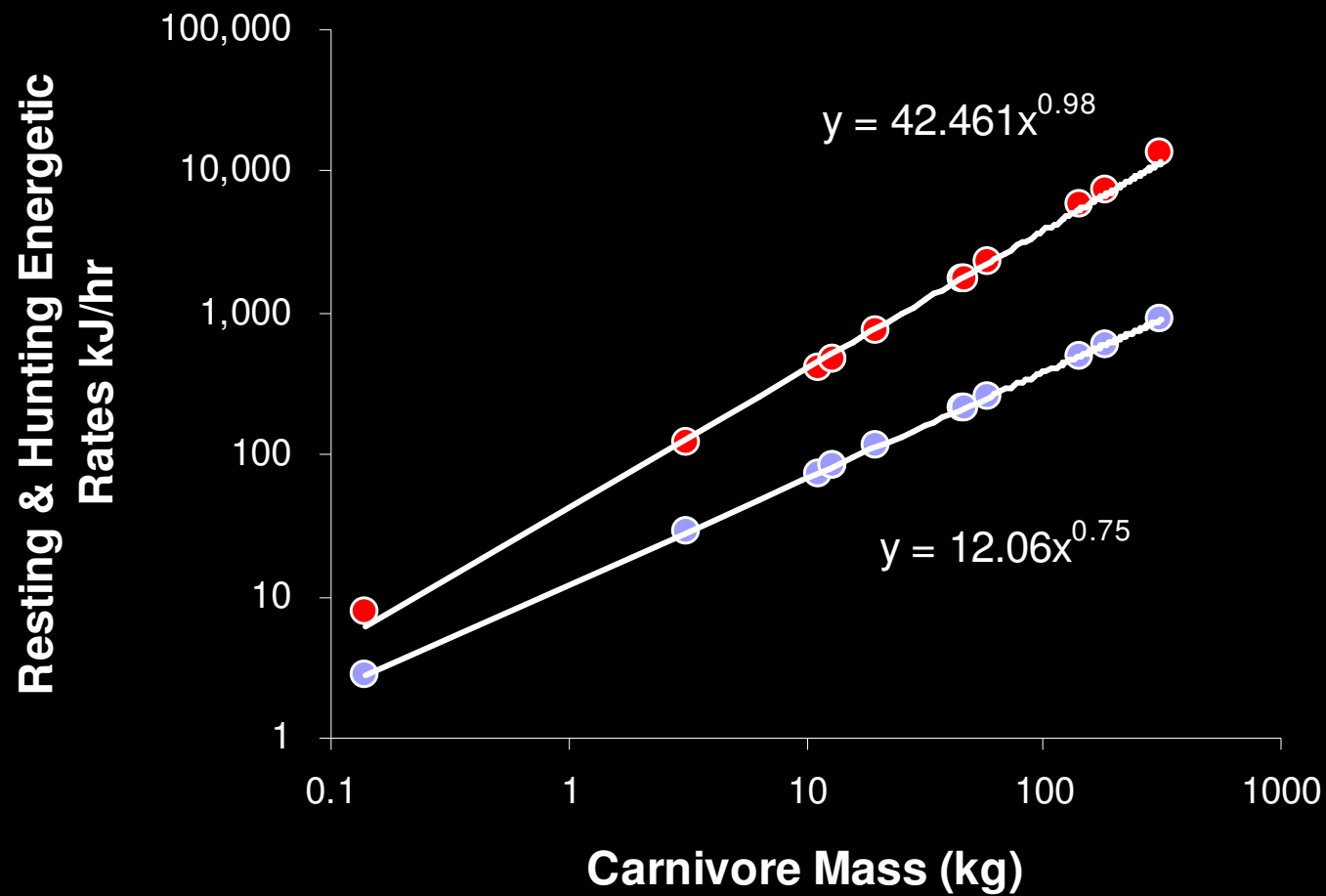
$$E_r = 3.34 M_c^{0.75}$$

$$E_h = 10.7 M_c^{0.684} \times \underline{0.25} M_c^{0.44} + 6.03 M_c^{0.697}$$

Schmidt-Nielsen (1984)

- Speed estimates based on carnivore day range (Carbone et al 2005)

Scaling of Resting and Hunting Rates

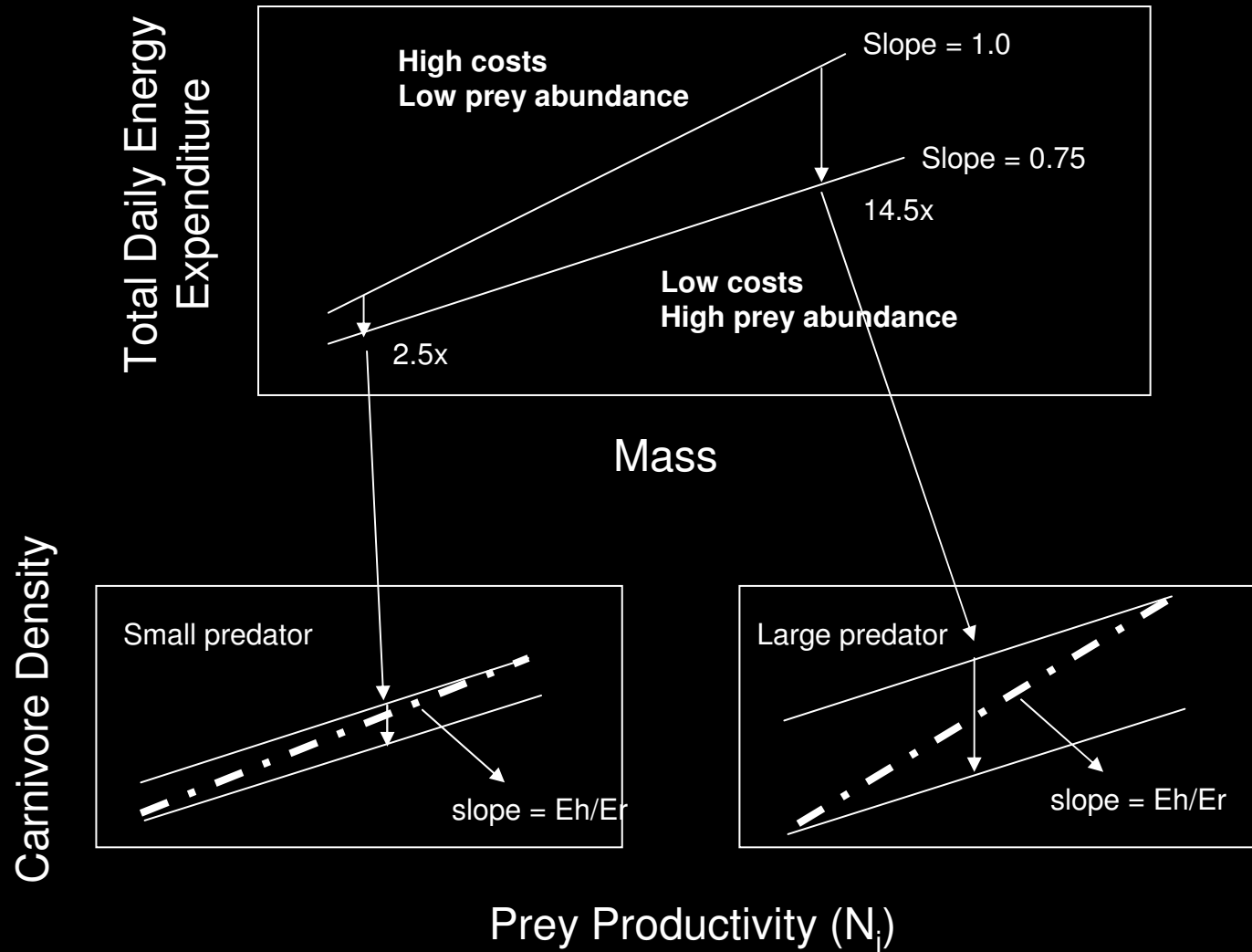


Prey abundance - intake and energetics

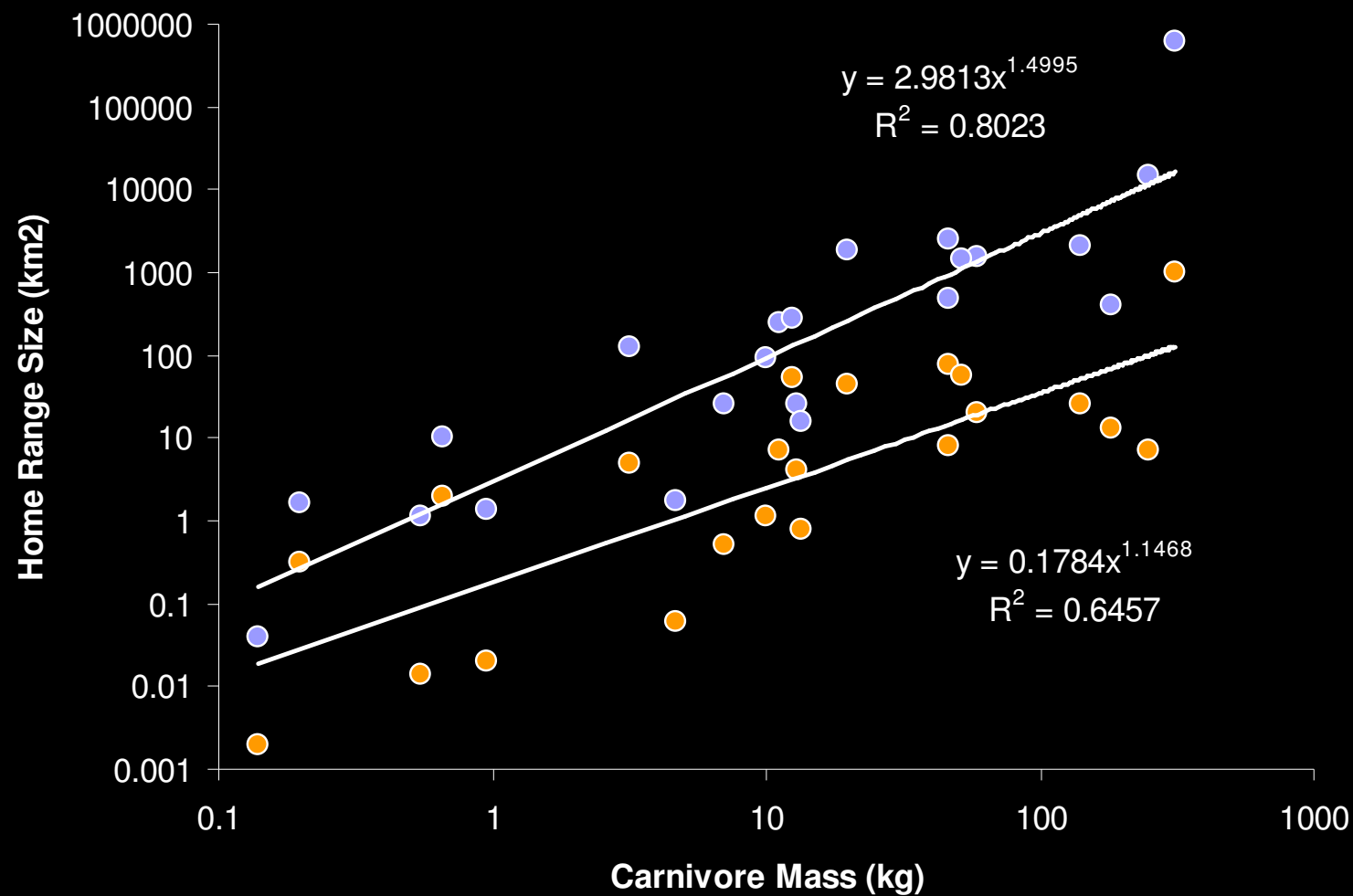


- Gas model predicts $\lambda \propto N_i$, prey density
- Intake $\propto \lambda M_i$
 - Encounter rate and prey mass
- Lower encounter rate - higher costs
 - Extreme high prey density, daily costs $\Rightarrow E_r$ (low costs & lower scaling)
 - Extreme low prey density, daily costs $\Rightarrow E_h$ (high costs & higher scaling)
- E_h/E_r should be important

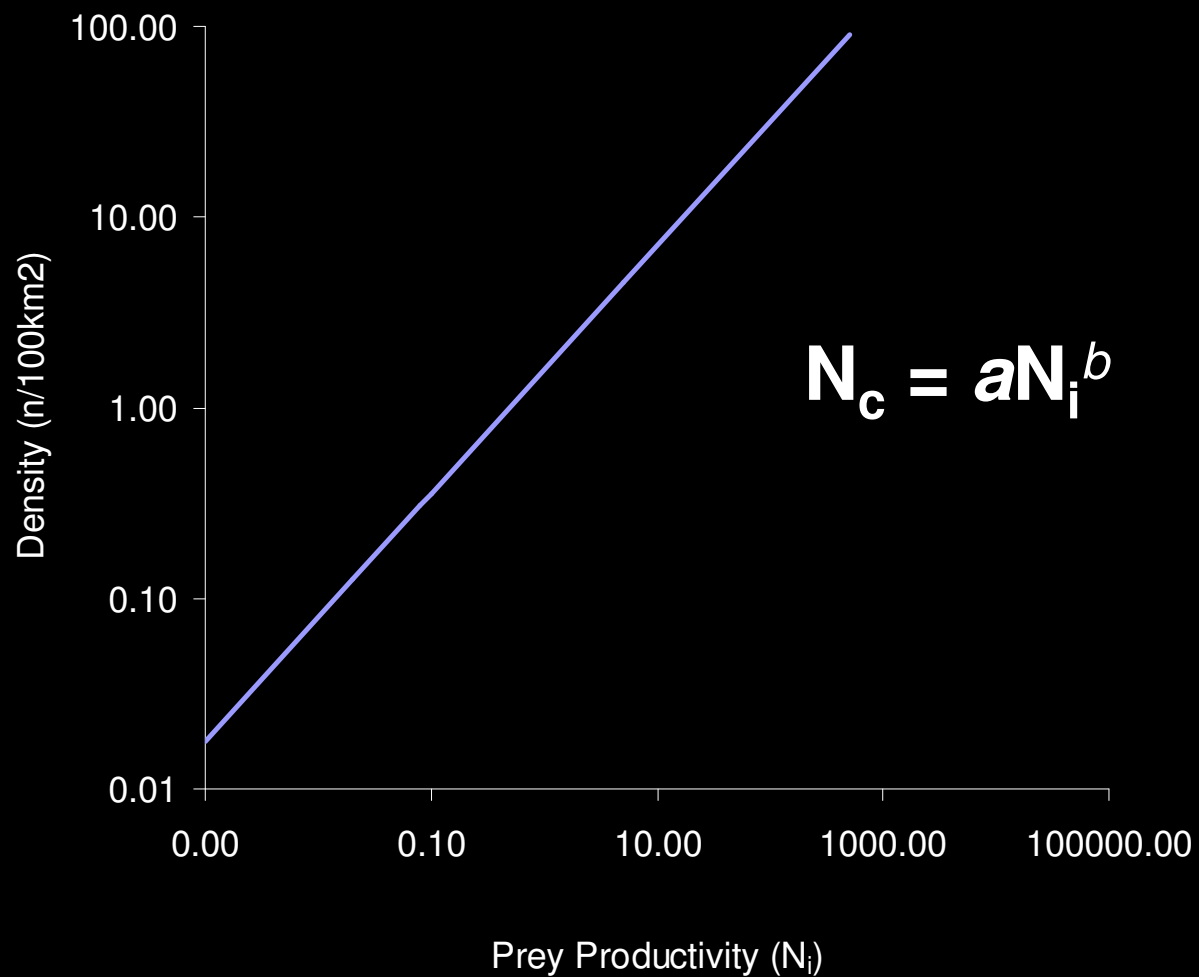
Graphic Illustration



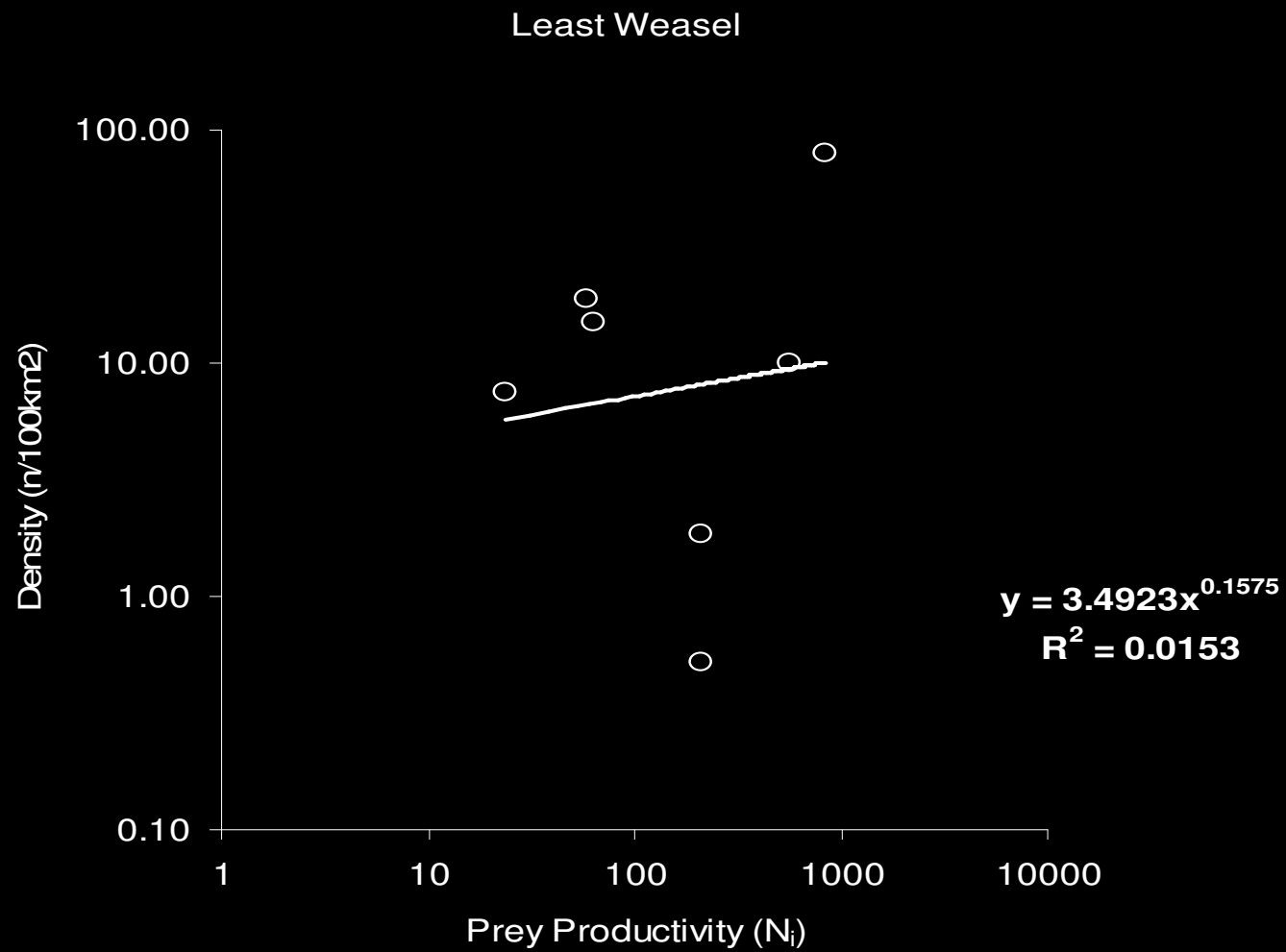
Home Range Analysis



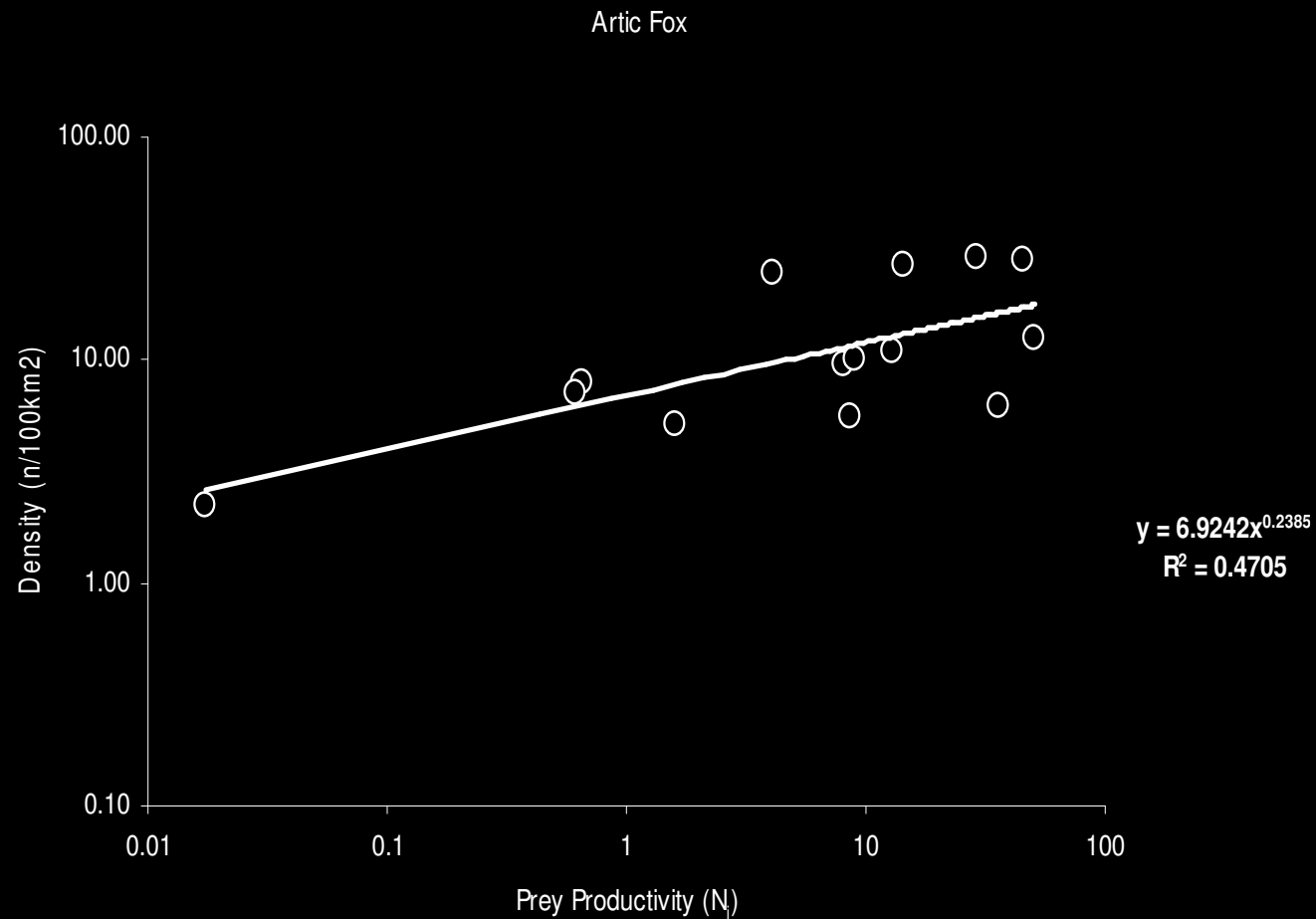
Predator Population Responses



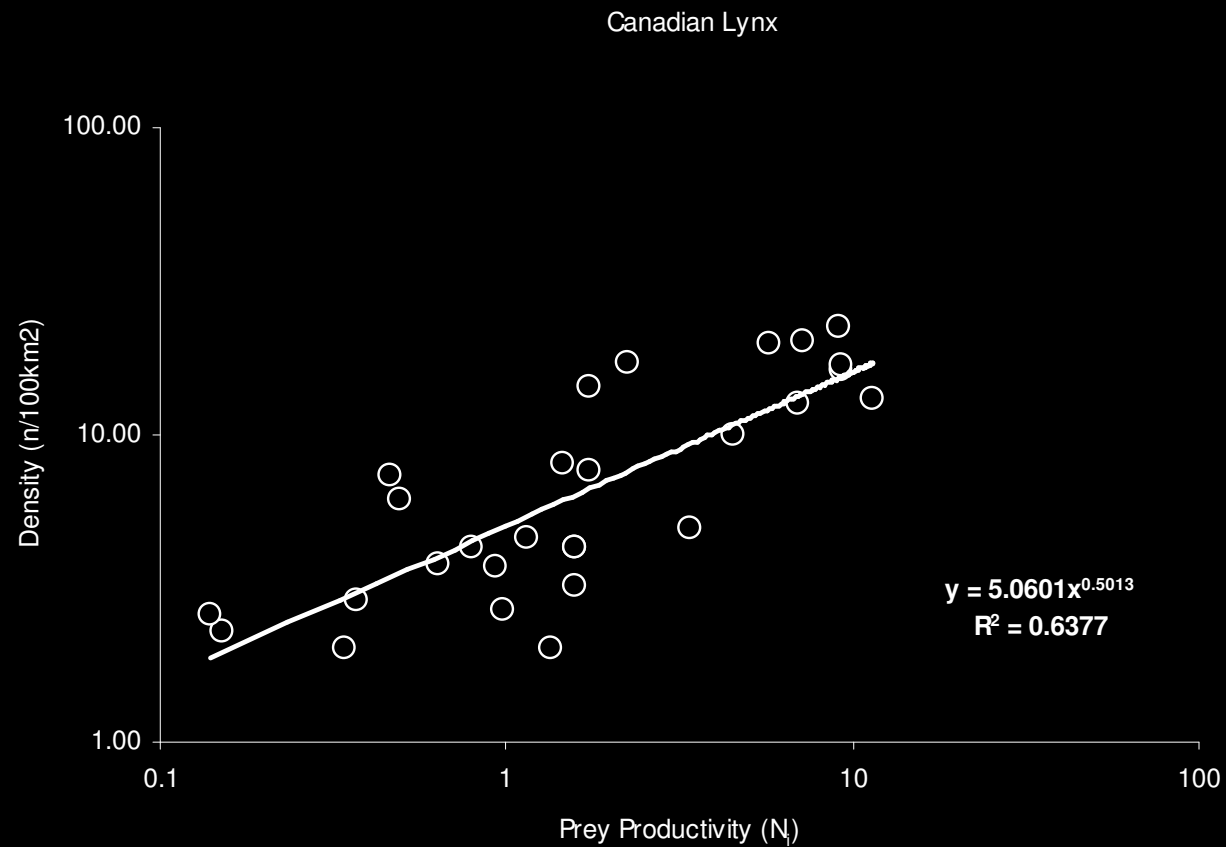
Predator-Prey Population Response



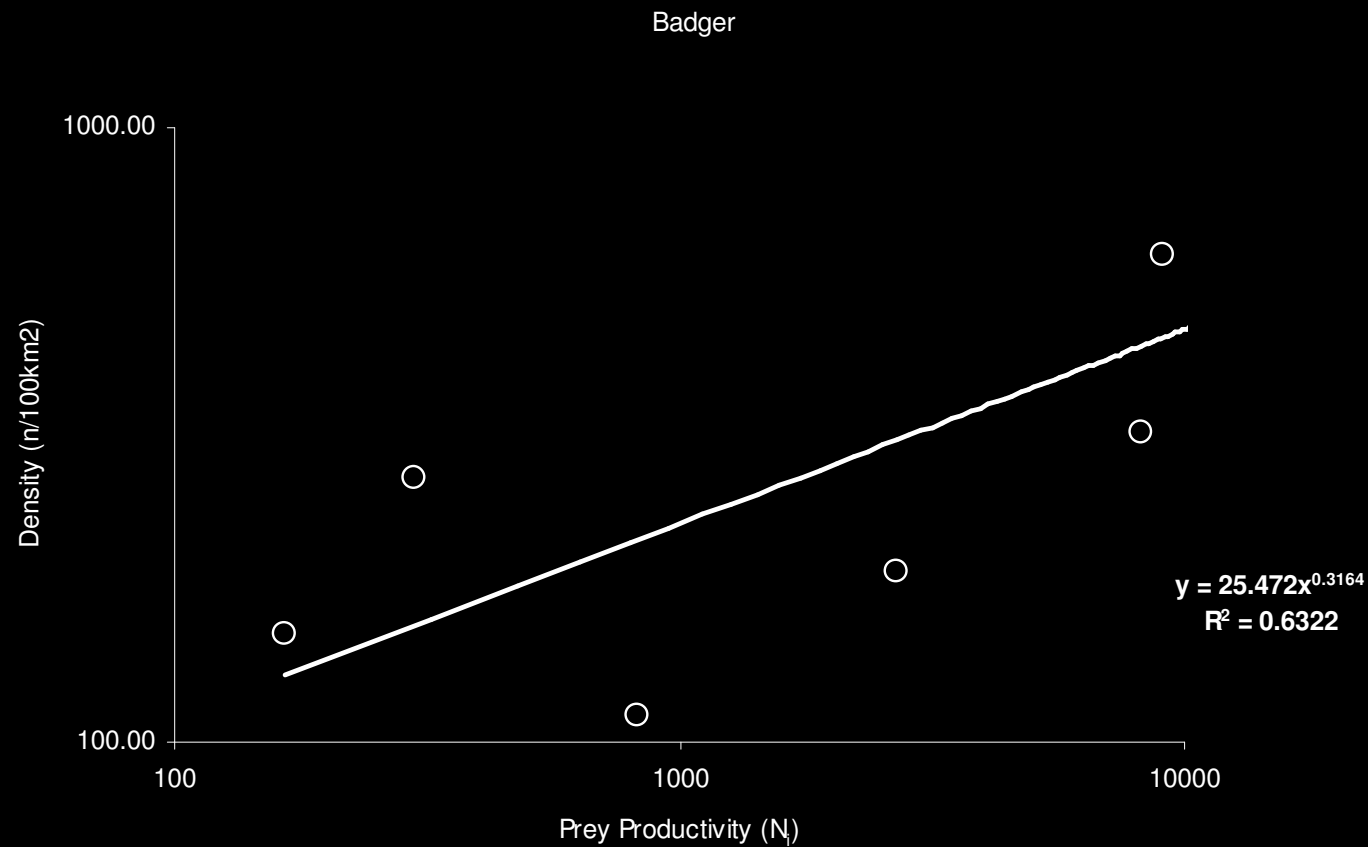
Predator-Prey Population Response



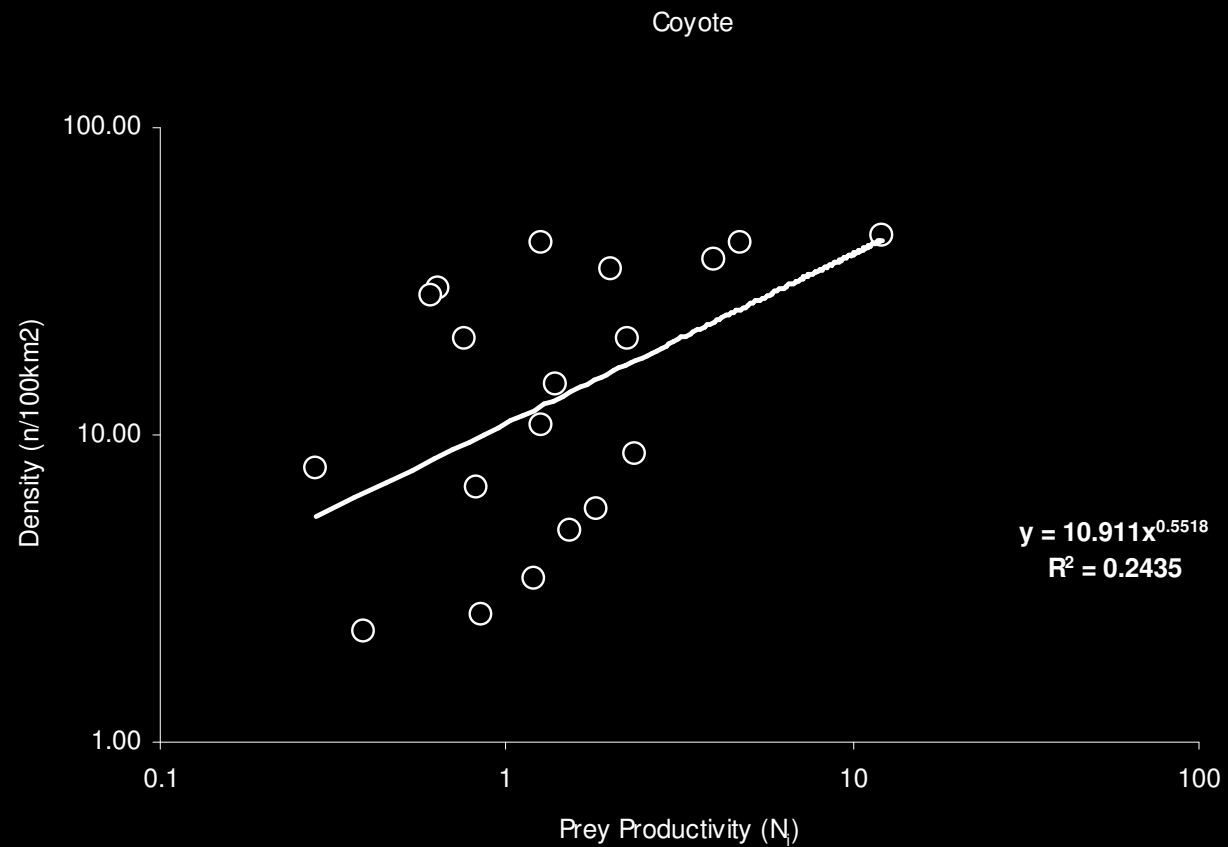
Predator-Prey Population Response



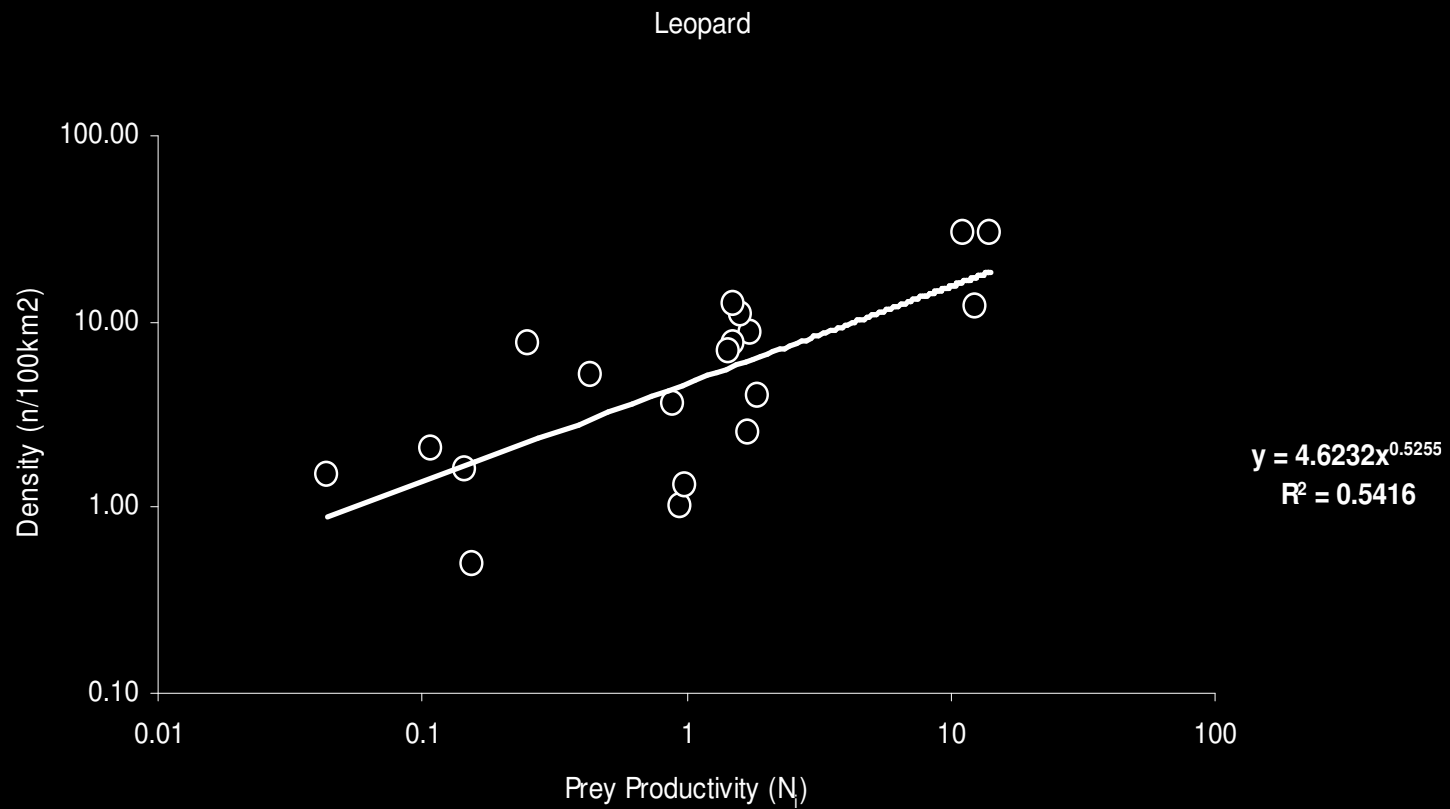
Predator-Prey Population Response



Predator-Prey Population Response



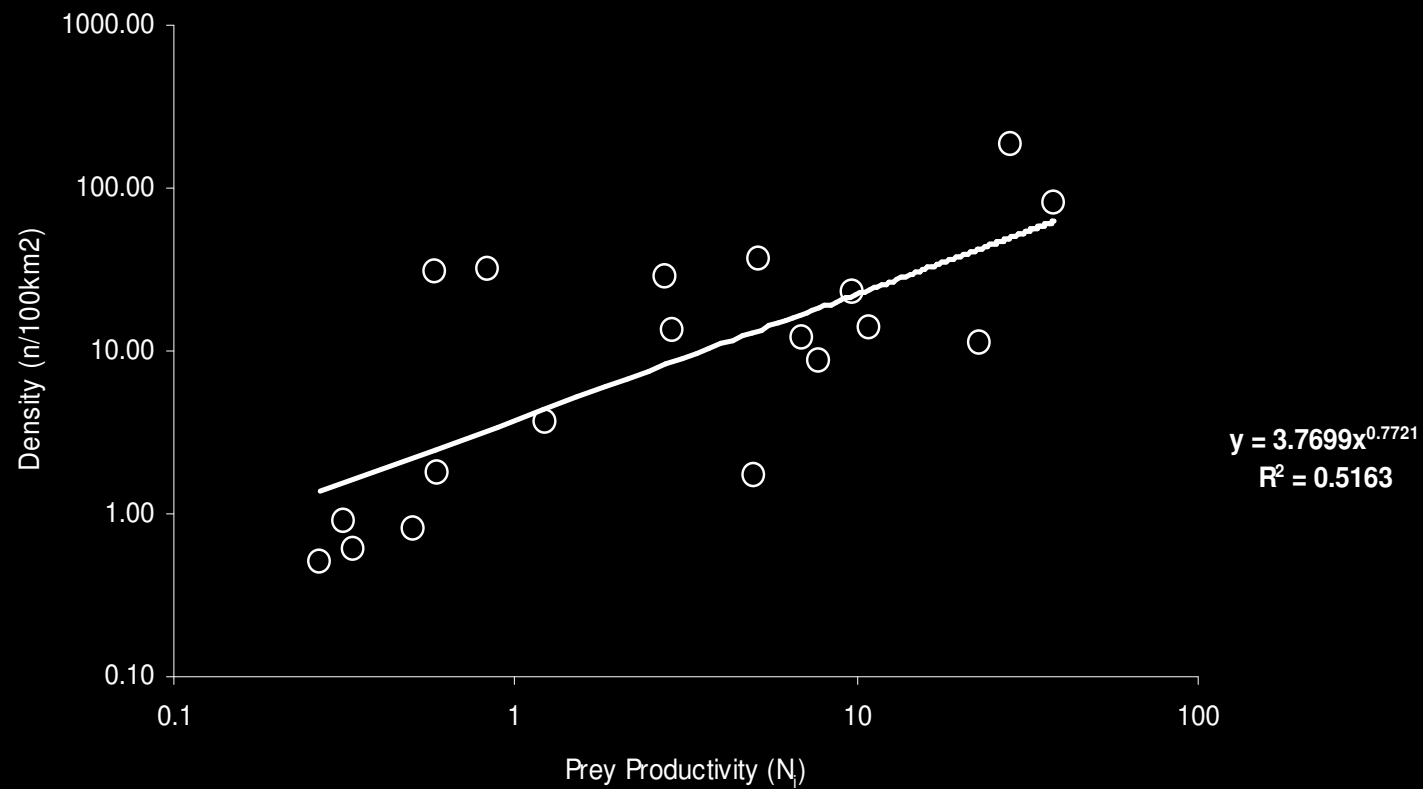
Predator-Prey Population Response



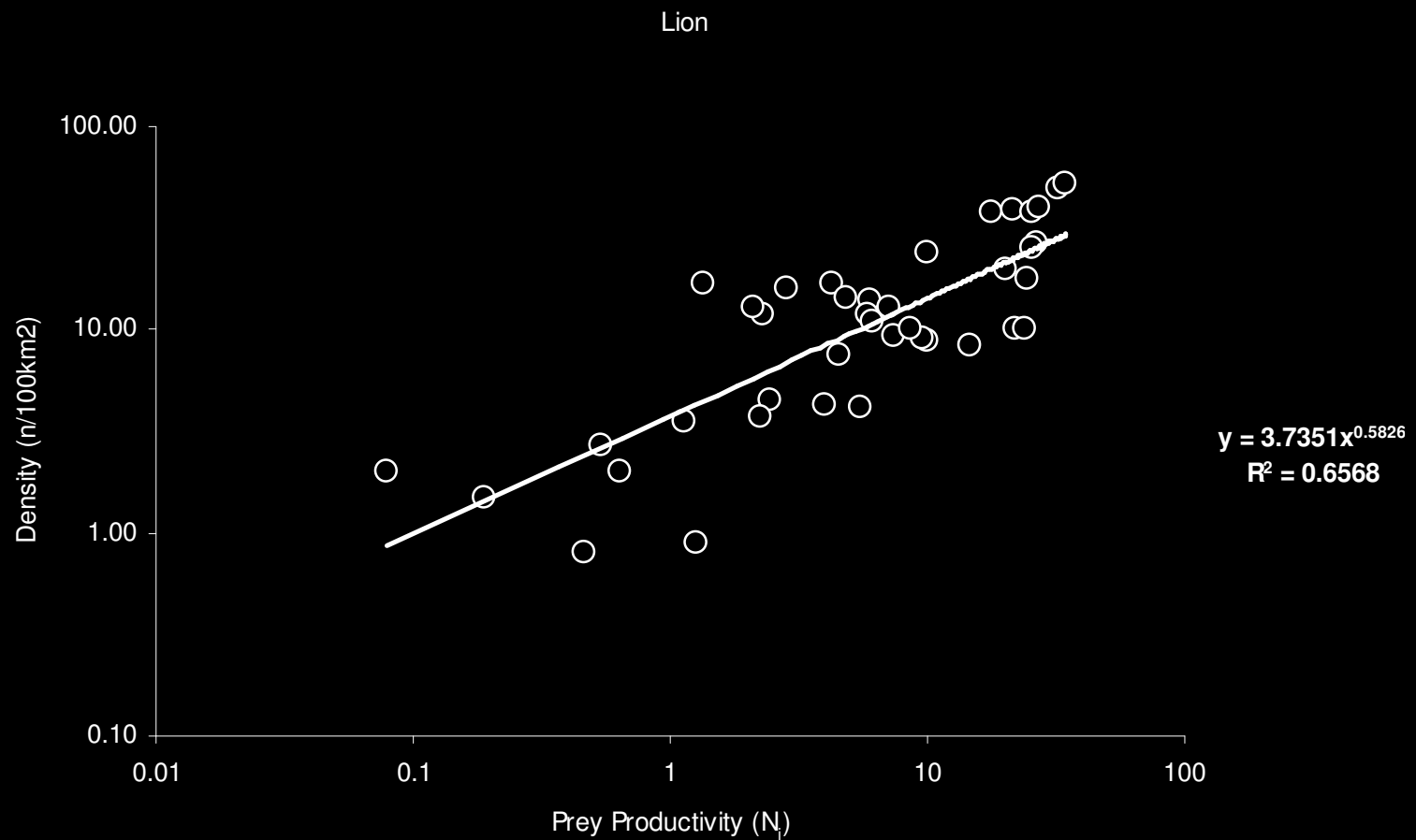
Predator-Prey Population Response



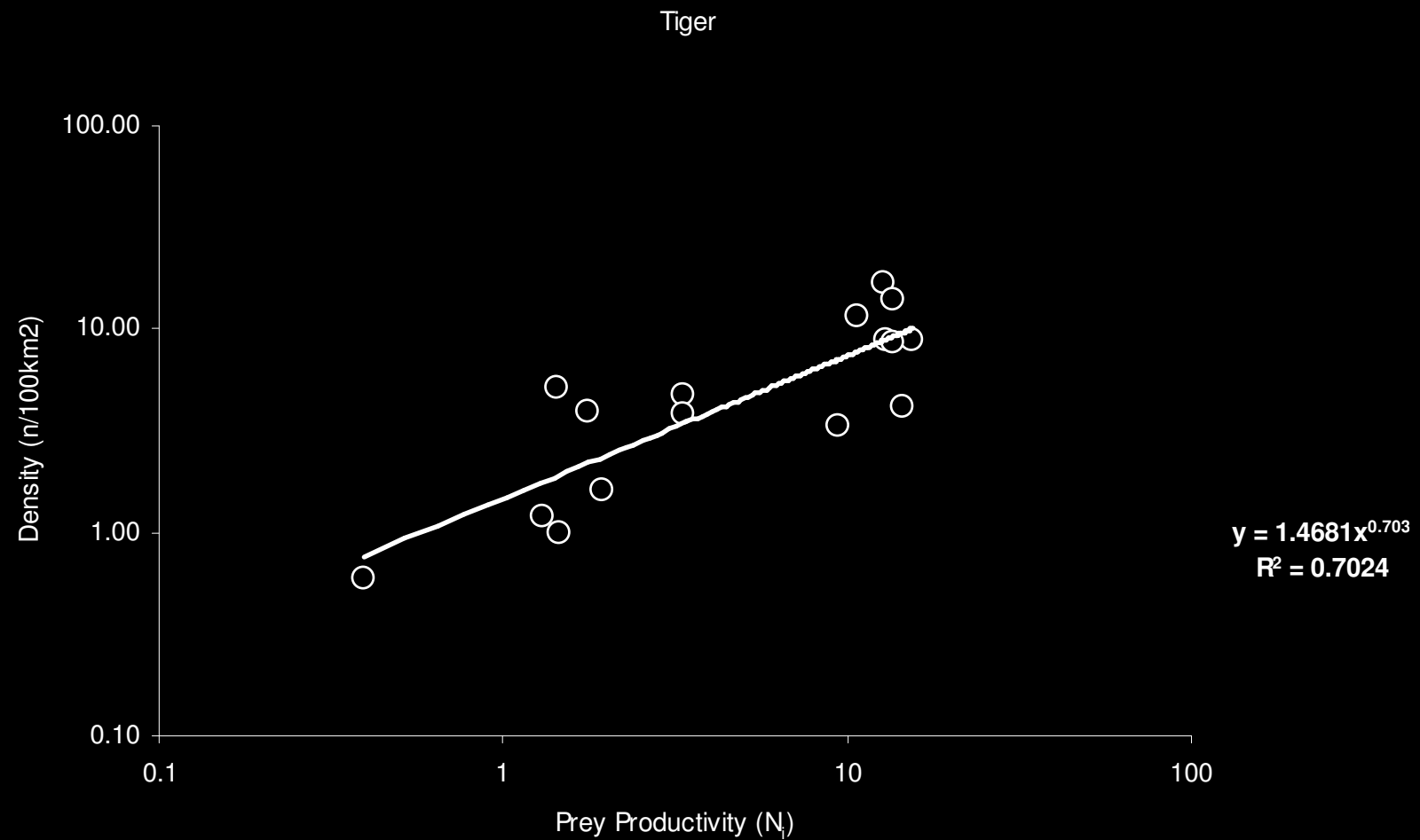
Spotted Hyena



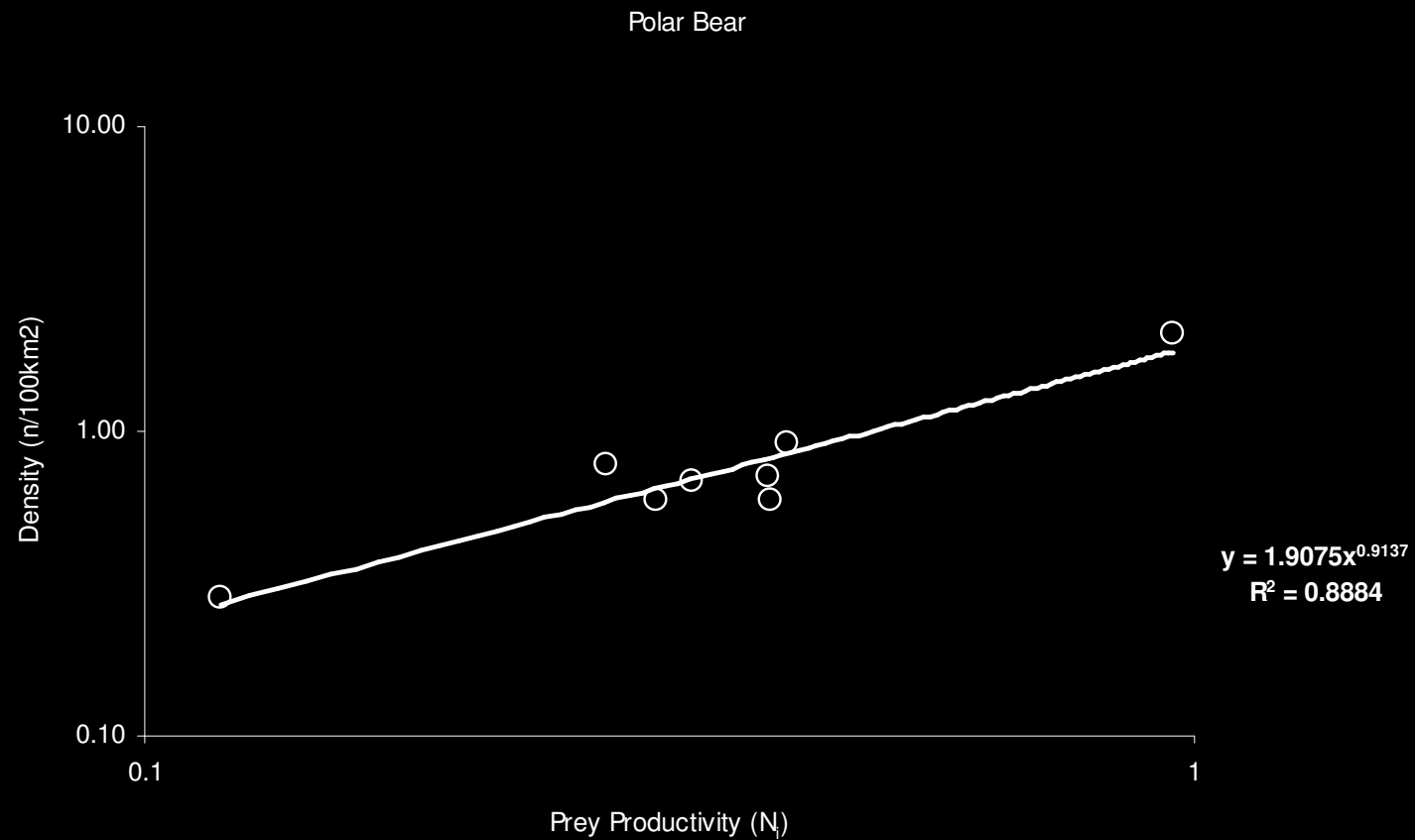
Predator-Prey Population Response



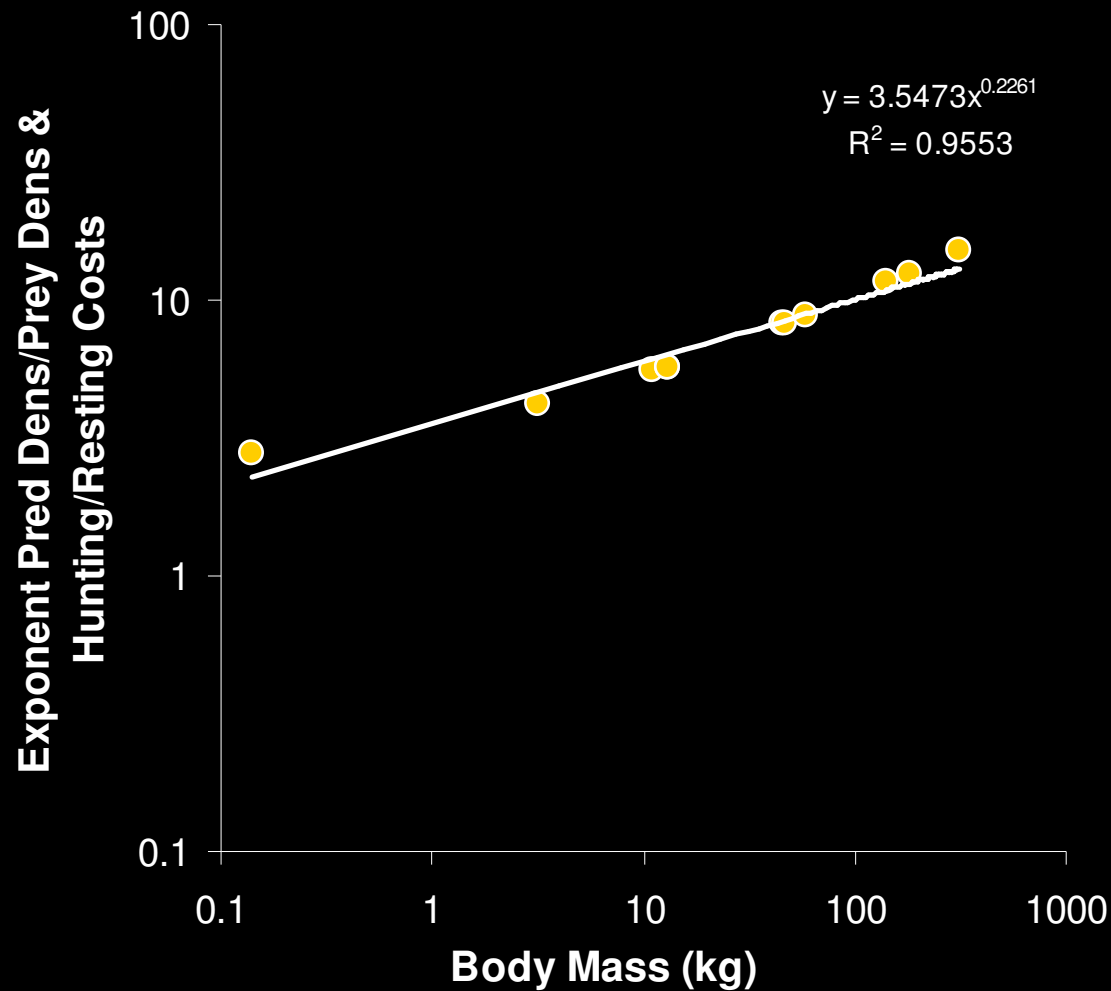
Predator-Prey Population Response



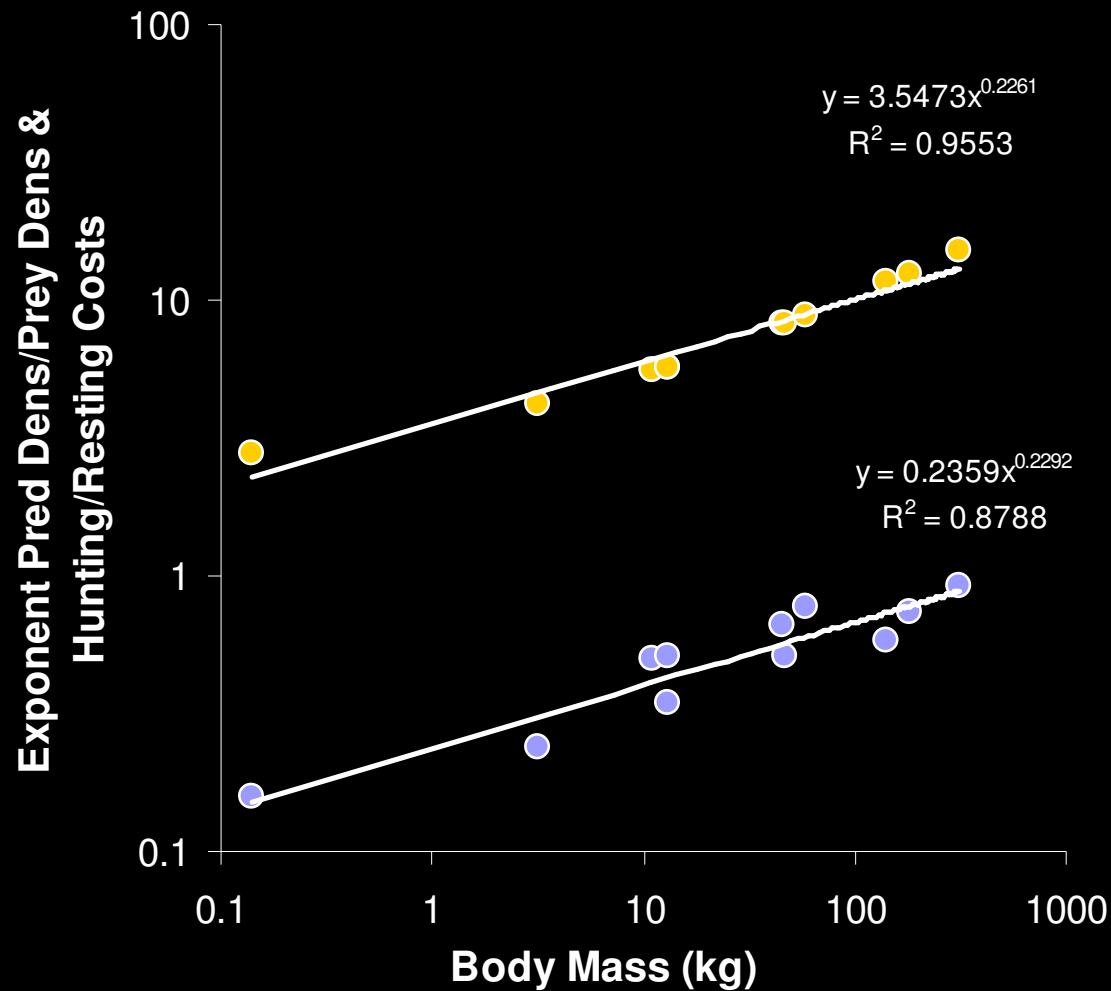
Predator-Prey Population Response



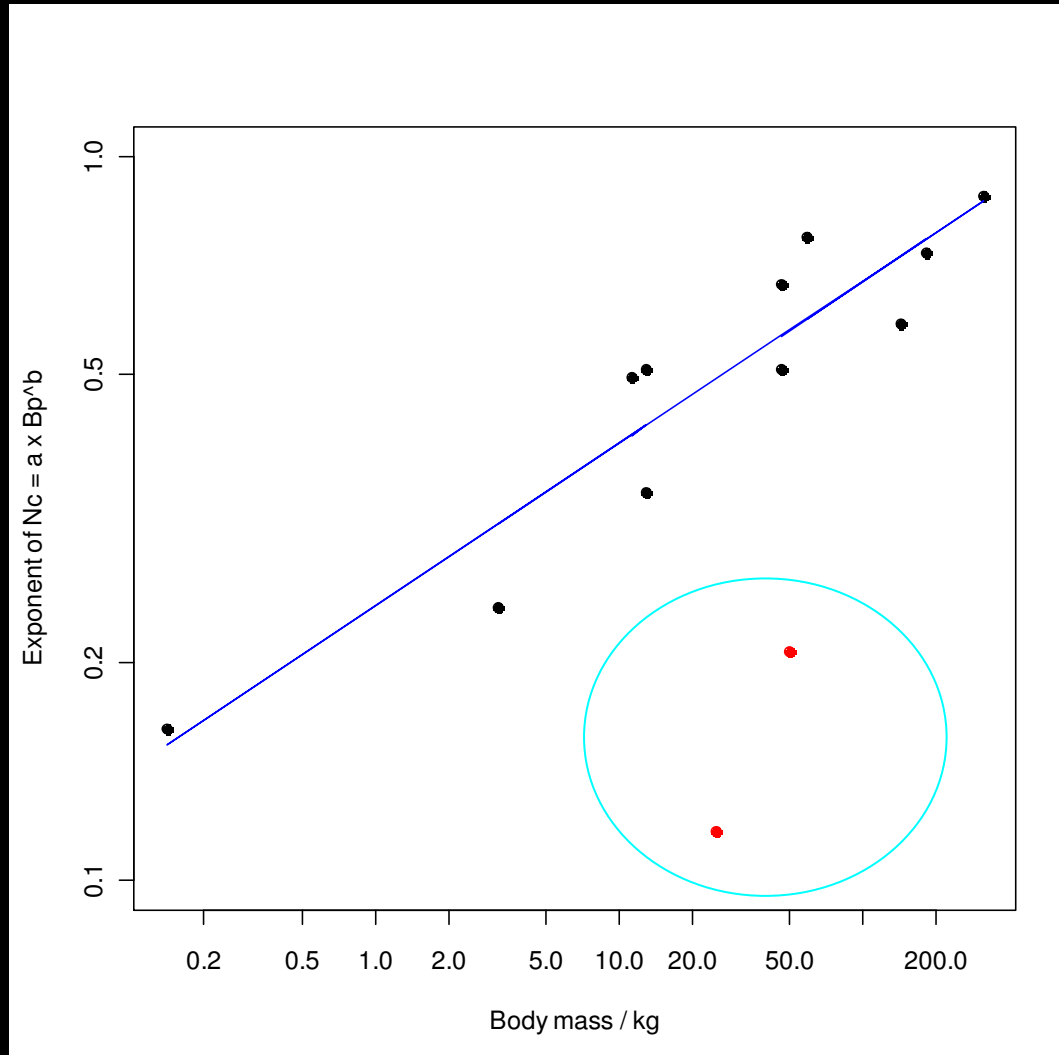
Scaling of Carnivore Population Responses



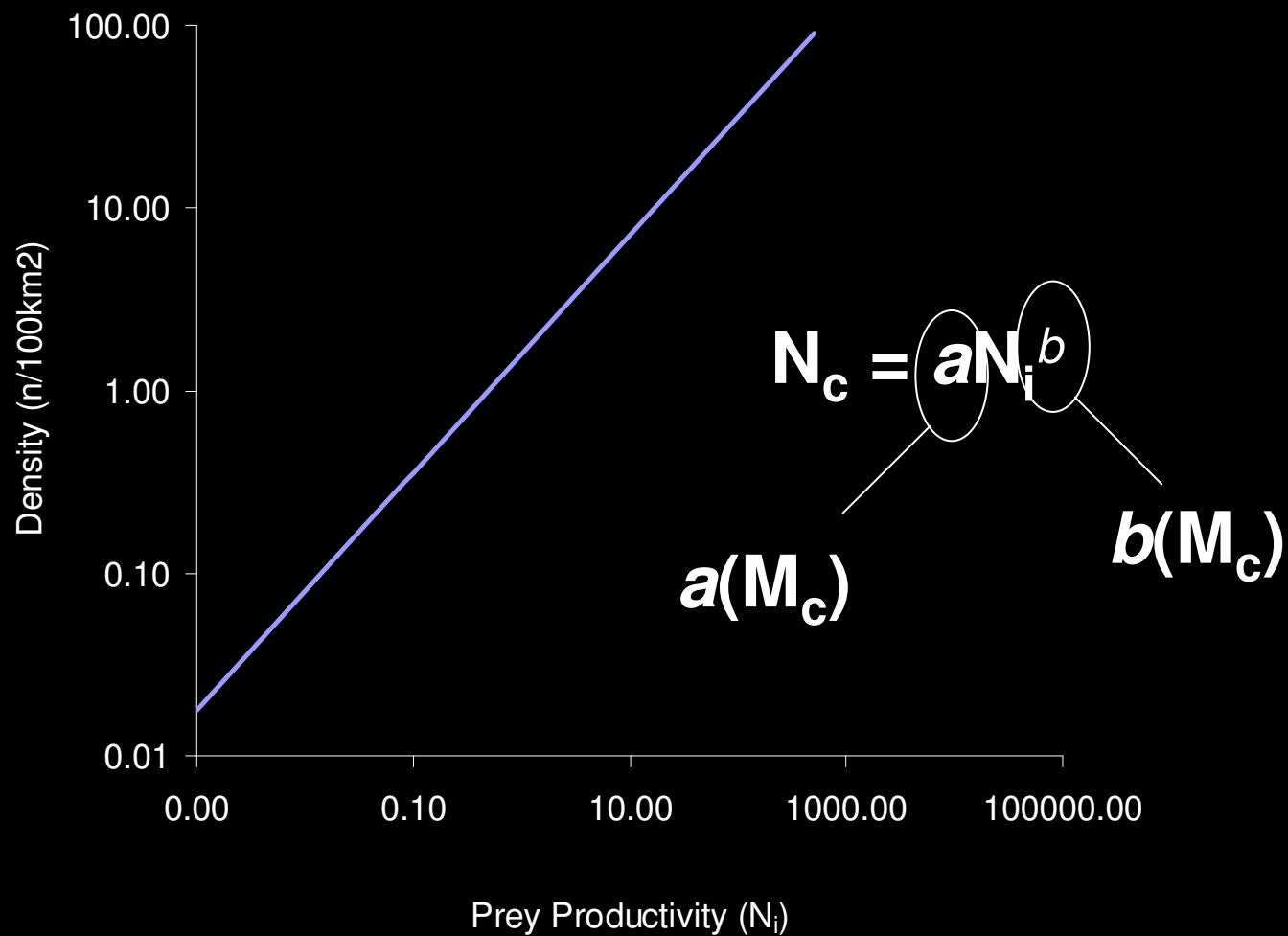
Scaling of Carnivore Population Responses



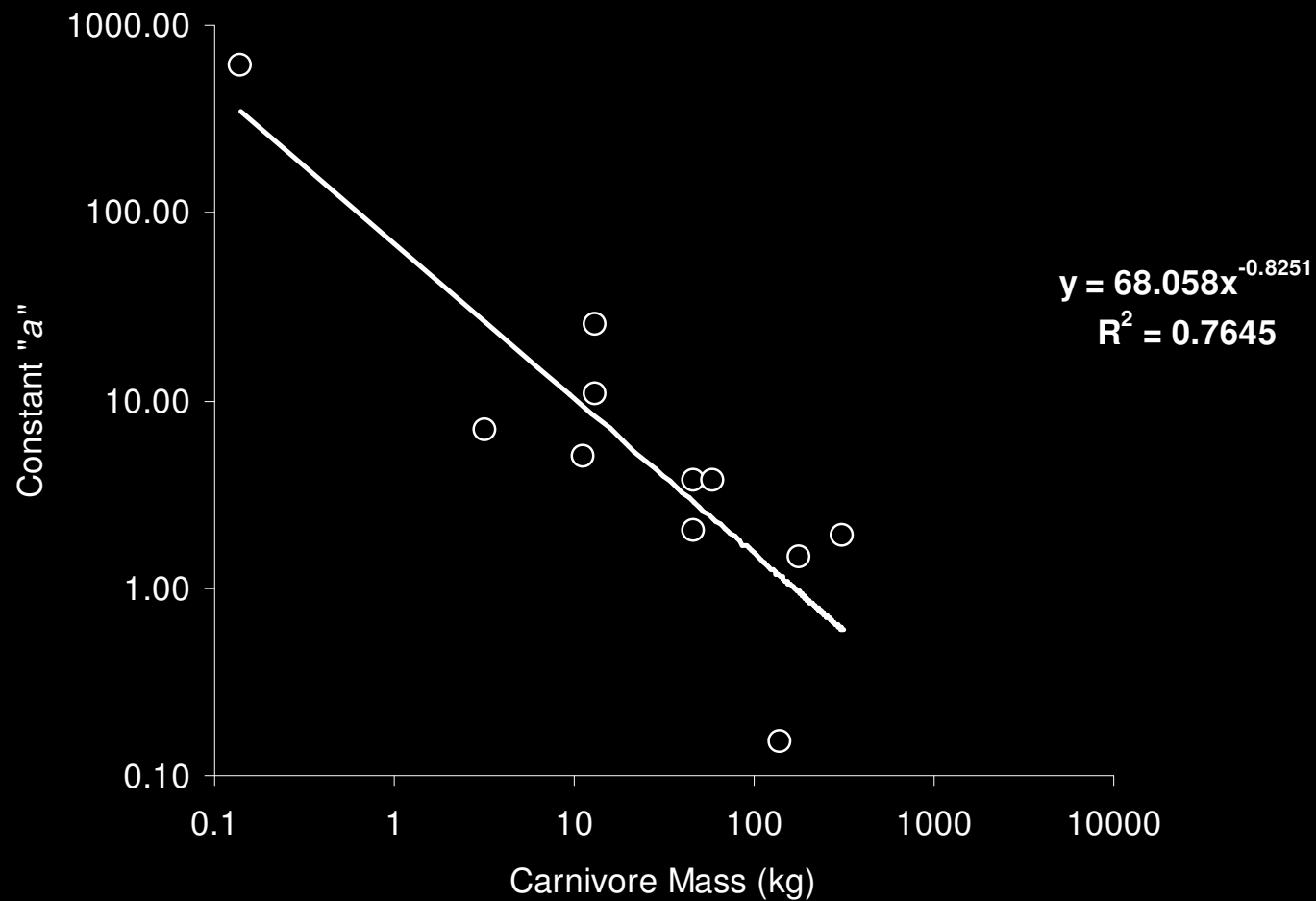
Exceptions!



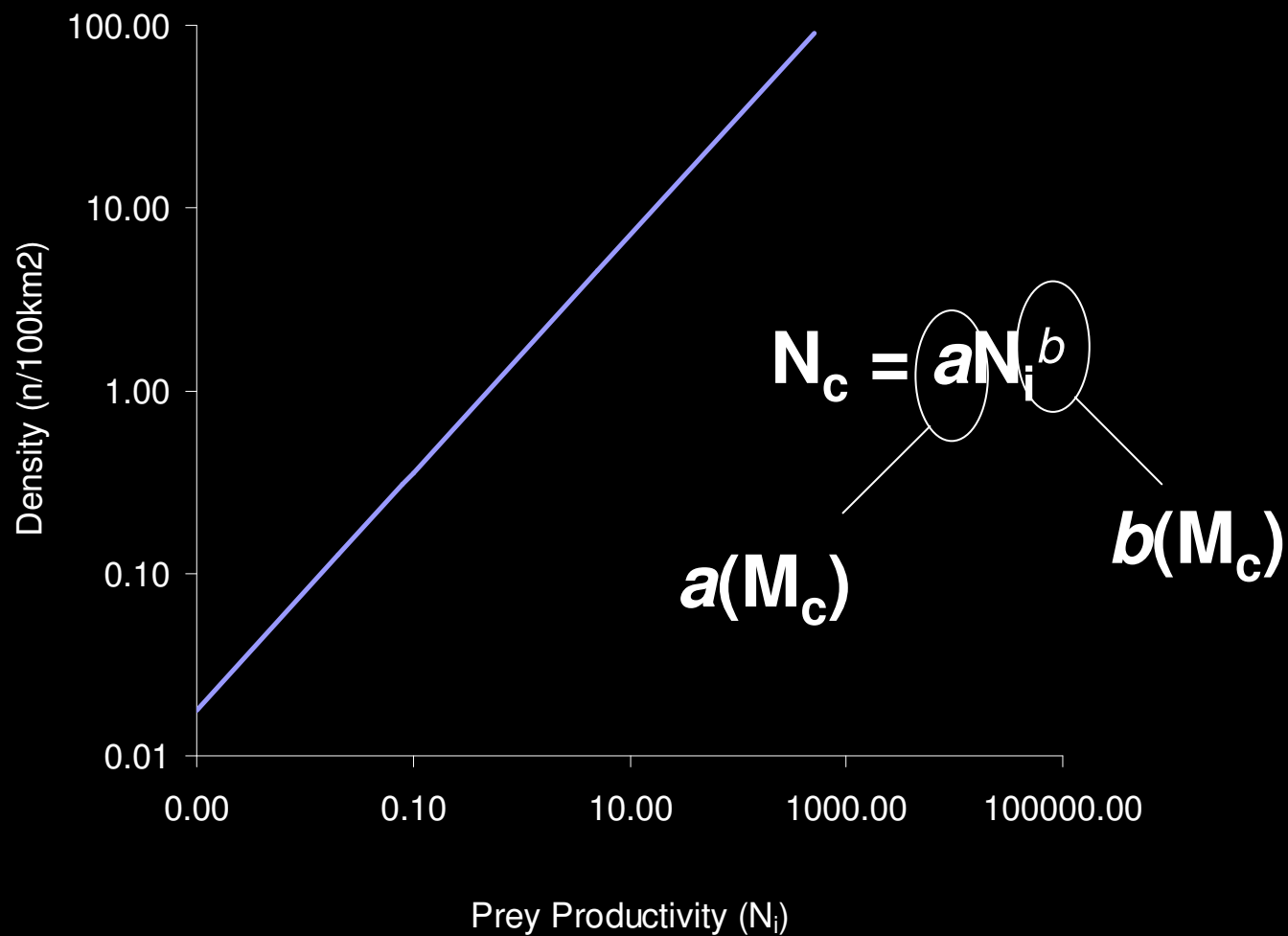
Predator Population Responses



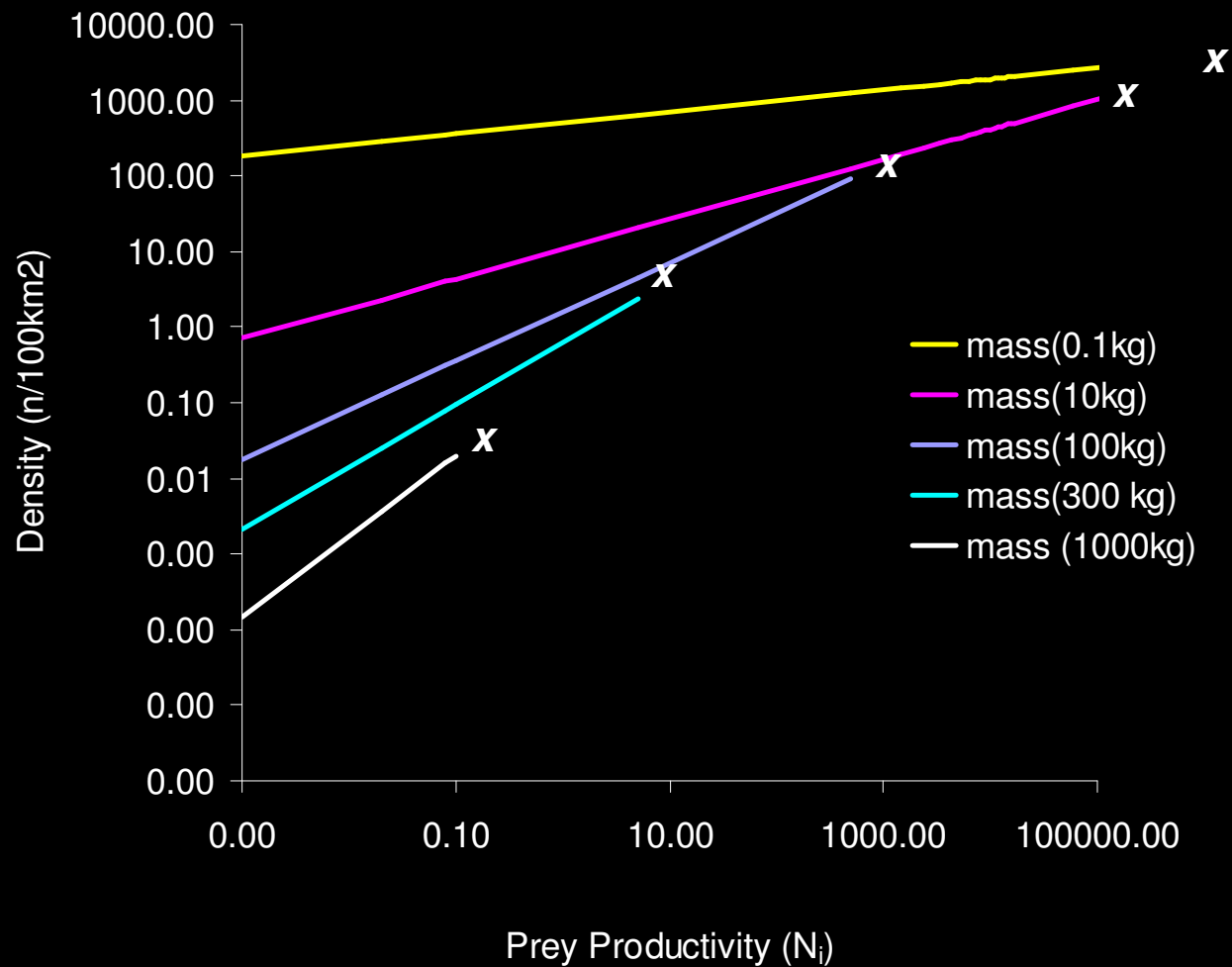
Constants in Pred-prey power relationships



Predator Population Responses



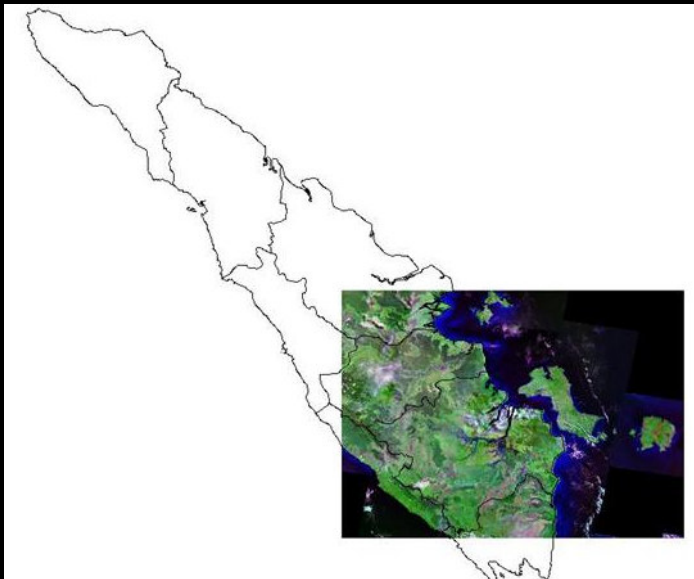
Predator Population Responses



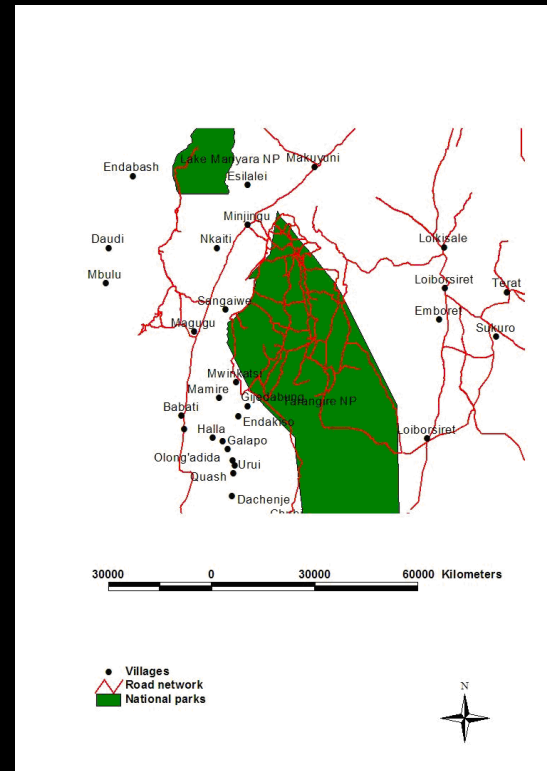
Response to Threats – Habitat Loss



Response to Threats – Sumatra & Tanzania



- Tom Maddox
- Joe Smith
- Emily Fitzherbert



- Sarah Durant
- Maurus Msuha

Habitat Loss - (Sumatran Mammals)



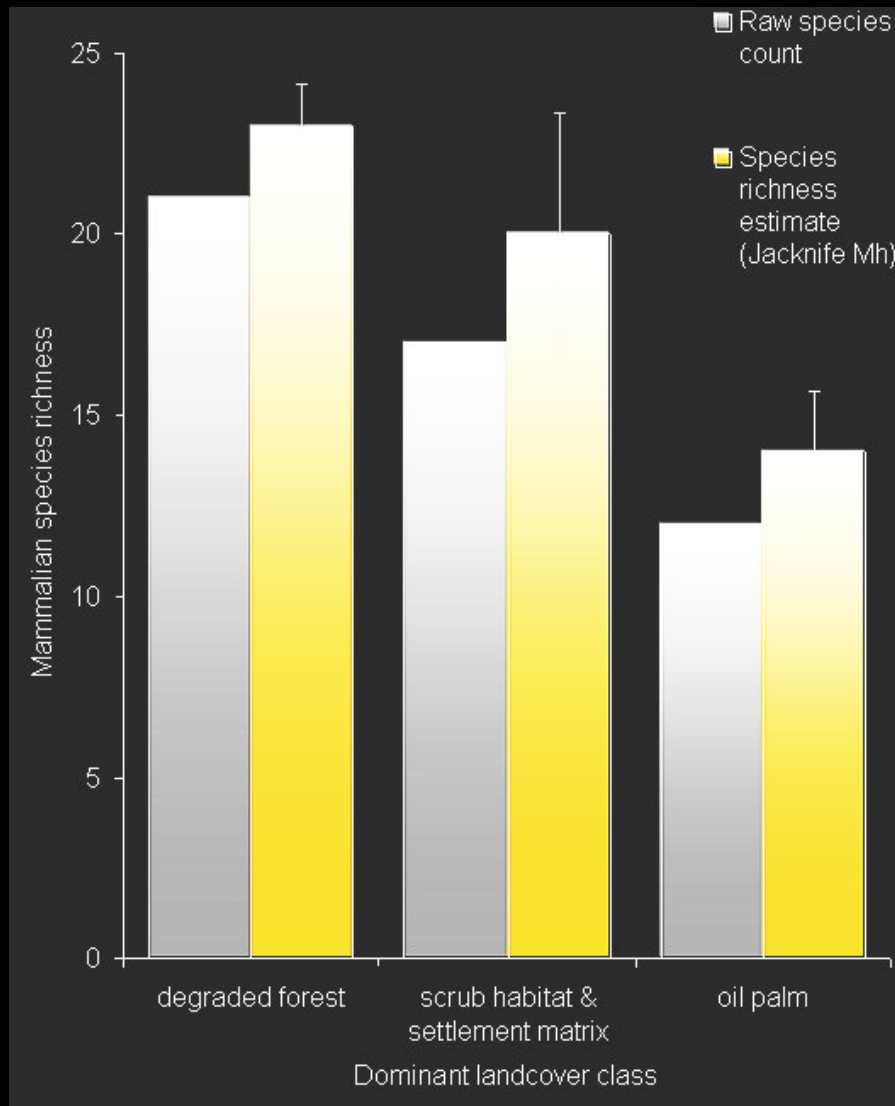
Degraded Forests



Scrub settlement Matrix



Oil Palm Matrix



Smith, J. (2007). Mammalian Occurrence in Human-Dominated Landscapes, Upgrade report. Imperial College

Habitat Loss - (Sumatran Mammals)



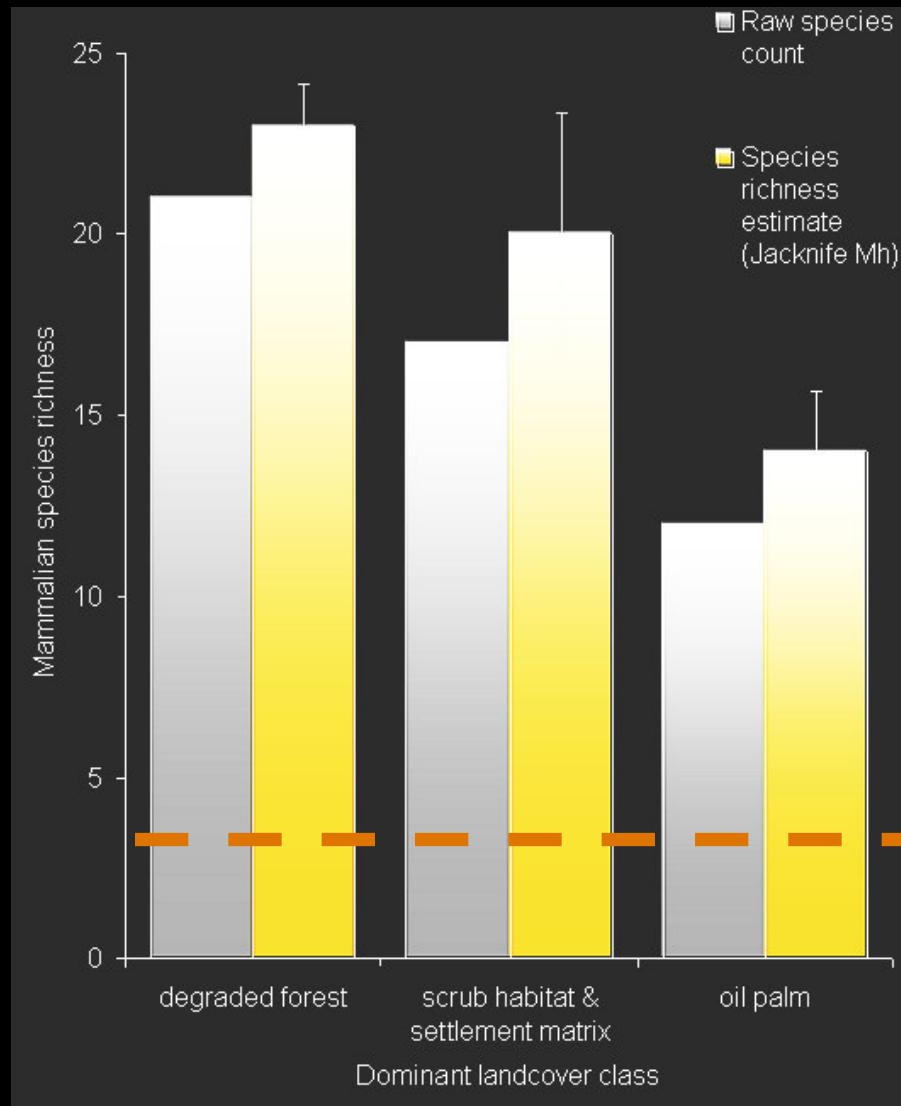
Degraded Forests



Scrub settlement Matrix



Oil Palm Matrix



Pure Oil Palm

Smith, J. (2007). Mammalian Occurrence in Human-Dominated Landscapes, Upgrade report. Imperial College

Habitat Loss - (Tanzanian Mammals)



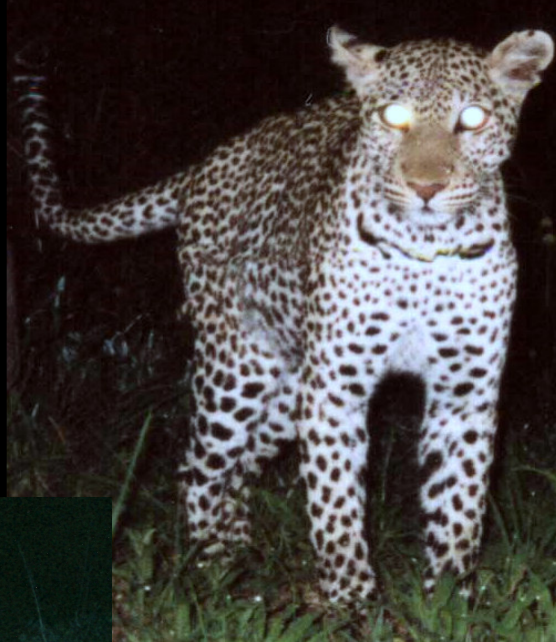
Summary of species diversity in Tarangiri NP and Farmlands for wet and dry season respectively (standard deviation in brackets)

	National Park	Farmlands
Observed Species Richness	61	26
Estimated Species Richness (Jackknife1)	74 (± 3.81)	33(± 2.74)

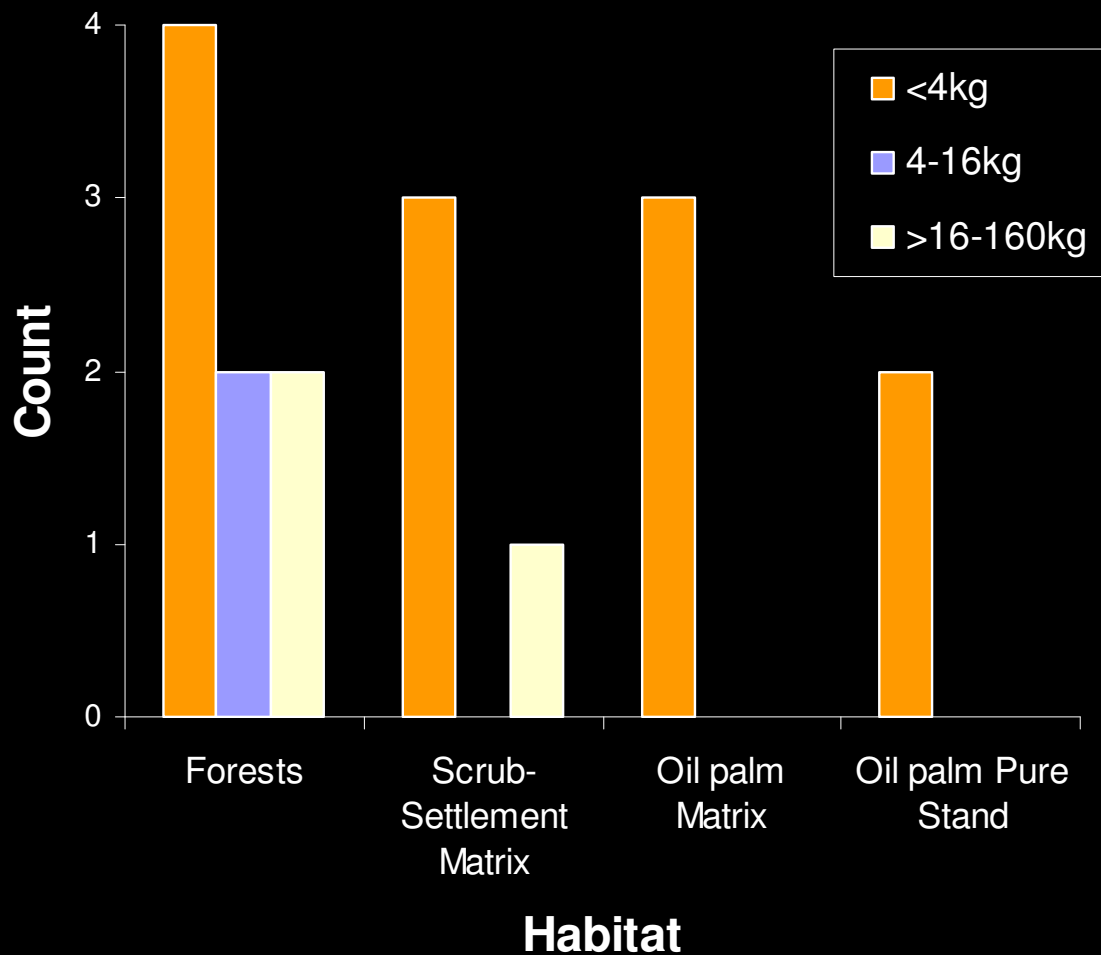
Msuha, M.J. (2006). Human Impacts on Carnivore Biodiversity Inside and Outside Protected Areas in Tanzania. *Upgrade Report*, University College London.

Response the Threats - Which Carnivores?

ZSL

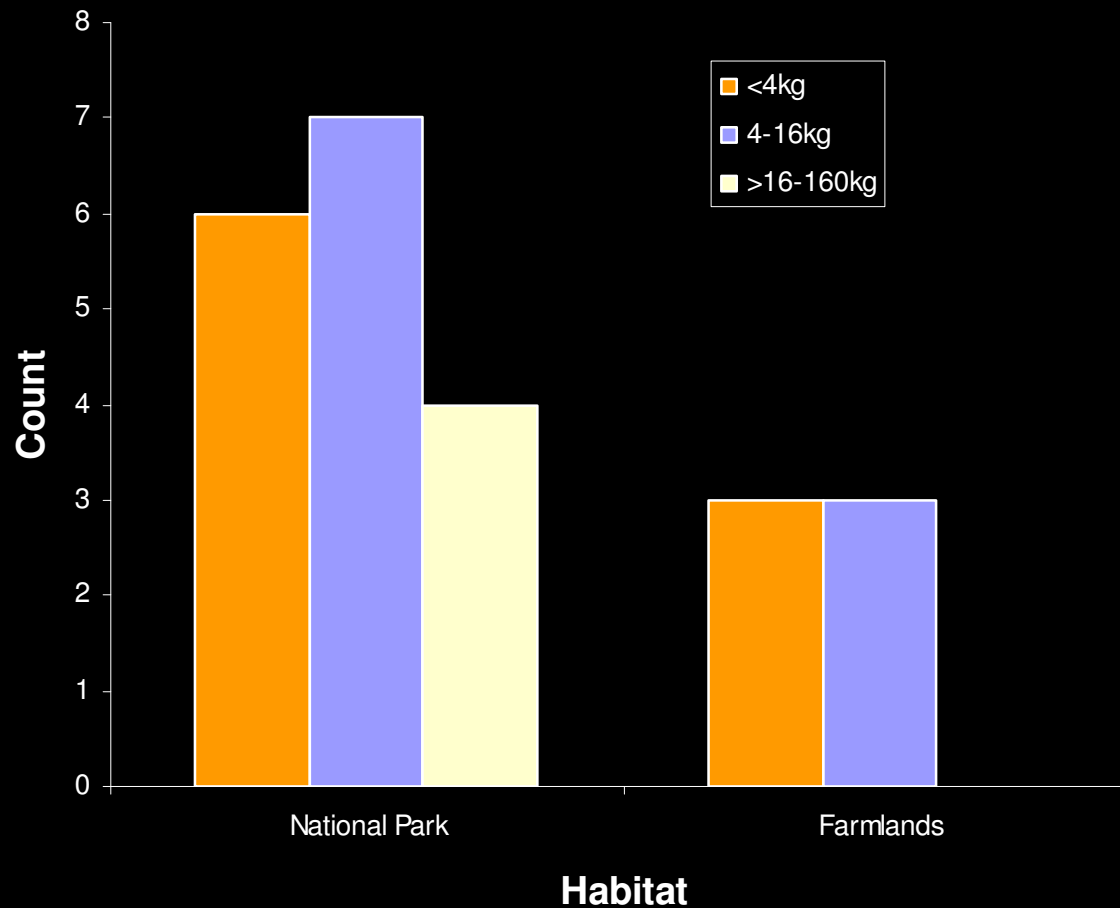
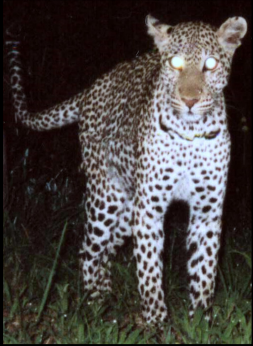


Habitat Loss - (Sumatran Carnivores)



Smith, J. (2007). Mammalian Occurrence in Human-Dominated Landscapes, Upgrade report. Imperial College

Habitat Loss - (Tanzanian Carnivores)



Msuha, M.J. (2008). Human Impacts on Carnivore Biodiversity Inside and Outside Protected Areas in Tanzania. *Upgrade Report*, University College London.



Response to Threats Mammalian trait database



- 25 types of life history & ecological, spatially referenced data
- >100,000 data lines from ~4000 reference sources
- <http://www.pantheria.org.uk>

“whereas extinction risk in smaller species is driven by environmental factors, in larger species it is driven by a combination of environmental factors and intrinsic traits”

Cardillo *et al.* 2005. Multiple Causes of High Extinction Risk in Large Mammal Species *Science* 309: 1239-1241

Jones *et al.* in press.

Collaborators



- Sarah Durant
- Tom Maddox
- Nathalie Pettorelli
- David Macdonald
- John Gittleman
- Georgina Mace
- Marcus Rowcliffe
- Walter Jetz
- Jim Brown

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