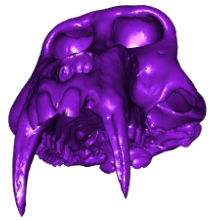
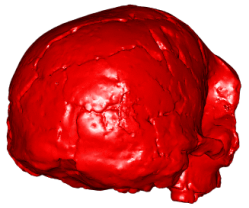
Oxford Palaeoclub – 26 Jan 2021

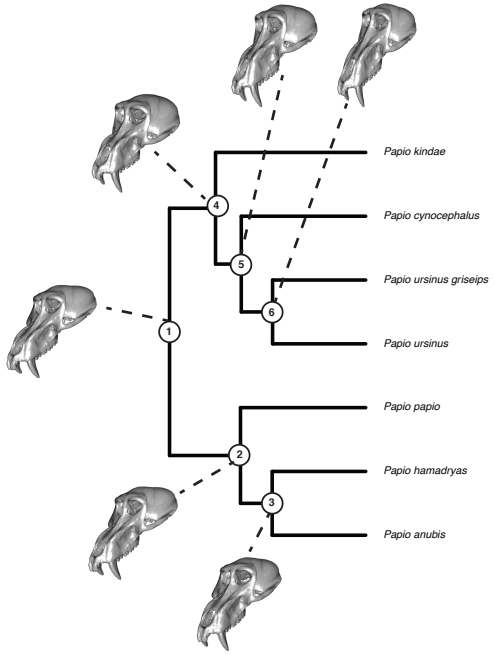
Primate Evolutionary Ecomorphology

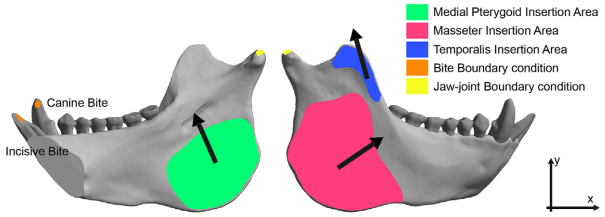
Combining GM + Biomechanics + PCMs

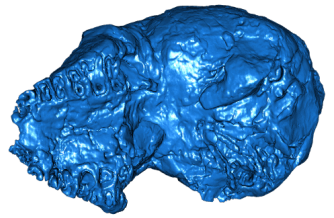
Dr. Thomas A. Püschel











Paleo Primate Project Gorongosa

Primate Models for Behavioural Evolution LAB

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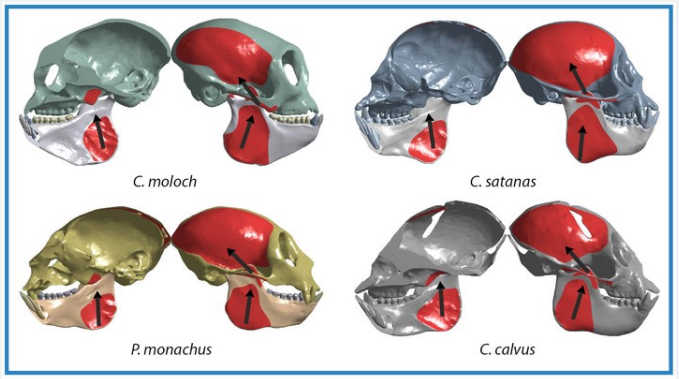
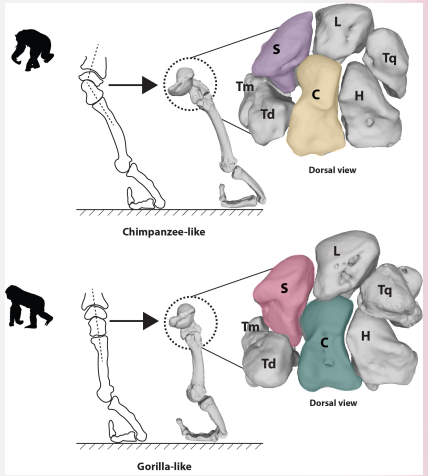
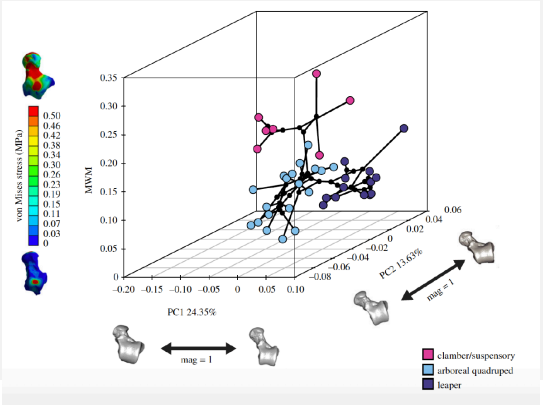
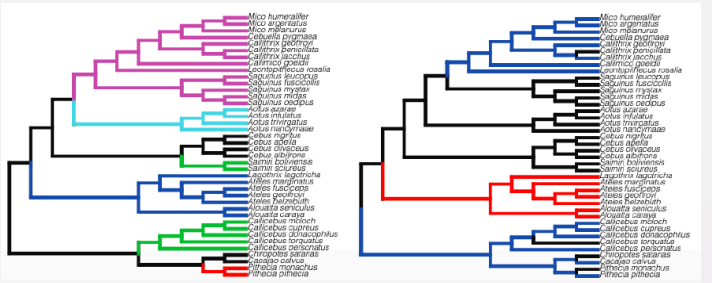
Outline

1. Brief definitions
2. Description of the applied methods
3. Examples









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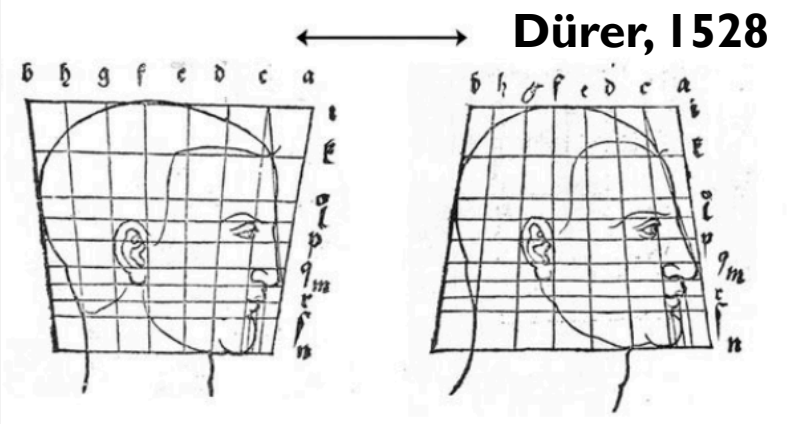
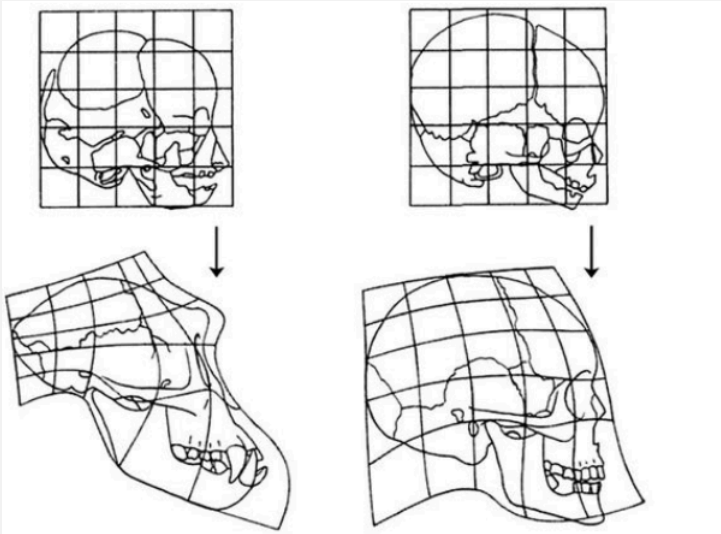
Why is it important?



Dürer, 1528



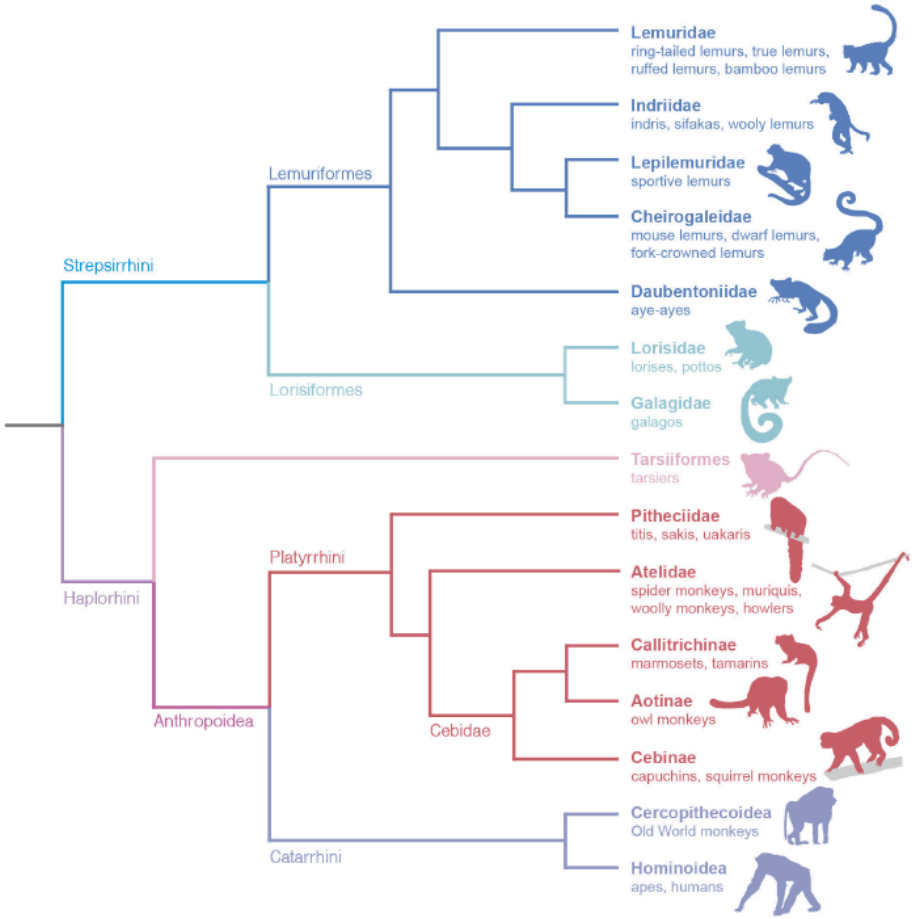
Thompson, 1917

Galileo, 1638.

Primates

- Extant primates are quite diverse, with more than ~ 600 species recognised by the IUCN https://www.iucn.org/ ranging in size from minuscule mouse lemurs (30 g) to large gorilla silverbacks (200,000 g).

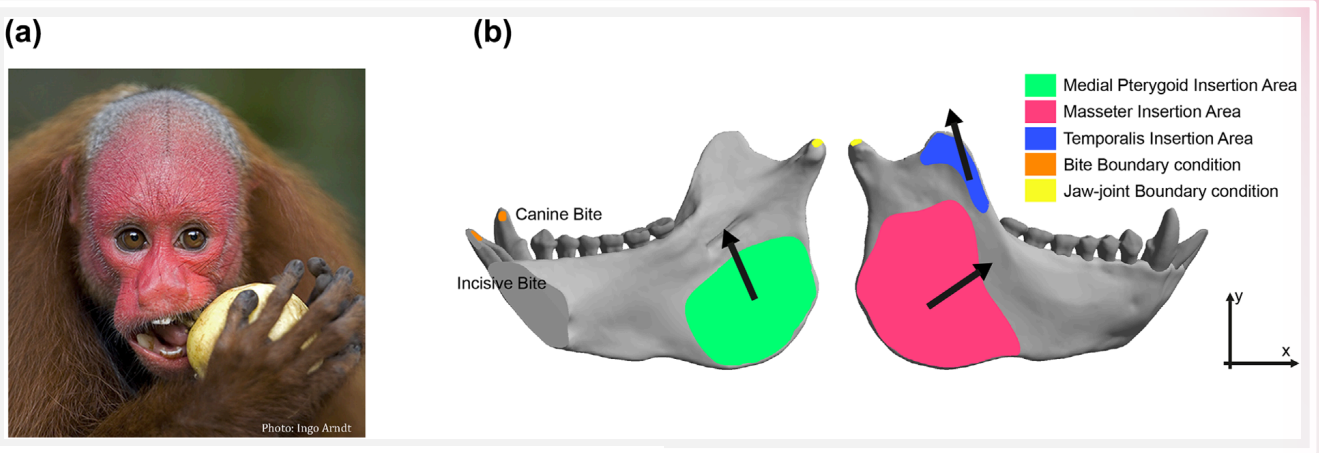
- Most examples in this presentation are focused on platyrrhines or New World Monkeys (NWM).

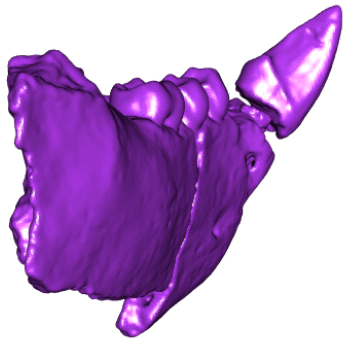


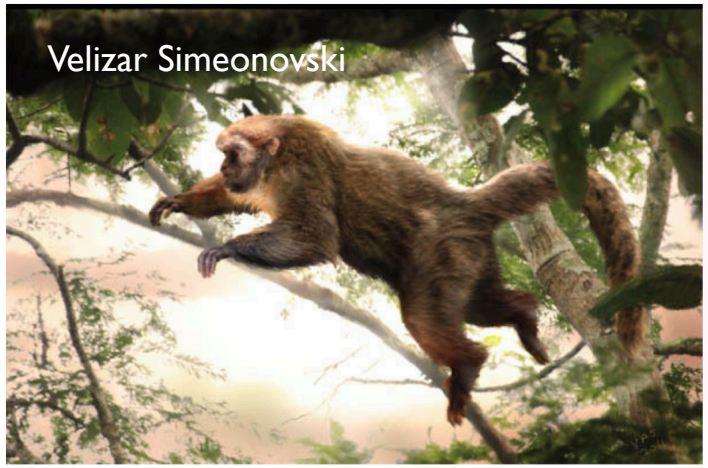
Püschel, T. A. (2017). Morpho-functional analyses of the primate skeleton: applying 3D geometric morphometrics, finite element analysis and phylogenetic comparative methods to assess ecomorphological questions in extant and extinct anthropoids.

Ecomorphology

- **Ecomorphology** or **ecological morphology** can be defined as the characterisation of the adaptive relationship between the morphology of an organism and its ecological role.



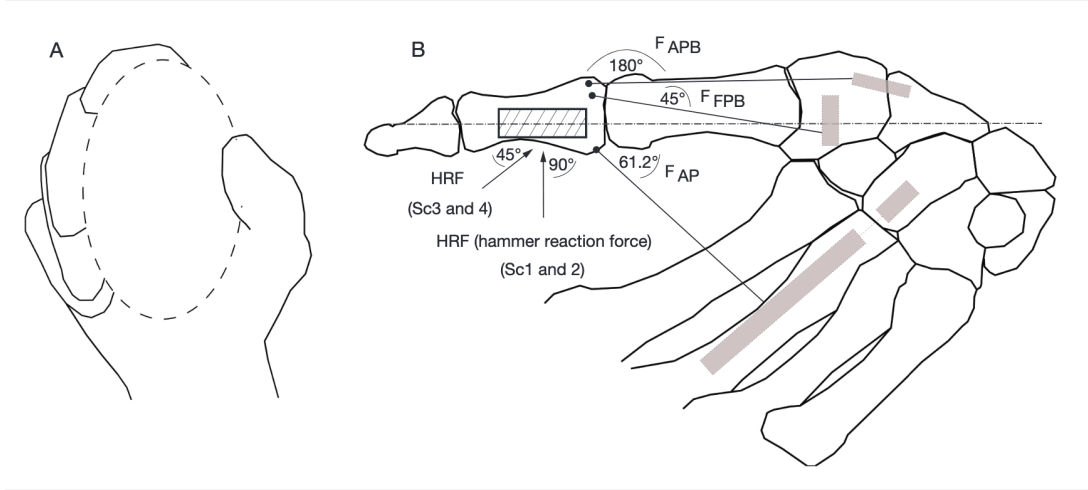


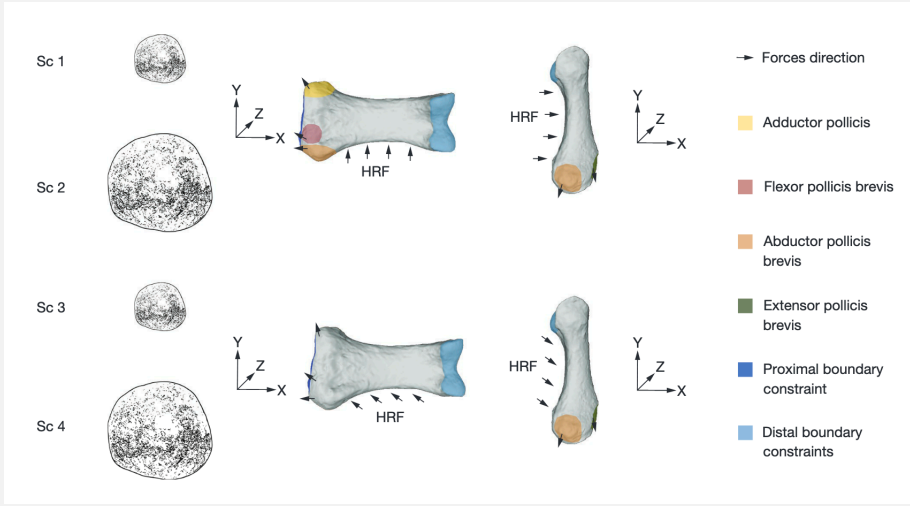


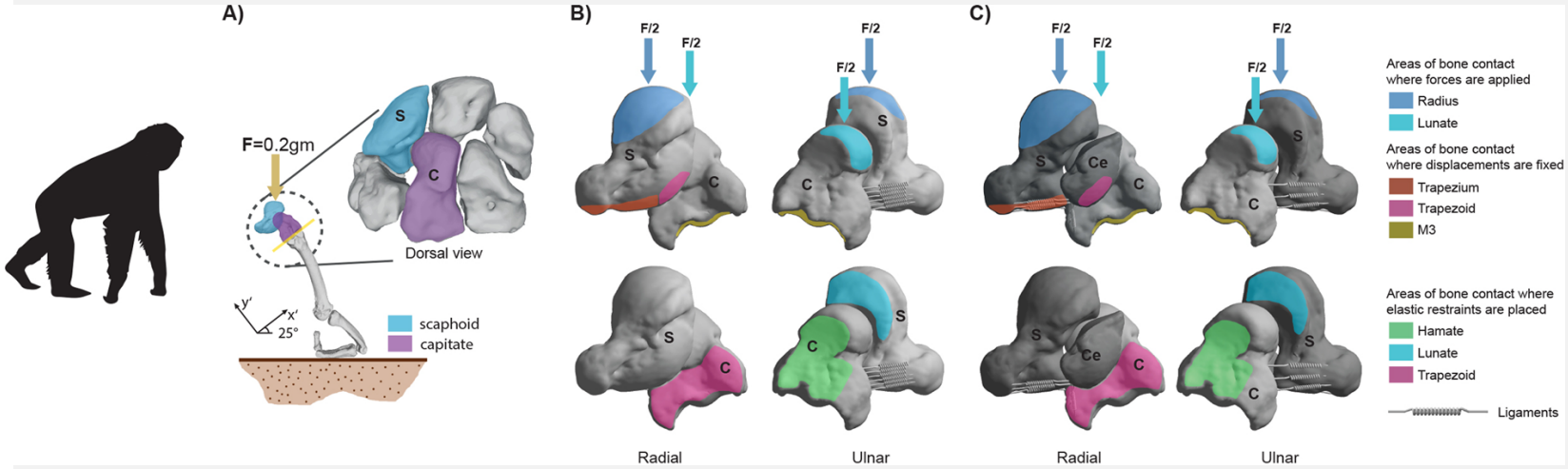
Cebupithecia sarmientoi

Püschel, T. A., Marcé-Nogué, J., Kaiser, T. M., Brocklehurst, R. J., and Sellers, W. I. (2018). Analyzing the sclerocarpy adaptations of the Pitheciidae mandible. *American Journal of Primatology* 80, e22759. doi:10.1002/ajp.22759.

Biomechanics





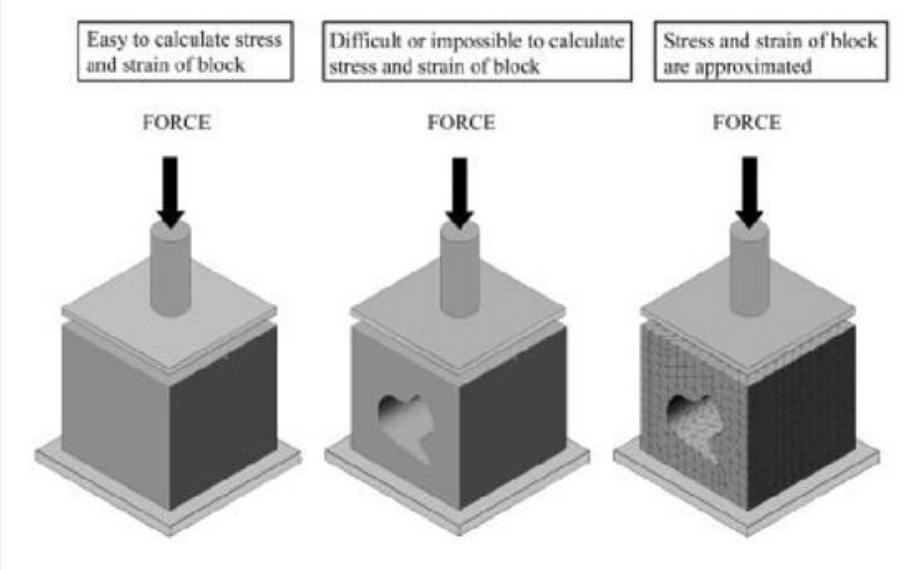


Bucchi, A., Püschel, T. A., Lorenzo, C., and Marcé-Nogué, J. (2020). Finite element analysis of the proximal phalanx of the thumb in Hominoidea during simulated stone tool use. Comptes Rendus Palevol 19, 26–39.

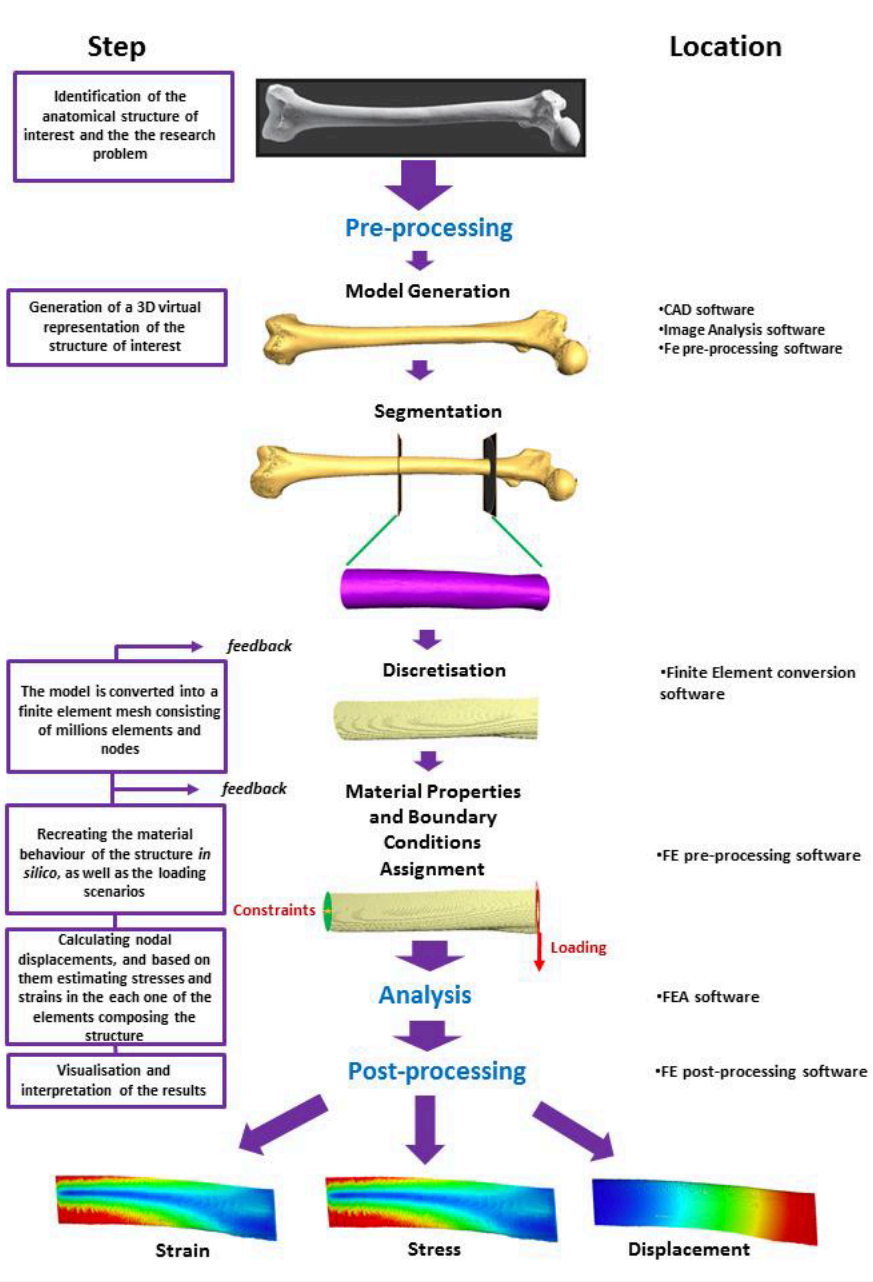
Püschel, T. A., Marcé-Nogué, J., Chamberlain, A. T., Yoxall, A., & Sellers, W. I. (2020). The biomechanical importance of the scaphoid-centrale fusion during simulated knuckle-walking and its implications for human locomotor evolution. *Scientific Reports*, *10*(1), 1–7. https://doi.org/10.1038/s41598-020-60590-6

Finite Element Analysis

Finite Element Analysis (FEA) is a general modelling technique that can be used for structural, thermal, fluid, and acoustic analyses, amongst others.



Richmond, B. G., Wright, B. W., Grosse, I., Dechow, P. C., Ross, C. F., Spencer, M. A., et al. (2005). Finite element analysis in functional morphology. *The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology* 283A, 259–274. doi:10.1002/ar.a.20169.

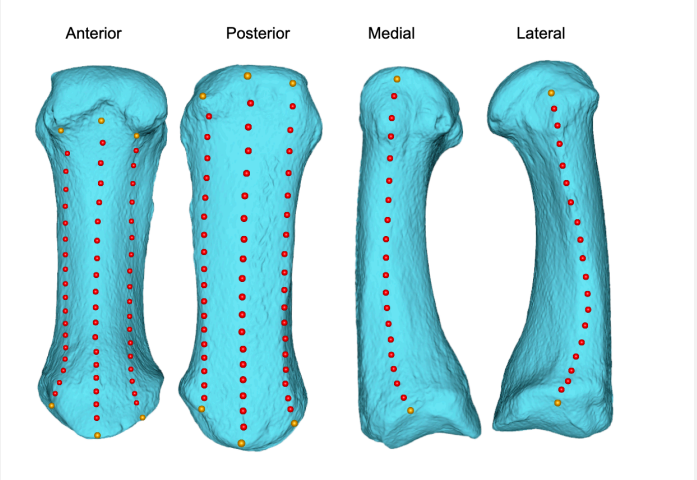


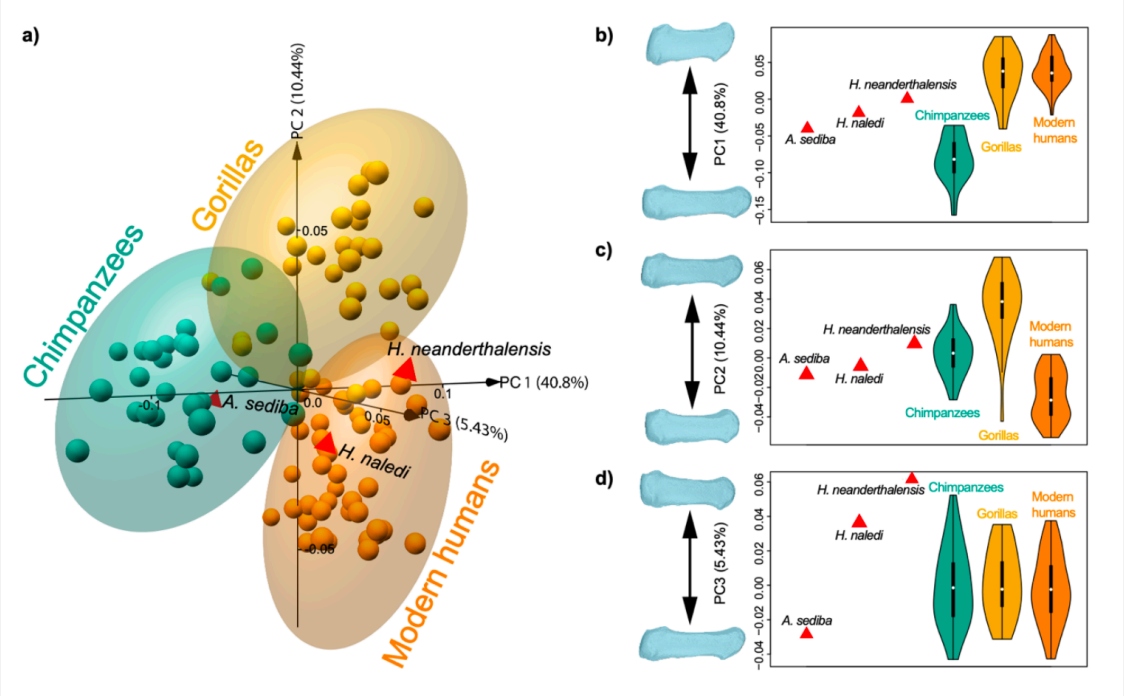
Püschel, T. A. (2012). Biomechanical modelling of Human Femora: a comparison between Agriculturalists and Hunter-Gatherers using FEA, GMM and Beam Theory.

Shape

- **Geometric morphometrics (GM)** comprise a set of techniques for the analysis of form (i.e. shape and size) that utilise as primary data Cartesian coordinates rather than linear distances, angles, ratios or other measurements.

- GM has become the standard tool to quantify morphology in organismal biology.



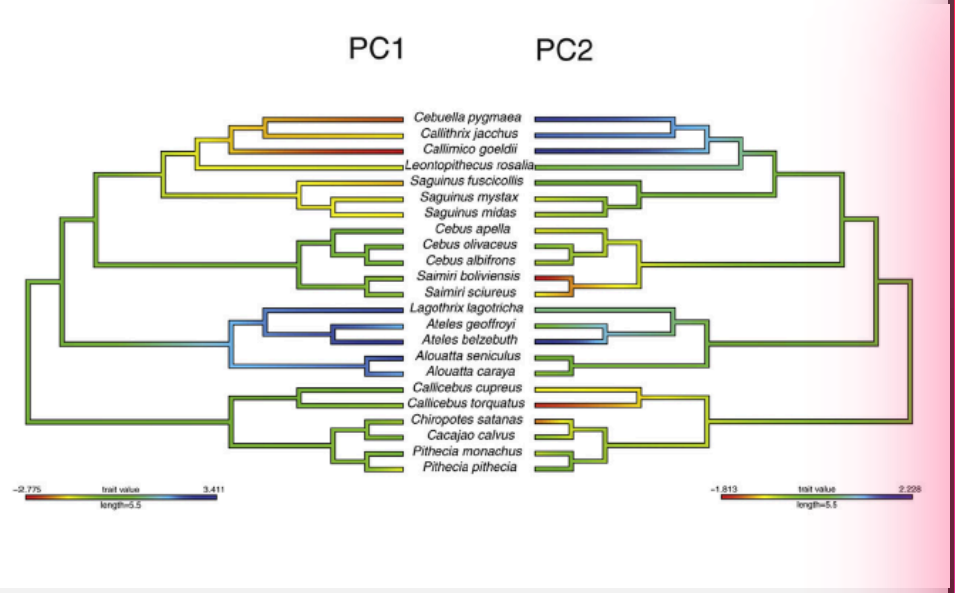


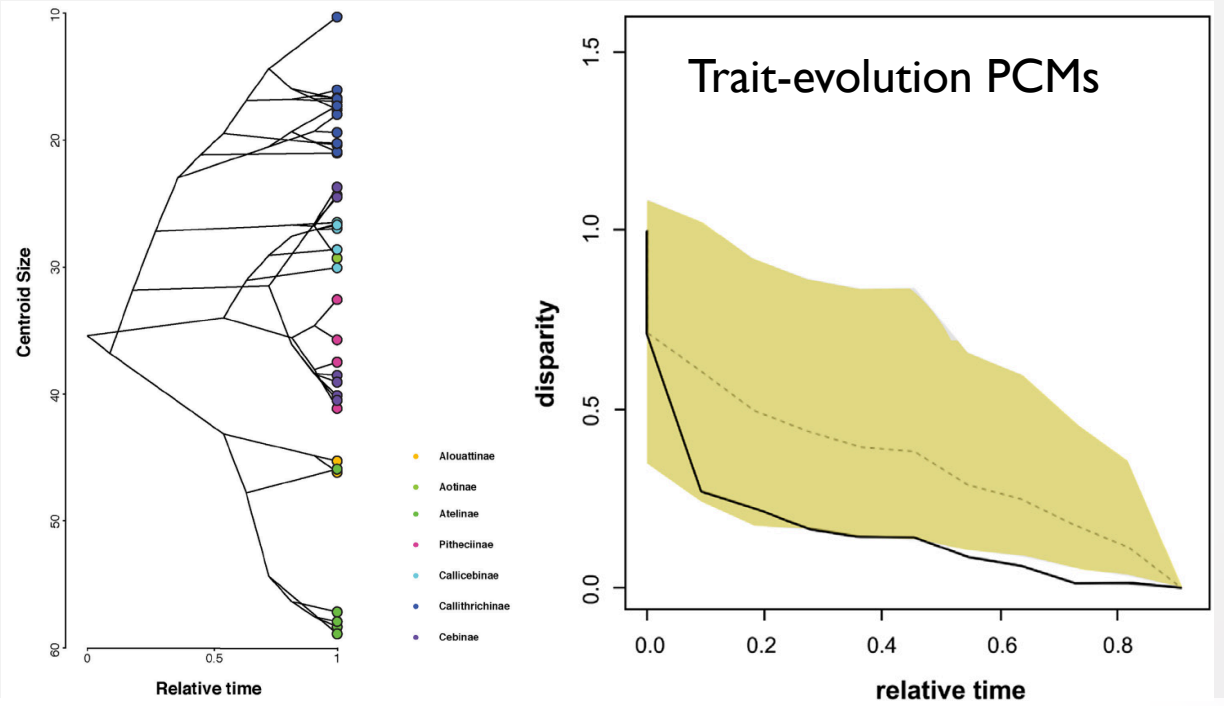
Morley, J., Bucchi, A., Lorenzo, C., and Püschel, T. A. (2020). Characterizing the body morphology of the first metacarpal in the Hominidae using 3D geometric morphometrics. *bioRxiv*, 2020.04.30.070326. doi:10.1101/2020.04.30.070326.

Phylogenetic comparative methods (PCMs)

- Modern **phylogenetic comparative methods** (PCMs) area series of statistical procedures applied to analyse phylogenetic trees, and frequently, their association with trait/phenotypic data.

- Currently there are two main sub-families of methods within the PCMs, which can be broadly classified as those focused on **trait evolution** and those used to investigate **lineage diversification**.

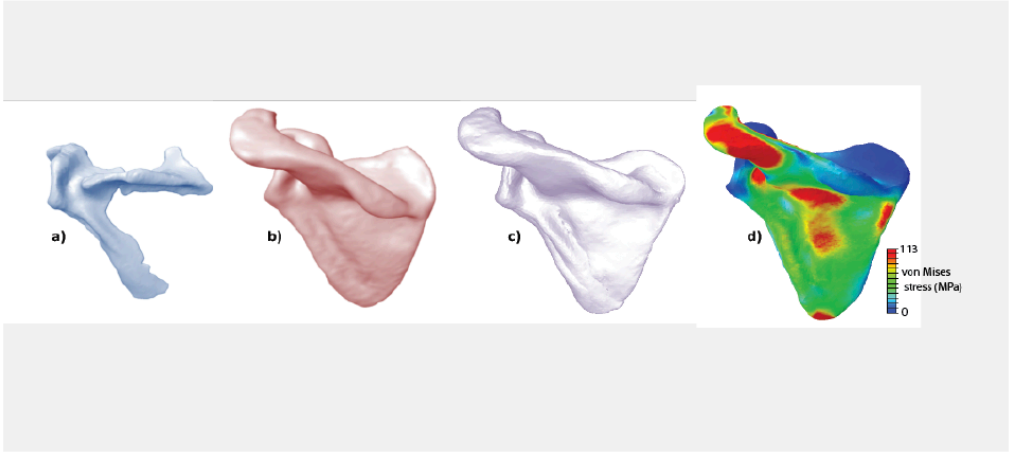


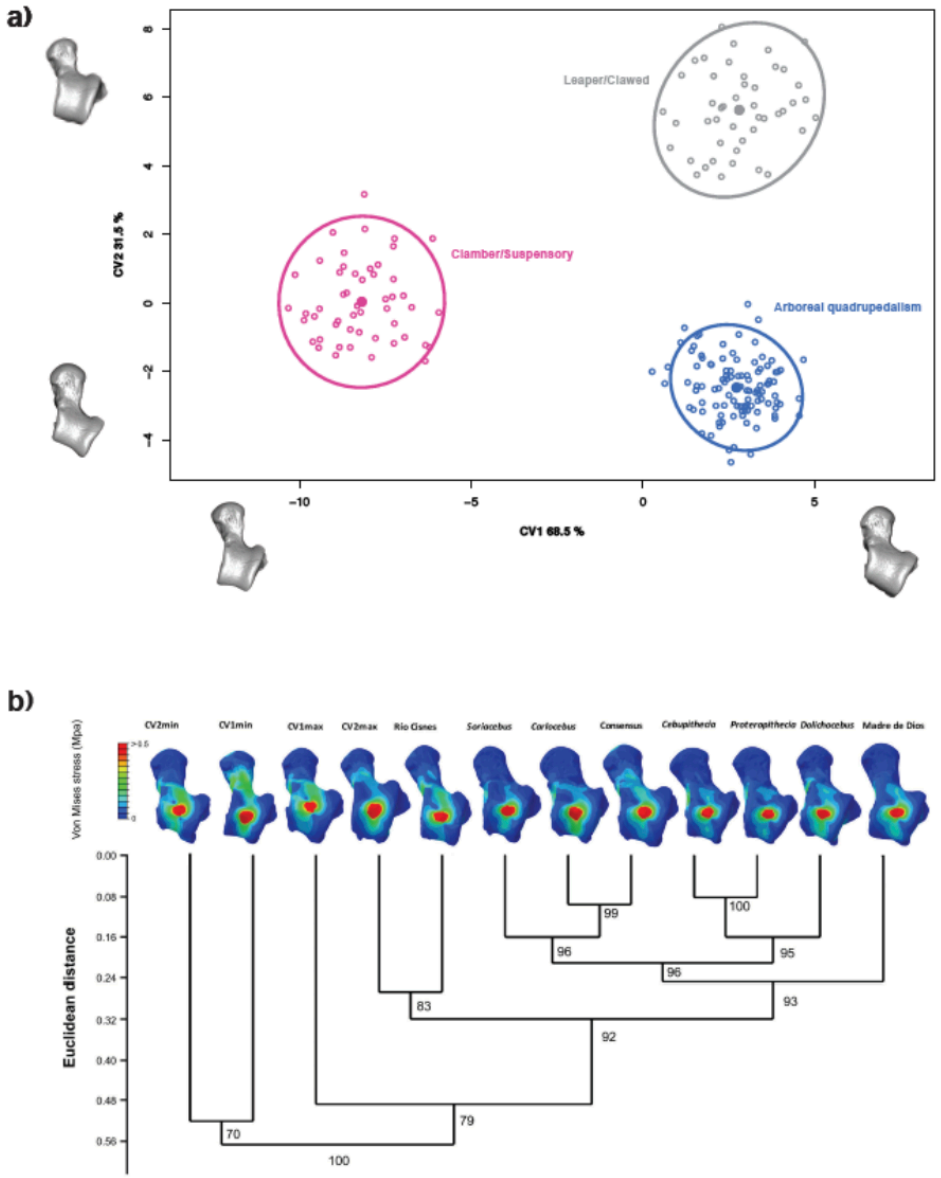


Püschel, T. A., Gladman, J. T., Bobe, R. & Sellers, W. I. The evolution of the platyrrhine talus: A comparative analysis of the phenetic affinities of the Miocene platyrrhines with their modern relatives. *Journal of Human Evolution* **111**, 179–201 (2017).

Approaches combining FEA and GM

1. GM as data generation/manipulation tool for FEA





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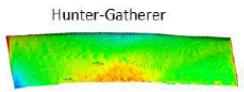
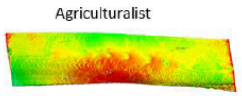
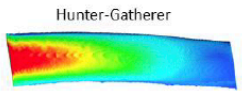
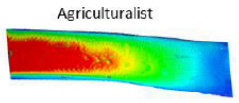
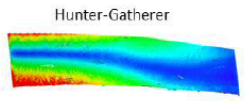
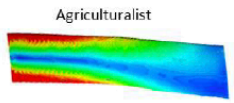
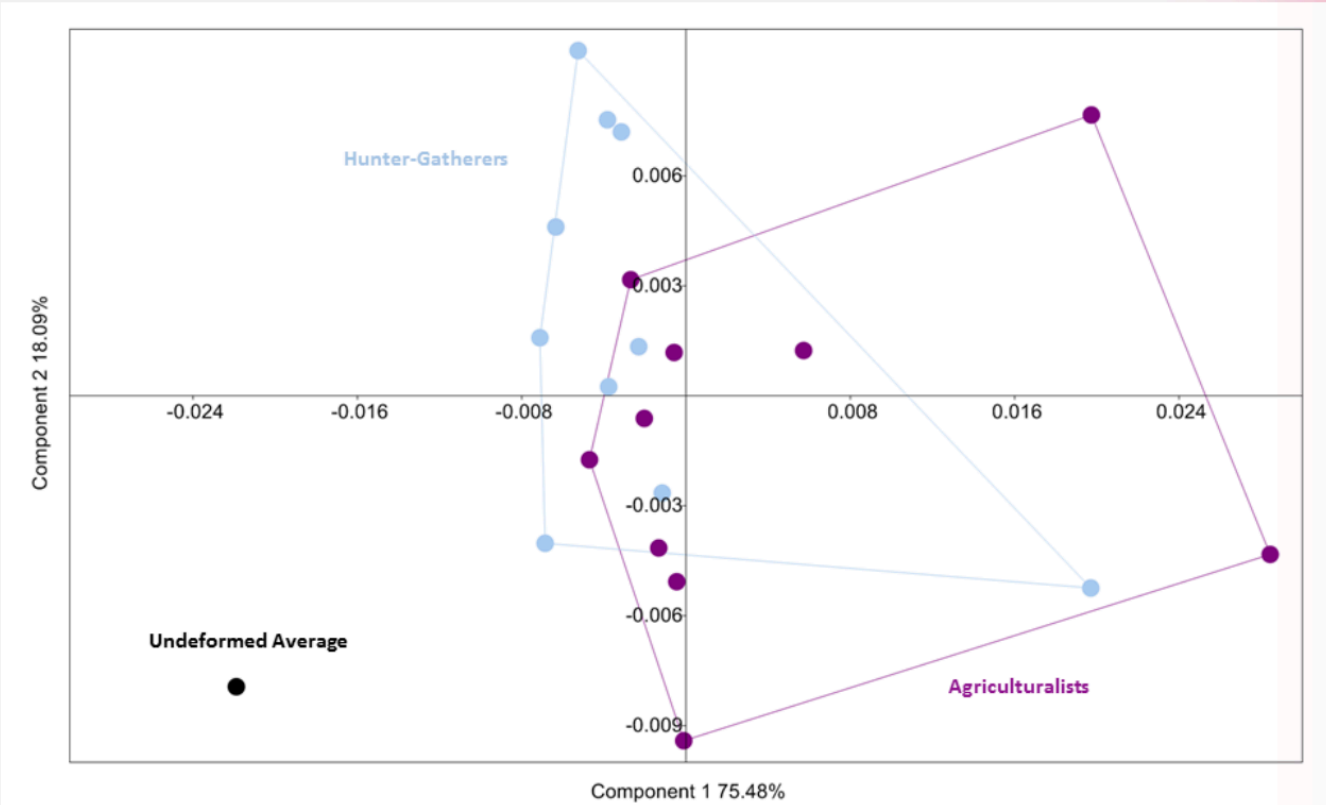
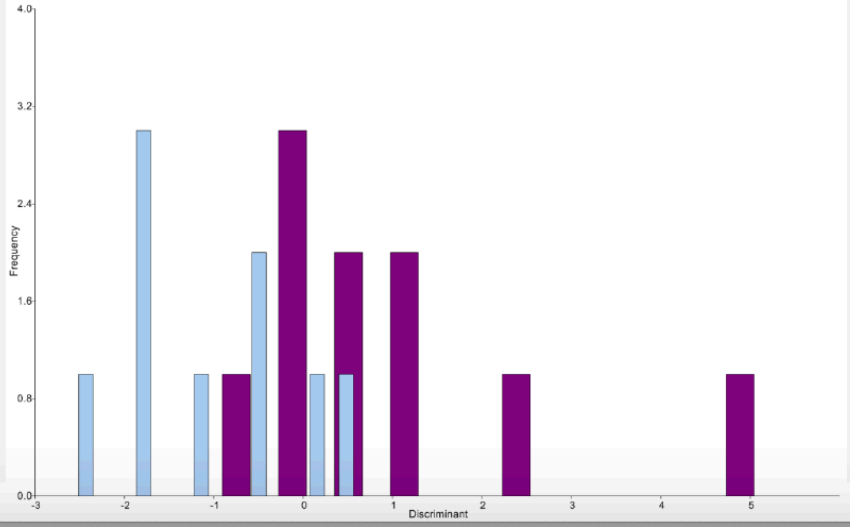
Approaches combining FEA and GM

2. GM as a tool to analyse deformations after FEA analysis

Compression	Medial Bending	Posterior Bending
Hunter-Gatherer  Agriculturalist 	Hunter-Gatherer  Agriculturalist 	Hunter-Gatherer  Agriculturalist 





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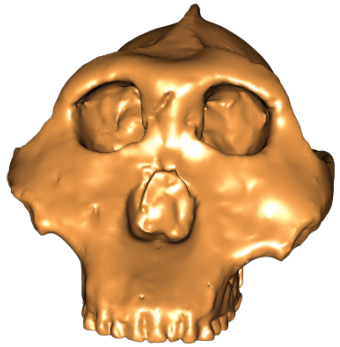
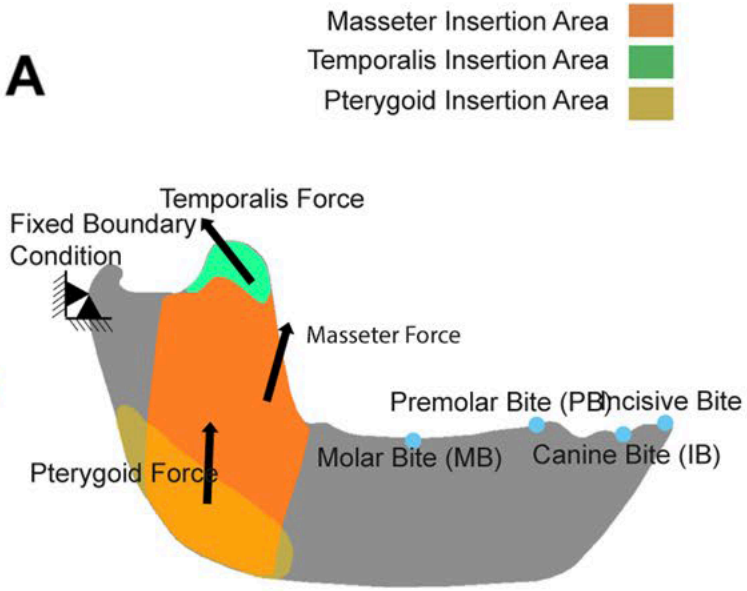
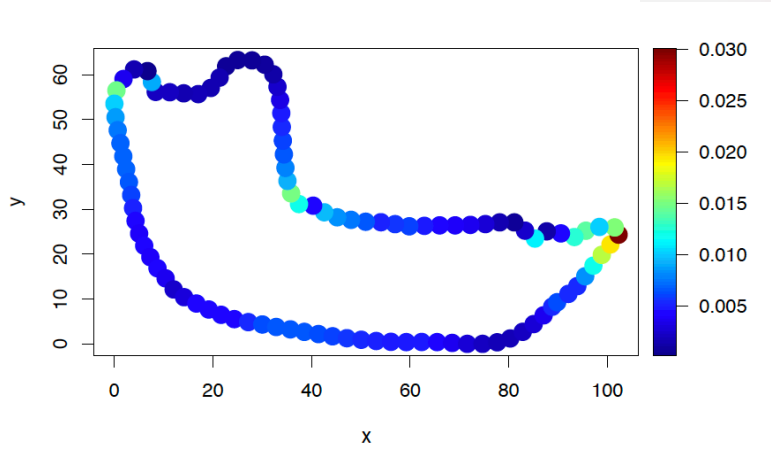
Approaches combining FEA and GM

3. GM and FEA combined by analysing their results using multivariate statistical tools



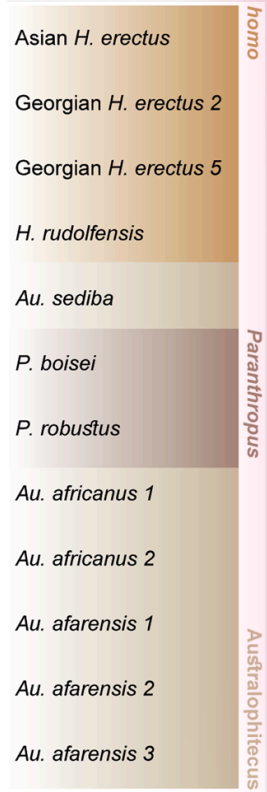


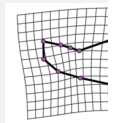


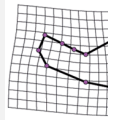
Marcé-Nogué, J., Püschel, T. A., Daasch, A., & Kaiser, T. M. (2020). Broad-scale morpho-functional traits of the mandible suggest no hard food adaptation in the hominin lineage. Scientific Reports, 10(1), 1–11. https://doi.org/10.1038/s41598-020-63739-5

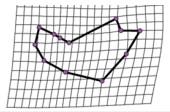
Approaches combining FEA and GM

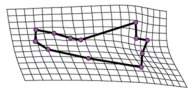
Species/Specimen	Biomechanical data		Morphometric data	
	Posterior probabilities		Posterior probabilities	
	Hard-food eater	Soft-food eater	Hard-food eater	Soft-food eater
Au. afarensis	0.324	0.68	0.17	0.83
Au. africanus	0.32	0.68	0.11	0.89
Au. sediba	0.25	0.75	0.17	0.83
Asian *H. erectus*	0.35	0.65	0.57	0.43
Georgian *H. erectus*	0.41	0.59	0.12	0.88
H. rudolfensis	0.26	0.74	0.14	0.86
P. boisei	0.09	0.91	0.17	0.83
P. robustus	0.42	0.58	0.27	0.73

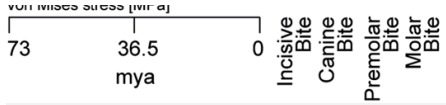












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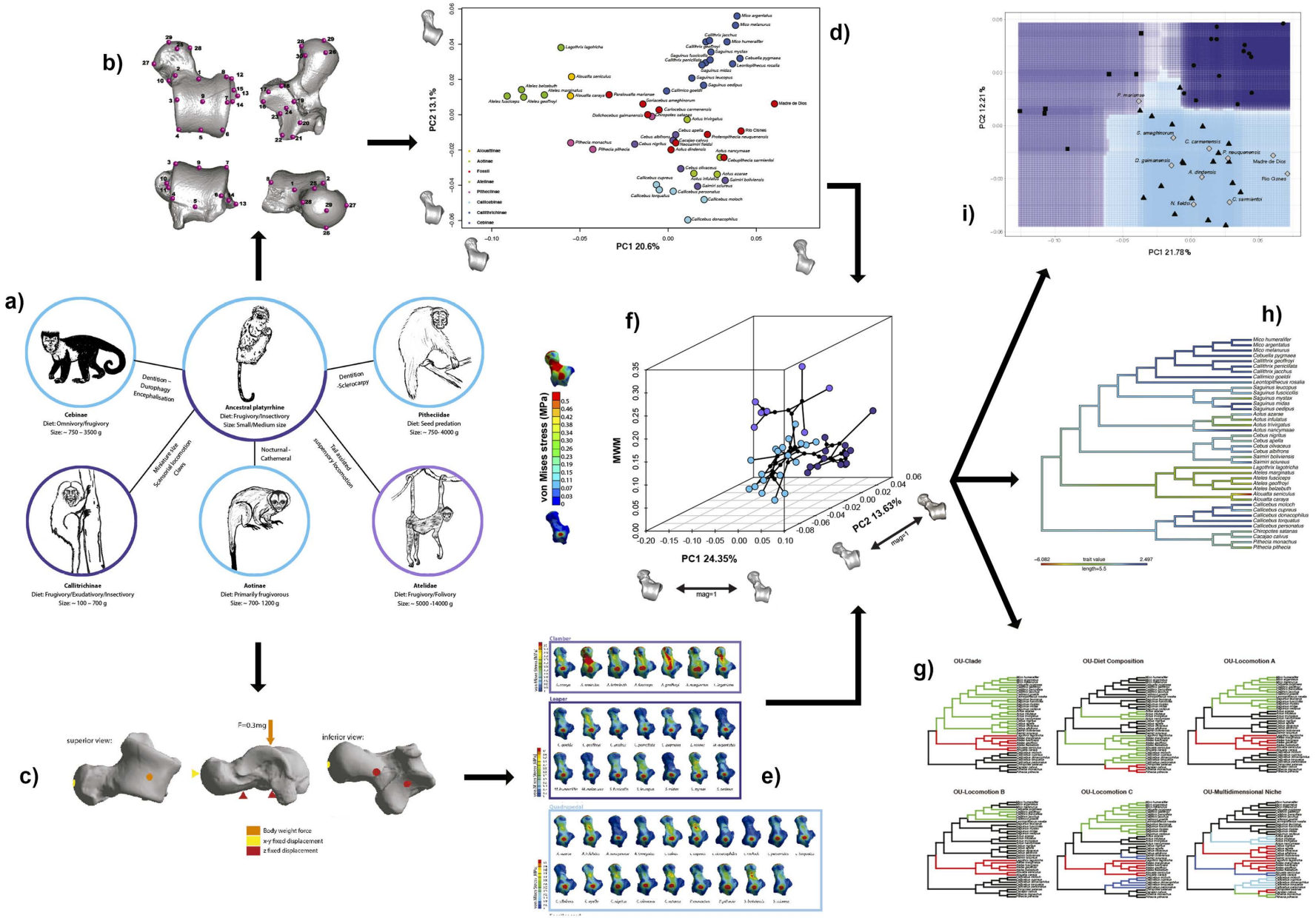
A possible workflow



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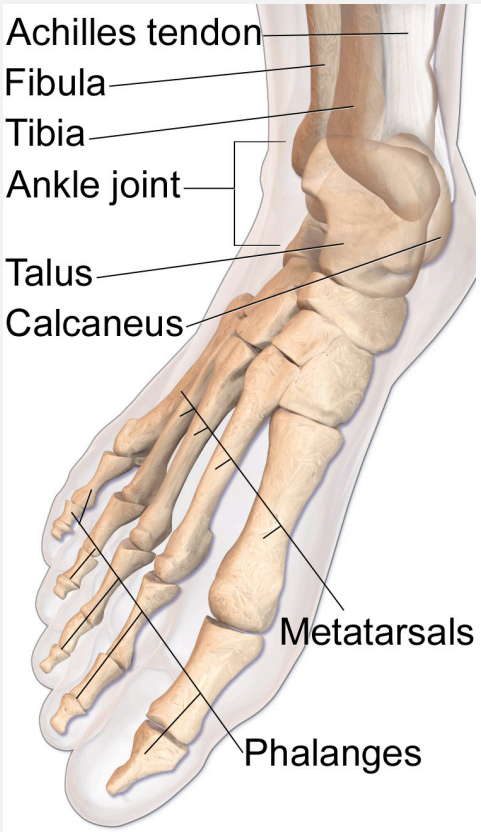
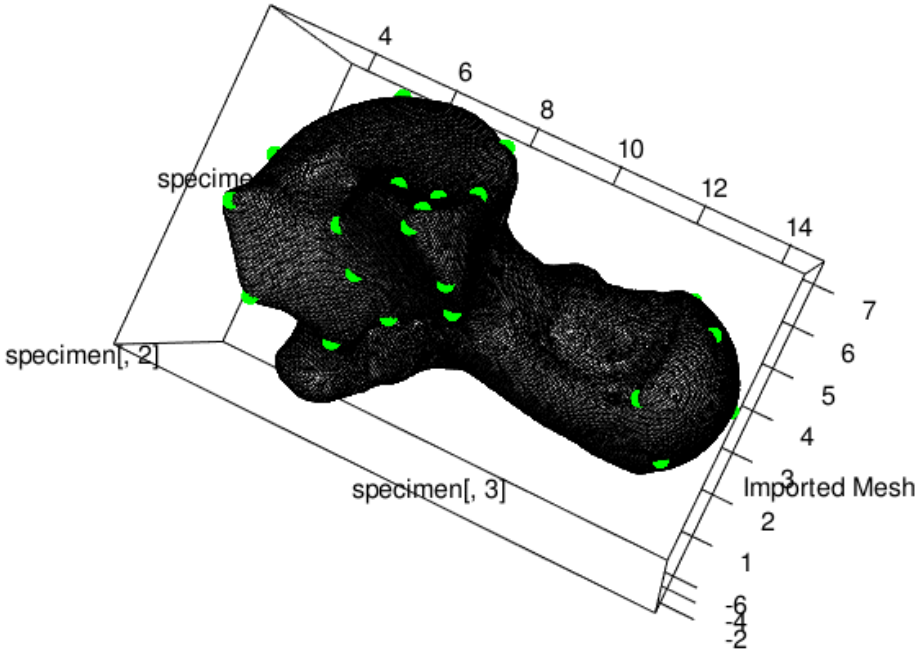
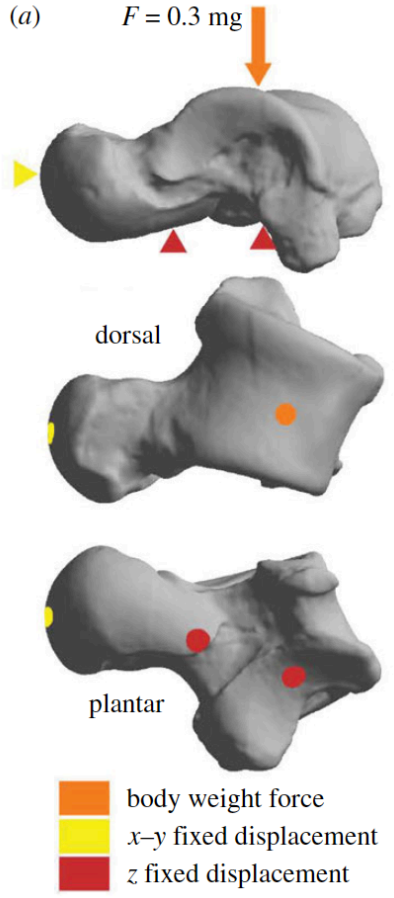
Example: the platyrrhine talus



Lower Leg and Foot





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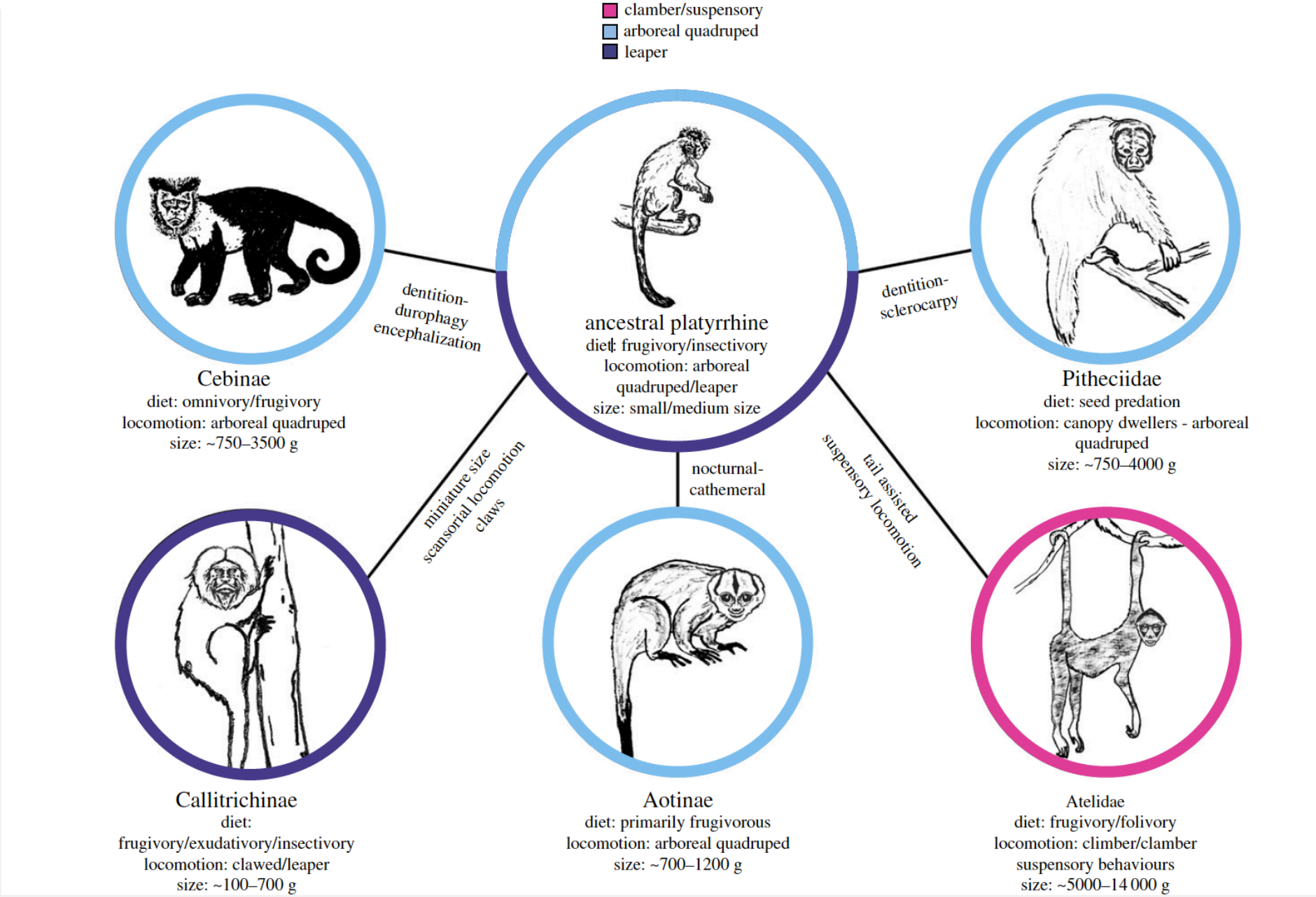

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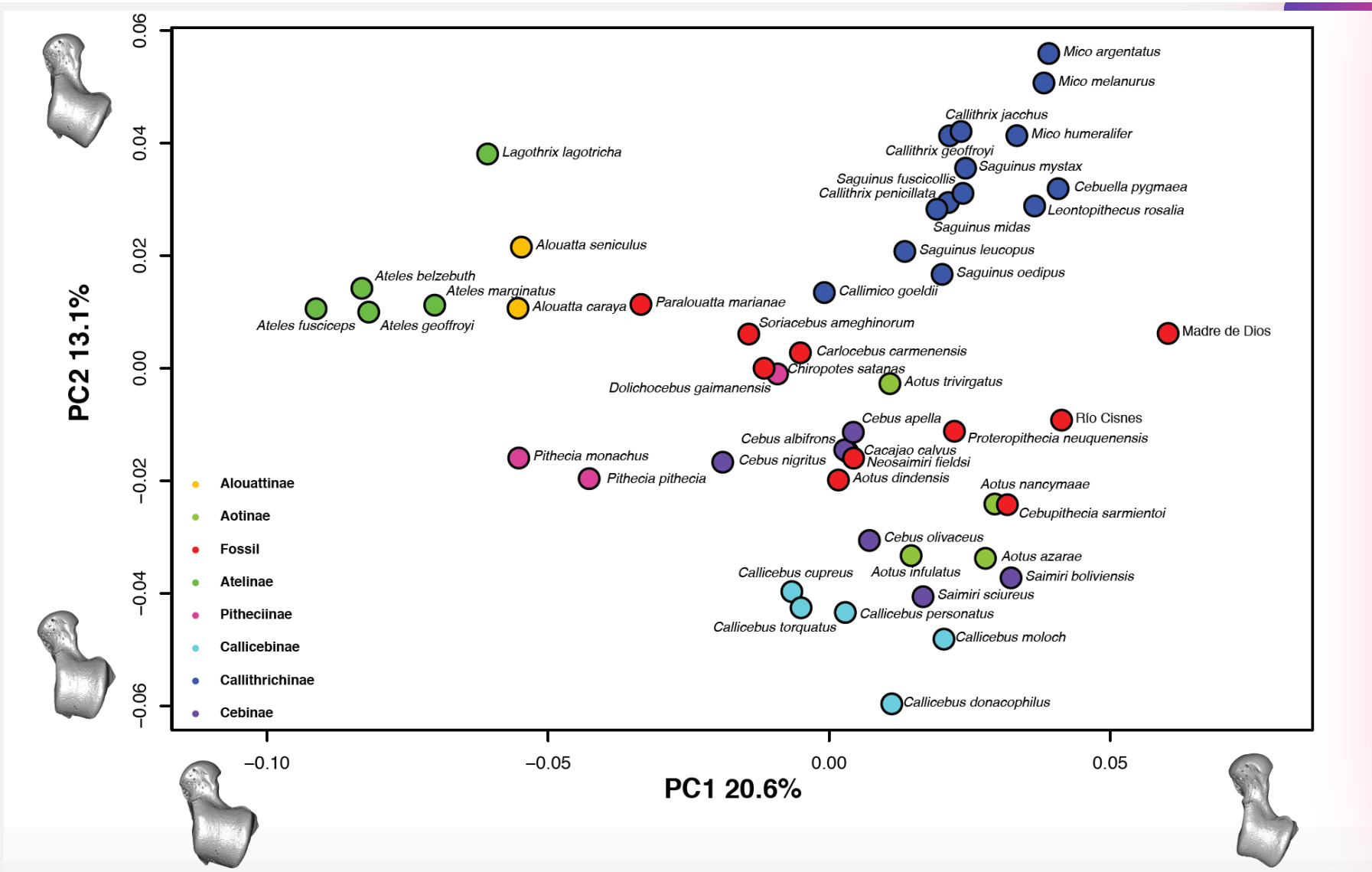
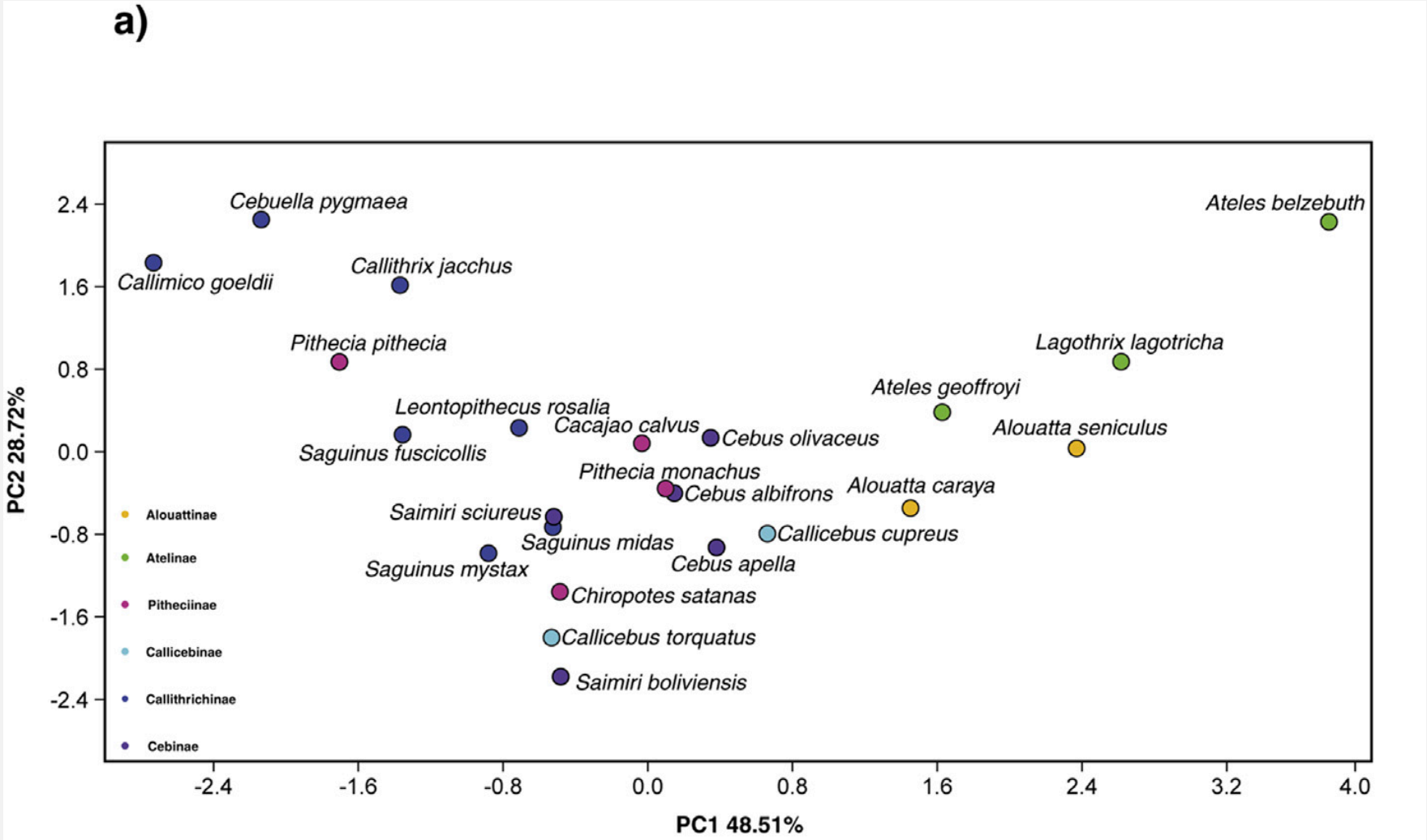
PCA: Shape



Püschel, T. A., Gladman, J. T., Bobe, R. & Sellers, W. I. The evolution of the platyrrhine talus: A comparative analysis of the phenetic affinities of the Miocene platyrrhines with their modern relatives. *Journal of Human Evolution* **111**, 179–201 (2017).

PCA: Locomotor data



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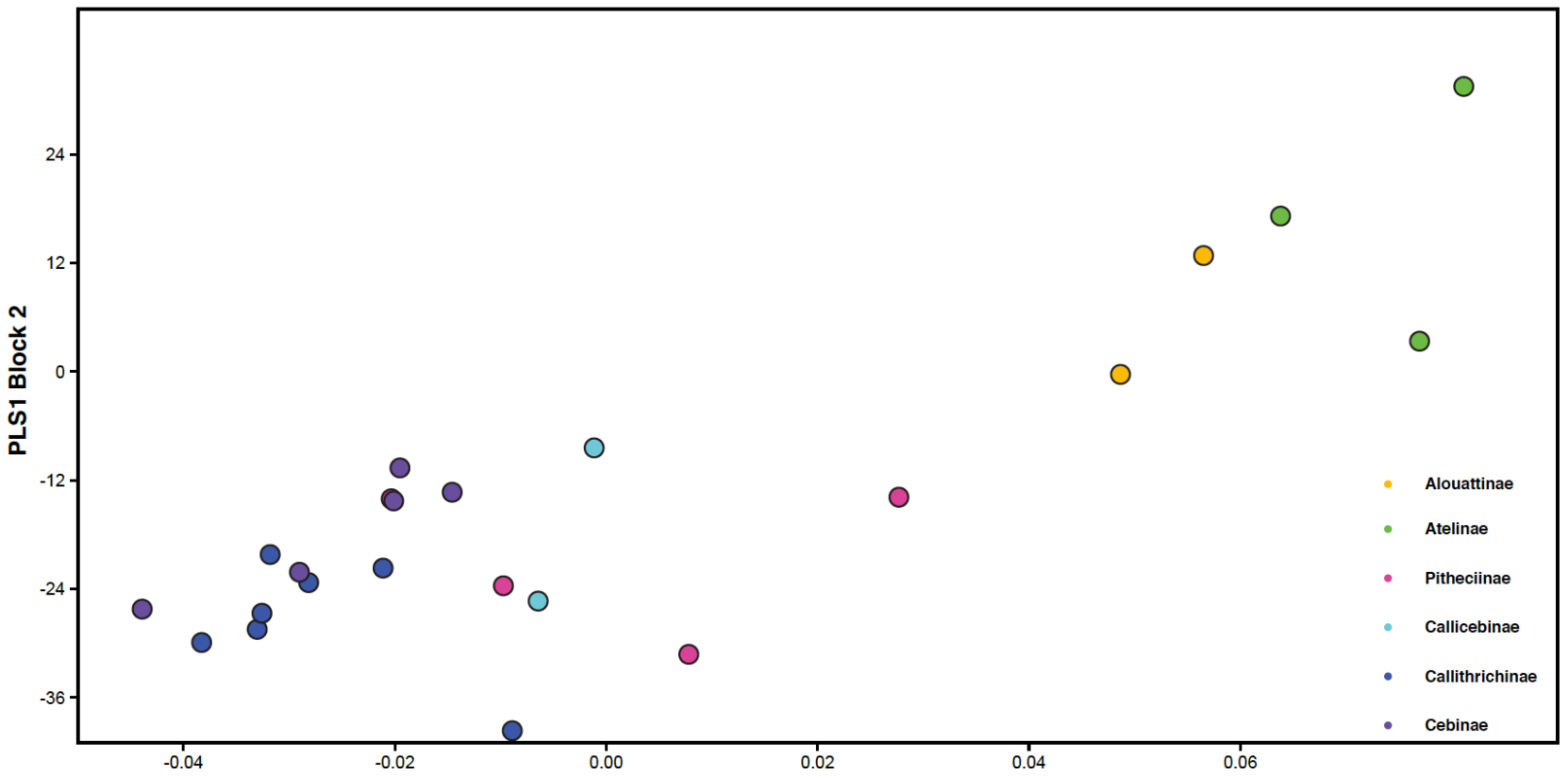
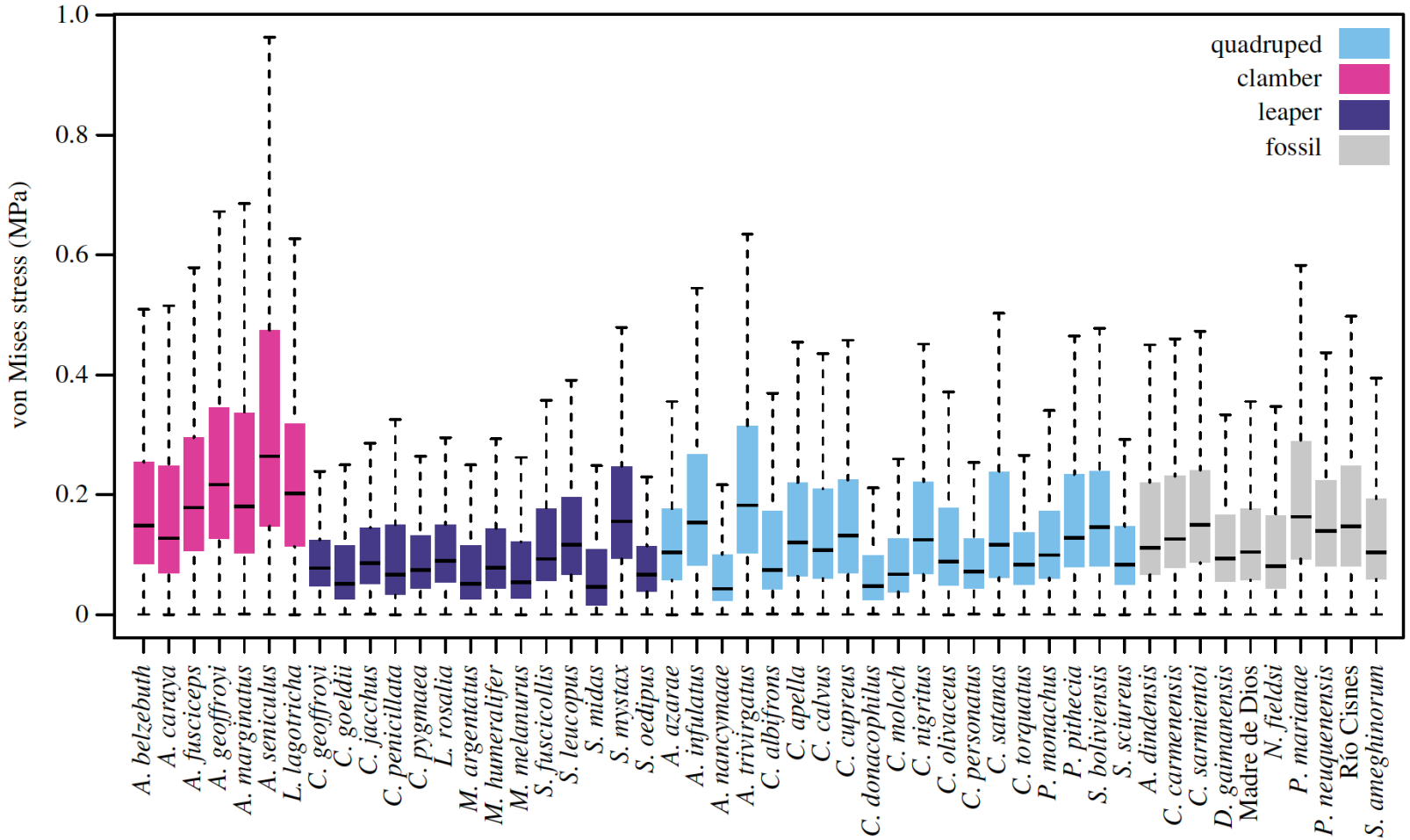
PLS: shape and locomotor data



r-PLS: 0.84; p-value: 0.0022; 10,000 permutations

Püschel, T. A., Gladman, J. T., Bobe, R. & Sellers, W. I. The evolution of the platyrrhine talus: A comparative analysis of the phenetic affinities of the Miocene platyrrhines with their modern relatives. *Journal of Human Evolution* **111**, 179–201 (2017).

Stress data



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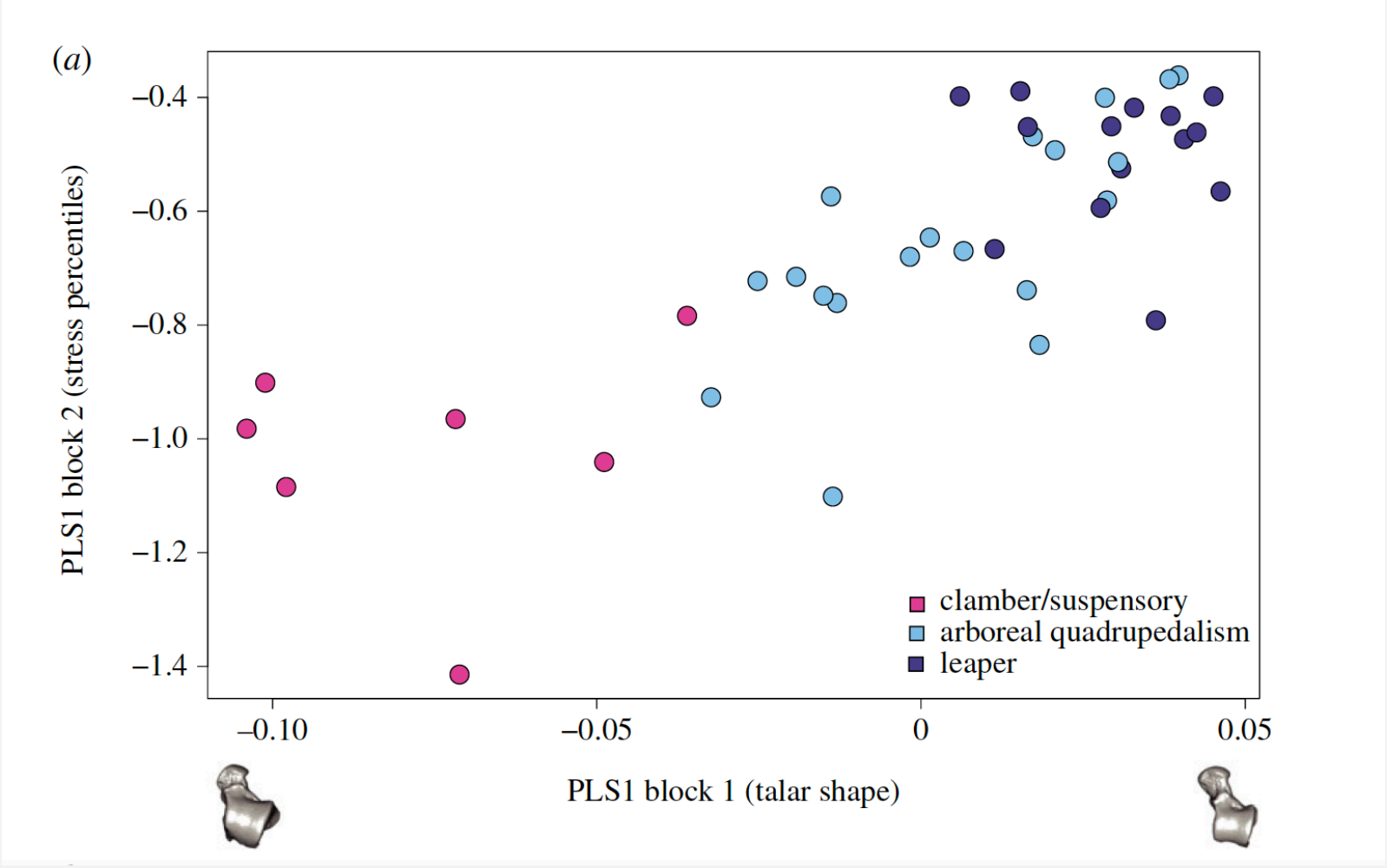
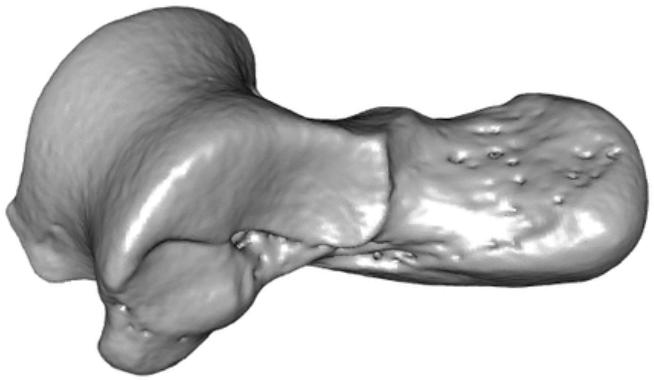
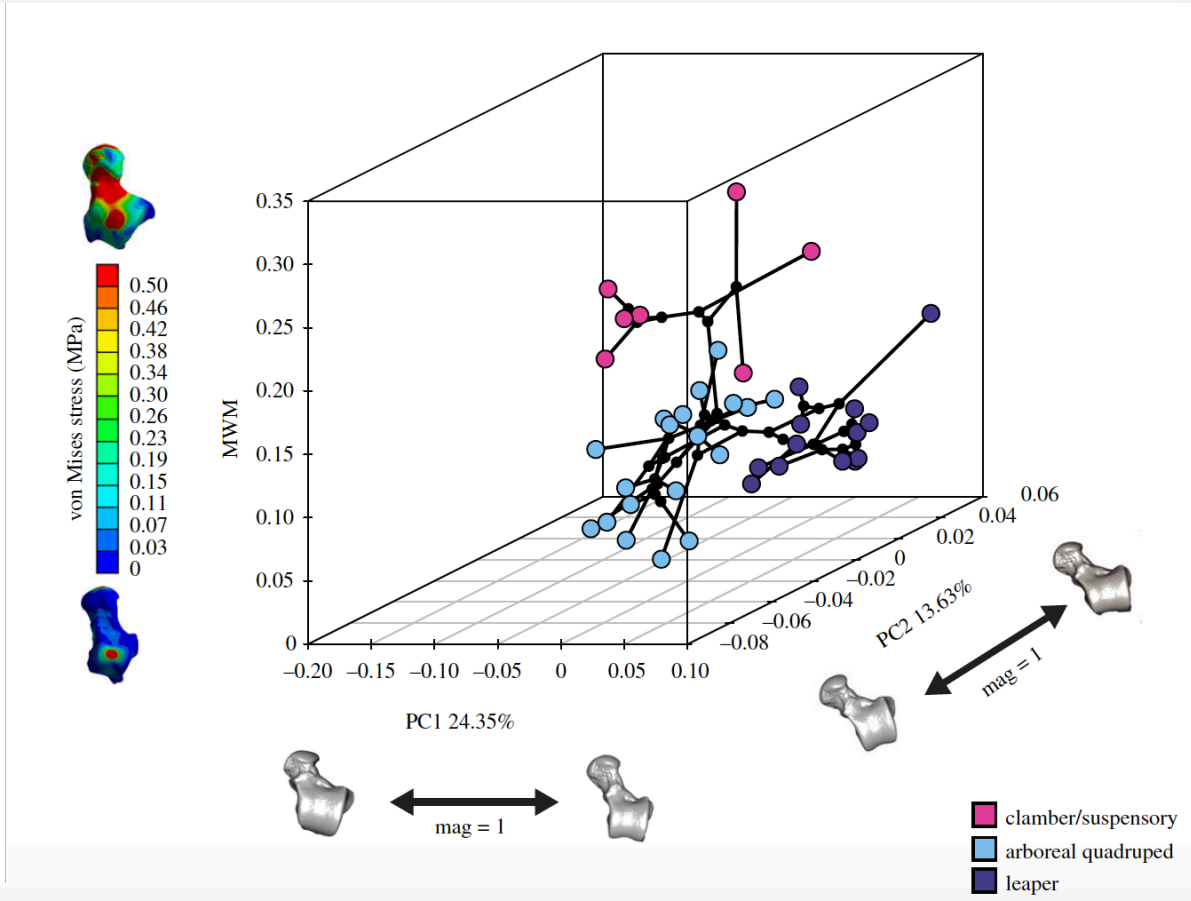
PLS: shape and stress data



r-PLS: 0.8; p-value: 0.0002; 10,000 permutations

Püschel, T. A., Marcé-Nogué, J., Gladman, J. T., Bobe, R. & Sellers, W. I. Inferring locomotor behaviours in Miocene New World monkeys using finite element analysis, geometric morphometrics and machine-learning classification techniques applied to talar morphology. *Journal of The Royal Society Interface* **15**, 20180520 (2018).





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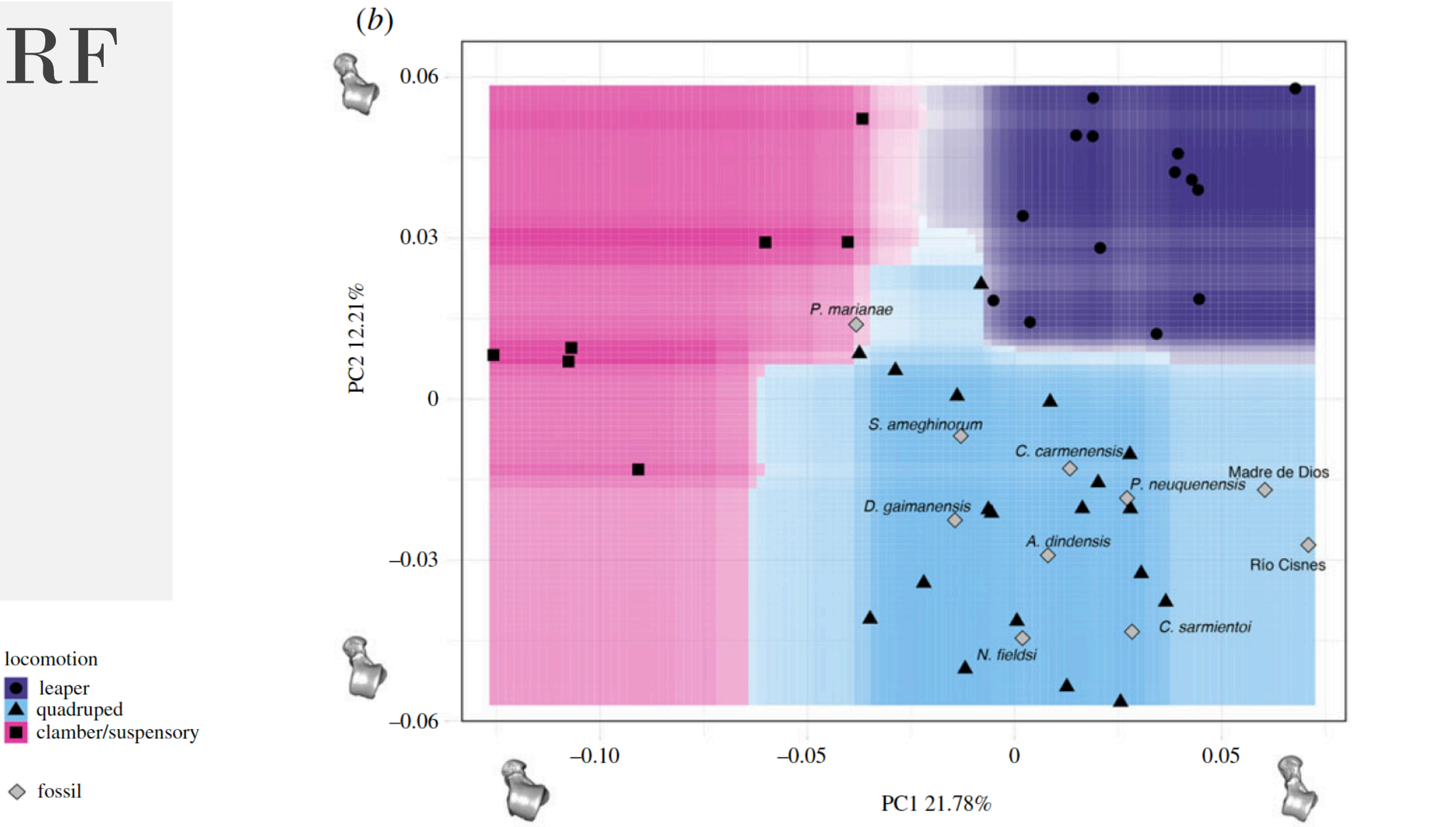
RF



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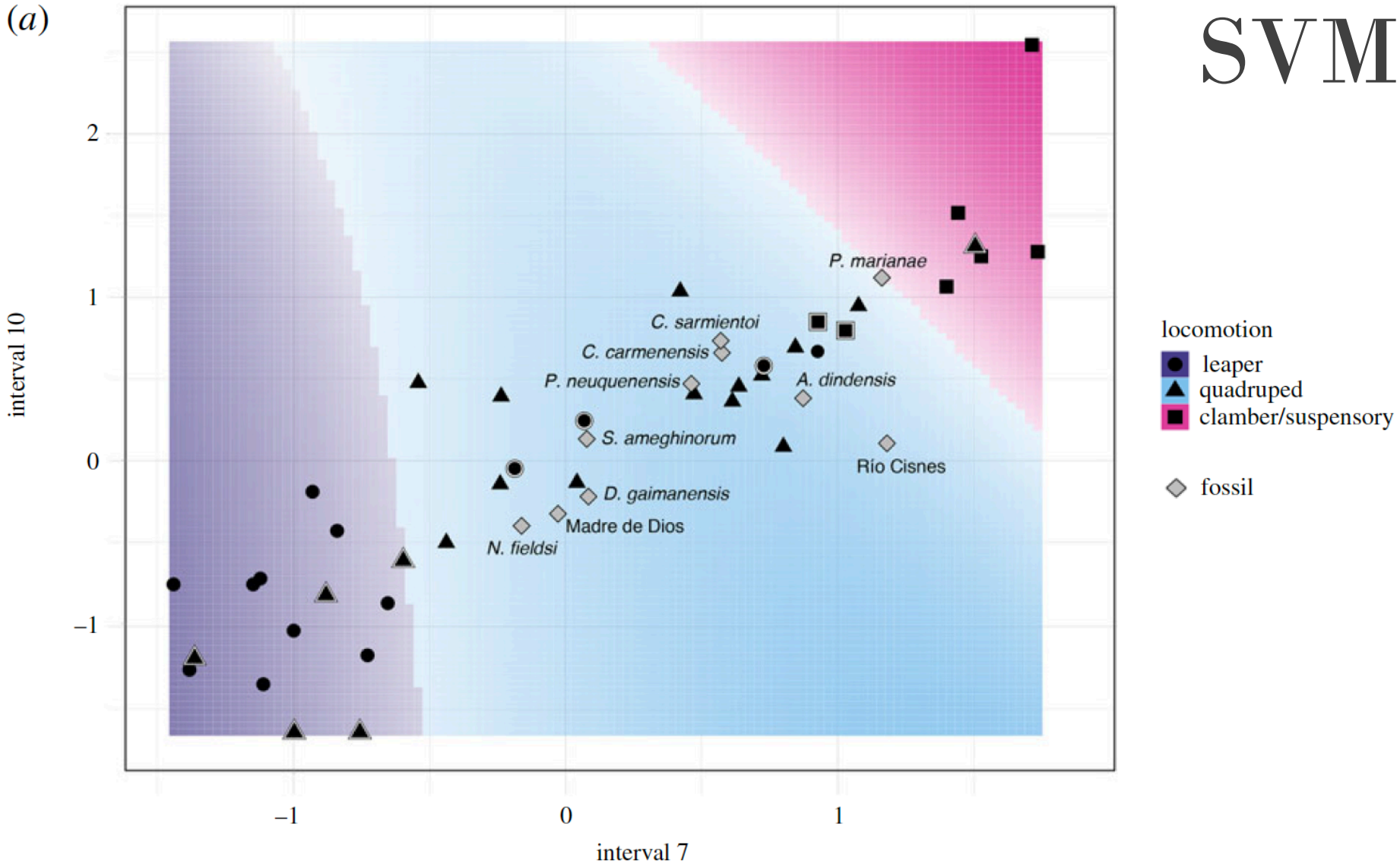
SVM



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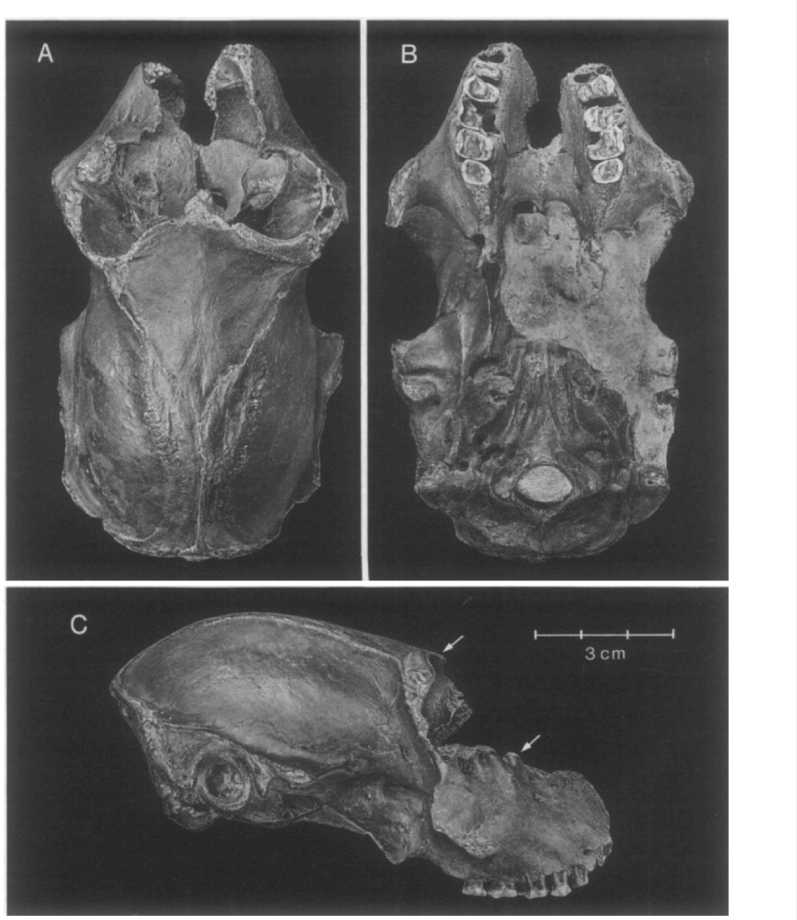
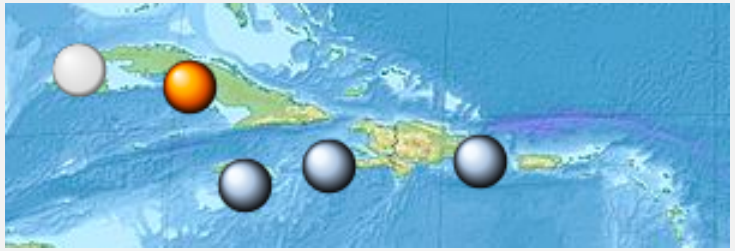
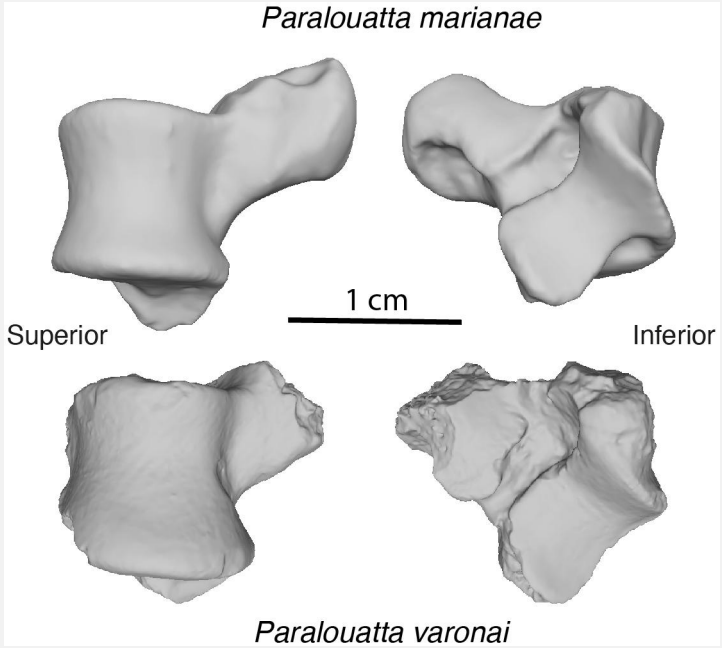
Paralouatta



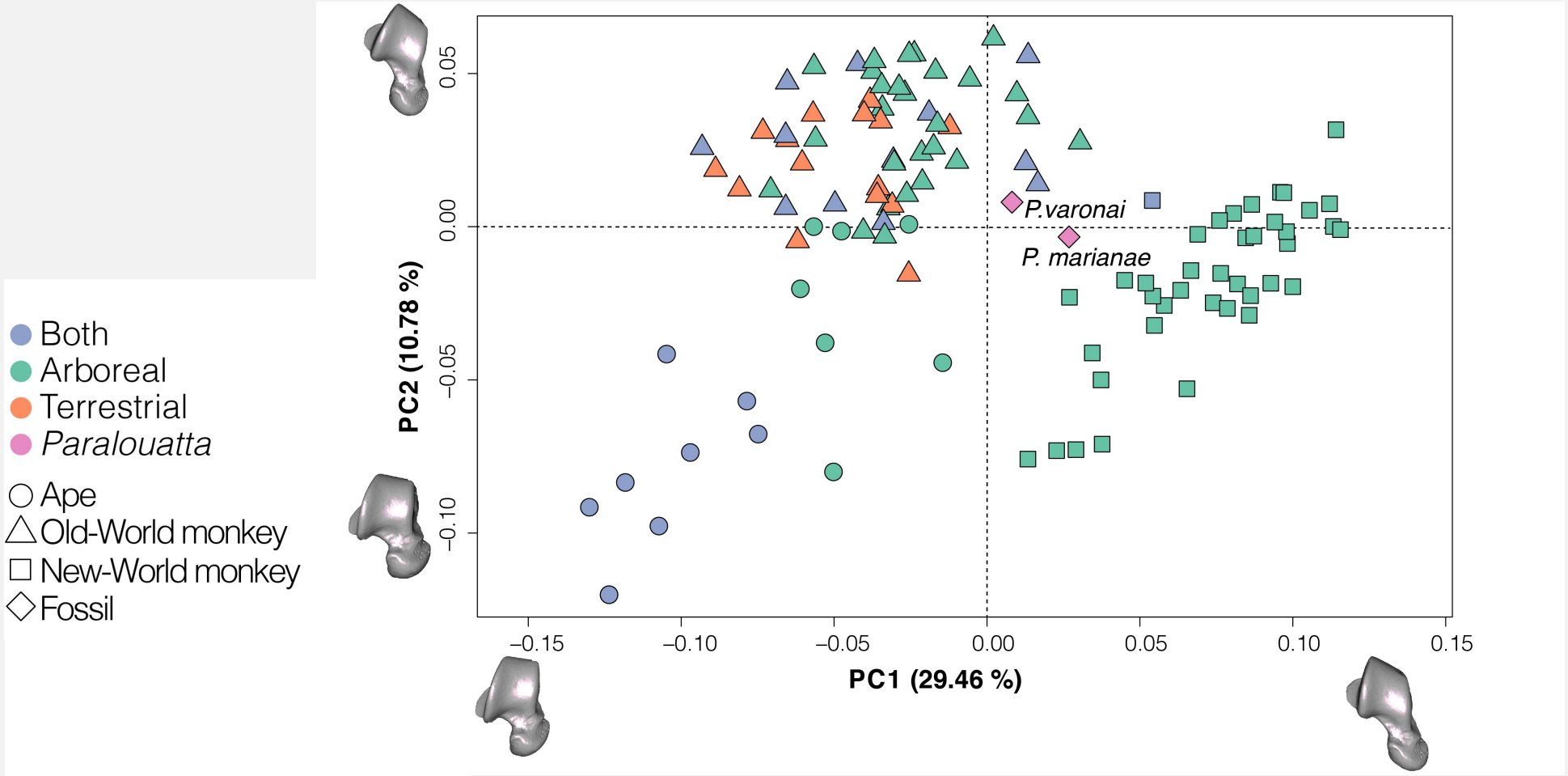




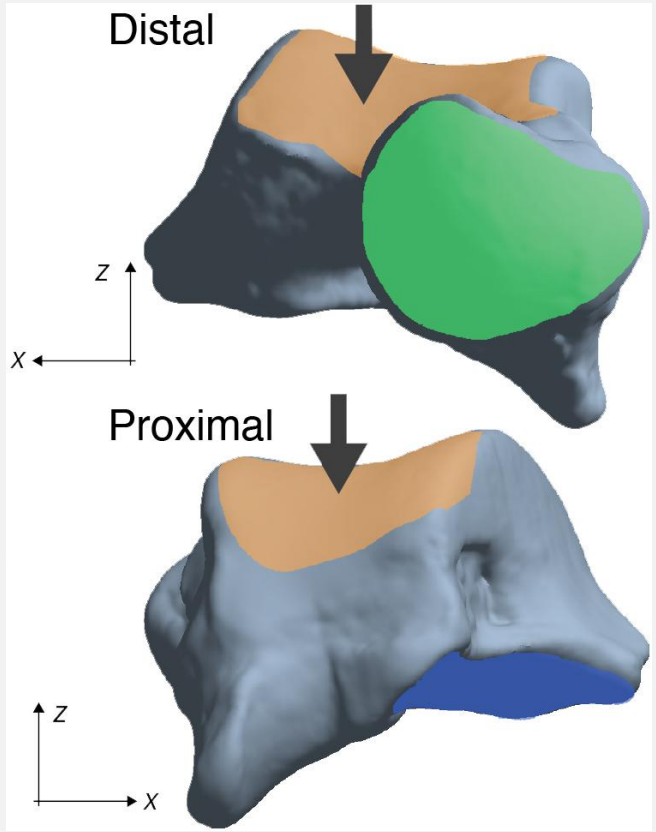
Rivero, M., and Arredondo, O. (1991). Paralouatta varonai, a new Quaternary platyrrhine from Cuba. *Journal of Human Evolution* 21, 1–11. doi:10.1016/0047-2484(91)90032-Q.

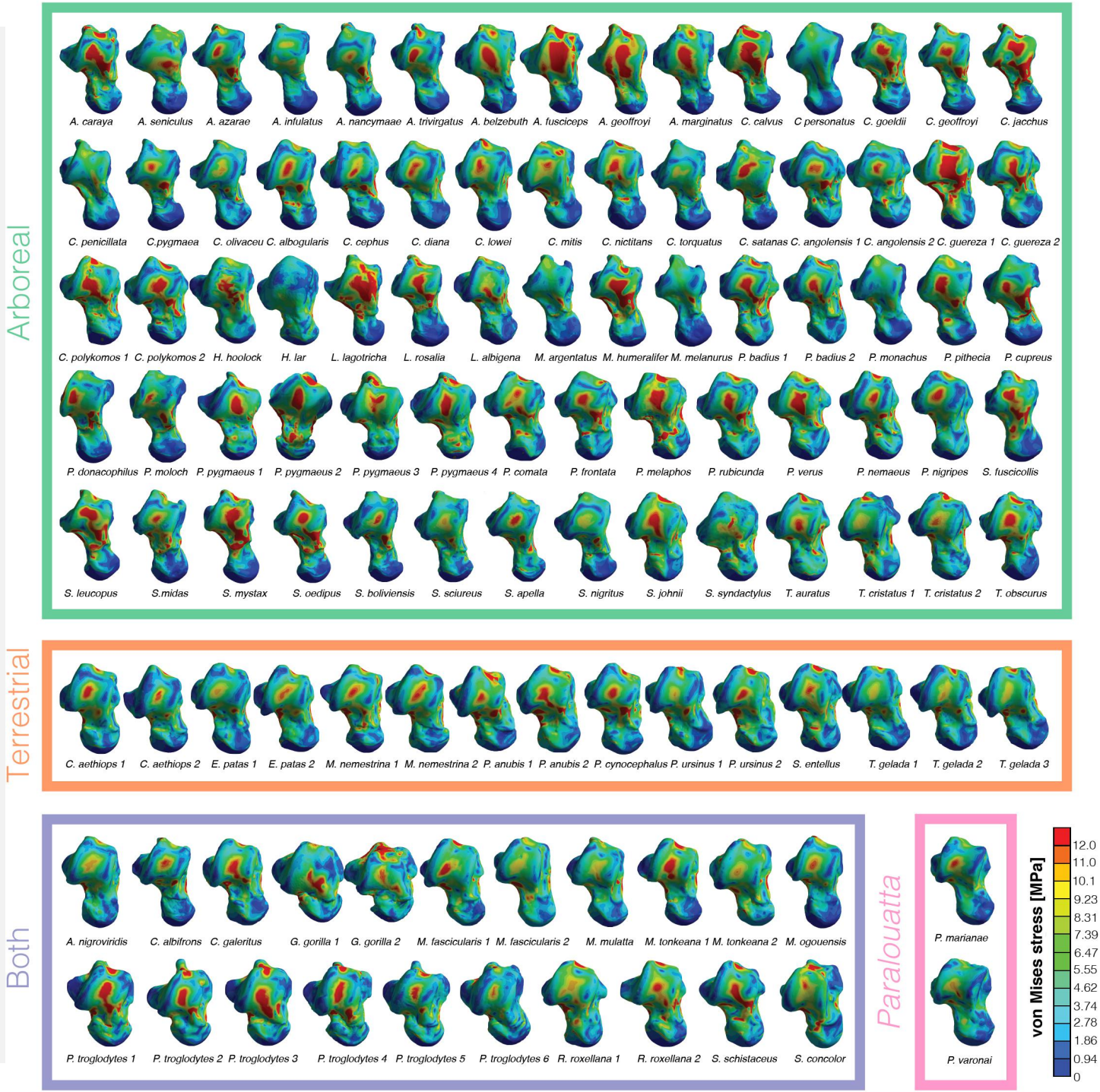
MacPhee, R. D. E., and Meldrum, J. E. F. F. (2006). Postcranial Remains of the Extinct Monkeys of the Greater Antilles, with Evidence for Semiterrestriality in Paralouatta1. *Am Museum Novitates* 3516, 1. doi:10.1206/0003-0082(2006)3516[1:PROTEM]2.0.CO;2.

Results: Morphometric PCA

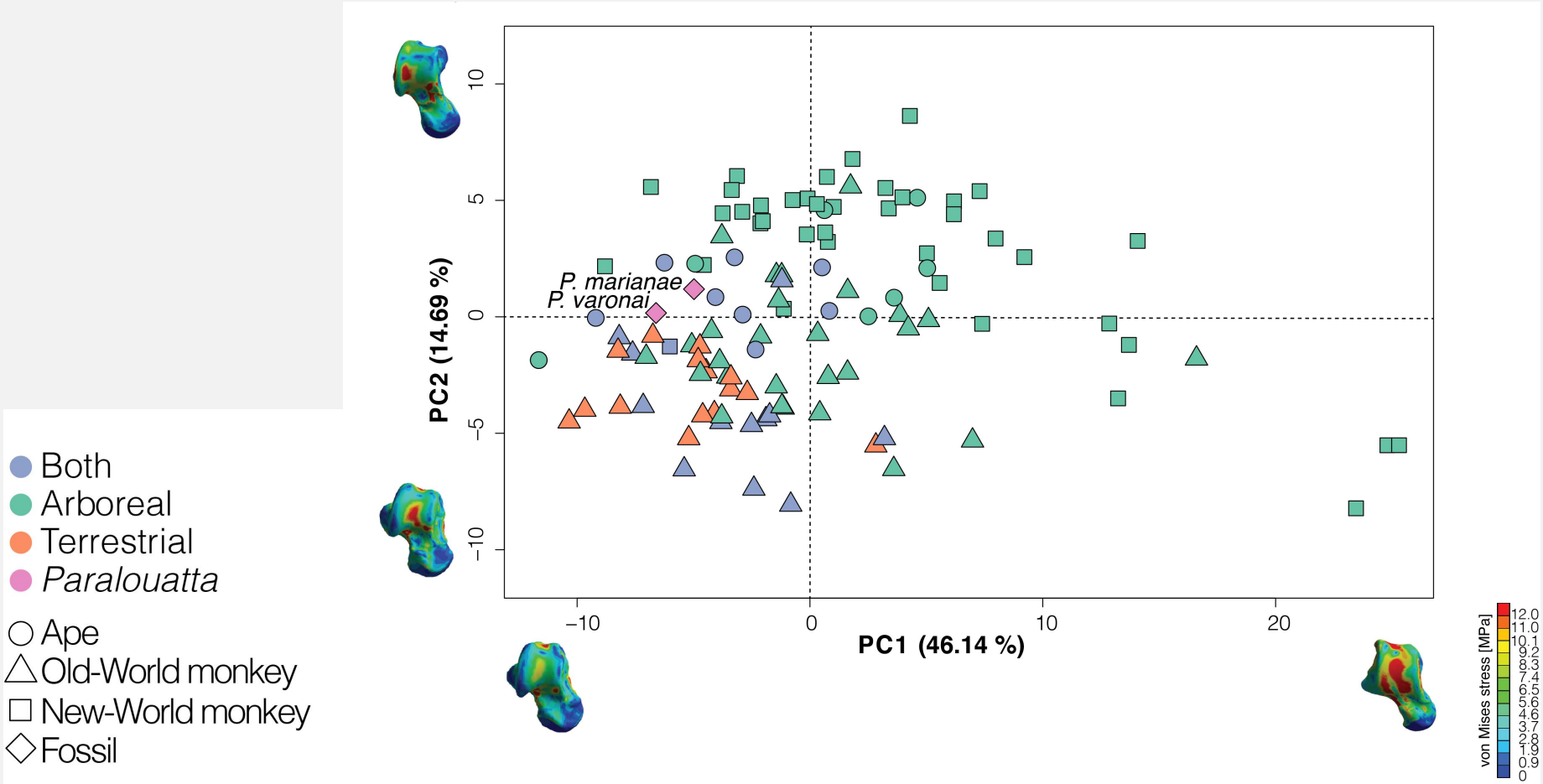


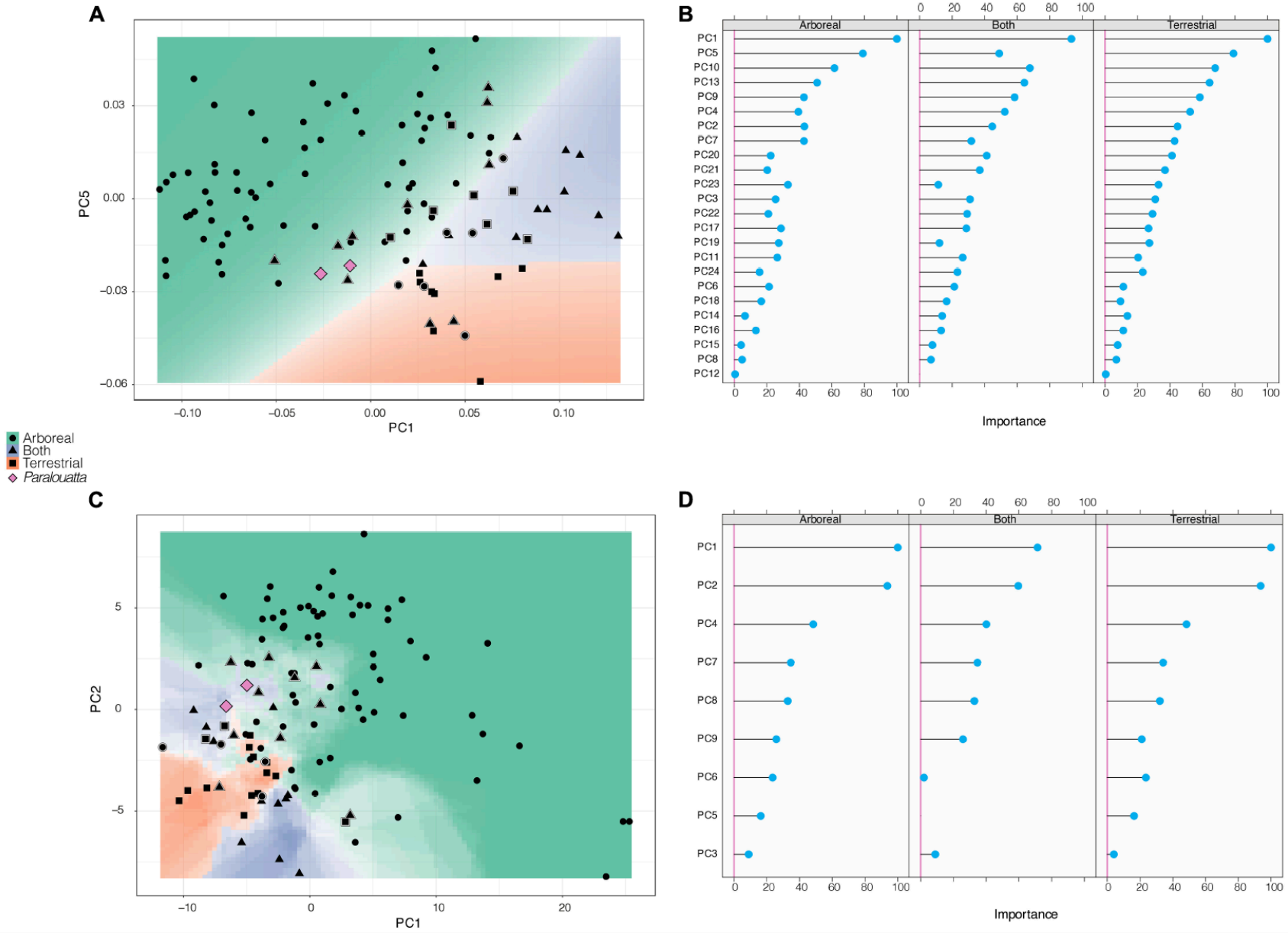
Biomechanical results



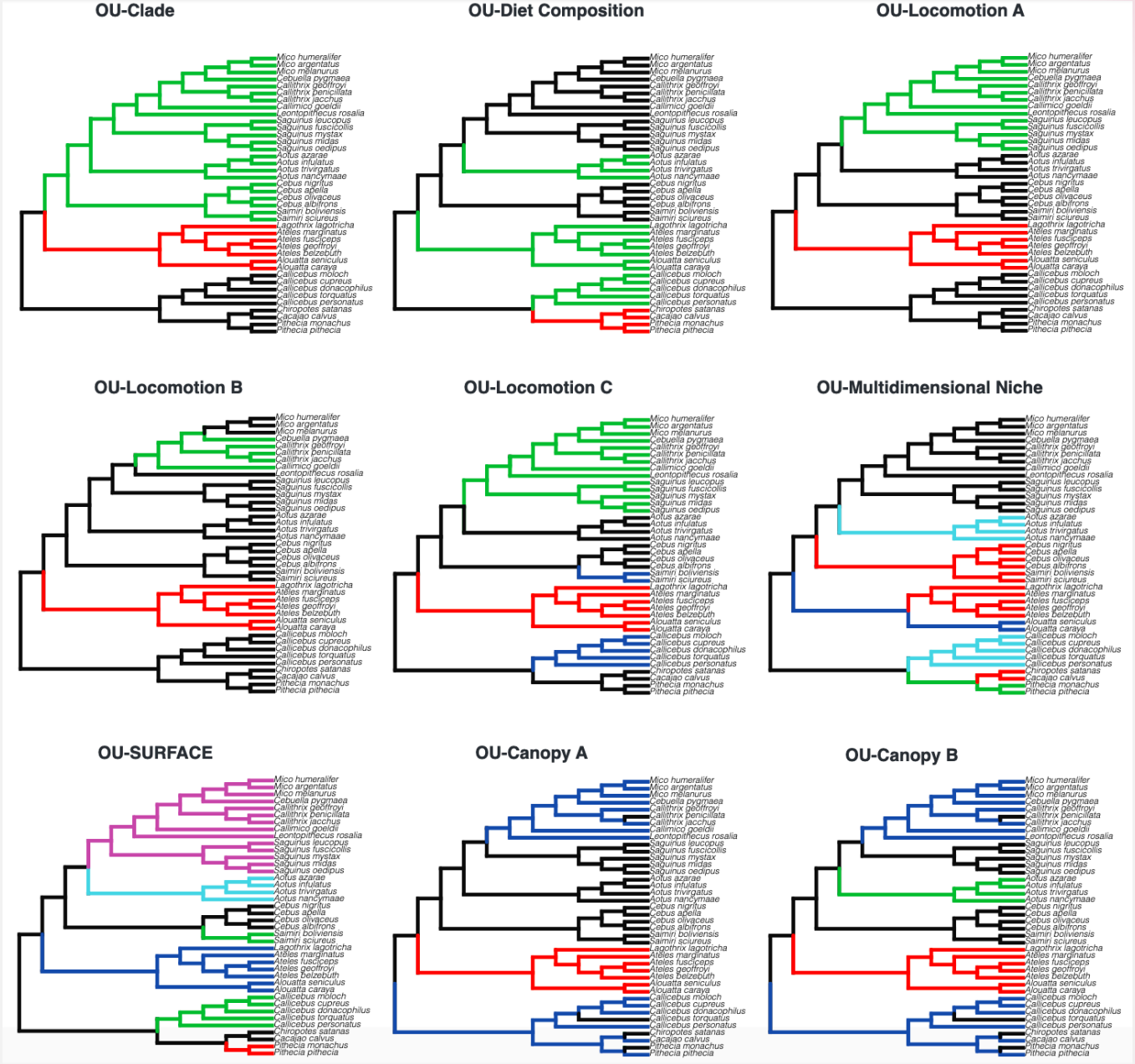


Results: Biomechanical PCA




A
B
C
D
PC5
PC1
PC2
Arboreal
Both
Terrestrial
Paralouatta
Importance

Evolutionary modelling



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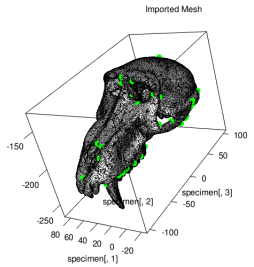
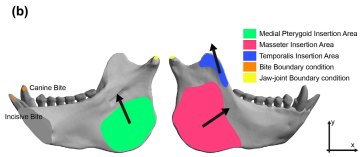
Conclusions

FEA allows us to address ecomorphological questions from a mechanics point of view, while **GM** provides information about the influence of shape differences.

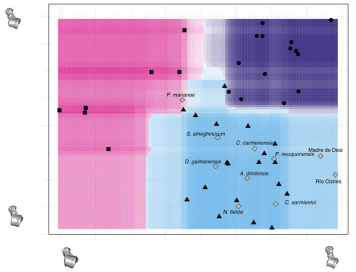
If combined in the context of **evolutionary theory (e.g., by applying PCMs)**, a new framework is generated that enables testing hypotheses regarding the relative contribution of a specific function or morphology in the evolution of a particular clade.

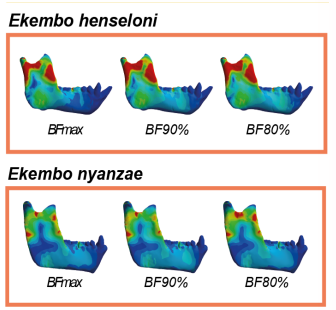
Morphometrics



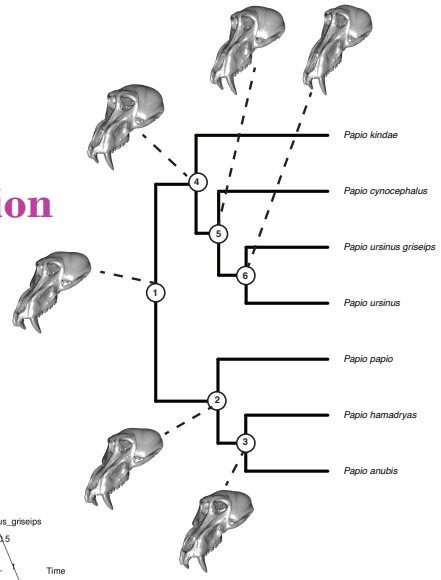


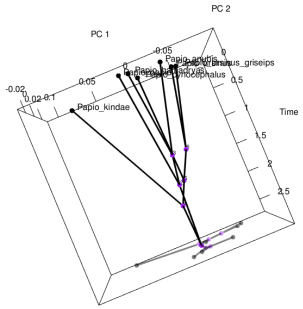
Palaeobiology



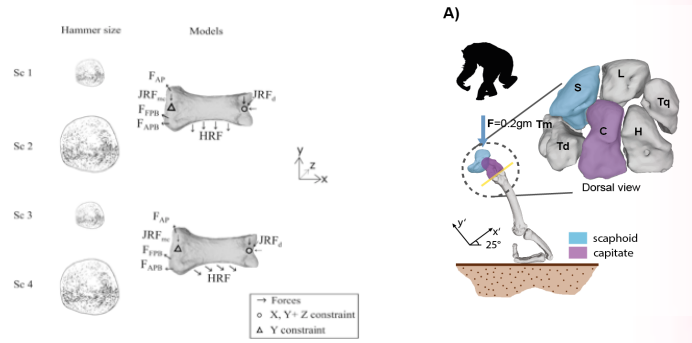


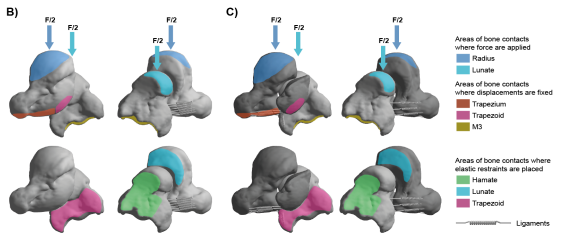
Primate evolution



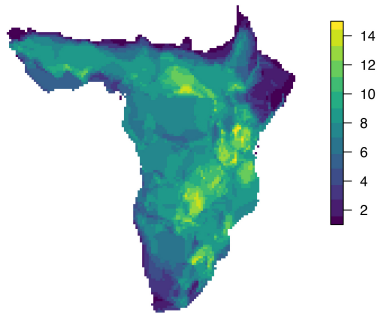


Biomechanics





Palaeoecology



Thank you!

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