A comprehensive study of key paleoenvironmental changes using major faunal turnovers focusing in the Turkana Basin, Kenya

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ABSTRACT

Lake Turkana in Kenya, Africa has been home to many discoveries that are critical for understanding human evolution. These include a *Paranthropus bosei* cranium, *Homo ergaster* type specimen, cranium and full skeleton, *Homo rudolfensis* cranium, *Homo habilis* cranium, *Paranthropus aethiopicus* cranium, *Australopithecus anamensis* mandible, *Kenyanthropus platyops* cranium, and hominin footprints. However, we have limited understanding of the factors that drove adaptations observed in hominins. To date, efforts to understand the environmental underpinning of these adaptations have been based mainly on isotopic analysis of paleosols, using carbon and strontium isotopes from paleosols and comparing carbon dioxide ratios taken from paleosols to modern day carbon dioxide ratios taken from soil. The environmental information that is extracted from these isotopic analyses is limited. The purpose of this study was to diagnose significant environmental transitions based directly on faunal turnover of aquatic/amphibious and fully terrestrial biotas in the middle-late Miocene to the Recent. By compiling and creating a comprehensive synthesis of previous research in the Turkana Basin, I was able to document faunal turnover and then determine environmental changes. Based on analysis of hippopotamids, equids, suids, elephantids, rhinocerotids, proboscideans, antelopes and primates, I was able to diagnose significant environmental changes at the late Miocene transitioning to early Pliocene. During this time, there was a change from lowland wooded tropical forests with alluvial grassland to a savannah grassland with riparian tropical rainforests. This compilation of environments from modern and recent faunal habitats are supported with previous isotope research, supporting this method of determining environmental change. By comparing the results gathered through this research against environmental changes gathered previously through isotope data, this research would begin to establish a new model of diagnosing environmental changes through fossil records alone.

INTRODUCTION

Discoveries in Turkana Basin: (Turkana Basin Institute, 2015; Tuttle, 1988)

- 1969- *Paranthropus bosei*
- 1971- *Homo ergaster/erectus* type specimen
- 1972- *Homo rudolfensis* cranium
- 1973- *Homo habilis* cranium
- 1981- Hominid footprints
- 1984- *Homo ergaster/erectus* skeleton (Brown et al., 1985)
- 1985- *Paranthropus aethiopicus* cranium
- 1990- *Paranthropus bosei* calvaria (Brown et al., 1993)
- 1994- *Australopithecus anamensis* mandible (Coffing et al., 1994)
- 1999- *Kenyanthropus platyops* cranium

Previous Research:

The majority of environmental research in the Turkana Basin area has been isotopic based. Stable carbon isotopes have been used to reconstruct hominin diets based C_3 and C_4 in on tooth enamel (Cerling et al., 2013; Cerling et al., 2013; Cerling et al., 2011) and other mammals in the area as well (Uno et al., 2011). By using C_3 and C_4 and their corresponding flora, the ratios found in tooth enamel are used to determine the type of food fauna was eating. This determination can be extrapolated to diagnose paleoecology of the region at various times. Bond ordering paleosol carbonates has also been used to determine temperature by examining the distribution of ^{12}C-^{18}O bonds and determining the temperature during formation (Passey et al., 2010). In other isotopic research, strontium isotopes taken from lacustrine fish fossils were used as a climate proxy. The proxy recorded orbitally forced variation in summer monsoon intensity and $^{87}Sr/^{86}Sr$ variability was determined by precession, which allows researchers to create an astronomically-tuned climate framework (Joordens, et al., 2011).

Purpose:

The purpose of this study is to diagnose significant environmental transitions based directly on faunal turnover of aquatic/amphibious and fully terrestrial biotas in late Miocene to the Pliocene. By determining the faunal change, the environmental change can be inferred from the habitats of the fauna involved. By checking the results gathered through this research against environmental changes gathered previously through isotope data, I hope to begin to establish a new method of diagnosing environmental changes through fossil records alone.

METHODS

To analyze the faunal turnover, I compiled a comprehensive synthesis of previous research in the Turkana Basin. For each paper, I documented the age and the fauna collected. In doing this, I was able to document faunal turnover and then correlate that turnover to environmental changes. I kept my focus to the late Miocene to Pliocene and used both aquatic/amphibious and fully terrestrial biotas. Faunal turnover and modern genus habitats were gathered from previous research, as was various interpretations of the region based on isotope research, and the two were compared against each other. By examining the change in fauna overtime, as well as the change in environment, as well as the explanations for those changes, correlations between environmental change and faunal turnover could be found.

DATA AND RESULTS

Genus	Habitat	Evidence
Sus scrofa	rooting foraging behavior; lowland tropical rainforests;	modern foraging experiments-prefer fine grained sand based soils, little to no rock cover, during dry season,
Chleustochoerus	Late Miocene; humid forest edge or areas of open steppe	configuration and high position of cranio-mandibular joint capable of crushing and grinding; simple structure of crown surface of cheek teeth suggests softer food that extant relatives
Rhinoceros	Wet alluvial grassland; dry savannah grassland, eastern seasonal swamp forest	monitering of modern rhino habitat utilization; direct evidence like dung, foot prints, wallowing digitized and plotted; sightings plotted against type of habitat
Proboscideans; *Gomphotherium*	Miocene; wooded habitat (trees, shrubs, herbs); diet composed of dicots	cheek tooth morphology

Table 1: Mammal type, habitat and evidence for present during the Miocene to determine overall ecology of region. Data gathered from Elledge et al., 2012; Hou et al., 2013; Sarma et al., 2011; Fox et al., 2003; Leakey, 1996.

Genus	Habitat	Evidence
Kobus vardoni	Savanna grasslands and floodplain wetlands (past research); during dry season concentrated in middle of floodplain	Aerial counts
(*Hippotragus equinus*)	Prefer grassland over savanna	Observation of antelope in Nylsvley Nature Reserve
Hippopotamus amphibius	Rivers, lakes, wetlands; riparian grasslands and woodlands	Ground, boat and aerial monitoring and counts
Hippopotamus amphibius	Wet season: Riverine woody species: Dune grassland, riverine woodland, riverine forest, open riverine forest; Preference for short green grass. Dry season: move further inland away from river.	Ground tracking
E. grevyi, E. quagga	Equatorial steppe: grasses	Mesowear sampling
Elephas maximus borneensis	Riparian forest (sand and open grass); degraded forests with freshwater swamp forests, secondary dry-land forest	Landscape suitability modeling
Elephas maximus	Natural forest (tropical deciduous), grassland and forest plantation)	Mapping of vegetation using satellite imaging; Elephant habitats mapped by direct or indirect observation
Loxodonta africana	*Acacia* and *Combretum* woodland of height 2-5 m; savannah grassland	Woody layer monitored annually, annual game counts via helicopter
Colobus guereza , Cercopithecus mitis, C. ascanius	Tropical forests	Line-transect census
Procolobus rufomitratus	Tropical rainforest	Microsatellite data combined with paleohistorical data
Cercopithecus mitis kandti	Bamboo (59.9%), Maesa lanceolata (18.7%), Hypericum revolutum (6.8%), Galiniera saxifraga (2.1%) and Ilex mitis	Grid cell in home range to quanitify food trees
Cercopithecus aethiops aethiops	In lowlands: riverine vegetation (south-west doum palms); In highlands: pure eucalyptus stands with Opuntia undergrowth, through acacia-dominated savanna habitats to dense riverine vegetation	Survey using GPS

Table 2: Mammal type, habitat and evidence for present during the early Pliocene to determine overall ecology of the region. Data gathered from Jenkins et al., 2003; Heitkonig et al., 1998; Kanga et al., 2011. O'Connor et al., 1986; Shulz et al., 2013; Estes et al., 2012. Baskaran et al., 2013. de Boer et al., 2015. Fashing et al., 2012; Allen et al., 2012; Twinomugisha and Chapman, 2008; Zinner et al., 2002; Leaky, 1996.

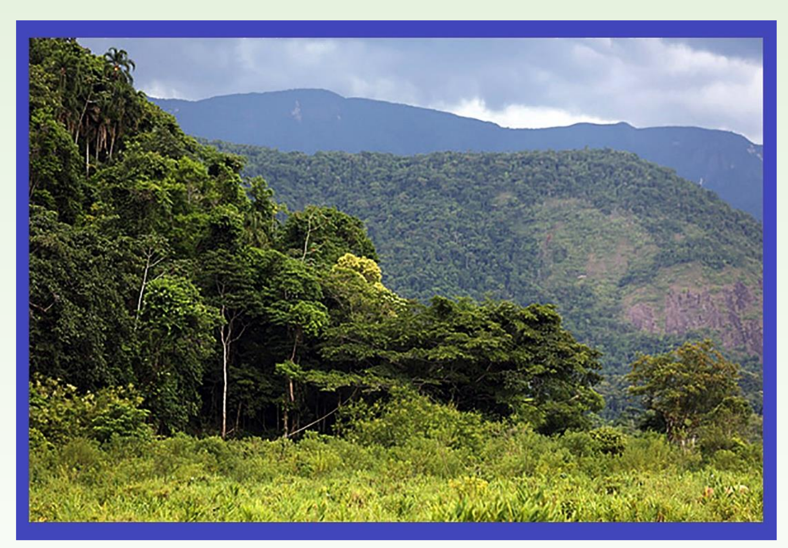

Figure 1: Representation of interpretation of Turkana Basin environment in Late Miocene. Image: Mongabay.com

Figure 2: Representation of interpretation of Turkana Basin environment in Pliocene. Image: Sebastian Kennerknecht

CONCLUSIONS

With the foundation of my model being the assumption that species living in a certain environment today are there because their ancestors evolved into that environment, I took various habitats of descendants of species found in the Turkana Basin and combined them to estimate the regional paleoenvironment. With the faunal change provided by Leakey (1996), I researched the modern descendants of genera found in the late Miocene and the early Pliocene. Based off of the modern environments and one paleoenvironment interpreted from cheek morphology, one possible interpretation of the environment in the late Miocene is a lowland wooded tropical forest with an alluvial grassland and in the early Pliocene is a floodplain savannah with a riparian tropical rainforest. While being able to interpret an environment from just faunal turnover could be a practical model to have, it is only useful if it can be proven accurate. Isotopic research has been the dominant method to attempt to determine paleoenvironment. By cross-checking my findings against isotopic data of the same time span, I can better determine if my interpretations are correct and this model accurate. Most isotope data is gathered from carbon isotopes (C_3 or C_4) in fossil teeth, which can provide an estimation of the diet of that particular individual. A majority of C_3 indicates a prevalence of shrubs or trees, and a majority of C_4 indicates a prevalence of grasses (Cerling et al., 2013; Cerling et al., 2013; Cerling et al., 2011; Uno et al., 2011). Based off of isotope data taken from herbivore families spanning the Late Miocene to Pliocene, Uno et al. showed a trend from diets mainly consisting of shrubs and trees (C_3) towards diets mainly consisting of grasses (C_4). The paleoenvironmental transition outlined in their research parallels the one in mine: a change from a wooded environment to one that is grassland with some wooded areas.

Given that this isotope data supported my own, my model has been proven viable for this region and time frame. To be able to apply my model universally, I plan to continue research in various fossil localities and regions to bolster the data for this model, as well as determine additional methods that involve observing environmental changes in modern ecology and establishing markers for analyzing and reconstructing fossil ecological communities.

REFERENCES

Allen, Julie M., Michael M. Miyamoto, Chieh-His Wu, Tamar E. Carter, Judit Ungvari-Martin, Kristin Magrini, and Colin A. Chapment. 2012. Primate DNA suggests long-term stability of an African rainforest. *Ecology and Evolution*, 2(11): 2829-2842.

Baskaran, Nagarajan, Govindarajan Kannan, Uthrapathy Anbarasan, Anisha Thapa, and Raman Sukumar. 2013. A landscape-level assessment of Asian elephant habitat, its population and elephant–human conflict in the Anamalai hill ranges of southern Western Ghats, India. *Mammalian Biology*, 78: 470-481.

Brown, B., A. Walker, C.V. Ward and R.E. Leakey. 1993. New *Australopithecus boisei* calvaria from east Lake Turkana, Kenya. *American Journal of Physical Anthropology*, 91: 137-159.

Cerling, Thure E., Fredrick Kyalo Manthi, Emma N. Mbua, Louise N. Leakey, Meave G. Leakey, Richard E. Leakey, Francis H. Brown, Frederick E. Grine, John A. Hart, Prince Kaleme, Hélène Roche, Kevin T. Uno, and Bernard A. Wood. 2013. Stable isotopic-based diet reconstructions of Turkana Basin hominins. *PNAS*, 110(26): 10501-10506.

Cerling, Thure E., Kendra L. Chritz, Nina G. Jablonski, Meave G. Leakey, and Fredrick Kyalo Manthi. 2013. Diet of *Theropithecus* from 4 to 1 Ma in Kenya. *PNAS* ,110(26): 10507-10512.

Cerling, Thure E., Emma Mbua, Francis M. Kirera, Fredrick Kyalo Manthi, Frederick E. Grine, Meave G. Leakey, Matt Sponheimer, and Kevin T. Uno. 2011. Diet of *Paranthropus boisei* in the early Pleistocene of East Africa. *PNAS*, 108(23): 9937-9341.

Coffing, Katherine, Craig Feibel, Meave Leakey, and Alan Walker. 1994. Four-million-year-old hominids from east Lake Turkana, Kenya. *American Journal of Physical Anthropology*, 93:55-65.

de Boer, Willem F., Jordi W. A. Van Oort, Michael Grover, Mike J. S. Peel. 2015. Elephant-mediated habitat modifications and changes in herbivore species assemblages in Sabi Sand, South Africa. *European Journal of Wildlife Research*, 61: 491-503.

Elledge, Amanda E., Clive A. McAlpine, Peter J. Murray, Iain J. Gordon. 2012. Modelling habitat preferences of feral pigs for rooting in lowland rainforest. *Biological Invasions*, 15:1523-1535.

Estes J.G., Othman N., Ismail S., Ancrenaz M., Goossens B., et al. 2012. Quantity and Configuration of Available Elephant Habitat and Related Conservation Concerns in the Lower Kinabatangan Floodplain of Sabah, Malaysia. *PLoS ONE* 7(10): e44601

Fashing, Peter J., Nga Nguyen, Patrick Luteshi, Winstone Opondo, Julie F. Cash, Marina Cords. 2012. Evaluating the Suitability of Planted Forests for African Forest Monkeys: A Case Study From Kakamega Forest, Kenya. *American Journal of Primatology*, 74: 77-90.

Feibel, Graig S. 2011. A Geological History of the Turkana Basin. *Evolutionary Anthropology*, (20): 206-216.

Fox, David L., and Daniel C. Fisher. 2003. Dietary reconstruction of Miocene *Gomphotherium* (Mammalia, Proboscidea) from the Great Plains region, SUA, based on the carbon isotope composition of tusk and molar enamel. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 206: 311-335.

Heitkonig, Ignas M. A. and Norman Owen Smith. 1998. Seasonal selection of soil types and grass swards by road antelope in a South African savanna. *African Journal of Ecology*, 36: 57-70.

Hou, SuKuan, Tao Deng, Wen He, and ShanQin Chen. 2013. Foraging behavior of *Chleuastochoerus* (Suidae, Artiodactyla: A case study of skull and mandible morph-functional analysis. *Science China: Earth Sciences*, 57: 988-998.

Jenkins, Richard K.B., Honori T. Maliti, and Graham R. Corti. 2003. Conservation of the puku antelope (*Kobus vardoni*, Livingstone) in the Kilombero Valley, Tanzania. *Biodiversity and Conservation*, 12: 787-797.

Joordens, Josephin C.A., Hubert B. Vonhof, Craig S. Feibel, Lucas J. Lourens, Guillaume Dupont-Nivet, Jeroen H.J.L. van der Lubbe, Mark J. Sier, Gareth R. Davies, Dick Kroon. 2011. An astronomically-tuned climate framework for hominins in the Turkana Basin. *Earth and Planetary Science Letters*, 307: 1-8.

Kanga, Erustus M., Joseph O. Ogutu, Han Olff, and Peter Santema. 2011. Population trend and distribution of the vulnerable common hippopotamus *Hippopotamus amphibius* in the Mara Region of Kenya. *Fauna and Flora International*. 45(1):20-27.

Leakey, Meave G., Craig S. Feibel, Raymond L. Bernor, John M. Harris, Thure E. Cerling, Kathlyn M. Stewart, Glenn W. Storrs, Alan Walker, Lars Werdelin and Alisa J. Winkler. 1996. Lothagam: A record of faunal change in the Late Miocene of East Africa. *Journal of Vertebrate Paleontology*, 16(3): 556-570.

O'Connor, T. G. and B. M. Campbell. 1986. Hippopotamus habitat relationships on the Lundi River, Gonarezhou National Park, Zimbabwe. *African Journal of Ecology*, 24: 7-26.

Passey, Benjamin H., Naomi E. Levin, Thure E. Cerling, Francis H. Brown, and John M. Eiler. 2010. High-temperature environments of human evolution in East Africa based on bond ordering in paleosol carbonates. *PNAS*, 107 (25): 11245-11249.

Sarma, Pranjit Kumar, B.S. Mipun, Bibhab Kumar Talukdar, Rajeev Kumar, and Ajit Kumar Basumatary. Evaluation of Habitat Suitability for Rhio (Rhioceros unicornis) in Oran National Park using Geo-spatial Tools. 2011. *ISRN Ecology*: 1-9.

Schulz, Ellen and Thomas M. Kaiser. 2013. Historical distribution, habitat requirements and feeding ecology of the genus *Equus* (Perissodactyla). Mammal Review, 43: 111-123.

Twinomugisha, Dennis, and Colin A. Chapman. 2008. Golden monkey ranging in relation to spatial and temporal variation in food availability. *African Journal of Ecology*, 46: 585-593.

Uno, Kevin T., Thure E. Cerling, John M. Harris, Yutaka Kunimatsu, Meave G. Leakey, Masato Nakatsukasa, and Hideo Nakaya. 2011. Late Miocene to Pliocene carbon isotope record of differential diet change among East African herbivores. *PNAS*, 108(16): 6509-6514.

Zinner, Dietmar, Fernando Pelaez, and Frank Torkler. 2002. Distribution and habitat of grivet monkeys (Cercopithecus aethiops aethiops) in eastern and central Eritrea. *African Journal of Ecology*, 40: 151-158.

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