ROMANIAN ASSOCIATION OF GEOMORPHOLOGISTS

REVISTA DE GEOMORFOLOGIE (2022) **24(2)**: 5–15
DOI: 10.21094/rg.2022.103
www.geomorfologie.ro, http://revistadegeomorfologie.ro

An Analysis of Gorillas as Zoogeomorphic Agents

Andrea PIÑON[1], David R. BUTLER[1*]

[1]Department of Geography and Environmental Studies, Texas State University, San Marcos, TX 78666, U.S.A.

Received 9 April 2021; Revised 19 December 2022; Accepted 19 December 2022
*Correspondence to: David R. BUTLER; e–mail: db25@txstate.edu

ABSTRACT

Gorillas are among the most charismatic and well-researched species on the planet, yet their role as zoogeomorphic agents has gone largely overlooked. Knowledge on how gorillas contribute to landscape formation and decay is vital for future conservation planning and habitat suitability modelling. The purpose of this study is to conduct a content analysis of literature to identify gorilla zoogeomorphic activity and to aggregate and organize data into nine zoogeomorphic categories. Data obtained was used to provide a qualitative and quantitative summary of inter/intra-specific gorilla zoogeomorphic activity, and the extent of literature available on the subject. Categories of gorilla zoogeomorphic activity include: (1) soil scratching and (2) soil scraping of the forest floor; (3) excavating chambers and holes; (4) bare/semi-bare soil nest site building; (5) hand/knuckle and footprints; (6) excavating insect mounds; (7) tool use and associated geo-morphic implications (8) trunk uprooting, and (9) trampling. All four gorilla sub-species (*G. gorilla*, *G. beringei*, *G. graueri*, *G. dielhi*) were represented in the literature with evidence presented from nine countries in central Africa. Nest construction, mound disturbance, and excavated surface depressions were most fre-quently documented. Nests and mounds each made up 22 percent and excavated holes encompassed 16 percent of the literature. Soil-scraping, tool use, and trunk uprooting were poorly represented, making up 6 percent, 1 percent, and 2 percent of the total literature, respectively.

KEYWORDS Gorilla, Zoogeomorphology, Geomorphology, Primate, Africa

1. Introduction

Gorillas (*Gorilla spp.*) are among the most charis-matic and well-researched species on the planet, yet their role as zoogeomorphic agents has been largely overlooked. Zoogeomorphology (Butler, 1992) is the study of animals as geomorphic agents, that is, their role in sculpting, modifying, and maintaining the Earth's physical surface. Animals transport, erode, and displace earth material through their burrowing, wallowing, trampling (Butler, 1992) and building of dens, nests, and dams (Butler and Sawyer, 2012).

Gorillas exert an exceptional degree of geomorphic influence. They biomechanically transform the earth's surface by removing and transporting earth material to exploit food resources within their habitats. Their behaviour elicits a biotic–abiotic two-way interaction that results in a physical landscape imprint. This signature then becomes susceptible to other exogenic forces that initiate and exacerbate local geomorphic processes, thereby, maintaining topographic transformation (Fig. 1a). In some cases, weathered and eroded areas will improve access to resources which encourages future biomechanical activity (Fig. 1b). Figure 1 illustrates a conceptual model of these processes.

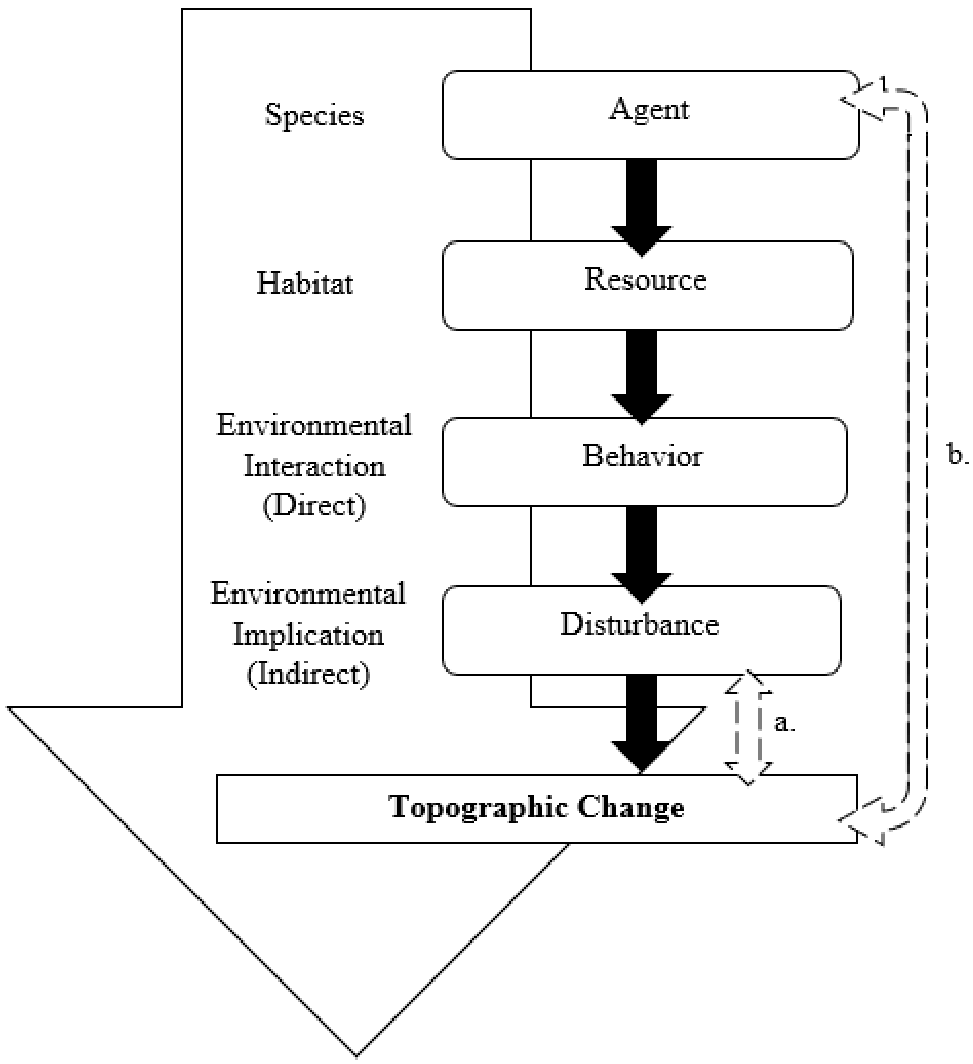

Figure 1 Conceptual model of gorilla zoogeomorphology and associated feedback mechanisms

Currently, reports of gorilla zoogeomorphic activity are scattered throughout the literature of various disciplines and mostly functions as supplementary data to primary research goals. Emphasis lies on phylogenetics, socio-behavioural and feeding ecology, with limited zoogeomorphic data. Nest site research has been the most successful in illustrating the extent of earth material excavated by gorilla. Their relatively large size and ubiquitous nature makes nest constructions easier to detect in dense forest landscapes.

Early studies by Schaller (1963) and Fossey (1983) contributed some of the first accounts of gorilla zoogeomorphology. Schaller (1963) published detailed illustrations of nest site topographic spatial arrangement and quantified data of surface disturbance stemming from gorilla geophagy.

Table 1 Examples of gorilla zoogeomorphic activity. Impacts cited from Butler (1995)

Category	Species	Site	Activity	Impact	Source
Soil Scratching	*G. gorilla*	N–NNP	465 soil-scratching traces in search of insects	Pedoturbation, increased soil infiltration, vegetation removal, surface and slope instability and collapse, rock and soil transport, erosion	Nishihara and Kuroda, 1991
Soil Scraping	*G. beringei*	VNP	5m x 2m bare soil patch on slopes created from individuals observed engaging in geophagy	Pedoturbation, increased soil infiltration, vegetation removal, surface and slope instability and collapse, rock and soil transport, erosion	Schaller, 1963
Excavated Chambers & Depressions	*G. beringei*	VNP	Holes ranging between 13 cm–30 cm (depth) x 13 cm–25 cm (width) excavated by gorillas digging for plant roots	Surface and slope instability, erosion, transport and deposition of earth material, pedoturbation, pit and mound microtopography	Schaller, 1963
Bare & Semi-bare soil bottom nest site	*G. beringei*	VNP	1 gorilla observed digging day nest into hillside to create a sitting platform	Pit and mound microtopography, plant seed nursery sites, erosion, surface and slope instability, increased soil fertility, transport and deposition of earth material	Schaller, 1963
Excavated Insect Mounds	*G. gorilla*	LR	Gorillas broke apart 54 *Cubitermes sp.* mounds	Transport and deposition of earth material, erosion, increased soil infiltration and fertility, pedoturbation of termitaria and soil surface	Tutin and Fernandez, 1983
Trampling	*G. beringei*	VNP	Evidence of 15m^2 trampled area in bamboo habitat within Mt. Visoke–Mt. Karisimba saddle region	Erosion, reduction and/or complete loss of vegetation, increased soil bulk density, soil fertility from animal feces, formation of slope treads	Plumptre, 1993
Hand/knuckle & footprints	*G. beringei*	N–NNP	466 traces of gorilla hand and/or footprints	Transport and deposition of earth material, pedoturbation, erosion	Nishihara and Kuroda, 1991
Trunk Uprooting	*G. beringei*	VNP	Gorilla uprooted tree at base to break ant mound	Pit and mound microtopography, vegetation loss, erosion	Watts, 1989
Tool Use	*G. gorilla*	N–NNP	1 observation of female using detached trunk as postural support to test water depth as she crossed swamp	Pit and mound microtopography, vegetation loss, erosion	Breuer, Ndoundou–Hockemba, and Fishlock, 2005

Two decades later, Dian Fossey (1983) reported a brief account of a cavern created by seasonal gorilla "soil–eating binges on Visoke's ridges" (52), a phenomenon hypothesized because of the soil's high calcium and potassium content (Fossey, 1983; Mahaney, 1993). She observed the subsequent effect of the surrounding root architecture in adapting and eventually supporting the 'eaten' chasm, a form of phytogeomorphic activity. Within the same region, Plumptre (1993) noted extensive trampling in the saddle region located between Mt. Visoke and Mt. Karisimba in Volcanoes National Park (VNP). It was caused by the extensive use by *G. beringei* as access trails between resting sites and food sites. Nishihara and Kuroda (1991) conducted the first and only detailed field study of *G. gorilla* soil-scratching behaviour. They determined this behaviour to be a seasonal phenomenon exhibited during the wet season when the soil became softer and easier to break. Table 1 provides more examples of gorilla zoogeomorphic activity.

Gorillas are important biomodifiers that contribute to soil displacement, mass movement, and pedoturbation. Their landscape constructions (e.g., Fossey, 1983) create new habitat for sympatric species potentially making them ecosystem engineers. The purpose of this study was to explore gorilla behaviour and habitat use through the lens of zoogeomorphology. A content analysis of literature found either in print or online within twenty nine journals, four books, and seven organization webpages (Table 2) was exhaustively mined to capture the greatest extent of data possible.

Table 2 Content reviewed (1963–2014)

Journal	
African Journal of Ecology	Journal of Biogeography
African Journal of Physical Anthropology	Journal of Human Evolution
American Journal of Primatology	Journal of Mammalogy
Animal Behaviour	Journal of Primatology
Behavioural Processes	Journal of Tropical Ecology
Biodiversity and Conservation	Journal of Zoology
Biotechnology, Agronomy, Society and Environment	Nature
Ecological Applications	PloS Biology
Folia Primatol	PloS One
Folia Primatologica	Primate Conservation
Forest Ecology and Management	Primates
International Journal of Primatology	Stochastic Environmental Research & Risk Assessment
Journal of Applied Ecology	Tropics

Book	**Organization**
Gorilla Biology: A Multidisciplinary Perspective	Dian Fossey Gorilla Fund International
Gorillas in the Mist	The Cross River Gorilla Conservation Program
The Mountain Gorilla. Ecology and Behavior	The Leakey Foundation
Mountain Gorillas. Three Decades of Research at Karisoke	World Wildlife Fund
	United States Fish and Wildlife Service
	World Resources Institute
	International Union for Conservation of Nature and Natural Resources

Table 3 Identified gorilla zoogeomorphic categories and their descriptions

Category	Description
1. Soil scratching	Scratching of the forest floor with hands.
2. Soil scraping	Scratching of the forest floor with incisors.
3. Excavated chambers and depressions	Excavation of soil horizon greater than 13 cm (5 in).
4. Bare/semi-bare soil nest sites	Individual or group nests constructed entirely of soil or with soil exposed nest cup bottom and herbaceous rim.
5. Insect mound excavations	Mechanical dismantling of insect mounds.
6. Trampling	Soil compaction along frequently used individual and group feeding/ranging trails with clear reduction or complete loss of vegetation.
7. Hand/Knuckle and footprints	Soil surface indentations of prints.
8. Tool use	Earth surface disturbance resulting from the use of detached object as a tool.
9. Trunk uprooting	Uprooting of shrub and tree trunks.

Under the auspices of published zoogeomorphology studies on other animals, this study organized data collected from the literature into nine categories of gorilla zoogeomorphic activity (Table 3). These include (1) soil scratching (with hands) and (2) scraping (with incisors) of the forest floor; (3) chambers and depressions created from surface excavation; (4) bare and semi-bare soil nest site constructions; (5) insect mound excavation; (6) trampling; (7) hand/knuckle and foot prints; (8) surface disturbance as a result of tool use; and, finally, (9) trunk uprooting (e.g., Schaller, 1963; Casimir, 1979; Fossey, 1983; Carroll, 1986; Mahaney, Watts and Hancock, 1990; Nishihara and Kuroda, 1991; Plumptre, 1993; Remis, 1993; Tutin and Parnell, 1995; Breuer, Ndoundou–Hockemba and Fishlock, 2005; Wittiger and Sunderland–Groves, 2007).

The knowledge that could be generated on the zoogeomorphic impacts of gorillas is far-reaching. Do *Gorilla spp*. contribute to landscape formation and decay? If they do, to what extent do they impact and initiate geomorphic processes? This study begins answering these questions and represents the first of its kind dedicated to examining existing data through the lens of zoogeomorphology.

2. Data

Raw data was generated using printed and online literature published between 1963 and 2014 in twenty nine journals, four books, and seven government and non-profit organization websites (Table 2). Key words such as, “gorilla and nest” or “gorilla and scratch” initiated the search, and afterwards, author–supplied key terms and database subject terms guided future searches. Journals listed in Table 2 were not initially selected for the literature review, rather, the list was generated from relevant articles collected for the content analysis. The purpose of initiating searches using key terms instead of journals was to mitigate the issue of fragmented data published in journals from multiple disciplines. The definition of zoogeomorphology served as a guide to identify and aggregate the data into nine categories (Table 3) of gorilla zoogeomorphic activity.

3. Methods

3.1 Region and species

The tropical climate in central Africa has distinct long wet seasons (September through June) with heavy precipitation exceeding 2,000 mm (80 in). The dry season (July through August) is brief with precipitation decreasing towards the east and west coasts and with increasing latitude from the Equator. Average annual temperatures range from 25–28°C (77°F to 82°F) (Kayiranga et al., 2017). Vegetation is characterized by a patchwork of primary and secondary evergreen and deciduous mixed–species, tropical lowland and montane rainforest with marshy clearings and gallery forests (Mehlman and Doran, 2002). This region is recognized for its high level of biodiversity, endemism, and location of one of the largest tracts of intact contiguous tropical forest. The Congo and Nile River are the two primary watersheds in the region. The Congo Basin drains an area of ~3.8 x 106 km^2 and contributes 50 percent of all annual freshwater discharge (~1300 km^3) from central Africa to the Atlantic (Upstill–Goddard et al., 2017). The Nile River has a drainage area of 3,176,541 km^2 that stretches across 11 countries (6,695 km) (Belete et al., 2018).

This study examined peer reviewed articles on wild gorilla populations (Fig. 2) with no limitations on the length of the study period. There were no set requirements for the year of publication. Simply, the literature was mined as early as zoogeomorphic data was made available. All four sub-species of gorilla taxa were included with no preference given to the number of individuals or size of group observed. Subjects also included extinct and extant populations in protected regions of central Africa.

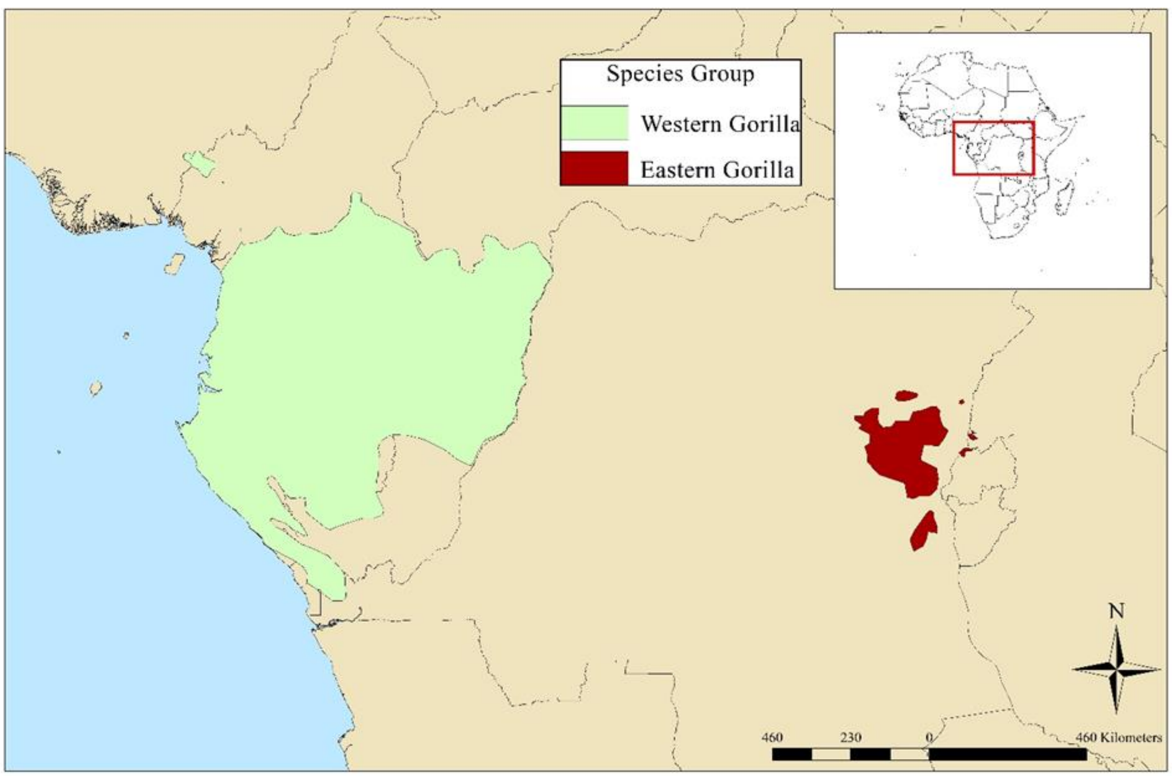

Figure 2 Gorilla population distribution in central Africa

3.2 Analysis

This content analysis was conducted using fundamental principles of zoogeomorphology and wildlife ecology to uncover new insights on existing literature and guide the systematic classification of categories and sub-categories. Subject areas in gorilla habitat use, movement and foraging patterns, and food and resource selection were mined for zoogeomorphic activity. Information was organized by sub-species, protected region, and qualitative and quantitative data. Aggregate data sets and descriptive information was derived using measures of central tendency (mean, median, mode) and dispersion (standard deviation). If data provided in the literature was a range, the median was taken from that range (e.g., 13–30 cm depth of excavated hole, median = 21.5) and that value used in the meta-analysis.

4. Results

A total of 106 documented cases of zoogeomorphic activity were recovered from the content analysis. A total of nine protected regions in Central Africa were represented in the content analysis. These include (1) Dzanga–Sangha Dense Forest Reserve (–SDFR) and (2) Dzanga–Ndoki National Park (D–NNP), Central African Republic; (3) Nouabalé–Ndoki National Park, Republic of the Congo; (4) Volcanoes National Park (VNP), (5) Virunga National Park (ViNP), (6) and Kahuzi–Biega National Park, (K–BNP), Democratic Republic of the Congo; (7) Lope Reserve (LR) and (8) Moukalaba–Doudou National Park (M–DNP), Gabon; and Dja Biosphere Reserve (DBR), Cameroon.

Soil scraping, tool use, and trampling zoogeomorphic activity was least documented in the literature indicating a critical need for research. The earliest documentation of zoogeomorphic activity was by Schaller in 1963 on his study of *G. beringei* in VNP. The latest was a 2014 study on *G. gorilla* nest sites in the DBR.

4.1 Soil scratching

Soil scratching is the mechanical manipulation of the physical surface using fingers and toes. Raking of soil removes or degrades surface vegetation resulting in decreased surface stability, increased soil infiltration and pedoturbation of surface material. Depressions of highly scratched areas can incise and widen from exogenic fluvial processes that erode and transport material.

Evidence of scratching was documented among 3 sub-species of gorilla (*G. gorilla, G. beringei, G. graueri*) within 5 protected regions (D–NNP, D–SDFR, K–BNP, N–NNP, VNP). The content analysis demonstrated that 10 percent (n=11) of the literature, across all zoogeomorphology categories (n=106), documented gorilla soil scratching.

Observed scratching bouts were most frequent with only a single publication (Nishihara and Kuroda, 1991) dedicated to this subject. Their article was the sole provider of photographs of soil scratching traces. Moreover, their study documented 465 traces of soil that had been scratched at an average frequency of 0.84 traces/km^2.

4.2 Soil scraping

Soil scraping is the mechanical manipulation of the physical surface using the incisors. Gorillas exhibit sexual dimorphism in their dental morphology. The mean length of a canine pair ranges from 10.8 mm (adult female, Booth, 1971) up to 33.58 mm (adult male, Manning and Chamberlain, 1994) making them efficient soil masticating machines. Soil scraping was documented among *G. beringei* only. This form of zoogeomorphic activity results in decreased bulk density, increased soil infiltration, and loss of surface stability from earth material removal (e.g., rocks, ground vegetation). Evidence for scraping consisted of identification of disturbed sites, bout observation, and indirect evidence (e.g., soil smeared gorilla faces, Schaller, 1963). The content analysis returned documented evidence of 4 sites where gorillas had scraped the floor. Tooth marks were located on small, vertical bluffs situated on exposed layers of quartz and white stone (Schaller, 1963). Schaller (1963) noted a scraped soil patch located on a slope on Mt. Mikeno, VNP, that measured 5 m long x 2 m wide. Literature was scarce on this subject with scraping data making up 6 percent (n=6) of all zoogeomorphic data retrieved from the content analysis (n=106) across all categories.

4.3 Excavated chambers and depressions

Digging by gorillas leaves significant physical impressions on the landscape that vary in size and shape. Biomechanical transformation of the landscape leads to pedoturbation and erosion; and if located on slopes, the movement of material downslope and backfilling of holes (Butler, 1995). Excavations for this category range as small as 17 cm^3 (derived from meta-analysis) of displaced soil from plant uprooting to large caverns created from incessant geophagy by gorilla groups (e.g., Fossey, 1983, 53). Publications documenting this type of zoogeomorphic activity mostly encompassed gorilla digging bouts. A meta-analysis of this data returned a total of 8 observations of gorillas digging holes, mostly for sub-surface plant parts to consume. In one of those instances, an author noted holes created from the ripping and dismantling of grass and mud by a gorilla during a display behaviour (Wittiger and Sunderland Groves, 2007). Only two articles (Schaller, 1963; Yamagiwa et al., 1991) measured hole dimensions. 16 percent (n=17) of zoogeomorphic peripheral data recovered from the content analysis (n=106), across all categories, provided documentation of pits and depressions. Three subspecies (*G. diehli*, *G. beringei*, *G. graueri*) within 5 protected areas (K–BNP, KGS, ViNP, VNP) were found to be zoogeomorphically active. The most significant report of landscape formation was the creation of a large cavern (no dimensions provided) located in VNP that had been so highly incised from gorilla geophagy that it became large enough to allow individuals to enter and feed on the soil (Fossey, 1983).

4.4 Bare/semi-bare soil bottom nest site

Gorillas construct day and night nests with limited topographic restrictions on location. Nest construction results in morphological changes to the surface that include pit-mound topography, surface instability, pedoturbation, and erosion. Constructions have been found on ridges, saddle regions, and variable slope (flat–40°) terrain. Because of their conspicuous nature, they are one of the most researched zoogeomorphology categories (22% of literature included in content analysis, n=106). For this study, only nest sites with fully exposed and partial-bare soil nest cups were considered. Zoogeomorphic activity found in the literature includes direct and indirect evidence of nest site construction.

A meta-analysis of the data revealed a total of 2851 individual soil nest sites with an average life span of 4.3 days for bare soil sites and 19.1 days for semi-bare soil nests (Blom et al., 2001). A total of 379 group nesting areas were counted where either all individuals in the group constructed a soil nest or at least one soil nest was accounted for in the literature. Only one observation of a gorilla engaging in day nest construction was found in the literature. Unfortunately, only a single depth measurement of a nest cup (38 cm) was recovered from the literature from Schaller (1963). He also noted a nest rim made from nearby vegetation constructed 61 cm high from the surface. The gorilla rested on the soil bottom.

4.5 Excavated insect mounds

Gorillas search for surface and subsurface dwelling insects (e.g., ants, termites) to consume by mechanically dismantling or digging up mounds. Fragments are then further broken apart to reveal insects (Cipolletta et al., 2006). It is a patchily distributed and seasonal behaviour that results in faunal turbation of termitaria and surface soil, and in situ weathering and erosion of mound pits. Four articles documented zoogeomorphic impacts from mound excavation for *G. gorilla* and *G. berengei* within four protected areas (i.e., D–SDFR, D–NNP, LP, VNP). Data consisted of observed bouts of mound dismantling, number of visits to mounds, and evidence of disturbance where there was no gorilla present but adjacent knuckle prints were clearly visible next to mound. A meta-analysis of data in the literature revealed that soil particles ranged in size from 3 cm to 50 cm wide ($\bar{x}$=13.5 cm, n=203). Cipolletta et al. (2006) recorded soil bits that reached 5cm in length. 540 bouts of gorillas excavating mounds were documented with a total of 150 observed minutes. On average gorillas spent 25 minutes breaking apart mounds. A total of 764 affected mounds were accounted for in the literature. 506 were insect nests constructed against large trees. 9 nests had to be dug out of the ground, and 94 were free-standing mounds. 96 broken mounds were broken to harvest *Cubitermes sp* and 5 to access *Dorylus sp*. A total of 446 ($\bar{x}$=111) visits to mounds were counted. No data could be found on the extent of displaced soil or size of pits created.

4.6 Trampling

Trampling occurs when frequently used areas result in a visible contrast between degraded areas of vegetation loss and adjacent areas with intact surfaces. Trampling alters plant communities by compacting the soil and influencing infiltration rates and leads to physio-chemical changes from compaction and deposition of faecal matter (Butler, 1995). Trampling has been documented among eastern gorillas (*G. beringei*, *G. graueri*) within VNP only. *G. beringei* had the greatest impact in bamboo habitats with a total of 10 m^2 of affected area and in the saddle region of VNP, evidence of 5 m^2 (Plumptre, 1993) of trampling. A meta-analysis of *G. graueri* ranging data gathered from Yamagiwa (1991) returned a total average distance travelled (m) between feeding sites of 695 m. From that total, 237 m were travelled between two ant feeding sites and the remaining 458 m were between ant feeding sites and "other" (250) feeding sites. Gorillas targeted 8 sites located on ridges and 10 sites on slopes (no percent gradient provided). Although no evidence of trampling was provided, the author cited frequent insectivore during the wet and dry seasons. This leads to the assumption that some degree of trampling exists on the condition that the same feeding sites are consistently targeted. To gain an understanding of potential pressure exerted on the surface from ranging, a meta-analysis of average touch-off pressure (N/cm^2) data (Matarazzo, 2013) was conducted. Seven captive individuals (3 silverbacks, 4 adult females) exert a total average pressure of 14.07 N/cm^2/hand (20.41 lbs/in^2; 28.14 N/cm^2, 40.81 lbs/in^2 for both hands) and an average 2.01 N/cm^2/hand (2.91 lbs/in^2; 4.02 N/cm^2, 5.83 lbs/in^2 for both hands) of pressure per individual. Gorilla groups range from 2–30 individuals per group (Schaller, 1963), therefore, the degree of pressure exerted on the earth's surface ranges between 8.04 N/cm^2 (11.6 lbs/in^2) of pressure for small groups and a maximum 120.6 N/cm^2 (174.9 lbs/in^2) of pressure for large groups. These values will vary with group structure, area, and habitat use. The primary argument is that gorillas have the potential for extensive trampling and transformation of surface dynamics. Further research is needed to document their zoogeomorphic imprint.

4.7 Hand/knuckle and footprints

Gorillas exhibit primarily quadrupedal knuckle–walking locomotion with occasional bipedalism (Matarazzo, 2013). Their weight (136–68 kg) and the extent of surface area covered by their foot and knuckle prints initiates variable degrees of geomorphic influence on access trails. Transport and mixing of soil occur when dirt is sucked beneath their feet and hands and is deposited in other locations. These effects are pronounced in soft terrain such as mud and sand where imprints can be deep. A meta-analysis of Schaller's (1963) measurements of gorilla tracks returned an average disturbed surface area of 134.4 cm^2 (12.8 cm width by 10.5 cm length) for one knuckle print and 409.2 cm^2 (15.1 cm width by 27.1 cm length) for one footprint. Theoretically, if all four extremities are considered, one individual has the potential to impact 0.026 m^2 of surface area with both knuckles and 0.081 m^2 with both feet in a single step. Gorillas exhibit an even distribution of surface pressure along their knuckles when they touch-off the ground during movement. A total of 466 tracks and 54 trails with clear foot and knuckle prints were accounted for in the literature. Cipolleta et al. (2006) noted *G. gorilla* knuckle prints during 13 days in the field. The content analysis indicated studies documenting surface disturbance from foot and knuckle prints was scarce compared to other zoogeomorphology categories. Six individual accounts of measured earth disturbance (all from Schaller, 1963) made up 13 percent of quantified zoogeomorphic data sets (n=45) available across all categories. Three cases of either observed zoogeomorphic behaviour or physical indications of zoogeomorphic activity made up 5 percent of all qualitative zoogeomorphic data sets (n=61) available across all categories. Together, available data suggesting the geomorphic significance of gorilla tracks is a mere 8 percent (n=106) indicating a need for more research.

4.8 Tool use

The definition of tool use has undergone multiple revisions and is a behaviour rarely observed among wild gorillas (Grueter et al., 2013). Beck's (1980) definition is widely accepted and defines tool use as "*the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper and effective orientation of the tool*". The content analysis revealed one observed occurrence of tool use of geomorphic significance. Breuer, Ndoundou–Hockemba, and Fishlock (2005) documented a female *G. gorilla* that used a detached tree branch to probe swampy substrate to test the water depth in front of her as she attempted to cross. Within the context of zoogeomorphology, emphasis is not on the behaviour but on the geomorphic implications. The prodding action and wading by the gorilla contribute to mixing and transport of swamp bottom substrate and disrupts the structural function of hydrophytic vegetation if disturbed.

4.9 Trunk uprooting

Trunk uprooting is the mechanical displacement of shrubs or trees resulting in pit-mound microtopography which contributes to local soil erosion and mixing of horizons. The destabilizing effects of trunk uprooting are pronounced on slopes (Pawlik, 2013) when the structural root architecture is removed. Two articles documenting this activity were obtained from the content analysis making up 1.8 percent of all zoogeomorphic datasets (n=106) available across all categories. No attempts were taken to measure the degree of soil displaced from the resulting pit-mound formations. Watts (1989) observed a male silverback uproot a tree trunk to dismantle an ant mound supported by its base. Breuer, Ndoundou–Hockemba, and Fishlock (2005) witnessed a female uproot a small tree trunk (approximately 1.3 cm long and 5 cm thick) at the edge of a swampy clearing. She used the trunk with one hand to stabilize herself while she dredged aquatic herbs towards her with the other arm.

5. Conclusion

Gorillas have captured the attention of researchers from many scientific disciplines, but few studies have provided detailed zoogeomorphological data on their impacts on the landscape. Current studies on these increasingly threatened animals have made substantial contributions to their protection and conservation of their habitats. Lacking is research exploring the role of gorillas as zoogeomorphic agents.

This study has identified nine categories of zoogeomorphic impacts by gorillas, all of which require additional quantification. Those categories include: (1) soil scratching and (2) soil scraping of the forest floor; (3) excavating chambers and holes; (4) bare/semi-bare soil nest site building; (5) hand/knuckle and footprints; (6) excavating insect mounds; (7) tool use and associated geomorphic implications (8) trunk uprooting, and (9) trampling.

Gorilla zoogeomorphic activity presented are intended to lay the grounds for future field study and invite new research insights into one of the most well-explored species on the planet. Research is necessary to refine our understanding of their role as bio-modifiers. Without this knowledge, vital pieces of information could be excluded in future conservation planning and habitat suitability modelling.

References

Beck B. 1980. *Animal Tool Use*. Garland STPM Press New York NY.

Belete M, Deng J, Zhou M, Wang K, You S, Hong Y, Weston M. 2018. A new approach to modeling water balance in Nile River Basin, Africa. *Sustainability* **10**(3): 810–824.

Blom A, Kpanou JB, Prins HHT, Almaši A, Heitkönig IMA. 2001. A survey of the apes in the Dzanga–Ndoki National Park, Central African Republic: A comparison between the census and survey methods of estimating the gorilla (Gorilla gorilla gorilla) and chimpanzee (Pan troglodytes) nest group density. *African Journal of Ecology* **39**(1): 98–105.

Booth S.N. 1971. Observations on the teeth of the mountain gorilla (Gorilla gorilla beringei). *American Journal of Physical Anthropology* **34**(1): 85–88.

Breuer T, Ndoundou–Hockemba M, Fishlock V. 2005. First observation of tool use in wild gorillas. *PLoS Biology* **3**(11): e380.

Butler DR. 1992. The grizzly bear as an erosional agent in mountainous terrain. *Zeitschrift für Geomorphologie* **36**(2): 179–189.

——— 1995. *Zoogeomorphology – Animals as geomorphic agents*. Cambridge University Press New York NY.

Butler DR, Sawyer CF. 2012. Introduction to the special issue – zoogeomorphology and ecosystem engineering. *Geomorphology* **157**–**158**(2012): 1–5.

Carroll RW. 1986. Status of the lowland gorilla and other wildlife in the Dzanga–Sangha Region of southwestern Central African Republic. *Primate Conservation* **7**: 38–41.

Casimir MJ. 1979. An analysis of gorilla nesting sites of the Mt. Kahuzi region (Zaïre). *Folia Primatologica* **32**(4): 290–308.

Cipolletta C, Spagnoletti N, Todd A, Robbins MM, Cohen H, Pacyna S. 2006. Termite feeding by Gorilla gorilla gorilla at Bai Hokou, Central African Republic. *International Journal of Primatology* **28**(2): 457–476.

Fossey D. 1983. *Gorillas in the Mist*. Houghton Mifflin Company Boston MA.

Grueter CC, Robbins MM, Ndagijimana F, Stoinski TS. 2013. Possible tool use in a mountain gorilla. *Behavioural Processes* **100**: 160–162.

Kayiranga A, Ndayisaba F, Nahayo L, Karamage F, Nsengiyumva JB, Mupenzi C, Nyesheja EM. 2017. Analysis of climate and topography impacts on the spatial distribution of vegetation in the Virunga Volcanoes massif of east-central Africa. *Geosciences (Switzerland)* **7**(17): 1–18.

Mahaney WC. 1993. Scanning electron microscopy of earth mined and eaten by mountain gorillas in the Virunga Mountains, Rwanda. *Primates* **34**(3): 311–319.

Mahaney WC, Watts DP, Hancock RGV. 1990. Geophagia by mountain gorillas (Gorilla gorilla beringei) in the Virunga Mountains, Rwanda. *Primates* **31**: 113–120.

Manning JT, Chamberlain AT. 1994. Fluctuating asymmetry in gorilla canines: A sensitive indicator of environmental stress. *Proceedings: Biological Sciences* **255**(1343): 189–193.

Matarazzo S. 2013. Manual pressure distribution patterns of knuckle–walking apes. *American Journal of Physical Anthropology* **152**(1): 44–50.

Mehlman PT, Doran DM. 2002. Influencing western gorilla nest construction at Mondika Research Center. *International Journal of Primatology* **23**(6): 1257–1285.

Nishihara T, Kuroda S. 1991. Soil-scratching behaviour by western lowland gorillas. *Folia Primatol* **57**(1): 48–51.

Plumptre AJ. 1993. The effects of trampling damage by herbivores on the vegetation of the Parc National des Volcans, Rwanda. *African Journal of Ecology* **32**(2): 115–129.

Remis MJ. 1993. Nesting behavior of lowland gorillas in the Dzanga–Sangha Reserve, Central African Republic: Implications for population estimates and understandings of group dynamics. *Tropics* **2**(4): 245–255.

Schaller G B. 1963. *The Mountain Gorilla. Ecology and Behavior*. The University of Chicago Press Chicago IL.

Tutin CEG, Fernandez M. 1983. Gorillas feeding on termites in Gabon, West Africa. *Journal of Mammalogy* **64**(3): 530–531.

Tutin CEG, Parnell RJ. 1995. Nest building by lowland gorillas in the Lope Reserve, Gabon: Environmental influences and implications for censusing. *International Journal of Primatology* **16**(1): 53–76.

Upstill–Goddard R, Salter ME, Mann PJ, Barnes J, Poulsen J, Dinga B, Fiske GJ, Holmes RM. 2017. The riverine source of CH4 and N2O from the Republic of Congo, western Congo Basin. *Biogeosciences* **14**(9): 2267–2281.

Watts DP. 1989. Ant eating behavior of mountain gorillas. *Primates* **30**(1): 121–125.

Wittiger L, Sunderland–Groves J. 2007. Tool use during display behavior in wild cross river gorillas. *American Journal of Primatology* **69**(11): 1307–1311.

Yamagiwa J, Mwanza N, Yumoto T, Maruhashi T. 1991. Ant eating by eastern lowland gorillas. *Primates* **32**: 247–253.