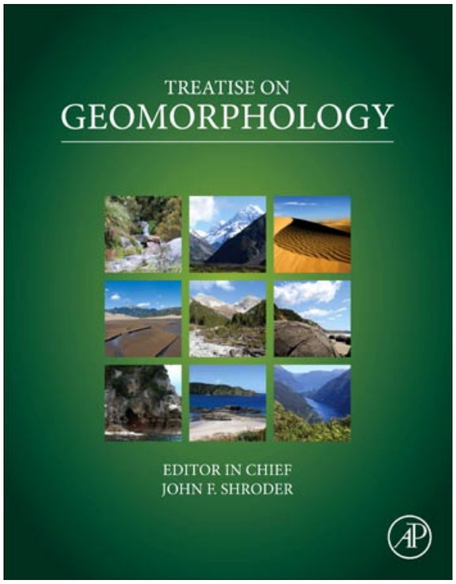

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12.16 The Faunal Influence: Geomorphic Form and Process

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Glossary

Ecotone A transition area of vegetation between two different plant communities, such as forest and grassland, or forest and tundra.
Geophagy The eating/ingestion of soil.
Lithophagy The eating/ingestion of rocks.
Phytogeomorphology The study of the geomorphic effects of plants.
Zoogeomorphology The study of the geomorphic effects of animals.

Abstract

Zoogeomorphology is the study of the geomorphic effects of animals, ranging from small invertebrates to large vertebrates such as elephants and bison. It was not until the late twentieth century that geomorphologists began examining the geomorphological activities of, and resultant landform features created by, animals. Animals engage in a variety of geomorphic activities including trampling, loading, digging/foraging for food, geophagy, lithophagy, nest building, burrowing, mound building, and damming of streams by beaver. These activities have both direct and indirect geomorphic impacts, as well as impacts on vegetation density, species richness, and distribution that, in turn, also have geomorphic influences. Feral animals and introduced species impact landscapes in much the same way as do free-ranging, native populations. We suggest that the zoogeomorphological effects of animals may be fruitfully examined at ecotones, where animal actions seem particularly notable and measurable.

12.16.1 Introduction

Zoogeomorphology is the study of the geomorphic effects of animals (Butler, 1992), including both invertebrates and vertebrates (both ectothermic, i.e., 'cold-blooded', and endothermic, i.e., 'warm-blooded'). The field of zoogeomorphology has expanded rapidly since the mid-1990s, with the publication of Butler's (1995) book *Zoogeomorphology – Animals as Geomorphic Agent* and many subsequent studies from around the world. At roughly the same time, the study of ecosystem engineering was being defined by Jones and associates in the field of ecology (Jones et al., 1994), with additional efforts in examining the role of animals as agents of landscape change coming from the field of wildlife management (e.g., Beyer et al., 1994).

Why, however, had the role of animals (the 'faunal influence') as agents of landscape development and change been essentially ignored up to the late twentieth century? Butler (1995) stated that traditional geomorphology textbooks focused on established geomorphic topics such as weathering, volcanism, and fluvial, glacial, and other surface processes but examined these processes in a world largely devoid of life. A recent study by Stine and Butler (2011) documented the dearth of biogeomorphology in geomorphology textbooks from throughout the twentieth and early twenty-first centuries, and even within the very limited amount of biogeomorphic material presented in those books, less (to none) of the material was devoted to the role of animals as geomorphic agents. Viles (1988) stated that the lack of geomorphic studies associated with biota was due to the influence and persistence of William Morris Davis's geographical cycle (Davis, 1899), with its focus on landscape scales of landform development

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through time. Another probable reason for the historical absence of zoogeomorphological studies was noted by Butler (1995), who indicated that many geomorphologists are trained in the fields of Earth science and have a poor background in the biological sciences. Butler believed that this limited background prevented geomorphologists from studying the effects of animals as geomorphic agents.

With the parallel development of the fields of zoogeomorphology and ecosystem engineering in the early-to-mid-1990s, conceptual frameworks were established within which the geomorphic impacts of fauna on the landscape could be assessed. In this chapter, we provide an overview of the major geomorphic influences of, and landforms created or shaped by, animals. We comment primarily on the effects of naturally occurring populations of animals in their native ranges; however, we also acknowledge the geomorphic impacts of domesticated animals as well as feral animals. Two subsequent chapters (*see* Chapters 12.18 and 12.20) in this volume of the treatise go into greater detail on two of the most geographically widespread and geomorphologically significant of these influences, the effects of burrowing by animals and the geomorphic and hydrological role of beavers on the landscape.

12.16.2 Categories of Geomorphic Impacts by Animals

Figure 1, taken from Butler (2006) and based originally on a similar version created by Hall and Lamont (2003), illustrates the primary geomorphic roles of animals on the landscape of the Earth. Categories include trampling, loading, digging, burrowing, and beaver damming. Butler (2006) noted definitions of each of these categories, and readers are referred to that paper.

12.16.2.1 Trampling and Loading

Each of the processes illustrated in **Figure 1** has both direct and indirect effects – trampling, for example, can directly remove sediment from a location by sediment clinging to, or being chiseled out of the ground, by hooves and paws of animals

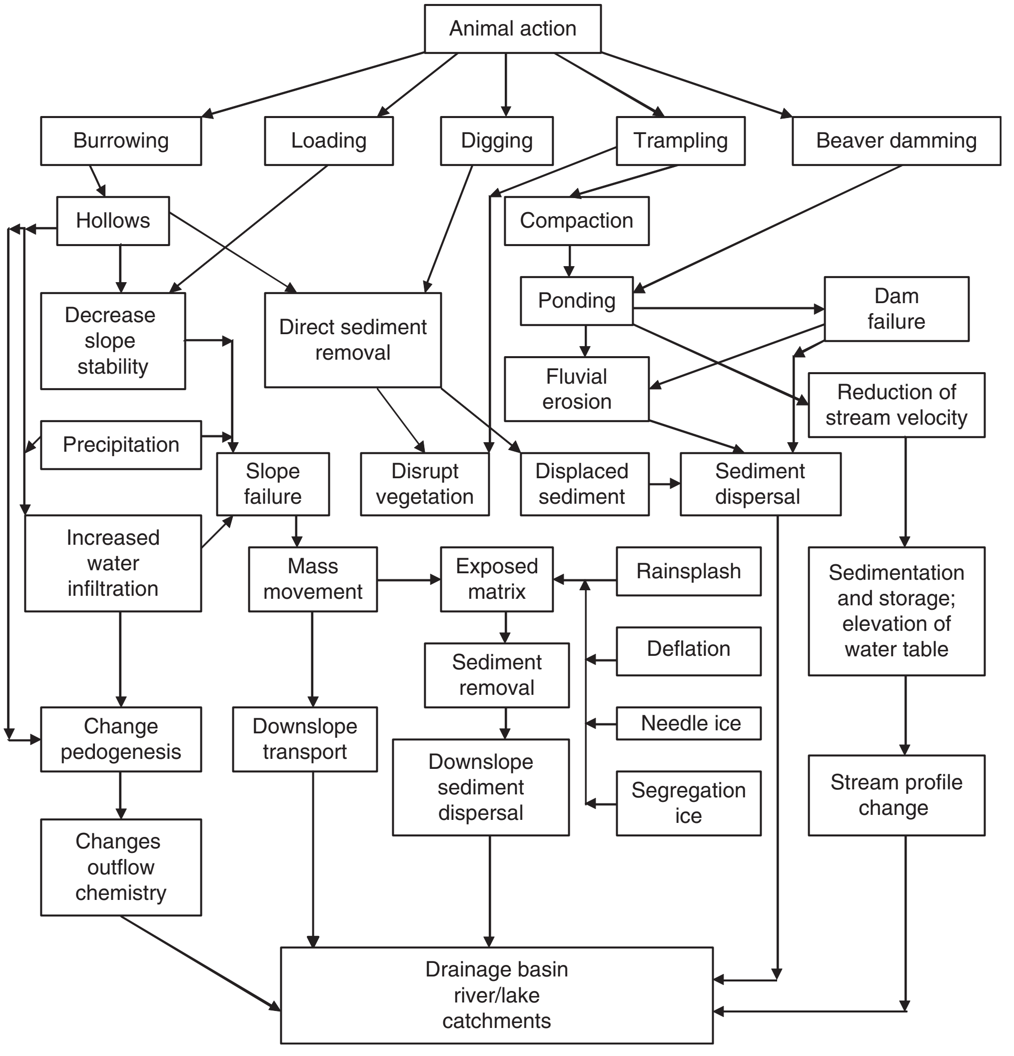

Figure 1 Flow paths of the geomorphic impacts of animals. Reproduced from Butler, D.R., 2006. Human-induced changes in animal populations and distributions, and their subsequent effects on fluvial systems. Geomorphology 79(3–4), 448–459, based on Hall and Lamont (2003).

(Bennett, 1999). Trampling by heavy animals such as hippos and elephants can create a widespread network of deeply incised trails (McCarthy et al., 1998) (**Figure 2**). Trampling also causes indirect effects by disrupting vegetation (see **Figure 1** for pathways), or compacting the surface and leading to ponding of water. In spite of the widespread acknowledgement of the impacts of trampling, few studies exist examining the actual forces induced by animals on ground surfaces. Bennett (1999) reviewed the scant literature available on the topic, and concluded that introduced grazing animals, for example, cattle and sheep, cause greater mechanical disruption of soil surfaces, leading to increased rates of soil erosion, compared to the indigenous grazing fauna of Australia.

Wallowing by large animals such as bison or elephants, which can conceptually be considered a form of trampling (Butler, 2006), exerts significant compacting force on the underlying sediment that may lead to ponding. Subsequent wallowing in mud in the same location initiates downward excavation via sediment removal as mud clings to the animal's coat/surface skin and is carried elsewhere (**Figure 3**). Wallowing also acts to concentrate carbon and nitrogen in the floor of wallows, leading to profound effects on soil biochemistry and local landscape heterogeneity (Eldridge and Rath, 2002).

Loading occurs when the weight of animals on a slope induces slope instability, and potential slope failure (**Figure 1**). Terracettes on hillslopes in areas where wild or

Figure 2 (a) Footprints of African elephant in sediment in Kruger National Park, South Africa, illustrating the broad trampling impact individual feet have. Note lens cap for scale. (b) Elephant and rhinoceros trail incised into the landscape, Kruger National Park, South Africa.

Figure 3 Elephant wallow, Kruger National Park, South Africa.

Figure 4 Terracettes attributed to elk grazing, Glacier National Park, Montana, USA.

domesticated animals graze have been attributed to loading (**Figure 4**), but few empirical studies exist to document this attribution. Loading in association with the effects of trampling were examined by Boelhouwers and Scheepers (2004) in hyper-arid Namibia, and it should be noted that loading and trampling, although illustrated as separate processes in **Figure 1**, will inevitably be operative together.

12.16.2.2 Digging

Digging is distinct from burrowing in **Figure 1**, although digging is certainly necessary in order to create a burrow. Digging in a nonburrow context refers to excavations of the surface by animals associated with food excavation, geophagy and lithophagy, and sediment excavation for habitat construction. Butler (1995) reviewed the scant literature on lithophagy (stone ingestion). Geophagy (soil ingestion) has received some recent attention among bird ecologists. Birds that practice soil ingestion, or geophagy, include geese, parrots, cockatoos, pigeons, cracids, passeriforms, hornbills, and cassuaries (Emmons and Stark, 1979; Wink et al., 1993; Diamond et al., 1999; Burger and Gochfeld, 2003). Beyer et al. (1994) reported percentages of soil ingestion in the diets of three avian species: sandpipers (*Calidris spp*.), 7–30%; Canadian geese (*Branton canadensis*), 8%; and wild turkey (*Meleagris gallopavo*), 9%. Munn (1994) studied parrot and macaw species' use of a clay-rich riverbank in the Peruvian Amazon as a nutrition source. Geomorphic impact was not discussed; however, it was noted that more than a thousand birds were viewed consuming the clay on the riverbank. Additional research on parrot and macaw geophagy in this region of the Peruvian Amazon has been published within the last decade. Brightsmith and Munoz-Najar (2004) observed 15 species of birds ingesting clay-rich soils during 191 h along the Tambopata River in southeastern Peru. Parrot, macaw, and parakeet species made up the majority of the Psittacidae family of birds present at the study site. Other species recorded include three pigeons, one guan, and one chachalaca. A total of 4334 birds were observed in a 56 m^2 area. The highest number of species to be seen practicing geophagy at a single site was reported as 28 species at a clay lick 500-m long and 25–30-m high along the western edge of the upper Tambopata River (Brightsmith, 2004). Powell et al. (2009) noted that up to 1700 parrots of 17 species were observed in a single day. Unfortunately, research addressing erosion rates along riverbank geophagy sites is wanting.

On the other end of the animal-size spectrum, geophagy by African elephants in Kenya significantly enlarges and modifies cave shape on Mount Elgon (Lundberg and McFarlane, 2006). Cave sediment is removed by 'tusking', an upward motion that carves out geophagous sediment from the cave wall in scars 2–4 cm wide and 10–30 cm long. Because of the size of elephants, tusking scars can extend up to 4 m high on cave walls, and up to 3 m deep on cave floors. Elephant geophagy also removes cave debris, further modifying the cavern system. Other examples of 'salt cave' excavation by geophagy have been described by Lundquist and Varnedoe (2006), who not only attribute some existing caves to geophagous excavation by modern animals such as bison and deer, but also note that some salt caves have been created via geophagy by now-extinct Pleistocene animals such as the milodon, a giant ground sloth.

Another unusual report of geophagy undertaken by large mammals was reported by Mattson et al. (1999), who described sites in Yellowstone National Park, Wyoming, USA, where grizzly bears (*Ursus arctos horribilis*) were excavating and consuming geothermally induced, hydrothermally altered sediments. Examination of 12 sites shows deep excavations, claw marks, and bear tracks. A total of 21 excavations at the 12 sites averaged 189.6 dm^3 in size, with a total excavated volume of 362.1 dm^3 per site. The ingested material was transported elsewhere, where it was later discovered in bear scats.

Digging for food (e.g., excavation of roots and tubers, digging out other animals in burrows/mounds) may cover a large local area. Foraging for food may result in notable landform creation and impacts upon surface and subsurface infiltration rates (Garkaklis et al., 1998, 2005). In the American western state of Idaho, for example, badgers (*Taxidea taxus*) excavate large volumes of soil and surface sediments that are deposited on the surface as fan-shaped mounds (**Figure 5**) while foraging for fossorial rodents (Eldridge, 2004). Densities of 790 mounds per hectare, covering 5–8% of the land surface, were recorded by Eldridge (2004) on the Snake River Plain of western Idaho. He estimated that these excavations and resultant mounded soil involved 26 tons of material per hectare. The surface distribution of mounds and excavations, in turn, produced impacts on the surface cover of plants, cryptogams, and litter, with attendant effects (**Figure 1**) on infiltration and surface runoff. The effect of American badgers is but one example of an animal with widespread geomorphic impacts via foraging efforts. Bragg et al. (2005) illustrated the significant geomorphic impacts of foraging porcupines in South Africa. Whitford (1998) described widespread foraging pits created by large goannas (*Varanus gouldii*) in eastern Australia, and illustrated that overgrazing by domesticated animals was reducing the spatial density of the pits. Two useful general reviews of the effects of animal foraging, and burrowing, in Australia (Eldridge and James, 2009) and from sites around the world including Australia, South Africa, Israel, and the USA (Garkaklis et al., 2004) contain quantitative data on foraging densities and tons of sediment excavated per site per year, and readers are directed to those publications for additional information. Additional examples of the geomorphic effects of digging for food may also be found in Butler (1995).

Birds are active geomorphic agents in excavating soil and rocks for construction of nests or nesting mounds, but little quantitative data exist from which conclusions can be drawn about the overall significance of these actions (Butler, 1995). Colonial seabirds excavate and utilize large numbers of pebbles in ground-nest construction (reviewed in Butler, 1995), but fewer studies have analyzed the impact of mud-nest construction. Brown and Root (1971) reported over 20 000 tons

Figure 5 American badger at burrow mouth with sediment fan.

of soda mud used by the lesser flamingos (*Phoeniconias minor*) of Tanzania, and Rowley (1970) reported that mud is a vital component in nest construction for approximately 5% of all bird species. Few of these species, however, construct nests entirely from mud. The Hirundinidea family, swallows and martins, are among those that do. Swallows are the only birds to build elevated attached nests composed entirely of mud (Rowley, 1970).

The barn swallow is the most widely distributed and abundant species of swallow in the world (Brown and Brown, 1999), indicating their potential as geomorphic agents. Barn swallows have a diverse habitat range and can occur in farmlands, rural areas, suburban areas, or villages. Colonial nesting sites occur in various structures such as barns or other farm outbuildings, bridges, wharves, boathouses, or culverts (Harrison, 1975). The colonies are relatively more abundant in human-built structures than in natural settings such as caverns and cliff sides. The site-specific requirements for their mud nests are the presence of a ledge and vertical wall to support the nest and a protective roof (Robbins et al., 1966; Link, 2004). They have an open-cup-shaped nest, compared to the gourd-shaped nest of the cliff swallow (**Figure 6**). Soler et al. (2007) reported an average nest volume of 189 cm^3 of sediment, although, the methods for this calculation were not described. Extrapolating that volume to the many thousands, if not millions, of nests around the world illustrates the

Figure 6 Barn swallow nests at Versailles, France.

potential geomorphic significance of nest-building activities, and offers an avenue for additional quantitative zoogeomorphic research.

12.16.2.3 Burrowing

Burrowing is a common process engaged in by a diversity of invertebrate and vertebrate species, ranging across a suite of insects and arthropods, worms, fish, amphibians, reptiles, birds, and mammals. Burrowing serves a variety of functions (Butler, 1995), including denning and rearing of young, protection of eggs, shelter from predators and protection from climatic stress, socialization, access to below-ground food sources, food caching, and sites for seasonal hibernation or estivation. In the broadest sense, burrowing encompasses features ranging from extensive underground tunnel complexes to simple shallow daybeds. **Figure 1** illustrates the myriad ways in which burrowing directly affects geomorphic processes. Additionally, through its influences on surface vegetation and soils, burrowing has indirect geomorphic ramifications via its influences on soil structure and texture, soil fertility, infiltration capacity, and the resulting changes wrought both in surface runoff and erosion and in production of vegetation cover (Butler, 1995). Because of the widespread nature and geomorphic significance of burrowing, Chapter 12.18 by Butler et al. in this volume of the treatise is devoted in detail to the direct and indirect geomorphic effects of burrowing and the related resultant landforms.

12.16.2.4 Beaver Damming

The genus *Castor* is comprised of two beaver species, the North American beaver (*Castor canadensis*) and the European beaver (*Castor fiber*). The former has been more intensively examined for its widespread geomorphic impacts across much of the continent of North America, but recent years have also seen a rise in interest in the impacts of European beaver. This recent interest has been associated with deliberate and inadvertent introductions and recovery of beaver populations in western and northern Europe. As one of the most significant ecosystem engineers (Jones et al., 1994) after humans, Chapter 12.20 in this volume of the treatise by Westbrook et al. is devoted to the geomorphological and hydrological impacts of beavers and beaver landforms, and readers are referred to that subsequent chapter.

12.16.3 Geomorphic Impacts of Domesticated and Feral Animals

Domesticated animals are easily included in the conceptual framework of **Figure 1**. The findings of Trimble and Mendel (1995) quantitatively demonstrated that heavy grazing by cattle, for example, increased soil compaction, reduced moisture infiltration, and enhanced surface runoff and erosion (**Figure 7**). Cattle trampling along river banks was also found to directly increase slope failure (loading) and result in increased erosion and sediment transport (Trimble, 1994; Trimble and Mendel, 1995).

The impacts of several domesticated animals as geomorphic agents has been well documented (Evans, 1998), and continues to be studied in various aspects (Isselin-Nondedeu et al., 2006; Isselin-Nondedeu and Bédécarrats, 2007). The impact of feral animals on the landscape, however, is generally difficult to recognize, and even more difficult to quantify. Feral hogs, whose geomorphic effects were briefly summarized by Butler (2006), disrupt vegetation via trampling, rooting for food, and creating hog wallows. Trampling and overgrazing by feral horses and burros, and the geomorphic actions of feral rabbits in Australia, have also been the focus of research summarized elsewhere (Butler, 2006).

Figure 7 Field overgrazed and heavily trampled by cattle, western Kansas, USA. Overgrazing allows invasion of field by ants. Ant mound is 18-cm high and 35-cm in diameter.

12.16.4 Zoogeomorphology at Ecotones

In establishing an agenda for additional and future research, we suggest that ecotones are ideal locations to study direct zoogeomorphological impacts and their attendant indirect effects on surface vegetation density and pattern. Alpine environments contain an abundant amount of wild animals and exhibit more readily identifiable disturbances than those that occur within the heart of an ecosystem (Butler, 1992; Hall et al., 1999; Hall and Lamont, 2003). Butler (1992) found that grizzly bears in Glacier National Park, Montana, USA, were likely to aid in the annual erosion of more sediment than a 100-year snow avalanche. Hall et al. (1999) found similar results for grizzly bear excavations in Canada. Doak and Loso (2003) emphasized the effects that excavation of dens by grizzly bears has on local vegetation in alpine regions, but focused primarily on the impacts to alpine vegetation density, richness, and pattern produced by bears removing vegetation via digging.

Research along alpine ecotones has focused primarily on the removal of soil and subsequent erosion of unconsolidated material. Insufficient research has been conducted on factors beyond excavation, trampling, and erosion. A logical avenue for future research should include not only the geomorphic impact that animals have on the environment, but also the secondary impact of vegetation on geomorphic features created by animals. In essence, the interaction of phytogeomorphology with zoogeomorphology is a likely worthwhile step for advancement of the discipline. Several early findings came close to this connection but failed to capture the heart of the connection. Moral (1984) was quick to identify the impact of Olympic Marmots on subalpine vegetation. He found that palatable vegetation near the center of marmot colonies was reduced and nonpalatable vegetation was greatly increased. The microgeomorphology created by the marmots was not included as an explanation of the distribution of vegetation. English and Bowers (1994) established that woodchuck (a species of the genus *Marmota*) burrows in fields were likely to alter vegetation characteristics of the entire field. They discovered that vegetation near burrows contained lower species richness but richness increased with distance from the burrow. Although actual burrows accounted for a small proportion of the entire field, the influence was evident over a much wider area. Although this study again identified the importance of marmots in vegetation distribution, geomorphology was not mentioned. The distribution of vegetation around marmot burrows was finally linked to the microscale geomorphic influences of marmots by Semenov et al. (2001), who found that plant species and richness surrounding primary marmot burrows in northern Siberia were greatly reduced. They also found that marmots modified the microtopography near the burrows and caused changes in soil properties that had a direct effect on the vegetation of the region (**Figure 8**). The connection between zoogeomorphology and the direct impact on vegetation has expanded to zokors in Tibet (Wang et al., 2008), pikas in Mongolia (Wesche et al., 2007), gophers in the American Cascade Range (Jones et al., 2008), and ungulates in Scandinavia (Cairns et al., 2007). This linkage between the impacts of phytogeomorphology and zoogeomorphology indicates substantial advancement of both subdisciplines and the foundation needed for continued study in the larger realm of biogeomorphology.

12.16.5 Conclusion

Research in zoogeomorphology has shown that animals are significant geomorphic agents, in a variety of environments, and need to be considered as important landscape drivers in

Figure 8 Marmot burrow and stony debris fan beneath the mouth of the burrow negatively impacts tundra vegetation, Olympic National Park, Washington, USA. Note lens cap for scale.

future geomorphology research. Future investigation of geomorphic agents should be conducted along ecotones where more apparent effects may be observed and quantified. Past research has poorly integrated the geomorphic effects of animals on plant distributions, and future research should attempt to identify linkages between these factors. These areas of cross-disciplinary research are ripe for study and exploitation by those willing to shed traditional research dogmas and conduct research beyond their home discipline.

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Biographical Sketch

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