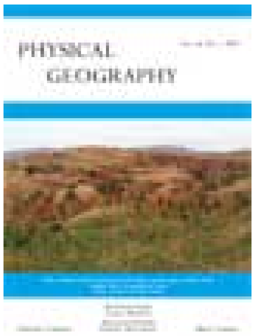

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It's an Insect's World, We Just Live on it: Exploring Entomogeomorphology as a Potential Subdiscipline of Geography

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It's an Insect's World, We Just Live on it: Exploring Entomogeomorphology as a Potential Subdiscipline of Geography

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ABSTRACT
There is little doubt insects and other "creepy crawlies" make up the bulk of life on Earth, and yet their immense influence on landscape change and development have not really garnered adequate attention in geomorphologic and zoogeographic research. What studies do exist focus almost exclusively on ants and termites. Unfortunately, this barely scratches the surface of the myriad of ways in which insects influence – and are influenced by – various landscape dynamics. There are so many more "earth movers" within the broad entomologic designation beyond the obvious anthills and burrows, and with them so much potential to discover new and exciting connections between Earth and its most abundant group of occupants. Honoring the chronically curious and exploratory legacy of the late Dr. Orme, this paper offers a review of extant research bridging geomorphology and entomology, supplemented by observational vignettes exploring "entomogeomorphology" as a potential branch of scientific exploration. Much like Dr. Orme's diverse research foci, there are very few landscapes left untouched by some form of insect activity and it is time we start paying more attention.

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INTRODUCTION

Thriving at the crossroads of countless scientific disciplines, geography and geomorphology are uniquely positioned to truly explore, and interpret, the world's complexities – one of which being the immeasurably dynamic influence of insects and terrestrial invertebrates on ecosystem evolution. While there is not necessarily a scarcity of research on the topic of entomological landscape change, the lack of cohesion and interdisciplinary collaboration among the literature has limited the potential of more comprehensive understanding. Inspired by the foundational concepts of biogeomorphology and

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TRIBUTE TO DR. ORMEAs an academic great-granddaughter of the late Dr. Anthony Orme, I never had the pleasure of working with him directly, but his passion and influence have transcended generations through inherited teachings, advice, and inspiration. What a profound testament to Dr. Orme's incredible legacy that his genuine curiosity and zeal for geography continue to shape and enrich scholars through his academic progeny. In the spirit of celebrating Dr. Orme's lineage, as well as his knack for finding meaning in even the most mundane details, this paper explores the small within the large: the role of insects and arachnids in shaping the world's landscapes and why they warrant a dedicated subdiscipline to best understand their complex environmental and geomorphological impact on Earth.

zoogeomorphology, this paper explores the potential benefits of establishing a new subfield within geomorphology – entomogeomorphology – dedicated to connecting the multitude of relevant literature and providing an academic foundation to further study insect:landscape interrelationships.

To that end, this paper serves two purposes: to highlight and review existing literature identifying common insect:landscape research themes, and to consider potential scales of entomogeomorphological studies via observational vignettes in true "Orme-ian" hands-on fashion. While spiders and other arthropods are biologically distinct from insects, much of their interactions with the physical landscapes are both significant and similar enough to be included under the "entomo-" terminology for the purpose of this paper. Just as Dr. Orme encouraged examining landscapes from various angles, the intent of this exploration is not to compile data or present findings, but rather to bring attention to a remarkable opportunity: bridging the gaps to construct an entomogeomorphologic framework and gaining an entirely new appreciation for the unimaginably diverse nexus of our planet and its most abundant residents – bugs.

EXTANT RESEARCH FOCI AND EXAMPLES

With most entomological species operating within one of the most complicated and dynamic interfaces on earth – its soils – there is little wonder why they have garnered attention from such a variety of scientific communities: from soil ecology (e.g. Jouquet et al., 2006) to agricultural economics (e.g. Bagyaraj et al., 2016); structural engineering (Jin & Kaplan, 2003) to bio-geo-chemistry (Dorn, 2014). Reflecting this diversity, the following review briefly highlights key research themes within entomogeomorphologic research from three primary perspectives: Insect-focused (e.g. entomology, biology), landscape-focused (e.g. agriculture, geography), and process-focused (e.g. engineering, ecology). Each subsection addresses geomorphologic insect and spider activity in unique ways and for vastly different purposes. Following each focus-specific discussion is simple observational vignettes – open-ended case studies – posing various pertinent questions, proposing future research ideas, and postulating the merits of a more collaborative entomogeomorphologic approach.

Entomology and insect behavioral research

In the simplest of terms, *entomology* is defined as "the study of insects" (Gullan & Cranston, 2010; Smith & Kennedy, 2009), so it stands to reason that the vast majority of entomology-based research on landscape change focuses on the insects themselves and how they impact – or are impacted by – said change. In fact, many of the earliest entomogeomorphologic studies fixated on tunneling insects as major geomorphologic agents, such as highlighting the rock decay potential of tropical ant species building multi-meter high anthills in Brazil (Branner & Reid, 1900) or endeavoring to classify the social and physical structure of nests created by various ant species in the UK – affectionately referred to as "Nature's Craftsmen" (McCook, 1907). Early studies such as these remained relatively observational and qualitative in nature, but they showcase an early recognition of the dynamic and complex relationship between insects and geomorphological processes.

Following the "Quantitative Revolution" throughout the geographic sciences (Chorley, 2019), there was a resurgence of entomological research regarding landscape

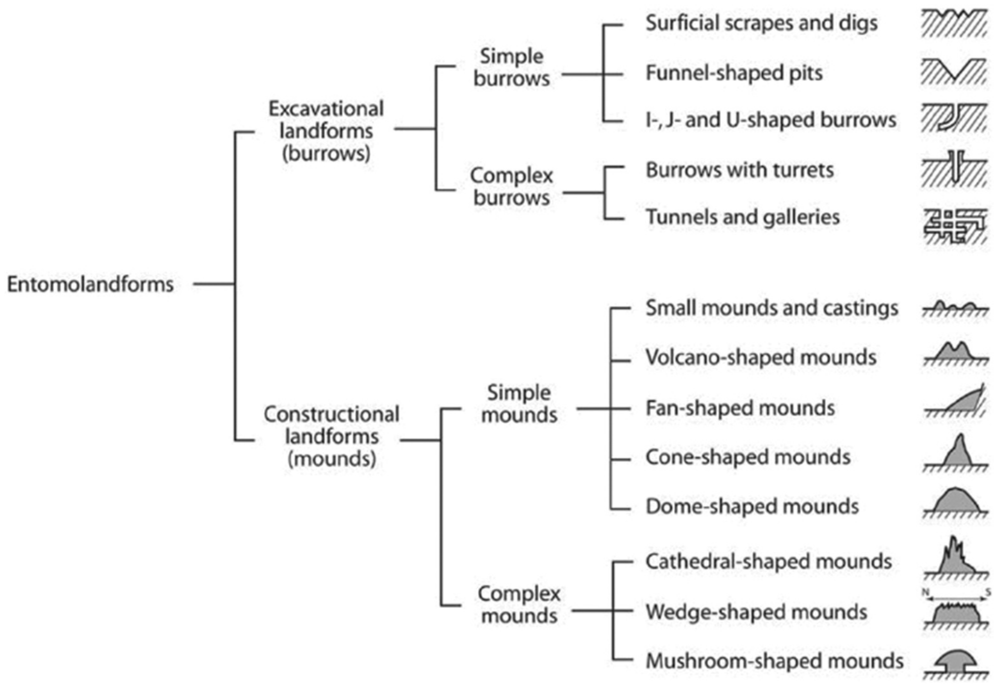

Figure 1. Basic breakdown of entomo-landforms from Bétard (2020), dividing forms into "excavational" and "constructional" categories.

change, again mostly related to burrowing ant and termite species (e.g. Butler, 1995; Goudie, 1988), as well as introducing new studies on insect-driven pedogensis (e.g. De Bruyn & Conacher, 1990; Cowan et al., 1985; Lavelle et al., 1997). More specifically, significant attention is given to direct habitat modification via various insect behaviors (e.g. trap hunting, burrowing, nesting, etc.) and how this relates back to species survival and evolution. Examples of such studies include researching the evolutionary convergence of certain mole crickets to more closely resemble their mammalian namesakes to better burrow in soils (Bidau, 2014); exploring the transient subterranean behaviors of nymphs and larvae, which later become terrestrial flying adults (Baird, 2014); or analyzing the underground burrows made by certain beetle species for seed hoarding and food caching (Hartke et al., 1998; Vander Wall & Smith, 1987), as well as periodic protection from predation (Gawałek et al., 2014). The current status of entomologically focused landscape change research is effectively presented by (Bétard, 2020), along with his proposed categorization of "entomo-landforms" – landscape features created directly through insect activities (Figure 1). Practicing this kind of entomological approach to landscape change, our first vignette explores insect and spider impacts within an abandoned church in the tropics:

Vignette #1: entomo-landforms of St. Joseph's Parish Church, Barbados

Approaching the imposing coral stone carcass of the desanctified St. Joseph's Parish Church in eastern Barbados feels almost post-apocalyptic: massive fissures transecting the entire

Figure 2. Different views of the St. Joseph's Parish Church: A) View of the crumbling exterior façade from the cemetery and walkway. Photo by Casey D. Allen, 2020. B) Interior of the structure from the southwest entrance. Much of the sunken foundation can be seen on the left of the image. Photo by author in 2020).

front façade, trees and vines emerging from seeming everywhere, broken stained glass windows now occupied by opportunistic birds and lizards (Figure 2). Cumulative land slippage has caused irreversible structural damage to the church's foundation and in October 2012, the structure was deemed no longer safe for worship, deconsecrated, and abandoned – although local caretakers continue to curate the adjacent cemetery and grounds (). The church's interior now houses an array of plants, animals, and, of course, insects – so what influences are they having on the church's crumbling edifices? Are they exacerbating foundation deterioration or perhaps provide structural cohesion and stability within loose materials? To address these questions, this vignette offers a brief preliminary exploration of entomo-landforms within the St. Joseph's Parish Church's interior and speculate their possible entomogeomorphologic ramifications.

Cursory examinations of the structure revealed three primary forms of entomogeomorphic activity: termite nests and trails, burrowing insect mounds, and spider webs/nests, (Figure 3). While there are several large termite trails across much of the western wall above the primary entrance, the only two visible nests were at the opposite end of the church in the northwest corner alcove. With the foundation cracked and large sections of heavily infested wooden substructure exposed, it is quite possible the termite trails coalesce below ground and transect the entire building – possibly exacerbating foundational instability. Subterranean insect activity is also indicated by a small scattering of soil mounds throughout the church. While the exact builders remain unknown, the very presence of the mounds suggest bioturbation below the church's foundation and the incremental removal of subsurface materials.

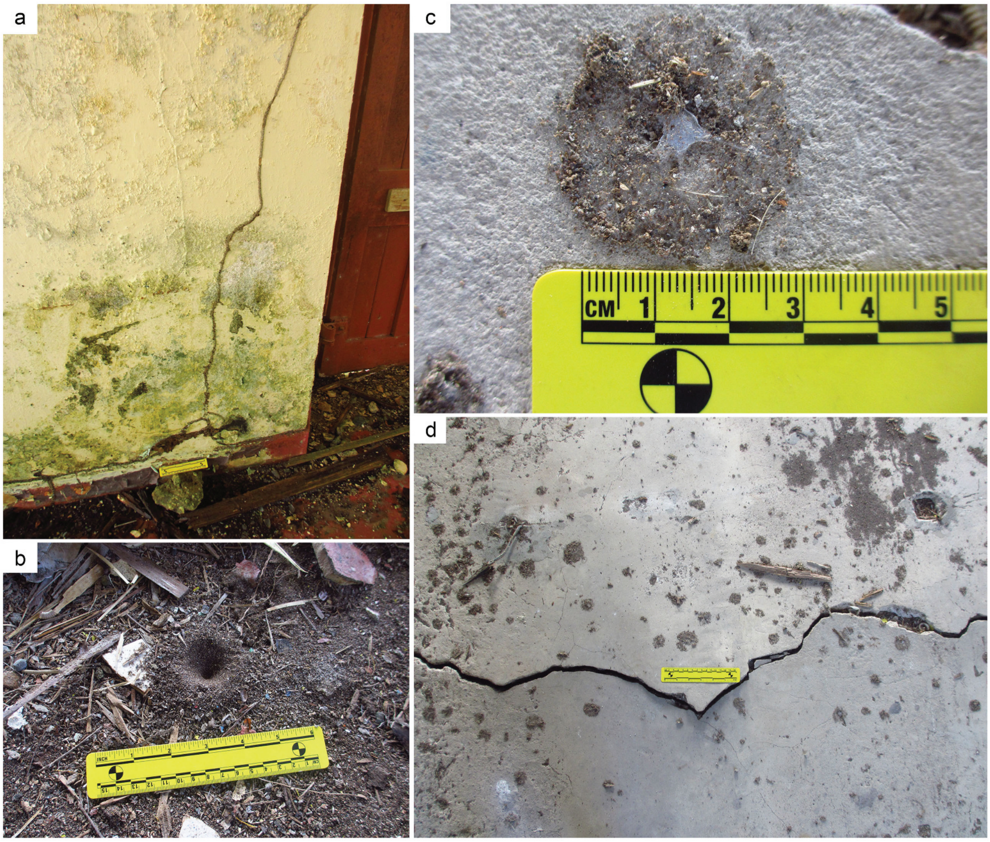

Figure 3. Entomo-landforms within the St. Joseph's Parish Church: A) Long termite trail running up the western wall by the main entrance. Note the nest in the chipped paint near the base of the wall. Similar nests are found throughout the structure. B) Small mound of detritus suggesting burrowing activity. Found mostly in areas of exposed sub-soils. C) Close-up view of a spider nest on the floor along the northern wall. D) Spread of spider nests along the main fissure in the northern foundation. All photographs by author, 2020.

Above ground, excavated materials are also being influenced by another group of entomogeomorphic agents recorded within the church: spiders. As expected with any abandoned building, there is an abundance of spider webs throughout the church, especially within the recesses and windows, however, more pertinent to this investigation were small burrowing spider nests on the ground that have accumulated collections of small particles and dust that would have otherwise eroded during rainfall events. The retention of soil materials by these spider colonies has perhaps enabled, or at least facilitated, the prolific advancement of epiphytic ferns and mosses across the church floor.

By no means is a complete list of insect activity with the St. Joseph's Parish church and substantially more research would be necessary to fully understand the complex impacts of their activities – but even this simple tour of the most obvious details poses a slew of intriguing questions regarding entomogeomorphic processes at play. Do the termites, in fact, underlay the entire church or are the exposed nests all separate colonies? Are the soil mounds refuse from termite activity below ground or from a different species? How deep do these burrows penetrate the church's subsurface? How much sediment has been "trapped" by ground nesting spiders and how has that impacted the growth of surrounding flora? Each and all of these questions have the potential to enhance scientific knowledge and understanding but require the encompassing – yet highly focused – lens of entomogeomorphology to untangle the intersecting dynamic of insect (and spider), landscape, and change.

Agricultural and landscape productivity research

Shifting focus from the insects themselves to the landscapes and ecosystems in which they play either beneficial or destructive roles takes us to another major branch of entomogeomorphologic research: agriculture. In fact, it would be fair to say the majority of existent research connecting insects with landscapes fit within this category. It is not difficult to see why when its main topics include key issues such as crop biodiversity, bioturbation and soil fertility, along with pest control and mitigation – each of global and economic significance. Must discussions within this area of study are not interested in why insects do what they do (i.e. entomology), but rather how they influence their surroundings and if their presence should be considered a blessing or a problem. The rest of this subsection with mirror this dualistic pattern by first exploring the ecological and agricultural benefits of entomogeomorphic activity and then addressing insects as pests and agents of landscape degradation.

Perhaps the most abundant topic of insect:landscape research, in agriculture and otherwise, is that of bioturbation – or how insects alter, move, perforate, and mix soils. Within soil sciences, the significance of "soil fauna" (which includes many insect species) within pedogenesis has been acknowledged for decades (Hole, 1981; Jenny, 1994), but very little research has been dedicated to understanding the complex geomorphological processes involved (Bétard, 2020; De Bruyn & Conacher, 1990) – due in part to the immense difficulty of obtaining detailed and reliable data from underground sources (Taylor et al., 2019; Wilkinson et al., 2009). Even though the exact processes and extents of insect bioturbation are still unclear, many studies have been able to identify their various positive indirect effects on soil productivity, including, but not limited to: increasing in carbon and nutrient levels (particularly nitrogen, phosphorus, and potassium) within soils by decomposing plant and animal materials underground (De Bruyn & Conacher, 1990); burrows and micropores increasing water retention and alleviating drought stress in crops (Johnson et al., 2016); enhancing soil aeration, humidity, and porosity by subterranean arthropods (Bagyaraj et al., 2016); as well as facilitating the processing and migration of surface soil litter into plant digestible compounds at root depth (Culliney, 2013).

As with most things, there are counterpoints and alternate views of insect activity and sustainable agriculture practices. The vast majority of literature on the subject of insect pestilence relates to herbivore species eating crops (c.f. Sharma et al., 2017), and while most of these studies are not necessarily directly related to geomorphology there have been some interesting studies on plant:soil feedback effects on above ground insect activity (Heinen et al., 2018; Kos et al., 2015). Additionally, and somewhat counterintuitively, some of the same studies discovering insect activity increases infiltration and water retention also found areas suggesting the opposite: casings and insect mounds creating bio-hardpans that increased runoff and erosion (Bagyaraj et al., 2016; Johnson et al., 2016). Soil erosion is a universal challenge far beyond just agriculture and requires a broader look at entomogeomorphic relations, and thus will be addressed in the next subsection. Before moving on, however, a brief musing on the compounding geomorphic impacts of pine beetle activity in the forests of Colorado's National Parks:

Vignette #2: pine beetles in the rockies – death of the forest or rebirth?

Embodying the vivid beauty of evergreen slopes, raw stone, and wild blue sky, the Rocky Mountain National Park (RMNP) in northern Colorado has undergone immense insect-driven landscape change over the past several decades. Slopes once covered by luscious verdant pine trees are now marred by desiccated grey foliage, barren escarpments, and naked trees dissected by burrows and scars (Figure 4). Who could have guessed the catalyst of such devastation would be an insect no bigger than a grain of rice? More than just the trees, the entire ecosystem has been altered by quite a formidable geomorphic and ecological agent: the Mountain Pine Beetle (Gibson et al., 2009). The visual impacts of pine beetle infestations are quite obvious but what of the park as a whole? The woods of the Rocky Mountains are far from the only forest transformed by pine beetles (Logan & Powell, 2001), so this vignette first speculates over repeat aerial photography within the RMNP, then ruminates the need for an integrated approach to better understand of beetle's general possible compounding entomogeomorphic influences on landscape evolution.

Visual analysis of the changing landscape surrounding Forest Lake within the head-land valley of the Big Thompson River reveal several interesting patterns and possible compounding entomogeomorphic impacts of mountain pine beetle infestation in the area (Figure 5). The most obvious changes are inconsistent tree density and color, advancing mass wasting to the northwest, and increased sedimentation of the lake itself –

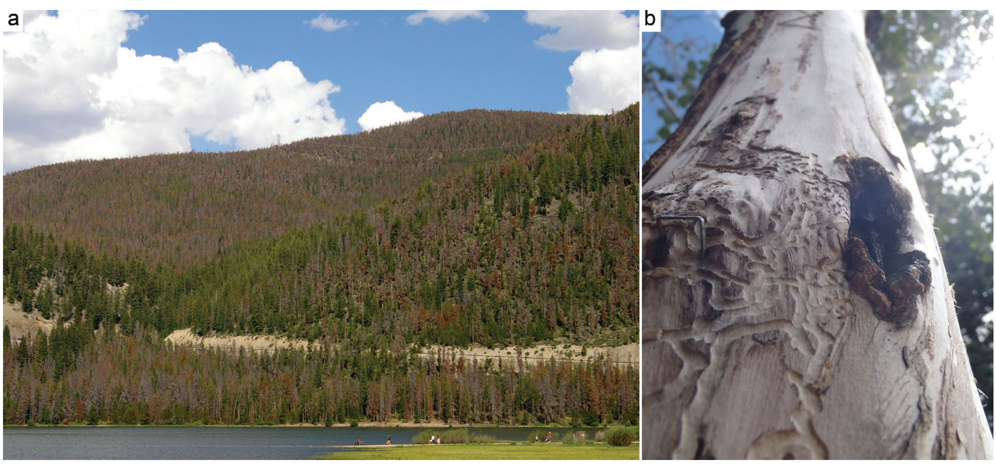

Figure 4. Beetle kill in the Colorado Rockies: A) Stand of pine trees showing the widespread mortality of beetle kill (brown-grey trees). Image from Wiki-Commons. B) Close-up view of beetle trails within exposed trunks of dead tree in RMNP. Photo by author 2015.

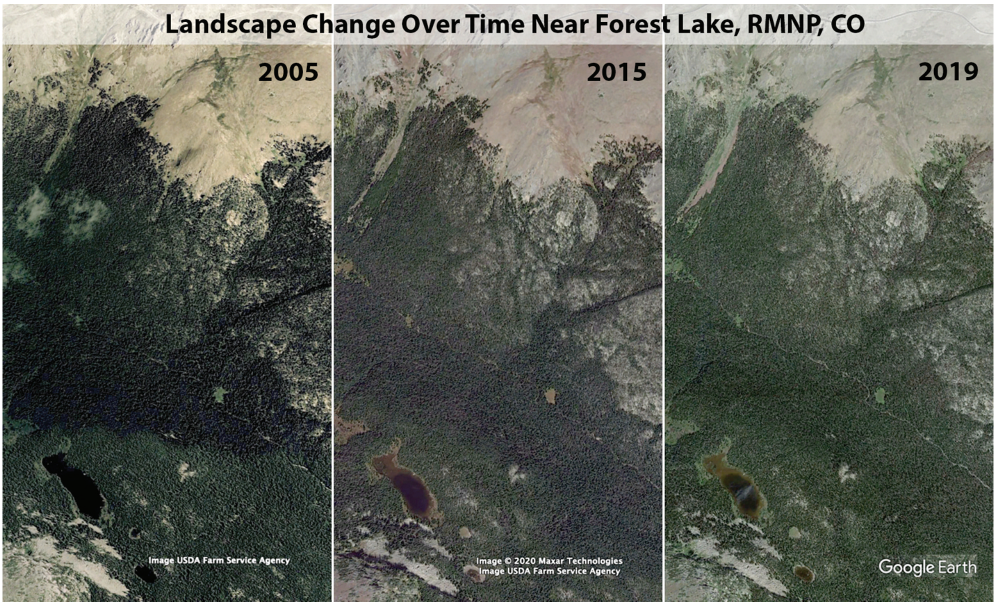

Figure 5. Repeat aerial photographs of Forest Lake in the RMNP. Sources of each photograph are included at the base of the image.

all three with possible ties to beetle activity. Loss of tree density and visual "browning" of the general canopy between 2005 and 2015 could easily relate to mortality from beetle activity and the resurgence in 2019 may indicate the regrowth of beetle resistant pine species or spreading aspen groves – as have been witnessed in many beetle laden forests (Pelz & Smith, 2013). The landslide scar in the upper left has growth considerably over the past several decades, most prominently between the 2015 and 2019 images with barren areas indicating active movement of materials. Are beetle occupied trees similar to post-fire trees and less resistant to mass movement? And what of Forest Lake itself? The transition from 2005 to 2019 shows a steady trend of sedimentation and possible eutrophication. Do pine beetles not only kill the trees but also alter soil chemistry or increase runoff potential? These questions may be rhetorical and based on circumstantial observations, but the possible implications of their study could reveal an entirely new perspective on forest evolution.

Exploring the holistic impact of pine beetles on forest geomorphology is a prime example of all the informational pieces being "on the board", so to speak, but disconnected and disjointed – thus eluding the larger trans-landscape implications and multidisciplinary examinations. There exist a plethora of papers and studies on the substantial ecological ramifications of mountain pine beetle populations (e.g. Kurz et al., 2008; Logan & Powell, 2001), even debating whether such infestations actually increase forest resilience in the long run (Romme et al., 1986). Similarly abundant are biological studies on the intense wildfire vulnerability of dead tree stands (e.g. Lydersen et al., 2019) and geomorphological investigations on landslide susceptibility of post-fire landscapes (e.g. Carabella et al., 2019), yet the connection of beetle activity and forest mass wasting remains relatively untouched. An entomogeomorphic approach is needed to connect these detached foci to better understand the complete impact of pine beetles on forest landscapes.

Ecosystem Engineering and Landscape Modification

Occupying yet another arm of the entomogeomorphology nexus is *how*, specifically, insects and arthropods construct, modify, and/or destabilize landscapes. We touched on this briefly in both previous sections (re: entomo-landforms in section one and soil erosion in section two) but here we will highlight the processes behind the forms and address insect driven landscape change on a broader scale. As with most organisms, many insect species have evolved to thrive within certain niches and exert energy to customize those niches to best fulfill their needs (Bétard, 2020; Cornelissen et al., 2016). Ongoing discussions within ecology classify such behavior as "ecosystem engineering" (Jones et al., 1994), although some studies have found not all bioengineering activities inherently benefit the "engineer" species (Jouquet et al., 2006).

The most obvious example of specifically *entomogeomorphologic* ecosystem engineering activities is perhaps the ubiquitous termite towers and debris piles, found in some places to represent an astounding 10 km^3 of excavated earth over 4000 years (Martin et al., 2018). Not only do these mounds signify a considerable amount of bioturbation, but also the creation of vast networks of subterranean tunnels and chemical modification of soils through the addition of bio-secretions and stabilizing agents (Jouquet et al., 2006). It is also worth noting that while many of these activities are quite miniscule their cumulative influence can alter major natural processes, such as caddisfly larvae altering stream sediment hydrology (Mason et al., 2019), certain mound building insect species excavating materials at the same rate, or greater, as much larger terrestrial mammals such as moles and groundhogs (Bétard, 2020), and the substantial potential for ants as biotic agents of stone deterioration (Dorn, 2014).

Within Bétard (2020)'s entomo-landform classification system (See Figure 1), nearly all exhibit a "mound" or "tunnel" moniker and are the result of deliberate ecosystem engineering, exerting direct – and indirect – influences on the host landscape. While this classification system represents encouraging progress towards establishing a legitimate "entomogeomorphology" subdiscipline, it remains overly focused on soil-based insect activity and risks neglecting other forms of insect:landscape interactions, such as potential insect-driven rock decay – something to be explored in our third and final vignette:

Vignette #3: desert beetles, spiders, and tafoni in petra, jordan

High above the narrow entrance to ancient Petra perches a lonely Nabataean monument: Djinn block X – a monolithic cube carved directly from the sandstone terrace upon which it stands resolute. Even more dramatic than its lofty station is this monument's mottled surface perforated with thousands of intricate and interlacing tafoni – cavernous rock decay features (Figure 6). Due to its relatively isolated location, only a handful of studies have been conducted at this site, mainly addressing possible environmental influences on the block's unique decay features (Groom, 2014; Paradise, 2013).

Take a second look, however, and another layer on this ancient stony colossus emerges – one of shimmery spider webs and delicate earthen nests: insect homes.

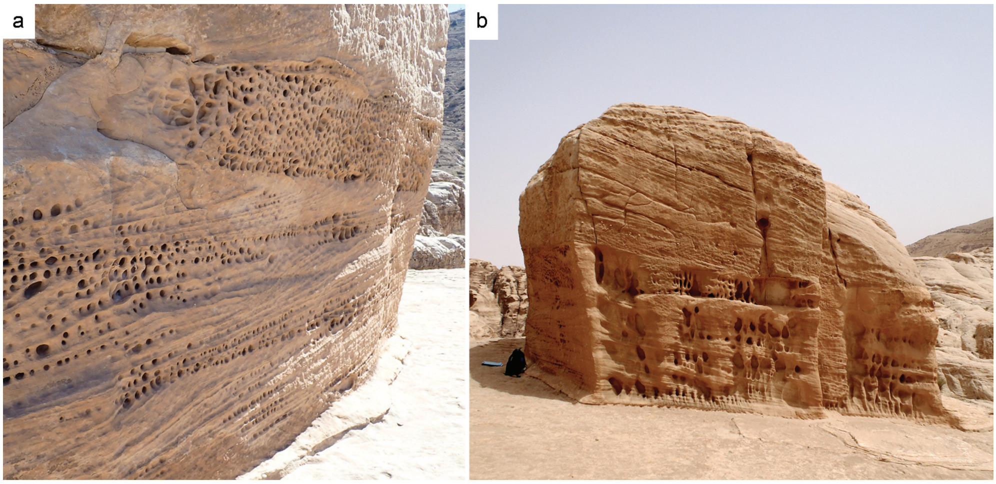

Figure 6. Tafoni and Setting of Djinn Block X above Petra, Jordan: A) Complex honey-combed tafoni across the western wall of the monument. Many of the caverns coalesce beneath the surface to create a "netted" structure. B) Context of the monument looking from the north. All four sides of the block have tafoni development and signs of insect occupation. Both photographs by author, 2016.

Nearly every aspect of Djinn Block X exhibits abundant tafoni and within many exist the miniature residences of desert spiders and winged beetles (Figure 7). To what extent are the petite caverns in which they dwell the result of pre-existing decay processes or the direct result of their presence? Did they actively excavate individual cells before occupation or merely take advantage of the shelter so generously offered by Mother Nature?

The question of influence does not stop with creation, either: now that these nests are built how might they impact the future rock decay? Do the lacey spider webs strewn across cavity openings enhance stone cohesion or exert destructive tension? And what of the chemical composition of regurgitated sediment used to construct earthen nests and barricade the small openings to various tafoni across the monument? Surely, these activities, at the very least, will have bearing on the development – or impediment – of rock decay features moving into the feature. And what of heritage management? Would it be best to remove such creatures? Or leave them be? There are so very few studies directed towards unraveling this mystery (Tiano, 2002; Wylie et al., 1987) – Even less related to stone heritage specifically, with nearly all sources focused on wood boring species only (c.f. Simonson, 1990). We need something new. Establishing an inherently multifaceted subdiscipline to adequately facilitate a better understanding of insect:rock decay relationships is critical to both scientific discovery and effectively informing conservation agencies across the globe.

THE CASE FOR "ENTOMOGEOMORPHOLOGY"

The road to "entomogeomorphology" has been largely pioneered by the development of two relatively young subdisciplines within the broader geomorphological context: "biogeomorphology" and the subsequent "zoogeomorphology". Both explore the dynamic relationships between the animate and inanimate – the geomorphologic implications of "life" – but to different levels of specificity. As the name indicates, "biogeomorphology" encompasses all forms of biota (flora *and* fauna) and how they influence,

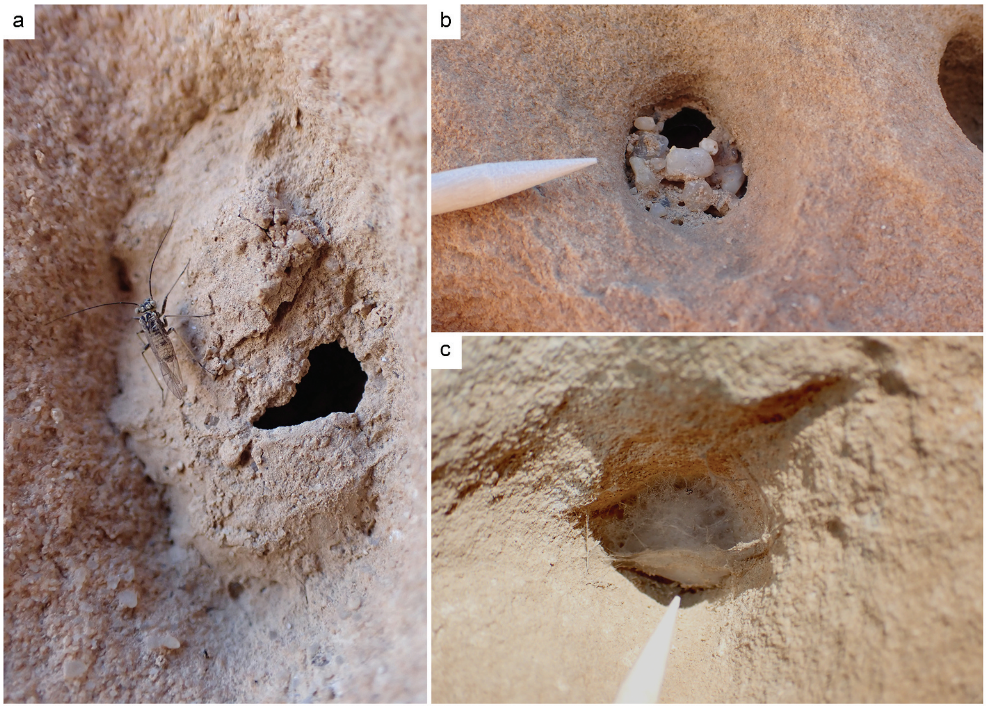

Figure 7. Insect activity and structures on Djinn Block X: A) Small earth covering tafoni cell with assumed insect occupant. The structure of the nest is approximately 6 cm tall and seems to be made of molded silt and fine-grained sand. B) Smaller nest constructed with sand clasts and pebbles. Tip of wooden stylus for scale. C) Silken nest, assumed to be spider-related, in deeper tafoni cell. Sand and dust particles stuck to outer edges. Same wooden stylus for scale. All photos by author, 2019.

and/or are influenced by, landscapes and landforms (H. A. Viles, 1988); while "zoogeomorphology", founded years later, focuses exclusively on animals as geomorphic agents, e.g. mole hills, beaver dams, fox holes, etc. (Butler, 1992, 1995).

The introductions of both subdisciplines were accompanied by convincing arguments for their validity, and necessity, for enhancing geomorphologic understanding – inspiring this paper's preliminary exploration of an even more specific "entomogeomorphology" subdiscipline. Addressing massive existential questions such as "how have life and landscape coevolved?" (H. Viles, 2020), the case for "biogeomorphology" is obvious and there have been many exciting advances in its implementation (c.f. Naylor et al., 2002). Commonly existing with the nexus of plant, earth, water, and soils, the study of insects as geomorphic agents falls squarely within the realm of biogeomorphology, but could also get easily buried under the grandeur of the subdiscipline's expansive breadth. Much like needing a magnifying glass to truly appreciate the complexity of an anthill when traversing a meadow, a more direct and concentrated body of literature and research is required to explore the specific geomorphologic interactions of insects and arthropods at and below Earth's surface.

Channeling the focus slightly, Butler (1995) argued for a more collaborative approach to biotic, specifically animal, roles in landscape development; noting significant strides in what he termed "zoogeomorphologic" research from biologists and animal ecologists as well as traditional geomorphologists (Butler, 1995). In his seminal book on the subject, Butler (1995) acknowledges the significance of terrestrial invertebrates – including insects – as drivers of landscape change, dedicating an entire chapter specifically to their study. That said, with insects composing the bulk of life on Earth, the study of their geomorphologic influence and role in landscape evolution deserve far more attention in the academic world. The establishment and promotion of "biogeomorphology" and "zoogeomorphology" have made major strides in that direction, but more is needed. The introduction of a highly focused, and yet inherently diverse subfield of "entomogeomorphology" could have a profound impact on developing a greater understanding of complex insect:landform interactions.

While Dr. Orme may never have published papers on insects or conducted research on their geomorphologic influences, he was not shy about promoting new ideas and the necessity of broadening scientific inquiries well into the multi-, trans-, and interdisciplinary realms in search of deeper understanding. In his own words:

> *" . . . when there are so many practicing geomorphologists, it is instructive to note that in the past many new ideas emerged from individuals who were reading widely and thinking deeply at the margins of conventional wisdom."*
>
> – Dr. Antony Orme (pg. 338; Orme, 2002)

Exploring the possibility of "entomogeomorphology" as an academic focus, in and of itself, celebrates this kind of marginal thinking with the capability of bridging myriad seemingly disparate disciplines. While this paper primarily presents a collection of musings and casual observations, it is difficult to deny the potential merit of entomologic/geomorphologic collaborations and a coherent subdiscipline dedicated to its investigation. In the end, I'd like to think a mind like Dr. Orme's would see a simple ant hill and stop to imagine what wonderfully complex and dynamic processes were taking place just under his feet. May that unfettered curiosity and intrepid quest for knowledge continue for many academic generations to come.

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Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

References

Bagyaraj, D., Nethravathi, C., & Nitin, K. (2016). Soil biodiversity and arthropods: Role in soil fertility. In A.K. Chakravarthy & S. Sridhara (Eds.), *Economic and ecological significance of arthropods in diversified ecosystems* (pp. 17–51). Springer.

Baird, I. R. (2014). Larval burrow morphology and groundwater dependence in a mire-dwelling dragonfly, Petalura gigantea (Odonata: Petaluridae). *International Journal of Odonatology*, *17* (2–3), 101–121. https://doi.org/10.1080/13887890.2014.932312
Bétard, F. (2020). Insects as zoogeomorphic agents: An extended review. *Earth Surface Processes and Landforms*, *45*(15), 3824–3841. https://doi.org/10.1002/esp.5003
Bidau, C. J. (2014). Patterns in Orthoptera biodiversity. I. Adaptations in ecological and evolutionary contexts. *Journal of Insect Biodiversity*, *2*(20), 1–39. https://doi.org/10.12976/jib/2014.2.20
Branner, J. C., & Reid, H. F. (1900). Ants as geologic agents in the tropics. *The Journal of Geology*, *8* (2), 151–153. https://doi.org/10.1086/620783
Butler, D. R. (1992). The grizzly bear as an erosional agent in mountainous terrain. *Zeitschrift für Geomorphologie*, *36*(2), 179–189. https://doi.org/10.1127/zfg/36/1992/179
Butler, D. R. (1995). *Zoogeomorphology: Animals as geomorphic agents*. Cambridge University Press.
Carabella, C., Miccadei, E., Paglia, G., & Sciarra, N. (2019). Post-wildfire landslide hazard assessment: The case of the 2017 Montagna del Morrone fire (Central Apennines, Italy). *Geosciences*, *9* (4), 175. https://doi.org/10.3390/geosciences9040175
Chorley, R. J. (2019). *Directions in geography*. Routledge.
Cornelissen, T., Cintra, F., & Santos, J. (2016). Shelter-building insects and their role as ecosystem engineers. *Neotropical Entomology*, *45*(1), 1–12. https://doi.org/10.1007/s13744-015-0348-8
Cowan, J., Humphreys, G., Mitchell, P., & Murphy, C. (1985). An assessment of pedoturbation by two species of mound-building ants, Camponotus intrepidus (Kirby) and Iridomyrmex purpureus (F. Smith). *Soil Research*, *23*(1), 95–107. https://doi.org/10.1071/SR9850095
Culliney, T. W. (2013). Role of arthropods in maintaining soil fertility. *Agriculture*, *3*(4), 629–659. https://doi.org/10.3390/agriculture3040629
De Bruyn, L., & Conacher, A. J. (1990). The role of termites and ants in soil modification-a review. *Soil Research*, *28*(1), 55–93. https://doi.org/10.1071/SR9900055
Dorn, R. I. (2014). Ants as a powerful biotic agent of olivine and plagioclase dissolution. *Geology*, *42*(9), 771–774. https://doi.org/10.1130/G35825.1
Gawałek, M., Dudek, K., Ekner-Grzyb, A., Kwiecinski, Z., & Sliwowska, J. H. (2014). Ecology of the field cricket (Gryllidae: Orthoptera) in farmland: The importance of livestock grazing. *North-Western Journal of Zoology*, *10*(2), 227-453. https://biozoojournals.ro/nwjz/content/v10n2/nwjz_141102_Gawalek.pdf
Gibson, K., Kegley, S., & Bentz, B. (2009). Mountain pine beetle. In *Forest insect and disease leaflet no. 2. FS-R6-RO-FIDL# 2/002-2009* (pp. 12). US Department of Agriculture, Forest Service, Pacific Northwest Region.
Goudie, A. (1988). *The geomorphological role of termites and earthworms in the tropics*. Paper presented at the Biogemorphology.
Groom, K. M. (2014). *Analysis of environmental influences on dressed stone decay: a case study of tafoni development on a hewn djinn block in petra, Jordan*. Masters of Science in Geography). University of Arkansas.
Gullan, P. J., & Cranston, P. S. (2010). *The insects: an outline of entomology* (4th ed.). Wiley & Sons Ltd.
Hartke, A., Drummond, F. A., & Liebman, M. (1998). Seed feeding, seed caching, and burrowing behaviors ofharpalus rufipesde geer larvae (Coleoptera: Carabidae) in the maine potato agroecosystem. *Biological Control*, *13*(2), 91–100. https://doi.org/10.1006/bcon.1998.0645
Heinen, R., Biere, A., Harvey, J. A., & Bezemer, T. M. (2018). Effects of soil organisms on aboveground plant-insect interactions in the field: Patterns, mechanisms and the role of methodology. *Frontiers in Ecology and Evolution*, *6*(106). https://doi.org/10.3389/fevo.2018.00106
Hole, F. D. (1981). Effects of animals on soil. *Geoderma*, *25*(1–2), 75–112. https://doi.org/10.1016/0016-7061(81)90008-2
Jenny, H. (1994). *Factors of soil formation: A system of quantitative pedology*. Courier Corporation.

Jin, H. J., & Kaplan, D. L. (2003). Mechanism of silk processing in insects and spiders. *Nature*, *424* (6952), 1057–1061. https://doi.org/10.1038/nature01809

Johnson, S. N., Lopaticki, G., Barnett, K., Facey, S. L., Powell, J. R., & Hartley, S. E. (2016). An insect ecosystem engineer alleviates drought stress in plants without increasing plant susceptibility to an above-ground herbivore. *Functional Ecology*, *30*(6), 894–902. https://doi.org/10.1111/1365-2435.12582

Jones, C. G., Lawton, J. H., & Shachak, M. (1994). Organisms as ecosystem engineers. In F.B. Samson & F.L. Knopf (Eds.), *Ecosystem management* (pp. 130–147). Springer.

Jouquet, P., Dauber, J., Lagerlöf, J., Lavelle, P., & Lepage, M. (2006). Soil invertebrates as ecosystem engineers: Intended and accidental effects on soil and feedback loops. *Applied Soil Ecology*, *32* (2), 153–164. https://doi.org/10.1016/j.apsoil.2005.07.004

Kos, M., Tuijl, M. A., De Roo, J., Mulder, P. P., & Bezemer, T. M. (2015). Species-specific plant–soil feedback effects on above-ground plant–insect interactions. *Journal of Ecology*, *103*(4), 904–914. https://doi.org/10.1111/1365-2745.12402

Kurz, W. A., Dymond, C., Stinson, G., Rampley, G., Neilson, E., Carroll, A., . . . Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature*, *452*(7190), 987–990. https://doi.org/10.1038/nature06777

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P.-A., Ineson, P., . . . Dhillion, S. (1997). Soil function in a changing world: The role of invertebrate ecosystem engineers. *European Journal of Soil Biology*, *33*(4), 159–193. https://www.documentation.ird.fr/hor/fdi:010015216

Logan, J. A., & Powell, J. A. (2001). Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). *American Entomologist*, *47*(3), 160–173. https://doi.org/10.1093/ae/47.3.160

Lydersen, J. M., Collins, B. M., Coppoletta, M., Jaffe, M. R., Northrop, H., & Stephens, S. L. (2019). Fuel dynamics and reburn severity following high-severity fire in a Sierra Nevada, USA, mixed-conifer forest. *Fire Ecology*, *15*(1), 43. https://doi.org/10.1186/s42408-019-0060-x

Martin, S. J., Funch, R. R., Hanson, P. R., & Yoo, E.-H. (2018). A vast 4,000-year-old spatial pattern of termite mounds. *Current Biology*, *28*(22), R1292–R1293. https://doi.org/10.1016/j.cub.2018.09.061

Mason, R. J., Rice, S. P., Wood, P. J., & Johnson, M. F. (2019). The zoogeomorphology of case-building caddisfly: Quantifying sediment use. *Earth Surface Processes and Landforms*, *44*(12), 2510–2525. https://doi.org/10.1002/esp.4670

McCook, H. C. (1907). *Nature's craftsmen: Popular studies of ants and other insects*. Harper & brothers.

Naylor, L., Viles, H., & Carter, N. (2002). Biogeomorphology revisited: Looking towards the future. *Geomorphology*, *47*(1), 3–14. https://doi.org/10.1016/S0169-555X(02)00137-X

Orme, A. R. (2002). Shifting paradigms in geomorphology: The fate of research ideas in an educational context. *Geomorphology*, *47*(2–4), 325–342. https://doi.org/10.1016/S0169-555X(02)00092-2

Paradise, T. R. (2013). Assessment of tafoni distribution and environmental factors on a sandstone djinn block above Petra, Jordan. *Applied Geography*, *42*, 176–185. https://doi.org/10.1016/j.apgeog.2013.04.011

Pelz, K. A., & Smith, F. W. (2013). How will aspen respond to mountain pine beetle? A review of literature and discussion of knowledge gaps. *Forest Ecology and Management*, *299*, 60–69. https://doi.org/10.1016/j.foreco.2013.01.008

Romme, W. H., Knight, D. H., & Yavitt, J. B. (1986). Mountain pine beetle outbreaks in the Rocky Mountains: Regulators of primary productivity? *The American Naturalist*, *127*(4), 484–494. https://doi.org/10.1086/284497

Sharma, S., Kooner, R., & Arora, R. (2017). Insect pests and crop losses. In R. Arora & S. Sandhu (Eds.), *Breeding insect resistant crops for sustainable agriculture* (pp. 45–66). Springer.

Simonson, K. E. (1990). Maintaining historic buildings: an annotated bibliography: US Department of the Interior.Washington, D.C., USA: U.S. Dept. of the Interior, NPS.

Smith, E. H., & Kennedy, G. G. (2009). History of entomology. In V.H. Resh & R.T. Cardé (Eds.), *Encyclopedia of Insects* (pp. 449–458). Elsevier.

Taylor, A., Lenoir, L., Vegerfors, B., & Persson, T. (2019). Ant and earthworm bioturbation in cold-temperate ecosystems. *Ecosystems*, *22*(5), 981–994. https://doi.org/10.1007/s10021-018-0317-2

Tiano, P. (2002). *Biodegradation of cultural heritage: Decay mechanisms and control methods*. Paper presented at the Seminar article.

Vander Wall, S. B., & Smith, K. G. (1987). Cache-protecting behavior of food-hoarding animals. In A.C. Kamil, J.R. Krebs & H.R. Pulliam (Eds.), *Foraging behavior* (pp. 611–644). Springer.

Viles, H. (2020). Biogeomorphology: Past, present and future. *Geomorphology*, *366*, 106809. https://doi.org/10.1016/j.geomorph.2019.06.022

Viles, H. A. (Ed). (1988). *Biogeomorphology*. Blackwell Publishing.

Wilkinson, M. T., Richards, P. J., & Humphreys, G. S. (2009). Breaking ground: Pedological, geological, and ecological implications of soil bioturbation. *Earth-Science Reviews*, *97*(1–4), 257–272. https://doi.org/10.1016/j.earscirev.2009.09.005

Wylie, F., Walsh, G., & Yule, R. (1987). Insect damage to aboriginal relics at burial and rock-art sites near Carnarvon in central Queensland. *Australian Journal of Entomology*, *26*(4), 335–345. https://doi.org/10.1111/j.1440-6055.1987.tb01978.x