Landform Analysis, Vol. 3: 35-40 (2002)

The environmental impact of crayfish biopedoturbation on a floodplain: Roanoke River, North Carolina Coastal Plain, U.S.A.

David R. Butler

The James and Marilyn Lovell Center for
Environmental Geography and Hazards Research
Department of Geography, Southwest Texas State University
San Marcos, TX 78666-4616, U.S.A.
e-mail: db25@swt.edu

Abstract: A terrestrial crustacean, the crayfish, creates widespread fine-scale landforms (mounds or "chimneys") on the floodplain of the Roanoke River in eastern North Carolina, U.S.A. These mounds are typically 12 cm high and 8 cm in diameter, and are composed of extremely high concentrations of clay. Non-crayfish-affected soils on the floodplain, regardless of coarser-scale landform type, are dominated by sand, illustrating that crayfish are a primary mechanism for concentrating clay and creating spatial heterogeneity on the floodplain.

Key words: zoogeomorphology, biopedoturbation, crayfish, Roanoke River, North Carolina

Introduction

Zoogeomorphology is the study of the role of animals as geomorphic agents (Butler, 1995). Recent years have seen a surge of interest in the methods by which animals geomorphically influence their environment. Examples include several papers that examine the geomorphological role of dam-building and excavations by beavers in North America and Europe (Butler & Malanson, 1995; Burns & McDonnell, 1998; Gurnell, 1998; Hillman, 1998; Meentemeyer *et al.*, 1998; Meentemeyer & Butler, 1999); burrowing by ground squirrels (Andersen, 1996), arctic foxes (Anthony, 1996), pocket gophers (Inouye *et al.*, 1997), rabbits (Pickard, 1999), and voles (Gómez-Garcia *et al.*, 1999); grazing and digging for food (Boeken *et al.*, 1995; Mallick *et al.*, 1997; Mattson, 1997; Mattson & Reinhart, 1997; Evans, 1998; Tardiff & Stanford, 1998); trampling by large herbivores such as bison, cattle, and sheep (Govers & Poesen, 1998; Fritz *et al.*, 1999; Hall *et al.*, 1999); geophagy (soil-eating) (Mahaney *et al.*, 1996a, 1996b); and the effects of fish on sedimentation patterns in tropical streams (Flecker, 1996).

In spite of this recent interest in the role of larger animals as geomorphic agents, however, it is noteworthy that little attention has been paid to the geomorphic impact of invertebrates, although invertebrates are among the most widespread and common of all animals on the planet (Butler, 1995). Exceptions include works that have examined the geomorphic and hydrologic effects of earthworms (Haria, 1995), ants (Hululgalle, 1995; Butler, 1996; Green *et al.*, 1999), scorpions (Rutin, 1996, 1998), snails and isopods (Shachak *et al.*, 1995), river crabs (Onda and Itakura, 1997), and salt-water mud shrimp (Ziebis *et al.*, 1996). This paper describes the geomorphology of crayfish mounds ("chimneys"), and examines the mound particle-size texture, compared to non-crayfish-affected soils on portions of the floodplain of the Roanoke River, on the Coastal Plain of eastern North Carolina, USA.

Background

Crayfish are terrestrial crustaceans found in low-lying terrain throughout the Gulf Coast region of the southern United States, as well as in such diverse habitats as the midwestern United States, eastern Canada, and Australia (Hobbs, 1981; Butler, 1995). Many crayfish species dig deep vertical and complex shafts leading to long-lasting underground burrows. Crayfish burrowing has occurred as a geomorphic and pedoturbational activity since at least the Triassic period (Hasiotis & Mitchell, 1993; Hasiotis et al., 1993).

The significance of crayfish as agents of zoogeomorphological landscape modification was first described in detail by Tarr (1884). His illustrations of crayfish mounds and burrows remain the standard, as witnessed by their utilization in a modified form by Grow (1981) in her examination of the burrowing behavior of crayfish (Figs. 2–4).

Crayfish burrows are complex and may be as long as 4–5 m (Hobbs, 1981; Hasiotis, Mitchell & Dubiel, 1993). Hobbs (1981) identified three categories of crayfish burrowers and burrows based on the amount of time spent in the burrow, its architecture, and its connection to open water:

- *Primary:* Crayfish construct burrows with complex architecture, unattached to open water, and spend the majority of their life in the burrow. Burrows are vertical, obtain great length, and branch out horizontally below the local water table (Hobbs & Whiteman, 1991; Hasiotis & Mitchell, 1993; Stone, 1993);
- *Secondary:* Crayfish construct burrows that are attached to open water and exhibit some branching and chamber development, and spend much time out of the burrow (Hobbs, 1981; Hasiotis & Mitchell, 1993); and
- *Tertiary:* Crayfish spend most of their lives in open water, burrowing only to reproduce or to escape desiccation (Hobbs, 1981).

The digging of burrows by crayfish results in the excavation and subsequent deposition of surface sediment. These deposits typically take the form of steep, conical mounds also known as crayfish "chimneys" or "turrets" (Fig. 1). The chimneys are surface entry points to a tunnel system frequently over 1 m in depth and chiefly 4–8 cm in diameter (Stone, 1993). In many cases the mounds, reportedly composed of silt and/or clay, become case-hardened by the sun so that they are an impediment to farm machinery. Burrows may so permeate the subsurface that farm machinery and livestock break through the surface and collapse into the underlying burrow system (Hobbs & Whiteman, 1991; Stone, 1993). The pedoturbational activities in burrow excavation and mound emplacement also, in some cases, bring deleterious levels of sodium salts to the surface, harming agricultural usage of the area (Hobbs & Whiteman, 1991).

The morphology and density of crayfish chimneys have been described in some detail. Hobbs (1884) reported a typical mound size as 15 cm wide and 10 cm high, and Grow and Merchant (1980, p. 231) reported mounds ranging in height from "a low mound to a tower more than 30 cm high". The most detailed descriptions of crayfish mounds were provided by Hobbs and Whiteman (1991). They reported densities of 2,730 mounds per hectare from one site in eastern Texas, with average mound heights of 12 cm and diameters of 28 cm. They reported that >17,000 kg of soil and 40 kg of sodium per hectare were brought to the surface each year, such that the entire surface "must have exhibited some stage of mound construction or erosion over a period of <3 years" (p. 128). At six other east Texas study sites described by Hobbs and Whiteman (1991), the estimated number of mounds per hectare was 44,124 (averaging 7 cm tall and 15 cm in diameter), 63,505, 31,214, 62,676, 61,775 (covering 15% of the surface area), and 42,470 (with >40,000 kg of soil moved per hectare). Individual mounds examined weighed up to 40 kg, although 11–25 kg was the normal range.

Fig. 1. Typical crayfish mound on the Roanoke River floodplain. Lens cap is 49 mm in diameter

The density of crayfish burrows and tunnels in areas of the southern Gulf Coast of east Texas, western Mississippi, and eastern Alabama is in fact so great that crayfish are a primary factor in the hydrology of the region. Stone (1993, p. 1,099) stated that, in poorly drained areas, "[w]hen water tables are near the surface, however, the network of large-diameter crayfish tunnels [...] allows lateral flow at rates unlikely to be equaled by the activity of any other burrowing organism", and noted that the effectiveness of crayfish in "mixing the surface of a very poorly drained soil seems comparable to that of large earthworms such as *Lumbricus terrestris* L. (alone or together with burrowing predators)". These conclusions about the hydrological effects of crayfish echo those presented by Onda and Itakura (1997) concerning river crabs, and illustrate the profound effects that terrestrial crustaceans can have on the geomorphology and hydrology of low-lying floodplains around the world.

The study area

The lower Roanoke River floodplain is located in eastern North Carolina, on the Coastal Plain physiographic province of the southeastern United States (Fig. 2). The floodplain contains a mosaic of alluvial bottomland forests that have developed as a consequence of complex and interrelated geomorphic, hydrologic and ecological processes. Floodplain topography is subtle, but small elevational differences can result in major differences in drainage, soils, and vegetation community composition. The annual flooding cycle constitutes the dominant geomorphic process influencing floodplain topography. Geomorphic features of the floodplain include oxbow lakes, natural levees, meander scrolls (ridge and

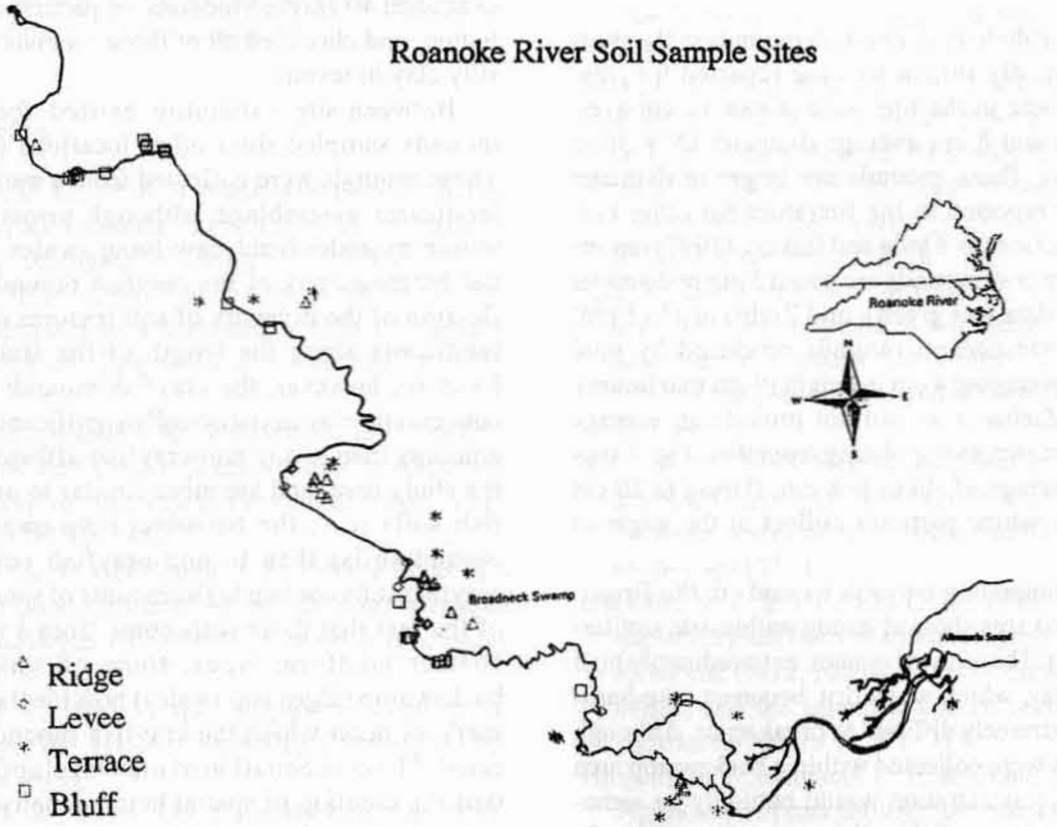

Fig. 2. Map of the soil sampling sites, Roanoke River, North Carolina. The location of the Broadneck Swamp intensive study area is labeled

swale topography), point bars, sloughs (areas of stagnant or sluggish water in meander scroll depressions), backswamp deposits, and terraces (Townsend & Butler, 1996).

Methods

Crayfish construct conspicuous entrance mounds, and these chimneys are particularly ubiquitous in backswamps of the lower Roanoke River, typically associated with the low-lying swales between adjacent "swells" or ridges. High numbers of mounds are located in the areas of Broadneck Swamp, and soils were collected from 30 crayfish mounds within a 10 m x 30 m plot in this area. An additional 13 mounds were randomly selected from a variety of additional floodplain sites, in order to determine the degree of spatial heterogeneity of crayfish mounds. Mounds were also photographed in the field, and the diameter and height were determined. An additional 102 soil samples, taken from four characteristic landform-types of the floodplain, were also collected for comparison with crayfish-affected soils. Particle size distribution of mounds and non-mound floodplain soils was determined using hydrometer analysis.

Results

The morphology of crayfish mounds in the study area are broadly similar to those reported for crayfish elsewhere in the literature, about 12 cm average height and 8 cm average diameter ($N = 30$ in both cases). These mounds are larger in diameter than those reported in the literature for other burrowing crustaceans. Onda and Itakura (1997) reported that river crab mounds are about 5 cm in diameter (no height data was given); and Ziebis *et al.* (1996) described the conical mounds produced by mud shrimp as averaging 4 cm in height (9 cm maximum). Although Ziebis *et al.* did not provide an average mound diameter, extrapolating from their Fig. 2 suggests an average of about 6–8 cm, flaring to 10 cm at the base where particles collect at the angle of repose.

Soils comprising crayfish mounds in the Broadneck Swamp area showed strong within-site similarity (Table 1). The mounds contain extraordinarily high levels of clay, which when dry, becomes case-hardened and extremely difficult to break apart. Although the mounds were collected within a backswamp area where clay concentration would naturally be somewhat high, non-crayfish soil samples from throughout the backswamp landform (Table 1) do not begin to approach these levels of clay concentration. The pedoturbational activities of the crayfish clearly concentrated the clay in extremely elevated levels that are statistically significantly different (alpha = .01) than the levels of non-mound soils. These results also corroborate those of Grow and Merchant (1980), who examined 40 crayfish mounds for particle size distribution, and classified all of those mounds as clay or silty clay in texture.

Table 1. Textural Data, Crayfish Mound Soils vs. Non-Mound Soils

Landform	Sand [%]	Silt [%]	Clay [%]
Crayfish Mounds, Broadneck Swamp ($N = 30$)	4.8 (2.5)*	4.6 (3.2)	90.6 (5.1)
Crayfish Mounds, Other Sites ($N = 13$)	31.4 (18.4)	12.2 (10.3)	56.4 (23.3)
Bluffs ($N = 27$)	62.5 (17.6)	13.9 (9.2)	23.6 (15.4)
Terraces ($N = 48$)	61.6 (10.0)	14.6 (8.1)	23.7 (9.4)
Levees ($N = 7$)	63.3 (16.8)	20.5 (7.1)	16.2 (10.8)
Backswamp Ridges and Swales ($N = 20$)	59.0 (11.2)	16.3 (7.0)	24.7 (12.2)

* Numbers in parentheses are Standard Deviation values.

Between-site variability existed for crayfish mounds sampled from other locations (Table 1). These mounds were collected from a more diverse landforms assemblage, although primarily from within meander-bend, low-lying swales. The spatial heterogeneity of the crayfish mounds is a reflection of the diversity of soil textures on similar landforms along the length of the study reach. Even so, however, the crayfish mounds spatially concentrate clay in statistically significantly greater amounts than in any non-crayfish-affected soils in the study area, and are more similar to other crayfish soils (*i.e.*, the Broadneck Swamp crayfish mound soils) than to non-crayfish soils. Non-crayfish soils contain high amounts of sand, in spite of the fact that those soils come from a variety of coarser landform types, some of which (*e.g.*, backswamp ridges and swales) provide the primary surfaces upon which the crayfish mounds are located The concentration of high levels of clay, and thus the creation of spatial heterogeneity at a fine scale, is thus clearly attributable to the mound-building activities of the crayfish.

Conclusions

Crayfish mounds are comprised largely of clay-size particles, and are typically about 12 cm high and 8 cm in diameter in the study area. These dimensions, the first reported from the North Carolina Coastal Plain, place the Roanoke River crayfish mounds within a typical range for such landforms. They are a dominant fine-scale landform imposed on the coarser-scale landforms of the floodplain. Given that the backwater sites of the Roanoke River floodplain clearly qualify as locations where the water table is near the surface, crayfish clearly must play an integral role in lateral throughflow and soil aeration in this environment. Crayfish may be a keystone species in inducing spatial heterogeneity of soil characteristics in an environment where soils of great similarity otherwise exist regardless of landform type.

Acknowledgments

This study was funded by a grant from The Nature Conservancy to Stephen J. Walsh, David R. Butler, Charles E. Konrad II, and Robert K. Peet. Assistance in the field for crayfish mounds and soil data collection was provided by Ms. Marilyn Wyrick and Mr. John Vogler. Ms. Wyrick and Mr. Michael Brown provided assistance in laboratory analysis of the non-crayfish soils data, and Mr. Vogler assisted with the laboratory analysis of the crayfish mounds.

References

Andersen, D. C., 1996: A spatially-explicit model of search path and soil disturbance by a fossorial herbivore. *Ecological Modelling* 89: 99–108.

Anthony, R. M., 1996: Den use by arctic foxes (*Alopex lagopus*) in a subarctic region of western Alaska. *Canadian Journal of Zoology* 74: 627–631.

Boeken, B., Shachak, M. & Brand, S. 1995: Patchiness and disturbance: plant community responses to porcupine diggings in the central Negev. *Ecography* 18: 410–422.

Burns, D. A. & McDonnell, J. J., 1998: Effects of a beaver pond on runoff processes: comparison of two headwater catchments. *Journal of Hydrology* 205: 248–264.

Butler, D. R., 1995: *Zoogeomorphology: Animals as Geomorphic Agents*. Cambridge, Cambridge University Press.

Butler, D. R., 1996: The Carolina Invasion of the Fire Ants. *In*: *Snapshots of the Carolinas: Landscapes and Cultures* D. G. Bennett. (Ed.). Association of American Geographers, Washington, D.C., 95–97.

Butler, D. R. & Malanson, G. P., 1995: Sedimentation rates and patterns in beaver ponds in a mountain environment. *Geomorphology* 13: 255–269.

Evans, R., 1998: The erosional impacts of grazing animals. *Progress in Physical Geography* 22: 251–268.

Flecker, A. S., 1996: Ecosystem engineering by a dominant detritivore in a diverse tropical stream. *Ecology* 77: 1845–1854.

Fritz, K. M., Dodds, W. K. & Pontius, J., 19[illegible]: The effects of bison crossings on the macroinvertebrate community in a tallgrass prairie stream. *American Midland Naturalist* 141: 253–265.

Gómez-Garcia, D., Giannoni, S. M., Reiné, R. & Gorghi, C. E., 1999: Movement of seeds by the burrowing activity of mole-voles on disturbed soil mounds in the Spanish Pyrenees. *Arctic, Antarctic, and Alpine Research* 31: 407–411.

Govers, G. & Poesen, J., 1998: Field experiments on the transport of rock fragments by animal trampling on scree slopes. *Geomorphology* 23: 193–203.

Green, W. P., Pettry, D. E. & Switzer, R. E., 1999: Structure and hydrology of mounds of the imported fire ants in the southeastern United States. *Geoderma* 93: 1–17.

Grow, L., 1981: Burrowing behaviour in the crayfish. *Cambarus diogenes diogenes* Girard. *Animal Behaviour* 29: 351–356.

Grow, L. & Merchant, H., 1980: The burrow habitat of the crayfish. *Cambarus diogenes diogenes* (Girard). *American Midland Naturalist* 103: 231–237.

Gurnell, A., 1998: The hydrogeomorphological effects of beaver dam-building activity. *Progress in Physical Geography* 22: 167–189.

Hall, K., Boelhouwers, J. & Driscoll, K., 1999: Animals as erosion agents in the alpine zone: some data and observations from Canada, Lesotho, and Tibet. *Arctic, Antarctic, and Alpine Research* 31: 436–446.

Haria, A. H., 1995: Hydrological and environmental impact of earthworm depletion by the New Zealand flatworm (*Artioposthia triangulata*). *Journal of Hydrology* 171: 1–3.

Hasiotis, S. T. & Mitchell, C. E., 1993: A comparison of crayfish burrow morphologies: Triassic and Holocene fossil, paleo- and neo-ichnological evidence, and the identification of their burrowing signatures. *Ichnos* 2: 291–314.

Hasiotis, S. T., Mitchell, C. E. & Dubiel, R. F., 1993: Application of morphologic burrow interpretations to discern continental burrow architects: lungfish or crayfish? *Ichnos* 2: 315–333.

Hillman, G. R., 1998: Flood wave attenuation by a wetland following a beaver dam failure on a second order boreal stream. *Wetlands* 18: 21–34.

Hobbs, H. H., Jr., 1981: The crayfishes of Georgia. *Smithsonian Contributions to Zoology* 318: 1–549.

Hobbs, H. H., Jr. & Whiteman, M., 1991: Notes on the burrows, behavior, and color of the crayfish *Fallicambarus (F.) devastator* (Decapoda: Cambaridae). *Southwestern Naturalist* 36: 127–135.

Hululgalle, N. R., 1995: Effects of ant hills on soil physical properties of a Vertisol. *Pedobiologia* 39: 34–41.

Inouye, R. S., Huntly, N. & Wasley, G. A., 1997: Effects of pocket gophers (*Geomys bursarius*) on microtopographic variation. *Journal of Mammalogy* 78: 1144–1148.

Mahaney, W. C., Bezada, M., Hancock, R. G. V., Aufreiter, S. & Perez, F. L., 1996a: Geophagy of Holstein hybrid cattle in the northern Andes, Venezuela. *Mountain Research and Development* 16: 177–180.

Mahaney, W. C., Hancock, R. G. V. & Huffman, M. A., 1996b: Geochemistry and clay mineralogy of termite mound soil and the role of geophagy in chimpanzees of the Mahale Mountains, Tanzania. *Primates* 37: 121–134.

Mallick, S. A., Driessen, M. M. & Hocking, G. J., 1997: Diggings as a population index for the eastern barred bandicoot. *Journal of Wildlife Management* 61: 1378–1383.

Mattson, D. J., 1997: Selection of microsites by grizzly bears to excavate biscuitroots. *Journal of Mammalogy* 78: 228–238.

Mattson, D. J. & Reinhart, D. P., 1997: Excavation of red squirrel middens by grizzly bears in the whitebark pine zone. *Journal of Applied Ecology* 34: 926–940.

Meentemeyer, R. K. & Butler, D. R., 1999: Hydrogeomorphic effects of beaver dams in Glacier National Park, Montana. *Physical Geography* 20: 436–446.

Meentemeyer, R. K., Vogler, J. B. & Butler, D. R., 1998: The geomorphic influences of burrowing beavers on streambanks, Bolin Creek, North Carolina. *Zeitschrift für Geomorphologie* 42: 453–468.

Onda, Y. & Itakura, N., 1997: An experimental study on the burrowing activity of river crabs on subsurface water movement and piping erosion. *Geomorphology* 20: 279–288.

Pickard, J., 1999: Tunnel erosion initiated by feral rabbits in gypsum, semi-arid New South Wales, Australia. *Zeitschrift für Geomorphologie* 43: 155–166.

Rutin, J., 1996: The burrowing activity of scorpions (*Scorpio maurus palmatus*) and their potential contribution to the erosion of Hamra soils in Karkur, central Israel. *Geomorphology* 15: 159–168.

Rutin, J., 1998: The contribution of scorpions (*Scorpio maurus palmatus*) to the preparation of available sediment on a sandy slope in Karkur, central Israel. *Geoökodynamik* 19: 89–101.

Shachak, M., Jones, C. G. & Brand, S., 1995: The role of animals in an arid ecosystem: snails and isopods as controllers of soil formation, erosion and desalinization. *Advances in GeoEcology* 28: 37–50.

Stone, E. L., 1993: Soil burrowing and mixing by a crayfish. *Soil Science Society of America Journal* 57: 1096–1099.

Tardiff, S. E. & Stanford, J. A., 1998: Grizzly bear digging: effects on subalpine meadow plants in relation to mineral nitrogen availability. *Ecology* 79: 2219–2228.

Tarr, R. S., 1884: Habits of burrowing crayfishes in the United States. *Nature* 30: 127–128.

Townsend, P. A. & Butler, D. R., 1996: Patterns of landscape use by beaver on the lower Roanoke River floodplain, North Carolina. *Physical Geography* 17: 253–269.

Ziebis, W., Forster, S. & Jorgensen, B. B., 1996: Complex burrows of the mud shrimp *Callianassa truncata* and their geochemical impact in the sea bed. *Nature* 382: 619–622.