Human-induced Ecosystem and Landscape Processes Always Involve Soil Change

DAN H. YAALON

Soil, the living skin of Earth derived from weathered rock materials and surficial biota, has been dubbed the "Earth's critical zone" by the US National Research Council. It is an inseparable part of nature's dynamic ecosystems, yet it is frequently disregarded when discussing landscape processes or resources and the consequences of land-use or land-cover change (Lambin et al. 2003). A recent review of domesticated nature (Kareiva et al. 2007)—which now encompasses about 50 percent of Earth's surface—also disregards soil changes, although it does point out that when humans change nature's landscapes, whether for agriculture or new housing developments, the trade-offs between the resulting benefits and harms must be understood and managed. Understanding the consequences of humans' domestication of ecosystem services will be incomplete, however, unless the effects of soil changes—and not only in the realm of agriculture—are also considered.

Humans are the current major cause of soil erosion, which is often the only soil process considered in studies of geomorphic processes. Here I wish to emphasize that soil erosion and degradation are not the only important soil processes in landscape ecosystems and land-use change; several processes of soil betterment have also been significant. Granted, the condition of soil is not as easily delineated as that of other domesticated biota or ecosystem services, but it should not be a neglected contributor to ecosystem services.

Agriculture started independently in several areas of the world, but the Near East continues to be regarded as the region where soil cropping first began, some 10,000 years ago. Since then, cultivation and soil management have induced an erosional loss of topsoils at a rate exceeding the natural rate of soil formation—soil bodies form from bedrock, saprolite, and sedimentary materials over hundreds or thousands of years. Most recently, Montgomery (2007) collected quantitative data showing that the rate of soil erosion from conventionally ploughed agricultural fields averages one to two orders higher than the rates of natural soil production. Loss of soil organic matter and plant nutrients is another common form of soil degradation. Avoiding soil erosion and nutrient depletion has become an important topic in planning for agricultural sustainability.

Yet soil change involves numerous ecosystem trade-offs. Cultivation and soil management have also improved many soil properties, which over the long term has affected the history of societies and civilizations (McNeill and Winiwarter 2004). Humans have boosted the productivity of many soils by adding manure, fertilizer, lime, marl, and mulch; by draining, terracing, and irrigating; and by undertaking other conservation and enhancement measures. Productivity increased manifold to feed growing populations while soil resources were limited. Irrigation, too, entails synergic trade-offs: it not only increases productivity in arid regions and during droughts but also leaves behind salts in the productive soil profile, which may eventually induce the salinization of the soils, reduce productivity, and cause the abandonment of the land.

Soil surveys and mapping at various scales have been progressing steadily in both developed and developing countries (see the International Soil Resource and Information Center's World Soil Information Web site at *www.isric.org*). By extrapolating from soil mapping done by the US Department of Agriculture/ Natural Resources Conservation Service (USDA/NRCS), it appears that there are about 300,000 specific soil series worldwide at the lowest level of the soil classification hierarchy. As the study and quantification of soils has proceeded, human-induced changes to soil—"metapedogenesis" (Yaalon and Yaron 1966), or "anthropedogenesis" (Richter 2007)—has become an important topic in the development of soil science. Researchers need to know what kind of soils are most affected by metapedogenesis, and how.

In their framework for human-induced soil changes, Yaalon and Yaron (1966) included a list of common anthropedogenic soil change processes, such as drainage and terracing. Richter (2007) lists the properties affected by these processes, such as a change in pH or aggregation. Clearly, erosional degradation is common, and the content of soil organic matter in arable agriculture has decreased by about half in soils worldwide.

Dan H. Yaalon (e-mail: yaalon@vms.huji.ac.il) is professor emeritus in the Institute of Earth Sciences at Hebrew University in Jerusalum, Israel.

Long-term field and laboratory experiments on soil organic carbon transformations and nutrient availability have therefore been at the center of soil-change research, but various regional and international organizations are now promoting also the study of other ecosystem services that may be affected by soil change. Arable cropping occupies 12 percent of Earth's surface, but irrigated lands, improved pastures, managed (and fertilized) forests, and abandoned and urban lands add to that total. This drastic human transformation of Earth's soils has taken place over half of the planet's land surface, necessitating a reclassification of soil resources. The impacts are regionally variable, as the "Human Footprint" world map demonstrates (see *www.ciesin.columbia.edu/wild_areas*).

A medium-scale spatial assessment of human-induced soil changes is not now possible. The following grouping, however, which employs USDA/NRCS soil classification terminology, may provide a useful general framework for nonspecialists working with soil data. First, the soil areas formed as the standard textbook model of pedogenesis from solid bedrock would have it are relatively small in relation to soil areas formed from upbuilding and bioturbation. Spodosols, alfisols, and ultisols are examples of soils formed this way.

According to geologic and geomorphic maps, there are about three to four times as many agricultural soils in lowlands and floodplains on more-or-less loose sedimentary materials, including loessial, glacial, alluvial, and colluvial deposits, periodically supplemented by additional eolian, alluvial, or colluvial deposits. Such soils are formed by what can be termed a cumulic, or upbuilding, soil model. They include entisols, inceptisols, and andisols, which are among the soils most affected by agriculture and most subject to both human-induced degradation and improvement.

A third large group of soils results from mixing by bioturbation (the pedoturbation soil model). This process can retard or even reverse horizonation, frequently resulting in considerable soil depth, as well as more desirable soil properties. Examples are mollisols, vertisols, and many oxisols. These soils are valuable for agriculture and are also subject to human-induced soil changes. (A poster and brief descriptions of these USDA/ NRCS soil orders can be downloaded at *http://soils.usda.gov/technical/soil_orders*.)

An important task ahead—especially in view of the ongoing climatic and environmental changes induced by humans—is to model and research the actual decadal pedogenic processes and effects of anthropedogenic changes. Spatial assessments of the areas must also be made. Soil changes cannot be disregarded any longer in discussions of ecosystem changes or landscape processes.

References cited

Kareiva P, Watts S, McDonald R, Boucher T. 2007. Domesticated nature: Shaping landscapes and ecosystems for human welfare. Science 316: 1866–1869.

Lambin EF, Geist HJ, Lepers E. 2003. Dynamics of land-use and land-cover change. Annual Review of Environmental Resources 28: 205–241.

McNeill JR, Winiwarter V. 2004. Breaking the sod: Humankind, history, and soil. Science 304: 1627–1629.

Montgomery DR. 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of Sciences 104: 13268–13272.

Richter DD. 2007. Humanity's transformation of Earth's soil: Pedology's new frontier. Soil Science 172. Forthcoming.

Yaalon DH, Yaron B. 1966. Framework for man-made soil changes: An outline of metapedogenesis. Soil Science 102: 272–277.

doi: 10.1641/B571102
Include this information when citing this material.