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COMMENT

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Land and people

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Our relationship with the landscape has developed through time and more and more the environment is responding to human-driven changes. Now is the time to steer this relationship towards a sustainable future, suggest our Editorial Board Members.

Humans have long exerted an influence on the land, through agriculture, infrastructure and global warming. In this Comment, our Editorial Board Members explain why if we can understand past and contemporary environmental and ecological responses, both above and below the surface, we can better predict and adapt to future changes, and reduce climate change impacts and enhance food security. In light of the pressures of climate change and population growth, there has never been a more urgent time to develop a sustainable relationship with our landscapes and ecosystems, in terms of biogeochemistry, agriculture and infrastructure.

Michael Storozum: Early human impacts

The dawn of the Anthropocene in 1950 signalled the beginning of rapid, global scale, human-induced transformations of the Earth's environments and climate. Nevertheless, premodern societies already produced long-lasting environmental legacies, which, while interesting in their own right, may also help better qualify the rate and scale of environmental changes seen during the Anthropocene.

From ancient mobile pastoralists in eastern Africa 3000 years ago who influenced soil health to the expansion of the Spanish and Portuguese empires during the Columbian Exchange after 1492 that dramatically changed Neotropical vegetation[1,2], complex interactions between socio-political and biophysical processes have shaped the pre-Anthropocene Earth system.

Cautionary tales of ancient societies that collapsed because of climate change, natural hazards or environmental degradation have often come to light in the past. However, the focus has shifted to exploring how ancient peoples successfully adapted to their environment. For instance, as witnessed by human-modified soils, ancient people both intentionally and unintentionally altered natural soil properties, which in some cases made anthropogenic soils more fertile and resilient than naturally occurring soils. Amazonian Dark Earths (*terra preta*) and European Dark Earths (plaggen soils) are fairly well known, but many less well-known types of anthropogenic soils are now being documented in the tropics and subtropics[3,4]. Conversely, ancient mining and smelting activities produced concentrations of heavy metals toxic to plant and animal life, in some cases even more severe than modern soil contamination[5,6]. Ancient human societies have had a wide range of impacts on the environment that can persist through to the present day.

Looking forward, more work is needed to share and standardize geochemical and other proxy data that may be fundamental for answering questions of where, when and how people in the past influenced their environment. Understanding the global distribution of anthropogenic soils and paleo-pollution will not only help place the rate of soil degradation seen in the Anthropocene within a deeper historical context, but perhaps, optimistically, reveal the fundamental role that human societies have played in building healthier soils throughout much of the

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Holocene. By sharing data and developing global research agendas, the paleoenvironmental community at large has the exciting opportunity to reveal the widespread legacy of premodern human–environmental interactions and increase the general awareness of the long-lasting ecological legacy of ancient societies.

Credit: Jose Antonio Alba/Pixabay

Erika Buscardo: Soils in a changing world

Climate change, land use and atmospheric nitrogen deposition are prominent drivers of biodiversity change. In turn, biodiversity governs processes at the interface between the biosphere and atmosphere and strongly influences feedbacks between the global carbon cycle and climate. Earth system models typically include a dynamic vegetation component to help represent such feedbacks, with the relationships between climate, plant physiology and carbon assimilation efficiency being the main focal elements.

Soil processes, as part of biogeochemical cycles, play an intrinsic role in the growth of plants through their contribution to plant nutrient acquisition and thus productivity, yet their representation in Earth system models is rarely supported by empirical evidence. Responses in belowground ecosystem structure and function to global environmental change could compromise plant productivity and the supply of services, affecting water and food security for human society. It is important, therefore, to better understand how belowground community diversity, function and biotic interactions change in response to environmental drivers. We also need a better grasp of the impacts of life below ground on aboveground community dynamics and biosphere–atmosphere feedbacks.

Disturbance impacts occur at different spatial and temporal scales and natural disturbances form an integral part of ecosystem functioning. As such, knowledge of the baseline natural variability of highly dynamic belowground communities is required to be able to assess significant divergence in ecosystem function in response to global change drivers.

Belowground community response to disturbance and subsequent recovery has been attributed to the resilience of these communities or their functional redundancy, i.e., overlapping contributions from distinct taxa to overall ecosystem function. However, belowground community structure and function can be temporally dynamic and complementary[7], whereby different constellations of soil fungi and bacteria contribute various ecosystem functions over time, resulting in an overall temporal stability in multiple ecosystem functions that may enhance resilience to disturbances.

How such belowground asynchronous complementarity may operate across different ecosystems, seasons and climate zones, and how it may shape overall ecosystem structure and function, and biosphere–atmosphere feedbacks will certainly continue to intrigue researchers.

Belowground communities, their ecosystem function and the supply of ecosystem services are more and more catching the attention of empirical scientists, modellers and policymakers. Technical advances, including next-generation sequencing tools, proteomics and stable isotope labelling methods, offer promising avenues to explore belowground diversity, food webs and biogeochemical cycles. Next-generation ecosystem experiments that aim to implement a model-based framework for empirical science will further accelerate our understanding of the links between belowground diversity and function and our ability to predict their response to global change. Emulating the new generation ecosystem experiments, as well as a tighter connection between Earth system modellers and empirical scientists promises to refine dynamic vegetation representation in model projections and reduce the uncertainty associated with them. Exciting discoveries of belowground structure and function are likely to await and will help improve our understanding below- and aboveground connections and wider ecosystem functioning.

Gerald Forkuor: Sustainable land use

Africa's population is rapidly growing, with its share of the global population projected to increase from 17% in 2020 to 39% by 2100 (ref. [8]). The continent is already grappling with low agricultural productivity and food security challenges. Tremendous efforts are needed to increase food production; however, arable land continues to undergo widespread degradation due to issues such as nutrient mining, erosion, overgrazing and pollution. Climate change and more frequent weather extremes, such as floods and droughts, further degrade land and reduce agricultural productivity.

Some efforts to counteract low productivity, however, can increase greenhouse gas emissions and derail efforts to meet global climate targets. Poor water management, fertilizer application and residue burning in rice production are, for example, major sources of potent greenhouse gases such as methane and nitrous oxide[9,10]. To ensure that the United Nations sustainable development goals and the African Union's Agenda 2063 for food and water security are realized at minimal environmental cost, science-based land management practices are needed to decouple agricultural productivity from greenhouse gas emissions.

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The Agriculture, Forestry and Other Land Uses (*AFOLU*) sector contributes the largest share of greenhouse gas emissions in Africa[11]. Thus, developing large-scale agronomic, livestock and forest management practices that increase productivity and reduce emissions is key to achieving enhanced production and environmental sustainability. However, it is impossible to effectively manage greenhouse gas emissions if there is limited capacity to quantify them in Africa.

Improved data infrastructure and research are needed to quantify emissions associated with specific land management practices under different land uses. Similarly, land use mitigation strategies should be informed by existing and potential future land use changes and their impact on greenhouse gas emissions under different climate scenarios. However, past studies that examined land use changes at various temporal scales mainly used coarse resolution satellite imagery and suffered from limited availability or poor-quality of data, partly due to cost. Such challenges have resulted in limited knowledge of land management practices that reduce greenhouse gas emissions while increasing agricultural productivity.

Improved greenhouse gas observation networks and in situ measurements[12] will enable the development of country-specific emission factors (IPCC tier 2/3)[13] and quantification and management of land use specific greenhouse emissions. It will reduce uncertainties in emissions inventory data on Agriculture, Forestry and Other Land Uses[14], which are currently estimated using emission factors extracted from default value databases (tier 1 methodologies).

Free earth observation data, such as those from the European Space Agency and United States Geological Surveys, are becoming increasingly available. Together with improvements in cloud-based computing infrastructure, this presents an opportunity to advance research into current and future land use and vegetation dynamics. Coupled with accurately quantified greenhouse gas emissions, this can support current and future land management practices that contribute to mitigation and adaptation objectives of countries.

Alessandro Rubino: Future roads in infrastructure

Infrastructures influence the way we live, economic production and consumption, and how we interact and relate. They connect goods and raw materials to factories, workers to their jobs, connect families and social groups and make resources and services available to households and businesses. From a social and economic point of view, efficient infrastructures help determine wellbeing and quality of life and impact development.

The long term and capital-intensive nature of infrastructures means that once the investment is sunk, the huge capital required to construction and implementation remains committed and unrecoverable for the entire useful life of the infrastructure, which can span between 20 and 50 years depending on the type of asset. Even simple assets like asphalt footpaths have a useful life of 20–30 years, while generation plants or oil, natural gas and sewer pipes last 50–90 years. These characteristics introduce an important intertemporal problem: the investment decision on infrastructure we take now will commit future generations for several decades to come.

In the aftermath of the coronavirus crisis most countries are defining fiscal stimulus measures, already amounting to nine trillion US dollars[15], that will provide support ranging from reduction of interest rates to direct government interventions and spending pledges. At the time we write, an enormous number of investment decisions are being made that will lock in development models for years to come. These decisions can have positive or negative implications for sustainable development goals and global carbon dioxide emissions, with profound repercussions both at the time of construction, during and beyond the useful life of the assets. Globally, investment in greening the energy sector needs to reach the astronomical level of an additional $1.1 trn per year between now and 2040 to meet the International Energy Agency's (IEA) green energy target[16]. Therefore, investing in the right green infrastructure now is crucial. But do we know which are the "right" infrastructures to build and how to do it sustainably?

Given how global carbon dioxide emissions resurged after the 2008 financial crisis, a trifle compared to the COVID-19 crisis, we cannot sleep peacefully waiting for the right investments to arise by themselves. Following that economic stagnation, carbon dioxide emissions declined by 400 million tonnes in 2009. But emissions rebounded by 1.7 billion tonnes in 2010 (ref. [17]), the sharpest upswing in history, driven mainly by developing Asia. We now know that infrastructure directly and indirectly affects sustainable development goals[18], in particular SDG 3, SDG 6, SDG 7, SDG 9 and SDG 11 have their targets aligned with sustainable infrastructure.

Notwithstanding this greater understanding of the role of long-lived assets, several countries are still committing most of their funds to brown recovery packages[19]. Numerous initiatives launched by the IEA and the World Bank suggest that green conditionality should be imposed to target sustainable long-term recovery schemes. Future research should help identify the barriers and determinants for new sustainable infrastructure, and help solve the traditional tri-lemma of how to develop infrastructure that are economically, socially and ecologically sustainable.

Credit: Siggy Nowak/Pixabay

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Additional information

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