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Smart Earth: A meta-review and implications for environmental governance

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ABSTRACT

Environmental governance has the potential be significantly transformed by Smart Earth technologies, which deploy enhanced environmental monitoring via combinations of information and communication technologies (ICT), conventional monitoring technologies (e.g. remote sensing), and Internet of Things (IoT) applications (e.g. Environmental Sensor Networks (ESNs)). This paper presents a systematic meta-review of Smart Earth scholarship, focusing our analysis on the potential implications and pitfalls of Smart Earth technologies for environmental governance. We present a meta-review of academic research on Smart Earth, covering 3187 across the full range of academic disciplines from 1997 to 2017, ranging from ecological informatics to the digital humanities. We then offer a critical perspective on potential pathways for evolution in environmental governance frameworks, exploring five key Smart Earth issues relevant to environmental governance: data; real-time regulation; predictive management; open source; and citizen sensing. We conclude by offering suggestions for future research directions and trans-disciplinary conversations about environmental governance in a Smart Earth world.

1. Introduction

Over the past two decades, researchers and practitioners in earth sciences, ecology, and cognate disciplines have been creating innovations in environmental monitoring technologies that combine Information and Communication Technologies (ICT) with conventional monitoring technologies (e.g. remote sensing), and Environmental Sensor Networks (ESNs, which are spatially distributed monitoring networks containing high densities of sensors and actuators). These technologies, which we collectively label “Smart Earth,” have proliferated due to the rapid decrease in cost of cloud-based computing and innovations in Machine to Machine (M2M) infrastructure (Hogan et al., 2012; White, 2016), enabling unprecedented environmental management applications. Simply put, Smart Earth is the set of environmental applications of the Internet of Things, and is thus analogous to the widely discussed “Smart City,” (Marvin et al., 2015), but articulated across a much wider range of ecosystems and land use types.

Smart Earth technologies enable terabytes of environmental data to be derived from terrestrial, aquatic, and aerial sensors, satellites, and monitoring devices, relying on a rapidly diversifying set of sources—including “wearables” and biotelemetric technologies devised for humans, animals, and even insects. New cloud-based Web platforms have been created that enable the aggregation, analysis, and real-time display of these unprecedented streams of environmental data. Scientists are also applying innovations in AI, Big Data analytics, machine learning, 3D object-recognition algorithms, and genetic learning to the study and administration of ecological processes (Koomey et al., 2013; Gabrys, 2016; Goodchild, 2007; Kitchin, 2014; Gale et al., 2017; Pettorelli et al., 2014; Schwab, 2017; Zyl et al., 2009). Collectively, these developments have dramatically increased scientists’ ability to assess spatiotemporal changes in abiotic conditions as well as biotic communities.

We contend that the volume, integration, accessibility, and timeliness of the data provided by Smart Earth technologies potentially creates the conditions for significant changes in environmental governance. To date, the majority of research on this topic has focused on the potential implications for conservation and waste reduction, pollution mitigation, mapping environmental degradation, geosecurity, and disaster management (Goodchild and Glennon, 2010; Resch et al., 2014; Koomey et al., 2013). However, although a few scholars have engaged with questions of the implications of these technologies for environmental governance (e.g. Gabrys, 2016), this issue remains relatively under-studied from a multi-disciplinary perspective. This paper seeks to address this gap.

Our paper begins from the premise that Smart Earth technologies have the potential to disrupt existing modes of environmental governance. Here, environmental governance is defined from an analytical (rather than normative) perspective as the set of social actors and

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institutions (including laws, rules, norms, customs), as well as data-gathering and decision-making processes, engaged in environmental decision-making (Bridge and Perreault, 2009; Ostrom, 1990). Our definition is broadly aligned with social scientists engaged in the study of environmental governance at a global scale (e.g. the Earth System Governance Project), notably those who study the institutional and epistemological realignments of environmental governance globally (e.g. Biermann et al., 2010, 2012). Our analysis of potential pathways for innovation in environmental governance coupled with Smart Earth technologies is related to and inflected by, but distinct from, governance trends such as the partial redistribution of decision-making power from state to non-state actors (e.g. the emergence of non-state market-driven governance systems), and the rescaling of governance above and below the nation-state (Biermann et al., 2012; Cashore, 2002; Cohen and McCarthy, 2015; Reed and Bruyneel, 2010).

The purpose of this meta-review is to provide a synthesis of key issues and critiques that Smart Earth poses for environmental governance. Smart Earth enables a series of shifts: the time-space compression of data availability and decision-making (which in turn enables automated real-time regulation and new prediction capabilities); the multiplication of modalities and agencies of environmental sensing; the proliferation of new environmental governance actors; and, potentially, a much higher degree of transparency in data collection, accessibility, and integration. Taken together, these innovations create the conditions for potentially significant transformations in environmental governance.

Consider, as an example, Sustainability Standards Organisations (SSOs). New forms of access to real-time, continuous information on environmental data from “virtual” monitoring platforms are challenging the “static, limited, and closed “analog” model of auditing conventionally employed by [SSOs]” (Gale et al., 2017). In the past, SSO audits were conducted through brief, intermittent field visits by small teams of auditors and experts. Smart Earth technology creates the potential for continuous monitoring and assessment of the validity of sustainability claims. This in turn enables the emergence of private regulatory bodies and real-time auditing processes which will drive changes in SSOs (Auld and Gulbrandsen, 2010; Carse and Lewis, 2017). The SSO example illustrates the co-evolution of technology and governance occurring across different environmental domains and scientific disciplines, including established fields such as landscape ecology and geography, as well as emergent sub-fields such as environmental digital humanities, animal biotelemetry, and citizen sensing.

Our paper presents a systematic meta-review of this literature. Our intention in conducting this review is to identify the key issues that Smart Earth poses for environmental governance. To conduct this meta-review, as detailed in Section 2, we surveyed the scholarly literature (1997–2017) across the full range of academic disciplines to create a database of 3187 articles (discussed in Section 3). In Section 4, we present key issues and critiques relevant to environmental governance debates, including: data (the opportunities and challenges of using big data to provide temporally and spatially comprehensive coverage for monitoring, in contrast to intermittent and low-density monitoring); real-time regulation (including real-time and potentially automated decision-making through the use of mobile platforms to communicate to field-based actors and receptors, such as ship captains, farmers, fishers, and hunters); enhanced predictability, particularly in situations where data was previously unavailable; the technical and ethical implications of open data; and the evolution of citizen engagement through new modalities such as citizen sensing, which incorporate new variables (such as noise and sound) that extend our ability to “sense” the environment (Helmreich, 2015). Section 5 concludes by offering suggestions for future research directions regarding environmental governance in a Smart Earth world.

2. Methods

Our analysis presents the results of a meta-review of the academic literature on Smart Earth. We conducted a manual search of 17 journals spanning a range of disciplines including computer science, environmental studies, ecology, eco-informatics, and social studies of science. Our manual search included the following journals: Ambio, Annual Review in Environmental Resources, Ecological Informatics, Environmental Humanities, Environment and Planning A, Environment and Planning D, Journal of Applied Ecology, Big Data and Society, Annals of the American Association of Geographers, Global Environmental Change, Global Environmental Politics, International Journal of Digital Earth, PNAS, Nature, Science, Social Studies of Science, Trends in Ecology and Evolution.

Through this review, we identified the keywords most frequently used with respect to Smart Earth, as well as commonly-used terms related to earth processes relevant to Smart Earth topics: remote sensing, eco-informatics (and ecological informatics), Big Data, biomonitoring, citizen sensing, cloud computing, data visualization, fiber optic, Internet of Things, drones, citizen science, fourth industrial revolution, Digital Earth, biomonitoring, and Program Earth. Keywords relevant to earth processes related to Smart Earth-related topics: ecosystem services, environment, ecology, Anthropocene, planet, habitat, species, biodiversity, animal migration, geology, geomorphology, conservation, ecosystem, species distribution, migration, and climate. We then conducted a search using these keywords across the full range of disciplines in the natural sciences, social sciences, and humanities, on Web of Science and Google Scholar. Using paired combinations of keywords, we generated 176 discrete paired search terms. With each paired search, we identified the top 100 most cited papers, inclusive of the period 1997–2017, the period which best captures the onset phase of Smart Earth research. This strategy identified the most highly-cited papers (7892 papers in total). Each paper’s abstract was reviewed to determine whether or not the paper focused on Smart Earth issues, resulting in a database of 3187 articles, the citations from which were used to generate a content cloud (Fig. 1). These articles span the natural and social sciences, and humanities, and include such disciplines as ecology, environmental humanities, geography, geomorphology, and marine biology; and such topics as animal migration studies, eco-informatics, pollution monitoring, remote sensing, and science and technology studies (STS).

3. Smart earth: overview

This section provides an overview of the Smart Earth literature, which is characterized by a focus on Smart Earth techniques and technologies. Twenty years ago, many of the technologies that are now

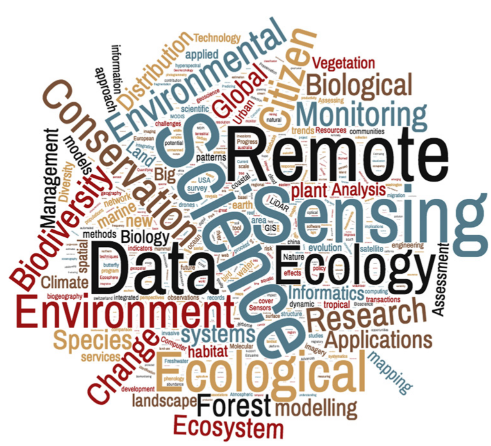

Fig. 1. Smart Earth – Content Cloud.