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Review paper

Integrating technologies for scalable ecology and conservation

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ABSTRACT

Integration of multiple technologies greatly increases the spatial and temporal scales over which ecological patterns and processes can be studied, and threats to protected ecosystems can be identified and mitigated. A range of technology options relevant to ecologists and conservation practitioners are described, including ways they can be linked to increase the dimensionality of data collection efforts. Remote sensing, ground-based, and data fusion technologies are broadly discussed in the context of ecological research and conservation efforts. Examples of technology integration across all of these domains are provided for large-scale protected area management and investigation of ecological dynamics. Most technologies are low-cost or open-source, and when deployed can reach economies of scale that reduce per-area costs dramatically. The large-scale, long-term data collection efforts presented here can generate new spatio-temporal understanding of threats faced by natural ecosystems and endangered species, leading to more effective conservation strategies.

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1. Introduction

Ecologists and conservation practitioners have proven themselves adept at incorporating emerging technologies into field data collection efforts (Pimm et al., 2015). The innovative use of technology is expanding the bounds of traditional ecological inference and conservation strategies (Snaddon et al., 2013). Continuing to expand efficient data collection in both time and space is crucial in the face of the enormous pressure that global changes are exerting on natural ecosystems (Rockström et al., 2009). Rapid habitat and biodiversity losses (Pimm et al., 2014), illegal wildlife harvest and trade (Milner-Gulland and Bennett, 2003), and climate change (IPCC, 2014) all affect ecosystems across the globe and increasingly require more than just field surveys to understand, monitor, and report on their effects.

Traditional field inventory plots and other sampling strategies are, and will continue to be, a crucial tool in the arsenal of ecologists for understanding local-scale processes and the functioning of ecosystems. Yet field surveys are costly to set up and maintain over many years (Berenguer et al., 2015), and they are extremely difficult to utilize in remote regions of the world. Just as concerning, in heterogeneous ecosystems field plots may actually provide biased estimates of ecological properties and processes (Marvin et al., 2014). The technologies we discuss here can help to overcome many of these shortcomings, especially when used in combination. Smart deployment and use of these technologies can open up new ecological scales to investigate the assembly, competition, dispersal, and migration of organisms and their interactions with the surrounding environment. Additionally, combating illegal activities such as poaching/hunting, logging, and encroachment require efficient monitoring and tangible evidence for investigating and prosecuting offenders. Preventing human–wildlife conflict, especially with large animals that can cause serious injury or death, often requires similar deployment of these technologies.

Here we provide descriptions and a synthesis of multiple technologies that can be deployed at different scales, with two hypothetical examples of how they can be integrated to increase the scale (both temporal and spatial) and dimensionality of ecological and conservation research. Increasing the resolution and area over which data are collected is important for identifying and mitigating threats to protected ecosystems, as well as understanding and uncovering ecological patterns and processes. Moreover, these data can be better integrated into dynamic global vegetation models (DGVMs) when the spatial and temporal scales accurately represent the process of interest (e.g., productivity, mortality). Most of the technologies discussed here or their associated data are low-cost, open-source, or freely available, and have proven applications for ecologists and conservation practitioners alike. The economies of scale achievable by these technologies can make any up-front expense for their purchase or development cost-effective. In Table 1, we provide example studies from each of the six main technologies that are described in more detail below. Our aim is simply to provoke discussion among researchers about the potential for integrating multiple technologies into their work, rather than providing a comprehensive critique of each emerging or established technology.

2. Remote sensing technology

2.1. Satellite

Satellite remote sensing platforms offer widespread geospatial coverage and, in many cases, long temporal records of Earth's biomes. However, most satellites (especially those satellite data providers offering free data access) lack the spatial resolution for organismic-level analysis, and often have limited spectral ranges, constraining their potential applications (Asner, 2015). While this is rapidly changing with the recent revolution in the way Earth-observing satellites are designed, built, and deployed (see discussion of cubesats below), the traditional large-platform satellites still have many advantages. An interactive overview of many operational satellites can be found at satsummit.github.io/landscape.

Government-sponsored satellite sensors have the longest temporal data archive of earth-observing images and are often freely available to the public. NASA's Landsat program just passed its 44th year of continuous operation, providing an incredible opportunity to analyze ecological and land use dynamics over very large areas (e.g., Hansen et al., 2013). There are many other optical multispectral and active sensors (e.g., radar, laser) that produce data at spatial resolutions ranging from 30 m to 1 km, offering data products for understanding vegetation dynamics and biomass, climate and weather patterns, and biophysical variables like surface temperature, soil moisture, and CO_2 flux (e.g., Goetz et al., 2009). Increased cooperation