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Thematic Section: Bringing Species and Ecosystems Together with Remote Sensing Tools to Develop New Biodiversity Metrics and Indicators

Integrating Remote Sensing into Wildlife Monitoring for Conservation

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Effective wildlife monitoring is a prerequisite for effective wildlife conservation since, without time-series data on species populations and threats, evidence-based adaptive management will be difficult to achieve. Technological advances in remote sensing offer more opportunities for data collection than ever before. However, if we are to enhance data sharing and the use of data by decision-makers, methods must be relevant to local user needs and be integrated into monitoring schemes with appropriate goals and indicators.

In recent years, conservation project managers have increasingly turned to technological innovations to enhance wildlife monitoring, and remote-sensing devices deployed in space, in the air and on the ground are more realistic and affordable options than ever before. Satellite-based remote sensing of wildlife habitats and (sometimes) wildlife populations (see Pettorelli et al. 2014) has been complemented by the newest generation of Earth-based sensors, including camera traps (Rovero & Zimmermann 2016, Murphy et al. 2017), acoustic recording devices (Alvarez-Berríos et al. 2016, Deichmann et al. 2017) and unmanned aerial vehicles or drones (Christie et al. 2016, Thapa et al. 2018). These sensors, as well as emerging methods such as environmental DNA monitoring for tracking community composition (Biggs et al. 2015, Valentini et al. 2016) and genetic monitoring for identifying individuals within populations (e.g., Gray et al. 2013), provide new opportunities for enhancing the quality and volume of wildlife monitoring data and reducing the time people need to spend on the ground to collect it. If used in systematic ways (e.g., Beaudrot et al. 2016), remote sensing can also help fill the data gaps that exist in high-biodiversity tropical countries (McRae et al. 2017) and help build time-series data of higher temporal and spatial resolution.

However, there is a risk that excitement over the technologies, encouraged by donors keen to show their support for innovation, may lead to practitioners deciding on which tools to use before they have decided on what they want to measure. Among the numerous blockages to the collection and use of biodiversity data for management, weak monitoring plans and tools that are poorly adapted to local conditions are cited regularly as problems (Stephenson et al. 2017a). Remote sensing therefore needs to be applied only when appropriate to the local situation and when it can be used to answer specific monitoring questions. The decision to use technology should also be based on project objectives and the availability of appropriate budgets and technical skills (Schmeller et al. 2017).

Guidance abounds on how to develop monitoring plans (e.g., BirdLife International 2006, CMP 2013) but, essentially, an appropriate monitoring system for a biodiversity project can be developed by answering the following five questions: (1) What are we trying to achieve (i.e., which species or habitats are we targeting and what do we want to see happen to them as a result of our actions)? (2) What does success look like (i.e., what quantitative changes do we expect to bring about in biodiversity and the pressures that threaten it)? (3) What do we need to measure to demonstrate if we have achieved success (i.e., what indicators do we select)? (4) How do we collect data to measure success (i.e., what monitoring methods, tools and protocols will we use? Are remote sensing devices relevant and feasible)? (5) How will we use the data for adaptive management (i.e., how should data be analysed and in what format should they be presented? What decisions need to be taken to respond to the trends identified)?

Many conservation agencies use the pressure–state–benefit–response model (an interlinked indicator framework that measures how well actions reduce threats and improve biodiversity and human livelihoods) to gain a better understanding of the complexities of conservation action (Sparks et al. 2011, Stephenson et al. 2015a). In this context, animal and plant population trends are the ultimate state indicator, confirming how target species are faring. Therefore, wildlife monitoring should be a necessary and key management practice for any stakeholder trying to conserve or manage populations, whether a government, non-governmental organization, local

Table 1. Key issues to consider in developing and implementing a wildlife monitoring scheme.

Stage of scheme	Key issues to consider (with relevant references)
Design	Ensure scheme can answer key management questions and adapt it over time to take account of emerging issues and changing circumstances (Likens & Lindenmayer 2018)
	Ensure scheme addresses the needs of data users, as well as data collectors (Stephenson et al. 2017a)
Indicator selection	Use the same core indicators across sites to allow the aggregation of results and to link them to higher-level goals such as the Aichi Targets and Sustainable Development Goals (Stephenson et al. 2015a) Essential Biodiversity Variables offer a framework to facilitate data integration across scales and across core indicators (Navarro et al. 2017). Include pressure indicators to ensure threats are monitored (Crees et al. 2016)
Choosing monitoring methods and tools	Make sure methods are locally relevant and cost effective. While remote sensing may be attractive, it can be more costly than using local observers and will only capture certain taxa. Drones are increasingly popular, but their advantages over other tools are rarely assessed and implementation is limited by flight range, regulatory frameworks and a lack of validation (Christie et al. 2016). Camera traps tend to be used for large mammals and large birds, and acoustic recording devices for vocal birds and amphibians. Less well-known species may also be important elements of local biodiversity. Recent work has expanded standardized monitoring tools to include taxa such as invertebrates and plants (e.g., Van Swaay et al. 2015, Borges et al. 2018) but, in these cases, remote sensing is often not relevant
Data collection	Use standardized protocols to follow best practices for ensuring robust sampling design, statistical power and consistent replication of methods. Observations of species and threats are most valuable when generated from systematic protocols so that data can be collected in common formats, shared and scaled up (Stephenson et al. 2017b, Turak et al. 2017). Examples include tool-based protocols as with camera trapping (Rovero & Zimmermann 2016), site-based protocols such as Important Bird Area monitoring (Buchanan et al. 2013) and threat-based monitoring protocols such as the Spatial Monitoring and Reporting Tool (SMART; http://smartconservationtools.org)
	Engage stakeholders as far as is appropriate and feasible, as this is likely to speed up the use of data for decision-making and to enhance sustainability (Danielsen et al. 2014). Local stakeholders could be integrated into the use of remote-sensing technology by, for example, helping deploy devices and assisting in the analysis of photographs and audio recordings
Data sharing	Share data as widely as possible by uploading them into national, regional and global databases of relevance. This allows monitoring at scale, including measurement of global metrics on the delivery of environmental goals (Secretariat of the Convention on Biological Diversity 2014, McRae et al. 2017, Navarro et al. 2017)
	Present data in formats such as maps, graphs and dashboards that facilitate easy interpretation (Han et al. 2014, Stephenson et al. 2015a, 2015b) so that results can be translated into adaptive management actions (reformulating priorities, changing or replicating strategies, etc.)

community, donor or business. However, to be effective and to learn from recent research, wildlife monitoring schemes (especially those using remote sensing) should be developed and implemented while taking into account key issues around monitoring design, indicator selection, data collection methods and protocols and data sharing (Table 1). Furthermore, it is essential that more effort is made by conservation agencies and donors to support the development of capacity for monitoring where it is most needed: in high-biodiversity countries (Schmeller et al. 2017, Stephenson et al. 2017b). It is also important to document and share examples of wildlife monitoring, highlighting what works well and what works less well (Stephenson et al. 2015b). This is especially important with remote sensing, as practitioners need help with understanding the relative advantages and limitations of different tools.

In conclusion, remote sensing offers many opportunities for wildlife data collection if integrated into well-structured monitoring plans with clear goals and standardized protocols. However, remote-sensing techniques have their limitations (Christie et al. 2016, Aebischer et al. 2017), and if we are to move beyond a focus on large mammals and birds to include less well-known fauna, modern technology should be complemented by traditional field survey methods (Stephenson et al. 2017b). Therefore, in many wildlife monitoring schemes, drone-based and satellite-based sensors, camera traps and acoustic recording devices ought to be used alongside people in boots on the ground.

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