Diversity

Delivering a Global, Terrestrial, Biodiversity Observation System through Remote Sensing

GRAEME M. BUCHANAN,*‡ ANDREW NELSON,† PHILIPPE MAYAUX,† ANDREW HARTLEY,† AND PAUL F. DONALD*

*Royal Society for the Protection of Birds, The Lodge, Sandy, Bedfordshire SG19 2DL, United Kingdom
†Institute for Environment and Sustainability, Joint Research Centre of the European Commission, Ispra, Italy

Introduction

Land-cover change is of major concern to conservationists because of its generally negative impact on biodiversity (Brooks et al. 2002). There is a clear need to track these changes, and such information could make a major contribution to a global biodiversity observation system. Monitoring of biodiversity is an essential component of conservation because it allows problems to be identified, priorities to be set, solutions to be developed, and resources to be targeted (Balmford et al. 2003). Monitoring also allows assessments of progress toward targets and indicators in unilateral and international conservation-policy instruments (e.g., Convention on Biological Diversity [CDB]), of the impacts of international conservation policy (Donald et al. 2007), and of other policy sectors (Donald et al. 2001). Nevertheless, a paucity of information has led to a poor understanding of the cost-effectiveness of conservation policies (Ferraro & Pattanayak 2006), exposing them to criticism (Stokstad 2005).

The overwhelming majority of species and ecosystems receive no systematic monitoring, and there is a conspicuous mismatch between the distribution of monitoring effort and the distribution of terrestrial biodiversity at a global scale (Green et al. 2005). The need to improve monitoring is widely recognized (Balmford et al. 2003; Pereira and Cooper 2006), and although some systematic monitoring of terrestrial biodiversity for conservation is undertaken locally in the developing world (e.g., Danielsen et al. 2008), there is no protocol to tackle the issue at a global scale. Traditionally, monitoring of populations or habitats has involved field-based observations, an approach that is time consuming, requires specialist skills and resources, and is difficult in remote or politically insecure areas.

Although field-based monitoring needs to continue, a global biodiversity-observation system, based on changes in land cover assessed from data collected by earth observation (also known as EO or remote sensing), would address the current shortfall in monitoring. Recent announcements on free higher-resolution satellite-image data (Group on Earth Observation 2007; U.S. Geological Survey 2008) begin to make an EO-based monitoring system a real possibility because until now the high cost of appropriate remotely sensed images has been a major limitation for conservation monitoring. Although EO data may not be appropriate for monitoring all threats to biodiversity directly (e.g., poaching), it is appropriate for monitoring of land-cover change. Land-cover change is of particular concern because, for example, the most prevalent threats to a network of sites of high conservation importance entail land-cover changes that could be monitored remotely (Buchanan et al. 2008). Although the potential of EO data in biodiversity conservation and monitoring has been recognized (Turner et al. 2003; Pettorelli et al. 2005) and utilized (e.g., Buchanan et al. 2008), there is still no systematic protocol for its use in terrestrial biodiversity monitoring for conservation at continental, let alone global, scales. We argue that developing an EO-based biodiversity observation protocol would require knowledge of the distribution of biodiversity, an ability to monitor land-cover change, and an understanding of the impacts of land-cover change on populations. We

‡*email graeme.buchanan@rspb.org.uk*
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summarize knowledge in each of these 3 areas and suggest that a global biodiversity observation protocol now lies within existing capabilities.

Distribution of Biodiversity

The distributions of individual species and of sites of high species richness, diversity, or conservation significance are increasingly well documented. Systematic atlases of species distributions are limited to certain parts of the world and devoted largely to birds (Gibbons et al. 2007), but extent-of-occurrence maps are increasingly available for most regions (e.g., Stuart et al. 2004; Orme et al. 2005), although these vary in reliability (Rodrigues et al. 2004). Such maps could be refined with distribution data for which collection protocols already exist (e.g., http://gbif.org; http://worldbirds.org) and with environmental and especially land-cover data derived from EO data (Osborne et al. 2001; Rondinini et al. 2005). A growing number of global initiatives have identified areas of high conservation value or importance at regional scales (Brooks et al. 2006) and at scales amenable to management, such as World Database Protected Areas (WDPA 2006) and Birdlife International's Important Bird Areas (Fishpool & Evans 2001). Although there is often a lack of concordance between different site-selection processes (Brooks et al. 2006), it seems unlikely that many areas of global conservation significance are not captured by at least one assessment.

Monitoring Land-Cover Change

The wide range of spatial and temporal resolutions of EO data permits the development of a flexible observation system appropriate to the type of land-cover changes that threaten biodiversity. Indeed, variation in threat (spatial, temporal, and intensity) requires that the main technical parameters of EO tools (spatial and temporal resolution, sampling density, classification techniques, and validation) also vary (Mayaux et al. 2008). Earth-observation data are widely used to identify common land-cover types, such as forest, but scarcer land-cover types and gradations may be more difficult to identify (something that may be problematic where these form important habitats). In such cases, field knowledge, including the collection of ground-truthed data or the use of very high-resolution imagery (including on-line sources, e.g., http://earth.google.com), may be needed. Such additional information may aid monitoring of subtle changes (e.g., very high-resolution images for the monitoring of selective logging; Asner et al. 2005) and potentially other threats (e.g., invasive species or grazing management).

Threats requiring rapid conservation response, such as fires (or changes in fire regimes), could be monitored in near-real time, although at low spatial resolution (e.g., Justice et al. 2002). Other more pervasive threats, such as agricultural encroachment, deforestation, dam construction, or the spread of illegal settlements, may require monitoring at higher spatial resolution at longer intervals (e.g., Skole & Tucker 1993).

Responses of Species to Land-Cover Changes

Although EO data can be used to track changes in habitats that in themselves are of conservation importance, individual organisms or populations cannot generally be monitored directly. Instead population change could be assessed indirectly through relationships linking distribution or abundance to measures of land cover or land-cover change. Species distributions have been mapped from EO data (Gotteschalk et al. 2005), but the use of EO data to make inferences on the effects of land-cover change on populations has not been widely exploited. Although detailed relationships between distribution or abundance and measures of land cover do not exist for the majority of species, even crude estimates of geographical or elevational range and habitat preferences of species can be used to surmise the likely consequences of land-cover change and its likely impacts on species' conservation status (e.g., Buchanan et al. 2008). Operational management would benefit from such analyses at higher spatial resolutions, and global reporting obligations could be met with statistical estimates at national or regional levels. Currently, the few global land-cover maps that are potentially appropriate for such reporting have limitations in legends or spatial and temporal resolutions, even though some biomes have been mapped in detail (e.g., Bartholomé & Belward 2005).

Developing a Global Biodiversity Observation System

Our knowledge in the 3 key areas appears sufficient to allow EO data to make a substantial contribution to a global terrestrial biodiversity observation system for practical conservation, although collection of field data will continue to underpin monitoring. An EO-based system should involve continued collaboration between those who have biodiversity-monitoring skills (particularly in developing countries, where such a system is most needed) and EO practitioners. In outlining what we believe to be the main characteristics of an EO-based contribution to a biodiversity-monitoring protocol (Table 1), we recognize the need for any system to be simple, sustainable, and readily applicable to a range of

Table 1. Key characteristics for consideration in the development of a global terrestrial biodiversity-monitoring system based on earth-observation (EO) data.

Characteristic	*Suggested reasoning and/or solution*
Prioritized toward sites and species of conservation value or importance	targeted monitoring of areas of recognized conservation importance or value and of a size amenable to management and suitable habitat within the ranges of species of greatest conservation concern (IUCN Red List); at global scale, could be assisted by mapping globally spatial distribution of biomes with 0.5–1 km data (MODIS, SPOT-VEGETATION); at local to regional scale, digital boundary delineation with 5- to 30-m-resolution data (Landsat, SPOT, IRS, CBERS, DMC)
Temporal and spatial resolutions appropriate for practical conservation	detailed, fine-scale land-cover change over a range of timescales for management, advocacy, and CBD reporting at global (through sampling) or local to regional scales with 5- to 30-m data (Landsat, SPOT, IRS, CBERS, DMC, ASTER) for, e.g., deforestation, agricultural encroachment at 3- to 5-year intervals or 0.5- to 2.5-m data (IKONOS, Quickbird, SPOT 5) for, e.g., canopy-cover reduction, invasive species; low-resolution near real-time coverage to detect rapid changes in land cover at regional to global scale with 0.5- to 4-km data (SPOT-VEGETATION, MODIS, MSG, GOES)
Sustainable, allowing long-term indices to be developed, and flexible, to use new types of EO data	long-term guarantee of fine-resolution satellite images at a suitable cost is a prerequisite of a system, whereas open access to large databases of coarse-resolution parameters is another fundamental; coordination falls in remit of GEO
Combine EO and field data, and strong involvement of local stakeholders and conservationists	despite coverage of EO data, field-based monitoring (supplied by key stakeholders) will not be replaced; could help the verification of EO interpretation while continuing to monitor threats not associated with land-cover change; key stakeholder and local user involvement also should increase ownership
Robust and easily implemented	simple protocol developed with users in developing countries; capable of being implemented at multiple centers (increased proximity to users) and delivering comparable for continental level statistics; local ecological knowledge important for accuracy and relevance of analysis; long-term capacity will need development
Information transfer to regional and global assessments of biodiversity change	need for consolidated information for wider conservation initiatives at the country (NGOs, governments) and wider levels (2010 global biodiversity target of CBD, IUCN WCPA, UNEP Global Environmental Outlook, CBD Global Biodiversity Outlook, Ramsar Convention on Wetlands, and the African-Eurasian Waterbirds Agreement)

habitat types and threats. Through this system, a small team with low-level resources (especially compared with completely field-based monitoring) could potentially monitor land-cover changes in areas of high biodiversity across a continent. The system may in most cases be unable to produce precise estimates of trends of individual species, but should allow the production of composite and decomposable indices likely to reflect the trajectories of suites of species. This would help countries meet their obligations under CBD reporting and other global initiatives.

Targeting species and sites of highest conservation value or priority would result in the highest biodiversity conservation priorities being monitored, whereas wider countryside monitoring would monitor potential habitat for threatened assemblages. A direct, empirical approach identifying changes in the extent of defined land cover would mean the direct consequences to biodiversity of detected changes could be assessed. Addressing these issues should produce a blueprint for the basic structure of a suitable system. It may also contribute to ecosystem-services monitoring. For example, EO data could help in assessing changes in carbon stock (but see GOFC-GOLD 2007). Incorporation of other EO data, especially radar, could monitor, for example, erosion (Kimura & Yamaguchi 2000) or carbon (GOFC-GOLD 2007). The basic system would, however, primarily address the recognized need for protocols capable of producing information at spatial and temporal scales appropriate to monitoring the planet's biodiversity and our impacts on it.

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