of REDD+ mechanisms and funding are still being developed, the signatories have agreed on the need to establish realistic baseline rates of forest loss from which to calculate emissions reductions (see go.nature.com/gofoch).

With care, offsets can help to reconcile development and conservation. But if they allow governments to renege on their commitments by stealth, biodiversity offsets could cause more harm than good. ■

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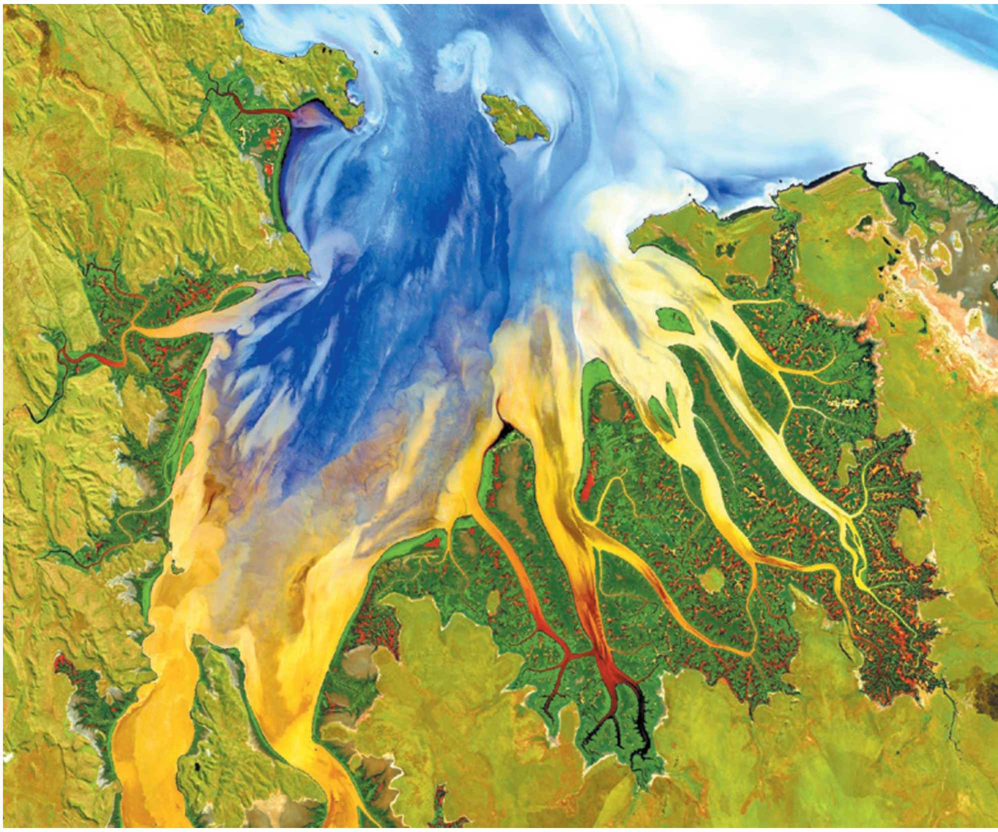
1. Bull, J. W., Suttle, K. B., Gordon, A., Singh, N. J. & Milner-Gulland, E. J. *Oryx* **47,** 369–380 (2013).
2. Aiama D. *et al. No Net Loss and Net Positive Impact Approaches for Biodiversity:* (International Union for Conservation of Nature, 2015); available at go.nature.com/gfkgkz
3. Pilgrim, J. D. & Bennun, L. *Conserv. Lett.* **7,** 423–424 (2014).
4. International Union for Conservation of Nature. *Biodiversity Offsets Technical Study Paper* (International Union for Conservation of Nature, 2014); available at go.nature.com/5fcpj1.
5. Kormos, R. *et al. PLoS ONE* **9,** e111671 (2014).
6. Maron, M., Bull, J. W., Evans, M. C. & Gordon, A. *Biol. Conserv.* http://dx.doi.org/10.1016/j.biocon.2015.05.017 (2015).
7. Temple, H. J. *et al. Forecasting the Path Towards a Net Positive Impact on Biodiversity for Rio Tinto QMM* (International Union for Conservation of Nature, 2012); available at go.nature.com/29puf2
8. The Biodiversity Consultancy. *Independent Report on Biodiversity Offsets* (International Union for Conservation of Nature, International Council on Mining and Metals, 2012); available at go.nature.com/jxrht9
9. Watson, J. E. M., Dudley, N., Segan, D. B. & Hockings, M. *Nature* **515,** 67–73 (2014).
10. Bos, M., Pressey, R. L. & Stoeckl, N. *Environ. Sci. Policy* **42,** 1–15 (2014).



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Estuary sediment and vegetation patterns in Australia, captured by NASA's Landsat 8 satellite in 2013.

Agree on biodiversity metrics to track from space

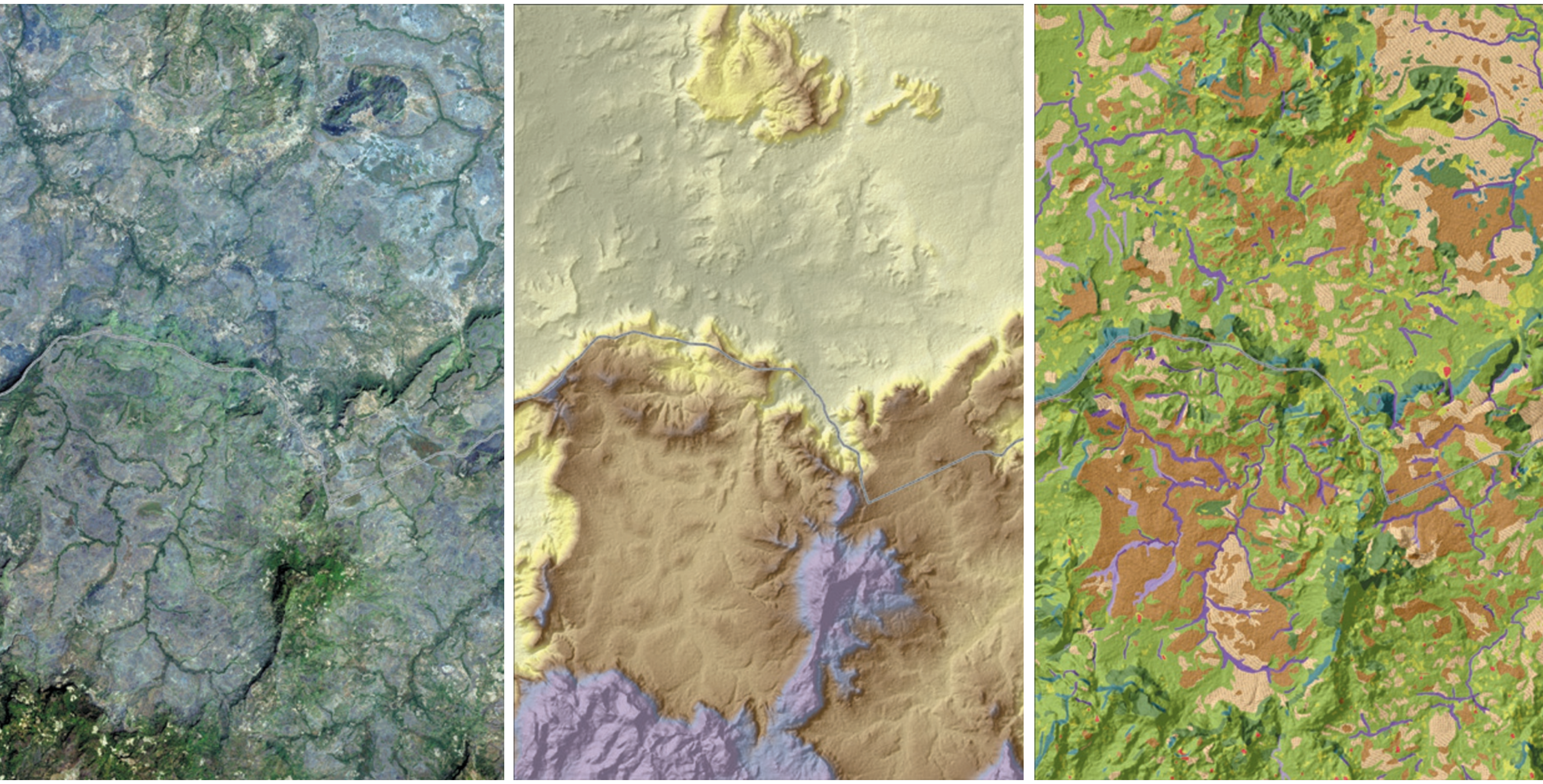
Ecologists and space agencies must forge a global monitoring strategy, say **Andrew K. Skidmore, Nathalie Pettorelli** and colleagues.

Global biodiversity loss is intensifying. But it is hard to assess progress towards the Aichi Biodiversity Targets for 2011–20 set by the Convention on Biological Diversity (CBD). Target 5, for instance, aims to halve global deforestation rates by 2020; but reliable indicators for deforestation that can be monitored remotely have not been developed or agreed on. National biodiversity monitoring programmes differ widely, most data sets are inconsistent, and few data are shared openly.

To focus priorities, ecologists have proposed classes of 'essential biodiversity variables' — including species traits and populations, and ecosystem function and structure[1]. But measuring these on the ground is laborious and limited.

Satellite remote sensing is crucial to getting long-term global coverage. It can rapidly reveal where to reverse the loss of biological diversity on a wide range of scales in a consistent, borderless and repeatable manner[2]. Quantities such as vegetation productivity or leaf cover can be measured across continents from space. But there is no agreement on how to translate these measurements into metrics that are relevant for biodiversity monitoring.

We call on conservation and space agencies to agree on a definitive set of biodiversity variables and how these will be tracked from space, to address conservation targets. Methods to derive these variables and the set of satellites needed to observe them must also be decided, to ensure continuous ▶



Combined, images from Landsat 8 (left) and the Shuttle Radar Topography Mission (centre) show land cover on the Senegal–Guinea border in 2014.

USGS

monitoring. To stimulate discussion, we propose ten variables that capture biodiversity change on the ground and can be monitored from space (see 'Ten variables'). These range from leaf nitrogen and chlorophyll content to seasonal changes in floods and fires.

MISSING LINK

Why have researchers been unable to define a standard set of biodiversity variables to monitor from satellites? Because of inadequate access to satellite data; uncertainties in the continuity of observations; and temporal and spatial limitations of satellite imagery. The problem is exacerbated by a lack of communication between the ecology and remote-sensing communities.

Historically, land imaging has been less of a focus for Earth observations than, say, weather. For years, access to satellite images was restricted for security or commercial reasons. Now, with more data available from publicly funded space agencies, it is time to push for monitoring of biodiversity change from satellites. For example, individual tree species or animals can be imaged, for a fee, in extreme detail (31-centimetre resolution) by WorldView-3, a private Earth-observation satellite owned by DigitalGlobe of Longmont, Colorado.

Biodiversity is hard to quantify. It is not measured in physical units, such as centimetres of precipitation or degrees of temperature. It involves the details of how energy (sunlight, microwaves or laser beams) interacts with living organisms. There is often a mismatch of scales in the definition of remote-sensing and ecological units.

For instance, measuring forest degradation from space requires an agreed definition of a forest and of what constitutes degradation. Without these, it is hard to compare forest distribution across a large geographical extent or across time. Definitions change. In the 1990s, the Food and Agriculture Organization of the United Nations defined forests as ecosystems with a minimum of 10% canopy cover of trees or bamboo associated with wild flora[3]. That definition was updated in 2005 with a minimum height of 5 metres for trees, while dropping the earlier references to bamboo and wild fauna[4]. Such shifts influence perceptions of where forests are, as well as where they used to be.

"The growth of open satellite-image archives such as Landsat is leading to more sophisticated data products."

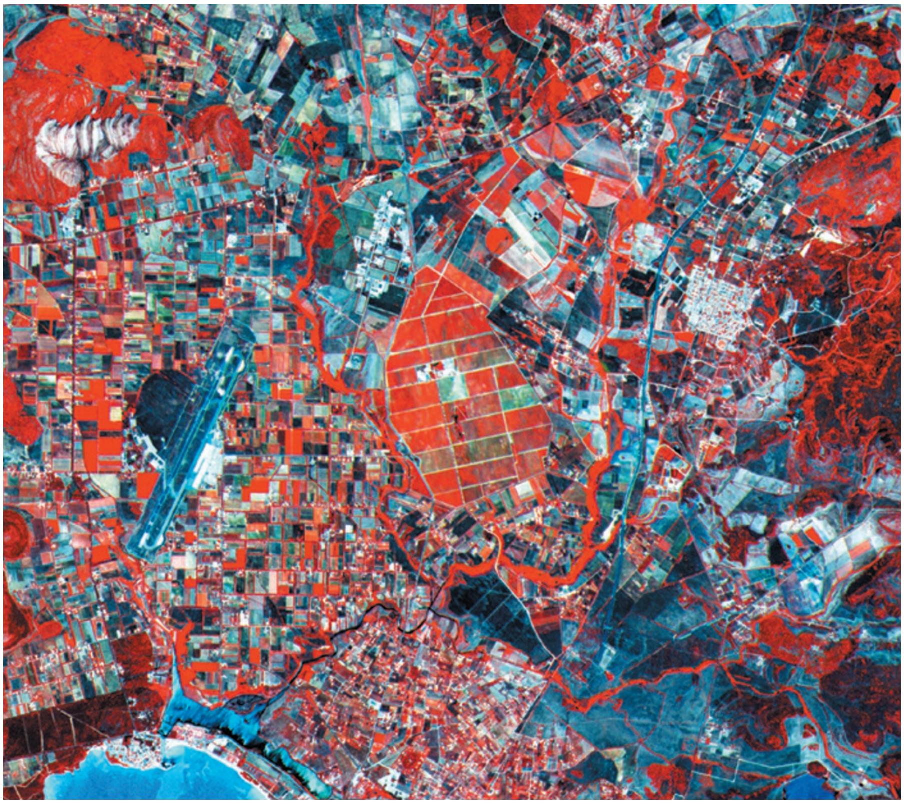
Progress is being made. The Landsat satellite series launched in 1972 by NASA was the first of its kind to evolve a global acquisition strategy and to deliver free data[5]. NASA's Sustainable Land Imaging programme, initiated last year, ensures Landsat-quality data collection for the next 25 years. The Sentinel-2 satellites, part of the European Copernicus programme, will have five-day revisit times and deliver free data until 2028.

Advanced sensors to be launched within a decade will provide increasingly accurate information on traits such as vegetation height and plant-species characteristics. These include the NASA Global Ecosystem Dynamics Investigation Lidar and the German Aerospace Center's high-resolution and wide-spectrum satellite EnMAP.

Now, ecologists and space agencies must define a joint list of essential biodiversity variables that can be monitored remotely. Some countries have made a start under the CBD-mandated Biodiversity Indicators Partnership global network. For example, the South African National Biodiversity Institute has derived 16 indicators for tracking fresh water, river, coastal and marine habitats[6].

Some critics argue that deriving information on biodiversity from space on a global level remains to be demonstrated. Because characterizing species traits or ecosystem structure requires data on diverse scales (spatial, temporal and spectral), data from multiple missions must be combined.

The growth of open satellite-image archives such as Landsat is leading to more sophisticated data products. For example, maps that show global forest cover change were produced for 2001–13 by the University of Maryland, Google, the US Geological Survey and NASA[7]. Joined-up thinking between ground-based data providers, space agencies, product engineers, researchers and policy-makers is needed to align the


Vegetation (red) on Italy's Sardinia, imaged by the European Copernicus Sentinel-2A in 2015.

TRACKING BIODIVERSITY

Ten variables

Proposed variables for satellite monitoring of progress towards the Aichi Biodiversity Targets.

Species populations
- Species occurrence

Species traits
- Plant traits (such as specific leaf area and leaf nitrogen content)

Ecosystem structure
- Ecosystem distribution
- Fragmentation and hetrogeneity
- Land cover
- Vegetation height

Ecosystem function
- Fire occurrence
- Vegetation phenology (variability)
- Primary productivity and leaf area index
- Inundation

technical specifications of sensors on board satellites and in-product algorithms.

We convened two workshops earlier this year to bring together experts from the remote-sensing and ecology communities to generate a list of candidate remotely sensed variables for reporting on the Aichi targets. The meetings, in Leipzig, Germany, and in Frascati, Italy, were funded by the Group on Earth Observations Biodiversity Observation Network (GEO BON), a network of organizations, scientists and practitioners established in 2008 under the auspices of the intergovernmental GEO.

The ten candidates we identified include continuous and biophysical variables such as leaf area as well as threshold-based thematic measures such as land cover. Participants mapped the variables onto the Aichi targets using CBD guidelines[6]. This was the first time that such a link has been made to inform global environmental policy.

The list is meant to stimulate discussion about which variables are most important. For example, vegetation height is key to inferring trends in biomass (and thus reducing deforestation, as in Aichi target 5) and ecosystem services (relevant to Aichi target 15 on restoring degraded ecosystems).

JOINED-UP APPROACH

What next? By the end of the year, the GEO BON should develop a plan for refining the list of variables proposed here. The GEO secretariat should promote the use of such variables to the CBD and Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The CBD should review, update and endorse the plan. IPBES should adopt the proposed measures for thematic, regional and global assessments of biodiversity and ecosystem services.

The GEO secretariat should support the definition of a coherent and comprehensive set of remotely sensed biodiversity variables and related products, and pass these requirements to the Committee on Earth Observation Satellites (CEOS). CEOS coordinates cooperation between space-agency satellite missions and product development. The GEO BON's plan should be updated with feedback from this process and recirculated.

The biodiversity community needs to recognize the potential and limitations of image processing for biodiversity monitoring. Remote-sensing experts should seek a deeper understanding of ecological concepts and requirements to minimize semantic confusion and to ensure that the collected data are used in the most appropriate and useful way. Those working in natural-resource management will need to be trained in biodiversity conservation and remote sensing.

Research funding agencies (such as the research directorate of the European Commission and the US National Science Foundation) must lend their support. They should seek proposals for interdisciplinary, multinational case studies that demonstrate the use and impact of remotely sensed biodiversity variables for tracking the impact of conservation actions and environmental policies worldwide. ■

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1. Pereira, H. M. *et al. Science* **339,** 277–278 (2013).
2. Turner, W. *Science* **346,** 301–302 (2014).
3. Food and Agriculture Organization of the United Nations. *Forest Resource Assessment 1990* (FAO, 1993).
4. Food and Agriculture Organization of the United Nations. *Global Forest Resource Assessment 2005* (FAO, 2005).
5. Wulder, M. A. & Coops, N. C. *Nature* **513,** 30–31 (2014).
6. Secades, C., O'Connor, B., Brown, C. & Walpole, M. *Earth Observation for Biodiversity Monitoring: A Review of Current Approaches and Future Opportunities for Tracking Progress Towards the Aichi Biodiversity Targets* (Secretariat of the Convention on Biological Diversity, 2014).
7. Hansen, M. C. *et al. Science* **342,** 850–853 (2013).

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