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Perspective

Free and open-access satellite data are key to biodiversity conservation

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Abstract

Satellite remote sensing is an important tool for monitoring the status of biodiversity and associated environmental parameters, including certain elements of habitats. However, satellite data are currently underused within the biodiversity research and conservation communities. Three factors have significant impact on the utility of remote sensing data for tracking and understanding biodiversity change. They are its continuity, affordability, and access. Data continuity relates to the maintenance of long-term satellite data products. Such products promote knowledge of how biodiversity has changed over time and why. Data affordability arises from the cost of the imagery. New data policies promoting free and open access to government satellite imagery are expanding the use of certain imagery but the number of free and open data sets remains too limited. Data access addresses the ability of conservation biologists and biodiversity researchers to discover, retrieve, manipulate, and extract value from satellite imagery as well as link it with other types of information. Tools are rapidly improving access. Still, more cross-community interactions are necessary to strengthen ties between the biodiversity and remote sensing communities.

Contents

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1. Introduction

Biodiversity underpins the health of ecosystems and the services they provide to society. Yet biodiversity is in rapid decline globally, despite commitments by governments to reduce the rate of loss (Butchart et al., 2010). Monitoring is an essential part of biodiversity conservation, allowing governments and civil society to identify problems, develop solutions, and assess effectiveness of actions and progress toward meeting the Aichi targets set by the Convention on Biological Diversity (Secades et al., 2014). Satellite imagery has emerged as a vital tool for monitoring the status of environmental parameters relevant to biodiversity conservation (Horning et al., 2010; Pettorelli et al., 2014; Buchanan et al., 2009). Tackling a global challenge like biodiversity loss requires the assembly of global information products across multiple spatial and temporal scales. Satellite remote sensing is especially useful at generating consistent observation records of key drivers of biodiversity change (i.e. land cover and land use dynamics, climate variables, and sea surface conditions) from a local to global level (Hansen and Loveland, 2012; Townshend et al., 2012; Zhu et al., 2012). A recent review of the needs of the biodiversity research and conservation communities for satellite remote sensing (Leidner et al., 2012) uncovered three factors, which are rooted in government and commercial policies and actions, that ultimately have a disproportionate impact on the utility of satellite data for understanding changes in biodiversity. These factors are data continuity, data affordability, and data access.

1.1. Data continuity

Data continuity refers to the need to preserve and improve existing long-term archives of satellite remote sensing products. Habitat loss and degradation, species invasions and changing climatic conditions are among the most significant threats to biodiversity globally (Millennium Ecosystem Assessment, 2005). These threats can impact biodiversity at a range of spatial and temporal scales, requiring global data collection and long time series of data acquisitions to understand trends and develop robust predictions about their future impacts on biological diversity. Multi-decadal, continuous Earth observation information is only available from a very few satellite systems. The joint U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA) Landsat program and the U.S. National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) instrument provide the longest global-coverage time series. For four decades, Landsat satellites have enabled detection of change on the Earth's land surface and in its shallow coastal waters. AVHRR instruments on NOAA satellites have captured ocean and land surface observations for over three decades. While other satellite data sets provide complementary information, they do not provide such long and consistent time series.

Systematic data acquisition strategies that capture inter- and intra-annual environmental changes (natural and anthropogenic) are critical to achieve and enhance data continuity. Programs such as Landsat provide an excellent example of the challenges associated with developing a strategy. Currently, international cooperators have captured approximately 5 million Landsat scenes, which now reside in archives outside the U.S. Although not all of these scenes are unique to those already in the U.S. archive, there are more images outside the USGS central archive than within it. Consequently, the USGS has begun a Landsat Global Archive Consolidation (LGAC) program Wulder et al., 2012. LGAC is updating all international cooperator imagery into a common format for users and retaining a copy in the global archive at USGS. To date over 3 million scenes have been received from different international ground stations, a third of which are unique additions to the USGS archive. The repetitive global nature of these images is especially important for those working in places with persistent cloud cover, where capturing every available clear pixel of imagery is a necessity due to frequently obscuring clouds. These areas are among the most biologically diverse and often located in places having less capacity for *in situ* monitoring (Romijn et al., 2012).

Data continuity requires both ensuring the long-term records of imagery together with bringing additional satellite systems into a global network that will increase the total amount of useful data. In February 2013, NASA and USGS launched the next Landsat, the Landsat Data Continuity Mission, now known as Landsat 8. With the launch of the Sentinel-1A C-band radar in April 2014, the European Space Agency (ESA) and the European Commission have initiated an important series of dual satellite constellations known as Sentinels. The Sentinel-2 mission, planned for launch in 2015 and 2017, will provide medium spatial resolution (10 m to 60 m – comparable to Landsat resolution of 30 m at most channels) imagery of global land surfaces and coastal waters every five days (Landsat currently has a revisit time of 16 days) (Berger et al., 2012; Drusch et al., 2012). Together with Landsat, these satellites will provide the potential to observe any area on our planet's surface with landscape-scale data every three to four days. Finally, there is a need for continuous availability of reference data as the use of remote sensing imagery requires *in situ* information for calibration and validation. International initiatives like the Committee on Earth Observation Satellites (CEOS) Land Product Validation Working Group foster community consensus on protocols for land product validation (Olofsson et al., 2012), data collection, analysis, and accuracy reporting and make these reference data available for free.

1.2. Data affordability

The cost of satellite imagery matters as it has a large impact on its use and the resulting societal benefits (Mathae and Uhlir, 2012). If too expensive, imagery will not be used as extensively as originally intended. Conservation is chronically underfunded (McCarthy et al., 2012) and governments and civil society will only use these data for implementing conservation policies and monitoring their progress if they can afford them. Many global satellite products are still expensive. In 2008, the USGS began providing open access to all Landsat imagery – new imagery and the entire U.S. archive dating back to 1972, over 5 million images – at no cost to users via the internet (Woodcock et al., 2008). This policy shift, in line with data policies previously instituted by NASA, NOAA, and the Brazilian Government, had a tremendous impact on data availability and greatly fostered the current movement to derive global products from Landsat imagery. It also resulted in a dramatic increase in the distribution of this imagery by over two orders of magnitude within two years (Fig. 1). Although difficult to quantify, the biodiversity and conservation communities are important users of these satellite images. Roughly 10 percent of publications for 2013 found in a Web of Science search on "Landsat" also contain the terms "biodiversity," "biological diversity," or "conservation." Through this policy change, users around the world are accruing the full return of the U.S. investment in Landsat satellites over four decades. National government satellite imagery developed for research and applications purposes is a public good of the highest order (Raunikar et al., 2013). We envisage that Europe too will see its investment in Sentinel missions rewarded over the coming years as the research and conservation communities take up these free data.

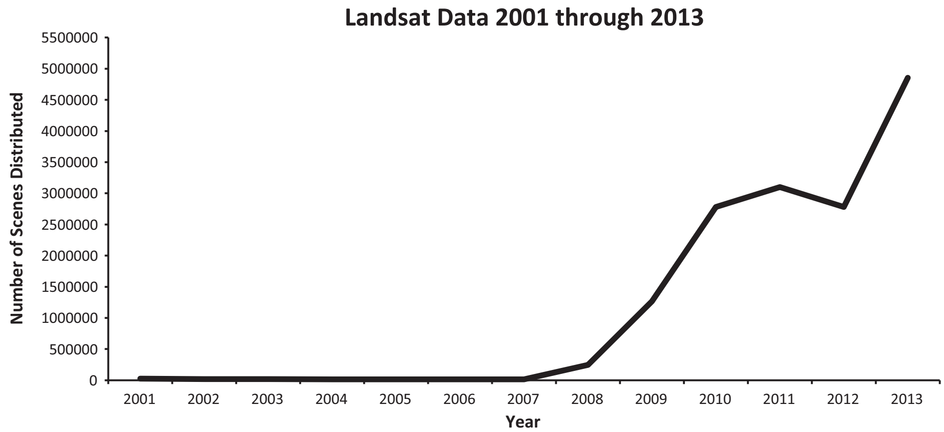

Fig. 1. Number of Landsat scenes distributed per year. Prior to December 2008, when all Landsat data in the USGS archive were made freely available, the number of scenes distributed per year ranged from 14,805 to 33,583. In November 2011, Landsat 5 acquisitions were suspended due to degradation of the instruments, which likely accounts for the dip in scenes distributed in 2012.

1.3. Data access

Data access, in this context, broadly describes the ability of end users to discover, retrieve, and manipulate data and extract useful information from satellite imagery for implementation and monitoring of biodiversity goals. Access continues to be limited because of the lack of effective data distribution strategies, tools, and technical capacity of end users. The Internet provides a platform for making satellite datasets globally available. Following different approaches, both the USGS Landsat archive and Google Earth™ have developed specific websites, tools, and distribution mechanisms to facilitate access. Both have had a profound impact on the widening use of geospatial data. In Europe, the Copernicus Programme has developed a platform to provide information on the instruments, the ground segment processing, the performance of the data products, how to access the data of the Sentinels, and how to process it via free toolboxes (https://sentinel.esa.int).

Manipulation of raw imagery is a barrier to satellite data access as it can be beyond the capabilities of users in the conservation and biodiversity communities. Satellite imagery providers, typically space agencies and research organizations, should continue to make not only the raw imagery more accessible, but also provide higher level products (e.g. orthorectified, atmospherically-corrected data products) that are easier to use. For example, USGS provides multi-year Global Land Survey products consisting of collections of images centered on specific years (1975, 1990, 2000, 2005, 2010) that are terrain-corrected and provide a basis for large-scale land cover mapping efforts (Townshend et al., 2012). There is also its LandsatLook, which consists of full spatial resolution, 3-band terrain corrected and georeferenced color images ready for use without the need for image processing software. In addition, Google has produced global forest cover change maps, derived from Landsat data, now available for examination and analysis (Hansen et al., 2013). Centralized, shared websites providing access to a range of higher level data products are a tremendous asset to new users, along with standardized techniques for the production of higher level products (De Sy et al., 2012). Finally, capacity-building strategies that significantly increase technical abilities by improving access to training and education in using satellite-based observations and tools for ecological purposes are essential for broadening applications to global biodiversity conservation. Interdisciplinary training in applied remote sensing, such as the AniMove.org program, is especially required to broaden the application of remote sensing in the biodiversity and conservation user communities. However, few international programs seem to exist and they are often targeted more at government users than civil society. Until such issues are addressed, data access is likely to remain the key limitation to widespread use of satellite imagery.

Increased access to preprocessed and value-added data would allow greater use of satellite imagery by conservationists with limited remote sensing skills and knowledge. In particular, there is a great need for regularly updated global land cover products at higher (e.g. 30 m) spatial resolutions. In addition to the already-available global maps of forest cover change (Hansen et al., 2013), ongoing activities by Chinese and U.S./European teams of researchers under the auspices of the international Group on Earth Observations (GEO) are seeking to complete efforts to create a repeatable global land cover product for the world community (Gong et al., 2013). ESA will release the first Land Cover Essential Climate Variable global map products as part of its Climate Change Initiative (CCI) during 2014 for epochs centered around years 2000, 2005, and 2010 (ESA Climate Change Initiative; Bontemps et al., 2011). This effort has been extended for three more years with the notable objective to produce similar global land cover map products for the year 2015 and the 1980s and 1990s epochs. The development of user-friendly, intuitive, and centralized data portals, which fill the semantic, technological, and technical gaps existing between data providers and data users, would likely significantly increase the use of remote sensing by the conservation and biological research communities. Such data portals should provide guidance to select the most appropriate data sets based on the user's needs. CEOS and GEO could coordinate the organization of such data portals by their space agency members to enable broad searches of remote sensing data covering a given location and time frame.

Citizen science moreover has an outstanding potential to enhance the use of satellite imagery for biodiversity and conservation, e.g. by providing more reference information or through the online mapping of roads and buildings (Newman et al., 2011). Developing citizen science approaches (such as e.g. http://www.galaxyzoo.org or http://geo-wiki.org) to support and augment satellite image analyses could improve processing capacities spatially (larger extent, more detail), temporally (short-term land use/cover change) and thematically (more species/habitats monitored), and help solve the ongoing challenge of fully integrating remotely-sensed data of environmental parameters derived from satellites with the countless *in situ* observations of biodiversity components (Pratihast et al., 2013).

1.4. Going forward together

To increase the use of satellite imagery for ecological and conservation purposes requires a commitment by both the biodiversity and remote sensing communities to promote a higher level of interdisciplinary work among these communities, creating opportunities for the advancement of both disciplines (Pettorelli et al., 2014). Solutions may include sharing existing biodiversity data more widely via web interfaces (e.g. Movebank, Smithsonian Wild, etc.). Both communities could also promote good practice through special sessions on the use of Earth observations for biodiversity conservation at appropriate annual meetings, conferences, and workshops.

Data continuity, increased affordability and better access are essential if satellite images are to play a more instrumental part in biodiversity monitoring, and support international efforts led by the Convention on Biological Diversity to reduce current rates of biodiversity loss. To this end, international coordination in satellite data collection is key to achieve a better integration of what are often very different satellite datasets, ensuring a robust and unbroken record of changes to life on Earth. CEOS and GEO, especially through the GEO Biodiversity Observation Network (GEO BON) and the CEOS Group on Remote Sensing for Biodiversity, are playing leading roles in promoting this integration. More affordable data will be necessary to monitor effectively the progress toward international conservation targets. At present, there are few examples of government satellite systems making imagery at spatial resolutions from 15 to 60 m available free of charge to all users (Wulder et al., 2012). ESA intends to make all Sentinel imagery available at no cost. Such a free and open data policy will have a dramatic impact on our ability to understand how biodiversity is being affected by anthropogenic activities and how best to respond. But biodiversity researchers and conservation practitioners need to step up too, and better integrate remote sensing products into their research agendas and activities.

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References

Berger, M., Moreno, J., Johannessen, J.A., Levelt, P.F., Hanssen, R.F., 2012. ESA's sentinel missions in support of earth system science. Remote Sens. Environ. 120, 84–90.

Bontemps, S. et al., 2011. Revisiting land cover observations to address the needs of the climate modelling community. Biogeosciences 8, 7713–7740.

Buchanan, G.M., Nelson, A., Mayaux, P., Hartley, A., Donald, P.F., 2009. Delivering a global, terrestrial biodiversity observation system through remote sensing. Conserv. Biol. 23, 499–502.

Butchart, S.H.M. et al., 2010. Global biodiversity: indicators of recent declines. Science 328, 1164–1168.

De Sy, V. et al., 2012. Synergies of multiple remote sensing data sources for REDD+ monitoring. Curr. Opin. Environ. Sustainability 4, 696–706.

Drusch, M. et al., 2012. Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote Sens. Environ. 120, 25–36.

ESA climate change initiative <http://www.esa-landcover-cci.org/?q=node/148>.

Gong, P. et al., 2013. Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data. Int. J. Remote Sens. 34, 2607–2654.

Hansen, M.C., Loveland, T.R., 2012. A review of large area monitoring of land cover change using Landsat data. Remote Sens. Environ. 122, 66–74.

Hansen, M.C. et al., 2013. High-resolution global maps of 21st-century forest cover change. Science 342, 850–853.

Horning, N., Robinson, J.A., Sterling, E.J., Turner, W., Spector, S., 2010. Remote Sensing for Ecology and Conservation: A Handbook of Techniques. Oxford University Press, New York, NY.

Leidner, A.K., Turner, W., Pettorelli, N., Leimgruber, P., Wegmann, M., 2012. Satellite remote sensing for biodiversity research and conservation applications: a Committee on Earth Observation Satellites (CEOS) workshop. <http://remote-sensing-biodiversity.org/images/workshops/ceos/CEOS_SBA_Biodiversity_WorkshopReport_Oct2012_DLR_Munich.pdf>.

Mathae, K.B., Uhlir, P.F. (Eds.), 2012. The case for international sharing of scientific data: a focus on developing countries. In: Proceedings of a Symposium. National Academy of Sciences, Washington, DC.

McCarthy, D.P. et al., 2012. Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. Science 338, 946–949.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC, p. 8.

Newman, G., Graham, J., Crall, A., Laituri, M., 2011. The art and science of multi-scale citizen science support. Ecol. Inform. 6, 217–227.

Olofsson, P. et al., 2012. A global land cover validation dataset, part I: fundamental design principles. Int. J. Remote Sens. 33, 5768–5788.

Pettorelli, N., Safi, K., Turner, W., 2014. Satellite remote sensing, biodiversity research and conservation of the future. Philos. Trans. R. Soc. B 369, 20130190.

Pettorelli, N. et al., 2014. Satellite remote sensing for applied ecologists: opportunities and challenges. J. Appl. Ecol. 51, 839–848.

Pratihast, A.K., Herold, M., De Sy, V., Murdiyarso, D., Skutsch, M., 2013. Linking community-based and national REDD+ monitoring: a review of the potential. Carbon Manage. 4, 91–104.

Raunikar, R.P., Forney, W.M., Benjamin, S.P., 2013, What is the economic value of satellite imagery? U.S. Geological Survey Fact Sheet 2013-3003. <http://pubs.usgs.gov/fs/2013/3003/fs2013-3003.pdf>.

Romijn, J.E., Herold, M., Kooistra, L., Murdiyarso, D., Verchot, L., 2012. Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+. Environ. Sci. Policy 20, 33–48.

Secades, C., O'Connor, B., Brown, C., Walpole, M., 2014. 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, Montreal, Canada, Technical Series No. 72).

Townshend, J.R. et al., 2012. Global characterization and monitoring of forest cover using Landsat data: opportunities and challenges. Int. J. Digital Earth 5, 373–397.

Woodcock, C.E. et al., 2008. Free access to Landsat imagery. Science 320, 1011.

Wulder, M.A., Masek, J.G., Cohen, W.B., Loveland, T.R., Woodcock, C.E., 2012. Opening the archive: how free data has enabled the science and monitoring promise of Landsat. Remote Sens. Environ. 122, 2–10.

Zhu, Z., Woodcock, C.E., Olofsson, P., 2012. Continuous monitoring of forest disturbance using all available Landsat imagery. Remote Sens. Environ. 122, 75–91.