Chapter 20

Epilogue: Toward a Global Biodiversity Monitoring System

Gary N. Geller, Jeannine Cavender-Bares, John A. Gamon, Kyle McDonald, Erika Podest, Phil A. Townsend, and Susan Ustin

The loss of biological diversity in our era is occurring at a faster rate than at any time in the recent past. To effectively manage losses and avoid catastrophic outcomes, it is imperative to advance the understanding of how ecosystems are changing, what is being lost, and the fundamental causes driving extinction. With this in mind, the Group on Earth Observations Biodiversity Observation Network (GEO BON) was started in 2008 to begin building a global observation network and support improved management of the world's biodiversity and ecosystem services (Scholes et al. 2008). Despite good progress, much work remains to fully realize this vision, and RS has an important role to play – its potential to contribute to monitoring biodiversity and ecosystems has long been discussed in the literature, and it has proven to be extremely valuable (e.g., Stoms and Estes 1993; Nagendra 2001; Cash et al. 2003;

G. N. Geller (✉) · E. Podest

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
e-mail: gary.n.geller@jpl.nasa.gov

J. Cavender-Bares

Department of Ecology, Evolution and Behavior, University of Minnesota,
Saint Paul, MN, USA

J. A. Gamon

Department of Earth & Atmospheric Sciences, University of Alberta, Edmonton, AB, Canada
CALMIT, School of Natural Resources, University of Nebraska – Lincoln, Lincoln, NE, USA

K. McDonald

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
The City College of New York, City University of New York, New York, NY, USA

P. A. Townsend

Department of Forest and Wildlife Ecology, University of Wisconsin, Madison, WI, USA

S. Ustin

Department of Land, Air and Water Resources, University of California Davis,
Davis, CA, USA

Turner et al. 2003; Jetz et al. 2016; Luque et al. 2018). The chapters in this book examine the use of RS to characterize and monitor biodiversity, focused largely on plant diversity. The authors have collectively explained the technologies involved and the analytical and conceptual approaches available for applying RS to monitor changes in the multiple dimensions of biodiversity and for evaluating ecosystem condition and function. The techniques discussed reflect recent advances in RS technologies, which have enabled massive increases in the amount of data available, and data science, which has developed new methods for applying these data to the detection and prediction of biodiversity. These advances are occurring in parallel with those in computing technology and statistical and analytical methods. Integrating all of these advances creates new opportunities to monitor biodiversity change and ecosystem condition and function at a global scale. Coincidentally, these opportunities arise at a time when the climate is changing rapidly and human population continues to grow, both of which further increase pressures on the world's natural systems and its biodiversity, accelerating declines that began decades ago. The emergence of international efforts to develop a global biodiversity monitoring system that can integrate RS with traditional field methods offers some hope that the ability to assess change and enhance management efforts can be improved.

Spaceborne RS has special value for monitoring these biodiversity changes because it is global, consistent, periodic, and, for Landsat, has a retrospective record going back more than 40 years. A system that combines the techniques, approaches, and lessons learned described in this book's 19 chapters would support monitoring Earth's biodiversity globally and at unprecedented levels of spatial and temporal resolution. Such a system would facilitate breakthroughs in scientific knowledge as well as provide previously unavailable information to manage biodiversity and natural resources. But spaceborne RS, by itself, is not enough. Utilizing it requires a suite of additional data, including airborne RS and a wide variety of in-situ measurements, so these must also be part of any global monitoring system.

How can these many pieces be brought together? It seems a fitting way to end this book by briefly exploring ideas for a system that can do that.

20.1 Current Situation

Most RS technology and instrumentation are developed and operated by government space agencies such as the National Aeronautics and Space Administration (NASA, USA) and the European Space Agency (ESA, Europe); while there are others, these organizations currently provide the bulk of the world's freely accessible data. Agencies such as these acquire, store, manage, and process data; they distribute data that support development of the algorithms used to generate these products. While some recent projects take a different approach, traditionally, development was assigned to specific funded teams to develop algorithms, which were then used to generate a mostly static list of standard products over the life of a particular satellite program. These products are available for download by individual users who can then process them further and apply them to problems of interest.

This approach was compatible with the computing environment available at the time; since then, however, huge advances in computing technology, including greatly decreased cost and the availability and flexibility of the cloud (which, in turn, enables new levels of co-development), have enabled alternative approaches. In fact, these approaches are necessitated by the increase in the amount and diversity of RS data available (e.g., downloading huge volumes of data for local processing is impractical).

20.2 Remote Sensing for Global Biodiversity Monitoring: Building on GEO BON

Taking advantage of these new opportunities requires not only a new level of agility in algorithm and product development but also new approaches for data management and processing. For example, collaboration both within and across disciplines is crucial because advances in science often require multidisciplinary collaboration. Effective use of data from different sources or collected at different times and scales requires a greater degree of data sharing and collaboration than is currently common. Not only have advances in understanding ecosystems and the interaction of their many components made the science increasingly multidisciplinary, but technology, particularly its move toward cloud computing, makes collaboration both easier and more natural. The workspaces the cloud provides also facilitate experimentation with and exploration of both algorithms and data, and the cloud addresses the data volume issue by “bringing the user to the data.”

Recognition of the benefits of multidisciplinary collaboration, shared workspaces, and a shift toward cloud computing is not completely new. The NASA Earth Exchange, for example, first became available in 2012, and Google Earth Engine started around the same time. The ESA Thematic Exploitation Platforms, which focus on specific themes, began in 2014, and the European Commission-funded Data and Information Access Services started to go online in 2016. Most recently, development began on the Multi-mission Algorithm and Analysis Platform (MAAP), a cloud-based, joint NASA-ESA activity that will support several new missions. Key features of MAAP include support for collaborative algorithm development as well as flexibility in terms of which algorithms are developed or products generated. However, despite the critical importance to society, no system has yet emerged that provides these and the suite of other capabilities and data needed to monitor biodiversity or related ecosystem functions.

A concept for such a system is summarized as a high-level architecture in Box 20.1. It makes extensive use of RS data, particularly satellite RS, because that is the only practical way to obtain the periodic coverage needed for regular global monitoring. As such, it augments GEO BON’s global monitoring work with a focus on RS and cloud-based processing that can take advantage of a variety of new technology-enabled opportunities. It also anticipates several new sensors and sensor types, particularly imaging spectroscopy, lidar, and radar; these technologies and their application to biodiversity monitoring are discussed in many of the book’s

Box 20.1 System Concept Overview

The system concept consists of several basic components that reside in the cloud. At the bottom is a large data store that feeds the processing area and also acts as a repository for published products. The RS feedstock consists largely of analysis-ready data (ARD), which are data that have been preprocessed to simplify further processing. A variety of other data (in-situ, airborne, and ancillary data such as DEMs) also reside there or are accessed directly from the provider's site during processing. The "sandbox" serves two purposes. First, it supports the development of algorithms by providing a space where code can be developed, shared, and tested; published algorithms can be stored in an "algorithm warehouse." The sandbox also provides a space for experimentation by scientists that need, for example, to run an existing algorithm with nonstandard parameters, to run their own models, or to combine data and algorithms in new ways in support of their research. A variety of tools are available to support both types of sandbox users. The processing area is where algorithms are staged and then run to generate products; depending on the product, processing may involve a chain of steps that produce intermediate products that may or may not be published. On the far right is a toolbox with tools to find and access the products in the data store as well as to interact with, understand, and utilize the data; these latter tools are of particular importance for applied users.

chapters. Importantly, the architecture is inherently flexible, providing a suite of basic capabilities that can be utilized in a variety of ways; for example, which algorithms are developed and how they are assessed and published depends upon the data the system hosts and how the system is governed. Box 20.2 summarizes some

Box 20.2 Some Key Characteristics of a Global Biodiversity Monitoring System

- Easy collaboration and facilitation of cross-discipline interactions. This enhances algorithm development, scientific experimentation, and applications.
- Agility and flexibility in algorithm development and data processing approaches. This facilitates a broad range of algorithms and products, makes the system responsive to the needs of users of all types, and can increase product quality.
- Integration – including fusion among different sensors, such as optical and radar, as well as among RS and in-situ data. Integration also involves addressing the challenge of data interpretation across spatial and temporal scales. The data already available provides opportunities that have not yet been fully utilized, in part because different types of data are handled by different communities.
- Simplified processing. Development of analysis-ready data will save both algorithm development time and computer resources. Analysis-ready data are standardized data for which some key processing steps, such as atmospheric correction, have already been executed.
- Utilization of advancing technologies. These include those related to sensors, such as imaging spectroscopy, thermal, radar, and lidar, but also of genomic technology, and those related to processing huge volumes of time series data in the cloud.
- Derived products and tools to increase usability and understanding. To extract the full value from data acquired and the products derived from it, many users, particularly decision-makers such as land managers, will need more highly derived products as well as tools to help them understand what the data mean and the problems they can address. A cloud-based system can facilitate development, generation, analysis, and sharing of derived products.
- Increased access to in-situ, flux tower, and airborne or UAV RS data. These data are absolutely essential because they tie the spaceborne data to what is happening on the ground. Although a tremendous amount of this type of data has been collected, only a fraction of it is accessible for integration with satellite RS data. These data will be needed to take full advantage of the opportunities discussed, but accessing them is a challenge.

of the key characteristics that such a system should have. Most of these explicitly take advantage of advancing science and technology, but there are some that technology alone cannot enable. Addressing these is important because they limit the value that a system can extract from RS data and thus the value of those data to society. By addressing the challenges of integrating vastly different data types

across a range of spatial and temporal scales – and particularly when combined with the new and forthcoming spaceborne sensors – such a system will enable a new era for biodiversity monitoring, and it will be global.

A system like that in Box 20.1, of course, is only part of the picture – the other part, upon which it completely depends, acquires the data it utilizes. While many of these data are collected by the spaceborne instruments operated by several space agencies, utilizing them to understand biodiversity on the ground depends critically on in-situ data. Integrating the two is a key challenge at hand, as discussed in the introduction to the book (Chap. 1), and is what enables inferences to be made from space about the biodiversity on the ground. Airborne data is often used as an intermediary – basically, a “scaling tool” for understanding the scale dependence and process-level understanding of signals related to biodiversity (Gamon et al., Chap. 16). Thus, off the bottom edge of the figure in Box 20.1, there exists a huge suite of data collection activities that are not shown. While some of those data are made widely available – the Global Biodiversity Information Facility (GBIF) is an excellent example – a tremendous amount of in-situ and airborne data remains inaccessible or difficult to locate and utilize (see Fernández et al., Chap. 18). The data may not be published online, but even if published the variables collected, the methods used, and the formats of the data are often specific to each activity because they are operated by independent projects or organizations.

Lack of standardization is one of the challenges involved in developing an integrated system for biodiversity monitoring, though this issue is starting to be addressed. GEO BON and its parent organization (the Group on Earth Observations, GEO), the International Long-Term Ecological Research (ILTER) site network, the US National Ecological Observatory Network (NEON), and a variety of sponsors and other organizations are working to enhance coordination and to develop guidelines and standards. Many of these activities are sponsored by governments, and in fact it is government agencies that can best facilitate and develop coordinated, operational observation systems. Thus, one of GEO BON’s focal areas is development of national and regional Biodiversity Observation Networks (BONs), and as discussed in Fernández et al. (Chap. 18), GEO BON is developing a suite of Essential Biodiversity Variables to provide top-level guidance on what data these BONs should collect and to facilitate development of standards. For spaceborne RS data, the Committee on Earth Observation Satellites (CEOS), which includes most national space agencies, facilitates the coordination of missions as well as of data standards.

Even a brief overview of a system concept like this should discuss how to ensure that the products it generates meet the needs of its target users. The “usability” of any product depends on who the user is and their level of expertise. Historically, most RS-based datasets and products have been oriented toward scientific users who have the resources and expertise to process them further. However, other users such as land managers or decision-makers, whose expertise lies elsewhere, require more specialized and more highly derived products – as well as user-friendly tools that enable them to explore and understand the meaning of those products for efficient application. These tools appear toward the right edge of the figure in Box 20.1.

As GEO BON has demonstrated, a global biodiversity monitoring system must be a coordinated effort among many international and national organizations and user communities and be built upon the vast amount of existing knowledge and data that has already been acquired. Taking full advantage of RS data and several advancing technologies will provide new insights into the status and trends in biodiversity, ecosystem functions, and ecosystem services and support operational monitoring at new scales. This will vastly enhance the understanding of our biological systems, how they are changing, and how society should respond.

Acknowledgments Many of the ideas presented in this Epilogue reflect discussions within the workshop on “Unlocking a New Era in Biodiversity Science” at the Keck Institute for Space Studies. Participants, in addition to the chapter authors, included Laura Bertola, Elizabeth Blood, Ana Carnaval, Patrick Comer, David Coomes, Néstor Fernández, Christian Frankenberg, Robert Guralnick, Walter Jetz, Troy Magney, José Eduardo Meireles, Charles Miller, Enrique Montes, Frank Muller-Karger, Helene Muller-Landau, Ruth Oliver, Monica Papeş, Ryan Pavlick, Naiara Pinto, David Schimel, Anna Schweiger, Gary Spiers, Derek Tesser, David Thompson, Woody Turner, and Maria Tzortziou. The research described herein was in part carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA; government sponsorship acknowledged.

References

- Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jäger J, Mitchell RB (2003) Knowledge systems for sustainable development. *Proc Natl Acad Sci* 100:8086
- Jetz W, Cavender-Bares J, Pavlik R, Schimel D, Davis FW, Asner GP, Guralnick R, Kattge J, Latimer AM, Moorcroft P, Schaepman ME, Schildhauer MP, Schneider FD, Schrodt F, Stahl U, Ustin SL (2016) Monitoring plant functional diversity from space. *Nat Plants* 2:16024. <https://doi.org/10.1038/NPLANTS.2016.24>
- Luque S, Pettorelli N, Vihervaara P, Wegmann M (2018) Improving biodiversity monitoring using satellite remote sensing to provide solutions towards the 2020 conservation targets. *Methods Ecol Evol* 9:1784–1786. <https://doi.org/10.1111/2041-210X.13057>
- Nagendra H (2001) Using remote sensing to assess biodiversity. *Int J Remote Sens* 22:2377–2400
- Scholes RJ, Mace GM, Turner W, Geller GN, Jurgens N, Larigauderie A, Muchoney D, Walther BA, Mooney HA (2008) Toward a global biodiversity observing system. *Science* 321:1044–1045
- Social Learning Group (2001) Learning to manage global environmental risks. A functional analysis of social responses to climate change, ozone depletion, and acid rain. MIT (Massachusetts Institute of Technology) Press, Cambridge, MA
- Stoms DM, Estes JE (1993) A remote sensing research agenda for mapping and monitoring biodiversity. *Int J Remote Sens* 14:1839–1860
- Turner W, Spector S, Gardiner N, Fladeland M, Sterling E, Steininger M (2003) Remote sensing for biodiversity science and conservation. *Trends Ecol Evol* 18:306–314

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (<http://creativecommons.org/licenses/by/4.0/>), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.