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INTERDISCIPLINARY PERSPECTIVES

Building capacity in remote sensing for conservation: present and future challenges

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Abstract

Remote sensing (RS) has made significant contributions to conservation and ecology; however, direct use of RS-based information for conservation decision making is currently very limited. In this paper, we discuss the reasons and challenges associated with using RS technology by conservationists and suggest how training in RS for conservationists can be improved. We present the results from a survey organized by the Conservation Remote Sensing Network to understand the RS expertise and training needs of various categories of professionals involved in conservation research and implementation. The results of the survey highlight the main gaps and priorities in the current RS data and technology among conservation practitioners from academia, institutions, NGOs and industry. We suggest training to be focused around conservation questions that can be addressed using RS-derived information rather than training pure RS methods which are beyond the interest of conservation practitioners. We highlight the importance of developing essential biodiversity variables (EBVs) and how this can be achieved by increasing the RS capacity of the conservation community. Moreover, we suggest that open-source software is adopted more widely in the training modules to facilitate access to RS data and products in developing countries, and that online platforms providing mapping tools should also be more widely distributed. We believe that improved RS capacity among conservation scientists will be essential to improve conservation efforts on the ground and will make the conservation community a key player in the definition of future RS-based products that serve conservation and ecological needs.

Introduction

Conservation managers, practitioners and policymakers increasingly rely on geospatial information and analysis to assess habitat status and pressures, understand species distribution and vulnerability, monitor external threats and more effectively plan conservation action and response. As a consequence, geographic information systems (GIS) have been applied widely for conservation prioritization and planning as it is well documented in the biological sciences literature (Myers et al. 2000; Brooks et al. 2006). Spatially explicit, systematic conservation planning (Margules and Pressey 2000; Groves et al. 2002; Pressey and Bottrill 2008) has been extensively used to set conservation priorities, assessing measures of anthropological threat and biological significance, and identify and map locations where conservation actions are needed (Wilson et al. 2007; Trombulak and Baldwin 2010).

Increasingly, a large amount of geospatial information is derived from satellite and aerial image processing and analysis, also known as remote sensing (RS), and these data hold tremendous potential for conservation application (Turner et al. 2003; Buchanan et al. 2008; Rose et al. 2015). Today, access to remotely sensed data has been vastly improved, and many aerial and satellite data are freely available [e.g. moderate resolution imaging spectroradiometer (MODIS), Landsat and Sentinel]. Data providers are increasingly able to serve imagery that is already pre-processed, thereby eliminating much of the work required to prepare the data for analysis. Moreover, increased technological capability of some personal computer systems allows users to better manage and analyse RS data. However, direct use of RS-based information for conservation decision making remains limited. Reasons for this might include (1) remotely sensed data are large in volume, more complex than standard GIS data and, therefore, require more advanced systems with high storage and processing capacity; (2) the acquisition of satellite data has historically been too costly for most organizations and institutions to afford and (3) as a consequence, conservation organizations and institutions have not invested in building capacity for RS in terms of personnel and technological requirements, and this has limited further the use of remotely sensed datasets.

As a result, many conservation-based organizations and institutions have developed capacity catered more to building GIS rather than RS expertise. Furthermore, RS training opportunities for conservation professionals, that are aligned to conservation applications, are not widely offered; yet, an example of this is given by the lack of RS modules dedicated to ecology and conservation in the wide range of training available at ConservationTraining (https://www.conservationtraining.org/course/index.php, accessed on 24 August 2016).

A lot of the current RS training is provided by degree programs at institutes of higher education, but we believe that, beside what offered by academia, professional trainings in conservation applications of RS are greatly needed to increase the capacity of those working in the conservation field.

In this paper, we identify current needs and challenges for building RS capacity in conservation and present results from a survey of RS conservation professionals designed to better understand the vision, needs and priorities for conservation RS capacity development. We argue that the best and most cost-effective approach for building such capacity should focus on increased understanding of RS basic principles, increased data access and production of relevant conservation datasets, and the development of best practices and data analysis tools for their use in conservation. Increasing remote sensing capacity among conservation practitioners and decision makers will also allow these users to actively contribute to the definition and production of new remotely sensed datasets and indicators that address conservation needs.

Role of Remote Sensing in Conservation

Remote sensing has made significant contributions to conservation globally as satellite observations first highlighted an increase in forest loss in the Amazon during the 1970s. Since then, studies have demonstrated meaningful use of RS data analysis for ecology and conservation (Kennedy et al. 2010; Pettorelli et al. 2011; Rose et al. 2015). They provide examples that can be grouped thematically into topics that include (1) identifying and mapping undisturbed terrestrial habitat (Potapov et al. 2008; Tyukavina et al. 2016) and species-specific suitable habitat (Goetz et al. 2007; Bergl et al. 2012), (2) analysing species-specific resource use (Stoner et al. 2016), (3) investigating multi-temporal changes in habitat quality (Buchanan et al. 2008; Nackoney et al. 2014) and (4) developing dynamic RS-based decision support systems to support wildlife conservation and management (Jantz et al. 2016). Recent advances in high-end data computing have for the first time allowed huge archives of imagery to be leveraged, resulting in multi-temporal data on global tree cover loss (Hansen et al. 2013), mangroves (Giri et al. 2011) and global fire activity (Chuvieco et al. 2008).

Rose et al. (2015) highlighted 10 *critical questions* in conservation that could be best solved through RS. These questions, which covered 10 broad conservation themes, defined a conceptual framework for using RS to improve conservation outcomes. Very recently, the Group on Earth Observations Biodiversity Observation Network (GEO BON) similarly identified a set of variables necessary for long-term biodiversity monitoring (Skidmore et al. 2015). Out of the 22 *essential biodiversity variables*, or EBVs, that were proposed, 14 can be monitored using RS data. Both efforts, the 10 critical questions and the EBVs, provide clear arguments for increasing the capacity for integrating RS into conservation practice.

Training Needs and Challenges

Access to RS methods relevant to conservation applications and the applied use of conservation-related RS data in training courses is critical for conservation NGO employees, national parks managers and other conservation professionals. During a workshop on Remote Sensing for Conservation, organized at the Joint Research Centre of the European Commission in 2013, several working groups discussed the use of RS by conservation scientists and practitioners and the main needs and challenges in using RS data to address conservation questions (Leidner et al. 2013). One of the key points highlighted was a lack of understanding about how RS could contribute to solving certain conservation-related problems in addition to the particular capabilities and limitations of RS observation in monitoring and mapping specific environmental phenomena. Taking into account the differences in objectives and use of RS methods and data in conservation policy and research, RS trainings for conservation professionals need to be structured to overcome these knowledge gaps. Training a RS scientist can involve years worth of technical, engineering and applied training, including courses on the physics of light and light–object interactions, atmospheric science, sensors and advanced image processing and analysis (e.g. signal interpretation, classification techniques and algorithm development). Applied training in conservation RS, however, should instead target the goals and needs of a conservation practitioner and be shaped around answering pertinent ecological and conservation questions that utilize methods and data derived from RS observation. In this context, the standard RS modules that teach image (pre-)processing and the methods applied to derive spectral indices [e.g. leaf area index (LAI), normalized difference vegetation index (NDVI), fraction of absorbed photosynthetically active radiation (FAPAR)] become less relevant. Conservationists instead need to learn the ecological meaning of vegetation spectral indices and become aware of the basic RS principles behind image acquisition that affect the quality of the derived products. Training should therefore focus on how to use information derived from RS technology in order to conduct scientific analysis and make informed decisions.

Through targeted training, conservation professionals can benefit from the rapid growth of RS-based information and derived datasets and learn how these products can be used to drive conservation analysis and decision making. Trainings should provide (1) understanding of basic RS principles and RS-derived information, (2) knowledge about how to access and use these data and products for environmental analysis, (3) information about how the accuracy and resolution (i.e. spectral, spatial and temporal) of the original raw data may affect a particular study and (4) basic principles of RS data analysis (e.g. time-series) and data formats (raster and vector datasets). The use of open-source mapping software (e.g. QGIS, R, GRASS) is also essential to open RS to all categories of users. With this focus, capacity development tools for conservation practitioners could be more cost- and time-effective and better engage the conservation community in the same way that GIS training did over the past 10 years.

Conservation Remote Sensing Network Survey

Considering the growing attention dedicated to RS data and products, and their improved quality and availability, there is strong need to build a network of users in the conservation community with appropriate knowledge and understanding of the opportunities and limitations of RS technology and products in order to improve conservation monitoring, implementation and planning. The Conservation Remote Sensing Network (CRSNet, http://remote-sensing-conservation.org/about/, accessed on 16 June 2016) was established in 2013 as a direct response to this need. This community aims to (1) improve the dialogue between the conservation-based users of RS technology and products and the scientists that develop those products, (2) increase RS capacity in conservation programs and (3) increase collaboration between RS experts and ecologists. CRSNet includes over 500 members, encompassing individuals from various disciplines and professional affiliations that range from academia and NGOs to industry and space agencies.

Recently, CRSNet conducted a survey (see Appendix S1) to better understand members' main needs and expectations concerning RS technology and data. The survey asked about members' level of RS expertise and training needs, and asked them to identify main gaps and priorities in the current RS data and technology as applied to conservation. In total, 140 people participated. The survey participants were summarized according to the general location(s) of their study regions (Fig. 1) and their professional affiliations (Fig. 2). In both cases, it was possible that participants were associated with multiple geographic areas and professional affiliation categories. Both terrestrial and marine regions of the world were represented as study regions, and several participants had a global-level focus. Participants from academic and NGO institutions were the most represented in the group.

Answers to questions that asked about participants' specific RS expertise were based on the participants' self-assessment. The average values were summarized by professional affiliation class (Fig. 3), with values ranging between 1 and 5, value 1 indicating a beginner level and 5 a proficient user. Categories of RS expertise included data use, image pre-processing and image processing. Although there was a general balance in terms of overall expertise across affiliation type, the private sector self-assessed to have slightly higher expertise in most of the image pre-processing and processing techniques.

The survey also asked questions related to RS training access, ranging from online to in-person courses by affiliation type. Results showed much higher access to training opportunities for participants working in academia,

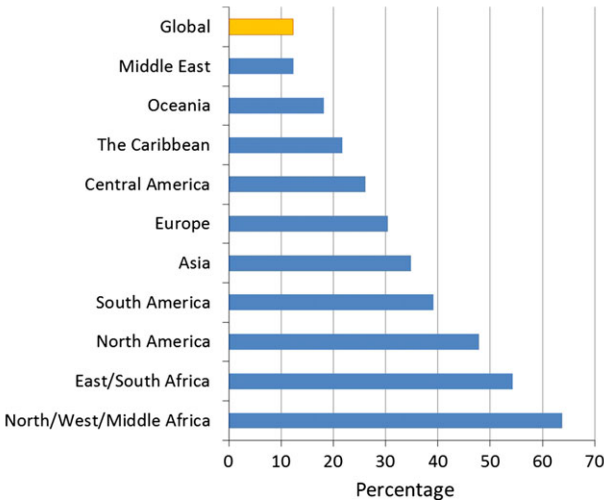

Figure 1. The distribution of the survey participants according to their study region(s). Note that one person can be working on more than one region.

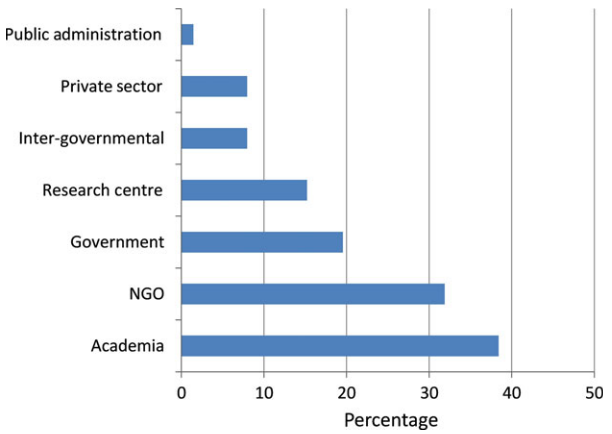

Figure 2. The distribution of the survey participants according to their professional affiliation. Note that one person can have multiple affiliations.

especially trainings conducted in-person by a live instructor (Fig. 4).

Besides access to training, the survey asked about participants' use of commercial and open-source software for image processing and spatial data analysis. Results showed a general tendency in using software for spatial data analysis rather than image processing, commercial software are more spread than open-source regardless the affiliation type (Fig. 5), with ArcGIS being the most widely used package. The open-source software, R, was reported to be used by up to 40% of the survey participants. Only in the academic and research affiliations did other open-source software (i.e. GRASS GIS, QGIS) reach a similar level.

The CRSNet survey also asked participants to identify priorities in specific topics related to conservation RS. Results included (in the order of high to low priority) the need to acquire software and processing tools, production of publications and reports, development of guidelines about satellite data products and where to download them, funding opportunities, understanding policy impacts and highlighting success stories, organizing and attending community meetings (in-person society meetings, webinars, etc.) and learning about member news and projects. Additionally, high importance was also given to the preparation of guidelines, reviews and recommendations about the (1) use of satellite products in conservation, (2) existing software for the analysis of satellite-based products and (3) data collection to validate RS products.

The participants' priorities as identified through the survey provide especially valuable information for designing trainings in RS for conservationists. We believe that greater access to training could improve the overall capacity of the conservation community in making use of RS data and tools and promote appropriate methods and datasets for analysis and decision making. The survey results suggested that CRSNet could play a substantial role in leading increased collaboration between scientists and practitioners in the conservation community. This can potentially foster a new generation of RS datasets specifically tailored to ecology and conservation needs, thereby improving current conservation decision making and effectiveness.

Current Remote Sensing Training and Opportunities

Current training opportunities in RS are often focused on teaching the use of software packages for image processing and data analysis, with no specific objectives related to ecology and conservation. Perhaps one of the most prominent centres for formal postgraduate academic training (>20,000), based primarily on the number of graduated students in RS application and spatial science, is the Faculty of Geo-Information Science and Earth Observation (ITC) at the University of Twente. ITC provides degree, diploma and certificates in geo-information science and earth observation using RS and GIS with a focus on natural resource management and training for environmental managers from developing countries. In addition, a number of short-course training opportunities (often 1 or 2 weeks in duration) have more recently emerged that are specifically dedicated to conservation RS. The Smithsonian-Mason School of Conservation (http://smconservation.gmu.edu, accessed on 16 June 2016) offers courses in species distribution modelling and

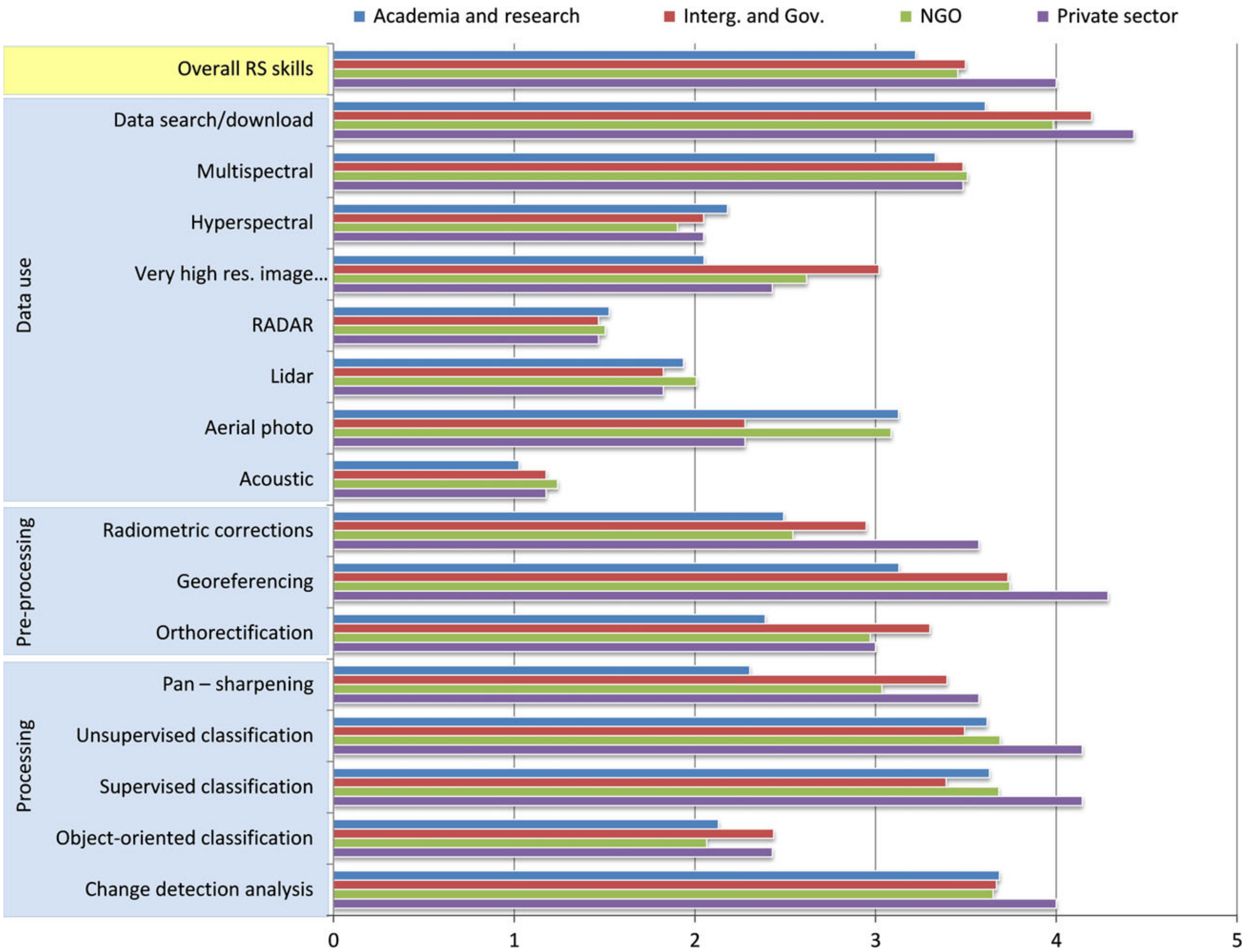

Figure 3. Remote sensing skills by affiliation type based on participants' self-assessment (level 1: beginner, level 5: proficient).

ecological geospatial statistics, among others. NASA's Applied Remote Sensing Training (ARSET) program (http://arset.gsfc.nasa.gov/eco, accessed on 16 June 2016) has offered a series of webinars devoted to the fundamentals of RS for conservation application as well as land management and wildfire monitoring. These webinars covered topics such as satellite sensors and their applicability to different environment-related problems and featured real-world application of data and tools for monitoring animal habitats and animal movement, land cover change, fire detection, among others. Another RS training opportunity, that although is not specifically focused on conservation has components very relevant to it, is the joint NASA and USAID program, called SERVIR (http://www.servirglobal.net, accessed on 16 June 2016). SERVIR provides 2-week trainings on the use of NASA data for sustainable development-related activities and policies; examples include global navigation systems, introduction to GIS and RS, land cover mapping from satellite image data using eCognition and the use of the software program R for REDD+ applications. To complement these tools, SERVIR also provides training in web-based services (e.g. Google Earth Engine, GPOD (http://gpod.eo.esa.int, accessed on 16 June 2016).

The Remote Sensing for Biodiversity & Conservation website (http://remote-sensing-biodiversity.org/, accessed on 16 June 2016) is a source of news and information about upcoming conservation RS training opportunities and conferences, it gathers the networks focused on conservation RS and lists a wealth of both terrestrial and marine RS data resources. Similarly, the Spatial Ecology Wiki (http://www.spatial-ecology.net, accessed on 16 June 2016) provides a platform for posting trainings and tutorials geared towards open-source software for ecological data analysis.

Next Steps for Training

In order to increase the current use of remotely sensed information by conservation scientists and decision makers, targeted approaches are needed. Trainings should

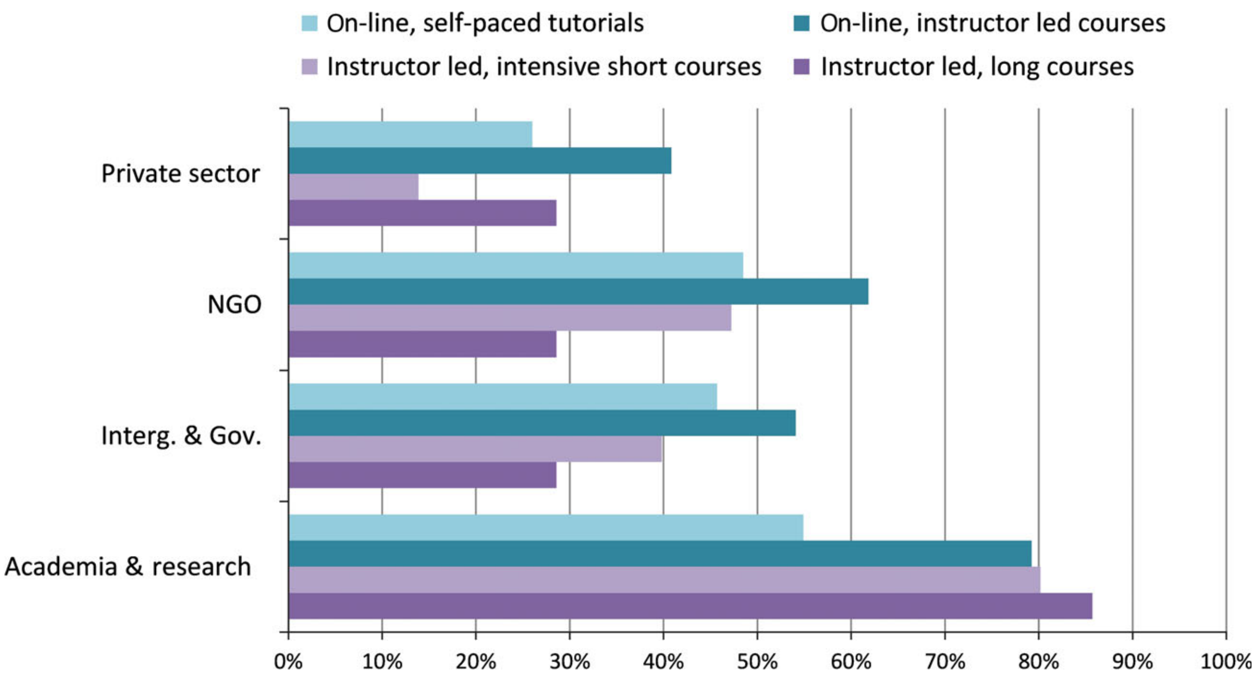

Figure 4. Access to different types of training by affiliation type.

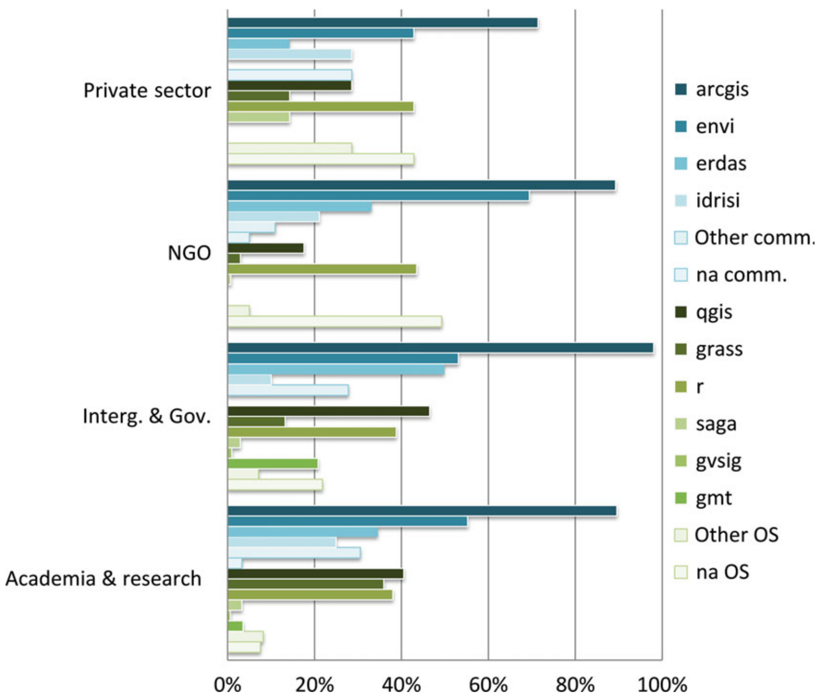

Figure 5. Use of commercial (comm.) versus open-source (OS) software by professional affiliation.

focus on the use of the growing pool of derived products rather than raw satellite data and image processing; moreover, training modules should be shaped around answering specific ecological questions and teach how to derive indicators and relevant environmental variables (e.g. EBVs) from current RS products. More emphasis on the application of RS data analysis methods for conservation purposes is needed, such as time-series analysis with Landsat and Sentinel datasets (e.g. detection of land cover and land use change and fire occurrence). Similarly, webinars can serve a wide user community, highlighting new RS products such as deforestation data and demonstrating how to use these data to answer pertinent conservation questions.

The use and continued development of open-source software packages are crucial for teaching applied data analysis methods. Open-source software packages, which are available free of charge, can increase the use of RS data among non-RS experts at no cost; in addition, open-source software is much more accessible especially to users in developing countries who lack the financial resources to purchase commercial software packages (Rocchini and Neteler 2012; Wegmann et al. 2016). Another advantage of using open-source software is that the programming code used to develop the software packages is shared openly, so that the software can be modified to suit individual needs. Many open-source software packages have online user forums that are actively maintained and promote collaboration across the globe. It is likely that RS experts will continue to rely on proprietary software such as Esri products, ERDAS, ENVI/IDL and eCognition; however, open-source software such as the RStoolbox package in R (see Wegmann et al. 2016), GRASS, QGIS, OTB, SAGA and GDAL provide much of the same functionality, at no cost.

An opportunity to enrich current trainings is also offered by the new map-based platforms that host online public data and allow dynamic mapping. Such platforms have increased in recent years, including those primarily directed toward ecologists and conservation practitioners. These online platforms contribute to a wide dissemination of RS data and product visualization, and generally facilitate broader access to RS-based information. They are easier to use by non-RS experts as they do not require image processing, mapping capability or high-end computer capacity. Some examples of such platforms are the IMPACT toolbox developed by JRC–European Commission (Szantoi et al. 2016), the Global Forest Watch (http://www.globalforestwatch.org/, accessed on 16 June 2016) developed by the World Resources Institute, and the FIRMS Web Fire Mapping (https://firms.modaps.eosdis.nasa.gov/firemap/, accessed on 16 June 2016) developed by NASA. Finally, by taking a collaborative approach, conservation NGOs, government scientists and RS specialists working in ecology could pool their resources to develop materials for online tutorials or instructor-led courses. Instructor-led courses are often preferred over online courses because they facilitate direct interaction between the students and the teacher and often provide networking opportunities as well. However, they generally require more resources than online trainings and, unless they are recorded, have a lower chance of being repeated in the future.

Standardizing conservation-based RS training curriculum and methods would be useful to provide comparable training content across courses and also deliver course content on a wide range of topics, like those described by Rose et al. (2015). This might lead to a 'Sourcebook of Remote Sensing Approaches for Conservation' that would allow a transfer of methods and approaches across different regions and organizations, and also allow conservation practitioners to compare how various methods are implemented and integrated into their unique decision-making processes. Harmonization of the topics relevant to the most common RS tasks in environmental analysis could also be beneficial, such as (1) basic RS principles (image acquisition, spatial, temporal and spectral resolution, data accuracy), (2) the use and development of vegetation indices, land cover classifications and other datasets important for environmental analysis and (3) fundamentals of conducting analysis with RS-based datasets, including their application to solving environmental problems and their main challenges and limitations. From a technical perspective, harmonization of methods could be achieved by developing user-friendly add-ons that could be launched from an open-source software platform to provide a suite of conservation-related tools such as land cover change analysis or retrieval of data from online sources. Trainings should be built around commonly used and freely available datasets such as tree canopy and tree cover loss data provided by Hansen et al. (2013), MODIS-based vegetation data, fire products and other data derived from Landsat and Sentinel satellite programmes. Different applications of data, ranging from high to low spatial resolution, should also be featured. It is important to acknowledge that the RS needs of conservation practitioners, who are engaged in applied problems on the ground, might differ significantly from the RS needs of ecological researchers. Rather than analysing the distribution of a single species across decades, conservation practitioners might focus instead on identifying locations of deforestation hotspots within a species range that might require more rapid response. Training curricula should be sensitive to these differences and introduce tools and data accordingly so that multiple needs and situations are addressed.

Similarly, to prepare a new generation of conservationists, academia should offer to both undergraduate and graduate level students more interdisciplinary curricula and courses to integrate conservation and RS topics. This will also facilitate the creation of future interdisciplinary research centres that focus on conservation topics.

Outlook

Although the enormous potential for RS in ecology and conservation is well known, knowledge of pertinent datasets, methodological approaches and examples of direct application of RS to conservation problems is still limited. Trainings focused on ecological and conservation applications are greatly needed to improve and increase the application of RS in these disciplines. In light of the recently launched European Space Agency's (ESA) Sentinel satellites, the new upcoming Sentinels (planned for launch between 2017 and 2020) and other satellite missions such as Landsat 9, hyperspectral missions and the GEDI Lidar mission, we expect a rapid increase in datasets valuable for conservation studies. The coordination of the ESA Sentinel programme with NASA will increase satellite data availability and, more importantly, access to a number of improved products useful for monitoring both terrestrial and marine ecosystems. Both programmes are making data available as subsets with smaller file sizes, which will make on-demand RS application more viable for users in regions with limited bandwidth. Because conservation practitioners will need to increasingly understand how to use new products with improved spatial, temporal and spectral resolutions, training curricula will need to keep pace with these technological improvements. In addition, as RS technology develops in scope, it will be increasingly important to foster a RS-informed conservation community that can provide important feedback to satellite programme managers and RS experts about what products are most needed and how existing data can be improved in order to increase conservation effectiveness. The Conservation Remote Sensing Network (CRSNet) provides a valuable platform to help achieve this goal; in addition, it provides a diverse information network to share updates on existing and new datasets, information on training opportunities, methodological approaches and valuable lessons learned on the ground.

Continued development and advances in making RS software open access and more user-friendly will facilitate the use of RS products among conservation practitioners around the globe. This should be paired with efforts to make RS-derived data freely available and easily accessible and usable. Online mapping platforms that allow users to visualize and map data relevant to environmental monitoring are key; in addition, the data should be freely downloadable for more experienced users who wish to conduct further analysis.

Our outlook for conservation RS and capacity building is very positive. Events centred around the theme of conservation and environment with RS are increasing, such as the Zoological Society of London's (ZSL) Remote Sensing for Conservation symposium held in 2014 and the ESA Living Planet Symposia, recently held this past May 2016. Satellite and aerial sensors and technology are evolving rapidly, and data providers now have greater opportunity and experience higher urgency to share their data openly. The use of drones and unmanned aerial vehicles (UAVs) is also growing among conservation managers, providing a wealth of high-resolution data for targeted geographic areas that can help monitor environmental pressures that might be more difficult to assess otherwise (e.g. wildlife poaching). As a consequence, awareness of RS capabilities and interest in applying new RS technology and data are growing enormously within the conservation community and are generating momentum for a coordinated action to develop dedicated RS trainings for conservation. True success will depend on addressing the variety of users' needs and expectations to ensure that capacity development efforts generate increased RS expertise in the conservation community so that on-the-ground conservation actions and decision making become most effective.

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Supporting Information

Additional supporting information may be found online in the supporting information tab for this article.

Appendix S1. Basic Demographic Information

