Remote Sensing in Ecology and Conservation
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INTERDISCIPLINARY PERSPECTIVES

Remote sensing training in African conservation

Helen Margaret de Klerk[1] & Graeme Buchanan[2]

[1]Department of Geography and Environmental Studies, Stellenbosch University, P. Bag X1 Matieland, Stellenbosch 7602, South Africa
[2]Conservation Science, RSPB Scotland Headquarters, 2 Lochside View, Edinburgh Park, Edinburgh EH12 9DH, United Kingdom

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Correspondence
Helen Margaret de Klerk, Department of Geography and Environmental Studies, Stellenbosch University, P. Bag X1 Matieland, Stellenbosch 7602, South Africa.
Tel: +27 21 808 9322;
Fax: +27 21 808 3109;
E-mail: hdeklerk@sun.ac.za

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Abstract

The potential of remote sensing (RS) to assist with conservation planning, implementation and monitoring is well described, and particularly relevant in African areas that are inaccessible due to terrain, finances or politics. We provide an African perspective on remote sensing (RS) training for conservation and ecology over the last decade through investigating (1) recent use of RS in African conservation literature, (2) use of RS in African conservation agencies, (3) RS training by African institutions and (4) RS capacity development by ad hoc events. Africa does not produce most of the research using RS in conservation and ecological studies conducted on Africa, with authors with correspondence addresses in the USA predominating (33% of a bibliometric analysis), although South Africa-based authors constituted 20% (with an increase between 2000 and 2015), Kenya 6% and Tanzania and Ethiopia 4% each. Ideally research should be conducted close to the point of use to ensure relevance and data residence in the country concerned. This is a point for attention, possibly through international funding to increase the capacity of African academic institutions to conduct research using RS to answer conservation questions. Part of this will need to include attention on data and software costs, internet speeds and human capacity. Data costs have been alleviated by free Landsat and MODIS data, and the Copernicus programs, but there is need for higher resolution imagery to be freely available for certain conservation projects. Open Source software may well offer a long-term solution to software costs. This would require that teaching is realigned to employer requirements, which are shifting in many countries and agencies from proprietary software to Open Source due to licensing costs. Low internet connectivity in many areas of Africa might limit the uptake of new data processing options that require connectivity, although over time these tools may become available to more users. However, human capacity is developing. Of the 72 academic institutions surveyed, a number of conservation programs supplied either tailored RS teaching or used 'service modules' to provide RS skills to young graduating conservation professionals, showing a recognition of the importance of RS in conservation in Africa. This study highlights the success of capacity development in Africa, and the increasing use of remote sensing for conservation in Africa.

Introduction

It is well recognized in the literature that remote sensing (RS) has potential to provide much data and knowledge to aid conservation managers and decision makers (Buchanan et al. 2009; Turner et al. 2003; Turner 2014; O'Connor et al. 2015). There has been a long history of the application of remote sensing in Africa. One of the first publications to recommend the use of RS in conservation in Africa is Wicht's (1945) use of aerial photography for mapping vegetation in South Africa. Wicht saw the value of remote sensing images to provide back-drop information on infrastructure (railways and fire breaks) and natural processes (e.g. fire and invasive alien plant infestations). Further applications have seen remote sensing being used to map and monitor land cover

(Stuckenberg et al. 2012; Verhulp and Van Niekerk 2016) and threats to Important Bird Areas (Buchanan et al. 2009; Tracewski et al. 2016), habitat availability for specific species (Buchanan et al. 2011; Piel et al. 2015), potential conflicts between wildlife and agriculture (Wallin et al. 1992) and habitat degradation (Lück-Vogel et al. 2013). Despite the breath and history of applications of remote sensing to conservation, many have suggested that the remote sensing community is not meeting the needs of the conservation community and that there is a need for a better dialog between the two (Rose et al. 2015; Pettorelli et al. 2014). Topics identified by conservationists in which development is needed to improve the uptake and use of remote sensing in conservation is diverse, but a recurring theme is education. The development of remote sensing capacity and knowledge within the conservation community was identified as one of the possible solutions to the disconnect between the two fields (Turner 2014). Many of the assessments of needs from the conservation community have been undertaken in and primarily focused upon users based in North America and Europe (e.g. Rose et al. 2015). Although many of the participants have experience in working outside these areas, there has been no dedicated assessment of the state of use of remote sensing, and user needs in Africa. This is despite this continent being biodiversity rich, and a region to which remote sensing could make a large difference for conservation monitoring.

Here, we describe the use of remote sensing in African conservation through (1) a bibliometric analysis of peer-reviewed published research literature over the last 15 years; (2) describe the current use of remote sensing data in conservation through interviews with conservation field staff and conservation specialist technical staff in various conservation organizations and (3) describe the processes in place to educate the conservation community of Africa in the use of RS by surveying various academic conservation programs. In doing so we hope to provide a record of where the current state of play lies, and also identify where processes need to be improved. We hope that the study will feed into the improved provision of remote sensing training for African conservationists, tailored to the needs of this community.

The recent uses of remote sensing in African conservation in scientific literature

To describe the recent history of scientific output of the application of remote sensing in conservation and ecology research in Africa, a bibliometric analysis was conducted in Web of Science using the following combination of keywords and criteria (adapted from de Araujo Barbosa et al. 2015): (1) the literature should include the following combination of keywords: remote sensing OR earth observation OR Landsat OR Lidar OR MODIS OR SPOT OR Radar, AND conservation OR ecology, AND each of the African country names (see Appendix S1 for list of individual African countries listed); (2) only scientific peer-reviewed journals, including reviews, were considered; (3) articles written in English, or other languages with English bibliometric information, were considered and (4) only articles published between 2000 and 2015 were analyzed. We used the output of these searches to describe trends in the number of publications produced over years and according to author affiliation. For the six African countries who had published the highest number of articles, we were able to look at trends in their publication rate over time.

We identified 580 studies which met our search criteria. The number of publications that integrate remote sensing and conservation in Africa has increased fivefold from 2000 to 2015 (Fig. 1). Around 34% of the research is led by researchers whose correspondence address was in the USA. About 21% of the literature was led by authors whose address was in South Africa, whereas authors in

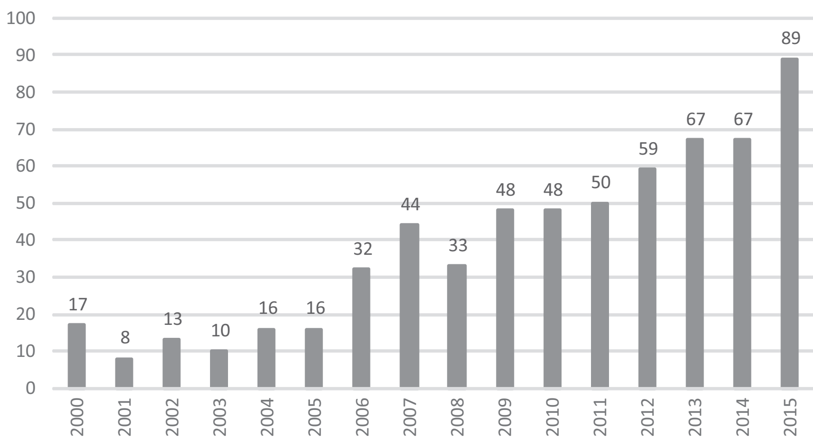

Figure 1. Number of peer-reviewed publications integrating remote sensing and conservation in Africa (meeting all the search criteria) per year from 2000 to 2015.

Kenya produced 6%. Authors in Ethiopia and Tanzania each produced 4% (Fig. 2). Together authors with addresses in African countries accounted for 51% of records (Table 1, Fig. 3). A steady growth of publications on conservation and RS is seen in South Africa, but not in Kenya, Ethiopia or Tanzania (Fig. 4).

Based on cases where the source of data was given in the abstract of the article, Landsat data were the most widely used data, accounting for around 50% of all studies. MODIS data in one form or another came second, at around 20% of studies (some studies could occur in both categories). Thus, these two free platforms were used in the majority of studies. This no doubt highlights the importance of free data (see, e.g. Turner 2014). Active data (radar and LiDAR) featured to a much lower extent with just 22 and 17 studies. These data types are newer, and until recently not widely or freely available. Sentinel 1, as part of Copernicus program, is making radar data widely available for free, so we might see an increase in the use of these technologies in the future. The cloud penetrating abilities of radar might make it particularly useful in areas of Arica which have heavy cloud cover, and for which optical data are of little value.

Figure 5 provides a broad illustration of the topics occurring within the keywords of the articles we considered. After conservation (one of the search terms), vegetation and forest appeared to be prevalent words. Management and National Park were also apparently frequently occurring words. This might indicate that studies were being undertaken with a view to informing management.

Use of remote sensing in conservation organizations in Africa

To determine the current use of RS (data and tools) in conservation to support decision making and environmental management, we used semi-structured interviews to determine the current use of RS in four conservation organizations in Africa (see Appendix S2). The focus was on conservation field staff and the use of RS products or tools to aid their daily core functions, and conservation specialist technical staff who produce data, information products and tools to assist conservation field staff and decision makers at all levels (those reviewing development applications; regional development and conservation plans and national policies). We present results in a discursive rather than quantitative way. Surveys indicated that remote sensing data were initially used as backdrop images for mapping relevant features by the majority of respondents. In particular, the applications were for digitization of land cover features such as wetlands, vegetation, fire scars and patches of invasive alien plants, and infrastructure, roads, trails and fire breaks. These initial steps were generally taken around the late 1990's/early 2000's. Such data capture was often based on hard copy aerial photographs. One notable example of where these proved useful in generating more interest was in CapeNature where the distribution of digital images (with ArcView) leads to requests for and the subsequent acquisition of an organization-wide Landsat mosaic (15 m pan sharpened). As field staff gained confidence with the use of digital tools, they required finer spatial (and temporal) resolution. A national initiative that provided SPOT (2.5 m) country-wide annually from 2005 provided a significant boost to the spatial and temporal frequency with which important features could be mapped. The use of visual interpretation remains a large focus of remote sensing data analysis and the majority of respondents noted that online data sources (Google Earth™) were very valuable in their work, and continue to be used.

The interviewees' perceptions of the barriers inhibiting a greater application of satellite remote sensing in conservation in Africa were, in order of importance, data costs, specialized software costs and the costs of training and

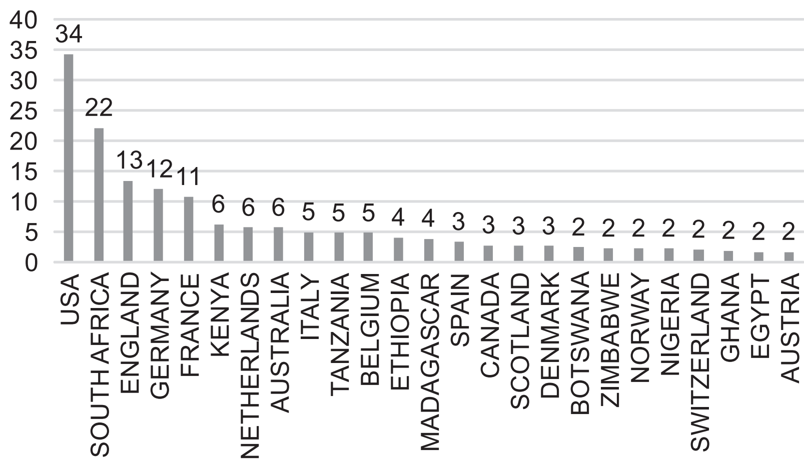

Figure 2. Percentage of peer-reviewed publications integrating remote sensing and conservation in Africa (meeting all the search criteria) per country of authors 2000 to 2015 (countries with two or more percent shown).

Table 1. Number and percentage of records with authors in different countries who have published articles meeting the search criteria.

Countries	No. of records	Percentage of records
USA	189	34
South Africa	122	22
England	74	13
Germany	66	12
France	59	11
Kenya	34	6
Australia	31	6
Netherlands	31	6
Italy	27	5
Belgium	26	5
Tanzania	26	5
Ethiopia	22	4
Madagascar	21	4
Spain	18	3
Canada	15	3
Denmark	14	3
Scotland	14	3
Botswana	13	2
Nigeria	12	2
Norway	12	2
Zimbabwe	12	2
Switzerland	11	2
Hungary	10	2
Austria	9	2
Egypt	9	2
Cameroon	8	1
Democratic Republic Congo	8	1
Namibia	8	1
Uganda	8	1
Wales	8	1
Burkina Faso	7	1
Benin	6	1
Finland	6	1
Morocco	6	1
Portugal	6	1
Senegal	6	1
Sweden	6	1
Algeria	5	1
Japan	5	1
Indonesia	4	1
Mozambique	4	1
Peoples R China	4	1
Poland	4	1
Sudan	4	1
Tunisia	4	1
Zambia	4	1
Brazil	3	1
Czech Republic	3	1
India	3	1
New Caledonia	3	1
Panama	3	1
Papua N Guinea	3	1
Reunion	3	1
Angola	2	0
Argentina	2	0
Chile	2	0
Congo	2	0
Cote d'ivoire	2	0
Fr Polynesia	2	0
Israel	2	0
Jordan	2	0
Laos	2	0
Nepal	2	0
New Zealand	2	0
South Korea	2	0
Taiwan	2	0
Thailand	2	0
Bhutan	1	0
Burundi	1	0
Cambodia	1	0
Central Africa Republic	1	0
Chad	1	0
Comoros	1	0
Costa Rico	1	0
Cyprus	1	0
Ecuador	1	0
Fiji	1	0
Greece	1	0
Guinea Bissau	1	0
Iran	1	0
Ireland	1	0
Luxembourg	1	0
Malaysia	1	0
Mali	1	0
Mauritius	1	0
Mongol Peo Rep	1	0
Oman	1	0
Peru	1	0
Philippines	1	0
Qatar	1	0
Russia	1	0
Saudi Arabia	1	0
Seychelles	1	0
Singapore	1	0
Sri Lanka	1	0
Swaziland	1	0
Syria	1	0
Vietnam	1	0

skills development. IT infrastructure and access to internet is also a significant factor (see also Szantoi et al. 2016; Clerici et al. 2013). Many of the low-to-medium resolution datasets have been free for many years (e.g. MODIS and Spot Vegetation and Proba V which replaced SPOT Vegetation). In 2007, the medium-resolution Landsat data (30 m) became free, something welcomed by the conservation community (Turner 2014). The release of all Landsat data for free saw even greater uptake of these data

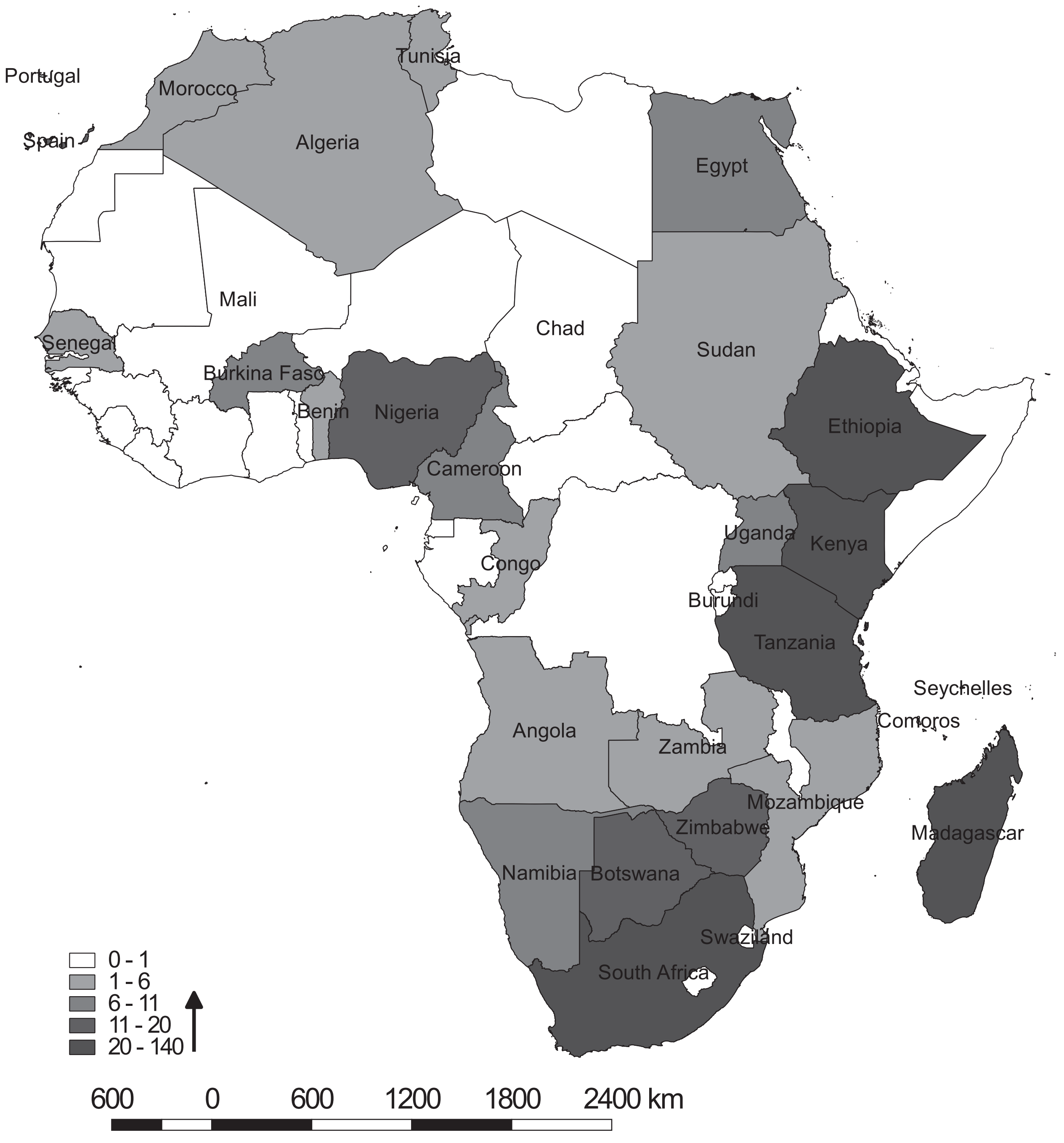

Figure 3. Number of peer-reviewed publications integrating remote sensing and conservation in Africa (meeting all the search criteria) produced by authors with addresses in Africa.

(see increase in papers post 2007 in Fig. 1). This allowed RS specialists to move on to image interpretation, including the evaluation of various fire products for use in specific vegetation contexts (de Klerk 2008; de Klerk et al. 2011), investigating the use of RS classification approaches (pixel-based and object-based) and classification algorithms to solve various conservation questions, such as the mapping of low-density or isolated invasive alien plants and naturally fragmented and isolated environmental features (de Klerk et al. in press).

Interviewees indicated that there remained certain applications that require spatial resolutions of 1–5 m,

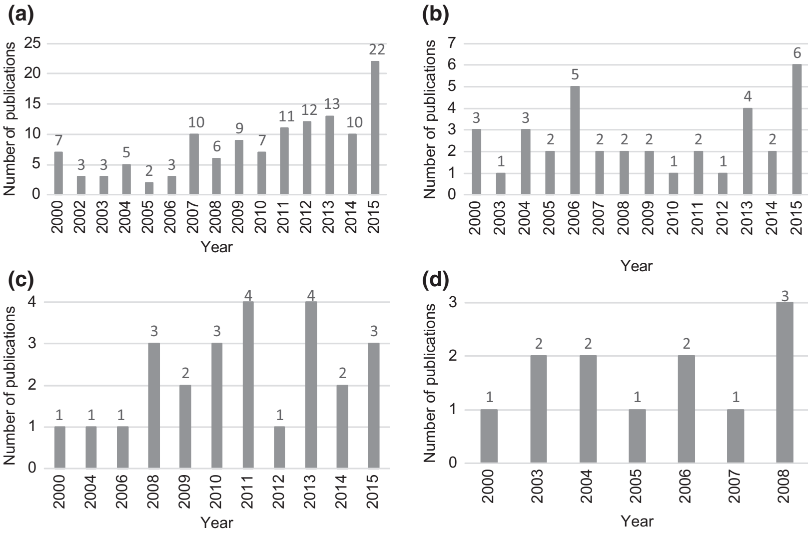

Figure 4. Trends in the number of peer-reviewed publications integrating remote sensing and conservation (that meet all the search criteria) with authors that have correspondence addresses in (A) South Africa (127 in total), (B) Kenya (35 in total), (C) Tanzania (26 in total) and (D) Ethiopia (24 in total).

Figure 5. The current use of remote sensing data in conservation organizations based on keywords.

such as mapping bracken fern invasion in Nyika Plateau, where SPOT 6 or even finer-scale World View imagery is preferred. These datasets remain unaffordable for African conservation agencies and can only be utilized through partnerships with European agencies or institutions. As such they are not suitable for operational monitoring on a regular basis. However, images down to approximately 10 m, including radar data will be made available through the Copernicus program, making progress toward the operationalization of these analyses.

Full and proper interrogation of images requires that first they are pre-processed. The survey respondents who were using these data in the early 2000's had to apply time-consuming pre-processing for atmospheric correction, radiometric correction, orthorectification and pan sharpening, reprojecting and mosaicing before they were able to use images or distribute them to their field-based colleagues. Data are now often supplied with these corrections having been applied (i.e. level 3 processing). These images can now be used off the shelf, reducing the amount of time dedicated to the pre-processing of images, although this is still required for more advanced application of RS imagery for specific classification exercises, which then requires access to licenses of expensive software. The Biodiversity and Protected Areas Management Program's (BIOPAMA, http://rris.biopama.org/) Regional Reference Information System RRIS provides a solution to the preprocessing of Landsat imagery and outputs classified land parcels (segments) which is useful for landscape or habitat monitoring (Szantoi et al. 2016). Most of the advanced software is generally priced beyond the budget of African conservation organizations. The majority of those who responded noted that they used QGIS, a free GIS package with image processing capabilities. While GRASS (https://grass.osgeo.org/), Python (https://www.python.org) and R (https://www.r-project.org/) provide some future potential, the current workforce is not highly conversant with these Open Source software and programming languages. This situation could change as individuals are taught how to use these packages as increasing numbers of universities train students in R and other Open Source software. However, these skills are not being taught by all universities. Development of training material targeted at those who want to use these freeware packages, including code (e.g. Wegmann et al. 2016), is a route to develop these skills.

In terms of future data and products needs expressed by conservation agencies in Africa, the key needs are mapping the extent, and changes in the extent, of habitats (~land cover), assessing the effectiveness of conservation activities, mapping ecosystem services and developing capacity. We have already considered the latter above. BIOPAMA RRIS addresses changes in six to eight land class types (Szantoi et al. 2016). Mapping land cover encompasses many attributes, including mapping land cover disturbances, invasive species and agricultural encroachment and mapping the impacts of domestic grazing. These largely match previous assessments of the needs of the conservation community primarily based on surveys of conservation communities in North America and Europe (Rose et al. 2015; Green et al. 2011), as well as assessments that included the needs of users outside these areas (e.g. Buchanan et al. 2015).

RS training by African institutions

Of the 360 universities in Africa (Association of African Universities AAU; http://www.aau.org/membership/), we surveyed: (1) at least two to four institutions per country; (2) whose program details were available online (and working at the time of the study); (3) whose program information was available in English (we acknowledge that this is a limitation in Arabic, French and Portuguese speaking countries); (4) by preference including the larger institutions within a country, in the capital or major cities and(5) who offered programs that focused on conservation and environment, in terms of biodiversity (rather than conservation of soils and farming practices, such as agro-biodiversity conservation practices). A number of institutions surveyed did not offer conservation or environmental programs and focused on business and/or technology. Determination of the depth of the RS teaching in a program was difficult, but at the minimum we accepted the description of a remote sensing course that taught basic georeferencing and orthorectification; collection of control points and warping and conversion between vector and raster as acceptable (e.g. see Table 2). In some cases this was hard to define and we erred on the "generous" side where additional information warranted the decision. For instance, Egerton in Kenya offers four programs that are relevant to environmental management. The website (http://www.egerton.ac.ke/index.php/Faculty-of-Environment-and-Resources-Development/faculty-of-environment-and-resources-development.html) does not provide detailed course information for the RS and GIS components, but the lecturer responsible for RS and GIS into these programs, Dr. George Eshiamwata, provided more insights and his webpage indicates his RS and GIS skills. Where a university offers more than one conservation/environmental program, we have listed each separately, as some might include RS and GIS and others not.

Of the 72 university programs surveyed across Africa (Fig. 6), 47 either did not offer environmental or conservation programs or had no course material online to evaluate whether RS teaching was integrated into the program. Seventeen did integrate RS teaching into their environmental or conservation programs, while nine offering environmental or conservation programs did not include RS teaching. A number of those that did integrate RS into environmental or conservation programs, did so as contextual learning, that is, RS teaching was tailored to the conservation students. Examples include the University of the Western Cape's BSc Biodiversity and Conservation Biology and Kenyatta University's Environmental Studies (Resource Conservation). These are both undergraduate programs. Similar approaches are used in post-graduate programs, such as the MPhil Environmental Science at the University of Ghana and the MSc Conservation Biology at the University of Cape Town, FitzPatrick Institute. Frequently these RS and GIS courses are comprehensive, such as the example from Egerton in Kenya where the course "ENSC 404: Environmental Information System" offered in four of the environmental degrees covers "concepts and foundation of geo-informatics; remote sensing; photographic systems, thermal and multi-spectral scanning and image processing; components and applications of an environmental information system (EIS); characteristics of spatial data; models of spatial information; spatial relationships and algorithms; spatial analysis (such as route planning, map overlay, buffer zoning, etc.); database models for spatial data; errors in spatial data; sources of raster spatial data; sources of vector spatial data; ethical issues and spatial data; cartographic communication – the display of spatial data; coordinate systems and map projections; and Mobile EIS (location based services, combination with positioning, e.g. GPS, Galileo)" (Dr. George Eshiamwata pers. comm.). The University of Rwanda has even created a degree that acknowledges how crucial RS and GIS is to environmental management in its name; the "MSc in Geo-Information of Environmental and Sustainable Development" where "the module aims at equipping students with methods for formulating predictive models and applies them in environmental modelling using GIS and RS data and tools" (Dr. Emmanuel Havugimana pers. comm.). In other cases, descriptions are brief and hard to evaluate, such as that of Masters of Geography at the University of Liberia, which simply describes course GEOG 410 as "Air Photo Interpretation; Spatial Organization" (http://www.tlcafrica.com/lu/ul_course_master_list_geography.htm).

Other conservation programs utilized 'service' modules from Geomatics (or GeoInformatics) Departments within the same institution, such as the MSc Environmental Protection and Management at The Chinhoyi University of Technology, Malawi, The Polytechnic and Stellenbosch University's Department of Conservation and Ecology BSc in Conservation Ecology.

Encouragingly, there was evidence that integration of RS teaching into conservation programs can be achieved

Table 2. Example of academic programs for conservation and ecology students in Africa that include remote sensing teaching.

Academic program	Remote sensing teaching	GIS teaching	Description or comment	Source
University of the Western Cape: BSc Biodiversity and Conservation Biology	Y	Y	RS: Biodiversity Information Management:; Classification of satellite imagery (supervised, unsupervised and object-based approaches); General internet mapping; Geographical Information Systems (GIS) and remote sensing GIS: Mapping using a Global Positioning System (GPS) and analysis of these data; Digitizing using online resources; Geostatistics and spatial interpolations for modeling point data; Use of spatial data to develop species distribution data and to define meta-populations and identify species with conservation-critical distributions; Development of principles of a biodiversity/taxonomic data base.	https://www.uwc.ac.za/Faculties/NS/Biodiversity_Conservation_Biology/Pages/Programmes.aspx
Kenyatta University: Environmental Studies (Resource Conservation)	Y	Y	RS: Remote Sensing for Environmental Sciences; GIS: Natural resource mapping and cartography: Introduction to basic concepts and applications of geographic information systems. Spatial analysis systems; applications of GIS technology to natural resource systems; spatial analysis systems; applications of GIS on natural resource systems; spatial data entry; data compilation; and map output; basic concepts on cartography; Concepts and foundations; energy interaction in the atmosphere and with earth features; data acquisition; photographic and electronic data types; platforms and sensors; data processing; film spectral sensitivity and processing – black and white color films; color concepts; fundamentals of aerial photography, imagery interpretations and mapping; earth resource satellite and sensors (Landsat, SPOT, NOAA, Radarsat and others); applications in environmental monitoring and management	http://www.ku.ac.ke/schools/environmental/index.php/programmes/undergraduate-programmes/91-programmes/308-bachelor-of-environmental-studies-resource-conservation
Egerton University: BSc in Natural Resources	Y	Y	One GIS and Remote sensing is a Unit = Concepts and foundation of geo-informatics; Remote sensing; Photographic systems, thermal and multi-spectral scanning and image processing; Components and applications of a Environmental information system (EIS); Characteristics of spatial data; Models of spatial information; Spatial relationships and algorithms; Spatial analysis (such as route planning, map overlay, buffer zoning, etc.); Database models for spatial data; Errors in spatial data; Sources of raster spatial data and introduction to	George Eshiamwata (gweshiamwata@gmail.com); http://www.egerton.ac.ke/index.php/Natural-Resources/dr-george-w-eshiamwata-phd.html; http://www.egerton.ac.ke/index.php/Faculty-of-Environment-and-Resources-Development/faculty-of-environment-and-resources-development.html

(*Continued*)

Table 2. Continued.

Academic program	Remote sensing teaching	GIS teaching	Description or comment	Source
			remote sensing; Sources of vector spatial data; Ethical issues and spatial data; Cartographic communication – the display of spatial data. Coordinate systems and map projections; Remote sensing, Geo-DBMS (spatial ADT's, spatial indexing, etc.), Mobile EIS (location-based services, combination with positioning, e.g. GPS, Galileo); Examination of remote sensing and EIS applications in agriculture; Conventions and policy issues; Computer models; Laboratory assignments.	

even in smaller institutions, such as the MSc Environmental Protection and Management at the Chinhoyi University of Technology, Malawi (see the course entitled "Geographical Information Systems & Remote Sensing" at http://www.poly.ac.mw/index.php/poly/msc_environ_protection). The delivery of this course by a small university should be seen as an indication of what can be achieved.

One lecturer mentioned that the costs of proprietary software place limitations on the number of students they can train. A number of institutions utilize or rely heavily upon Open Source software such as QGIS and GRASS. Open Source software is being taught in other institutions due to the growing demand of employers for trained professionals able to use Open Source software, as some government and conservation agencies are also battling with licensing costs of proprietary software. This is a trend seen in many parts of Africa.

RS capacity development by ad hoc events

Training of specialist RS and GIS staff in conservation organizations in Africa was initially through self-training, on-the-job learning and occasional workshops and course work. We are aware of a number of initiatives that have resulted in RS training being provided to the conservation community in Africa. These include the ESRI Society for Conservation GIS conferences, a series of training events by Conservation International for mapping forest loss, multiple courses by the European Commission's Joint Research Centre and the workshops run by the Cooperative Institute for Meteorological Satellite Studies (CIMSS; https://cimss.ssec.wisc.edu/; accessed 8 July 2016) and Space Science and Engineering Center (SSEC; http://www.ssec.wisc.edu/) at the University of Wisconsin-Madison presented in southern Africa. These ad hoc training events have played an important role in training specialist RS staff, although younger employees have been through formal academic RS programs. SSEC has an active education and outreach policy and program with professional development programs offered around the world (see http://cimss.ssec.wisc.edu/rss/; accessed 8 July 2016). We are aware that one work unit in the European Commission's Joint Research Centre (EC-JRC) has run four courses alone in the last 2 years. These have attracted a range of attendees from academic, governmental and park management, and the courses focused on mapping land cover change using a free tool (Szantoi et al. 2016). This one unit has also delivered training in Monitoring for Environment and Security in Africa (MESA; http://rea.au.int/mesa/) and specific conservation training with the eStation (Clerici et al. 2013) in the Intergovernmental Authority on Development (IGAD). ESRI Society for Conservation GIS conferences provides exposure to technology trends and networking with different types of industries such as military and urban planners. NASA has an in-depth introduction to using remote sensing on their web site (ARSET). Due to the disparate nature of these courses, it is difficult to assess how wide an outreach they have. Indeed, it is mainly through our connections with those running these programs as well as individuals who have attended them that we are aware of them so it is likely that there are many more that we are not aware of. We are unaware of a central place where all of these courses and training options are documented.

Discussion

That remote sensing can make a contribution to conservation monitoring is well established, and is underlined

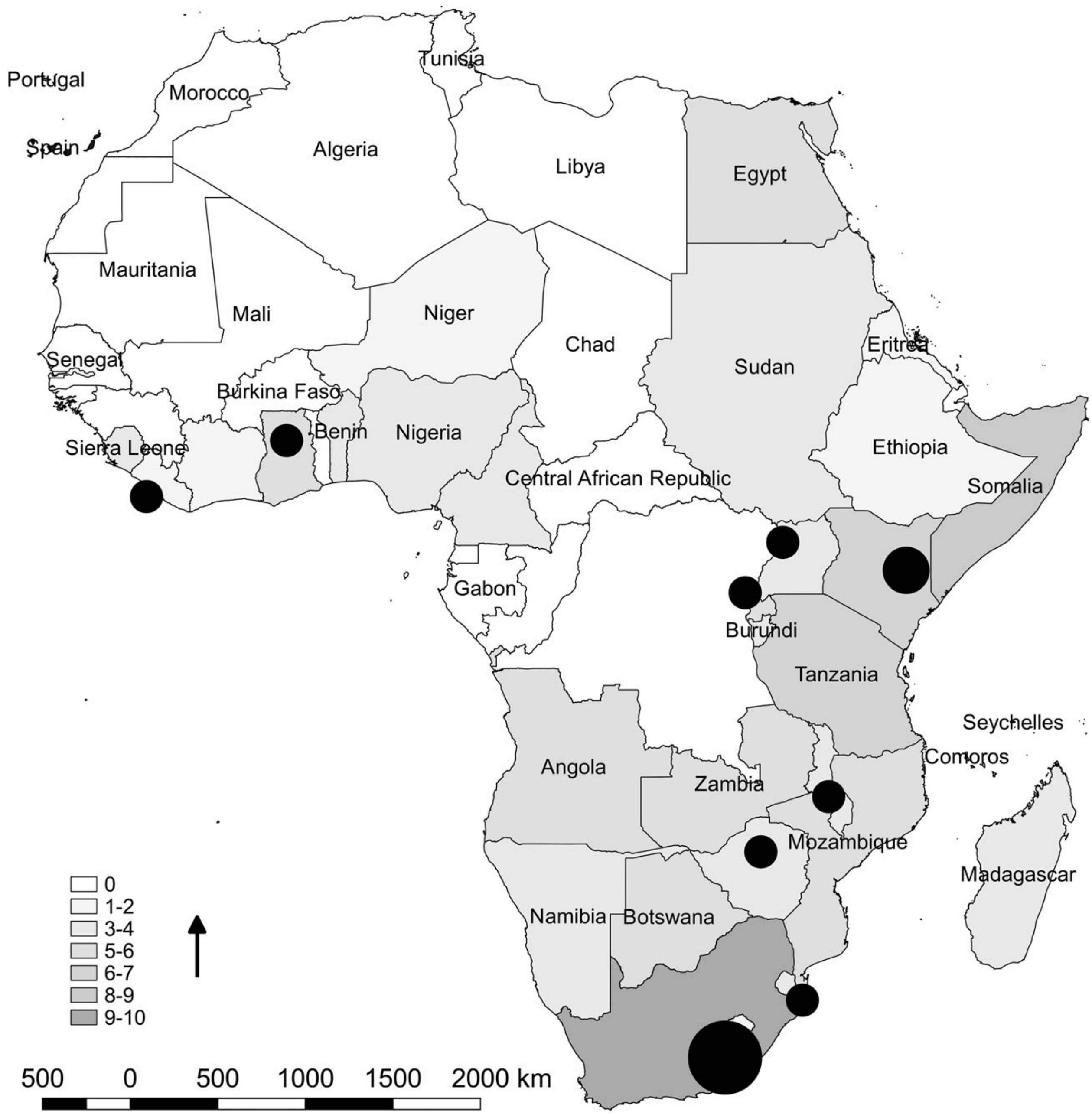

Figure 6. The number of academic institutions registered with the Association of African Universities surveyed per country (grey shades) and the number that have RS teaching included in a conservation or environmental program (size of circles).

here by the increasing number of studies that have applied these data in Africa. Increased capacity within the conservation community in African countries would be most beneficial as it would develop the skills closest to point of use. Strong links between those doing the analysis and those managing the resources, whether a park or a species, are likely to result in the best outcomes for conservation. However, the majority of studies published in the peer review literature have been led by authors or institutions based outside the continent. We cannot assess the degree to which these studies developed capacity within Africa, but given the relatively low level of interaction generated from the subsequent interviews with the conservation community, it is possible that in many cases the majority of analysis was undertaken outside Africa. Undertaking image analysis within Africa, or at least training people to do so, could increase the capacity to do analysis locally, resulting in both better skills and a shorter distance between analysis and use. Given that there is a feeling in the conservation community that not all analysis using remote sensing are answering the questions that the conservation community need answered, we suggest that having the skills closer to the point of use should result in the analysis being targeted toward the most pressing needs.

There is evidence that the capacity to undertake such studies within Africa is increasing. South Africa has increased the number of published articles that have used remote sensing for conservation between 2000 and 2015. The increase in just one country, however, might indicate that there remains a gap in skills and barriers to growth in post-graduate teaching programs and facilities. International funding could be used to develop these programs and facilities, enabling African countries to undertake a larger proportion of their own research. The target audience for research might also be responsible for the spatial disparity in output – conservation and research organizations based outside of Africa might have agendas which differ from national organizations within Africa, resulting in the difference in the location from which studies were undertaken. The analysis described was based on just the academic output. As such, it will not capture the use of remote sensing data for ongoing monitoring or in cases where studies have not been written up or published. Consequently, it may present a slightly skewed picture.

We considered the responses from conservation staff in Africa to identify what the opportunities and limitations on uptake of remote sensing were. The free data policy for the Landsat program, Landsat 8 in particular, and MODIS have impacted positively on use of remote sensing in conservation organizations in Africa. And most probably on academic research too. The importance of free observation data to all users has been recognized (Turner et al. 2003), and this applies as much (if not more) in Africa as in other parts of the world. Encouragingly, other providers are increasing access to free data. The Copernicus program of European Space Agency (ESA), through which Sentinel and other data are already, and will continue to be, available, and the continuing and NASA programs, will feed a significant portion of this need. However, high-resolution data are not always available through these initiatives, and some respondents indicated that the inclusion of, for example, SPOT 6 data would be very useful as the costs of these images are still prohibitive and are only accessed through partnership projects or very localized funded studies. But as Landsat resolution data are perhaps the most appropriate for mapping land cover change (Mayaux et al. 2005; Wegmann et al. 2016), the availability of these data at around 30 m resolution continues to be an important step forward. However, it is important to communicate with those in Africa that these data are available. Recent experience has indicated that not all conservationists who use remote sensing data are aware that Landsat images are now free, and have not been taking advantage of these data. It is essential that these programs undertake outreach to ensure that as many potential users as possible are aware that these data are available and are free.

Initiatives do exist through which African countries are trying to improve and maintain access to data. Notable is AfriGEOSS. This describes itself as an "initiative of the intergovernmental Group on Earth Observations (GEO), [which] was formed in 2014 to coordinate access to and use of Earth observations – from satellites, airborne and ground- and marine-based systems – across the African continent. The 27 AfriGEOSS members are focusing their efforts on data access and dissemination, forest management, food security, urban planning and water resources management, as well as contributing to achieving the 2030 Sustainable Development Agenda in Africa." The Regional Visualization and Monitoring System, SERVIR, is another, aimed at improving Geo-Information access to improve sustainable development with 20 contracting member states (https://servirglobal.net/Regions/ESAfrica). The South African National Space Agency (SANSA, http://www.sansa.org.za/) serves as a repository of imagery that is also available from the original suppliers, such as Landsat 8 and historical SPOT 5 imagery. It provides a download station for MODIS data, but these can also be accessed from USGS.

In addition to these initiatives, many images are now also available rapidly in Google Earth Engine (GEE), an online environment for the analysis of satellite images and other spatial data. This platform, which is currently free, allows users to access and process images in a cloud environment. Consequently, the need for expensive desk top or cluster processers is obviated. GEE users can write code in multiple languages including Python and JavaScript, which while allowing for a high degree of flexibility in processing and automation of processes, might be a block for casual users. But development of skills in these languages could pay big dividends. As this platform allows users to analyze images in the cloud, the need for good internet connections to download images is also obviated. This is an online, cloud-based platform. Consequently, internet connectivity is required to run processes and extract results. The current internet stability and speed in many African countries might mean that this potentially useful tool is, unfortunately, out of reach. The improvement of connectivity would therefore be of great value in increasing the accessibility of this tool.

It would appear that, theoretically at least, access to data will be less of an obstacle in the future than it has been. The open data policies of NASA and ESA should be welcomed. However, the issue of downloading and processing these data remains for many. Internet speeds in many parts of Africa, including within many institutions surveyed, can be slow. This might become an issue when multiple images are required, something that might become an important issue as images are captured with a greater frequency. In addition, historically, the use and manipulation of images required software which can be expensive. Open Source software such as QGIS, and programming languages such as Python, and R have helped with the visualization and manipulation of imagery, although data still need to be downloaded. Advances in R, together with better access to appropriate code (Wegmann et al. 2016) should increase the uptake of R and Python for image analysis as, theoretically, there are no obstacles to undertaking advanced analysis using these programming languages. As already noted, Google Earth Engine requires users to have an internet connection to use the interface. In addition to user processing, GEE also supports data produced by others, such as the global forest loss map (Hansen et al. 2013). Access to these data, and future data (e.g. water bodies, Pekel et al. 2014), will reduce the need for individuals to undertake their own classifications, making detection and quantification of land cover change much easier. Some of these data, with the addition of alerts for forest loss, are also available online through Global Forest Watch. Users of GEE can use code developed by others, and placed online (e.g. through GitHub). These data have already been used for global conservation purposes (e.g. Tracewski et al. 2016).

Countries are recognizing that access to data is key to empowering society to participate in decision making in various arena's, including conservation and town and regional planning; promotes transparency and accountability, public management and policy of government agencies (Davies 2014). South Africa has legislated the public's right to access data through the Promotion of Access to Information Act, Act 2 of 2000 (Republic of South Africa 2000). This is mostly facilitated through data portals (e.g. https://web1.capetown.gov.za/web1/OpenDataPortal/; accessed 24 June 2016). Where internet access is not available, or insufficient for downloading large files, or only intermittent, plans are being made to distribute key datasets via DVD at public facilities (or nodes) such as libraries. This will sound archaic to some, but it is a pragmatic solution in many situations and previous iterations of the distribution of town planning products as CD or DVD for public use were successful as the public engaged with these products (e.g. Maree and Vromans's 2010 biodiversity sector plan for the Witzenberg, Breede Valley and Langeberg Municipalities compiled DVDs that provided land-use planners with data layers on land use, conservation priorities, infrastructure and potential conservation corridors). Older initiatives include the Aster Spectral Library (version .2) distributed on CD in 1998 by the California Institute of Technology; The Water Resources eAtlas: watersheds of the world CD distributed by IUCN, WRI, Ramsar and IWMI; and the Earth science reference handbook and data products handbooks CD distributed by NASA in 2006. The supply of off-line versions of the web-based IMPACT (Szantoi et al. 2016; The satellite IMagery ProCessing Toolbox) and eStation+, which uses a parabolic antenna (Clerici et al. 2013), continues the duel online/off-line to cater for different internet capabilities.

Many African academic institutions have recognized the need for young conservation professionals to be equipped with remote sensing and GIS tools and either offer tailor-made remote sensing and GIS courses into their conservation programs (both at undergraduate and post-graduate levels), or make use of 'service modules' presented by other departments, typically Geography or Engineering departments, to provide RS and GIS teaching into the conservation program. Many of the RS teaching offerings are substantive and cover a wide range of important topics from image registration and atmospheric correction to classification and modeling. Retention of individuals with these skills within conservation might be an issue, but the greater availability of this type of training to more people will potentially reduce the flow of skilled individuals from conservation jobs. In addition to the formal university education we also documented a range of courses and workshops that are run by a diverse range of parties. These span those involved in conservation through multinational governmental organizations to software companies. The number of these courses and workshops that have been run remains unknown, but it is likely that there are many more than those which we know about as we have based our description on personal knowledge. The establishment of a central register of these courses could prove useful for those interested in these topics. It is understandable that in many cases they are targeted to specific end users, but a wider knowledge of the type of workshops being run could not only improve access to courses through demand but also potentially reduce overlap and make for a more efficient use of resources.

New and emerging technology will also play a part in the increased uptake of the use of remote sensing data. For example, PeaceParks's Sustainable and Safe Environmental Travels (SENSA) is being piloted in Kgalagadi Transfrontier Park. The app can facilitate tourist trip planning, safety and tourist management. The tourist user can plan their trip and upload the places they will stay and routes they will use onto their cellphone or android device. There are communications at the TweeRivieren check-in site where they hire a Rock Star unit that connects to the Iridium satellite constellation and to the android device via Bluetooth. This enables communication between the tourist and park staff about safety issues, such as a flat tyre; if the tourist are going to run late for the camp closing time, and compliance issues, such as if the tourist drives off road, which are picked up with a geofence on the unit. Visitors are also provided with information of what vegetation type they are traveling through and heat maps of species sightings over last 60 days. PeaceParks provides awareness of the tool and assists with deployment in campsites/hotspot hubs to support satellites, base mapping and training on use and deployment of units. Development of similar systems that allow local conservation groups to report incidents of degradation to sites they visit to a central system could be developed in a similar way, especially where mobile phone network coverage is extensive (e.g. Kenya). In return, data from remote sensing alert systems (e.g. fire alerts) could be sent to local stakeholders for their near real-time investigation. Thus, a two-way flow of information could be developed.

In summary, the uptake of remote sensing in conservation is increasing, and while African countries are leading on some of this expansion, the majority are either not participating or not expanding output. But there are a number of universities that are delivering some component of remote sensing and GIS in environmental conservation courses. Ideally the impact of these courses will, over time, be increased use of remote sensing in conservation, and possibly published scientific papers. With the increase in freely available remote sensing data, it is now perhaps access to suitable internet to download images, and the cost of software which are the major obstacles. Free software or online cloud processing platforms might ultimately be what liberates the use of remote sensing in African conservation.

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Supporting Information

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

Appendix S1. List of the 54 African countries used in the bibliometrics search conducted in Web of Science (from https://www.countries-ofthe-world.com/countries-of-africa.html

Appendix S2. Semi-structured interview questions.

