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# LEGAL FACETS OF USE OF REMOTE SENSING TECHNOLOGY IN SUSTAINABLE FOREST MANAGEMENT

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*Historically forestry has been concerned mainly with the assessment of timber resources and the management and utilization of closed forests for the production of wood. In the pre-Independence era, India's forest policies focused on generating revenue by selling timber and other forest produce (Forest Act, 1865), and facilitating the conversion of forest lands for agriculture and timber-logging (Forest Act, 1894). Attention was occasionally given to the sustainable use and conservation of forest; as a result we reached a stage where conservation of forest became a dire necessity. A shift occurred following Independence, as forest policies began to be framed towards management (National Forest Policy, 1952). The goal was to achieve ecological balance and maintain India's forest area as 33 percent of the country's total land cover. The Forest Conservation Act, 1980 emphasized on governing the diversion of forests for non-forest purposes. At present modern technological applications can go a long a way in helping the mankind for the environmental conservation. Based on the concept of IoT, an intelligent and interoperable network of devices interconnected through a dynamic, global infrastructure network can be created to connect and exchange data across locations at any time. These technology-driven smart sensors can be key to preserving India's forests, while also providing data that can serve as a catalyst towards more sustainable forest management. With the help of remote sensing devices, the condition, distribution, and types of the forests can be ascertained easily, and likewise customized laws can be construed for the conservation of a particular area of forests. Different areas can be demarcated for afforestation. Forest fires, weather conditions and natural calamities like floods can be determined with this technology. Forest mapping can be accomplished easily on the whole landmass of a country. United Nations Office for Outer Space Affairs (UNOOSA) is working towards achieving lot of benefits from the space technology for the humanitarian causes. Indian Space Research Organisation (ISRO) is also contributing to the forest conservation for many decades. Supreme Court of India and other courts in the country has taken help from the remote sensing techniques in deciding many cases relate to land use. In this paper an attempt is made to highlight the use of remote sensing techniques towards sustainable forest management and various legal aspects involved.*

*Keywords: Forest Conservation, Remote Sensing, Sustainable Development, Forest Mapping*

## 1. Introduction

Technology, if used for environmental conservation can be highly useful in achieving those targets, which are not easy to achieve manually. Remote, as the name describes being distant and sensing means to ascertain the situation of a place or thing. So remote sensing is the science, which aims to gather information from a distant location from the source of data. "Image Analysis" is the science that is used to interpret the data that is being gathered from a remotely sensed image with certain specific criteria. An instrument or a gadget, which gathers thematic information from a distance, is known as a "Remote Sensor". Data gathering activities can be enhanced by the use of electromagnetic spectrum with its various segments.[1] These unmanned aerial vehicles and satellites are the new gadgets for forest monitoring and may go a long way in the conservation of forests.

Remote Sensing is the science of acquiring, processing and interpreting images that record the interaction between electromagnetic energy and matter.[2] It is the acquisition of information about an object without being in physical contact with it.[3] This is a very apt technology for mapping and monitoring the various terrains of earth without (in actual sense) physically going there. This activity is done by the help of the satellites, which are navigating in the space around the Earth. Remote sensors can be fixed on huge variety platforms, which could be space or air-based, functioning at diverse elevations besides working at diverse intervals of time. Data received from the remote sensing satellites is being used at a high level to map and to monitor the natural resources present in the earth and they may be present at distant locations spread on a huge area. The classification of the satellite systems is generally done on the basis of their spatial resolution into the environmental satellites *viz.,* Meteorological Satellite (Meteosat), Geostationary Operational Environmental Satellite (GOES), National Oceanic and Atmospheric Administration (NOAA), Landsat, etc., These environmental satellites act as good devices for daily or weekly environmental monitoring and that too for huge areas like the continents, sub-regions or the countries.

Generally, these satellites are used for monitoring the meteorological situations, oceanography and recently and most importantly for monitoring forests and other vegetation spread across the globe like large pastures, grasslands and other areas. Landsat with its multi spectral scanner can offer imagery to a very high resolution for the study of the land and its various uses like land use and forestry. The electromagnetic waves when received by the sensors of the satellite then produce certain electric signals and then these signals are processed or converted into

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[1] *GLS LAB, 'Remote sensing'<http://gis-lab.info/docs/books/aerial-mapping/cr1557_15.pdf> accessed 17 April 2018*

[2] *(F.F. Sabins in his book "Remote sensing: principles and interpretation" Defines it like this)*
[3] *Win Baker, 'Remote sensing Definition' <http://members.home.nl/wim.h.bakker/rsdef.html> accessed 15 November 2017"(As defined by Charles Elachi in ther book "Introduction to the Physics and Techniques of Remote Sensing)*

utilizable products like images and photographs. Then further studying these photographs with aid of computers or human eyes, an analysis of the data so collected, can be done by the experts and these can derive knowledge about changes in the earth's natural resources both qualitatively and quantitatively. These remote sensing devices are highly useful in the field of forestry. Without physically going to the forest area, very important information related to the type of forest, forest fire, land degradation, size and location of forest, deforestation and agro forestry parameters could be obtained by this device.[4] An overall forest conservation and management can be achieved if this technology is used all over the world.

## 2. Remote Sensing and Forest Conservation

It is difficult to manage huge forests manually. Lot of infirmities are observed like miscalculation and stating wrong locations. With remote sensing this job has become easier and more accurate data has been received by such devices. The manual method of forest census is very exhaustive and expensive and most of the times not accurate as well. The remote sensing and the global positioning system (GPS) have revolutionized the forest resource assessment, its valuation, supervision, monitoring, classification, administration and management and have reduced the expenditure in all these exercises a lot. All the natural resources and the landscapes can be mapped and ascertained by the remote sensing devices and the GPS technology. Within forest ecology and management, there is a diverse range of applications for remote sensing, including the measurement of cover, vegetation structure, vegetation chemistry and moisture, biodiversity, and soil characteristics. These variables are critical for understanding forest ecosystem functions and processes, as well as classifying forests into specific communities, ecosystems, and biomes.[5]

Forest conservation and management through space technology can act as a precursor in the conservation and management of forests in India. Since India is a big country with very vast acreage of forest land spread over from all the four corners of the country and also the Andaman and Nicobar and Lakshya deep Islands which makes the assessment of the forests difficult for the forest department manually. Systematic observations are required over a long period of time to develop new monitoring instruments and algorithms to provide insights into the processes.[6] So the remote sensing and the GIS, can easily do work and also the biodiversity amongst the forest strands can also assessed easily. A lot of time and money can be saved by the use of this technology.

The mapping of forests and the variety of flora present in there can be easily done by remote sensing techniques and is a very popular method for doing surveys related to forest and its floral biodiversity. The Wide-Field Sensor (WiFS) and Advanced Wide-Field Sensor (AWiFS) data facilitated the assessment of the land and water features and phenomena encompassing large

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[4] *J.P Malingreau, FAO, Forest Document repository, 'Satellite monitoring of the world's forests: A review'<http://www.fao.org/docrep/v0290e/v0290e06.htm#TopOfPage> accessed 4 March 2018*

[5] *Alex M. Lechner, Giles M. Foody, et.al., "Applications in Remote Sensing to Forest Ecology and Management," One Earth, 407, May 2020.*

[6] *Frank J. Ahern, et al. (eds.), Global and Regional Vegetation Fire Monitoring from Space: Planning a Coordinated International Effort (SPB Academic Publishing BV, 2001) 102*

areas. Light Detection and Ranging (LiDAR) remote sensing is a breakthrough technology for forest resources inventory. It offers a great potential for forest conservation and management. The utility of the remote sensing data for forest canopy density mapping and monitoring on various scales is well established by now. The nationwide forest studies carried out by National Remote Sensing Agency (NRSA) and Forest Survey of India (FSI) have amply demonstrated the scope of satellite remote sensing in forest mapping and monitoring. Multispectral data such as that from IRS LISS-4 with 5.8m, *IKONOS* with 1 m, and *QuickBird* with 0.61m spatial resolutions provide an unprecedented opportunity to monitor the forests.

Now this Indian remote sensing programme is being applied to making the inventory of wildlife habitat, doing census of wildlife and many other related activities. Surveys done by the ground method are tedious and are not accurate as well. National forest policy also suggests adopting these practices for mapping the forests and collecting the data there of and this data to be revised every 10 years. India being a mega diverse country with an area of 2.4% of the total earth's area needs to utilise this technology for the conservation of biodiversity and the forest. Over exploitation of the natural resources and loss of floral and faunal biodiversity and their habitations can be easily traced by the remote sensing devices, these gaps can then be filled by taking measures which are to devise by looking at the harm done and at a particular location. A lot of fragmentation and degeneration of the landscape, which has taken, place due to over exploitation of natural resources can be mapped and then rectified by rehabilitation measures like afforestation etc. Remote sensing and GIS can play a positive role in assessment of biodiversity rich areas both at domestic and at international levels. This data can later on be matched with the assessment done at the ground level through ground assessment methods. Forest fires which are usually manmade in India can also be helped by the remote sensing. That is to say that by the assessment of the forests, the forest types can be figured out and forests prone to fires can be found out and proper precautions can then be taken to combat this menace.[7]

## 3. Legal aspects of remote sensing

### i) International paradigm

Remote sensing as already addressed earlier have many benefits, but it also gives the power to the countries possessing satellites to observe the territories of other countries as well. These concerns were raised at the international forums and many provisions related to international law and multilateral treaties on space applications arise.[8]In 1986 a comprehensive consensus was adopted at the United Nations on the principles related to the Remote Sensing. The United Nations (UN) Resolution Relating to Remote Sensing of the Earth from Outer Space was adopted by consensus on 3 December 1986.There are fifteen principles that guide the activities of the United

[7] *S.P.S. Kushwaha, 'Remote Sensing and GIS for Forest Monitoring and Management' available at: <http://isebindia.com/09-12/12-10-01.html> accessed 15 June 2018*

[8] *B L Deekshatulu, V Raghu et.al.,Overview of the legal aspects of remote sensing,https://link.springer.com/article/10.1007/BF02995700,( Accessed on Sep.5, 2018)*

Nations member states. The crux of these principles is that remote sensing activities shall be used for peaceful purposes. The principles themselves are not legally binding, being a General Assembly resolution, but to the extent that they represent state practice, they have considerable weight. And all such activities shall be guided by the article VI of the Treaty on Principles governing the activities of States in the Exploration and use of outer space, including the Moon and other celestial bodies.[9]

It may be noted that the UN Resolution applies to remote sensing activities "for the purpose of improving natural resources management, land use and the protection of the environment." Since such usage arguably would not require quality of spatial resolution better than in the range of 10 meters, any VHR issues might fall outside the scope of the Resolution. Another issue following from this, somewhat narrow, definition of remote sensing for the purposes of the Resolution, is that it might be taken to exclude from its scope any military activities. This, however, is of relatively little importance, since few of the other Principles contained in the Resolution could carry legal force as well as practical weight when it comes to military and security-related remote sensing activities.[10]

**ii) Law and Policies related to remote sensing in India**

As such there is no specific law on the use of remote sensing in forest conservation is there is India. But many a times the local authorities in a State may make provisions in their local laws pertaining to use of remote sensing for forest management for *e.g.,* A provision for remote sensing has been there in NCR region (Gurugram) **Gurugram Metropolitan Development Authority Act, 2017** where the role of remote sensing is emphasized in finding various geographical features. As per Section 2 (1)(f) of Gurugram Metropolitan Development Authority Act, 2017:"geospatial based system" means processes and technology used to acquire, manipulate, plan and store datasets and information that identifies geographic location, characteristics and other attributes of natural or constructed features in the notified Area and includes -(i) boundaries of natural or constructed features and jurisdictions;(ii) statistical data;(iii) information derived from, among other things, mapping, remote sensing and surveying technologies.[11] This makes the task easier for the authorities in ascertain various features related to land.

- **National Map Policy, 2005**-This policy was announced by Government of India on May 19, 2005. The preamble of this policy elucidates the importance of high quality spatial data in various features such as **socio-economic development, conservation of natural resources, infrastructure development etc** .The main objective of this policy is to provide, maintain and allow access to the National Topographic Database (NTDB) of the SOI conforming to national

[9] *UN General assembly, A/RES/41/6, 95th plenary meeting, 3 December 1986,Principles relating to remote sensing of the Earth from space, http://www.un.org/documents/ga/res/41/a41r065.htm(Accessed onSep.5, 2018),*
[10] *Ibid., Principle I*
[11] *Gurugram Metropolitan Development Authority Act, s 2 (1)(f) (2017).*

standards. To promote the use of geospatial knowledge through partnerships and other methods for various beneficial purposes for the society at large.[12]

- **Remote Sensing Data Policy (RSDP) 2011**-This policy was adopted by Government of India for managing and/ or permitting the acquisition/dissemination of remote sensing data in support of developmental activities. The policy guides the government as well as data provider and focuses on the purpose of the satellite and distribution of the data so collected from the satellite. The national security is the foremost issue in the dissemination of data. This policy focuses on the checks of the distribution of data. National Remote Sensing Centre (NRSC) of the Indian Space Research Organisation (ISRO)/ DOS is vested with the authority to acquire and disseminate all satellite remote sensing data in India, both from Indian and foreign satellites. NRSC is also supposed to maintain a systematic National Remote Sensing Data Archive, and a log of all acquisitions/ sales of data for all satellites.[13] The general limitation of policy is that it is not so much effective during implementation. When any policy will be implemented, there must be some lacuna or violation. But violation of policy is not like violation of law which can be adjudicated in the court of law. All Indian laws are as per the Constitution and this is strictly followed. Hence any violation of law means that of the Constitution. So though the RSDP still exists, but it will not be so effective like law made by the Parliament. Hence any lacuna or violation of RSDP has no such legal effect in the court of law.[14]

## 4. Use of Remote Sensing Techniques and Environment Conservation- Judicial Approach in India

Due to this technology, it has become easy for the courts to decide the legal matters where issues related to boundaries and other physical features of the land are involved. It is difficult to assess certain parameters manually but with remote sensing and land use mapping this task has become easy and accurate results are drawn. Remote sensing can be highly beneficial in the conservation of environment leading to sustainable development. The Supreme Court of India took the help of remote sensing technology in **Intellectuals Forum, Tirupathi *v.* State of A.P. and Ors**[15] and ordered for the restoration of two lakes based on the information received by the satellite imagery. The competing interests of protecting environment and social development were solved with the help of technology and the Supreme Court could assess a clear picture of the situation. Since, the High Court gave importance to social development, and in return this petition was filed

[12] *National Map Policy 2005, Objectives*
[13] *National Remote Sensing Centre, Indian Space Research Organisation, Remote Sensing Data Policy,(5 Sep.2018), https://nrsc.gov.in/Remote_Sensing_Data_Policy*
[14] *MalayAdhikari.," Remote Sensing: An Analysis of Policy and Law with Reference to India" http://www.indiageospatialforum.org/2012/.../ppt/Malay%20Adhikari.pdf (Accessed on April 29, 2013)*
[15] *2006 (3) SCC 549*

before the Supreme Court for maintaining the *status quo* of two lakes which were to be converted for meeting requirements of shelter. The Supreme Court held,

> *"Intention for development will not be enough to sanction the destruction of local ecological resources. Balance has to be brought between requirements of shelter and preservation of two lakes. Since developmental activities were going on for long period, natural resources of these lakes were lost and the loss was irreparable."*[16]

Hence, due to impossibility no order could be given to preserve the water bodies already at the verge of depletion. But an order for stoppage of further construction in the area could be made. On the other hand, in **Tata Housing Development Co. Ltd. & Ors *v.* The Goa Foundation and Ors**[17] the Supreme Court of India by an order dated 17.9.2003 held that "Report dated 4.6.1998 submitted by National Remote Sensing Agency which disclosed that the appellant's plot was surrounded by agricultural land and did not fall within a reserve forest."[18] Here also the remote sensing technology helped in deciding the case. Remote sensing technology is highly useful in assessing the boundaries of many agricultural and other lands leading to better judgments.

It was held in **T. N. Godavarman Thirumulkpad *v.* Union of India**[19] by an order dated 10.4.2006, where, as per an order dated 1st April, 2005, Central Empowerment Committee (CEC) was directed to again examine the entire matter and file a report in the light of the documents which were brought to the notice of the Court. This report was eventually filed on14.4.2005 and was known as third report and in compiling this report the help was taken by the Regional Remote Sensing Agency besides the Forest Survey of India, and the South-East Coal Field Limited. This report, inter alia, shows that a request was made by CEC to Forest Survey of India to carry out photo interpretation of the satellite imagery of the area by comparing imageries of different period and to give views about vegetation, forest cover, number of trees etc. Simultaneously, the National Remote Sensing Agency was also requested to give their comments on the satellite imagery of the area in and around the land area allotted to Maruti along with significant changes in the forest cover during different periods, reliability and accuracy of the interpretation and methodology for identifying the areas allotted etc. The site was also visited between 12-13th April, 2005 during which the coordinates of the area allotted to Maruti were verified by a technical expert of FSI using the Differential Global Positioning System (GPS) and the ground truth verification of the area was carried out along with Regional Director, Forest Survey of India, Nagpur. The report also noticed that during the visit, inspection of other areas was also carried out and discussions were held with the Principal Chief, Conservator of Forests, Chhattisgarh Forest Department, Conservator of

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[16] *Id., at p. 573*
[17] *[2003] 11 SCC 714*
[18] *Id*., at p. 723
[19] *[1995] 202 WP*

Forests, Bilaspur Circle, District Collector Korba, Divisional Forest Officer, Officers of SECL, members of the Bilaspur Environment Society, K.K. Srivastava, representative of the applicant, representatives of the forest trade unions of the area, public representatives, representatives of Maruti and other interested parties. Detailed reference has been made in the third report to the interpretations of experts including that of the Forest Survey of India."[20] In compiling the third report in this case remote sensing technology was highly useful in coming to the conclusions. Technology now has been helping the courts in deciding the matters accurately. Remote sensing had been useful in demarcating the borderlines of the forests and any encroachment can be checked upon as in the case of Sanjay Gandhi National Park authority, Bombay High Court decided the case of encroachment on the forest land with the help of remote sensing and GIS applications. The land, which was illegally encroached upon, was returned to the Sanjay Gandhi National Park authority.

## 5. Legal issues related to data available through remote sensing

Many a times the use of remote sensing technologies results into certain legal issues viz., Security of State, Unauthorized interference in military base and neighbouring countries areas etc. *for e.g.,* Google Mapathon is an annual event organised by Google which invites the public at large to participate in the improvements of google maps through a map editing service Google map maker which is available online. This event was held in the year 2013 for the first time in India. One of the participant Vishal Sahni, who won the event mapped the city of Pathankot, which was pretty close to the military base. This was objected by Survey of India and a complaint was filed against the Google for violating the laws of the land resulting thereby on 21st March 2013 the Surveyor General asked the company to stop the event as Google did not seek any permission from the government agency to start the event.[21] Moreover the 1986 resolution is not having any legally binding effect. There is a need for new international binding instrument that specifically let remote sensing technologies to be used for environmental conservation.

## 6. Conclusions and Suggestions

The sustainable management of forests can be achieved by assessing various parameters attached with the forests like the position and exact location of forest, the type of soil, the weather conditions, the extent forest cover, the density of forests and knowing the perspective land for

[20] *Ibid.*
[21] *Sandeep Joshi,Google didn't take permission for Mapathon, The Hindu,(Apr. 24, 2013 04:29 IST), https://www.thehindu.com/news/national/google-didnt-take-permission-for-mapathon/article4648589.ece*

afforestation. This can be achieved with the help of remote sensing technology, where through the satellites such data can be procured and utilised for future enhancements on forestry and agroforestry purposes. The aim of having an ecologically sustainable forest can be achieved by this technology, which provides up to date information about various issues associated with the forests and weather conditions. For effective management of forests and for a sustainable development various factors related to forest management can be found and these can be discovered with the help of remote sensing technology.

Sustainable development of forests with remote sensing technology can be achieved by analysing the data collected by remote sensing. The information thus derived from the imagery can be beneficial in the many ways *viz.,*

i. **Distribution of forests across the country**- By this technology distribution of forests all the countries can be assessed by the satellite imagery. The remotest areas where assessment cannot be done manually can be easily assessed by this technology.
ii. **Types of forests-** Various types of forests from closed forests to degraded forests to open forests can be determined by this technology. Types of forests like the pine forests, long leaved forests; deciduous forests, evergreen forests, and thorn forests also can be pinpointed with their exact location and expanse on earth.
iii. **Tree density volume estimation of forests-** Tree density can also be established by this technology and the density of the crown of the tree can also be determined. The health of the forests in this manner can be recognised and the wellbeing of the ecosystem can also be documented.
iv. **Scope of afforestation**-Place and land for the plantation of new forests can be found out with help this technology and wastelands, other prospective lands and their soil types and the weather conditions can also be determined for growing new forests.
v. **Monitoring of tree plantations**- By the assistance of space technology, tree plantations new or old and the health of the forest and the ecosystem can be judged.
vi. **Demarcating different zones**- Different geographic zones can be demarcated with the help of this technology. And then based on the zone topography and climatic conditions, type of new future forests can be determined and plantations can be done likewise based on the species of tree, which will be successful in that particular zone.
vii. **Biodiversity assessment**- By the help of this technology the biodiversity of the forests of a particular place and even whole Earth can be determined and the number of wild life and their migrations and movements can be ascertained. The loss of biodiversity can also be calculated to a very large extent.
viii. **Assessments of forest damage due to fires**-Forest fires, which almost occur every year, do a lot of harm to the forests and forests biodiversity. This harm can be understood with

the help of the help of remote sensing and the exact location of the terrain and the expanse of loss can also be determined.

ix. **Assessments of grasslands-** Detailed spatial data on grassland can be determined with the help of remote sensing and strategies for biodiversity conservation in the grasslands can be formed on the basis of the data so collected by the satellite imagery.

x. **Assessment of wetlands**- Similarly detailed spatial data wetlands can be assessed and improved strategies for its conservation and preservation can be made for future applications. Forest resources assessment- Assessment of land suitable for potential forest can be done by remote sensing data and this will further help in mapping land resources, quality of the soil can also be determined and then the type of forest or type of crop which can be grown on that land successfully can be done. This technique is beneficial both for forests and agricultural activities.

xi. **Assessment of deforestation, desertification of land**-Deforestation, land desertification and land degradation can be easily determined by this technology and then measures to do afforestation and other activities for the improvement of the ecosystem can be done.

xii. **Future planning for forest cultivation**- Using this technology and looking at the type of terrains and various environmental factors can do future planning for new plantations of the forests.

In this manner remote sensing can be highly useful for the sustainable management and development of the forests. Land coverage, main rivers, streams, canopy of trees, slopes, lands, main streets, land cover for a city and forest development can be assessed by this technology. This can perform floods and hydrological analysis, monitoring of fauna and tree plantations, landslides and erosion analysis, weather monitoring. Identification of various landscapes like parks, streets, railway tracts, crop plantations, buildings, and number of villages and other settlements can be adjudged by this technology. Assessing the data provided by the remote sensing can do the planning for future development of forests and also sustainable development of it. On the basis of the data so collected with the help of remote sensing laws can be formulated for the conservation of forests. Different sites and topographies require different upkeep for the conservation of forests and likewise varied laws need to be construed for a customised forest conservation leading to sustainable development. Here technology can be highly beneficial for construing laws for the conservation of forests, as different regions demand different management. Technology and legal regime can work together for the conservation of forests. Various legal cases pertaining to land use have been solved with the help of remote sensing. The information given by the remote sensing devices is quick and accurate.

The field of remote sensing is evolving rapidly, especially because it is at the interface between engineering, computer science, geography, and various disciplines that utilize the

technology to support forest ecology and management. The number, range, and performance (i.e., number of bands and spatial resolution) of platforms and sensors are increasing dramatically, and more diverse players ranging from governments to private industry are developing and operating remote-sensing systems. Earth observation systems are now being launched and operated as satellite constellations rather than single satellites, as was the case in the past. This provides greater revisit time and also supports data-fusion products (i.e., combining multispectral and SAR data) through overlapping image footprints and similar spatial resolutions. Recently, the ESA launched the Sentinel satellite constellation, which includes two multispectral satellites and two SAR satellites. The Sentinel series is expected to be joined by another ESA Earth observation satellite in 2024, the Fluorescence Explorer, to monitor chlorophyll fluorescence in terrestrial vegetation.

Closer to the ground, UAV remote sensing has a significant role in providing smaller organizations and research groups with the ability to capture remote-sensing imagery at unprecedented spatial resolutions and at any time. The most common sensors used are multispectral red-green-blue (RGB) and near infra-red radiation (NIR) sensors, although there is a trend toward miniaturizing all forms of sensor technology, including LiDAR and hyperspectral sensors. The production costs are also decreasing, meaning that such technologies are likely to become much more affordable and ubiquitous. For example, the cost of an airborne LiDAR survey can be quite prohibitive, which has meant that its application has been limited and is rarely used for monitoring where frequent recapture is required, even though it is unmatched in its ability to capture the 3D structure of forest ecosystems. In parallel with the rapid advance in sensor technology and platforms, the classification and processing of remote-sensing imagery are advancing in leaps and bounds. Techniques from computer vision, along with the use of machine-learning methods (including deep learning), are now being applied to remote sensing, and we are likely to see a dramatic transformation in the algorithms being applied, especially for specific types of applications, such feature detection. These approaches usually require high-performance computing, which is commonly provided in the cloud.

Although private networks have been and continue to be developed, the freely available GEE platform has had enormous uptake in the remote-sensing community and beyond. It is a combination of image repository (it includes nearly all freely available remote-sensing imagery and products, such as surface reflectance and vegetation indices), high-performance computing, and web-based mapping application. Cloud computing has great potential for reducing remote-sensing workflows and also the ability to process data at much larger and even global extents. Using GEE computationally intensive applications, such as multitemporal mosaics (i.e., creating an image where pixels are based on the median annual value) and temporal trend analyses (e.g., analyses of disturbance and recovery with LandTrendr), is simplified. What formerly would have

required huge computing resources, expertise, and a team of people can now be done on a desktop with an internet connection by a single operator.

Even though processing methods and remote-sensing systems are advancing rapidly, freely available data from Landsat, the Moderate Resolution Imaging Spectroradiometer (MODIS), and the new Sentinel satellites are likely to still have critical roles in supporting forest ecology and management across the world, especially in developing nations. Most of the world's high-biodiversity and intact forests are found within the tropics in developing nations with limited budgets and technical expertise. Moreover, additional remote-sensing technical challenges are that, unlike temperate forests (which are often dominated by a single species), forests in these landscapes can be highly diverse and structurally complex and frequent cloud cover must be dealt with. However, the future is promising, remote-sensing data are coming down in price across the board, UAV technology is cheaper, there is more freely available remote-sensing data and pre-processed data products (i.e., Landsat surface reflectance products), and with platforms such as GEE, there is a reduced requirement for expensive information-technology infrastructure. These advances are resulting in a greater democratization of remote sensing to support forest management and conservation in parts of the world where environmental issues are the most pressing.