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Bunjil Forest Watch a Community-Based Forest Monitoring Service

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1. Introduction

Imagine the power of an Internet-enabled social network that tracked disturbances to the world's most precious forests. Independent observers could expose failings in forest management and help improve governance.

This scenario is not far-fetched, although satellite-monitoring technology has to be made more accessible to non-technical, grass-roots organisations that are independent of official agencies. The good news is that new and organic forms of social organisation and activism are possible by merging the blogosphere with new public tools such as CrowdMap.com. (Ushahidi, 2011). One example is an interactive map developed to show land grabs linked to political elites in Sarawak (Malaysia Today, 2011).

This essay proposes a free public online service that provides non-expert conservation groups in remote locations with alerts about recent forest disturbances in their area. It also explains how such a service might work. Many of the required technical components already exist in various forms.

Local conservation groups living in remote forest areas should not need to understand all the technologies behind the service; nor have advanced computing resources or broadband at their disposal. They should be able to just sign-up to receive free, timely reports about recent disturbances in their area, in their own language, on their phone.

Under the proposal, local groups would control which areas are monitored by subscribing to the service. On receiving reports about a disturbance, the groups would perform enforcement activities according to their judgment and circumstances. They would also provide feedback by responding to the reports.

It is critical that the complex collection and processing of remotely sensed data be completely automated.

The proposal puts the public at the centre by actively encouraging the participation of volunteer observers to perform the routine task of regularly checking new images obtained via satellites. The volunteer observers need not be experts nor have any other connection with the local group other than a common desire to preserve the forest. The service itself would provide all the training for volunteers to become competent observers.

Removing barriers to participation allows the service to be widely deployed. It is envisaged that environmental NGOs would promote the free service to communities in forest regions, while soliciting volunteers from among their international support base.

A system that can provide this service would need to combine:

- Automated detection, collection, processing and delivery of new satellite images;
- A public online volunteer observer registration system.
- Automated distribution of observation tasks to volunteers;
- An open registration system to add new protected areas;
- Automated delivery of reports to remote conservation groups;
- And a process for local groups to respond to the reports with on-the-ground information.

These features must all be integrated by a task-based workflow system. The workflow issues messages to volunteers when new images are ready and to local groups when new reports are made. It promotes regular interaction by actively prompting users to complete tasks and by providing encouragement for completing tasks. It also prompts the local groups to provide feedback on the reports they receive.

The proposed monitoring service would build on the accomplishments of existing deforestation monitoring systems, but differ in a number of ways:

- It is geared towards early detection and intervention in user-selected areas, rather than a complete regional analysis;
- It is completely online and cloud hosted, so there are no infrastructure requirements for users;
- It is non-institutional, relying instead on online relationships and reputations;
- It formally separates observation and response into separate roles;
- It is completely workflow based. New data triggers tasks to create reports, which create new tasks;
- It is tightly integrated with online training, wikis, blogs and discussion forums;
- It relies on continuous user feedback for quality control and ground data collection.

Volunteers would be able to register with minimal barriers to entry and then be encouraged to develop their skills and knowledge with online training and networking with other volunteers.

This design is not an argument against automated detection. On the contrary, algorithms that can highlight deforestation and degradation assist volunteers to identify disturbances and help them know when to raise an alert.

Nor is this an argument against developing capacity among local groups to perform their own monitoring. Using volunteers as a resource has several benefits. First, they already have familiarity with and access to modern computers, monitors, broadband bandwidth and social networks. Second, they belong to different networks than the local groups. These may be crucial for exposing corruption and lobbying internationally. Third, there are likely to be many more volunteers in urban areas willing to spend time monitoring, and this allows the local group to spend scarce resources on activities such as verification, enforcement and reporting. Finally, the service may foster a greater awareness of and connection to deforestation issues among the volunteers, as well as develop invaluable cross-cultural relationships between and among the local groups and the volunteers.

This alert service would not work without complementary conservation strategies. Strategies include protected areas, UN-REDD, sustainable development, land reform and anti-corruption programs. National monitoring programs would also be required for systematic coverage and to measure net verifiable national reductions as required for REDD (Nepstad, et al., 2009).

REDD stands for Reduced Emissions from Deforestation and Degradation. This UNFCCC program is based on the idea that developed countries wishing to reduce climate change can pay developing countries to reduce CO₂ emissions from deforestation or forest degradation

through the implementation of policies such as strengthened law enforcement, fire management or sustainable forest management. The framework requires measuring the existing carbon stored in the forest and estimating what would be emitted under a business as usual scenario. A project to avoid those emissions is proposed and at the end of a set time period, the actual emissions are measured and compared to what would have happened. The reduced emissions have a financial value that can be traded in carbon markets. Some of the value is hopefully transferred to the locals as income for preserving the forest. Redd-Monitor.org has a good introduction to REDD and its many controversies. REDD is important but not essential to this service.

Just as REDD threatens to recentralise forest governance (Phelps et al., 2010), this service may help democratise forest monitoring away from national forest departments where the capability and governance is not yet in place, and towards grass-roots organisations.

There are several challenges to achieve this. One critical ingredient is regular, low-cost access to recent satellite images - and automated processing of those images into a format volunteers could reliably decode.

To eliminate costs to end users, the system should be based on open-source software, cloud-hosted, and have free regular access to timely satellite data. The solution needs to focus on simplicity of use and hide as much complexity as possible behind a well-designed web-application.

2. Purpose

"Never depend upon institutions of government to solve any problem. All social movements are founded by, guided by, motivated and seen through by the passion of individuals."

Margaret Mead

This tool could provide a complementary self-selecting targeted approach to monitoring areas of high conservation value wherever a local group wishes to protect their forests from external threats.

The main purpose of the service is to provide local conservation groups with timely information about forest disturbances in their area and to provide them with increased opportunities to respond quickly to recent deforestation, particularly illegal logging and land clearing. A recent study of Sumatra and Kalimantan found that at least 6.5% of all forest cover loss had occurred in land where clearing was banned, and a further 13.6 % where it was legally restricted (Broich et al., 2011).

A secondary purpose is to develop networks between people working to conserve remote areas and 'environmentalists' in populated, digitally-connected areas.

3. Who are the users?

"Enforcement against illegal deforestation is clearly a state function, but civil society can provide a formidable assist with timely, high-quality, user-friendly information."

Three Essential Strategies for Reducing Deforestation
(Aliança da Terra et al., 2007)

This proposal separates forest monitoring into two main roles, the *volunteer observers*, who regularly review the latest satellite images and the *local groups*, who rely on alerts when disturbances are detected. Other roles include the sponsors & NGOs, satellite data providers, and developers.

3.1 Local groups

“Community Forest Management (CFM) establishes formal systems between communities and Forest Departments in which communities have the right to controlled amounts of forest products from a given parcel of forest and in return agree to protect the forest and manage it collectively. Mostly these parcels are relatively small, from 25 to 500 hectares, being managed by groups of 10 to 50 households. A number of countries have used CFM very effectively to reverse deforestation and degradation processes”

GOFC-GOLD Sourcebook (GOFC-GOLD, 2010)

The service needs to be promoted to community-based conservationists who may live in remote forest communities and who may be difficult to reach via conventional marketing channels. The service must be distributed to the networks used by local groups and use a language they share.

Local groups could be environment advocacy groups, rangers protecting a park, indigenous people protecting their land or community based forest managers. The local groups might be participating in a REDD project, or other programs.

Groups may be isolated both physically and politically. Over 1150 rural activists have been killed in conflicts related to land in Brazil alone, according to Catholic Land Pastoral (Dangle, 2011). Murder convictions are rare and even rarer for those that hire the gunmen. Fighting deforestation is also dangerous in Indonesia and Malaysia. In Papua New Guinea, where more than 800 languages are spoken in one of the most biodiverse regions on earth, deforestation is running at over 1.5%pa, most of it illegal.

“States with rain forests are often unable to collect optimal revenue from the massive profit earned by timber companies that harvest state forests because this profit already has a hidden destination. Heads of state and their political supporters are siphoning off these moneys to become phenomenally wealthy.”

David Brown, PhD Dissertation (Brown 2001)

As much as possible, the solution must remove the barriers for local groups to have access to timely reports. The groups cannot be assumed to have expertise in remote sensing, but may be able to interpret maps, directions or coordinates. Computer literacy cannot be assumed, but access to a mobile phone is almost universal. Access to smart-phones, GPS and phone cameras is becoming increasingly common but is not yet universal. Some literacy in the predominant national language is required by at least one member of the group or a trusted partner. The capacity to visit, investigate and record deforestation events in their locality is important. The ability to prevent or discourage deforestation in some way is also important. Engaging local groups would be the first bottleneck to expanding the reach of the service. Enhancing the monitoring capability could expose enforcement bottlenecks in that region. Other capacity constraints such as computation, memory and bandwidth are easier to overcome. It is unlikely to be difficult to recruit sufficient volunteers as each volunteer could potentially review an image 180km on a side (Goodman, 2010).

The ‘user-experience’ for local groups should be designed to be sensitive to local and regional cultural norms and languages.

3.2 Volunteers

The volunteer observers sign up to monitor satellite images on behalf of a local group. The volunteers may be distributed around the world with no direct connection to the local group other than through the monitoring service. They must have adequate time and Internet access.

The Internet, as a low cost medium with global reach, can facilitate the formation of global virtual communities - compensating for a lack of critical mass of activists in a given country (Ackland et al., 2006), (Chadwick & Howard, 2009). Creating a critical mass is an even greater challenge for remote communities in developing tropical countries.

Community Based Forest Monitoring could rapidly engage environmental activists who are already active users of the Internet. It may be quicker to develop the observational capability among digitally connected volunteers, and develop collaborative networks, than building the capacity in remote communities.

To design the volunteers' "user-experience" it is necessary to understand their reasons for participating. Volunteers may be motivated and inspired to be active by ecological experiences and connections with nature; a sense of personal responsibility; a desire to change the world and feeling that they could make a difference; by fear and anxiety about ecological crisis and commitments to justice; or by influential people and social networks (La Rocca, 2004). It also has to be cool. Barriers to becoming active include time available: lack of skills or confidence; alienation or lack of opportunity. Challenges for keeping volunteers active include making the work enjoyable and meaningful; making a difference and responsibility to the local groups.

Each volunteer's participation is sustained by the regular tasks assigned to them and by feedback from the local group.

Volunteers are not necessarily living in the same country as the local group, although this might become common in tropical countries with advanced urban populations such as Brazil, Malaysia and Indonesia. They may even come from among the local group. Volunteers should ideally share a common language with the local group they serve. The volunteer user-experience needs to at least cater for English, French, Spanish, Portuguese and Bahasa speakers to cover the main tropical forest regions.

Volunteers need to recognise the limitations on the local groups' ability to combat illegal loggers, especially the great danger, difficulty reaching sites, and limited law enforcement.

3.3 Environmental NGOs

Non-Government Organisations could promote the volunteering opportunity to their members. They also provide a narrative structure to the regular tasks and feedback.

It is possible (but not necessary) that local groups and volunteers enter into agreements to preserve the forest. These could be through a NGO. The service forms a backbone of information exchange and monitoring that may support the terms of the agreement by building trust among the parties.

NGOs may wish to rebrand the service as their own. Associating the service with their trusted reputation gives credibility to the service while at the same time the service extends their offering and builds their networks.

Environmental NGOs with strong regional networks among local groups are important in promoting the service through the local groups' networks. These NGOs may even partner with local groups who need assistance with subscriptions, communications or translations in some regions.

International NGOs with large member and supporter networks are important for promoting the service to potential volunteers. NGOs constantly struggle to find new and meaningful ways to engage with their supporters, beyond asking for donations. By allowing volunteers to 'adopt' a threatened area, the NGO provides an opportunity for supporters to feel they are contributing in a direct and meaningful way.

3.4 Sponsors

Sponsors may provide a financial incentive to the local group to preserve the forest. It is not essential for the financial agreement to be integrated into the monitoring service. Sponsors can add incentives for subscribing to the system. Project sponsors may be affiliated with volunteers, NGOs or local groups or in a combination.

Sponsors or NGOs may target then reach out to local groups in areas identified as high risk (Sales et al., 2011).

Sponsors are also critical to financing the development, operation and maintenance of the system.

4. Existing deforestation monitoring systems

Before describing the proposed service in detail a review of existing deforestation monitoring programs is presented.

Detecting deforestation and forest degradation from space by observing changes in light reflected from the canopy is not a straightforward task. Nevertheless, detecting deforestation from space has developed over several decades and is now considered routine (Asner, 2009). Detection of forest degradation is harder but also possible.

Brazil has the largest and most systematic use of remote sensing for environmental protection of any country. Some notable operational systems include DETER and PRODES by the Brazil Space Agency, INPE; SAD by Brazilian not-for-profit IMAZON; and CLASlite by the Carnegie Institution for Science which is also focused primarily on the Amazon.

Between 2005 and 2008, PRODES indicated deforestation in the Amazon had slowed compared to what it would have been without the detection and enforcement. However, more recent data from INPE indicates deforestation rates have accelerated by 27% from August 2010 to April 2011 (BBC, 9 May 2011 & The Guardian, 12 June 2011).

4.1 INPE: DETER & PRODES

"If you are going to do prevention and enforcement, you need to be there as rapidly as possible."

Gilberto Câmara, Director of INPE quoted by Alexei May in NYT (May 2008)

The Brazil Space Agency INPE runs DETER and PRODES. The newer DETER system can detect large scale illegal logging in near real time while PRODES has higher resolution but results are only updated annually.

DETER provides an update every 15 days and sends alerts to Brazil's Ministry of Environment enforcement agency IBAMA, and police. Loggers are fined and sometime have their property confiscated. DETER relies on a range of satellites including Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the China-Brazil Earth Resources Satellite CBERS-2.

The Brazil Space Program for monitoring the Amazon commenced during the Cold War as a military operation, but was later re-purposed to facilitate economic development and expansion. Now the technology has further developed and applied to the detection of deforestation. IT systems tend to reflect the organisation that created it (Rajão & Hayes, 2009). Originally designed by specialists for use by officials and agencies, it is now evolving into an open system.

The technology and capability developed by INPE should have global applicability, although it is currently only deployed over the Amazon region. Expanding deforestation

detection systems beyond Brazil's national borders is challenging. Especially to protect areas covered by reluctant, indifferent or corrupt government agencies; where the government has limited jurisdiction; and where the country has no capacity to access and interpret the results or to enforce protection.

INPE committed in 2008 to making the data and technology publicly available, through the Data Democracy Initiative of the Committee on Earth Observation Satellites (CEOS). The commitment extends to governments of developing nations. The *CBERS for Africa* project will provide CBERS images to African countries as part of the Group on Earth Observation. INPE software has also been released as open source as the SPRING library and INPE has released code for applications TerraLib, TerraView and Marlin built on SPRING. However, a non-specialist would be unlikely to figure out how to extract meaningful data from the current systems.

4.2 AMAZON's deforestation alert system

Instituto do Homem e Meio Ambiente da Amazônia (IMAZON) developed *Systema De Alerta de Desmatamento* (SAD) to monitor deforestation in the Amazon. SAD reports monthly. Like DETER it uses the low spatial resolution (250m) images from the Moderate Resolution Imaging Spectrometer (MODIS) aboard ASTER and publishes data on Amazon deforestation rates each month. Unlike DETER, SAD uses Normalised Difference Fraction Index (NDFI) to detect not only deforestation but also forest degradation. This picks up a lot more land that is degraded. Both SAD and DETER results have been challenged by powerful opponents and withstood rigorous analysis.

ImazonGEO is an open-source open-data Spatial Data Infrastructure (SDI) from Imazon that integrates remote sensing with law enforcement (Souza et al., 2009).

Neither SAD nor DETER are good at detecting deforestation less than 25ha (Escada et al., 2011). PRODES is better at detecting small-scale disturbances, but has low temporal resolution. One technique to improve detection capacity is to combine data from higher spatial resolution sensors with high temporal resolution sensors. This involves using the older but higher resolution images to extract better information from the newer but lower resolution images. Cloud cover can affect temporal resolution by preventing the satellite from capturing a clear image. Cloud cover particularly affects the humid tropics. Access to a range of sensors on different satellites can improve the frequency of capturing cloud free images.

4.3 FORMA

Forest Monitoring for Action (FORMA) is a prototype system by the Centre for Global Development that achieves good resolution using Time Series or Trajectory Based Methods based on the MODIS Vegetation Continuous Field product (VCF) to look at long term trends in change in NDVI. FORMA can detect deforestation the size of a football field. It also detects fires in near real time. The 2009 prototype covers Sumatra and is updated monthly (Hammer et al., 2009).

4.4 CLASlite

Carnegie Landsat Analysis System Lite (CLASlite) [claslite.ciw.edu] is an automated satellite mapping approach that performs statistical analysis on raw satellite images to detect sub-pixel changes in forest cover. While broad-scale clear felling is easy to detect, CLASlite can also detect selective logging down to one or two trees. It is able to distinguish undisturbed forest from recent degradation and regrowth.

After calibration, pre-processing, atmospheric correction, and cloud masking steps, CLASlite will analyse the spectrum reflected in each pixel. Vegetation that photosynthesizes has a different spectral signal from dead trees, rocks or soil. A 'Monte Carlo' analysis then produces a range of possible combinations that converge on the most likely explanation for the data (Asner, 2009). By determining the fractional cover from canopy, dead wood and bare surfaces, CLASlite can provide maps of the forest's composition, including where it has been disturbed. If a tiny red reflection is picked up indicating bare earth, and that signal forms a line over several pixels, the most likely explanation would be a road.

Detecting new logging tracks early increases the opportunity to combat deforestation and degradation, as these are often the first indication of more extensive logging to come.

For input, CLASlite can use a wide variety of satellite imagery including: Landsat 4 and 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), ASTER, Earth Observing-1 Advanced Land Imager (ALI), *Satellite pour l'Observation de la Terre 4 and 5* (SPOT), and MODIS.

4.4.1 Applicability

Originally designed for lowland tropical forest, the CLASlite detection method has been tested on imagery from Borneo, Madagascar, the Hawaiian Islands and Mozambique (Asner, 2009).

To generically detect deforestation and disturbance, the method needs to identify changes in forest canopy cover without being overly sensitive to variation in forest type (Asner, 2009).

Results show that very different forests can be directly assessed and compared anywhere in the world by the system (Asner, 2009).

4.4.2 Licencing

CLASlite was created by Greg Asner and the Department of Global Ecology, Carnegie Institution for Science. CLASlite is supported by the Gordon and Betty Moore Foundation, the John D. and Catherine T. MacArthur Foundation, and the endowment of the Carnegie Institution for Science.

According to the end user license agreement, the Carnegie Institution intends to work with third parties in the dissemination and use of CLASlite for the purpose of conducting environmental studies and monitoring. The user agreement protects Carnegie's proprietary information, restricts copying and requires attribution to Carnegie in all reports. Results obtained from the use of CLASlite, are to be used for non-profit purposes only. The technology is provided for free to governments and others in Latin America (Tollefson, 2009).

The software could have additional utility if published as a modular library with an Application Programming Interface (API). This would allow it to be mashed-up into new applications. Porting the software to Google Earth Engine should demonstrate this.

4.4.3 Deployment and outreach

A 2008 grant from the Moore Foundation has allowed the CLASlite team to provide training and technology transfer in most tropical forest nations in the Andes-Amazon region, stretching from Venezuela and Guyana across to Peru, Ecuador, and Bolivia (Carnegie, 2008).

The capacity building program provides one-day workshops and technical support to government, academic and NGOs in the region. The aim is for each country to build up its own remote-sensing team (Regalado, 2010).

The CLASlite user website is intended as a space for collective knowledge building to improve forest monitoring and management in the Andes-Amazon region.

4.4.4 Constraints

"While the principal advantage of CLASlite is that it opens options to users who are not necessarily specialists, it is necessary to have people who know exactly what can and cannot be done with CLASlite. I don't know if I would call this a difficulty, but it is a characteristic shared with other approaches to monitoring deforestation."

Manuel Peralvo, Ecuador (CLASlite, 2009)

Although CLASlite is presently only available to non-commercial institutions in the Andes-Amazon Region, it demonstrates that forest monitoring can become an everyday activity that no longer requires huge investments in computers or expertise (Knapp, 2008).

CLASlite presently requires some user technical training to install and maintain. To what extent could the preparation of images for CLASlite and the creation of maps be automated? The steps for preparing CLASlite input are not trivial. They depend on the satellite sensor and rely on third party software such as ENVI or ERDAS to:

- Geo-reference the image to a UTM projection (WGS-84 ellipsoid);
- For LANDSAT, resample the thermal band to match the spectral image resolution;
- Reorder bands, if necessary;
- Save the image to GeoTIFF or ENVI format;

These steps are largely repetitive for regularly monitoring new images of the same location, so an automated image workflow could be contemplated. How well would CLASlite or its successor perform unsupervised is unclear.

A new version of CLASlite is being integrated with Google Earth Engine.

4.5 Other monitoring technologies

The state of the art in forest monitoring is advancing on many fronts. New satellites and sensors are increasing resolution and hyper-spectral bands. Forest monitoring systems must remain adaptable to operationalize new sensors and algorithms as they become available.

The PALSAR (Phased Array L-Band Synthetic Aperture Radar) sensor aboard the Japanese ALOS satellite also showed it is possible to detect forest disturbances even through cloud cover (Kellndorfer, 2008). Unfortunately the satellite failed in April 2011. This capability is useful against illegal loggers who use persistent cloud cover to hide their operations.

Airborne LiDAR (Light Detection And Ranging) is opening up a new dimension particularly for the estimation of carbon in a forest.

Much effort is now focussed on political, financial and technical systems for valuing and measuring, reporting and verifying carbon stored in forests for the UN-REDD program. Using LiDAR this is technically possible but still difficult as it introduces carbon inventories, which are sensitive to forest type. The required political and international financial institutions add further complexity. REDD projects work on longer-term financial cycles and may operate better at regional and national levels. The technology for REDD is significantly more complex than the detection of recent deforestation (easy) or forest degradation (harder but established). REDD should promote considerable innovation in forest carbon monitoring.

There are now many tools and standards from which to build a forest monitoring system. TerraLib, TerraView and Marlin are based on INPE's SPRING open-source library. OpenLayers and Geographic Resources Analysis Support System (GRASS GIS) from the Open Source Geospatial Foundation (OSGeo) are also useful open-source toolkits.

The Kings College London, KCL Geodata portal contains a collection of useful tools for environmental monitoring. [sites.google.com/site/consmapping]

4.6 Google earth engine

Google demonstrated a prototype of Google Earth Engine at the IPCC COP15 in Copenhagen in December 2009. Earth Engine is a project of Google.org, Google's philanthropic arm. It is supported by technology partners Greg Asner, the developer of CLASlite, Carlos Souza Jr. developer of IMAZON's SAD and others. Financial sponsors include Google itself as well as the Gordon & Betty Moore foundation, which also sponsored CLASlite.

As well as simplifying access to images, the Earth Engine will include algorithms that can transform the raw images into deforestation maps.

This engine will allow Google's vast storage, computational and bandwidth resources to be harnessed to provide post-processed images in a user friendly format. The problem of creating and maintaining IT infrastructure for distributing, storing and viewing large data sets is solved by moving the application to Google's cloud. Users need only have a web browser. The engine will "Facilitate transparency and security to their data and results. Because the data, analysis and results reside online, they can also be easily shared and independently verified." (Google.org, 2010)

Google Earth Engine is expected to include (GOFC-GOLD, 2010):

- Integrated access to many satellite data products;
- A means to request additional data from public databases;
- Tools for creating spatial and temporal mosaics of the data products;
- Built-in mapping and monitoring algorithms;
- Atmospheric correction, if desired (See Asner, 2009);
- CLASlite forest-view, forest-cover or forest-change maps;
- Imazon SAD functionality;
- An API to introduce new algorithms;
- A geoviewer such as Google Earth browser plug-in;
- Google Fusion Tables;
- Just-in-time computation.

Both CLASlite [code.google.com/p/claslite] and Imazon's open-source Spatial Data Infrastructure (SDI) [code.google.com/p/imazon-sad] are being ported to Google Earth Engine.

The prototype catalogue currently includes access to incomplete archives of many Earth monitoring satellites including LANDSAT, Terra & Aqua and various products from MODIS. These include Surface Reflectance images at multiple frequency bands, and mosaics or composite products such as MODIS Enhanced Vegetation Index (EVI) and Burn Area Index (BAI).

The beta site demonstrates the potential with a high-resolution forest map of Mexico created in record time. Despite the potential, a casual visitor to the prototype may be disappointed as it does yet not contain recent images. To detect recent deforestation, the catalogue must be updated continuously. The solution must include a means to add to the catalogue on demand, and to load other data products.

There is a lack of documentation regarding the prototype. An API has been foreshadowed but no product roadmap has been announced.

All data will be ortho-rectified on import. This makes it possible to mix images from other sensors. A multi-sensor approach can adapt to missing or poor quality data leading to improved continuity. Ortho-rectified maps can be published to Google Maps or other viewers. This also makes it easier to combine the output with other maps and data.

It is unclear what form of open access will be granted to Google Earth Engine. The company has announced it is giving away 10 million hours of CPU per year, but not said how this will be metered. Developer access to code and user access to applications has yet to be defined. Implementing applications SAD and CLASlite into an API promises to create a next generation Spatial Data Infrastructure with unprecedented storage and computation power, increased usability, and universal accessibility for civil society.

5. Bunjil forest watch

Bunjil Forest Watch is a web service proposed by the author for the rapid detection and reporting of deforestation. Existing technology would provide the building blocks from which such a service might be built.

This application does not attempt to measure, report and verify, just to detect, and let people on the ground verify and report back. This is simpler than the technology required for REDD. It is designed as an alarm bell to disrupt deforestation as it occurs and to assist advocacy. It emphasises speed of detection and intervention over systematic regional cover.

The system proposed here is likely to work best on smaller scales. Many conservation issues apply at landscape scales where changes of geology or hydrology lead to unique ecosystems and conservation hot-spots. Sites that may be too big to easily monitor on the ground, may not be so big that local groups are unable to do field inspections or enforcement.

The architecture comprises modules to collect satellite data; to process the images into maps; to enlist volunteers; to create and distribute tasks; to facilitate observation tasks; to generate and distribute disturbance reports and to ensure the integrity of the processes.

Before describing each architectural component of Bunjil Forest Watch, a story about how it could work will help tie the pieces together. Imagine the end user's perspective:

"As a conservationist, wishing to protect my land from illegal clearing, I want to know about any changes to my land as soon as possible so that I can respond to them. I don't know much about satellites, and I can't afford to pay someone to continually check for new data. If a service could just email me to tell me when something changes and where, it would help me protect my land."

The local group learns of the existence of the forest watch service through their networks. A member may either visit the web site and self-subscribe or have a partner in a regional environment organisation set up the subscription on their behalf.

The main web site has a link in multiple languages to take the user through the online subscription process to add a site to the monitoring list. The subscription records the name and contact details for the group, information about the area they wish to monitor and why. The borders of the area of interest can be defined by outlining them on a map. It is essential that this process not intimidate users by asking questions they may be unable to answer. Also, it should provide a help button to ensure that potential subscribers get assistance to complete the process.

Anyone can register to be a volunteer observer. Observers may be recruited via environmental NGOs. During registration the observer is asked to commit to promptly completing any observation tasks sent to them, and to complete the online training. A volunteer may be assigned to one or more parts of a conservation area.

New subscriptions may need to be processed by an expert group who can choose data products and processing appropriate for the biogeography of the Area Of Interest (AOI). Automated mapping algorithms may require tuning with locally-relevant training data and

forest definitions in order to produce maps that reflect different definitions of forests, deforestation and degradation.

These experts may be drawn from among the volunteers, developers, environmental NGOs academics or remote sensing professionals. Selecting the appropriate satellite sensors, bands, algorithms and layers is complex. However, this need only be done once to set up the initial settings for a periodic monitoring service. When new images become available, the system must be able to process them automatically, adjusting for clouds, rainfall, haze, and seasons, while still presenting useful images to the observer. The goal should be to reduce the amount of expert input as much as possible through automation. The expert group may also need to vet subscriptions.

Once a subscription is established the system must discover any new imagery that covers the conservation area of interest as soon as it is published. This calls for an automated 'satellite spider' to troll the databases of earth monitoring providers round the clock and to check the metadata describing new images to determine if they are relevant to an area of interest. Satellite images are large, and require processing before they are useful for detecting changes to forest canopy. The spider does not download the images, just the metadata necessary to check if they are relevant. When a new relevant image is found, the spider signals the processing engine.

The processing engine fetches the new image, and performs the necessary adjustments, such as atmospheric correction; cloud detection; ortho-rectification and forest-cover spectral analysis. The actual steps depend on the satellite, sensor, and band and whether these steps have already been completed by the data provider.

Once the image has been processed into a map showing forest cover, it is necessary to access older images or maps of the same place so that a comparison can be made. This is used to detect recent changes, either manually by an observer or using a forest-change algorithm. Finally the processing engine signals to the task manager.

The Task Manager creates a new observation task and emails or tweets the volunteer using the following template:

Dear <Name>, A new image is available for <Conservation Area>. The image was created on <Date>. Your task is to look for recent changes to forest cover and file a report by <Date Due>. Click on this [link](#) to start your task before <Date> or click [here](#) if you are unable to start this task.

The link opens a web application showing both the new and old images covering the area of interest. The area to be inspected is clearly outlined. Any areas where the forest-change algorithm has detected recent change are also highlighted. The observer is repeatedly tasked with reviewing the same area on a regular basis, and only needs to identify whether the change indicates a disturbance in that area. Basic training in image classification can be provided as an online course with completion being part of the registration process for observers.

The volunteer can mark or outline any disturbance she sees using a small set of mark-up tools. She then adds a description to the place-mark, such as 'new road', 'fire', 'crops' or 'clearing'. These place-marked descriptions are automatically collated into a disturbance report. When finished, she reviews the report and clicks send. If no disturbances are observed she files an empty report to complete the task. If unsure about a change, she may mark the location with a question for a more experienced observer to review and complete the task.

On completing her task she immediately receives encouraging feedback and a summary of her cumulative activity and credits, as well as a list of other tasks that may be attempted.

Other tasks can include online training, or assisting other volunteers. These interactions reinforce the volunteers' motivation to remain active.

If any disturbance is reported, the system sends an email or text message alerting the local group. The direct contact details of local groups and volunteers are shielded in the system. The report includes the description and coordinates of each disturbance. If the group has Internet access, they may also review the raw images and maps in a web application, or a low-resolution version if bandwidth is limited.

The local group acts on the report according to their judgement and resources. The local group may also forward the report to an enforcement agency, or send a ranger to investigate on the ground. They should not be pressured into actions by volunteers from the relative safety of a foreign country.

The service asks the local group to respond to each report. The response can be via return email or text, or online. Each response is stored with the report to ensure transparency and to assist with accuracy and other issues. While a no comment response is allowed in some circumstances, the groups are encouraged to include in the responses the accuracy and utility of the report, what investigations were performed and describe any steps taken to deter future disturbances. This feedback helps the service improve. The local group may also update the integrated wiki of their area at any time.

6. Architecture

This section describes the main components of the proposed system.

Because the system aims to provide a free service to local groups, while keeping volunteers engaged, usability is a primary concern. Difficult to follow instructions and slow or erratic responses must be avoided. All interactions must be self-explanatory and support multiple languages.

6.1 Subscription manager

This module handles requests from a local group to protect a conservation area and manages the steps in the subscription process. It also manages the local group's secure online account. Each subscription must include at least the following data before reports can be generated:

- Coordinates of the area of interest;
- Contact details to send reports;
- Report media supported (Fax, SMS, MMS, Email, Hi Def Web, Smart-phone);
- A name for the Local Group;
- Preferred language and other languages spoken;
- A unique name of the area of interest, such as a park or local name;
- Aims of the monitoring project;
- A commitment to use the reports to prevent deforestation.

The subscription manager may also capture:

- Sponsoring NGO & contact details, if applicable;
- The local group's access to technology such as GPS, broadband or smart-phones;

A means to hide the base location and identity of the local group behind an intermediary, such as an NGO should be available when requested.

The Subscription Manager also generates a geo-wiki for each subscription and encourages the local group to add further information to complete a profile of their land. To make subscriptions easier, this need not be completed immediately. This wiki template has sections for:

- Describing the area, e.g. geography, ecology, history, threats;
- Identifying any priority conservation areas within the area of interest, such as critical habitats;
- Uploading photos, stories, expert reports, and biographies of locals (if safe to do so);
- Visitor stories and photos.

The site geo-wiki is moderated by the local group (or their NGO partner) so anyone can contribute. Each subscription also has a message forum dedicated to it, for sharing intelligence about the local area. This would be in the local group's language. The moderator also has the option to request the boundary of the area of interest be nominated for inclusion in the World Database on Protected Areas [protectedplanet.net]. Conversely, if the protected area is already recorded in the database, then the subscription manager should be able to import this definition.

6.2 Satellite data service

There are many high resolution satellites from multiple providers. Satellite sensors such as Landsat TM and ETM+ (USA), Terra ASTER (USA-Japan), CBERS-2 (China-Brazil), SPOT MSS (France), and IRS-2 (India) provide data required for high resolution mapping of deforestation, logging, and other tropical forest disturbances (Defries et al., 2009). Each sensor has its own characteristics, making it more difficult to compare scenes.

The coordinates of subscribed areas may be submitted to the satellite operator's mission planners to increase the probability or frequency that the site will be scanned.

The application does not access the satellites directly, but relies on public data providers such as USGS, ESA, JAXA and INPE.

For rapid detection, the properties to look for in a satellite data service are:

- Covers the area of interest;
- Sensor has a suitable resolution and frequency bands;
- New images are continuously acquired at reasonable frequency;
- Data is (or can be) geometrically and radiometrically corrected;
- New data is processed and published as soon as it is captured;
- A notification service is available, containing meta-data describing the images, so that a spider can be configured to discover images;
- Meta-data is published using open standards;
- Free access to the public or at least copy-controlled access for not-for-profits at no cost.

If free public access is not available, it may still be possible to negotiate restricted access that allows the application to create and display deforestation maps without sharing the raw data files.

6.3 Satellite spider

The satellite spider is a component of the application that continually looks for new images covering each subscribed area of interest. The spider maintains the coordinates of all active subscription areas. It trawls the image meta-data on online databases. It requires a separate 'plug-in' for each satellite data service supported. For example, USGS supports

an RSS service that allows the spider to read an XML data feed describing the latest LANDSAT data [landsat.usgs.gov/Landsat7.rss]. The spider must convert from latitude and longitude of the area of interest to the path and row of the satellite [glovis.gov]. Other providers may offer a Web Map Service (WMS). The spider runs 24/7 but does not actually download or process any images. Each time a new image is found that is relevant to monitoring an area of interest, the spider sends a request to the processing engine to download it and create a map.

6.4 Image processing engine

The image processing engine must download images found by the spider, process them automatically into forest-change maps and store them in a map server.

The processing algorithms used are no different from those developed for existing detection systems, i.e. ortho-rectification, geo-registration, atmospheric correction, cloud removal, NDVI spectral analysis or 'unmixing'.

The processing engine has significant bandwidth and computation requirements and must be cloud hosted to avoid infrastructure maintenance.

The Google Earth Engine API promises to provide much of this functionality. Alternative toolkits are available to do processing. Amazon.com could be used for cloud storage and computation.

While a variety of sensors, data products and algorithms exist, the processing engine should aim to present a consistent display, independent of these factors. For example, a standard colour scheme and legend could be used to classify disturbance types. For a non-expert, the most easily understood imagery is high-resolution natural colour such as seen on Google Earth. However they are not updated regularly on Google Earth. Also, this is not the best format for detecting forest disturbance. Normalised Difference Vegetation Index (NDVI) images can complement visual images. Fire alerts should be integrated into the community based monitoring service. Existing fire detection systems based on MODIS, such as Indofire (Landgate, 2009) could be interrogated daily and send alerts to the volunteer and local group if a fire is detected near the area of interest. Fires are highly correlated with deforestation in many countries, depending on agricultural practices.

Once the processing engine has created the map it signals the workflow system to create an observation task.

6.5 Map server

The Processing Engine stores new maps in a map server. The map server must keep a time-series archive of forest-change maps and images for each area of interest, as well as disturbance reports, place-marks and corresponding responses from local groups. The map server does not need to store raw satellite data that is available elsewhere.

When a volunteer is conducting an observation task, the Observation Portal requests maps from the map server to be displayed using an established API. Responsiveness to these data requests is important to the volunteer's experience of the Observation Portal.

6.6 Volunteer manager

This module handles requests from volunteers to register, and it manages their account and profile. Their real identity should be secured by the system. The manager records which

languages are spoken and the preferred countries or regions in which the user may wish to volunteer.

The Volunteer Manager keeps track of tasks assigned and completed and any training the volunteer completes. It suggests available e-courses in which the volunteer can enroll.

Volunteers may self-register and deregister, and edit most of their profile, but not their qualifications, ratings or feedback.

Volunteers must pass some basic training and assessment, and agree to a code of conduct before qualifying. Observation tasks are only assigned to qualified volunteers.

6.7 Observation portal

The Observation Portal is a web application for comparing images and annotating disturbances. It could be built on existing geographic display tools such as OpenLayers or Google Maps.

The Observation Portal must be configured to assist the volunteer complete the observation task. The link embedded in the volunteer's email (or tweet) should open the portal at the correct coordinates and zoom, and display the correct layers to show the latest image and differences to previous images. Also displayed are any enhancements, such as fire detection, or outputs of automatic deforestation detection systems if available. The date each image was captured, the task id and due date are shown by default. The boundaries of the area of interest and relevant park boundaries should be displayed.

It is crucial this is displayed automatically as soon as the user clicks the task-link in their email. Expecting volunteers to navigate to an online database, find, order and download images, then load them into the viewer would lead to a high failure rate. These defaults must either be setup automatically, or be preset by an expert when a subscription is created.

Correct initial settings allow the novice volunteer to concentrate on observation rather than learning and adjusting the tools. Zooming, panning and selecting from a small set of layers are essential for the task.

The user has options to display meta-data if desired, such as the sensor, band and processing steps. They may also call up earlier reports, images or maps that outline earlier disturbances, or predefined elements such as roads or management boundaries. Protected area boundaries may be accessed from online resources such as the World Database on Protected Areas [protectedplanet.net] via the Subscription Manager.

The user experience is simplified down to just the graphic elements necessary to help the novice user to complete the current task, rather than present a rich and complex GIS interface.

Why use human observers to compare the before and after images when automatic detection is possible?

Firstly, because automatic detection can only create a map. It must still be interpreted by humans. Although the algorithm could send alerts automatically, the local group may need to analyse to check for false alarms. Secondly, volunteers may also become advocates. By exposing illegal deforestation to a globally connected audience, they increase awareness and engagement beyond national and bureaucratic hierarchies. New international networks among local groups and volunteers may help embolden local authorities and communities to better protect forests.

One way to visually compare images or maps is to view them side-by-side. One service that demonstrates this technique is AnotherEarth.org (Firth, 2011). It displays two Google Earth

javascript windows side-by-side in a browser. Both new and old imagery is displayed from an identical viewpoint. Panning or zooming one window will pan or zoom the other to the same viewpoint. Because the images are geo-referenced, aligning old and new images can be automated and differences easily observed. Another technique is the before-after rollover developed by Andrew Kesper at the Australian Broadcasting Corporation to show the changes following natural disasters (Kesper, 2011). Other techniques include flicking or fading between images. Research on user preference and performance is required to determine the best methods.

The Observation Portal also presents a reporting panel to the user. This contains a simple set of screen icons for drawing point, line or polygon place-marks. Each new place-mark or polygon includes a standard form for classifying disturbance types as well as free text annotations. The date, observer and task id is recorded automatically in each place-mark. The observer may create multiple place-marks for a single disturbance report, and may edit them until the task is sent. Once sent, the report can only be edited under version control.

Completing the task is simply a matter of pressing 'Send', as the Workflow System automatically distributes the report, and ensures it is recorded and a response received.

The reporting panel is implemented using a standard GIS toolkit.

6.8 Report manager

"A final important element is the portal for integration of ground-sampled data into this platform; including data from smartphones used in trials in community-based forest monitoring"

REDD Sourcebook (GOFC-GOLD, 2010)

This module manages the collection, storage and transmission of disturbance reports created by volunteers in the Observation Portal. It delivers the report to the local group, using the agreed contact details and method (email, text). The report manager also requests and manages feedback from the local group to rate the accuracy of each report and record any activities the local group made in response to the disturbance.

The report manager archives all the reports relating to each protected area. Both the reports and associated feedback are stored in the geo-wiki for the area of interest, together with any maps created by the processing engine. They may be used for future research or tuning the system. They can be searched geographically, visually, temporally, by disturbance type or by volunteer.

The Report Manager can translate standard fields in the report if there is a mismatch between the language of the report and the recipients. Automatic translation within major languages could be integrated. Other translations would need to be referred to a regional NGO.

A disturbance report will contain:

- a reference to the originating task - so all task parameters are archived;
- the handle of the volunteer who completed the task, which links to their public profile;
- the time and date the report was completed;
- geo-referenced place-marks created by the volunteer;
- completed forms and annotations created by the volunteer for each place-mark;
- severity of the disturbance - from minor to serious;
- observer's confidence of the accuracy of the disturbance.

Once a local group responds, the report may also contain:

- veracity response: indicates whether the observation indicated a real change or not;

- accuracy response: how accurate were the coordinates in the report. This may help detect alignment issues;
- conservation value of the information - whether it helped reduce impacts;
- comments or photos uploaded by the local group or NGO;
- actions taken, such as referrals to law enforcement.

A response may be entered directly by the local group if they have web or smart-phone access, or by the NGO. The response may also add comments to the volunteer's report.

Even when the local group has no GPS or other capability to record coordinates in their response, their text or photos can still be referenced back to the original disturbance report, and therefore indirectly geo-referenced.

Local groups can also forward reports to enforcement agencies. Carlos Souza of Imazon describes a reporting system that will “allow users to ... be able to identify cases of illegal deforestation that are being judged, send requests, as protests, to prioritize cases with the environmental agencies and courts, monitor the length of the proceedings, and receive alerts about the status of the process. We hope that this type of geo-wiki tool can engage civil society in order to accelerate the cases and bring positive pressure on the enforcement system to properly punish violators. This is important, because the application of enforcement law represents the major bottleneck to stopping illegal deforestation in the Brazilian Amazon” (Souza et al., 2009).

6.9 Workflow system

The workflow is the central control process that keeps the system alive by responding to external events and ensuring tasks are created, assigned and completed. The workflow ensures new data is processed, tasks are assigned and reports reach the people on the ground quickly and reliably. A good workflow system allows business rules and process logic to be encoded in a flexible but rigorous language, rather than buried in code.

Yet Another Workflow Language (YAWL) is one open-source workflow language and implementation (Hofstede et al., 2008).

Workflow systems are now commonplace in corporate enterprises to encode and automate business processes. Examples include defect management systems. Workflow systems can also facilitate virtual organisations, such as open-source software collaboration teams. A workflow typically describes an artefact as it is transferred from one stage to another.

For this forest monitoring application, the flows would describe a raw or processed satellite image, an observation task, or a report. The workflow system assigns tasks to people or groups; manages the scheduling and email notification system; and supports resolution, escalation and exception processes.

A new task is triggered when a new forest-change map is ready. The system assigns an observation task to the selected volunteer. The observation task may be reassigned to another volunteer if it remains in a queue for too long, or if the first volunteer requests a review. When a disturbance report is created, a new task ensures that it is sent to and acknowledged by the correct local group, and also ensures the local group sends a response within a reasonable time.

Within this basic flow are many alternate possibilities, exceptions and error cases. A flexible workflow engine allows core behaviours to be reconfigured to suit ad-hoc organisations as they evolve. There is no reason to limit Bunjil Forest Watch to a single instance. Different groups may find reasons to build and deploy variations to meet unforeseen needs.

6.10 The social network

A community-based forest monitoring system needs a wiki to encourage and strengthen community ties and share information. Social network software must be integrated into the solution to allow volunteers to interact with other volunteers, local groups, experts and the public, and to develop monitoring skills.

The social network tools consist of a geo-wiki for each local group and subscribed area, a public profile page and optional blog for each volunteer, a general wiki for the application user guide, FAQ and support in multiple languages, and a discussion forum for posting questions and defects.

Many of the interactions are automatically generated by workflow tasks. A user's reputation is updated each time one of their reports is verified. Reports and photos uploaded by local groups may be automatically added to the site wiki and geo-located with the original disturbance report. Other interactions are initiated by users or prompted by the workflow, to keep the geo-wiki up-to-date.

The social network could be implemented by customising an existing open-source Content Management System (CMS), such as Radiant or Wordpress. There are many mass-market social network sites; however a high level of integration and customisation is required to integrate with the workflow and keep the focus on the tasks. The social network must support volunteers and local groups to combat deforestation.

The site geo-wiki could well be integrated into the UNEP's *ProtectedPlanet* [protectedplanet.net] or *Atlas of Our Changing Environment* [na.unep.net/atlas/google.php]. These global Wikis already have much of the functionality required to define a community-based protected area, add to a blog, and upload geo-located photos. Using existing infrastructure is easier than creating a new site, provided the workflow integration can be achieved. The social network could also link to content in relevant environment sites such as Mongobay.com or GloboAmazonia.com.

Each volunteer has a profile page and optional blog for sharing stories about the observing experience. A volunteer's real identity can be hidden, but their online reputation as a volunteer is tracked, including the punctuality, reliability and accuracy of their reports.

6.11 Online learning

Bunjil Forest Watch will rely on a Learning Management System (LMS) to manage online and collaborative training for volunteers. This includes a wiki, forum, course material, videos and exams. The main purpose of the online learning module is to improve volunteers' observation skills and knowledge. The need for training users has been identified by both the CLASlite and IMAZON teams.

The training describes a volunteer's responsibilities and shows examples to help illustrate the kind of satellite images or maps the student will be likely to encounter and the sorts of changes to look out for. The training also shows how to create a report.

To qualify as an observer, the volunteer must complete an online test where they review pre-analysed images and correctly identify threats. Further training is available to retain and increase competency and to broaden knowledge in subjects relevant to forest monitoring, for example forest ecology; remote sensing; sustainable development or cross cultural communication. *Instituto de Pesquisa Ambiental da Amazônia* – IPAM, have an online course on *The Amazon Rainforest and Climate Change*. [ipam.org.br/curso/login]

Volunteers must complete some online training to qualify as an observer. Only qualified observers receive real assignments and can send reports. This is to discourage uncommitted and unreliable users.

Volunteers receive credits as they complete training modules. They also receive credits as they successfully perform observation tasks. Credits increase the volunteer's grading. This allows volunteers to perform more critical tasks and assist or review others.

The Learning Management System manages the syllabus of courses; enrolment in e-courses; and serves the training and examination material. The LMS can also be based on open-source software for example Chamilo [chamilo.org], Wikiversity [wikiversity.org] or Khan Academy [khanacademy.org].

Volunteers can also create course material for other users.

Local groups can also access the training. Unlike volunteers, they are not required to complete training to receive reports.

7. Discussion

7.1 Mobiles and Smart-phones

Local groups are not required to have knowledge of GIS, or remote sensing, but often will have access to a mobile phone and be within mobile range. Africa has already achieved 50% mobile phone penetration, rising at 20% pa. "Smart" phones with GPS and camera are now a mass-market technology in developed countries, but may remain too expensive for many local groups in developing countries for some years. However, a phone "app", would greatly improve the utility of the service. It would incorporate the deforestation report, the original forest change map, and a GPS to direct the group directly to the disturbance. Using camera, messaging and GPS it would be simpler to file a response that is automatically and reliably cross-referenced and geo-located in time and space.

Open Data Kit [opendatakit.org] by the University of Washington and Google.org is an open-source multilingual suite of mobile data collection tools for the Android platform. Woods Hole Research Centre has trialled the technology for collecting data from REDD forest plots.

Smart-phones will greatly assist collecting reliable evidence for both scientific and enforcement purposes. The smart-phone app could be included as an enhancement, but making access to a smart-phone a requirement for participation risks limiting access to many groups.

7.2 Accuracy

"There has to be trust in the forest-monitoring data, and these nations have to see them as their own ... There's this face-to-face collaboration that is really critical."

Dan Nepstad, quoted in *Nature* (Tollefson, 2009)

Volunteers, even with auto detection algorithms, still face a big challenge to correctly interpret the imagery, and distinguish a significant disturbance from artefacts such as data errors, seasonal variations or variations in viewing conditions. The generation of images is unsupervised and the viewer self-trained. This increases the likelihood of errors.

Quality control is important to reduce incorrect reports. False positives create unnecessary work and travel for the local group while false negatives mean disturbances are not picked up. Opponents of the local group can use errors or inconsistencies to undermine the reports. Maps prepared automatically for alerting may not reach the standards required for long-term REDD Monitoring, Reporting & Verification (MRV). But they may not be required to since a more rigorously controlled analysis can still be created later to prosecute a case.

The usual way to measure the accuracy of a new system is to compare the results with known data. A pilot of the system can be chosen to overlap with an established regional monitoring program and the results can be compared.

Additionally, as this system is repeatedly monitoring for change over fixed but relatively small areas, there is an opportunity to introduce self-correcting feedback. Ensuring the local users of the service report back to the observer on the quality of the reports gives a very good guide to the accuracy and performance of the system.

This is why local groups must rate the quality of each report they receive. The responses are automatically collated and generate statistics on each volunteer as they become more experienced. The reputation of the observers and local groups accumulate with each transaction. This feedback helps tune the service to identify poorly performing volunteers, unresponsive local groups, common false alarms and system biases or failures.

7.3 Public access

While the LANDSAT archive and other data are publicly available online, a conservation monitoring service may also need access to higher resolution imagery. High-resolution visual images may be easier for non-experts to understand. However there are trade-offs in costs, temporal resolution (frequency) and bandwidth. Many deforestation detection systems combine multiple sensors to make a statistical estimate of where deforestation is occurring. However, the critical factor for alerts is timeliness. The main business model for most high-resolution satellite providers is providing data to governments. Providing data for deforestation in remote areas, with suitable checks and balances, would not undermine this model and may enhance the reputation of the provider. For example, the GeoEye Foundation provides access to IKONOS (0.5m) resolution imagery to NGO's for humanitarian purposes.

After access to data, the next greatest issue is access to the technology to process the data. Fortunately, the owners and creators of the worlds most advanced forest monitoring systems share this aim. Increasingly, research is being published in open journals accessible to non-institutional scientists.

Another hurdle is access to computing capacity to produce the images. It is significant, but not unachievable. The cloud computing paradigm for IT infrastructure is applicable to this application. There may be infrastructure providers prepared to offer free access during low-demand for not-for-profit applications. Google's aforementioned commitment to donate ten million hours of CPU time per year is promising.

The interactive sessions must run as on-demand services, but these are data rather than computationally intensive.

7.4 Costs

The cost of computation continues to fall while speed continues to increase but removing all costs to local groups and volunteers is essential.

The registration and subscription processes ensure that no image is downloaded or processed unless there is a local group prepared to protect the area and there is a volunteer prepared to observe the images on a regular basis. This avoids wasted computation and data transfer as areas outside the area of interest are masked out of the calculation.

Obtaining regularly updated imagery at low cost is one of the key challenges. In 2008 the USGS made a decision that was a watershed for open access by providing free online LANDSAT data. Unfortunately, barriers to accessing the data remain, especially in Africa

where international bandwidth is limited (Roy et al., 2010). Barriers include limited tertiary education, especially in remote-sensing fields; conflicting national interests and priorities; inadequate awareness of potential uses; insufficient infrastructure and high data costs. The cost of implementing and maintaining the service must also be addressed. It is likely to be developed in a series of prototypes of increasing functionality.

7.5 Displacement

Although protected reserves reduce deforestation rates, they may not eliminate deforestation in the reserve completely (Clark et al., 2008). Displacement of deforestation occurs when an area is protected but its surroundings are not. If the area is reserved as a carbon bank then displacement is undesirable as emissions are merely moved rather than reduced. However displacement may be desirable if the purpose of the park is to protect a unique biodiverse area. For example, encouraging palm plantation corporations to shift expansions to areas already degraded by earlier logging, without destroying more primary forest, benefits both biodiversity and climate goals.

8. Conclusion

We can encode the motto *think global act local* into the DNA of our next generation of Earth observation infrastructure. This promises to open a new global front to combat illegal deforestation and degradation.

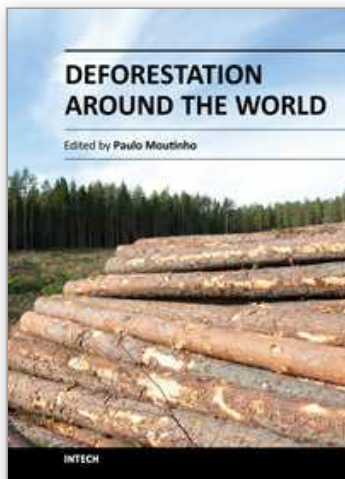
The solution described here could be built from existing open-source components, hosted on cloud infrastructure. More and more satellite imagery is freely available on public databases, and methods to process the images are advancing. This paper has described one way that these available resources could be put to better use.

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Deforestation and forest degradation represent a significant fraction of the annual worldwide human-induced emission of greenhouse gases to the atmosphere, the main source of biodiversity losses and the destruction of millions of people's homes. Despite local/regional causes, its consequences are global. This book provides a general view about deforestation dynamics around the world, incorporating analyses of its causes, impacts and actions to prevent it. Its 17 Chapters, organized in three sections, refer to deforestation impacts on climate, soil, biodiversity and human population, but also describe several initiatives to prevent it. A special emphasis is given to different remote-sensing and mapping techniques that could be used as a source for decision-makers and society to promote forest conservation and control deforestation.

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