BUNJIL – A SOCIAL NETWORK FOR PROACTIVE MONITORING OF TROPICAL RAINFORESTS

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A tool is proposed to help protect tropical rainforests through early detection of deforestation. The solution automates delivery of the latest satellite images into a collaborative geographic social network. This connects local conservation groups in remote tropical regions with a network of volunteers who share the timely analysis of satellite images. Volunteers are prompted to review the latest images of an area from various sources and mark-up any recent changes observed, such as new roads or clearings. The solution captures the coordinates and sends concise reports to the local group to respond to the observed threats.

The solution is called Bunjil Forest Watch.

INTRODUCTION

Imagine this. Isabella is a trained *Bunjil Forest Watch* volunteer and watches over a 10 000 hectare plot of Amazon rainforest in Peru. Her school friends William and Angus monitor adjoining plots. Isabella believes strongly that rainforests are the lungs of the planet and are home to a rich diversity of species. Each month, Isabella receives an email inviting her to log into *Bunjil Forest Watch*. She compares this month's satellite image with last month's, looking for changes. Last month she spied a new road and clearing. She marked the area of change on the screen and submitted a report. In Peru, a local indigenous group received a fax based on Isabella's findings. This alerted them to illegal logging activity. Ricardo, the local leader, checked out the new clearing and reported it to the regional authorities.

Considering useful applications for information technology one could scarcely find a more urgent and critical challenge than the conservation of tropical rainforests.

The UN declared 2010 the *International Year of Biodiversity* and the G8 Millennium Development Goals commit to 'a significant reduction of the current rate of biodiversity loss by 2010'.

> Forests are the most biodiversity-rich terrestrial ecosystem. They provide a wide range of values to humans, varying from timber, pulp and rubber, to environmental services. At the global level, forests play a crucial role in regulating the climate and represent a significant carbon reservoir. However forest biodiversity is threatened by deforestation, degradation and fragmentation (OECD 2008).

Tropical forests absorb about 18% of the CO_2 added to the atmosphere each year from burning fossil fuels, substantially buffering the rate of climate change (Lewis 2009). Deforestation contributes 20% of global CO_2 emissions (IPCC 2007).

A 'characteristic widely cited as an important contributor to effectiveness in reducing deforestation is the response to illegal activity within the protected area; including the probability of getting caught and the seriousness of the sanction if caught' (Clark et al. 2008).

A tool is proposed that distributes remote-sensing earth observation satellite data, of selected areas of conservation value into collaborative social networks, to create an early warning system

for park rangers, indigenous land owners or other stakeholders in remote localities who wish to preserve their forest environment.

The tool's purpose is early detection to assist enforcement actions. Enforcement occurs within a wider conservation framework that may include protected reserves; incentives to support protection; conservation education; land tenure or other governance reforms.

Local conservation groups rarely have the time, technical know-how, finances or bandwidth to obtain and regularly analyse the latest available satellite information. They may be a self-organised unaffiliated group, with no official recognition and very limited access to communications technology, education and computer literacy. Language and education can be a barrier to adoption of technology. A remote village might only have an old PC, a slow satellite link, a phone, perhaps a GPS, perhaps not. For them to benefit from the remarkable outputs of the space and information revolutions requires partnerships to bridge the digital divide.

This paper provides blueprints for a 'neighbourhood watch' service that makes it affordable and really easy for local groups to receive up-to-date reports about changes affecting their remote region from a network of non-expert volunteers in developed countries.

To be useful, the reports need to be timely; to show or describe changes; to be easily created by volunteers and be understood by the local groups. The reports need to be created in, or translated into, local or regional languages and be transmitted to low bandwidth destinations for display on low-resolution screens, or communicated to people who have no screens and perhaps no maps. The solution must also adapt to the complex adaptive social networks of the local groups.

The proposed solution has two direct objectives:

- to provide a local group with timely reports of recent changes in their area; and
- to increase engagement among volunteers and collaboration between people in advanced economies and people living in and from rainforests.

SOCIAL CONTRACTS

The main actors in the *operation* of the solution are:

- **Local Groups** who subscribe to the service to get reports about changes in their area and may be related to an enforcement organisation
- **Sponsors** who maintain the **Collectors** (Application Servers), liaise with local groups and attract volunteers
- **Volunteers** who register to review and report
- **Space Agencies** who provide satellite imagery.

The main actors in the *development* of the solution could be:

- **Funding Organisations** who fund development of the solution
- **Experts** who provide technical advice
- **Development Organisations** that coordinates development of the software and tutorial material
- **Sponsors** who operate the solution and adapt it to their requirements.

An engineering bias towards the technology risks ignoring social infrastructure and neglecting the design of proper incentives and institutional arrangements. The local group uses the service in the context of a wider conservation program that may include education, institutional structures at different spatial scales and incentives for conservation (such as REDD offsets), and protection areas (Wells 1996). Elinor Ostrom, the 2009 Nobel Laureate for Economics warns:

> The sheer variety of cultural biological adaptations to diverse ecological conditions is so great that I am willing to make the following assertion: any single, comprehensive set of formal laws intended to govern a large expanse of territory containing diverse ecological niches is bound to fail in many of the areas where it is applied (Aligica 2003).

The wider social framework is beyond the scope of this paper, but some contracts to manage the development and operation of the solution can be described.

When local groups subscribe to the service they enter an agreement with the sponsoring organisation to use reports in a constructive way according to a mutually agreed policy. Local groups also commit to provide regular feedback on the quality of the reports.

Sponsoring organisations may enter contracts with space agencies to use non-public data efficiently and responsibly to achieve conservation goals. It may be a requirement to digitally protect some images for copyright. These contracts provide access to a wider range of quality data, while protecting the space agency's existing business. Sponsors also maintain the IT or use service providers. They also have privacy and reporting obligations to their patrons, the volunteers and local groups.

When volunteers register they must complete online training to qualify. Then they agree to provide timely and accurate analysis.

Volunteers must understand they don't have any land rights over the territory they observe. Local groups are best placed to make appropriate responses to the observed threats. This solution should not override sovereignty or the needs and values of local people.

Conservation activists in remote areas may risk their lives when acting on a report while volunteers are well out of harm's way. Volunteers need to be considerate of the inherent risks and inequalities.

Development of the solution also relies on formal or informal open source software development agreements. Developers and their sponsors need to have confidence in the solution to invest time and money.

REDD

Reducing Emissions from Deforestation and forest Degradation (REDD) has been gaining momentum in climate change policy (The Nature Conservancy 2009). The *Little REDD+ Book* (Trivedi and Mardas 2008) describes the REDD building blocks as:

- carbon accounting
- base-lining emissions growth from the business-as-usual case
- developing a strategy for emissions reductions
- monitoring the results

- trading of credits for avoided deforestation.

The proposed solution does not tackle carbon accounting, base-lining or trading, but could play a monitoring and assurance role within a REDD agreement. Foreign-owned illegal logging operations receive no income from REDD. So a local group entering a REDD project must still protect their domain and demonstrate how deforestation will be avoided.

The solution may also operate independently of a REDD project. Perversely, areas with low or no deforestation cannot demonstrate business-as-usual baseline emissions, so may be hard to protect with REDD credits. Also, the carbon offsets only have market value because they permit additional industrial pollution elsewhere, so the savings are only as good as global emission targets.

HOW IT WORKS: SETUP

AREA SELECTION

An area of interest is defined when a local group subscribes to the service. The area's boundaries are agreed between the local group and the sponsors. It need not be a park or reserve. It may be an area surrounding a reserve.

Selection criteria for a site include the conservation objectives, which may include carbon retention, biogeography or natural resource considerations. Selection must also consider the park or state boundaries and jurisdictions. Other important criteria are the capability of the local group to visit and counter threats through proactive action, the ability of the solution to detect the main threats, and the number of qualified volunteers available.

Another factor to consider is the biogeography of the protected area. Larger integrated bioreserves tend to support more species than smaller isolated reserves (Wilson 1988). Selected areas will change over time to adapt to a changing environment.
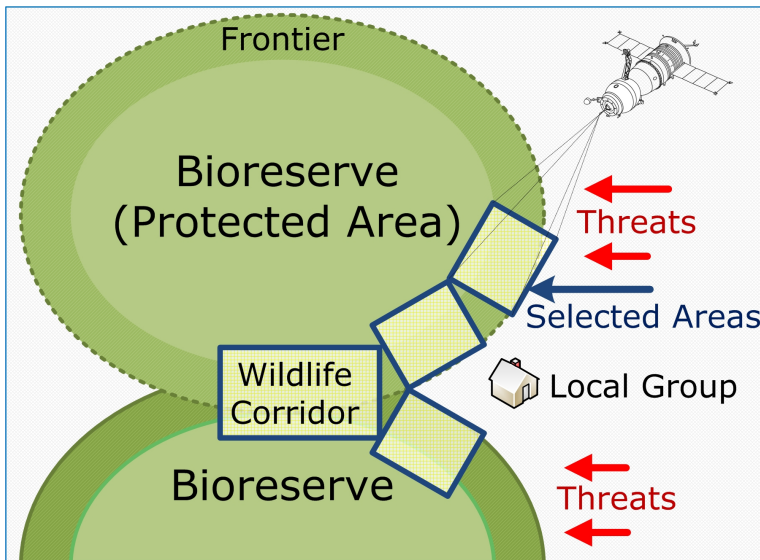

Figure 1 Geography of bioreserves, threats and selected areas of interest

SUBSCRIBING

Once an area is selected, the sponsor sketches its boundary into the collector. Information about the local group and the park's history, geography and threats are published to assist volunteers.

The best way to contact the local group is stored, including email, fax or phone and the preferred language for reports.

Once an area is subscribed, the collector modifies its query to include the new area in searches for new observations. The sponsors may choose to only collect observations from certain sensors.

Large areas are subdivided into tiles. Tiles can be prioritised so that areas of greatest risk are assigned to volunteers first.

The sponsor continues to attract and train volunteers then assigns them to tiles in the new area.

SENSOR SELECTION

The development, launching and mission control of expensive earth observation satellites is the domain of space agencies, such as NASA, JAXA, ESA or SPOT. In selecting appropriate sensors for the solution, factors to consider are cost; resolution; timeliness and data type (radar, thermal, visual, multispectral).

Publicly available observation data can be downloaded without cost from some missions, including Landsat. A pilot of the solution could just use public datasets.

Because cloud cover is particularly common in the tropics, a cloud penetrating radar sensor that is also effective at sensing vegetation is ideal, such as the ALOS PALSAR sensor.

OBSERVATION SCHEDULE

For prevention, timeliness of reports is essential. Availability of new observations is limited by many factors, including orbit, cloud cover, storage and bandwidth. The solution would be useful with new observations each month or so, but faster schedules allow a more proactive response. Too fast would be a drain on the space agencies, volunteers and local groups and is not required.

Even using public Landsat data, the collector would still register its interest in an area with NASA to increase scheduling priority for the area. Otherwise the sensor will not be activated. Observations affected by partial cloud cover can still be used by volunteers to detect changes in the areas of the image that are not obscured.

On-demand observation requests would not normally be required. The solution should adjust to the gaps and delays in the mission's observation schedule.

VOLUNTEER REGISTRATION AND QUALIFICATION

It is the volunteers who animate this system. Potential volunteers are recruited through sponsors' channels to visit the portal. Here they see descriptions of the endangered areas, from which they can choose an area to adopt.

The volunteer creates an account on the collector to register, but must complete online training to qualify as an observer. The training describes a volunteer's responsibilities and displays examples to help understand the kind of satellite images they are likely to encounter and the sorts of changes to look out for. The training includes an animation showing a report being created. The volunteer must then complete an online test where they must review stock images

and correctly identify threats. On passing the assessment, the volunteer agrees to a code of conduct before qualifying as an entry-grade observer.

Only qualified observers can receive assignments or send reports. Further training is available to retain and increase competency. Grading allows volunteers to perform more critical tasks and assist others.

The collector now assigns unallocated tiles to the volunteer. To reduce the need for translations, the volunteer's preferred language is usually matched to that of the local group.

HOW IT WORKS: OPERATION

With the collector deployed, a local group subscribed and volunteers qualified, the system is now primed to respond to new images.

COLLECT OBSERVATION

An Earth Observation Satellite sweeps over a swath of the topics. On this orbit, there is just a little cloud cover, and the observation schedule indicates that at least one customer has registered an interest in the area directly below. This raises the priority enough to cause the satellite to capture and transmit an observation. At the base station, the raw observation is converted, corrected and published in a public online database.

The collector regularly queries the databases and soon finds the new observation covering an area of interest and downloads it. Depending on the observation type, the collector will crop and extract the relevant spectral bands useful for detecting vegetation and recombine them into a single false colour image called a Normalized Difference Vegetation Index (NDVI). The collector projects the observation as an overlay in the geobrowser's coordinate system. Parts of the image affected by cloud are discarded so as not to bother volunteers whose tiles are affected. The main objective is to show where rainforest vegetation has *changed* since the last sweep. The collector may create a difference image between this and the last clear observation in another overlay. Metadata about the observations are retained, especially the date of capture.

This automatic process requires skill and expertise to develop so it can be repeatedly applied to new data. The techniques can then be reused.

The collector parcels the observation into tiles and creates volunteer assignment tasks. Each task is packaged as a link that is emailed to a volunteer. Each email contains the due date and a unique KML URL that takes the volunteer directly to their task in the browser and shows an overview of the new image to review.

RECEIVE TASK

A volunteer opens the email notifying her of a new assignment and clicks the link to go to the geobrowser where she can immediately accept or reject the observation assignment. If not accepted promptly she knows the collector could reassign her task to another. By accepting, she commits to completing the task promptly.

The volunteer starts the observation as the collector sends detailed image tiles into her geobrowser. The volunteer checks the new image for any changes relative to earlier observations. As she pans her view across the terrain, her geobrowser downloads more tiles of the new master

image. The task's boundaries can be clearly marked by a square or polygon optionally rendered to overlay the surrounding landscape.
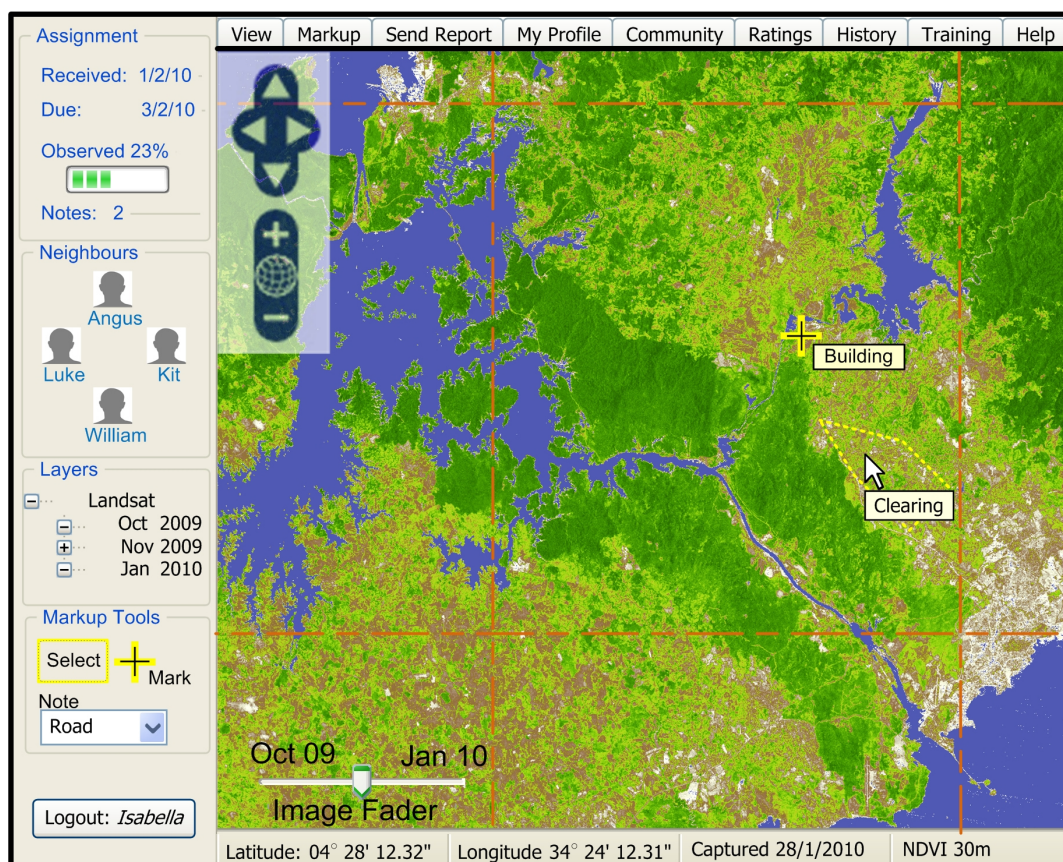

Figure 2 Geobrowser Interface (Prototype)
Background image for Geobrowser interface is courtesy of NASA Visible Earth. http://visibleearth.nasa.gov/view_rec.php?id=16701

By adjusting the multi-temporal slider she can fade between older and newer images of the same location, or choose to view them side-by-side. If the collector has draped the images over a 3D Digital Elevation Model (DEM) the accuracy and realism is increased. It means she can also tilt the view – a useful feature for mountainous forest areas.

CREATE & SEND REPORT

If the volunteer detects a change, she can use a drawing tool within the geobrowser to create a place-mark that indicates the location of the change. She can enter text in an agreed language to describe what has changed. A drop down box helps categorise common events such as a new road, building, crop or clearing. The place-mark can be a flag that marks the spot, or a line drawn around the affected area. Just by drawing these outlines, accurate latitude and longitude

coordinates are automatically calculated and embedded in the report. The image dates also assist to understand when the disturbance occurred.

Because she has been observing this area for some time, she did not need to consult the online tutorial that explains how to use the tools; or how to interpret images. Volunteers are not highly trained experts, but act as interpreters of complex visual data to alert the local groups.

After marking up the observation she clicks Send to complete her task. The collector immediately forwards the report describing the location, timeframe and nature of any changes to the local group using the prearranged method. Delivering reports to the local group may involve a translation if the volunteers and locals do not share a language.

If no data connection exists the sponsor may call the local group on a mobile or satellite phone; or send an email or fax. If the local group doesn't have access to maps or GPS the sponsor must provide directions to the disturbance. The report may optionally include compressed images if there is sufficient bandwidth. If the local group has good bandwidth they may view the observations directly.

RESPOND TO REPORT

The local group investigates and takes the appropriate preventative action to reduce deforestation within the wider conservation framework. Locals would often travel to the site to identify the nature and cause of the disturbance. In some cases they may respond with questions that the sponsor can answer or refer to the volunteer. Although existence of a report provides an earlier and wider audience to the disturbance, there is no automated way to respond.

The local group commits to respond to each reported incident, using their own language and agreed method. The response will:

- identify, verify and characterise the disturbance
- correct information in the report, or add further details
- indicate reasons why the disturbance could be not be verified (resources, inaccessibility, lacking information)
- categorise the disturbance as legal/illegal, planned/unplanned or expected/not-expected
- describe what if any preventative actions were or could be taken.

These responses are not time critical, and can be provided by web-form, paper or verbally. They help the sponsor track the quality of the service.

COVERAGE AND CAPACITY

To estimate the dimensions to which the solution must scale to address deforestation on a global scale, it is useful to ask how many hectares need be monitored and how many volunteers that would take.

Forest covers 30% of earth surface or 4,000 million ha. 28% of forests or 1120 million ha are considered tropical. 13 million ha are lost each year, mainly to agricultural expansion in the tropics, including 6 million ha/yr of primary (undisturbed) forest (FAO 2000). The net loss after reafforestation was estimated at 8.9 million ha/yr. Most reafforestation occurs in temperate forests in developed countries (FAO 2005). There is considerable uncertainty in these figures (Wikipedia::Deforestation).

Space Agency

NASA

Observation Store

Web Service

Sponsor

Collector

Image Store

Reports & Feedback Store

Local Group Manager

Fax Server

Image Processor

Reports Manager

Tile Assignment Mgr

Web Server (Local Groups)

Satellite Spider

Auditor

Social Network Forum

Training Manager

Volunteer Manager

Email Server

Volunteer Metrics

Assignment Manager (Taskmaster)

Web Server (Volunteers)

Web Server (Sponsors)

Local Group

Volunteer

Figure 3 Component architecture

It is not necessary for this solution to monitor every tropical forest that exists, but to select those which are not only at risk but also where proactive monitoring can supplement the wider conservation framework.

Historical trends can help predict where the 6 million ha of primary forests will be lost each year using tools such as RALUCIAPA (Mulligan 2008). This helps the sponsor select areas more effectively. The risk will be on the edges of the forests and around roads and rivers through forests (UNEP). Concentrating on these frontiers reduces the area to monitor, but because the area at risk is neither identified nor static, and is not contiguous, the monitored area may need to be considerably more than 6 million ha for a globally effective coverage.

Assume a volunteer could reasonably monitor a square with side dimensions between 10 km (10,000 ha) and 50 km (250,000 ha). The larger tile would only be useful for detecting gross deforestation events, while the smaller tile could allow the volunteer to monitor canopy changes more closely. A realistic tile area will vary due to factors such as:

- the resolution, coverage and nature of images;
- the size, complexity and dynamics of the geography;
- conservation objectives and threat types;
- availability of local groups;
- availability of volunteers;

To monitor one million ha with perfect assignment of tiles to volunteers would take 100 volunteers using 10km tiles or 12 volunteers handling 50km tiles. A realistic example is the Kalimantan Forests and Climate Partnership demonstration activity that aims to protect 100,000 hectares of peat-land (KFCP 2008). This would need 10 volunteers. To monitor all 112 million ha of tropical forests indiscriminately would take around 11,200 volunteers using the small tiles.

Recruiting and communicating with that many volunteers is not unprecedented, especially if shared among different regional sponsors. It could prove much harder to scale the local conservation frameworks than the volunteer networks.

Can the avoided carbon emissions avoided by this solution be estimated? For a given project monitoring a defined tropical forest area where the baseline historic deforestation rate is known, the avoided deforestation can be measured. If the carbon content per hectare has been audited, then the avoided emissions can be determined using REDD frameworks. It is not the technology but the project that avoids deforestation within a wider conservation framework. A well-designed project can also contribute to sustainable development goals.

What processing, bandwidth and storage capacity would be needed? The main bandwidth is in fetching observations from space agencies and serving images to volunteers. Other traffic, such as sending reports and maintaining the social networks, use negligible bandwidth.

A typical satellite observation could be 250 MB, depending on the sensor's bands, area, and resolution. A collector may retrieve 100 observations per month, depending on the observation schedule over the area of interest. 25 GB/month is large for a domestic user, but not large for a host-host connection.

Using KML super-overlays, the collector only serves processed images to the volunteer's geobrowsers on demand. As the volunteer pans or zooms, more of the image is downloaded. It

is bandwidth efficient, but responsiveness from the server becomes important to the quality of service. Predicting and preloading the images in the task improves responsiveness.

A typical observation task might cause the collector to serve 3MB of images per volunteer per minute over 10 minutes (50kbit/s avg.). This depends on resolution, complexity and layering in the image, and observer behaviour. The Collector need only serve the latest images because the older high res underlay could be served directly by Google Earth Engine or other servers using a mash-up.

The collector must serve multiple volunteers performing their assigned tasks at the same time. A service with 1000 volunteers might be designed to handle a busy-hour of 100 active tasks. (5 Mbit/sec avg.), or could use cloud technology such as the solution prototyped by Google.org for virtually unlimited storage and capacity limits (Moore & Luers 2009).

Storage also depends on the size of the area of interest and size of the observations. Long-term retention of the observations is not required since space agencies maintain these archives. The collector would archive the concise reports, and may cache post-processed images generated for the raw observation data for a limited time. Volunteers do not need to maintain local copies of images in the long term, but some caching is likely,

There appears to be no technical capacity roadblocks. The main capacity challenge is developing the wider conservation frameworks and capabilities in remote areas.

ISSUES

ACCURACY

There is a photogrammetric challenge to automate the preparation of satellite observations for a geobrowser. Projection accuracy is crucial to the result, as volunteers will be marking what they see in the browser, which will be translated to coordinates in the local groups' GPS. An error in the projection may not be discovered until a ranger is dispatched to the GPS coordinates to investigate. Furthermore, as the volunteers are comparing images taken at different times, the projections of the two overlays must align with each other for the volunteer to make sense of any differences.

SECURITY

There is a risk that rogue volunteers could register and qualify and then attempt to thwart the results by misreporting changes. The local groups must check each report and provide feedback so poor quality advice would soon become apparent. Local groups should also be asked to report large disturbances that they learn of independently to the monitoring. This could help identify volunteers who failed to report changes.

Experienced and trusted volunteers can review and audit reports. Mentoring inexperienced volunteers can raise the quality of reports. Reducing the rate of misreporting reduces the number of unnecessary expeditions by the local groups, and increases their confidence in the reports.

Rogue volunteers may try to register to learn where there are coverage gaps. The archive of reports could be valuable to researchers but could also be used by illegal loggers to look for monitoring gaps in which to target their operations. Access to the solution and the reports needs careful consideration by the sponsor.

MOTIVATION

Keeping volunteers motivated is essential to the success of the scheme, so the sponsor must use the network to maintain contact with the volunteers with regular updates on their collective success.

The collector rates each volunteer's time to respond, area observed and number of events detected. The collector sums the total hectares surveyed by the volunteer to help keep the volunteers and sponsors motivated.

The collector assesses how thoroughly a volunteer's survey has covered the tile as it responds to pan and zoom commands. The collector even warns when the volunteer has missed a patch.

While volunteers earn points for prompt, thorough and accurate analysis, they would also like to know how much forest they have saved individually and collectively. This could be provided in the sponsor newsletters.

Volunteers may become bored when nothing changes or feel loss when an adopted area is destroyed. The sponsors may need to re-assign volunteers to different areas as needs change, and this can also be disruptive to the volunteer's routine and enthusiasm. The social network may help addressing this risk.

The solution must not only grade but also train volunteers and continually assess their performance. Misinterpretations may lead to erroneous reports.

AUTOMATIC FEATURE DETECTION?

Why rely on volunteers when it is possible to automatically extract features and detect change. Feature extraction using image processing to detect clearing is an advanced technology (Moore & Luers 2009), that can supplement the volunteer network but not replace it. Volunteers' create an important human network as they collaborate to tackle a small part of an enormous problem from their living room. They may provide donations and courage to the local groups. They collaborate with people in the developing world to effect change. They promote their project to their peers. They may engage in political activities. The volunteer organisation can be a collective force to challenge vested interests in illegal and unsustainable practices. There is still a role for automated observation especially when the local groups are not isolated and powerless, and also for baseline pan-tropical audits.

LIMITATIONS ON DETECTION

Not all disturbances can be detected by this solution. For example game harvest is a widespread form of tropical forest disturbance that is undetectable at large spatial scales (Butler 2007).

Selective logging creates even more damage to fragile tropical ecosystems than deforestation alone (Asner 2005). It is now possible to quantify selective logging by analysing spectral data for information about the extent of vegetation in the forest canopy, the amount of debris on the forest floor and how much bare soil is exposed (Asner 2005). This technique is well beyond the capabilities of ordinary volunteers to detect without advanced image processing (Moore & Luers 2009).

DISPLACEMENT

Although protected reserves reduce deforestation rates, they may not eliminate deforestation in the reserve completely (Clark et al. 2008). Displacement of deforestation also occurs when an

area is protected but its surroundings are not. Displacement may be desirable if the purpose of the park is to protect a unique area. If the area is reserved as a carbon bank then displacement is undesirable as emissions are merely moved rather than reduced. The purpose for reserves can overlap. 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 (CIFR 2009).

The solution can be used to reinforce monitoring within conservation reserves. It may also be employed to detect deforestation in the surrounding area. Outside the protected reserve, the enforcement framework will be different.

COMMERCIAL CONSIDERATIONS

The local conservation groups should receive the service for no financial cost. Their only commitment is to promptly review and provide feedback on how they responded to the disturbances. How they respond to the report is their decision within the wider framework. The local groups may receive training and communications support from the sponsoring organisation.

A sponsor must demonstrate their conservation objectives to the space agency to justify access to images beyond the public domain observation data. Sponsors also provide the collector's processing, storage, hardware and bandwidth.

Software development and ownership should be based on the GPL licence, which provides freedom for sponsoring organisations to customise their portals while keeping intellectual property in the public domain.

Commercial variants of the technology can be expected. They could operate in separate collectors, run by a monitoring company using different access agreements. They may use paid observers instead of volunteers or even train local groups to be the observers. If the solution is used for profit or is propriety, instead of open-sourced, then very different contracts would result.

The initial challenge is to secure start-up funding to develop an open solution to a point where it gains a community of supporters to take it to the next level. Although governments may provide start-up funding, operational funding should come from each sponsor because they are trusted to work independently with the local groups and space agencies and have a base from which to attract volunteers.

TECHNOLOGY SURVEY

This proposal stands on the shoulders of existing technologies and research projects including: remote sensing satellites; the Internet; broadband networks; geographic information systems and open source software. A complete survey is impossible, but some of the most relevant can be mentioned.

An introduction to remote sensing is published online by NASA (Short 2009), as is the Landsat handbook (NASA 2009).

A useful sensor for regular monitoring of cloud-prone forests is the multispectral cloud penetrating radar (PALSAR) aboard the ALOS satellite (JAXA 2009).

The Brazil space agency INPE has two systems for measuring deforestation. Prodes, a yearly satellite analysis, detects deforested areas down to six hectares, while Deter, picks up areas down

to 24 hectares in real-time, giving law enforcement information to act quickly to stop further destruction. The Brazil program can also detect canopy thinning (Asner 2005).

UNESCO's Open Initiative on the use of Space Technologies to support World Heritage monitors threatened sites by satellite. Planet Action, a non-profit initiative launched by Spot Image and ESRI in 2007 cooperates with UNESCO and NGOs by donating observation images and expertise to eligible projects (Planet Action 2009). Google demonstrated at COP15 in Copenhagen a prototype that enables online, global-scale observation and measurement of changes in the earth's forests (Moore & Luers 2009).

Tim Flannery imagines a scheme modelled on an eBay marketplace 'linking people like you and me, who are eager to purchase our climate security, to tropical subsistence farmers who are willing to sell us that security by preserving their forests'. This would bypass government channels to ensure the 'people that live in and from the forests benefit from their protection' (Flannery 2008).

Rare Conservation's social marketing tools motivate local communities to protect their natural surroundings. Rare's 'Pride campaigns' build grassroots support for conservation by training local conservation leaders to use commercial marketing tactics to build awareness, influence attitudes, and enable meaningful change. Rare coordinates these campaigns through the *RarePlanet.org* social-network portal (Rare 2009). The Forest News Agency is a global inter-language media network to empower isolated forest dependent communities to build their knowledge of sustainable forest management techniques (TFNA 2009).

Although satellites are expensive to launch and operate, remote sensing has become more accessible through publicly available images; open source geographic software; affordable broadband; increasing computer power, memory to price ratios and display resolution.

There are common standards for serving maps, images and geospatial information directly into browsers (OGC 2009). Open source tools such as OpenLayers (OSGF 2009) keep the costs down and the technology open. OpenLayers supports many of the projections, mark-up tools and layer management needed for this solution.

TerraLook, Terrascope and RALUCIAPA (Mulligan 2008) serve Landsat false colour image overlays into a browser to provide 'visual change detection for non remote-sensing specialists who may be interested in environmental change research and conservation monitoring'. Terrascope 'brings history to Google Earth' and also includes a GeoWiki for sharing observations. This proposal adds to that technology automated image collection, process flows and task distribution.

Standards and databases created for REDD could also be used by the solution, such as the Global Carbon Monitoring System (GCMS 2009).

This solution also benefits from remote area navigation and communications technology, including affordable GPS receivers. OLPC laptops designed specifically for children in poor and remote communities would also be suitable for this solution (OLPC 2009).

CONCLUSION

The next stage is to attract development funding, technical experts and partnerships with future sponsors to complete the specification and produce a pilot.

If successful, the solution could be applied to other environments.

There is no one solution to protecting the tropics' incredible biodiversity. Any partial solution needs flexibility to adapt to unanticipated site-specific issues, and to pay close attention to the needs of local people (Potvin et al. 2007).

ACKNOWLEDGEMENTS

Bunjil is an eagle from the Wurundjeri Dreamtime who watches over mankind. The solution is called *Bunjil Forest Watch* with the blessing of Wurundjeri elder Aunty Joy Murphy.

Background image for Fig 2 Geobrowser interface is courtesy of NASA Visible Earth. http://visibleearth.nasa.gov/view_rec.php?id=16701.

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