



## HARNESSING MULTIPLE TECHNOLOGIES TO COMBAT DEFORESTATION – A CASE STUDY IN THE ALTO MAYO PROTECTED FOREST IN SAN MARTIN, PERU

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### ABSTRACT

The authors developed a pilot forest monitoring system in the Alto Mayo Protected Forest, a critically important ecosystem that provides freshwater ecosystem services, habitat for endemic species and forest carbon storage for climate mitigation in San Martin, Peru. The novel forest monitoring system aims at combating deforestation within the protected area, and integrates three components: satellite imagery, acoustic sensors and drones. Setting up a technology-enabled monitoring system in remote regions presents unique challenges, and we highlight the importance of capacity building and local engagement, as well as the need to plan for flexibility to solve technical challenges.

**Key words:** deforestation, monitoring, protected area management, drones, acoustic sensors, satellites, enforcement, remote alert

### INTRODUCTION

Humid tropical forests are critical for mitigating global climate change, conserving biodiversity and ensuring the provision of ecosystem services, including freshwater, to the local population (Costanza et al., 1997; Saatchi et al., 2011; Brandon, 2014; Seymour & Busch, 2016). The Alto Mayo Protected Forest (AMPF) covers approximately 182,000 hectares of high value land for biodiversity conservation and watershed protection in the Peruvian Amazon. This area is part of the larger Abiseo-Condor-Kutukú Conservation Corridor, one of the most threatened ecosystems in the world and home to many endemic plants and animals of global importance, including the yellow-tailed woolly monkey (*Oreonax flavicauda*) and the San Martin titi monkey (*Callicebus oenanthe*) (Schulenberg & Awbrey, 1997). In addition, runoff from the AMPF gives rise to several major rivers and the provision of freshwater to local communities in the Alto Mayo basin and allows the economic activities on which local populations

depend. For example, the Yuracyacu River provides water for the city of Nueva Cajamarca, with over 35,000 people (INEI, 2007), while supporting the irrigation of over 9,000 hectares of rice cultivation downstream. The AMPF provides many additional local benefits including the prevention of soil erosion, the protection of soils in the lowland areas from torrential flows and floods, and the enhancement of scenic beauty (Alto Mayo Conservation Initiative, 2012). The high carbon stocks in the AMPF provide global benefits by sequestering carbon and release significant greenhouse gas (GHG) emissions when deforested. Acknowledging the cultural and ecological value of the area, the Peruvian government established the AMPF in 1987 as part of the National Service of Natural Protected Areas (SINANPE).

Despite its designation and recognition in providing ecosystem services and habitat for endemic species, deforestation continued unabated in the AMPF due to increasing pressure from a growing migrant population

and the expansion of conventional coffee farming. In response to these increasing threats, Conservation International (CI) began to work with local partners to promote the sustainable management of the AMPF for the benefit of both local and global populations, as well as for the range of biodiversity dependent on the forest. CI recognised that the key to achieving significant greenhouse gas (GHG) emissions reductions and safeguarding ecosystem service provision in the AMPF was the development of a mechanism that included an economic valuation of the forest that could show competitiveness with alternative land uses. This resulted in the development of a REDD+ project in the AMPF beginning in 2008. The REDD+ project, verified by the Verified Carbon Standard and the Climate, Community and Biodiversity Standards, has included the creation of conservation agreements with communities living within the AMPF and its buffer zone to stop deforestation in exchange for technical agricultural support.

While recent conservation gains in the AMPF have resulted in an overall reduction in deforestation (Alto Mayo Conservation Initiative, 2016), ecosystems continue to be deforested. One of the key challenges in stopping deforestation in the AMPF is the ability to effectively and efficiently monitor activities over vast forest areas with limited personnel (Alto Mayo Conservation Initiative, 2012). The size, remoteness and accessibility of the protected area limit patrolling activities. Remote sensing-based monitoring of the area is also hampered by persistent cloud cover. These limitations result in substantial lags between the time when a deforestation event occurs and the detection of the event. Critical time is lost, and the perpetrators are gone by the time the event is detected and the rangers can mobilise. This has resulted in the need for a system

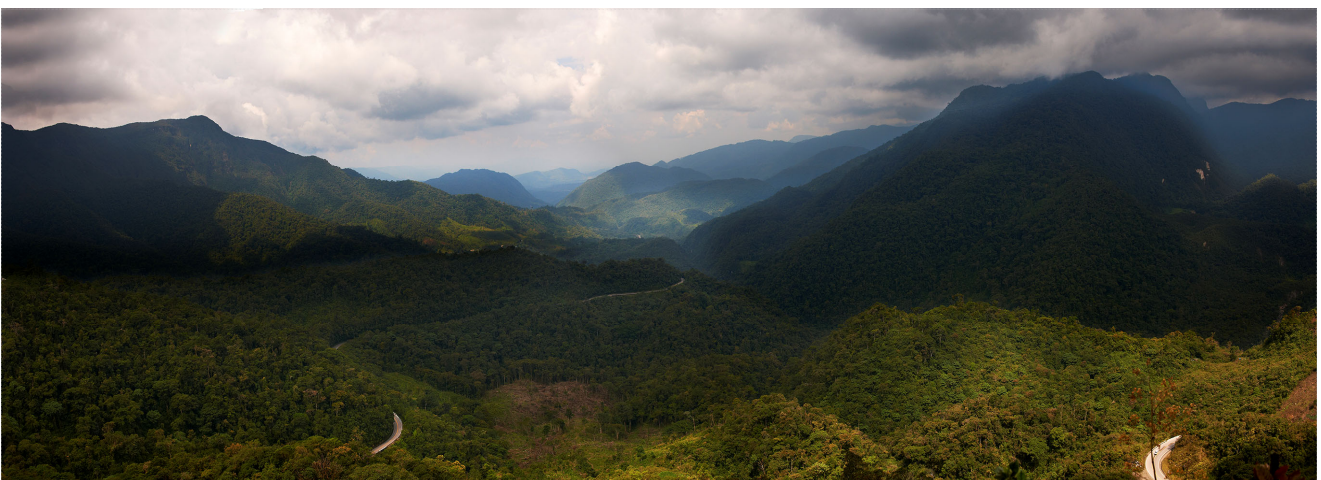
that enables rangers to react more quickly to deforestation events within the protected area to prevent forest loss and deter other illegal activities.

We describe a novel, integrated forest monitoring system that leverages cutting edge technology to empower rangers to stop deforestation in the AMPF. The system integrates three components: acoustic sensors, unmanned aerial vehicles and a satellite-based fire detection and near real-time alert system (Firecast). The joint application of these technologies allows forest disturbances to be detected more rapidly and across a larger geographic area than by conventional monitoring techniques.

## COMPONENTS OF THE SYSTEM

### Acoustic sensors

A customised network of acoustic sensors was developed and deployed by Rainforest Connection (RFCx) (<https://rfcx.org/>). The acoustic sensors, constructed using recycled cell phones and solar panels, were used to detect chainsaw sounds, the primary tool for forest clearance within the protected area. Each sensor continuously collects acoustic data and sends the information to a cloud server where it is processed using an algorithm that identifies acoustic event signatures. When an event is detected, an alert is created, and this information can be sent to rangers on the ground via email through Firecast (see below). The entire process, from the time that the event occurs to the alert delivery, takes only a few minutes making it a real-time monitoring system. The location of each sensor is recorded in the cloud server, and a single acoustic sensor can detect chainsaw sounds up to one kilometre away depending on the topography and the forest density.



Panoramic view of the Alto Mayo Landscape © Thomas Muller

## Drones

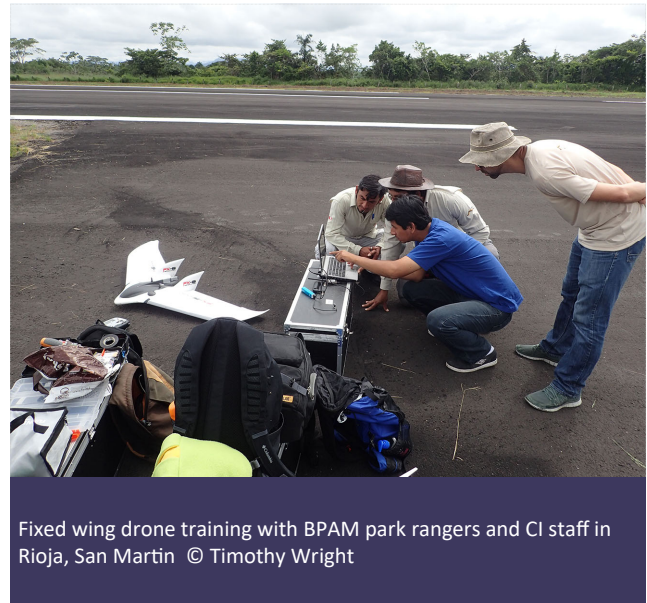
Due to cost reductions and access to open-source software, drones are increasingly used in a wide range of conservation applications (Kho et al., 2012; Zhang et al., 2016; Crutsinger et al., 2016). Drones used in this pilot study were implemented through a partnership with the University of Adelaide. Two main types of drone exist, with their own strengths and limitations: multirotor and fixed-wing. The authors deployed FX-61 fixed-wing drones outfitted with Canon S100 cameras. Fixed-wing drones were chosen because they have a longer flight time and can cover a superior distance to verify deforestation alerts from the acoustic sensors. The FX-61 drones can be piloted manually or using mission planning software such as Mission Planner (<http://ardupilot.org/planner/>). Manual piloting is useful to ensure that the drone does not run into any obstacle or to take control of the drone if an error occurs during the flight. However, for many applications, especially mapping and monitoring, it is preferable to use a mission planner to regularly survey an area of interest or fly the drone to a distant location for reconnaissance. After the drone has completed its mission, images are uploaded into an image processing software and orthomosaic images are created. Alternatively, the drone can collect video footage.

## Firecast

Firecast is an operational forest and fire monitoring and alert system developed by CI with support from NASA, ESRI and Logi Analytics (<http://firecast.conservation.org/>). The Firecast system disseminates near real-time email alerts of remotely-sensed active fires from NASA's Fire Information and Management System (FIRMS); it provides daily fire danger forecasts for the Amazon region based on satellite-derived measures of precipitation, temperature and relative humidity (Steininger et al., 2013); and generates annual 250-m Quarterly Index of Forest Cover Change (QUICC) forest disturbance alerts (Potter et al., 2003). Users can subscribe to specific areas of interest and receive tailored alerts whenever a fire is detected within that region. Since Firecast is already disseminating active fire data and annual forest disturbance alerts for Peru, and the rangers in Alto Mayo are familiar with the system, it was the tool of choice for disseminating alerts from acoustic sensors.

## IMPLEMENTATION AND RESULTS

A total of 10 acoustic sensors were deployed across the landscape along the south-eastern edge of the AMPF, covering an area of approximately 4,200 ha. The most challenging aspect of setting up the network was the lack of wireless connectivity within the protected area,



Fixed wing drone training with BPAM park rangers and CI staff in Rioja, San Martin © Timothy Wright

inhibiting the transmission of acoustic data from the field to the server. To address this issue, a cell phone repeater was set up in the buffer zone of the protected area to expand the mobile network; this network was then used to deliver the data from the acoustic sensors to the server. Alternative methods were tested to increase connectivity by linking sensors through a node/mesh system but were deemed insufficient because they would either require additional and currently unavailable technology, or they would be too expensive for long-term monitoring. Ultimately, the boosted cell phone network proved to be the most effective approach for implementing the pilot study.

Four fixed-wing drones were purchased, including two practice drones (without cameras) and two mapping drones (with cameras). To test the range of the FX-61 mapping drones, a successful 3 km mapping mission was performed in Rioja, outside the protected area, flying at an altitude of 150 m. The drone captured 245 images, which were used to create an orthomosaic image, using Pix4D image processing software (<https://pix4d.com/>), covering an area of 108,174 ha. A full report of the mission (in Spanish) is attached as supplementary material. We estimate that the battery of the drone could safely operate at twice this distance, making the functional range closer to 6 km. In the future, we will identify adequate landing zones within the AMPF, which can be used for reconnaissance or mapping missions within the protected area.

The Firecast system server was modified to check for chainsaw alerts from the cloud server, which analyses acoustic data every 10 minutes. Alerts were automatically sent by email to park rangers with the



The Rio Mayo in San Martin Peru © Thomas Muller

location of the acoustic sensor that was triggered, the time of the alert and a link to the audio file for manual verification. To limit the number of alerts from the same chainsaw event, new alerts from a sensor were only sent if of higher confidence than previous alerts within a 12-hour period. The chainsaw alerts and Firecast email dissemination were successfully tested in the field.

### LESSONS LEARNED AND DISCUSSION

Implementing new technologies in remote locations to tackle urgent problems presents challenges that require innovative solutions. One of the initial challenges was the remote geography; many regions in the AMPF are not readily accessible and there is almost no wireless connectivity within the protected area. Some technological experimentation was required to overcome this issue and scaling the pilot to cover the entire protected area will require increasing the connectivity and reliability of data transfer. The expansion of the acoustic network will target key areas within the protected area, based on risk or ecological significance.

The drone component of the integrated forest monitoring system was a success. The fixed-wing drones proved to have good flight time and range,

making them ideal for verifying deforestation alerts while penetrating further into the protected area. They are also well suited for medium area, high resolution mapping and may provide information on post-deforestation land use, forest regeneration and mapping different land use in the buffer area, such as sustainable coffee plantation. On the other hand, we found that performing long-range missions is not as simple as setting a waypoint near an alert or area of interest and sending a drone to investigate. The planning process required for a long-range mission is complex and can take significant time, due to the nature of the topography and the need to balance flight time, distance and image resolution. Another challenge was to identify adequate landing sites for the drones within the AMPF or its buffer zone. The amount of space required to land drones was a limiting factor within the dense forested protected area. Fixed-wing drones require approximately 100 metres of open space to glide in for landing. A combination of local knowledge and GIS analysis was used to identify landing zones throughout the protected area and buffer zone. Finally, we found that fixed-wing drones are more cost effective than multirotor drones, and that they have an adequate flight range; however, they are more complicated to operate, and additional capacity building was needed to transfer skills to park rangers. The fixed-wing drones proved to

be an asset in the monitoring system, but they require some practice and experience to be applied effectively. Integration with the Firecast system proved to be a successful way to communicate alerts via email. Both the fire and acoustic alerts could be combined in a single platform. Building upon a technology that is already being used in the field, such as Firecast, allows for greater coordination in monitoring efforts, and streamlines the process of receiving near real-time forest disturbance event alerts.

One aspect that was not fully considered before the start of this pilot was the effect that social factors could have on the success or failure of a pilot project. Social factors can impact the timeline of a project, and to ensure the longevity of the monitoring system in development, we worked with local land-owners within the buffer zone to house some of the equipment to expand the mobile network from their property. This kind of community engagement proved to be a successful way to ensure local buy-in and to prevent the equipment from being vandalised or stolen.

### CONCLUSIONS AND NEXT STEPS

Our pilot integrated forest monitoring system successfully demonstrated how the application of novel remote sensing technologies can be leveraged to detect deforestation events in near real-time. The use of an integrated forest monitoring system has the potential to reduce the latency between a deforestation event detection from months to minutes, allowing rangers to respond more quickly and effectively. Nevertheless, some system improvements are still needed.

A critical next step is expanding the acoustic sensor network to cover a larger proportion of the protected area. The key logistical challenge is how to deploy a whole sensor network in the most remote areas of the protected area where deforestation occurs. This will likely involve training local people, who can partner with rangers in the deployment and maintenance of the

acoustic sensors. Another consideration that needs to be addressed when expanding the acoustic sensor network is the reliability and consistence of data transmissions. Using the existing mobile network to transfer acoustic data proved problematic as the bandwidth limited the amount of data that could be transferred. Therefore, the next phase of the project will seek to streamline the acoustic data transmission by performing some of the detection analysis locally and using a satellite uplink to ensure a continuous flow of data from the field to the server.

Increasing the capacity of the drone fleet in the AMPF will also strengthen the monitoring system. The four fixed-wing drones that were acquired for this pilot allowed for long-range reconnaissance and detailed area mapping. However, there is an opportunity to expand the drone fleet in the AMPF and build capacity to better master drone technology. For example, compact multirotor drones could be taken on patrol and operated in areas that would be ill-suited for larger fixed-wing drones. The addition of multispectral sensors to the drones would also facilitate a range of additional vegetation mapping applications, such as monitoring vegetation health and stress or the impact of nutrient inputs.

The acoustic data can be leveraged to provide more information about deforestation trends and the effectiveness of conservation action in the region. Currently, the acoustic sensors are only being utilised for the detection and dissemination of chainsaw alerts. However, all the acoustic data is stored in the server, and this information can be used for additional applications. For example, the frequency and duration of chainsaw detections could help to determine whether a deforestation event is more likely for logging, land clearance for agriculture or firewood collection. The acoustic data can also be used to monitor biodiversity through the identification of individual species or through analysis of the soundscape to determine



Solar panel and acoustic sensor mounted in the canopy © James Reed



Drone image of an acoustic sensor installed in the forest canopy near the protected forest © Timothy Wright

biological richness (Pijanowski et al., 2011; Blumstein et al., 2011;). Additional analysis could also be conducted to link chainsaw disturbances to biological responses to better understand human–wildlife interaction.

Finally, it is critical to maintain and build capacity so that these technologies can be leveraged to greatest effect. Technology applications for enhanced forest monitoring are only as effective as the people who implement and maintain the system. The AMPF in Peru is an ideal location to test the integrated forest monitoring system because there is already technical capacity and commitment in place, as well as many pressing challenges. This pilot monitoring system may readily be applied to improve the forest monitoring system in Alto Mayo as well as to replicate it in other locations.

#### ABOUT THE AUTHORS

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## RESUMEN

Los autores desarrollaron un sistema piloto para el monitoreo de bosques en el Bosque Protegido Alto Mayo, un ecosistema de importancia crítica que proporciona servicios de los ecosistemas de agua dulce, hábitat para especies endémicas y almacenamiento de carbono forestal para la mitigación del cambio climático en San Martín, Perú. El novedoso sistema de monitoreo forestal apunta a combatir la deforestación dentro del área protegida e integra tres componentes: imágenes satelitales, sensores acústicos y drones. La configuración de un sistema tecnológico de monitoreo en regiones remotas presenta desafíos únicos, y destacamos la importancia de la creación de capacidad y la participación local, así como la necesidad de planes con cierto grado de flexibilidad para resolver los desafíos técnicos.

## RÉSUMÉ

Les auteurs ont mis au point un système de surveillance forestière expérimental dans la Forêt Protégée d'Alto Mayo, un écosystème d'une importance capitale qui fournit des services écosystémiques en eau douce, un habitat pour les espèces endémiques et une réserve de carbone forestier pour atténuer les changements climatiques à San Martín, au Pérou. Le nouveau système de surveillance des forêts vise à lutter contre la déforestation au sein de l'aire protégée et se compose de trois axes: l'imagerie par satellite, les capteurs acoustiques et les drones. La mise en place d'un système de surveillance basé sur la technologie dans les régions éloignées présente des défis uniques, et nous soulignons l'importance du renforcement des capacités et de l'engagement local, ainsi que la nécessité de démontrer de la souplesse au niveau de la planification pour résoudre les problèmes techniques.