OBLIQUE AERIAL PHOTOGRAPHY: A NOVEL TOOL FOR THE MONITORING AND PARTICIPATORY MANAGEMENT OF PROTECTED AREAS

Charlie J. Gardner[1,2,*], Xavier Vincke[1], Simon Rafanomezantsoa[1] and Malika Virah-Sawmy[1,3,4]

* Corresponding author: cg399@kent.ac.uk
[1] WWF Madagascar and Western Indian Ocean Programme Office, Antananarivo, Madagascar.
[2] Durrell Institute of Conservation and Ecology (DICE), School of Anthropology and Conservation, University of Kent, UK
[3] Plant Conservation Unit, Biological Sciences, University of Cape Town, South Africa
[4] Institute of Environmental Studies, School of Biological, Earth and Environmental Sciences, University of New South Wales, Australia

ABSTRACT

Protected areas are our principal conservation strategy, but require surveillance and monitoring for effective management. Many are threatened by shifting cultivation, a practice that is difficult to detect accurately with satellite imagery and is generally carried out clandestinely in isolated areas. Since 2010, oblique aerial photography has been used to detect, understand and rapidly respond to shifting cultivation in national parks and new protected areas in Madagascar. Protected areas are flown over annually at a height of 500 m above the ground along fixed transects spaced 3 km or 6 km apart: comparison of images between years reveals new clearings, which are accurately located and measured using Google Earth and GIS software. Aerial images are used by foot patrols to locate clearings on the ground and enforce rules (in national parks) or improve dialogue between protected area managers and shifting cultivators (in new protected areas). Oblique images are intuitively easy to understand and thus provide a powerful tool for discussions with resource users and other stakeholders to facilitate participatory management. The method used is significantly cheaper than the use of satellite images and requires minimal training, and thus has potential for use by protected area management agencies worldwide.

Key words: Biodiversity, conservation, deforestation, Madagascar, shifting cultivation, surveillance

INTRODUCTION

Our principal tool to stem biodiversity loss resulting from anthropogenic processes is the establishment and management of protected areas, which now cover over 15 per cent of the world's land surface (Juffe-Bignoli et al., 2014). Signatories to the Convention on Biological Diversity are required to extend the coverage of terrestrial protected areas to 17 per cent of their national territory by 2020 and ensure that they are 'effectively managed' (CBD, 2010), however their effectiveness depends on their ability to buffer their constituent ecosystems and species from the processes that threaten their viability (Gaston et al., 2008), and, globally, we know little about the success of protected areas in maintaining their condition over time (Cabeza, 2013; Geldmann et al., 2013). Key aspects of protected area management required to ensure their effectiveness include surveillance, which allows the detection of threats and facilitates the enforcement of rules, and monitoring, which permits managers to quantify changes over time and subsequently evaluate the effectiveness of management actions as part of the adaptive management cycle (Lindenmayer et al., 2012). In addition, managers must have an understanding of local resource use dynamics and the factors affecting the livelihood decision-making of adjacent communities if they are to develop appropriate, evidence-based strategies and interventions (Geoghegan & Renard, 2002; St John et al., 2013).

Habitat loss, and particularly deforestation, is the primary threat to biodiversity in tropical developing countries (Laurance & Peres, 2006; Bradshaw et al., 2009). Globally, there has been a shift in the drivers of tropical deforestation over recent decades, with industrial agriculture replacing shifting cultivation (also known as swidden agriculture or slash-and-burn) as the

Although extensive areas remain, almost all of Madagascar's forests are threatened by shifting cultivation © Louise Jasper

principal cause of deforestation in Latin America and South-east Asia (Rudel et al., 2009; Ziegler et al., 2009; Ziegler et al., 2012). However, in many other tropical developing countries, small-scale farmers practising shifting cultivation techniques for either subsistence or export-oriented cash cropping remain the principal agents of deforestation (Carr, 2009; Mertz, 2009; Gorenflo et al., 2011). Although data are scarce, the practice may support hundreds of millions of people worldwide (Mertz et al., 2009), amongst them the poorest of the rural poor (Angelsen & Wunder, 2003; Hulme & Sheperd, 2003). The enforcement of protected area rules, if unaccompanied by other measures, offers only a partial solution to shifting cultivation as a conservation problem, since it may simply displace the activity elsewhere (a phenomenon known as leakage, Ewers & Rodrigues, 2008; Kindermann et al., 2008).

Shifting cultivation is particularly difficult for protected area managers to detect, monitor and manage because, being illegal in most countries, it largely takes place in remote areas (Mertz et al., 2009; Heiniman et al., 2013). Remote sensing using satellite imagery provides a range of powerful tools that are increasingly used to monitor deforestation worldwide (Jensen, 2007), however the detection and monitoring of shifting cultivation in this way is problematic due to the highly dynamic nature of the phenomenon and the complex, small-scale land use mosaics that it produces, composed of fields, fallows of various lengths and secondary forests, each with complex spectral signatures (Asner et al., 2009; Mertz, 2009; Hurni et al., 2013a). As a result, remotely sensed data on deforestation patterns associated with shifting cultivation are rarely available at the regional or local scale required by protected area managers (Hurni et al., 2013b). In addition, satellite images may be expensive at the necessary resolution and available only after significant time lags, and require highly specialized technical expertise that is beyond the capacity of most State protected area management authorities and NGOs working on the ground in tropical developing countries. Critically, satellite images also tell managers little about the actors involved in shifting cultivation nor the factors affecting their livelihood decision-making, thus limiting their utility in developing tailor-made management responses. Further, the outputs of remote sensing analyses (essentially maps of various kinds) may be difficult to interpret by non-specialists, limiting their value as tools for communicating with and engaging other protected area stakeholders, including decision-makers, national and local authorities and shifting cultivators themselves. There thus remains a clear need for reliable, effective and efficient methods that can be used by protected area managers in tropical developing countries to rapidly detect and respond to shifting cultivation.

Here, we describe a new method for detecting and understanding shifting cultivation in protected areas in Madagascar, based on the use of oblique aerial photography in conjunction with the online tool Google Earth. We first describe the context and challenges of protected area management in Madagascar, and then outline the method used in aerial photography and image treatment, before describing how the outputs of the surveillance programme are used in protected area management. We then present some preliminary results on the effectiveness of the method in reducing deforestation in southwest Madagascar, and conclude by discussing the role of aerial photography in protected area management and the strengths and weaknesses of the approach with respect to the alternative method, remote sensing using satellite imagery.

MATERIALS AND METHODS

- **Study system**

Madagascar is a global conservation priority possessing an unparalleled combination of diversity and endemism (Brooks et al., 2006; Holt et al., 2013). The vast majority of the endemic biota is forest dependent (Goodman & Benstead, 2005), and is thus threatened by deforestation, which remains a major problem in all remaining forest areas – for example, 8.6 per cent of forest cover was lost in the decade from 1990-2000 (Harper et al., 2007), and deforestation continues to occur even within national parks (Allnutt et al., 2013). Most of this deforestation is associated with shifting cultivation (Casse et al., 2004; Gorenflo et al., 2011), which has been illegal throughout the country since pre-Colonial times (Raik, 2007) and takes two main forms – *tavy*, the cultivation of hill rice in the humid east, and *hatsake*, the cultivation of corn (and occasionally other crops such as tobacco, cassava and sorghum) in the dry west and south (Scales, 2014). In both regions the process involves farmers cutting the shrubs and smaller trees within a defined area of forest during the dry season (which lasts from about May to November), leaving the vegetation to dry for several months, and then burning it. The ash from burning fertilizes the soil which is sown and cultivated before the arrival of the rains in around November (north and east) or December-January (southwest), but the land is generally abandoned after 3-5 years due to declining fertility and the invasion of unmanageable weeds (Razanaka et al., 2001; Pollini, 2012).

The drivers of shifting cultivation are complex (Razanaka et al., 2001; Scales, 2014). Traditionally a subsistence activity, over recent decades the uptake of *hatsake*, in particular, has been heavily influenced by booms in the price of maize as an export crop (Blanc-Pamard, 2004; Minten & Méral, 2006; Scales, 2011). Since it takes place at the forest frontier, it is usually carried out by migrants: in southwest and western Madagascar these may be migrants from the far south fleeing drought or seeking cash with which to buy Zebu cattle (Réau, 2002; Casse et al., 2004), but also residents of the region who turn to the forest as a safety net when farming their permanent fields becomes insufficiently productive, for example following the loss of irrigation infrastructure, changing rainfall patterns or the destruction of their fields in extreme flooding events (Virah-Sawmy et al., 2014; Gardner, unpublished data). However, wealthy local residents may also be involved in the process, employing migrant labourers to carry out *hatsake* for them under a share-cropping arrangement (Minten & Méral, 2006; Scales, 2011).

As part of efforts to stem ongoing biodiversity loss, the Government of Madagascar committed, in 2003, to tripling the coverage of their protected area system (Kremen et al., 2008; Corson, 2014). Prior to 2003 the protected area network consisted of 47 strict nature reserves, national parks and special reserves (Randrianandianina et al., 2003) – 'strict' categories of protected area (IUCN categories Ia, II and IV respectively) managed by the State (through the para-statal Madagascar National Parks (MNP)) for conservation, research and recreation, and in which all extraction of natural resources was banned or highly regulated. The Durban Vision, as the expansion process became known, entailed major changes in the country's approach to protected area management.

Since the majority of sites prioritized for the creation of new protected areas as part of the Durban Vision (Kremen et al., 2008) are home to large populations of people that depend on natural resources to varying extents for their subsistence and household income, the existing model of strict protected areas was recognized as inappropriate. Most new sites are therefore proposed/

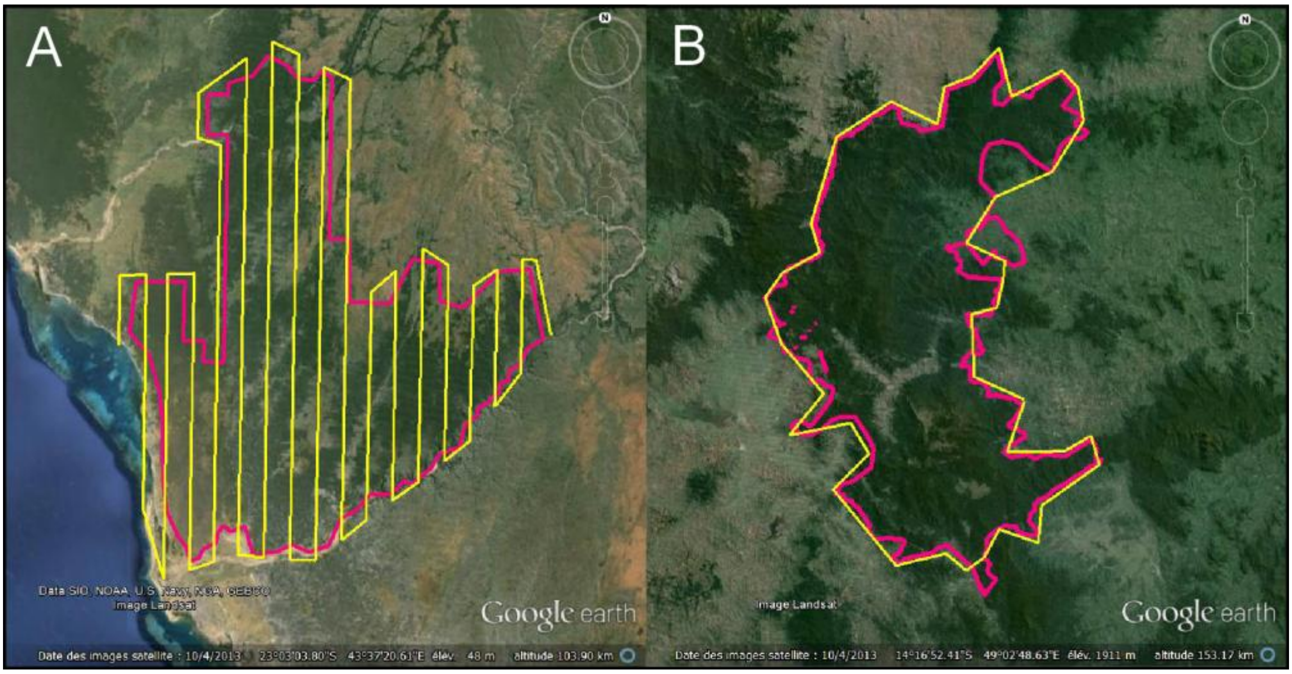

Figure 1: Satellite images of A) Ranobe PK32 new protected area in southwest Madagascar (sub-arid, low altitude) and B) Tsaratanana-Marojejy Corridor in northern Madagascar (humid, mountainous), showing different transects/flight routes used as a result of prevailing conditions. Protected area boundaries are marked in pink and flight routes shown in yellow. (Images produced on Google Earth)

designated as 'multiple-use' protected areas (IUCN categories III, V and VI) in which the sustainable use of natural resources is permitted according to a zoning plan (Gardner, 2011) (although shifting cultivation remains illegal throughout the country), and the majority are managed through shared governance arrangements by non-governmental organizations (NGOs), local community associations and regional authorities (Virah-Sawmy et al., 2014). The objectives of the new, expanded protected area system (SAPM), which includes the Durban Vision generation of new protected areas as well as the MNP-managed portfolio of strictly-protected sites, were expanded to include the conservation of Madagascar's cultural heritage and the sustainable use of natural resources for poverty alleviation and development alongside biodiversity conservation, but this creates a great challenge for managers since most traditional forms of resource use have negative impacts on endemic biodiversity (Gardner, 2009; Irwin et al., 2010). Thus approaches to protected area management have largely focused on improving the sustainability of existing land-use practices and developing alternative livelihoods to reduce dependence on natural resources (Gardner et al., 2013), as well as the contractual transfer of management rights to local communities through natural resource management transfers (Ferguson et al., 2014; Pollini et al., 2014). Neither MNP nor the NGO promoters of new protected areas have the authority to apply the law within protected areas, which remains the mandate of the State's Environment and Forests Service (MNP, 2014).

- **Oblique aerial photography**

Oblique aerial photographs are taken from a high point at an angle of approximately 45° from the observer, i.e. in between parallel and perpendicular to the ground, neither horizontal nor vertical. The method of oblique aerial photography described here has been developed by Aviation Sans Frontières-Belgique (ASF-B) since 2006, in collaboration with WWF Madagascar and Western Indian Ocean Programme Office (henceforth WWF), Madagascar National Parks (MNP) and the Madagascar Protected Area System (SAPM), and implemented since 2010. Initially focusing on national parks and new protected areas within the spiny forest ecoregion of southwest Madagascar, the programme was subsequently extended to include the Tsaratanana-Marojejy Corridor in northern Madagascar from 2011.

Each participating protected area is subject to an annual over-flight in a small, four-seat aircraft (Cessna 182). Permanent 'transects' are established over each site, and programmed into the GPS of the pilot to facilitate repeated transects. In the relatively flat and dry areas of southern Madagascar transects are laid in parallel and spaced 3 km apart, covering the whole protected area (Fig. 1a), however cloud cover associated with the mountainous rainforest of northern Madagascar can prevent flying across the centre of protected areas: in these sites, in addition to parallel transects, alternative transects are established around the forest edge at the base of the mountain to minimize the constraints of possible cloud cover (Fig. 1b). Since shifting cultivation

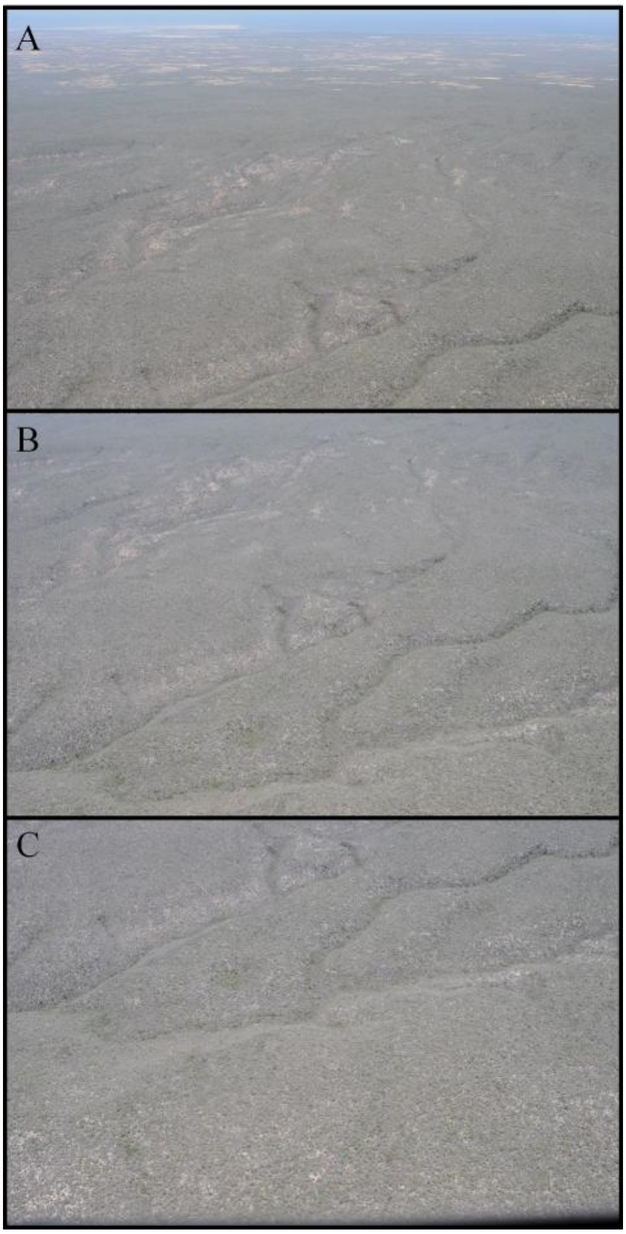

Figure 2: Representative sequence of photographs taken from a Cessna 182 aeroplane at an altitude of 500 m above Tsimanampesotse National Park at the end of the dry season. Photographs are taken perpendicular to the direction of travel, with three frames exposed every 3s (one with the horizon at the top of the screen (A), one covering the centre distance (B), and one covering the near distance with the plane window forming the lower border (C)) to ensure maximum coverage of the landscape. (Images: Xavier Vincke)

takes place primarily at lower elevations, this method nevertheless permits the observation of deforestation at the forest edge. In the spiny forest, parallel transects placed 3 km apart permit 100 per cent detection of new clearings > 0.5 ha in area; however, the distance between transects can be increased in order to reduce flight distance and therefore cost, with a resulting decrease in detection power. We estimate that transects spaced 6 km apart permit detection rates of approximately 80 per cent of new clearings > 0.5 ha in area.

All transects are flown at a height of 500 m above ground level with two observers taking photographs manually, perpendicular to the direction of travel (one facing left, and one facing right). Each observer takes three photographs every 3 s; one with the horizon at the top of the viewfinder, one a little lower, and the third with the bottom of the plane window at the bottom of the viewfinder. This allows the majority of the landscape to be covered (Fig. 2). All images are taken with a Nikon D300S with a fixed focal length of 28 mm, 400 ISO with automatic f-stop and shutter speed, and automatic white balance. The camera is connected to a global positioning system (GPS (Garmin, Pilot III)), therefore each photograph contains the geographical coordinates and height of the location from which it was taken amongst its properties. No stabilization apparatus is needed for the camera, which is simply hand held by the photographer.

Aerial transects in dry southwestern Madagascar are carried out in November-December, at the end of the burning season and before the start of the rains. Flights in humid eastern and northern sites are vulnerable to windy and cloudy weather, and therefore take place in July and August when conditions are most favourable.

- **Image analysis**

Photographs taken in successive years from the same transect and with the camera facing in the same direction can be directly compared to identify new sites of deforestation, following processing in Adobe Photoshop to increase clarity and contrast. On all substrate types, newly burned clearings can be easily distinguished from older clearings by their grey colour resulting from ash deposits; older clearings assume the colour of the substrate (white for limestone, red for sands and other soils).

The specific location of each identified clearing is determined using Google Earth and ARCview or ARCgis geographical information systems (GIS) software. KML files showing the flight route (transects) and protected area limits are loaded onto Google Earth, and the image of the clearing opened alongside (ideally on a second screen, although half-sized windows on the same screen are also possible). A landmark is created in Google Earth at the point from which the image was taken, using the geographical coordinates embedded in the image properties, and is given the same name as the image. Zooming in to the landmark until the height from which the image was taken (500 m) is reached, the view angle is then rotated until a view equivalent to that shown in the image is obtained. Comparing the aerial photograph and Google Earth image by eye, a polygon corresponding to

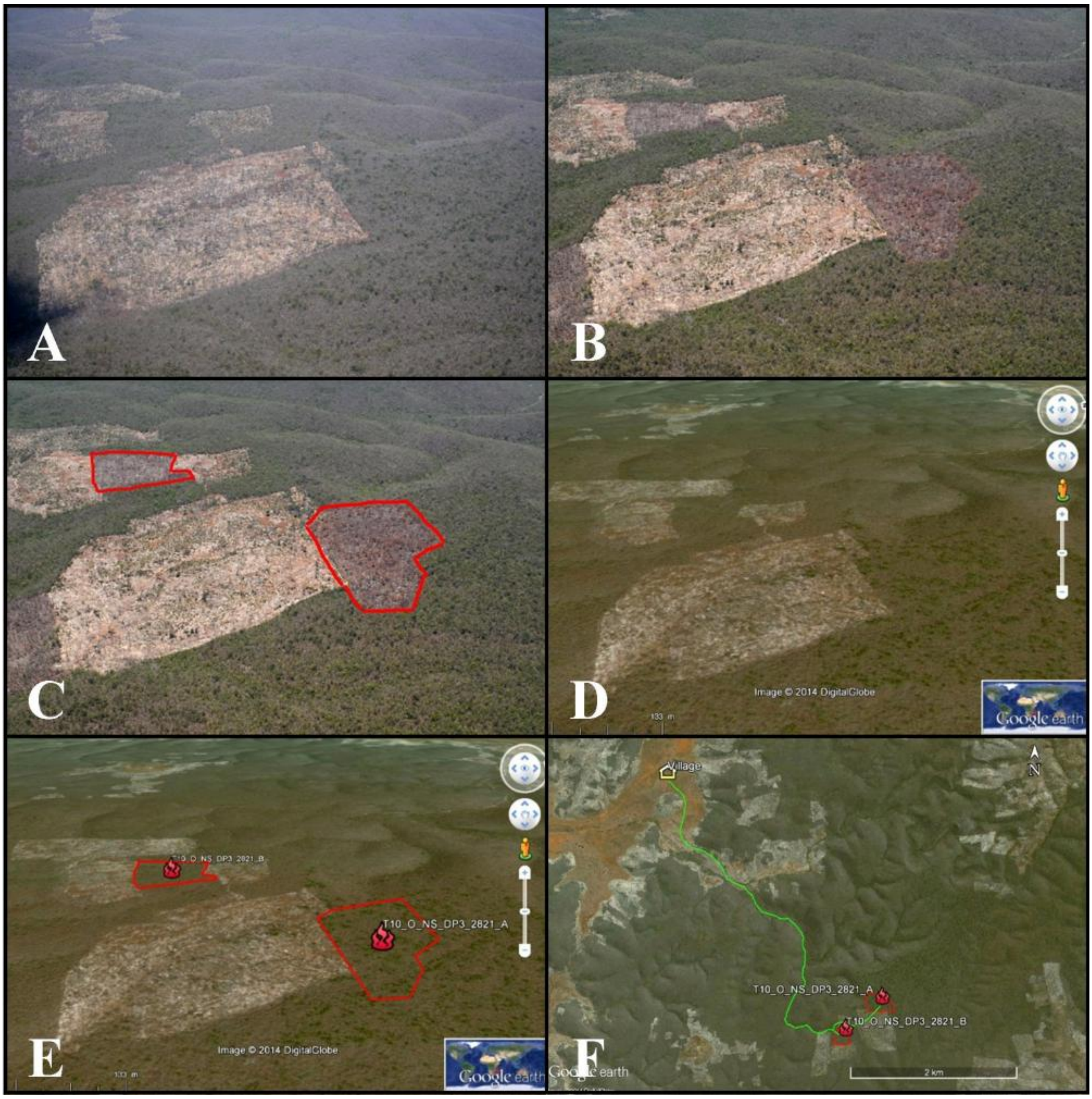

Figure 3: Sequence of images illustrating the analysis of oblique aerial photos taken as part of an aerial surveillance programme. The first two images show an area of Ranobe PK32 new protected area taken in November 2012 (A) and December 2013 (B). New clearings are clearly visible and marked in red (C). On Google Earth, an analyst zooms in to the point and height from which the image was taken, using coordinates embedded in the image properties, and rotates the view to find the view equivalent to the image (D). New clearings are manually drawn on Google Earth (E), and the data imported into GIS to calculate area and quantify deforestation rates. Maps are also produced on Google Earth to enable foot patrols to reach new areas of deforestation (F). (Images D-F produced on Google Earth, A-C by Xavier Vincke)

the clearing is then manually drawn on Google Earth and marked by a landmark at its centre (Fig. 3). The area of each polygon (clearing) is automatically calculated in Google Earth Pro but can also be calculated by importing the KML files of deforestation polygons drawn on Google Earth into GIS software. Plotting the cumulative area of new clearings allows managers to calculate and monitor the area and rate of deforestation on an annual basis.

Maps of new clearings produced on Google Earth are used by protected area managers to identify important areas of deforestation and prioritize sites for rapid intervention, which requires field staff to reach the locations on foot. For each clearing to be visited, aerial images and Google Earth are used to identify the nearest village and map accessible routes to the clearings using existing paths; once the most accessible route is identified, it is marked on the satellite image alongside hamlets and other features and landmarks. A vertical view of the image is printed and laminated, and serves as a map for foot patrols; the coordinates of landmarks along the route and other features are printed on the reverse side, providing a tool that allows patrols to easily locate new clearings by following the route marked on the map and using the 'go to' function on hand-held GPS units to reach selected landmarks.

- **Use of aerial photographs in protected area management**

While the monitoring of deforestation rates over time generates data that can be used to evaluate the effectiveness of management interventions as part of the adaptive management cycle, the primary use of oblique aerial photography is to enable the rapid detection of, and response to, deforestation in and around protected areas. Following the identification of priority sites for intervention through the analysis of aerial images, foot patrols visit each target area to engage with farmers practising illegal shifting cultivation. Foot patrols generally comprise staff of the protected area managers or promoters (i.e. MNP or NGO promoters, as well as representatives of community-based governance structures) and representatives of local authorities (for example the mayor of the commune and village leaders (elected and traditional) from the area in which the deforestation occurred); they may also include agents of the Environment and Forest Service, which has legal authority and responsibility for all Madagascar's forests. Patrols typically travel initially to the nearest hamlet to the observed clearing, and then visit the clearing itself with villagers from that hamlet.

The form of management intervention carried out by patrols varies according to management category and governance mode of the protected area in question: in strict protected areas managed by MNP, patrols focus on law enforcement and may involve the arrest of the perpetrators of the deforestation, or delivery of a summons to appear in court. In new protected areas, however, patrols do not enforce the law but focus on sensitization and communication, for which oblique aerial photographs are a powerful tool. Patrols visiting hamlets and villages adjacent to deforestation areas use oblique aerial photographs (printed and laminated) to initiate and illuminate discussions with shifting cultivators about their livelihoods, the impacts of their activities on the surrounding landscapes and potential alternatives or management responses, as well as to discuss the illegality of their activities and the existence of the protected area. Aerial imagery plays an important role in these discussions; agents initially use a close-up image of the village or hamlet in question, which helps to initiate villagers into the analysis of photographs as they recognize individual buildings, trees and other landmarks. Images situating the village in the wider landscape, alongside those showing the increase in deforestation in successive years, provide villagers with powerful new insight into the changes occurring in the surrounding landscape and the rate at which forests are disappearing. In addition to any direct dissuasion effects resulting from these visits by the authorities, the use of aerial photographs in discussions with shifting cultivator communities has allowed protected area management staff to gain knowledge and understanding of the social dynamics of shifting cultivation and the factors shaping the livelihood decisions of farmers that has proved invaluable in the formulation of management strategies, while also providing communities with an avenue to express their concerns directly to managers.

The ease with which oblique aerial photographs can be intuitively interpreted, compared to vertical pictures, maps and satellite images, renders them a powerful communications tool. As well as facilitating dialogue with shifting cultivator communities themselves, the images generated during the course of the programme have proved valuable for communicating with diverse audiences and protected area stakeholders. For example, the images have been used by WWF to highlight the severity of the shifting cultivation crisis afflicting southwest Madagascar and persuade regional decision-makers, including the Environment and Forest Service, the judiciary and decentralized regional authorities, of the urgency of implementing appropriate policies and ensuring the application of national forest law. In addition, the photographs formed the basis of a travelling public exhibition focused on deforestation and associated environmental problems (including erosion and sedimentation of coastal fishing grounds); the exhibition reached an estimated 10,000 people in 20 towns and villages across Madagascar, and provided an important opportunity for public education in a country where contemporary environmental issues are only rarely discussed in school curricula or mass media. The exhibition is now on permanent display at an environmental education centre managed by the NGO, Bel Avenir, adjacent to the Ranobe PK32 protected area, and is visited by hundreds of school children each month.

PRELIMINARY RESULTS

Since the launch of the programme in 2010, 58 surveillance flights have been carried out over 20 national parks, existing or proposed new protected areas, and management transfers. Preliminary analysis of deforestation rates indicates that deforestation has been reduced in areas subject to repeated aerial surveillance and accompanying field patrols; for example, in the southern part of Tsimanampesotse National Park, the total area of new deforestation fell from 20 ha in 2010 to

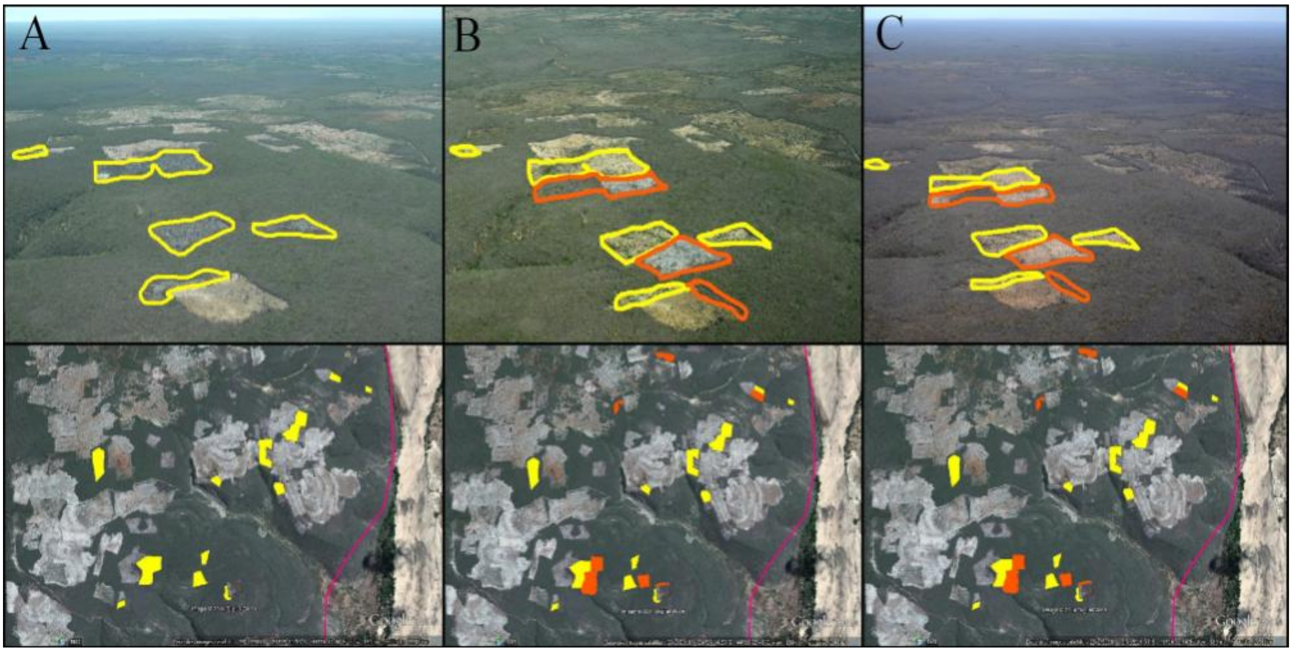

Figure 4 Time series of oblique aerial photographs (upper row) and satellite images from Google Earth (bottom row) of the southern extent of Tsimanampesotse National Park. Images are from (A) November 2010, (B) November 2011 and (C) November 2012. New clearings from 2010 are outlined in yellow and clearings from 2011 in orange: there were no new clearings in this area in 2012. (Lower row images produced on Google Earth, upper row by Xavier Vincke)

3.5 ha in 2012 (Fig. 4), a reduction of 82.5 per cent, while deforestation rates halved in Ranobe PK32 over the same period (the total area of new deforestation falling from 4,121.3 ha in 2010 to 2,020.5 ha in 2012). The observed declines in deforestation may be the result of the direct dissuasive effect of aerial surveillance and associated foot patrols on communities of shifting cultivators. However, it is difficult to attribute causality because many factors may contribute to the observed decreases, including other management interventions of the protected areas managers (such as alternative livelihoods programmes in surrounding areas) or wider socio-economic changes that may have reduced the attractiveness of shifting cultivation as a livelihood.

Further, rather than focusing only on the aggregate deforestation rates, it is also possible to calculate mean and median values for the size of individual cropland clearings through aerial image analysis using Google Earth Pro, and the number of new clearings established each season. This is important because it gives an indication of the number of farmers involved in shifting cultivation in different parts of protected areas, as well as an understanding of the methods used (e.g. large scale or small scale). For example, our results indicate that migrants, paid by local residents, generally practise large scale shifting agriculture in more remote areas, while local residents clear smaller plots in less remote areas. Such an understanding allows for a more targeted approach to conservation management with local resource users.

DISCUSSION

- **Role of oblique aerial photography in protected area management**

Since many of Madagascar's protected areas (both new, multiple-use sites and established strict protected areas) and their surrounding landscapes are home to large numbers of poor, rural people that depend to some extent on natural resources (including land) for their income, the managers of these sites face an enormous challenge – to conserve biodiversity without negatively impacting the capacity of local communities to meet their household needs. Thus management approaches have largely focused on reducing the impacts of existing resource use practices, and the development of more productive and sustainable forms of land use, such as improved agriculture and alternative livelihoods, designed to reduce the dependence of rural communities on forests and other ecosystems (Gardner et al., 2013). However, such poverty alleviation strategies ('distraction activities' (Milner-Gulland & Rowcliffe, 2007)) do not necessarily result in conservation gains, because beneficiaries may use their new income to invest in better tools and/or more labour with which to carry out even more shifting cultivation (Kull, 2000; Sievanen et al., 2005; St John et al., 2013). Thus livelihood/ distraction interventions implemented by protected area managers must be accompanied by robust resource management rules, and these rules must be effectively enforced. Oblique aerial photography provides a comparatively cheap, rapid and effective tool to facilitate rule enforcement (although it is not currently used for

Table 1: Cost in Euro of a single aerial surveillance campaign over i) Tsimanampesotse National Park and ii) a suite of four protected areas in southwest Madagascar. The cost for Tsimanampesotse National Park as part of a multiple protected area campaign was calculated as total cost multiplied by the proportional area of the site to total area surveyed.

Flight	Single protected area campaign					Multiple protected area campaign				
	FLIGHT COSTS									
	Area (ha)	Distance flown (km)	Price/hour (Euro)	Flight duration (hours)	Total cost	Area (ha)	Distance flown (km)	Price/ hour (Euro)	Flight duration (hours)	Total cost
Tsimanampesotse overflight	203,744	951	360	4.32	1,556	203,744	951	360	4.32	1,556
Toliara-Tsimanampesotse (x2)	-	284	360	1.29	465	-	284	360	1.29	465
Amoron'i Onilahy overflight	-	-	-	-	-	158,194	815	360	3.7	1,334
Toliara-Amoron'i Onilahy (x2)	-	-	-	-	-	-	140	360	0.64	229
Ranobe PK32 overflight	-	-	-	-	-	168,500	754	360	3.43	1,234
Toliara-Ranobe PK32 (x2)	-	-	-	-	-	-	127	360	0.58	208
Mikea overflight	-	-	-	-	-	184,639	991	360	4.5	1,622
Toliara-Mikea (x2)	-	-	-	-	-	-	416	360	1.89	681
Antananarivo-Toliara (x2)	-	1,500	360	6.82	2,455	-	1,500	360	6.82	2,455
Total	**203,744**	**2,735**		**12.43**	**4,476**	**715,077**	**5,978**		**27.17**	**9,784**
	FIXED COSTS									
	Unit cost (Euro)		No. Units	Total cost (Euro)		Unit cost (Euro)		No. Units		Total cost (Euro)
Per Diem and accommodation - Pilot		75	3		225		75		10	750
Landing tax and airport parking		21	1		21		21		5	105
Flight insurance		175	1		175		175		1	175
Total fixed costs (Euro)					**421**					**1,030**
Total flight + fixed costs (Euro)					**4,897**					**10,814**
Cost for Tsimanampesotse (Euro)					**4,897**					**3,081**
Cost/ha (Euro)					**0.024**					**0.015**

this purpose outside MNP-managed sites), and could also be used to evaluate the performance of management in competitive or contractual community-management initiatives such as management transfers or conservation contracts/direct conservation payments (Sommerville et al., 2010; Sommerville et al., 2011).

- **Strengths and weaknesses of aerial photography as a monitoring and management tool**

Aerial photography has been widely used in ecological research and conservation, for example to classify and map vegetation and habitat types over land and shallow seas (Zharikov et al., 2005; Cassata & Collins, 2008; Bradter et al., 2011), to track habitat or land cover change over long time periods (Asmamaw et al., 2011; Kull, 2012; Bailey & Inkpen, 2013), to estimate the density of focal species (Jansen et al., 2008; Buckland et al., 2012) and to detect advancing threats such as invasive species (Haby et al., 2010) and aquaculture (Bendell & Wan, 2011). Aerial surveys (which may or may not involve photography) are also widely used to monitor a range of animal species (Bouché et al., 2010; Parker et al., 2010; Kantar & Cumberland, 2013). However, we are not aware of any literature on the use of aerial photography to detect and monitor deforestation in and around protected areas, despite a number of practical advantages conveyed by the method. We suggest that oblique aerial photography has four main advantages compared with alternative remote sensing methods.

Cost

The cost of one annual surveillance flight of Tsimanampesotse National Park, excluding personnel time, is €4,897, or €0.024/ha (Table 1). However, since half of this cost is spent on flying the plane from the

Aerial photographs from WWF's programme have been used in a number of ways beyond surveillance and monitoring, including a travelling exhibition highlighting the impacts of shifting cultivation © Louise Jasper

capital Antananarivo to the centre of operations Toliara, important cost reductions can be made by carrying out the surveillance flight as part of a larger campaign over four protected areas; in this case the cost for Tsimanampesotse National Park declines to €3,081, or €0.015/ha, a reduction of 37.1 per cent. For this reason, WWF/ASF-B surveillance flights are always carried out over multiple protected areas in a single campaign.

For comparison, the cost of high-resolution satellite imagery lies in the range of €0.10/ha (EROS) to €0.22/ha (Kompsat) (although this is dependent on a range of specifications): the required imagery for Tsimanampesotse National Park would therefore cost €20,990-44,980, or 6.8 to 14.6 times the cost of aerial surveillance carried out as part of a multiple protected area campaign. However, we note that the costs of plane hire may be highly variable in different parts of the world, and that the costs of satellite imagery may decline in future.

Simplicity and ease of use

The oblique aerial photography method is simple and easy to use at every stage, facilitating its adoption and use by protected area management agencies in tropical developing countries worldwide. The rented plane does not need to be equipped with special photographic equipment, as is needed for vertical photography. The photography itself requires only a 30-minute training session since all camera settings are pre-set and unvarying, while the analysis of images requires only minimal training in the use of Google Earth and GIS software. In total a computer-literate person can become highly competent in image analysis following one day of training and one week of practice to develop the necessary skills. In contrast, the analysis of satellite imagery requires advanced technical knowhow that is beyond the capacity of most protected area management agencies in Madagascar and worldwide, and could therefore be expected to entail greater personnel costs.

Real-time data

Deforestation analyses based on satellite imagery cannot be performed until the requisite images are commercially available, which may be more than two months from the date of the image. This limits their utility to protected area managers, who may require real-time understanding of land use change within their sites for rapid intervention in the field. With oblique aerial photography, observers are able to pinpoint important sites of deforestation during the flight itself and, by selectively processing images from key sites first, can have the information necessary to support foot patrols available within 24 hours if required. However such rapid response is not usually required in the management of Madagascar's new protected areas, since farmers remain tied to their cleared lands for several months following surveillance flights, which take place at the start of the planting season.

Easy to interpret and versatile outputs

Oblique aerial images are intuitively easy to interpret compared to maps and satellite imagery, because they show objects (buildings, trees, landforms) from an angle which people can easily recognize. As a result, the images are not limited to deforestation analyses but can be used in a range of communications tools designed for different audiences. As well as providing a powerful tool for mutual learning and participatory decision-making between protected area managers and rural resource users, aerial photography generated by the surveillance programme has been used by WWF and its partners in i) lobbying regional decision-makers, ii) education of Malagasy children and the general public through travelling public exhibitions and use in the children's environmental magazine *Vintsy*, and iii) education and marketing aimed at foreign audiences, including funders, supporters and the general public, through varied media including calendars and posters, social media, and a forthcoming coffee table book. The images offer a powerful, striking and immediate illustration of the severity of Madagascar's environmental crisis and the urgency of taking action.

- **Constraints, caveats and further research**

In our experience, the use of oblique aerial photography for surveillance and monitoring of protected areas has several minor drawbacks. First, and like satellite imagery, the flights themselves require calm and cloud-free weather conditions: while this is generally the case in sub-arid southwest Madagascar where the surveillance programme has largely been carried out, adverse weather has proved problematic for the surveillance of mountainous sites in the country's humid regions. The problem has been largely overcome by altering flight routes to circumnavigate mountainous protected areas rather than (or in addition to) traversing them. Second, the analysis of imagery can be time consuming because many thousands of photographs are generated in a single surveillance flight and treatment time is proportional to the number of clearings observed. In general an experienced analyst can treat about 15 clearances in a day and can complete analysis of a protected area such as Tsimanampesotse National Park in six days: however, we are unable to generate comparable time estimates for the use of satellite imagery because such information is rarely published in research papers. Third, the treatment of images requires good spatial awareness, a characteristic that must be tested during recruitment for the post. Finally, the localization of clearings on Google Earth can be difficult if they occur in an area without recognizable landmarks, such as landforms or older clearings; however the vast majority of clearings occur at the forest frontier rather than within large blocks of homogeneous forest, and can thus be easily located in relation to older clearings.

Although oblique aerial photography is just a tool, the uses to which it is put may have major effects on both the effectiveness of protected area management and the wellbeing of shifting cultivator communities, topics which therefore warrant further investigation. Understanding how shifting cultivator communities respond to over-flights and associated patrols when these are used for i) law enforcement in strict protected areas and ii) discussions (but not law enforcement) in multiple-use protected areas, will require much further research, but would provide important contributions to debates on the social impacts of protected areas and the relative effectiveness of strict versus multiple-use protected area models. For example, it is important to know whether farmers no longer practising shifting cultivation within participating protected areas are displacing their agriculture elsewhere (Ewers & Rodrigues, 2008), intensifying their cultivation of existing farmland (Pollini, 2012), or abandoning the livelihood in favour of other activities (including opportunities arising from protected area-related projects). In addition, and in the context of recent discussions on the use of drones in conservation (Duffy, 2014; Humle et al., 2014), it would be interesting to compare the impact of aerial photography versus drones on the attitudes and behaviour of rural communities, since this will affect the outcomes and effectiveness of future management interventions.

CONCLUSIONS

WWF, ASF-B, SAPM and MNP have been carrying out oblique aerial photography over national parks and new protected areas in Madagascar's sub-arid spiny forests since 2010 and humid forests since 2011. The programme has provided protected area managers with a powerful new tool with which to tackle their greatest immediate challenge, deforestation from shifting cultivation. As well as providing quantitative data on deforestation rates, the programme has facilitated an

Oblique aerial photography allows protected area managers to orient foot patrols towards important areas of deforestation, and illuminates discussions with resource users © Louise Jasper

increased understanding by managers of shifting cultivation as a social process, and improved dialogue with cultivating communities and other stakeholders, thus contributing to more effective co-management. Our comparative data show that oblique aerial photography offers excellent value for money compared to the use of high definition satellite imagery, as well as conferring other benefits, and additionally can facilitate conservation communication of various forms. Oblique photography is relatively cheap, simple and easy to use, and we therefore believe it has great potential to contribute to protected area management efforts in tropical developing countries worldwide, when accompanied by appropriate actions on the ground.

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ABOUT THE AUTHORS

Charlie Gardner completed his PhD at the Durrell Institute of Conservation and Ecology (DICE), University of Kent in 2014, focused on reconciling conservation and development in Madagascar's rapidly-expanding protected area system. He was Scientific Adviser to WWF Madagascar from 2009 to 2013 and has published widely on Madagascar's biodiversity and its conservation. His book Life Amongst the Thorns: Biodiversity and Conservation of Madagascar's Spiny Forest (co-authored with Louise Jasper) will be published in 2015 by John Beaufoy Ltd.

Xavier Vincke works for Blue Ventures (BV) as the Sustainable Fisheries Project Manager in Toliara, Madagascar. He has more than 6 years' experience in biodiversity conservation in Africa and holds a degree in Biology. Before joining BV, he worked for the Oceanium de Dakar, a Senegalese NGO specialized in marine conservation, and for the Belgian NGO Aviation Sans Frontières – Belgique, developing an aerial surveillance methodology in partnership with WWF Madagascar and Madagascar National Parks. He was a Technical Assistant for the Aerial Surveillance Project of WWF Madagascar from November 2010 to October 2014.

Simon Rafanomezantsoa joined WWF Madagascar in 2003 and is currently the Terrestrial Programmes Coordinator. His areas of expertise include biodiversity conservation, community-based natural resources management, integrated water resources management and protected areas. He began his professional life with a US-based NGO The Peregrine Fund as a scientific researcher, then as a wetland project manager. He subsequently worked for 2 years in Switzerland, at the Secretariat of the Ramsar Convention on Wetlands as the Assistant to the Regional Coordinator for Africa, where he acquired international experience. He has the equivalent of MSc in Biology, Ecology and Environment from the University of Antananarivo.

Malika Virah-Sawmy started her career as a conservation biologist coordinating programmes for World Wide Fund for Nature (WWF) Madagascar and other local conservation organizations in the Indian Ocean. She has been working increasingly over the last ten years with local communities, businesses, NGOs, governments, and research organizations to find shared solutions for building socio-ecological sustainability in various sectors, with a focus on production practices relying on natural resources, and supporting market transformations that enhance environmental conservation and the livelihoods of smallholder farmers. She currently works for ENDEVA and supports business solutions to scale inclusive businesses in agriculture, climate change adaptation and mitigation, and ecosystem protection.

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RESUMEN

Las áreas protegidas son nuestra principal estrategia de conservación, pero precisan de vigilancia y monitoreo para una gestión eficaz. Muchas se ven amenazadas por la agricultura itinerante, una práctica que es difícil de detectar con precisión mediante imágenes de satélite y que suele llevarse a cabo de manera clandestina en zonas aisladas. Desde 2010, se ha estado utilizando la fotografía aérea oblicua para detectar, comprender y reaccionar con rapidez a la agricultura itinerante en los parques nacionales y en las nuevas áreas protegidas en Madagascar. Las áreas protegidas se sobrevuelan anualmente a 500 m de altura sobre el suelo a lo largo de transectos determinados de 3 o 6 kilómetros: la comparación entre imágenes revela los nuevos despejes que se localizan y miden con exactitud mediante Google Earth y el Sistema de Información Geográfica (SIG). Las imágenes aéreas son utilizadas por las patrullas a pie para localizar los despejes y hacer cumplir las normas (en los parques nacionales) o mejorar el diálogo entre los administradores de áreas protegidas y los agricultores itinerantes (en las nuevas áreas protegidas). Las imágenes oblicuas son de fácil entendimiento por lo que constituyen una herramienta eficaz para las discusiones con los usuarios de los recursos y otros interesados en procura de una gestión participativa. El método utilizado es significativamente más barato que el uso de imágenes de satélite y requiere una capacitación mínima, por lo que puede así prestar apoyo a las agencias de gestión de áreas protegidas en todo el mundo.

RÉSUMÉ

Les aires protégées sont au cœur de notre stratégie de conservation, mais leur gestion efficace nécessite surveillance et suivi. De nombreuses aires protégées sont menacées par les cultures itinérantes, une pratique difficile à détecter avec précision avec l'imagerie satellite et généralement effectuée clandestinement dans des régions isolées. Depuis 2010, les photographies aériennes obliques ont été utilisées à Madagascar pour détecter, comprendre et s'adapter rapidement aux changements de culture dans les parcs nationaux et les nouvelles aires protégées. Des survols annuels de ces zones ont lieu à une altitude de 500 m le long de pans-de-terre linéaires à intervalles de 3 km ou de 6 km. La comparaison d'images entre les années révèle de nouvelles clairières, qui sont situées avec précision et mesurées à l'aide des logiciels Google Earth et SIG. Les patrouilles à pied se servent de ces images aériennes afin de localiser les clairières sur le terrain pour faire respecter les règles (dans les parcs nationaux) ou pour améliorer le dialogue entre les gestionnaires d'aires protégées et les cultivateurs itinérants (dans les nouvelles aires protégées). Les images obliques sont faciles à comprendre de manière intuitive et constituent ainsi un outil puissant lors de discussions avec les utilisateurs des ressources et autres intervenants afin de faciliter la gestion participative. Cette méthode est nettement moins chère que les images satellitaires et ne nécessite qu'une formation minimale, elle peut donc être utilisée par les organismes de gestion des aires protégées dans le monde entier.