Passive acoustic monitoring as a law enforcement tool for Afrotropical rainforests

Hunting for wild meat is pervasive in Afrotropical forests and often the primary threat to large-bodied mammals even within protected areas (Harrison 2011), the effectiveness of which (at reducing hunting) is correlated with law enforcement efforts, especially anti-poaching patrols (Bruner *et al.* 2001; Struhsaker *et al.* 2005; Tranquilli *et al.* 2012). However, although tropical protected areas are critically underfunded (Blom 2004; Bruner *et al.* 2004) and law enforcement accounts for a substantial proportion of their budgets, few have mechanisms in place to evaluate and adaptively adjust anti-poaching strategies based on robust field evidence (Jachmann 2008). The increasing adoption of the Spatial Monitoring and Reporting Tool (SMART; http://smartconservationtools.org) for law enforcement monitoring is an important step toward improving protected area effectiveness. Such monitoring mechanisms depend on the quality of data inputs. For example, some law enforcement monitoring programs rely on evidence of hunting-related activity (hereafter "hunting sign"; eg spent ammunition cartridges) encountered during patrols to assess spatiotemporal hunting patterns and evaluate and design future actions. However, this method is prone to collection and interpretation biases because indirect hunting signs reflect only a fraction of actual hunting events; the relationship between hunting sign frequency and actual hunting intensity is unknown, and hunters can cover their tracks by, for instance, collecting spent cartridges, as observed in our study area. Furthermore, rangers are collecting the data (hunting sign) being used to evaluate their own effectiveness in reducing poaching. Where gun hunting is prevalent, we argue that law enforcement monitoring should be dissociated from anti-poaching activities and that assessing spatiotemporal changes in hunting patterns is best done by identifying where and when gunshots occur. We advocate the use of passive acoustic monitoring to revolutionize the resolution of law enforcement monitoring data and markedly improve the ability to design, evaluate, and adapt anti-poaching strategies based on changing hunting patterns.

We gathered baseline gun hunting data within Cameroon's Korup National Park (1259 km^2) by deploying 12 continuously recording autonomous recording units (ARUs; SM2+ Wildlife Acoustic Inc, Maynard, MA; Figure 1a) for two years (Jun 2013 to May 2015). Sound files (>189,000 hrs) were computer-scanned with a gunshot detection algorithm and putative gunshots verified visually and acoustically (Wrege *et al.* 2017). The ARUs detected 4023 gunshots across the study period within the 54-km^2 grid (based on a 1.2-km effective detection range of in-situ control gunshots) located at the core of the most patrolled sector of the park. Whereas acoustic monitoring showed a 12% increase in gun hunting between years, hunting sign encounter rates from monthly surveys of four 5-km line transects failed to detect the change (–4.1%) and hunting signs from ranger patrol data were too inconsistent to be analyzed. Moreover, acoustic data revealed that 68.6% of gun hunting took place at night when patrolling was minimal (Figure 1c). Gun hunting was more prevalent Tuesday through Thursday and intensified in the dry season (Nov–Feb), peaking during the weeks leading to Christmas Day and New Year's Day (Figure 1, b and d). On the basis of a 73.9% gunshot kill rate derived from concurrent surveys of 30 hunters who detailed the outcomes of 17,401 gunshots over one year, and assuming that the mean annual gun hunting pressure recorded in our study area is representative for that of the entire park (0.115 shots per day per square kilometer), we estimated that 39,053 animals are poached by guns alone across Korup National Park each year.

The benefits to protected area management from maintaining acoustic grids are clear. Passive acoustic monitoring provides unprecedented detail on spatiotemporal gun hunting patterns that deliver reliable and interpretable data, which can be used iteratively to evaluate and adapt anti-poaching patrol activities. Simultaneously, the data can provide insight on the occurrence and seasonal ranging of cryptic wildlife species (eg Kalan *et al.* 2016).

Passive acoustic monitoring is not without its challenges. The cost of transferring and storing the large audio files can be high and should be included in budgets. While deploying and maintaining ARUs requires only brief training, analyzing and interpreting acoustic data requires technical expertise. However, the benefits outweigh the challenges. The daily cost of monitoring gun hunting activity continuously and simultaneously across 54 km^2 was approximately US$15.80. In Korup, this was 23% less expensive than the per diems (excluding monthly salaries) of a four-member patrol, which could only monitor a fraction of the area discontinuously. More energy-efficient electronics on new ARUs reduce annual running costs (batteries) by 80%, further increasing the affordability of this approach as a law enforcement monitoring tool.

In summary, acoustic surveys can be a successful monitoring tool that promotes evidence-based adaptive management, making law enforcement more effective and cost-efficient while establishing protected area managers' accountability toward the supporting institutions (eg governments and donors) (Hockings *et al.* 2000). We foresee acoustic sensors becoming established conservation equipment similar to camera traps (Rowcliffe and Carbone 2008) and acoustic data becoming incorporated in leading law enforcement monitoring software (eg SMART). In fact, passive acoustic monitoring could be used to assess the impact on hunting of a broader range of activities such as educational programs, alternative

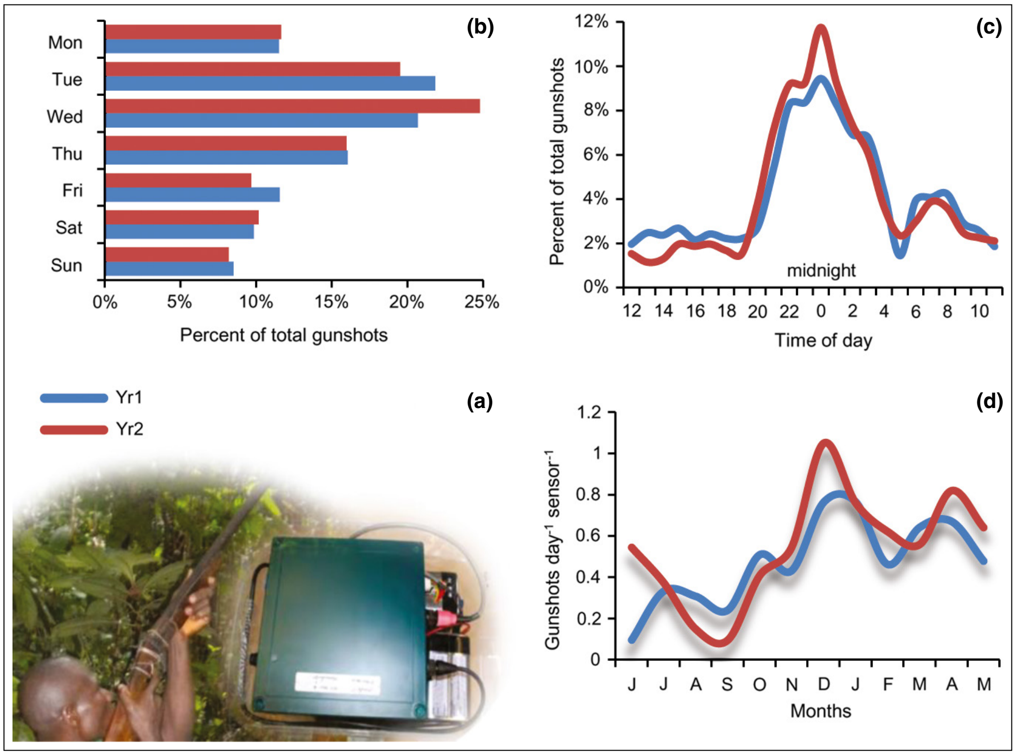

Figure 1. *(a) We deployed the autonomous recording units enclosed within a plastic container for additional protection from the elements and from wildlife, and powered them for ~3 months of continuous recording using six 6V alkaline lantern batteries. (b) Weekly distribution of gunshots detected during the study period (Saturday is the local market day). (c) 24-hour gun hunting activity pattern during the study period. (d) Seasonal variation in gun hunting intensity during the study period (mean of sensors' monthly mean number of recorded gunshots per day; rainy season: Jun–Sep, dry season: Dec–Feb).*

income earning initiatives, and – importantly – large development projects. For instance, we advocate the adoption of acoustic surveys by sustainability certifications (eg Forest Stewardship Council, Roundtable on Sustainable Palm Oil) to evaluate the impact of their members' activities on gun hunting pressure – both within their area of operation and in surrounding forests – and holding them accountable against transparent and robust pre-development baseline levels of hunting.

Christos Astaras[1]*, Joshua M Linder[2], Peter Wrege[3], Robinson Diotoh Orume[4], and David W Macdonald[1]

[1]*Wildlife Conservation Research Unit, Department of Zoology, University of Oxford, Oxford, UK* *(christos.astaras@fri.gr); [2]*Department of Sociology and Anthropology, James Madison University, Harrisonburg, VA;* [3]*Elephant Listening Project, Cornell Lab of Ornithology, Cornell University, Ithaca, NY;* [4]*Korup Rainforest Conservation Society, Mundemba, Southwest Region, Cameroon*

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