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Methodological challenges in monitoring bat population- and assemblage-level changes for anthropogenic impact assessment

Christoph F.J. Meyer*

Centro de Biologia Ambiental, Departamento de Biologia Animal, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal

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ABSTRACT

Recent years have seen increased attention to bats as an effective bioindicator group for assessing responses to drivers of global change, which concurrently has led to a revived interest in establishing a global bat monitoring network. To be effective and efficient, global-scale monitoring of bats will largely have to rely on integrating data collected as part of a network of regional monitoring schemes. Herein, I highlight and discuss some of the principal challenges faced in the monitoring of population- and assemblage-level changes of bats, focusing mainly on methodological and statistical issues and the selection of suitable state variables for quantifying regional trends in bat biodiversity. Particularly in the tropics, where detailed single-species monitoring is challenging due to high species richness, I recommend that monitoring programs focus on tracking changes in species turnover and composition as more informative measures of anthropogenic impact than species richness. Imperfect species detection is an important source of variation and uncertainty associated with animal count data. Bat monitoring programs need to correct for this, most importantly through the use of sampling protocols that rely on strictly standardized approaches and a well-balanced design, or *a posteriori* by using appropriate statistical models so as to avoid the detection of spurious trends. Multi-species occupancy models that allow for simultaneous assemblage- and species-level inference about occurrence and detection probabilities provide a suitable analysis framework for monitoring data, and are a comparatively low-cost approach that should prove useful especially in the regional monitoring of bats in the tropics. To ensure robust inference about temporal and spatial trend estimates in the state variables of interest, the efficacy of sampling designs should be carefully gauged at the design stage to ensure sufficient statistical power, and data should be collected according to a formal randomized design to allow for regional-scale inference. I stress the importance for long-term bat monitoring programs to have sustained funding, the need to establish trigger points for the application of appropriate mitigation measures, and for monitoring to be adaptive so as to maximize effectiveness and efficiency based on the data collected. Finally, I argue that to overcome the challenges associated with initiating monitoring networks in tropical countries – a major step towards the realization of global-scale bat monitoring – reliance on citizen scientists and participatory monitoring will be key.

Introduction

In the face of unprecedented global environmental changes, monitoring - the process of gathering information about one or several system state variables with the purpose of inferring changes in state over time or space (Yoccoz et al., 2001), is of universally recognized importance for biodiversity conservation (Jones et al., 2013a). In fact, it is nowadays one of the core endeavors of conservation biology (Marsh and Trenham, 2008).

Targets for biodiversity conservation are increasingly established globally and, especially after failure to meet the 2010 Convention on Biological Diversity (CBD) targets (Butchart et al., 2010), global-scale approaches to monitoring biodiversity change, as increasingly advocated by numerous authors (Jones et al., 2011; Pereira et al., 2010; Pereira and Cooper, 2006; Scholes et al., 2008, 2012), are urgently required. In order to be cost-effective, global-scale monitoring will largely have to rely on integrating data collected as part of a network of regional monitoring schemes (Jones, 2011) and a shift of focus for quantifying biodiversity trends, away from site-scale towards regional-scale approaches, is now apparent (Buckland et al., 2012) and needed as drivers of biodiversity loss tend to operate at larger scales (Jones, 2011).

* Tel.: +351 217 500000x22526; fax: +351 217 500028.
E-mail address: cmeyer@fc.ul.pt

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The planet is experiencing a widespread and pervasive defaunation crisis, highlighting the urgency of improved monitoring of populations, especially of functionally important taxa, including bats (Dirzo et al., 2014). In a recent review, Jones et al. (2009) championed the importance of bats as suitable indicators of biodiversity and global change as they are sensitive and demonstrably respond to a range of environmental stressors related to global climate change, anthropogenic habitat modification, and emerging infectious diseases – key drivers of worldwide bat population declines (Frick et al., 2010; Jones and Rebelo, 2013; Kingston, 2013; Meyer et al., forthcoming; Reeder and Moore, 2013). For instance, novel threats to bats such as the spread of White-Nose Syndrome that has led to swift and precipitous declines of several bat species in North America (Frick et al., 2010), call for well-designed and powerful monitoring schemes capable of rapidly discerning population declines. Given these threats, long-term monitoring of bats for anthropogenic impact assessment is becoming increasingly important. Jones et al. (2009) made a convincing case arguing for the implementation of a global bat monitoring network, a call that since has been reiterated (Willig, 2012). The growing interest in bats as an effective indicator group of global change processes (Flaquer and Puig-Montserrat, 2012; Van der Meij et al., 2015) is spurring efforts to widely adopt them along with other commonly monitored taxa such as birds and butterflies in regional monitoring programs (Haysom et al., 2013) whose results could subsequently feed into global assessments. Monitoring efforts for bats are currently biased towards higher latitudes (Meyer et al., 2010; Walters et al., 2013). Well-developed bat monitoring programs at national scales exist across Europe (Battersby, 2010), for instance the United Kingdom's National Bat Monitoring Program (NBMP; Walsh et al., 2003). However, implementation of a global bat monitoring network will require concerted efforts to rapidly scale up monitoring efforts to the global level (Walters et al., 2013). Recent initiatives such as the Indicator Bats Program (iBats), which aims to apply acoustic monitoring techniques to assess trends in bat populations from regional to global scales (Jones et al., 2013b), are undoubtedly an important step forward in this direction.

Poorly designed monitoring programs can result in poor decision-making and divert valuable resources from potentially effective interventions (Jones et al., 2013a) and there is now a substantial body of literature dedicated to the do's and don'ts of monitoring (Gitzen et al., 2012; Lindenmayer and Likens, 2010a; Lovett et al., 2007). In their seminal review of methodological and design issues associated with biodiversity monitoring programs, Yoccoz et al. (2001) stressed the need for any such program to be framed around a triad of fundamental questions, a call subsequently echoed repeatedly (e.g. Jones et al., 2013a): (1) why monitor, (2) what should be monitored and (3) how should monitoring be carried out?

Here, I highlight and discuss some of the major methodological and statistical challenges commonly faced in bat monitoring, i.e. focus on issues related to the "what" and "how" questions, issues which have been discussed on a general level elsewhere (Buckland et al., 2012, 2005; Jones, 2011; McComb et al., 2010). The importance of targeting monitoring programs to realistic, clearly-defined objectives, i.e. proper appraisal of the purpose of monitoring (the "why" question), essential for guiding program design can, however, not be overstressed (Ferraz et al., 2008; Jones et al., 2013a; Lindenmayer and Likens, 2010b; Nichols and Williams, 2006; Yoccoz et al., 2001). Those responsible for establishing bat monitoring initiatives certainly need to ensure that efforts are guided by carefully posed questions and objectives from the onset of a program. What and how to monitor will generally follow logically from clearly identified objectives and well-articulated questions (Lindenmayer et al., 2012; Yoccoz, 2012).

While the use of acoustic methods to globally monitor bats as, for instance, employed by the iBats Program, may constitute an efficient and cost-effective alternative to traditional bat survey methods, their wider application is not without challenges (Walters et al., 2013). All bat surveillance methods are inherently biased in one way or another (Hayes et al., 2009). Especially in the species-rich tropics, where echolocation call similarity is high and consequently species identification is difficult (Walters et al., 2013), and considerable fractions of the bat fauna are difficult to monitor using acoustic detection methods, bat monitoring programs should rely on a range of complementary methods (Meyer et al., 2014). The following discussion is therefore chiefly targeted at the monitoring of bats by direct methods of observation, i.e. through the use of traditional capture methods such as mist nets or harp traps (Kunz et al., 2009). Very similar issues do, however, apply to bat monitoring via acoustic methods (see Frick, 2013; Jones et al., 2013b; Walters et al., 2013) or based on colony counts, the latter being the prevailing method in existing temperate-zone bat monitoring programs (Haysom et al., 2013; Walsh et al., 2003). Throughout this paper, I mostly illustrate my main points with the findings and insights gained from an assessment of the suitability of tropical bats for long-term monitoring (Meyer et al., 2011, 2010, 2014). This is in part motivated by the fact that sampling and statistical challenges to monitoring are particularly acute for tropical bat populations and assemblages given their high species richness and large proportion of rare species they are comprised of. Moreover, tropical ecosystems and fauna are among the most imperiled worldwide and are undergoing unprecedented changes as a result of widespread deforestation, land-conversion, and defaunation (Bradshaw et al., 2009; Dirzo et al., 2014; Laurance et al., 2014). Tropical bats are sensitive to these threats and anthropogenic alterations of their environment (García-Morales et al., 2013; Meyer et al., forthcoming), underscoring the pressing need and urgency of monitoring their populations and assemblages in an effort to be able to mitigate human-induced environmental impacts.

Challenge 1: what to monitor? – Selecting (an) appropriate state variable(s)

Selection of (an) appropriate state variable(s) to monitor is one of the central decisions to be made from the outset of a monitoring program and should fundamentally be driven by the specific objectives of the program (Yoccoz et al., 2001). "Laundry-list" approaches to monitoring should be avoided, as they are highly cost-ineffective and too expensive to be sustained financially over the longer term (Lindenmayer and Likens, 2010b). In the context of global monitoring efforts, there is a lack of consensus about what to monitor; however, with the recent delineation of promising candidate Essential Biodiversity Variables (EBVs), capable of capturing major dimensions of biodiversity change, efforts are underway to remedy this (Pereira et al., 2013).

Monitoring of population change – abundance vs. occupancy

Population abundance is the natural choice for state variable, in fact, it is one of the most frequently used in wildlife studies (Marsh and Trenham, 2008; Pollock et al., 2002), and also an important candidate EBV (Pereira et al., 2013). Moreover, local abundance declines within populations are pervasive across a range of taxonomic groups (Dirzo et al., 2014), underscoring the necessity of rigorous population-level monitoring. *Abundance* is the most informative state variable in single-species population monitoring, and is for instance widely used in roost count-based bat monitoring schemes in the temperate zone (Battersby, 2010; Haysom et al., 2013). On the other hand, where monitoring relies on capture or