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# Bats in the Ghats: Agricultural intensification reduces functional diversity and increases trait filtering in a biodiversity hotspot in India

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ABSTRACT

The responses of bats to land-use change have been extensively studied in temperate zones and the neotropics, but little is known from the palaeotropics. Effective conservation in heavily-populated palaeotropical hotspots requires a better understanding of which bats can and cannot survive in human-modified landscapes. We used catching and acoustic transects to examine bat assemblages in the Western Ghats of India, and identify the species most sensitive to agricultural change. We quantified functional diversity and trait filtering of assemblages in forest fragments, tea and coffee plantations, and along rivers in tea plantations with and without forested corridors, compared to protected forests.

Functional diversity in forest fragments and shade-grown coffee was similar to that in protected forests, but was far lower in tea plantations. Trait filtering was also strongest in tea plantations. Forested river corridors in tea plantations mitigated much of the loss of functional diversity and the trait filtering seen on rivers in tea plantations without forested corridors. The bats most vulnerable to intensive agriculture were frugivorous, large, had short broad wings, or made constant frequency echolocation calls. The last three features are characteristic of forest animal-eating species that typically take large prey, often by gleaning.

Ongoing conservation work to restore forest fragments and retain native trees in coffee plantations should be highly beneficial for bats in this landscape. The maintenance of a mosaic landscape with sufficient patches of forest, shade-grown coffee and riparian corridors will help to maintain landscape wide functional diversity in an area dominated by tea plantations.

## 1. Introduction

The Western Ghats of India are, together with Sri Lanka, the eighth ‘hottest’ biodiversity hotspot in the world; but only 6% of the land remains under primary vegetation, and the human population density is higher than in any other hotspot (Cincotta et al., 2000; Sloan et al., 2014). To assess the impact of agricultural intensification on biodiversity we studied bats in a mosaic landscape typical of the Western Ghats, surrounded by protected, little disturbed forest. The landscape is dominated by intensive monoculture tea plantations under sparse shade from non-native trees, interspersed with forest fragments, forested riparian corridors, and coffee plantations which are mostly grown under a canopy of native trees (Mudappa and Raman, 2007). Since 2000 the Nature Conservation Foundation (NCF) has been working to extend and restore the forest fragments, and to encourage local coffee growers to maintain native shade trees rather than to shade their coffee with commercial timber trees (Mudappa and Raman, 2007). This is predicted to benefit a wide range of taxa. NCF has also been working to understand the relative diversity of different taxa in protected forests, forest fragments, and different types of plantations: from spiders, frogs and birds to small carnivores, primates and elephants (Kapoor, 2008; Kumar et al., 2010; Mudappa et al., 2007; Murali and Raman, 2012; Raman, 2006; Sidhu et al., 2010; Umapathy and Kumar, 2000). We have recently assessed the taxonomic diversity of bats in this landscape in the Western Ghats (Wordley et al., 2017, in prep.) and now aim to understand the changes in bat functional diversity in different habitats.

Bats are a species-rich and functionally diverse mammalian order playing important roles in insect control, pollination and seed dispersal (Altringham, 2011; Boyles et al., 2011; Kunz et al., 2011). In addition to being a major component of vertebrate diversity across much of the world, they have been recognised as a valuable bioindicator group (Jones et al., 2009). Despite this, bats are a poorly studied taxon in the palaeotropics whose conservation is generally not prioritized, and this is certainly true in India (Meyer et al., 2016). Little is known about the

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vulnerability of most palaeotropical bat species to disturbance and habitat modification. In conserving bats, as with other taxa, it is important to protect both taxonomic and functional diversity (Mouillot et al., 2011; Tilman, 2001; Villéger et al., 2008). Functional diversity is the variability in morphological and ecological traits among species, and is thought to be more important than taxonomic diversity for ecosystem resistance, resilience and functioning (Petchey and Gaston, 2006). Measuring taxonomic diversity alone may underestimate the loss of functional diversity in modified habitats (Mouillot et al., 2013). Species richness may, for example, be high in areas of intermediate disturbance, but this disturbance may act as a filter, allowing only a narrower range of trait values to persist (Edwards et al., 2014; Gray et al., 2014; Hanspach et al., 2012; Mouillot et al., 2013).

The increasing number of studies relating bat functional traits with habitat use in different regions globally provides opportunities to assess the strength of global and regional patterns in trait filtering. So far, studies relating bat species traits and environmental associations have been undertaken in Australia (Hanspach et al., 2012; Threlfall et al., 2011), the neotropics (Bader et al., 2015; Cisneros et al., 2015; Farneda et al., 2015; Jung et al., 2007) and the USA (Duchamp and Swihart, 2008; Ford et al., 2005), but there are very few such studies from the palaeotropics of Africa and Asia (Meyer et al., 2004). Relationships between morphological traits and extinction risk have been found both globally (Jones et al., 2003) and in temperate European and North American assemblages (Safi and Kerth, 2004). Examining functional diversity and trait filtering in the palaeotropics will facilitate the identification of the types of palaeotropical bats sensitive to forest loss, and in doing so provide a starting point for prioritizing research and conservation actions for the most potentially vulnerable species.

Traits such as body size, wing morphology, echolocation call frequency and diet are related to foraging behaviour and habitat preferences in bats. These have been used to assess the impact of land use change on functional diversity in a range of studies (e.g. Bader et al., 2015; Hanspach et al., 2012; Threlfall et al., 2011). For example, bats with long, narrow wings and high wing loading (low wing area in relation to body weight) are better adapted to hawking for small to medium-sized insects in open areas, while those with short broad wings and low wing loading are better adapted to short, slow flights in cluttered habitats, often plucking large insects from vegetation (Norberg and Rayner, 1987). Higher frequency, broadband echolocation calls (which give more information but attenuate more rapidly) are better adapted to cluttered habitats than lower frequency, narrowband calls, while low frequency calls travel further and can thus give information over a wide area in open habitats (Altringham, 2011; Denzinger and Schnitzler, 2013; Schnitzler and Kalko, 2001).

Many studies of functional diversity have measured functional group richness rather than functional diversity itself (Villéger et al., 2008). Assumptions must be made to fit species into groups and information is lost about the differences between species within each group (Villéger et al., 2008). Recently, multi-dimensional functional trait spaces have been used to calculate metrics such as functional richness, evenness, divergence and specialization that describe functional diversity (Villéger et al., 2011, 2010, 2008). These metrics correct many of the problems of older methods and have been used to study changes in communities due to human disturbance (Edwards et al., 2014; Mouillot et al., 2013). Here we use these metrics to assess functional changes in bat assemblages between habitats.

In this paper we quantify bat functional diversity in protected forests, forest fragments, coffee plantations under native shade and tea plantations. We also quantify bat functional diversity in riparian habitats; along rivers in protected forests, rivers with forested corridors and rivers with tea planted up to the banks. We assess the degree to which functionally important bat traits are filtered in these different habitats, with the aim of identifying the traits that affect bats' sensitivity to agricultural intensification.

We predict that functional diversity will decline and trait filtering increase as habitat disturbance (relative to undisturbed protected forest) increases. Based on bat studies from other regions (Bader et al., 2015, Hanspach et al., 2012, Denzinger and Schnitzler, 2013) loss of structural diversity and native plant species are expected to lead to both trait filtering and a decline in functional diversity. Greatest diversity is expected in riparian areas due to the additional presence of riparian specialist bats. The greatest bat functional diversity is therefore expected on rivers in protected area forests, and lowest diversity and greatest trait filtering in tea plantations.

## 2. Methods

### 2.1. Study site

The study was conducted on the Valparai plateau and in the adjacent Anamalai Tiger Reserve in the state of Tamil Nadu in the southern Western Ghats (N 10.2–10.4°, E 76.8–77.0°). The Valparai plateau is an agricultural landscape approximately 800–1600 masl, dominated by tea plantations and interspersed with shade-grown coffee plantations, eucalyptus plantations, forest fragments and riparian vegetation (Mudappa and Raman, 2007). The native vegetation is mid-elevation tropical wet evergreen forest of the *Cullenia exarillata*–*Mesua ferrea*–*Palaquium ellipticum* type (Pascal, 1988; Raman et al., 2009). For detailed maps of the study area see Wordley et al. (2015) and Mudappa et al. (2007). The average annual rainfall is 3500 mm, of which about 70% falls during the southwest monsoon (June–September) (Raman et al., 2009).

In protected area forest we used a single lane road, several unpaved vehicle tracks and rough walking tracks to walk between the acoustic sampling points, so each site had experienced some level of disturbance. Small scale firewood collection by local people occurred in at least two protected forest sites. Forest fragments and riparian corridors were remnant forest patches or secondary forest/overgrown plantations dominated by mature native trees. Many of these fragments have received supplementary planting to restore and extend them (Mudappa and Raman, 2007).

### 2.2. Data collection

We chose five sites for each of the seven study habitats, and between January and May 2010 to 2013, and in November–December 2014, we spent two non-consecutive nights capturing bats and recording echolocation calls of free flying bats at each site. January–May is the driest time between monsoons, so this is when most of the work was done. Some data were gathered in November–December 2014, which was also quite dry, due to problems in obtaining forest permits in earlier years. We caught bats and recorded them on the same night to reduce the effects of inter-night variation. At every site we caught bats using five ground level (6 m × 2.5 m) mist nets (Avinet TB Mist Net (Bat Net), 38 mm mesh in 75 denier, 2-ply polyester, 4 shelves) 50–200 m from the nearest acoustic sampling point, and recorded at five points 100 m apart for 15 min per point. We started recording 40 min after sunset, using a Pettersson D240X ultrasound detector (www.batsound.com) with a sampling rate of 307 kHz and a range of 10–120 kHz recording onto an Edirol R-09 (www.roland.com) digital recorder sampling at 44.1 kHz in WAV format. Nets were opened at sunset and closed after 2.5 h. Bats were identified to species using Bates and Harrison (1997) and Srinivasulu et al. (2010).

In riparian habitats the nets were set over the river in all locations, and the recordings were taken at the river banks, pointing at the river, so only species close to the river would be recorded. All rivers were at least 4 m wide at the point and time of sampling.

### 2.3. Sound analysis

Echolocation calls were visualised as spectrograms to measure call