Agriculture, Ecosystems and Environment 269 (2019) 88–96

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Bats as potential suppressors of multiple agricultural pests: A case study from Madagascar

James Kemp[a,*], Adrià López-Baucells[a,b,c], Ricardo Rocha[c,d], Owen S. Wangensteen[e], Zo Andriatafika[c,f], Abhilash Nair[c], Mar Cabeza[c]

[a] Center for Ecology, Evolution and Environmental Changes (cE3c), Faculdade de Ciências da Universidade de Lisboa, 1749-016, Lisboa, Portugal
[b] Granollers Museum of Natural Sciences, 08402, Granollers, Catalonia, Spain
[c] Global Change and Conservation Lab, Helsinki Institute of Sustainability Science, Faculty of Biological and Environmental Science, University of Helsinki, FI-00014, Helsinki, Finland
[d] Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge, CB2 3EJ, UK
[e] Norwegian College of Fishery Science, University of Tromsø The Arctic University of Norway, Norway
[f] Institute of Science and Technics of the Environment (ISTE), University of Fianarantsoa, BP 1264, Fianarantsoa, Madagascar

ARTICLE INFO

Keywords:
Chiroptera
Acoustics
Agriculture
Rice
Ecosystem services
Crop pests
Pest control
Metabarcoding

ABSTRACT

The conversion of natural habitats to agriculture is one of the main drivers of biotic change. Madagascar is no exception and land-use change, mostly driven by slash-and-burn agriculture, is impacting the island's exceptional biodiversity. Although most species are negatively affected by agricultural expansion, some, such as synanthropic bats, are capable of exploring newly available resources and benefit from man-made agricultural ecosystems. As bats are known predators of agricultural pests it seems possible that Malagasy bats may be preferentially foraging within agricultural areas and therefore provide important pest suppression services. To investigate the potential role of bats as pest suppressors, we conducted acoustic surveys of insectivorous bats in and around Ranomafana National Park, Madagascar, during November and December 2015. We surveyed five landcover types: irrigated rice, hillside rice, secondary vegetation, forest fragment and continuous forest. 9569 bat passes from a regional assemblage of 19 species were recorded. In parallel, we collected faeces from the six most common bat species to detect insect pest species in their diet using DNA metabarcoding. Total bat activity was higher over rice fields when compared to forest and bats belonging to the open space and edge space sonotypes were the most benefited by the conversion of forest to hillside and irrigated rice. Two economically important rice pests were detected in the faecal samples collected - the paddy swarming armyworm *Spodoptera mauritia* was detected in *Mops leucogaster* samples while the grass webworm *Herpetogramma licarsisalis* was detected from *Mormopterus jugularis* and *Miniopterus majori* samples. Other crops pests detected included the sugarcane cicada *Yanga guttulata*, the macadamia nut-borer *Thaumatotibia batrachopa* and the sober tabby *Ericeia inangulata* (a pest of citrus fruits). Samples from all bat species also contained reads from important insect disease vectors. In light of our results we argue that Malagasy insectivorous bats have the potential to suppress agricultural pests. It is important to retain and maximise Malagasy bat populations as they may contribute to higher agricultural yields and promote sustainable livelihoods.

1. Introduction

The pervasive conversion of forests for food production is a conspicuous symbol of the Anthropocene (Malhi, 2017). Large swaths of forest have already been cleared for agriculture and the encroachment of natural ecosystems is due to continue as human populations and food demand continue to rise (Giam, 2017). Madagascar holds a unique ensemble of ecosystems and wildlife that is almost unmatched in its biological uniqueness (Goodman and Benstead, 2005). However, despite its high level of endemism and species diversity, Madagascar's forests continue to face one of the highest rates of conversion in the world with approximately 1% of the island's forest cover being cleared each year (Rasolofoson et al., 2015; Eklund et al., 2016; Vieilledent et al., 2018). While most Malagasy biodiversity is adversely affected by agriculture-driven habitat modification, some 'winner' species benefit from habitat modification and increase their abundance in agricultural

* Corresponding author.
E-mail address: fc48961@alunos.fc.ul.pt (J. Kemp).

https://doi.org/10.1016/j.agee.2018.09.027
Received 19 June 2018; Received in revised form 28 August 2018; Accepted 4 September 2018

areas. Several of these are insectivorous birds (Martin et al., 2012; Rocha et al., 2015) and bats (López-Baucells et al., 2017b) that through the suppression of agricultural pests can provide valuable ecosystem services to local populations (Karp and Daily, 2014; Maas et al., 2016).

Rice (*Oryza* spp.) is one of the most important staple food crops worldwide (Muthayya et al., 2014). It is the main crop cultivated by Malagasy subsistence farmers (Kari and Korhonen-Kurki, 2013) throughout the island, and as in numerous other high-biodiversity regions across the tropics, much of the ongoing deforestation is due to agricultural expansion for rice production (McConnell et al., 2004; Neudert et al., 2017). Such a high dependency on rice creates problems when yields are affected by climatic events or pest outbreaks (Harvey et al., 2014). Insect rice pests are known to cause severe damage to rice crop yields (Oerke, 2006). Rice crop losses are predominantly caused by Lepidopteran stem borers found across several families such as the Noctuidae, Pyralidae, Tortricidae or Geometridae (Nwilene et al., 2013).

Modern day farming techniques incorporate Integrated Pest Management (IPM) to control pest populations (Stenberg, 2017). However, many small-holder farmers in sub-Saharan Africa are unable to access IPM techniques due to lack of financial capital or expertise (Parsa et al., 2014). A sustainable and low cost method to aid pest control and reduce crop losses is through biological control (Bommarco et al., 2013; Naranjo et al., 2015). Biological control, as part of a wider application of integrated pest management practices, can involve insectivorous bats, and has already been proven effective for pecan and rice farms in the USA and Catalonia (Brown et al., 2015; Puig-Montserrat et al., 2015). Multiple lines of evidence support that aerial hawking insectivorous bats provide valuable agricultural pest control services in both temperate and tropical regions (Boyles et al., 2011; Karp and Daily, 2014; Wanger et al., 2014; Brown et al., 2015; Russo et al., 2018). For instance, in the Mediterranean the soprano pipistrelle *Pipistrellus pygmaeus* was found to suppress rice borer moth *Chilo suppressalis* populations through opportunistic foraging (Puig-Montserrat et al., 2015). However, to date most research on tropical bat predation services has focussed on coffee and cacao agroecosystems (Maas et al., 2016), with limited research targeting rice (Wanger et al., 2014). One notable exception comes from Thailand where it was estimated that predation of white backed planthoppers *Sogathella furcifera* by wrinkle-lipped bats *Tadarida plicata* prevents rice crop losses valued at > 1.2 million USD (or > 26,000 rice meals) each year (Wanger et al., 2014).

Numerous bat species (particularly of the Molossidae and Vespertilionidae families) are known to coexist synanthropically by exploring newly available resources. These bat families have been shown to feed on pests (Brown et al., 2015) and to select crops as preferred foraging areas especially during insect pest outbreaks (Lehmkuhl Noer et al., 2012; Taylor et al., 2013a; Davidai et al., 2015). In fact, bats tend to select foraging areas based upon the resources available (Ancillotto et al., 2017), which makes them excellent pest suppressors during seasonal insect pest outbreaks.

Large colonies of molossid bats roost in buildings across Madagascar (Razafindrakoto et al., 2010; López-Baucells et al., 2017b). However, any potential predation services provided by these colonies are yet to be explored. Forty-two species of insectivorous bats occur in Madagascar, with several species occurring more frequently in anthropogenic landscapes as opposed to forest habitats (Randrianandrianina et al., 2006; Rakotoarivelo et al., 2007). In general, most studies have focused on the dry western region (Goodman et al., 2005; Kofoky et al., 2006; Bambini et al., 2010; Racey et al., 2010; Fernández-Llamazares et al., 2018) as opposed to the humid eastern zone (Randrianandrianina et al., 2006) and only a few studies have tackled habitat selection while none have addressed the potential pest suppressor role in agricultural areas.

The DNA metabarcoding of bat faecal pellets can offer valuable insights into the dietary preferences of bats and their potential role as pest suppressors (Bohmann et al., 2014; Swift et al., 2018). Recent diet analyses of multiple bat species have detected a wide range of arthropods in bat populations (Galan et al., 2018) including several economically important pest species (Taylor et al., 2017).

Here, we combine bioacoustics and DNA metabarcoding to investigate if Malagasy insectivorous bats are foraging within the island's agricultural matrix and if they are consuming important pest species. Specifically, we address the following questions:

i) How does total bat activity, species (or species-group) activity and assemblage composition change across a rice-dominated agroecosystem landscape? We hypothesise that due to higher insect availability some bats will be more active over rice fields compared to forested sites. We also predict a clear shift in assemblage composition from open to closed landcover types.
ii) Which species (or species-groups) are more common within the agricultural matrix? We predict that synanthropic molossids will be particularly abundant in rice fields but we still anticipate some forest associated species to forage outside the forest border.
iii) Are bats roosting within the agricultural matrix predating on agricultural insect pests? We expect bats to predate mainly on moths and beetles and we predict that several of these will be agricultural pests of rice and other crops.

2. Methods

2.1. Study area

Fieldwork was conducted primarily in the peripheral zone surrounding the Ranomafana National Park (RNP) (21°16′S, 47°20′E). The peripheral zone comprises over 160 villages with a population in excess of 50,000 in an area of approximately 500 km^2 (Kari and Korhonen-Kurki, 2013). Agricultural communities in the region, like many throughout Madagascar, cultivate rice through slash-and-burn agriculture (*tavy*) and irrigated paddies (Peters, 1998; Brooks et al., 2009). The RNP is located between the central highlands and the eastern lowlands and is of particular ecological and economic interest due to its high biodiversity and watershed protection role.

2.2. Bat surveys

Bats were surveyed from November to December 2015 in 54 sites in and around RNP (Fig. 1). Sites were clustered around seven villages (Kelilalina, Tsaratanana, Mangevo, Andriamamovoka, Amboasary, Mandriandry and Tolongoina) and were classified into five landcover categories: irrigated rice fields (n = 12), hillside rice fields (n = 8), secondary vegetation i.e. fallow agricultural land of mixed successional vegetation (n = 11), forest fragment (n = 9) and continuous forest in RNP (n = 15) (for landcover images and description see Supplementary materials Fig. A.1.). Bat activity was recorded using SongMeter SM2BAT + and SM3 autonomous bat detectors (Wildlife Acoustics, Concord, MA, USA). Detectors were secured to a tree at approximately 1.5 m with external SMX-II omni-directional microphones (Wildlife Acoustics, Concord, MA, USA). Detectors were set to record calls continuously from 18:00 until 06:00 for three consecutive nights at each locality. Bat activity was sampled for 1,956 h across a total of 147 detector-nights of sampling effort. Detectors were set with a 384 kHz sample rate, 12 kHz digital high pass filter, 18 dB trigger level, microphone bias off, and 36 dB gain. We used a 1.0 s trigger window minimum to capture calls prior to the initial trigger.

2.3. Bioacoustic analysis

Recordings were manually classified using Kaleidoscope software version 3.1.7 (Wildlife Acoustics, Concord, MA, USA). We defined a bat pass as a recording of five seconds maximum with at least two pulses with more than 20 dB of difference between the background noise and bat call (Appel et al., 2017) Call sequences were manually identified to