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Agroecological farming practices promote bats

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ABSTRACT

Intensive agriculture is a major driver of biodiversity loss, and a critical part of creating sustainable food systems is finding ways to balance production and conservation. While practices characteristic of agricultural intensification tend to erode biodiversity, agroecological farming practices can potentially support biodiversity and enhance pest suppression services. Bats are important predators of agricultural pests, yet little is known about how prescriptive management practices can be used to support bats and their associated pest-suppression services. We investigate how bats use natural habitat and conventional and organic farms in an agricultural landscape, ask which on-farm management practices may benefit bats, and examine how these management practices influence bats by mediating changes in habitat quality. We conducted acoustic surveys at 54 sites in the California Central Coast Region, a productive region with high ecological and economic value. We found higher bat activity in natural habitat compared to farms for total bat activity and clutter-adapted, but not open space bats, and slightly higher bat diversity in natural habitat compared to conventional farms. We found no effect of habitat type on species richness and a weak effect of habitat type on bat diversity, although bat community composition differed significantly between natural habitat and farms. Crop diversification increased the activity of all bat species and clutter-adapted, but not open space bats, regardless of the amount of semi-natural habitat surrounding farms. Both crop diversification and less frequent pesticide applications increased prey biomass, and the activity of clutter-adapted bats was positively correlated with greater Lepidoptera biomass. We suggest that improving habitat quality (increasing abundance of insect prey) through vegetative diversification and/or less frequent pesticide applications offers flexible management options to growers by considering both bat ecology and the constraints of regional agricultural management practices.

1. Introduction

Intensive agriculture is a major driver of biodiversity loss, and predicted intensification of agriculture suggests major shifts in land use patterns and biodiversity (Foley et al., 2005; Loos et al., 2014; Sala et al., 2000). Agricultural intensification is characterized by increased chemical and mechanical inputs, limited noncrop vegetation, and lower levels of planned biodiversity (Loos et al., 2014; Philpott, 2013). Although intensive agricultural production tends to erode biodiversity, ecological communities provide substantial benefits to humans, such as suppression of crop pests (Tscharntke et al., 2012). In many agroecosystems, insectivorous bats facilitate crop production by suppressing economically important insect pests (Maas et al., 2013; Maine and Boyles, 2015; Wanger et al., 2014; Williams-Guillén et al., 2015). The negative consequences of intensive agricultural systems on biodiversity and ecosystem services have spurred the development of agroecological farming schemes that promote ecological interactions, lead to the provisioning of ecosystem services, and support biodiversity (Gonthier et al., 2014; Hole et al., 2005; Ponisio et al., 2016).

Through the diversification of crops and habitats and the reduced use of pesticides, agroecological practices may improve habitat quality for insectivorous bats. These practices may increase bat dispersal across the landscape and provide more stable populations of insect prey, although bats in different functional guilds may have different responses to these practices. The addition of linear habitat - strips of perennial vegetation, such as treelines and hedgerows – can increase bat activity because many bat species utilize linear habitat as flyways for foraging and commuting (Frey-Ehrenbold et al., 2013; Verboom and Huitema, 1997). Linear habitats may reduce energy costs for commuting bats by providing shelter from wind and predators, increase foraging efficiency by concentrating insect prey, and serve as navigational aids (Verboom and Spoelstra, 1999). The positive effect of linear habitat is more pronounced for bat species with structure-bound ecologies (Frey-Ehrenbold et al., 2013; Verboom and Huitema, 1997). Open area bats

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are well-suited for crossing vast agricultural fields, whereas clutter-adapted bats are more strongly associated with forest and tend to stay closer to linear habitat (Schnitzler and Kalko, 2001). Lower levels of pesticide applications and increased plant diversity may also improve foraging habitat quality for bats by providing a more abundant insect prey base, although this mechanism has not yet been tested. Insect communities are more abundant in organic systems with lower pesticide use levels (Bengtsson et al., 2005; Hole et al., 2005; Wickramasinghe et al., 2004). Intercropping, crop diversification, and the maintenance of non-crop vegetation can all help to maintain insect populations by providing a variety of insect habitat niches, which is especially important in annual cropping systems with frequent disturbances (Letourneau and Goldstein, 2001; Letourneau et al., 2011; Nicholls and Altieri, 2013).

Many studies that investigate the impact of agricultural intensification on bats focus on categorical comparisons of management intensity (i.e. organic vs conventional). These studies show mixed responses (Williams-Guillén et al., 2015), perhaps because few studies consider both local farming practices and the effect of the surrounding landscape (e.g., Davy et al., 2007; Herrera et al., 2015; Lesinski et al., 2013; *but see* Froidevaux et al., 2017). Categorical comparisons are limited by the reality that farming practices likely vary within and may be shared among management intensity categories (*Appendix: Fig. S1*), making it difficult to pinpoint which practices drive observed patterns in biodiversity.

Because bats respond to factors at both local and landscape scales (Akasaka et al., 2010; Fuentes-Montemayor et al., 2013; Kelly et al., 2016), landscape context must be considered when evaluating the impact of local practices on bats. Farms with similar practices may be spatially aggregated (Gabriel et al., 2009; Teillard et al., 2012), making it difficult to disentangle the effects of local management practices from confounding landscape factors. A nested sampling design can be used to minimize variation in the surrounding landscape when evaluating the effect of local management intensity (Chamberlain et al., 2010; Letourneau and Goldstein, 2001). Accounting for specific on-farm practices and minimizing variation in the surrounding landscape between paired farms provides a more nuanced understanding of which on-farm management strategies or practices are likely to impact bat conservation outcomes.

Landscape-scale conservation efforts are important for bat conservation in agricultural landscapes (Frey-Ehrenbold et al., 2013; Froidevaux et al., 2017; Fuentes-Montemayor et al., 2013; Kelly et al., 2016), but may be challenging to coordinate among multiple private landowners (Mckenzie et al., 2013). In productive agricultural regions, such as California's Central Coast Region (CCR), the high cost of cropland encourages intensification, resulting in the conversion of perennial habitat to arable fields, the destruction of edge habitat, and simplified, homogenous landscapes (Tscharntke et al., 2005). With little remaining natural habitat, few incentives for growers to restore habitat, and the challenges associated with coordinated grower participation, a focus on local management practices as conservation solutions may be a more effective approach than landscape-scale conservation efforts, although the efficacy of local practices may depend on the landscape surrounding the farm (Concepción et al., 2012, 2008; Winqvist et al., 2012).

We investigate how bats use farms compared to surrounding natural habitat, assess which local practices may benefit bats, and ask if the influence of local practices on bats depends on the surrounding land use. Specifically, we ask: 1) How do bat activity, species richness, diversity, and community composition differ among natural habitat, organic farms, and conventional farms? 2) Which on-farm management practices (i.e., linear habitat, vegetative diversity, and pesticide use) underlie any observed differences in bat activity, species richness, and diversity? 3) Which on-farm management practices influence insect abundance, and are these the same practices that influence bat activity? 4) Does the influence of on-farm management practices on bats depend on the amount of semi-natural habitat in the surrounding landscape? For each question, we explore bat activity for all bat species and by functional guild.

We conducted acoustic surveys in the CCR and compared bat responses across site types (natural habitat, organic farms, and conventional farms) and in response to local practices by comparing paired organic and conventional farms that vary in their adoption of agroecological farming practices. We hypothesized that focusing on specific practices would better explain bat activity, diversity, and richness than categorical comparisons between organic and conventional farms.

2. Methods

2.1. Study area and sampling design

We conducted research in the CCR, an economically and ecologically valuable area. Farms in the CCR produce 13% of vegetables in the USA (USDA Census of Agriculture, 2009; USDA National Agricultural Statistics Service, 2012). To understand how bats respond to agricultural intensification at the farm scale, we worked on farms and nearby natural areas in Santa Cruz, Santa Clara, San Benito, and Monterey Counties, CA within a 60 km (N-S) by 70 km (E-W) region (Fig. 1a). We selected woodland patches (including riparian corridors) as natural habitat sites because remnant woodlands are important bat habitat in agricultural landscapes (Kniowski and Gehrt, 2014). Study sites in the CCR were selected to be representative of the range of farms and remnant woodland patches present in the study area using a combination of aerial imagery and based on the interest of private landowners and growers in participating in this research.

We used a nested design and selected three clustered sites (natural vegetation, organic farm, conventional farm) within a 1.5 km radius circle and repeated this design across the region (N = 18 clusters, N = 54 sites) (Fig. 1*a,b*). The sites exist along a landscape gradient of semi-natural habitat density (mean = 42%, range = 2–80%) and agricultural land use density (mean = 50%, range = 14–98%) within a 1.5 km radius. Organic farms sites were all certified organic (www.ccof.com) and used less intensive practices (organically-approved fertilizers such as compost and animal-based pellet fertilizers, multiple crop types, inclusion of habitat for beneficial organisms) than paired nearby conventional farms that used more intensive practices (use of synthetic fertilizers, pesticides, and herbicides; fewer crop types). Many farms grew a single crop variety, most commonly Brussel's sprouts, strawberry, broccoli, or lettuce. Farms with multiple crop varieties (mean = 2.7, range = 1–10, excluding one outlier farm described below) included a mix of vegetables (cucumber, cole crops, peppers, celery, peas, carrots, beets, lettuce), beans, squash, tomatoes, herbs, and strawberries. Within each farm pair, we chose monitoring sites in the center of fields planted in annual crops (vegetables or strawberries) with similar proximity to natural habitat. We used one detector for each site and placed detectors within fields (organic and conventional farms) and at the edge of woodland patches (natural sites) (Fig. 1c).

2.2. Bat acoustic monitoring and call identification

We sampled bats at all sites with passive acoustic bat detectors (Wildlife Acoustics SM2BAT with SMX-US Ultrasonic Microphone, Concord, MA, USA) from mid-June to early September 2014. Bat detectors were mounted on t-posts and microphones were elevated on 3 m PVC poles attached to the t-posts. We monitored bat activity levels and species richness at all sites. We did not compare feeding buzzes due to high subjectivity in distinguishing between a bat inspecting research equipment, a novel structure in their environment, and pursuing insect prey (Weller et al., 1998). We sampled each site for 6–7 nights during one sampling period from sunset to sunrise to account for high variability of bat activity across nights; the three sites clustered within each landscape (natural site, organic farm, conventional farm) were sampled