Diversity and foraging activity of bats in cultivated and uncultivated areas in agroecosystems of a Mediterranean-climate hotspot

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ABSTRACT

Bats are one of the least-studied vertebrate groups in Chile. We sampled six fruit farms in the Mediterranean-climate zone and three in a semiarid zone during 2015 and 2016, respectively. We assessed if activity (passes) and foraging (feeding buzzes) of bat species differed between cultivated and uncultivated intra-farm habitats. We found six bat species, all threatened and insectivorous. Tadarida brasiliensis was the most frequently recorded species. We found more activity and foraging in uncultivated than cultivated habitats in total, although the opposite trend was observed during springtime in semiarid region. More than a third of the bat passes were feeding buzzes in both habitats, suggesting the potential service to agriculture. Further investigation is needed to promote conservation of bats and their integration as biocontrols in agroecosystems in Chile.

The conservation status of bats has received increasing attention because of their key role in biodiversity in general and agroecosystems in particular [1]. Bats assist with agricultural production mainly through pest control and pollination [2], but they are declining in temperate and tropical ecosystems, due heavily to agricultural intensification [3].

Most bats species in Chile are insectivorous [4]. However, knowledge regarding their potential role in pest control is scarce in the country. The main area of fruit production (mainly table-grapes, stone and pome fruits) in Chile is in the Mediterranean-climate area of the country (c.a. 30 to 38°S; [5]), which is also an area of biodiversity richness, endemism and conservation threats [6]. Despite these ecological contexts, growers know little of either the biodiversity that inhabits their farms or of its conservation status [7].

The aim of this work was to assess if bat activity (passes and foraging activity) differed between cultivated and uncultivated habitats within the farms, in order to improve the knowledge of the taxa in Chile and to identify potential ecological patterns of importance for agricultural activity. We also explored nightly activity patterns of the more abundant species detected.

We studied nine fruit farms: six in the Mediterranean-climate area (O’Higgins administrative region) during September 2015, and three farms in the semiarid-climate zone (Coquimbo administrative region) during May and September 2016 (Figure 1). The main crops grown on these farms were citrus and table grapes, and all were under industrialized management (under applications of synthetic fertilizers, pesticides and technified irrigation). The flight of certain moth-pests of these fruit crops begin in September (spring), while the monitoring in May (autumn, against-season) allows to evaluate possible changes and migration patterns. In the semiarid-climate farms, semi-dense shrubland were the main vegetation types in the uncultivated areas, and in the Mediterranean-climate, besides shrublands, there are some sclerophyllous forest. Cultivated areas within farms varied between 25.5 and 223 ha (median = 46.5 ha), and the total area of farms ranged from 30.7 to 710 ha (median = 50.2 ha).

To identify each bat species and its activity, two Song Meter SM3Bat ultrasound recorders (Wildlife Acoustics Inc. Massachusetts, USA) were installed in each farm for one night: one inside the fruit-plots (at least 175 m from the border; cultivated area), and the second one in an area without agricultural management, but within the limits of the farms, preferably in areas with trees and other vegetation (native and naturalized species; uncultivated areas). There were 24 night-samplings in 12 dates of monitoring (six of Mediterranean-climate area during 2015 plus three in autumn and three in springtime of semiarid area of 2016), in cultivated as well as uncultivated intra-farm habitats. The monitoring time was adjusted to the night length, according to date and latitude (Table 1). Most of the fieldwork occurred during full moon period.

The recorded audio files were analyzed manually to obtain frequency values, using Avisoft SAS Lab Pro (Avisoft Bioacoustics, Berlin, Germany). Each species was classified using the features of echolocation calls, according to the values of frequency at the end of the call and frequency at the highest energy and duration

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of the calls; those values are the most representative parameters to differentiate bats in central Chile [8,9]. The hourly activity of different species was plotted for a 10-min period throughout the night, to observe how the activity of bat species fluctuate throughout the night (Figure 2). The foraging activity of each species was estimated by counting the number of feeding buzzes measured in the field, as it has been used for this purpose in agroecosystems [10].

From the acoustic data, the activity was estimated using detections (bat passes or feeding buzzes between them) per species in one-minute blocks.

Table 1. Dates and effort of bat samplings in farms in each field campaign.

| Farm number | Date of sampling | Sampling effort per night (minutes) |
|-------------|------------------|-------------------------------------|
| 4           | 22/9/2015        | 700                                 |
| 5           | 23/9/2015        | 700                                 |
| 6           | 24/9/2015        | 700                                 |
| 7           | 25/9/2015        | 700                                 |
| 8           | 26/9/2015        | 700                                 |
| 9           | 27/9/2015        | 700                                 |
| 1           | 2/5/2016; 5/9/2016 | 1395                              |
| 2           | 3/5/2016; 6/9/2016 | 1395                              |
| 3           | 4/5/2016; 7/9/2016 | 1395                              |

Figure 1. Location of fruit farms in the study area (Datum WGS84).
The rates of activity and total feeding buzzes per night were compared between cultivated and uncultivated habitats using a Poisson GLMM selecting habitat and species as fixed effects, and farm as random effect. The dependent variables were total passes and feeding buzzes per night, and logarithm of time (night length in minutes) was used as "offset" to model the rates [11]. The Fischer LSD test was used to make the comparisons. Analyzes were done with Infostat version 2018 [12].

From the seven bat species that potentially inhabited the study area, based on known distributions, six were recorded; all insectivorous, with conservation concerns, according to national and international classifications [13,14]. Five species of the family Vespertilionidae: *Histiotus montanus* (Philippi & Landbeck), *Lasiurus cinereus* (Palisot de Beauvois), *L. varius* Poeppig, *Myotis atacamensis* (Lataste), and *M. chiloensis* (Waterhouse) were found as well as *Tadarida brasiliensis* (I. Geoffroy Saint-Hilaire) from the family Molossidae. *M. atacamensis* was
found only on farms in the semiarid zone, which is consistent with its described distribution [15]. The two Lasiurus species recorded in the semiarid zone were found only in the autumn sampling (Table 2). We recorded L. cinereus in May (austral autumn) in the semiarid zone, but in September (austral spring) they were only found at higher latitudes within the Mediterranean-climate region. Their migration patterns may replicate what is seen in North America, where L. cinereus migrates to higher latitudes during springtime [16].

A total of 2383 bat passes were recorded and identified during all field campaigns: 475 in cultivated habitats and 1908 in uncultivated habitats. The generalist species T. brasiliensis was the most registered (48.3% of the total records), and it was encountered in all samplings. This could be explained by this species being a gregarious generalist, known to form large colonies, and with a large range extending from the north of the United Sates to the south of South America [17].

Out of all records (2383), 39.6% corresponded to feeding buzzes and similar proportions were observed in both intra-farm habitats (34.7% were feeding buzzes in cultivated and 40.8% in uncultivated habitats). The generalist species T. brasiliensis was the most registered (48.3% of the total records), and it was encountered in all samplings. This could be explained by this species being a gregarious generalist, known to form large colonies, and with a large range extending from the north of the United Sates to the south of South America [17].

All these findings are relevant, considering that bats are one of the least-studied vertebrate groups in Chile [15], and their role in agricultural landscapes is practically unknown. From a conservation perspective, focus should be more at landscape scales than at individual farms, given the high mobility of bats and how their activity is influenced by landscape features in agroecosystems [27]. From a functional perspective in agriculture, future research should involve the potential role of bats as pest regulators. A lack of ecological information for many bat species is probably the main factor that limits practical research in order to integrate insectivorous bats into agricultural practice as biological control agents [2]. If bats do significantly contribute to pest control and that information is known, farmers would have more incentives to promote their conservation in

Table 2. Activity (passes) and foraging (feeding buzzes) for each bat species in each climate zone, split between cultivated and uncultivated habitats (data standardized for 10 hours of monitoring [28]).

| Species         | Location/ sampling nights | Sampling month | Activity Index C | Feeding buzz C | Activity Index UC | Feeding buzz UC |
|-----------------|---------------------------|----------------|------------------|---------------|------------------|---------------|
| H. montanus     | Mediterranean area        |                | 0.14             | 3.14          | 0                | 0.86          |
| L. cinereus     |                           | Sep-2015       | 5.86             | 78.00         | 4.14             | 47.00         |
| L. varius       |                           |                | 1.57             | 10.43         | 0.14             | 1.14          |
| M. chiloensis   |                           |                | 0                | 27.14         | 0                | 12.71         |
| T. brasiliensis |                           |                | 29.29            | 116.29        | 12.86            | 46.57         |
| H. montanus     | Semiarid                  |                | 2.90             | 12.46         | 0                | 0             |
| L. cinereus     | Area                      |                | 0.29             | 1.16          | 0                | 0             |
| L. varius       | May-2016                  |                | 0.58             | 0.58          | 0                | 0             |
| M. atacamensis  |                           |                | 2.90             | 24.35         | 1.74             |               |
| T. brasiliensis |                           |                | 1.45             | 4.06          | 0                | 0.87          |
| H. montanus     | Semiarid                  |                | 10.96            | 8.30          | 1.19             | 0             |
| M. atacamensis  | Area                      | Sep-2016       | 21.93            | 15.70         | 9.48             | 2.07          |
| T. brasiliensis |                           |                | 23.11            | 10.37         | 2.67             | 1.19          |

C: cultivated habitat; UC: uncultivated habitat.
agroecosystems, which could then rely more on ecosystem services and less on external inputs.

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