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Foraging activity by bats in a fragmented landscape dominated by exotic pine plantations in central Chile

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We assessed foraging activity of insectivorous bats in a fragmented landscape of central Chile including native temperate forest, forest fragments, commercial pine plantations and local human settlements. Overall bat activity was noticeably greater along adult pine plantation edges, local human settlements and the edge of continuous forest than over interior habitats and unplanted forest plantation clear-cuts. Tadarida brasiliensis foraged mostly above human settlements and edges of adult pine plantations but avoided interior habitats. Lasiurus cinereus was more active along edges of both adult pine plantations and continuous forest than in clear-cuts and interior habitats of forest fragments. In contrast, Lasiurus varius, Histiotus montanus and Myotis chiloensis occurred not only along vegetation edges but also within the interior habitats of adult pine plantations. The high activity levels suggest that bats not only pass through exotic pine plantations, but that they are active in these habitats commuting and feeding, thus enhancing their capacity to persist in landscapes modified by humans in which exotic forestry plantations are an important component.

Key words: acoustic survey, insectivorous bats, forest fragmentation, pine-dominated landscape, Chile

INTRODUCTION

Habitat conversion and fragmentation are threats to biodiversity (Sala et al., 2000). A significant challenge facing conservation biologists is to know what organisms naturally occurring can survive in human-dominated landscapes and how to conserve them in these environments (Chazdon et al., 2009).

Due to their capability to navigate over extensive areas of fragmented landscapes, bats might exploit human-modified landscapes in ways that differ from that of terrestrial mammals (Law et al., 1999; Estrada and Coates-Estrada, 2002; Avila-Flores and Fenton, 2005). The conversion of natural forests to Pinus radiata monocultures is likely to reduce the diversity and abundance of insectivorous bats (Fukuda et al., 2009; Phommexay et al., 2011). However, more complex agroforestry systems (e.g., coffee-shaded plantations) might support high species richness of frugivorous and nectarivorous bats due to their resemblance to the original forested landscape (Estrada et al., 1993; Numa et al., 2005). Pinus radiata plantations need to be examined to assess which of these two models they most resemble.

The landscape of central Chile is currently dominated by monocultures of Monterrey pine plantations and agricultural fields, with sparse remnants of the native Maulino Forest, particularly along the coastal range (Echeverría et al., 2006). Despite being structurally simpler compared to the native forests, pine plantations might provide habitat for a suite of native taxa including insects, lizards, birds, small mammals, carnivores and also provide connectivity at the landscape level (Estades et al., 2012).

In this paper we assess the role of exotic pine plantations as foraging habitat for insectivorous bats by evaluating species richness and activity in native forest, pine plantations and human settlements. If bats also exploit plantations, it will reinforce the claim that such production-oriented landscapes might be simultaneously managed for biodiversity conservation, as required by the principles of the Convention on Biological Diversity (Estades et al., 2012).

MATERIALS AND METHODS

Study Area

The survey was conducted at Tregualemu area, in the Maulino Coastal Range of central Chile (35°59'S, 72°41'W to
35°59’S, 72°46’W). The study area included a 600 ha patch of coastal Maulino Forest (including the Los Queules National Reserve), Monterey pine plantations, scattered forest fragments, small villages and surrounding agricultural lands.

Field Work and Analysis

Bat activity was monitored in nine different habitats: (1) interior and (2) edge of continuous forest; (3) interior and (4) edge of forest fragments; (5) interior and (6) edge of mature pine plantations; (7) young pine plantations; (8) unplanted plantation clear-cuts; (9) human settlements. Sampling sites at edges were established 20 m from the border toward the interior of all habitats while interior sampling locations were placed at least 100 m from any edges or roads.

Bats were surveyed using an ultrasound bat-detector model D240X (Pettersson Elektronik AB, Uppsala, Sweden) coupled to a digital recorder (M-Audio MicroTrack II) and operated both in heterodyne and time-expanded modes. Time-expanded mode allows to record full-spectrum echolocation calls with a high-resolution sonogram of each bat vocalization. These full-spectrum echolocation calls were used to classify bat activity to species. Heterodyne recordings do not preserve duration, absolute frequencies, or the frequency–time course of the original signal, therefore, cannot be used to identify bat passes at species levels. As a consequence, heterodyne recordings were not included in the analyses at species level but were pooled with those recorded in time-expanded mode for total activity analysis, allowing full use of the recording information (Morris et al., 2010).

Within each habitat we set up five to ten sampling points, all of which were at least 150 m apart. Each sampling point was visited five or six times during two years between January 2010 and January 2012. To limit seasonal variation in activity, we restricted surveys to the summer season. We sampled different habitats on different nights. Surveys began at dusk and lasted three hours to coincide with peak foraging periods of aerial insectivorous bats (Kuenzi and Morrison, 2003). Bat activity was quantified by counting the number of bat passes per 10 minutes at each point within each habitat and then we randomly move to the next sampling point. A bat pass was defined as a sequence of more than two echolocation calls (Law et al., 1999). An index of activity was assessed as the number of bat passes per hour at any given habitat by each species. Further, an index of feeding activity was quantified by counting the number of feeding buzzes recorded. We digitized calls to computer and analyzed them using the Batsound 2.1 sound analysis software (Pettersson Elektronik AB, Uppsala, Sweden).

Indices of feeding and bat activity levels at different habitats were compared using a Kruskall-Wallis test (data could not be transformed to fit a normal distribution) followed by a post hoc test. All tests were performed with STATISTICA 8.0 (StatSoft, 2007).

Bat Species Identification

Passes of free-flying bats were classifying to species using Quadratic Discriminant Function Analysis (DFA). Classification functions were computed using a library of validated reference calls which consisted of 264 full-spectrum recordings from hand-released bats (Histiotus montanus, Lasiurus varius, Myotis chiloensis and Tadarida brasiliensis) at the location of study (Rodriguez-San Pedro and Simonetti, 2013). Variables used in this analysis were call duration, final frequency, slope frequency modulation, peak frequency, minimal and maximal frequency. DFA gave an overall correct classification rate of 90.0% for all reference calls. If there was uncertainty or inconsistency in the classification, that recording was considered unidentifiable and labeled as ‘unknown’.

RESULTS

A total of 100 hours were accumulated monitoring bat activity with a total of 937 echolocation sequences and 84 feeding buzzes. Of the total bat passes, we analyzed 750 time-expanded sound files that contained 490 identifiable echolocation sequences corresponding to five of the six species expected to occur in the study area: Histiotus montanus (66 passes), Lasiurus varius (127 passes), Myotis chiloensis (53 passes) and Tadarida brasiliensis (106 passes). Of the remaining 138 passes, 52 were classified as Lasiurus varius by comparing call parameters with references calls reported for this species in other regions (Barclay et al., 1999; O’Farrell et al., 2000) and 86 were classified as ‘unknown’. Histiotus macrotus was the sixth species expected, but it was not detected.

Human settlements and habitat edges supported the highest species richness, with five species, while the interior of forest fragments, unplanted plantation clear-cuts and the interior of continuous forest exhibited the lowest, with one and two species, respectively. Overall bat activity differed significantly between habitat types ($H_{8, 77} = 65.11, P < 0.01$ — Table 1). The highest activity rates were recorded along edges of adult pine plantations followed by local human settlements and the edge of continuous forest. The lowest bat activity levels were recorded at the interior of forest fragments and unplanted forest plantation clear-cuts. Feeding activity differ significantly between sites being slightly higher at the edges of adult pine plantations ($H_{8, 77} = 21.04, P < 0.01$ — Table 1).

At the species level, bat activity differed between sites. Activity of T. brasiliensis varied significantly between habitat types ($H_{8, 77} = 54.95, P < 0.01$ — Table 2), foraging mostly in human settlements. Interior habitats were avoided as no records of T. brasiliensis were recorded there. Activity of L. varius was significantly higher in the edge of adult forest plantations, the edge of continuous forest and local human settlements ($H_{8, 77} = 35.77, P < 0.01$ — Table 2) but no passes were recorded in unplanted forest plantation clear-cuts and interior habitats of forest fragments. Lasiurus varius occurred in local human settlements and along the edges of continuous forest, as well as in the interior
habitats of pine plantations ($H_{8, 77} = 49.55, P < 0.01$). *Histiotus montanus* was most active along adult pine plantation edges ($H_{8, 77} = 33.87, P < 0.01$ — Table 2) but also foraged in the interior of adult pine plantations and in local human settlements. It was never recorded in the interior of forest fragments or unplanted forest plantation clear-cuts. Activity of *M. chiloensis* was significantly higher along the edge of continuous forest ($H_{8, 77} = 33.70, P < 0.01$ — Table 2) but this species also preferred the interior adult pine plantations and the edges of adult pine plantations for foraging.

**DISCUSSION**

Our study reports finding five of six species of bats (*H. macrotus, H. montanus, L. cinereus, L. varius, M. chiloensis* and *T. brasiliensis*) that were expected to occur in the study area based on published distributional maps (Galaz and Yáñez, 2006). Because there are no previous studies of bats prior to fragmentation of the Maulino forest, or information on bats assemblages within forested landscapes in Chile, it is difficult to determine how different the bat assemblages of the fragmented Maulino forest is from the original assemblage. The echolocation repertoire of *H. macrotus*, the single species not recorded, is unknown from anywhere in its distribution, and therefore this species may have been included in those passes we labeled as ‘unknown’.

Fragmentation of the Maulino forest and the incorporation of commercial pine plantations are increasing the amount of edge, habitat that supports the highest bat species richness and activity levels. The combination of low physical clutter and the high insect prey availability typically found along edges (Pasek, 1988; Swystun et al., 2001), might account for the importance of this habitat for foraging bats. Bats avoid structurally cluttered habitats and focus their foraging in less complex habitats presumably for the ease of navigation (Grindal and Brigham, 1999; Patriquin and Barclay, 2003). The species in our study area are aerial-hawking hunters with varying levels of tolerance for structural complexity (Sleep and Brigham, 2003; Tibbels and Kurtz, 2003; Jung et al., 2012) and vegetation edges may provide foraging opportunities because they are relatively open. This pattern concurs with the behavior of insectivorous bats elsewhere that also rely on edges as foraging habitats (Grindal and Brigham, 1999; Morris et al., 2010).

Although monoculture plantations might reduce species richness (Ramírez and Simonetti, 2011), species richness and activity levels of bats were higher in exotic forest plantations than native forest, differing from studies of insectivorous bats in Borneo and Thailand (Fukuda et al., 2009; Phommexay et al., 2011). The low bat activity recorded in interior habitats of both the continuous forest and forest fragments is probably related to the high background clutter at these sites compared to pine plantations (Estades and Escobar, 2005), which probably interfere with flight maneuverability and reduces access to prey items (Brigham et al., 1997; Rainho et al., 2010). A factor that could explain the high bat activity recorded within adult pine plantation forests is the presence of internal service roads. Unlike continuous forest, commercial pine plantations are usually traversed by flyways (tracks, including roads and trails), which allow bats to access and use sites that are otherwise too cluttered (Adams et al., 2009; Webala et al., 2011). Energy requirements for

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**Table 1. Median (± quartile) values of total activity (measured as total number of passes per hour) and feeding index (feeding buzzes per total number of bat passes) in nine habitats.**

<table>
<thead>
<tr>
<th>Habitat categories</th>
<th>Total activity</th>
<th>Index of feeding</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median 1st–3rd quartile</td>
<td>Median 1st–3rd quartile</td>
</tr>
<tr>
<td>EPL</td>
<td>30.00 19.00–35.00</td>
<td>0.08 0.00–0.24</td>
</tr>
<tr>
<td>IPL</td>
<td>5.25 4.00–6.50</td>
<td>0.00 0.00–0.00</td>
</tr>
<tr>
<td>EFR</td>
<td>5.50 3.00–8.00</td>
<td>0.00 0.00–0.00</td>
</tr>
<tr>
<td>IFR</td>
<td>0.00 0.00–0.00</td>
<td>0.00 0.00–0.00</td>
</tr>
<tr>
<td>ECF</td>
<td>18.90 15.60–24.00</td>
<td>0.00 0.00–0.06</td>
</tr>
<tr>
<td>ICF</td>
<td>0.90 0.00–1.80</td>
<td>0.00 0.00–0.00</td>
</tr>
<tr>
<td>YPL</td>
<td>8.50 3.00–11.00</td>
<td>0.00 0.00–0.00</td>
</tr>
<tr>
<td>HS</td>
<td>20.50 11.00–33.00</td>
<td>0.00 0.00–0.23</td>
</tr>
<tr>
<td>UPLC</td>
<td>0.00 0.00–1.00</td>
<td>0.00 0.00–0.00</td>
</tr>
</tbody>
</table>
foraging flights and navigation are assumed to be greater in habitats with dense vegetation, which could account for the avoidance of high-cluttered habitats (Brigham et al., 1997; Sleep and Brigham, 2003). Bat activity recorded at the interior habitats of adult pine plantations was basically concentrated on the location of tracks, suggesting that these tracks provide suitable commuting and/or foraging habitats for bats within plantations regardless of the degree of structural clutter. This result corroborates other studies where forest tracks supported higher overall activity than off-track sites (Law and Chidel, 2002; Adams et al., 2009; Webala et al., 2011; Monadjem et al., 2010) and emphasizes the importance of linear elements to bats.

Insectivorous bat species use differently the fragmented landscape. *Myotis chiloensis* and *H. montanus* foraged mostly along edges of continuous forest and within pine plantations possibly as they are small and maneuverable in flight (Norberg and Rayner, 1987). Their short, round wings and frequency modulated echolocation enhances their feeding in back-ground cluttered space (Schnitzler et al., 2003). The high bat activity observed in local human settlements by *L. varius*, *T. brasiliensis* and *L. cinereus*, could be accounted for their ability to fly in open spaces and their reliance on insects that accumulate around streetlights (Avila-Flores and Fenton, 2005; Rydell, 1992; Jung and Kalko, 2010). The villages we surveyed were mostly illuminated, and generally scattered with small gardens and crop fields. Further, *T. brasiliensis* uses human-made buildings as roosting sites (Gaisler et al., 1998; Galaz and Yáñez, 2006).

*Histiotus montanus*, *L. cinereus*, *L. varius*, *M. chiloensis* and *T. brasiliensis* are regarded as Least Concern (IUCN, 2012). The high activity levels suggest that bats not only pass through exotic pine plantations, but that they are active in these habitats commuting and feeding, thus enhancing their capacity to persist in landscapes modified by human in which exotic forestry plantations are an important component. Exotic pine plantations provide habitats for bats which might enhance their conservation in human modified landscapes.

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**Table 2.** Median (± quartile) values of activity for each species in nine different habitats. Bat activity is expressed as the number of bat passes per hour per site. EPL — Edge of adult forest plantations; IPL — Interior of adult pines; EFR — Edges of forest fragments; IFR — Interior of forest fragments; ECF — Edges of continuous forest; ICF — Interior of continuous forest; YPL — Young pine plantations; HS — Human settlements; UPLC — Unplanted forest plantation clear-cuts. Different letters indicate significant differences among habitats in a posteriori test.
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LITERATURE CITED


