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Original Investigation

Pest control service provided by bats in Mediterranean rice paddies: linking agroecosystems structure to ecological functions

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ABSTRACT

Pest control through integrated pest management systems stands as a very convenient sustainable hazard-free alternative to pesticides, which are a growing global concern if overused. The ability of the soprano pipistrelle bat (*Pipistrellus pygmaeus*) to control the rice borer moth (*Chilo supressalis*), which constitutes a major pest of rice around the world, was studied in the Ebre Delta, Northeastern Iberia. Evidence was found on the ability of this particular bat species to control borer infestations: (a) the moth was consumed during at least the last two peaks of the moth activity, when most crop damage is done; (b) the activity of bats significantly increased with moth abundance in the rice paddies; (c) the pest levels have declined in the study area (Buda Island, Eastern Ebre Delta) after the deployment of bat boxes and their subsequent occupation by soprano pipistrelles. The value of the ecosystem service provided by bats was estimated at a minimum of 21€ per hectare, equivalent to the avoided pesticide expenditure alone. We suggest that this natural service can be enhanced by providing bat populations with artificial roosts in rice paddies were some key ecosystem features are present.

Introduction

"Any genuine improvement in the human condition on this planet must be concerned with rice" (Heinrichs and Miller, 1991). In recent decades, both rice scientists and farmers have gained experience in the cultivation of rice and there has been a shift from a primarily unilateral approach to insect pest control, relying strongly on insecticides, to a multilateral approach involving a combination of control tactics (Heinrichs and Miller, 1991). Scientists throughout the world strive to develop and implement strategies to control rice pests more effectively and economically, to improve crop productivity and consequently the welfare of human populations. According to Food and Agriculture Organization of the United Nations (FAO) statistics, the global production of rice increased linearly from 216 million tonnes (mt) in 1961 to 722 mt in 2011 (FAO). New strategies to control insect pests include the use of one insecticide per one specific target species combined with biological methods (such as the use of parasitoids). However, the adoption of non-chemical approaches to pest control is not evenly distributed around the world and occurs mainly in those regions where legal constraints limit the number of approved chemical products (c. a. European Union). Over-use of pesticides is still an issue to be addressed (Normile, 2013; Peng et al., 2009), particularly in those regions in which the vast majority of the world's rice production is concentrated, and the use of pesticides keeps growing (FAO).

Fifty percent of the insecticides used in rice fields in Asia target lepidopteran insects (Heong et al., 1994). In 1991 it was estimated that an average global annual yield loss of 10 million tonnes was caused by just three moths: the striped rice borer (*Chilo suppressalis*), the yellow stem borer (*Scirpophaga incertulas*) and the leaf folder (*Cnaphalocrocis medinalis*) (Herdt, 1991). The striped rice borer is an Asian moth currently present in paddies worldwide. The adults lay their eggs on the stems and leaves of rice plants, and the larvae bore the stems to feed on the internal tissues, compromising both plant growth and productivity, sometimes fatally.

In Europe most bats are insectivorous. Bats may eat up to 80–100% of their body mass in insects on a nightly basis (Kurta et al., 1989), and during the last decade several authors have drawn

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Fig. 1. A soprano pipistrelle (*Pipistrellus pygmaeus*) hunting a striped rice borer (*Chilo supressalis*), in the Ebre Delta. Photographic stroboscopic effect (series of short or instantaneous samples).
Courtesy of Oriol Massana

attention to the important contribution that bats make to insect pest control (Agosta and Morton, 2003; Boyles et al., 2011; Cleveland et al., 2006; Ghanem and Voigt, 2012; Kunz et al., 2011; Lee and McCracken, 2005; Leelapaibul et al., 2005; McCracken et al., 2012; Whitaker, 1995; Park, 2015). The referred contribution has been assessed by the presence of pests in the diet of wild bat populations or by taking a step further and accounting for the economic value of such an ecosystem service. Given the natural complexity of ecological systems it is difficult to place a monetary value on the services provided by bats, a fact that restricts how their importance is understood by the public (Fisher and Turner, 2008). Cleveland et al. (2006) estimated the economic contribution of bats to the cotton dominated agroecosystems of southern Texas, USA, to be $12–$173 per acre each year. By extrapolating these figures to the whole country, Boyles et al. (2011) valued bats' economic contribution to the USA's agroecosystems at between $3.7 and $53 billion/year. Even if the actual figures were lower, given the evidence gathered so far, the positive impact of bats on this aspect of the economy seems to be beyond dispute. This benefit can exceed the monetary value if the affected crop is a staple. For example, the pest control service provided by wrinkle-lipped bats' (*Tadarida plicata*) is responsible for securing the meals of 26,152 (±15,817 SD) people each year in Thailand alone (Wanger et al., 2014). All the aforementioned authors have stressed the consequent importance of protecting bat populations if the ecological service they provide is to be preserved.

Although there is no general agreement on how to define ecosystem services (Wallace, 2008), such services are generally regarded as ecosystem outcomes (e.g. use of less pesticides) that contribute to human well-being (Fisher and Turner, 2008; Fisher et al., 2009; Nelson et al., 2009; Wallace, 2007). Understanding the mechanisms that link ecological systems to human well-being is a fundamental task when studying ecosystem services (Haines-Young and Potschin, 2009). From a functional perspective, the human benefit (whether monetary or not) is the final outcome of a cascade process resulting in a service (Rollett et al., 2008).

The soprano pipistrelle (*Pipistrellus pygmaeus*, Fig. 1) was separated taxonomically from the common pipistrelle bat (*Pipistrellus pipistrellus*) on 1997 (Barratt et al., 1997). Previous studies on diet contain mixed data on diet and distribution (e.g. Vaughan, 1997). Soprano pipistrelle is a common European bat species occurring from the British Isles through much of continental Europe (including the islands of Corsica and Sardinia) East to Western Asia Minor, the Caucasus and Siberia (Dietz et al., 2009). It is more abundant in lowland areas and is frequently associated with freshwater bodies (rivers, lakes, wetlands, etc.), being common in coastal wetlands, where most paddies in southern Europe occur. The few unambiguous studies on diet indicate that they feed mainly on small diptera, though they include a wide array of small-sized aerial insects in their diet and is regarded as an opportunistic species (Bartonicka et al., 2008b). Following our success in improving soprano pipistrelle populations in Northeastern Iberia in a mixed landscape with both wetlands and paddies (Flaquer et al., 2006), we investigated the ability of the species to control striped rice borer populations. Having determined the potential of bats to control rice borer, we aimed to better understand under which environmental conditions soprano pipistrelles' populations could be enhanced to further promote their pest control ability. Since the experiment was conducted in a reduced area, we describe the conditions under which bat populations had been encouraged in the rice producing landscape of study, and emphasise the economic benefits they could provide. Although there is a long tradition of rice-fish culture aimed both at controlling pests and enhance food production (Xie et al., 2011), to our knowledge no other wild local vertebrate populations have been artificially manipulated for such a purpose and no previous research exists on enhancing bat populations as a pest biological control method in rice paddies.

Material and methods

Study area

We carried out the study within the Ebre Delta Natural Park (0°50′ E, 40°42′ N, Fig. 2), Catalonia, NE Iberia, which is one of the biggest deltas in Europe (320 km^2). Approximately 65 km^2 are wetlands, 240 km^2 are crops (203 km^2 of which are paddies) and 16 km^2 are urban areas that host around 5000 inhabitants. Mean annual temperatures range between 17 and 18 °C, mean annual precipitation between 500 and 550 mm, and mean annual evapotranspiration between 855 and 997 mm, in what is essentially a semi-arid Mediterranean climate, with a pronounced summer-drought.

Prior to this study, in 1999, 69 small wooden bat boxes, either with single or double compartment (Flaquer et al., 2006), were erected in Buda Island Natural Reserve (12.1 km^2, Fig. 2), a deforested area lacking suitable vertical structures for the bats to roost