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Bats and insect pest control: a review

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Abstract. Bats and insect pest control, an ecosystem service: a review. Bat conservation is important not only for biodiversity but also because these flying mammals provide ecological services essential for humans. In particular, bats are very useful for the control of insect populations and specifically pests to agriculture. Their diet very often includes Lepidoptera, a large order with several species very harmful to many plants of great economic interest. The diet of some European species of bats (e.g. *Rhinolophus* spp., *Hypsugo savi*, *Nyctalus leisleri*, *N. noctula*, *Barbastella barbastellus*, *Plecotus* spp., *Myotis brandtii*, *M. bechsteinii*, *Eptesicus serotinus*) includes high percentages of moths (Lepidoptera) and many of them are pests of economic importance. In the United States and Thailand some studies have economically quantified bats' value as pest control expecially against moths; in Europe these studies are still scarce and need to be promoted giving even more support to the protection of this outstanding order of mammals.

Agriculture, ecosystem services, Lepidoptera, moths, rice pests, *Chilo suppressalis*, olive fruit fly, *Bactrocera oleae*

Introduction

Only recently the protection of ecosystems and their conservation has been considered under economic implications trying to understand how natural processes are important for the life and survival of human beings. Those benefits, measurable in economic terms, were called "nature's services" (Daily 1997, Daily et al. 2000); later and still today are referred to as "ecosystem services" (Millennium Ecosystem Assessment 2005) and defined as benefits to humankind derived from resources and processes supplied by natural ecosystems.

The fundamental role of bats in maintaining ecosystems and their specific utility in the quality of life were certainly underestimated until a few years ago. Bats are, with more than 1,300 species, the second largest order of mammals (after rodents) and have colonized many different environments in all continents except Antarctica (Simmons 2005, Altringham 2011, Fenton & Simmons 2014). Over the past ten years, particular attention was paid to the economic value of bats in agriculture and forestry, also the subject of several systematic reviews (Boyles et al. 2011, Kunz et al., 2011, Ghanem & Voigt 2012, Boyles et al. 2013, Kasso & Balakrishnan 2013, Riccucci & Lanza 2014) that highlight the still poor knowledge of the ecosystem services of insectivorous bats in Europe. According to Boyles et al. (2011) in the United States the value of insectivorous bats connected to the agricultural sector is about 22.9 billion USD a year (ranged from 3.7 to 53 billion USD per year). These estimates include the decreased costs of pesticide applications reducing the development of pesticide resistance. Therefore there is an increasing interest of the American farmers towards bats and how to attract them in their own land, even installing artificial roosts such as bat boxes (California Agriculture 1998, Kiser & Kiser 2002).

Most of the bat species (about 70%) are insectivorous, as the early Eocene bats (Habersetzer et al. 1992, Simmons et al. 2008). In particular, some species from the fossil site of Messel (Germany) used to prey on Lepidoptera (Richter 1993). Insect pests are a major problem in agriculture and forestry (Hill 1983, 1987, 2008, Pollini 2013). Arthropods destroy between 18% and 26% of the annual production of crops worldwide, for a value of over 470 billion USD (Culliney 2014). All European species of Chiroptera are insectivorous (Dietz et al. 2009).

One of the most important ecosystem services of insectivorous bats is the control of herbivorous arthropods including pest insects (Kunz et al. 2011, Ghanem & Voigt 2012). Among insects, moths (order Lepidoptera) are major agricultural pests in many parts of the world (Zhang 1994, Hill 2008) and even in Europe, representing 91% of all lepidopterans (the other 9% are butterflies). Many of them are of great economic importance as pests of crops, horticultural plants or stored products and woollens. Most moths are active at night or dusk, like bats.

Studies on the diets of European bats are here briefly reviewed, mainly focusing on Lepidoptera and on species of moths considered as agricultural pests (Hill 1983, 1987, 2008, Robinson et al. 2010, Pollini 2013). The aim is to highlight the economic benefits of bats in insect pest control and the urgent need to implement conservation actions as many species of bats are endangered in several European countries (Temple & Terry 2007, Rondinini et al. 2013).

Moth-eating bats

Most of the studies on bats as biological pesticides refer to North America (Whitaker 1995, Cleveland et al. 2006, Federico et al. 2008, Boyles et al. 2011, Boyles et al. 2013). Foraging strategies and diet of many species of European bats are relatively well-known (Beck 1995, Vaughan 1997, Dietz et al. 2009, Lanza 2012).

The bat community in North America, as investigated by faecal analysis, consists of species that eat mainly Lepidoptera (Ross 1967, Whitaker & Hamilton 1998). According to Ross (1967) moths and beetles in North America, both representing very large groups, so numerous and diverse in types and sizes that they are almost universally available as food for insectivorous bats. Most African insectivorous bats also feed mainly on Lepidoptera and Coleoptera (Aldridge & Rautenbach 1987).

A high number of insect species in the diets of bats have recently been identified using molecular techniques on insect fragments in their faeces (Clare et al. 2009). Barnard (2011) provides a useful appendix with extensive lists of prey species.

Significant cases of pest control

It is of considerable interest the study carried out in Malta on the diet of *Plecotus gaisleri*. Borg & Sammut (2002) mentioned this species as *P. austriacus*, but see Spitzenberger et al. (2006). The examination of prey involved a bat present in a small room at the Museum of Natural History in Mdina (Malta), where bat ate its preys. Bats use to eat the soft parts of their prey, the wings and the hard ones are usually discarded. The discarded parts were collected and insect species identified included several pest moths: *Galleria mellonella* – pest of apiculture; *Autographa gamma* – the larvae feed on a wide variety of plants including pea (*Pisum sativum*), sugar beet (*Beta vulgaris*), cabbage (*Brassica oleracea*); *Chrysodeixis chalcites* – prefers tomato, potato and pulses, but also buds and fruits; *Heliothis peltigera* – prefers Solanaceae, Asteraceae and Fabaceae; *Spodoptera exigua* – is a small black cutworm but voracious on different crops, such as sugar beet, corn,

Table 1. List of some Lepidoptera (moths) of agricultural interest found in the diet of European insectivorous bats

bat species	% of Lepidoptera lepidopteran species	family	reference/s
Rhinolophus ferrumequinum	78% *Hepialus humuli* *Agrotis exclamationis* *Mesapamea secalis* *Noctua comes* *Noctua pronuba* *Scoliopteryx libatrix*	 Hepialidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae	Jones 1990, Beck 1995, Vaughan 1997, Barnard 2011
Rhinolophus hipposideros	19–89% undetermined		Vaughan 1997, Beck 1995, Lino et al. 2014
Rhinolophus euryale	69% undetermined		Goiti et al. 2004, Goiti et al. 2008
Rhinolophus mehelyi	>90% undetermined		Salsamendi et al. 2008
Myotis bechsteinii	53–97% undetermined	 Noctuidae	Vaughan 1997, Barnard 2011
Myotis brandtii	91% undetermined		Vaughan 1997, Barnard 2011
Myotis nattereri	30% undetermined		Beck 1995, Vaughan 1997, Barnard 2011
Barbastella barbastellus	73–99% undetermined		Jones 1990, Beck 1995, Vaughan 1997
Eptesicus nillssonii	56% undetermined		Beck 1995, Vaughan 1997
Eptesicus serotinus	34% undetermined	 Geometridae Noctuidae Pyralidae Sphingidae Tortricidae Yponomeutidae Zygaenidae	Beck 1995, Barnard 2011
	Odonestis pruni *Agrochola macilenta* *Agrotis ipsilon* *Amphipoea oculea* *Anarta myrtilli* *Autographa gamma* *Brachionycha nubeculosa* *Catocala electa* *Catocala fulminea* *Cucullia umbratica* *Euplexia lucipara* *Euxoa tritici* *Lacanobia thalassina* *Luperina nickerlii* *Melanchra persicariae* *Pachetra sagittigera* *Tholera cespitis* *Trachea atriplicis*	Lasiocampidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae	Mikula & Čmoková 2012: “more than 80% of the consumed moths were important agricultural pests”

Table 1. (continued)

bat species	% of Lepidoptera lepidopteran species	family	reference/s
Eptesicus serotinus (continued)	*Xestia castanea* *Xestia c-nigrum* *Mamestra brassicae* *Noctua comes* *Noctua fimbriata* *Noctua pronuba* *Stauropus fagi* *Aglais urticae* *Vanessa cardui* *Pieris napi* *Coenonimpha arcania* *Cydia pomonella*	Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae Notodontidae Nymphalidae Nymphalidae Pieridae Satyridae Tortricidae	Mikula & Čmoková 2012 (continued)
Vespertilio murinus	49% undetermined		Beck 1995, Barnard 2011
Hypsugo savii	53% undetermined		Beck 1995
Nyctalus leisleri	67% undetermined		Beck 1995, Vaughan 1997, Barnard 2011
Nyctalus noctula	19–36% undetermined	Noctuidae Pyralidae	Beck 1995, Vaughan 1997, Barnard 2011
	Melanchra persicariae *Mythimna pallens* *Hepialus humuli* *Triodia sylvina* *Ourapteryx sambucaria* *Odontopera bidentata* *Ematurga atomaria* *Bupalus piniaria* *Biston betularia*	Noctuidae Noctuidae Hepialidae Hepialidae Geometridae Geometridae Geometridae Geometridae Geometridae	Poulton 1929
Pipistrellus kuhlii	38% undetermined		Beck 1995
Pipistrellus nathusii	undetermined		Beck 1995
Pipistrellus pipistrellus	33% undetermined	Geometridae Noctuidae Pyralidae	Beck 1995, Barnard 2011
Pipistrellus pygmaeus	undetermined *Chilo suppressalis*	 Pyralidae	Barnard 2011, Flaquer 2011
Plecotus auritus	33% undetermined	Arctiidae Geometridae Hepialidae Notodontidae Nymphalidae Pyralidae Sphingidae Thyatiridae	Beck 1985, Vaughan 1997, Barnard 2011
	Abrostola triplasia *Agrotis exclamationis* *Amphipyra tragopoginis* *Anitype chi* *Apamea crenata*	Noctuidae Noctuidae Noctuidae Noctuidae Noctuidae	Robinson 1990

bat species	% of Lepidoptera lepidopteran species	family	reference/s
Plecotus auritus (continued)	*Apamea monoglypha*	Noctuidae	Robinson 1990 (continued)
	Apamea sordens	Noctuidae	
	Autographa gamma	Noctuidae	
	Autographa jota	Noctuidae	
	Autographa pulchrina	Noctuidae	
	Caradrina morpheus	Noctuidae	
	Cucullia umbratica	Noctuidae	
	Diachrysia chrysitis	Noctuidae	
	Lacanobia oleracea	Noctuidae	
	Lacanobia thalassina	Noctuidae	
	Mamestra brassicae	Noctuidae	
	Mesapamea secalis	Noctuidae	
	Mesoligia literosa	Noctuidae	
	Mythimna impura	Noctuidae	
	Naenia typica	Noctuidae	
	Noctua comes	Noctuidae	
	Noctua fimbriata	Noctuidae	
	Noctua janthina	Noctuidae	
	Noctua pronuba	Noctuidae	
	Oligia strigilis	Noctuidae	
	Phlogophora meticulosa	Noctuidae	
	Rhyacia simulans	Noctuidae	
	Rusina ferruginea	Noctuidae	
	Scoliopteryx libatrix	Noctuidae	
	Xestia xanthographa	Noctuidae	
	Deilephila elpenor	Sphingidae	
	Hepialus humuli	Hepialidae	
	Hepialus sylvina	Hepialidae	
	Nola cucullatella	Nolidae	
	Apamea monoglypha	Noctuidae	Buckhurst 1930
	Noctua pronuba	Noctuidae	
	Noctua comes	Noctuidae	
	Mamestra brassicae	Noctuidae	
	Mesapamea secalis	Noctuidae	
	Agrotis nigricans	Noctuidae	
	Agrotis exclamationis	Noctuidae	
	Leucania conigera	Noctuidae	
	Melanchra persicariae	Noctuidae	
	Spilosoma lubricipeda	Arctiida	Poulton 1929
	Noctua spp.	Noctuidae	
	Plusia sp.	Noctuidae	
	Autographa gamma	Noctuidae	
	Triphosa dubitata	Geometridae	
	Scoliopteryx libatrix	Noctuidae	
	Orthosia sp.	Noctuidae	
	Xylena exsoleta	Noctuidae	
	Eumorpha satellitia	Noctuidae	
Plecotus austriacus	90% undetermined	Arctiidae Drepanidae Endromidae Geometridae Lasiocampidae Lymantriidae Noctuidae	Beck 1995, Barnard 2011

Table 1. (continued)

bat species	% of Lepidoptera lepidopteran species	families	reference/s
Plecotus austriacus (continued)		Notodontidae Sphingidae Tetheidae Thiatiridae Tortricidae	Beck 1995, Barnard 2011 (continued)
Plecotus gaisleri	see text		Borg & Sammut 2002
Tadarida teniotis	65–88% undetermined		Whitaker et al. 1994, Rydell & Arlettaz 1994

tomato, green bean, tobacco, grapes; *Spodoptera littoralis* – among host plants there are cotton, horticultural crops (Solanaceae), corn; *Noctua pronuba* – causes fatal damage to many plants: carrots, strawberries, lettuce, tomato, potato, spinach; *Agrotis ipsilon* – infested plants: Swiss chard, corn, vegetable crops; *A. puta, A.segetum* – pests of various wild and cultivated plants.

The rice crops have a very important place in human nutrition; this graminaceous plant of Asian origin is the staple food for about half of the world's population (Kiple & Ornelas 2000, Timmer 2010) and it is cultivated in almost all countries (FAO 2014). The world rice crop is attacked by more than 800 species of insects and at least 20 can cause serious economic damages (Heinrichs 1994). In Asia, where more than 90% of the world's rice is produced, the average loss of yield due to pests is around 20% (Pathak & Khan 1994). In Thailand bats act as efficient biological control of rice pests (Leelapaibul et al. 2005, Wanger et al. 2014).

Conclusions

Bats play a relevant action in the protection of economically important crops against lepidopteran pests. Insects considered as pests, often concentrate in large quantities in cultivated landscapes, have been found in the diet of several species of bats. To install artificial roosts (bat boxes) can be a real important way to protect bats and to be very useful to agriculture as well. In the Ebro Delta (Spain), where there are some of the largest European rice paddies, soprano pipistrelle, *Pipistrellus pygmaeus*, acts as efficient biological controller of one of the most devastating pest, the rice striped borer, *Chilo suppressalis* (Lepidoptera: Pyralidae). In this area several bat boxes have been installed; they accommodate up to 4,500 bats and have greatly reduced the deleterious impact of this pest on rice crops, minimizing the use of insecticides (Flaquer et al. 2011). In France 24 samples were analyzed from droppings collected under artificial lodgings (bat boxes) on the edge of an olive orchard (sampling in September and October during the fly flight period). Four PCR tests were performed and the results show that six samples of bat droppings are positive showing an adult predation of the olive fruit fly, *Bactrocera oleae* (Diptera: Tephritidae), by *Pipistrellus kuhlii* (Ricard et al. 2008). The less pesticides used on crops the less we take in when we eat. Bats are among the best friends to organic farmers. They play a role in pest control and attracting bats to farms can make a significant difference to farmers who want to use natural biological insect control, rather than rely upon chemicals that may threaten our environmental and personal health.

Table 1 shows Lepidoptera species (mostly moths) found in the diets of European bats. Only species in the diet of a specific bat species are mentioned. About 80 species of moths are listed,

found in the diet of 22 species of bats. Lepidoptera make up a substantial part of the diet for *Rhinolophus* spp., *Myotis brandtii*, *M. bechsteinii*, *Nyctalus leisleri*, *N. noctula*, *Eptesicus serotinus*, *Hypsugo savii*, *Barbastella barbastellus*, and *Plecotus* spp. Among the eaten moths *Agrotis exclamationis*, *A. ipsilon*, *A. segetum*, *Autographa gamma*, *Chilo suppressalis*, *Chrysodeixis chalcites*, *Cydia pomonella*, *Galleria mellonella*, *Heliothis peltigera*, *Hepialus humuli*, *Mamestra brassicae*, *Naenia typica*, *Noctua fimbriata*, *N. pronuba*, *Odonestis pruni*, *Phlogophora meticulosa*, *Spodoptera exigua*, *S. littoralis*, *Xestia c-nigrum* are significant agricultural pests. Whenever possible Latin names were updated according to the current taxonomy.

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