Janice Pease

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August 23, 2018

Via Email

Honorable Kathleen H. Burgess, Secretary to the PSC Re: Case 16-F-0268, Application of Atlantic Wind LLC for a certificate of Environmental Compatibility and Public Need Pursuant to Article 10 for Construction of the North Ridge Wind Energy Project in the Towns of Parishville and Hopkinton, St. Lawrence County.

Dear Secretary Burgess:

Industrial wind is devastating to the bat populations, adding to the many factors which play a role in reducing their numbers worldwide.

While the wind industry likes to suggest that the advantage turbines provide to help reduce climate change (inadvertently benefitting all creatures) far outweighs their negative impact on the bats, that is yet to be seen. The data is simply not available to calculate the environmental/financial net losses accurately. With industrial wind's intermittent and unreliable energy, the advantages are not nearly as the wind lobbyists suggest.

The fragmentation/depletion of critical habitat due to wind turbines massive land use affects all animal species reliant on that space, ricocheting down the food chain. The loss of habitat as well as loss of carbon-sinks make the industrial turbine a very unlikely savior for any species. The net loss has simply not been calculated.

Farmers are easily drawn into the debate by hosting these “farms”, while receiving large financial payouts. These same farmers are seemingly unaware of the immense benefit that bats provide by eating insect pests, saving farmers billions/year. The weakening of the local ecosystems will most certainly result in lower crop yields as well as contribute to financial losses as well. Subsequently the “farmers” use of pesticides is partly responsible for the decline in bat populations. Unfortunately the negative impact caused by modern day farming, which is responsible impart for the industrial wind boom, is reducing bat numbers at an alarming rate.

Talk about biting the hand that feeds you…

There are so many unknowns that we are gambling with when we allow large scale projects to be implemented world-wide without proper research.

The fact is, we humans do not even know what to research until we observe the consequences of our actions.

In the case of industrial wind in relation to bats, there is much we do not fully understand, for instance how the bats are affected. At first glance it looked as if collusion was the culprit causing so much bat demise. While that is a factor, we now understand that barotrauma is to blame. The bats undergo great trauma as a result of the pressure change they experience as they get too close to the turbines. Bats are attracted to turbines due to the large number of insects which are drawn to the increased temperature around the turbines.

Barotrauma is invisible to the naked eye, but deadly just the same:

"The decompression hypothesis proposes that bats are killed by barotrauma caused by rapid air- pressure reduction near moving turbine blades [1,4,5]. Barotrauma involves tissue damage to air- containing structures caused by rapid or excessive pressure change; pulmonary barotrauma is lung damage due to expansion of air in the lungs that is not accommodated by exhalation. We report here the first evidence that barotrauma is the cause of death in a high proportion of bats found at wind energy facilities. We found that 90% of bat fatalities involved internal haemorrhaging consistent with barotrauma, and that direct contact with turbine blades only accounted for about half of the fatalities. Air pressure change at turbine blades is an undetectable hazard and helps explain high bat fatality rates." "Bats have large lungs and hearts, high blood oxygen-carrying capacity, and blood-gas barriers thinner than those of terrestrial mammals. These flight adaptations suggest that bats are particularly susceptible to barotrauma." "Bats' large pliable lungs expand when exposed to a sudden drop in pressure, causing tissue damage" ***-Barotrauma is a significant cause of bat fatalities at wind turbines***

Erin F. Baerwald, Genevieve H.D'Amours, Brandon J. Klug and Robert M.R. Barclay

The human race is dependent on bats, anything that reduces their numbers needs to be faced with serious scrutiny. Through our greed for energy production, companies are using our desperation to prosper. We need an energy solution that does less harm, settling for industrial wind is compounding the very issues we are racing against time to solve.

Respectfully,

Janice Pease

Janice Pease

**electronically signed*

Attachments:

- **Photographs of dead bat within the proposed project zone, a close look atone of the bat species that live in the area**

- List of bat videos that are informative and entertaining

- **Bats of New York** *New York State Department of Environmental Conservation*

- **Wind turbines make bat lungs explode** *Catherine Brahic*

- **Wind turbines killing tens of thousands of bats, including many on the endangered species list** *ontario-wind-resistance.org*

- **Wind Turbines in Israel Kill Many More Birds, Bats Than Expected** *Zafrir Rinat*

- **Action Plan for the Conservation of the Bat Species in the European Union 2014 - 2020**

- **Study: Wind Turbines Could Make This Endangered Bat Go Extinct** *dailycaller.com*

- **Ecological and Economic Importance of Bats (Order Chiroptera)**
Mohammed Kasso and Mundanthra Balakrishnan

- **CorrespondenceBarotrauma is a significant cause of bat fatalities at wind turbines** *sciencedirect.com*

- **Wind Farms Want Permission To Kill More Bats — A Lot More** *Madison Lee Choi*

- **Prestin and high frequency hearing in mammals** *Stephen J Rossiter, 1 Shuyi Zhang,2 and Yang Liu2*

- **ECOLOGICAL AND ECONOMIC IMPORTANCE OF BATS.** *Sheryl L. Ducummon Bat Conservation International, Inc.*

- **Role of bats in our ecosystems (ecosystem services)** *batswithoutborders.org*

- **Ultrasonicnoiseemissions fromwindturbines: potentialeffectsonbat species**
LoughboroughUniversity InstitutionalRepository

- **Bats Are Important** *batcon.org*

- **Bat** *Wikipedia (overview of bats)*

- **Eeek! Meet New York's 6 cave bats and 3 tree bats** *newyorkupstate.com*

Bat Videos:

- https://www.youtube.com/watch?v=9FVoTMOorXA
- https://www.youtube.com/watch?v=LbMqFGcxqHA
- https://www.floridamuseum.ufl.edu/bats/streaming/barn-interior/ (live streaming of interior of bat house)
- https://www.floridamuseum.ufl.edu/bats/videos/ (prerecorded videos of interior of bat house)
- https://www.youtube.com/watch?v=qJOloliWvB8
- https://www.youtube.com/watch?v=gZxLUNHEmPw
- https://www.youtube.com/watch?v=p08Y0oRAX3g
- https://www.youtube.com/watch?v=1Xwlvvx7uK0 (echolocation)
- https://www.youtube.com/watch?v=V3mpD2bCnzg (bat giving birth in facility)
- https://www.youtube.com/watch?v=9NtsQfRCKSI (bat giving birth in the wild)
- https://www.youtube.com/watch?v=_RWBUIiUoDc
- https://www.youtube.com/watch?v=b3w9ZbRQIek
- https://www.youtube.com/watch?v=WVz8rvIl_vY
- https://www.youtube.com/watch?v=Z4FCiezBpNo

Videos of bats and industrial turbines:

- https://www.youtube.com/watch?v=KRqu4WiLQfk
- https://www.youtube.com/watch?v=0jGzGcOkYR0
- https://www.youtube.com/watch?v=N9w0sjRqLqo
- https://www.youtube.com/watch?v=CxSdU-fozGY (bats interacting with turbines)
- https://www.youtube.com/watch?v=Udbcy8Y6vrY&t=123s
- https://www.youtube.com/watch?v=BXzWcxOaqvQ (Wind turbines cause barotrauma to bats)
- https://www.youtube.com/watch?v=h76Lbm0keZo (bat investigation of turbine at night)
- https://www.youtube.com/watch?v=wSi3SI0U8xg
- https://www.youtube.com/watch?v=VsTg6PK3CTE (bat collision with turbine)
- https://www.youtube.com/watch?v=3pkgwXwaajY

BATS
OF NEW YORK

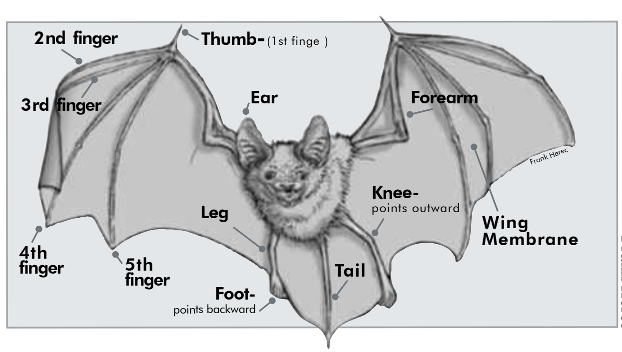
New York State Department of
ENVIRONMENTAL
CONSERVATION

Bats are misunderstood creatures. Repulsive to many and feared by others, these amazing, beneficial animals have an undeserved bad reputation. They are the only mammal that can truly fly (flying squirrels glide, not fly), and most bat species are insect-eating machines, performing incredible aerial acrobatics as they chase and devour 20-50% of their weight in insects each night.

Bats are mammals; they are warm-blooded, have fur or hair, give birth to babies, and nurse the babies with milk. Bats do not build nests, but often form nursery roosts with many females giving birth in the same area. Unlike southern sites, New York caves and mines are too cold for raising young. Baby bats (pups) are hairless when born and weigh up to 30% of their mother's weight. Newborns have well-developed feet and are soon able to hang securely from their perch when the mother is gone. Only the mother cares for the young.

The young are born in June to early July and grow quickly, with many flying and hunting within a month. Bats breed primarily in the fall; the females store sperm in their bodies and fertilize the egg the following spring.

Although often described as "flying mice," bats are not rodents and are more closely related to primates and people. In fact, bats' wings are similar to the human hand, having a thumb and four fingers. Bats' fingers can be as long as their body and provide support for the thin leathery wing membrane that extends to the ankle and tail. This thin membrane enables them to quickly and precisely maneuver during flight.



Frank Herec

The place where a bat sleeps is called its roost. Some bats roost in ones and twos, but many sleep in large groups. They typically hang upside down and can tilt their heads so far back, they can look behind them.

Bats are nocturnal, feeding at night and sleeping during the day. Contrary to the saying "blind as a bat," many bats see very well. However, because they hunt mostly at night, it's their keen hearing they rely on to accurately navigate in the dark. Using echolocation, these bats send out a series of rapid (up to 200 per second) pulses of sound too high for people to hear. When the sound bounces off an object, an echo returns which bats instantly analyze, enabling them to identify the location, size and shape of the object.

Depending on the species, bats eat a variety of things. However, 70% of bats worldwide, and all of New York's bats, consume flying insects. Other bat species eat fruit, nectar, small mammals, birds, lizards, frogs, fish, and blood. Predators include owls, raccoons, snakes and domestic cats.

Each fall, as temperatures drop and insect numbers decline, bats respond by either hibernating or migrating. Come spring, generally around mid April, they begin to return from their wintering sites.

Bats are extremely long-lived compared to mammals of similar size. The oldest ever documented was found in a New York mine where it had been banded 34 years earlier. New York is home to nine bat species, three are tree bats, the other six are cave bats.

Cave Bats

All six species of New York's cave bats spend the winter hibernating in caves and mines where they live off stored fat reserves. However, during the summer they live in a variety of places, including bridges, buildings, rock crevices, beneath loose bark, or in cracks or crevices in trees. Cave bats are identified by the lack of fur on their tail membranes and their rather plain brownish coloring. Indianas are more greyish and Pipistrelles can be nearly reddish yellow.

Northern Bat

Al Hicks

Myotis septentrionalis

This bat is commonly seen across the northeast during the summer. It forms small maternity colonies in the crevices of trees. Its large ears and high frequency call enable it to pick its way through dense forest clutter that other bats avoid. During winter, these bats sometimes hang from the cave's ceiling or along a wall with other bat species, but most are squeezed tightly into cracks and crevices in the rocks.

Wingspan– 9″; Body length– 2″

Little Brown Bat

Al Hicks

Myotis lucifugus

The most common bat in the state, little browns are the species most often encountered by people. They frequently occupy buildings during the summer, but also live in crevices and under loose bark in trees. Nearly 200,000 have been found wintering in one New York mine. A northern species, this is probably the bat you see flying low over the water on a summer evening.

Wingspan– 8-9″; Body length– 2″

Indiana Bat

Al Hicks

Myotis sodalis

Indianas are an endangered species. They are vulnerable because they occur in large concentrations in few places. Roosting in clusters of 300-400 per square foot, half of the Indianas in the northeast winter in just one N.Y. mine. Summer maternity colonies, ranging in size from a dozen to several hundred animals, generally occur in crevices of damaged trees or under the loose bark of living or dead trees. Indianas forage primarily along forest edges, and close to the tree tops.

Wingspan– 10″; Body length– 2″

Note: The pink noses of the Indianas in this photo distinguish them from the dark face of the little brown.

Eastern Pipistrelle


Al Hicks

Perimyotis subflavus

The eastern pipistrelle is widely distributed within New York hibernacula (wintering sites), but almost always in low numbers. Pipistrelles prefer warmer, moister portions of caves, and rarely cluster; typically hanging singly from the ceiling or along a wall. It is one of the state's smallest bats and can be identified from other cave bats by its reddish forearms and slightly yellowish-orange fur. In summer, pipistrelles inhabit open woods near water, rock crevices, and buildings, often forming small colonies in clumps of dead leaves hanging from tree branches. They can be seen chasing insects at tree top level early in the evening.

Wingspan– 9"; Body length– less than 2"

Big Brown Bat


Al Hicks

Eptesicus fuscus

The largest of New York's cave bats, the big brown weighs two to three times more than other cave bats and has a wingspan of nearly 13". Most tolerant of cold temperatures and low humidity, it often winters near the entrance of caves and mines, and is the state's only bat species to regularly winter in buildings. One of two bat species that often raises its young in buildings as well as trees, it is one of our most common summer bats. When using buildings, it generally limits nursery colonies to dozens, not hundreds, of individuals. Identified by its large size, dark ears and face, and glossy, light to dark brown fur, the big brown emerges early in the evening to forage high among the tree tops.

Wingspan– 13"; Body length– 3"

Small-footed Bat


Al Hicks

Myotis leibii

N.Y.'s smallest bat, the small-footed weighs less than a nickel. Its small size, jet black "raccoon" face mask and wings, long glossy fur, and tiny feet (hence, the name), distinguish it from other bat species. It could easily be called the rock bat as during the summer it often roosts and raises its young in accumulations of rocks, cliff faces, road cuts and concrete bridges with good sun exposure. It is the least frequently encountered bat in the eastern U.S during winter surveys, and more than half the individuals counted reside in just two mines in the Adirondack region.

Wingspan– 9"; Body length– less than 2"

Note: While bats are fascinating to watch, a few individuals can be vectors for some diseases, including rabies. And while only 0.5% of bats carry rabies, to be safe, people should avoid handling them. For more information, contact your local health department.

Written by Eileen Stegemann and Al Hicks

Tree Bats

As the name suggests, tree bats live year round in trees. They are more colorful than the generally brown cave bats, and reds and hoarys have distinct dark and tan wing membranes. Tree bats have fully furred tail membranes which they can curl up around their bodies like a blanket.

Because tree bats do not typically enter caves or mines or form large colonies, these species are harder to study. It is known that reds and hoarys roost alone from branches, hiding among leaves, and silver-haireds form small colonies and use crevices and hollows in trees. While most cave bats have one young per year, hoarys and silver-haired bats typically have two; reds as many as three or four. All three species fly south in winter to where warmer temperatures make finding a meal more reliable.

Red Bat

© Merlin D. Tuttle, Bat Conservation International, www.batcon.org

Lasiurus borealis

Although common in warmer southern states, the red bat is less abundant in New York. In the late 1800s, red bats were reported migrating in substantial flocks during the daytime. Today, daytime encounters rarely exceed more than a few individuals. Female red bats are noticeably grayer than the reddish-orange males. Reds typically roost low in the trees among dense foliage. They feed early in the evening.

Wingspan– 12″; Body length– 2-2 ¼″

Note: photo shows female red with pups

Hoary Bat

© Merlin D. Tuttle, Bat Conservation International, www.batcon.org

Lasiurus cinereus

The largest of New York's bats, hoarys weigh two to seven times more than other New York bats and have a wingspan that measures up to 16 inches. More of a northern species, and nowhere common in the state, they are most abundant in the Adirondacks. Hoary bats roost high in trees and typically forage far above the treetops.

Wingspan– 16″; Body length– 3½″

Silver-haired Bat

© Merlin D. Tuttle, Bat Conservation International, www.batcon.org

Lasyionicterius noctivagans

Once described as the most common bat in the Adirondacks, the silver-haired bat is perhaps the least frequently encountered bat species in the Northeast during the summer season. It prefers more northern habitats, roosting under loose bark or in tree cavities. This bat is one of the first to feed in the evening, sometimes starting before sunset. As the name implies, it has silvery-tipped hairs on its nearly black body.

Wingspan– 11″; Body length– 2-2 ⅓″

DAILY NEWS 25 August 2008

Wind turbines make bat lungs explode

By Catherine Brahic

Video: Wind turbines make bat lungs explode

(Image: stock.xchng)

"Beware: exploding lungs" is not a sign one would expect to see at a wind farm. But a new study suggests this is the main reason bats die in large numbers around wind turbines.

The risk that wind turbines pose to birds is well known and has dogged debates over wind energy. In fact, several studies have suggested the risk to bats is greater. In May 2007, the US National Research Council published the results of a survey of US wind farms showing that two bat species accounted for 60% of winged animals killed. Migrating birds, meanwhile, appear to steer clear of the turbines.

Why bats – who echolocate moving objects – are killed by turbines has remained a mystery until now. The research council thought the high-frequency noise from the turbines' gears and blades could be disrupting the bats' echolocation systems.

In fact, a new study shows that the moving blades cause a drop in pressure that makes the delicate lungs of bats suddenly expand, bursting the tissue's blood vessels. This is known as a barotrauma, and is well-known to scuba divers.

“While searching for bat carcasses under wind turbines, we noticed that many of the carcasses had no external injuries or no visible cause of death,” says Erin Baerwald of the University of Calgary in Canada.

Internal injuries

Baerwald and colleagues collected 188 dead bats from wind farms across southern Alberta, and determined their cause of death. They found that 90% of the bats had signs of internal haemorrhaging, but only half showed any signs of direct contact with the windmill blades. Only 8% had signs of external injuries but no internal injuries.

The movement of wind-turbine blades creates a vortex of lower air pressure around the blade tips similar to the vortex at the tip of aeroplane wings. Others have suggested that this could be lethal to bats, but until now no-one had carried out necropsies to verify the theory.

Baerwald and her colleagues believe that birds do not suffer the same fate as bats – the majority of birds are killed by direct contact with the blades – because their lungs are more rigid than those of bats and therefore more resistant to sudden changes in pressure.

Bats eat nocturnal insects including agricultural pests, so if wind turbines affected their population levels, this could affect the rest of the local ecosystems. And the effects could even be international. “The species being killed are migrants,” says Baerwald. “If bats are killed in Canada that could have consequences for ecosystems as far away as Mexico.”

Windy day

One solution could be to increase the minimum wind speed needed to set the blades in motion. Most bats are more active in low wind.

The study was funded by a number of bat conservation groups together with energy companies with a financial interest in wind energy, such as Shell Canada and Alberta Wind Energy.

Journal reference: *Current Biology* **(vol 18 p R696)**

Endangered species *– Learn more about the conservation battle in our comprehensive special report.*

Energy and Fuels *– Learn more about the looming energy crisis in our comprehensive special report.*

Wind turbines killing tens of thousands of bats, including many on the endangered species list

ontario-wind-resistance.org/2016/07/20/wind-turbines-killing-tens-of-thousands-of-bats-including-many-on-the-endangered-species-list

July 20, 2016

Canadian Wind Energy Association says that they are now, "concerned about reports that are based on limited data that have the effect of boosting estimates [of bird and bat kills]."

This is almost funny. It's not like we aren't *trying* to get all the data, but this is all CanWea will release! When I ASK for ALL the data in letters and FOI requests, the wind companies refuse with a curt "Don't give her anything." The MNRF and the FOI office thought Canadians should see this data. But the wind companies are adamant we never have access to the full reports.

So what does CanWea plan to do? They are going to make up another "system" to um… make it a all a little clearer, like mud. Dear CanWea, why not let Canadians see ALL the data? Don't make up another fancy system to hide it, just show us the bodies. Or are there too many? Either way, be prepared for a new scheme by this industry to hide them this fall.

London Free Press, John Miner

Wind turbines are killing bats, including ones on the endangered species list, at nearly double the rate set as acceptable by the Ontario government, the latest monitoring report indicates. Bats are being killed in Ontario at the rate of 18.5 per turbine, resulting in an estimated 42,656 bat fatalities in Ontario between May 1 and October 31, 2015, according to the report released by Bird Studies Canada, a bird conservation organization.

Ontario's Ministry of Natural Resources has set 10 bat deaths per turbine as the threshold at which the mortalities are considered significant and warrant action. The bats being killed by turbines in Ontario include the little brown bat, tri-coloured bat, eastern small footed bat, and northern long-eared bat, all on the endangered species list.

The Birds Studies Canada report draws its information from a database that is a joint initiative of the Canadian Wind Energy Association, Canadian Wildlife Service, Ontario Ministry of Natural Resources and Bird Studies Canada.

Brock Fenton, an expert in the behaviour and ecology of bats and professor in Western University's department of biology, said the bat deaths are a concern. Bat populations across

North America have been plunging with the emergence of a fungal disease called white nose syndrome. Read article

Wind Turbines in Israel Kill Many More Birds, Bats Than Expected

The impact of wind turbines on birds and bats exceeds tolerable levels recommended by nature authorities, and there is currently no solution to the problem

Zafrir Rinat
Dec 20, 2017 10:37 AM

A Falcon killed by a wind turbine in Israel.Hedy Ben Eliahou, Nature and Parks Authority

Wind turbines cause significant damage to bird and bat life in Israel, beyond the level deemed tolerable by nature authorities. The Parks and Nature Authorityy is mulling measures it will ask turbine owners to employ in order to reduce the damage.

Leaving aside 25—year old wind farm in the Golan Heights, there are two more modern wind turbine installations near Ma'aleh Gilboa and Ramat Sirin in northern Israel, which generate electricity. They are run by the Afcon business group in collaboration with local communities.

The turbine operators committed to monitoring the extent of harm to birds and bats from collision with the turbine blades, in cooperation with the Parks and Nature Authority The damage that ecologists observed, through foot patrols from July 2016 to July 2017, was worse than expected, they said last week in an interim report. At the next stage, dogs will be used to improve detection of wounded animals.

Beyond counting carcasses, the ecologists estimated the number of creatures hurt by each turbine over a year, factoring in "missing" carcasses due to predation and estimating the number of birds and bats that were struck but fell further away.

The trackers found that the average number of bird strikes per year for a single turbine was 23 at Gilboa and 17 at Sirin, and the average number of bat strikes was nine at Gilboa and seven at Sirin.

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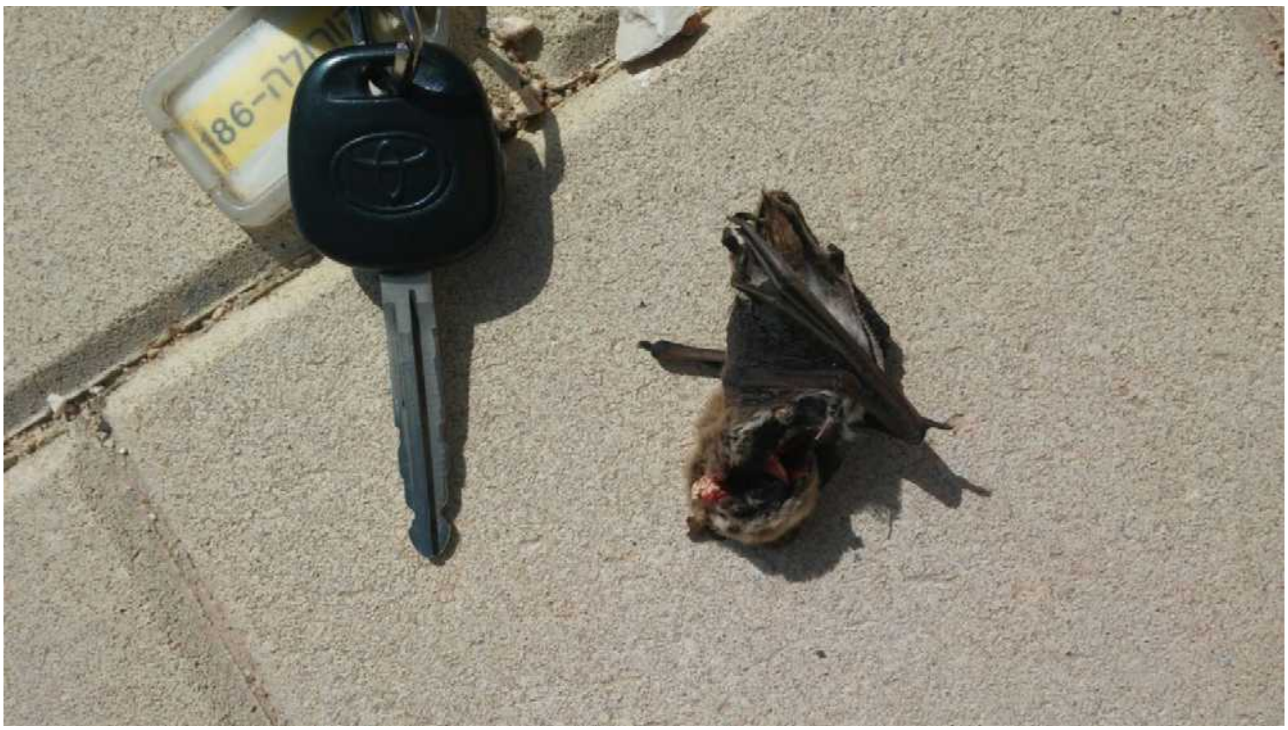
Injured birds include white storks, common kestrels and owls. Bat species found included the naked-rumped tomb bat and Kuhl's pipistrelle, which are insect-eaters.



Bats killed by wind turbines include tiny insectivores.Miriam Freund / Nature and Parks Authority

"These values verge on, or exceed, maximal levels for impact to birds and bats under the Parks and Nature Authority's policy," says the monitoring report. "These threshold levels are 14 birds and 10 bats per year. The figures indicate significant impact that could affect the stability of various bird and bat populations in the area, particularly for endangered species."

"Our estimates are very conservative. The impact could actually be much greater," says avian ecologist Ohad Hatzofeh, who works with the Parks authority. Not all the victims belong to endangered species, but many do in the case of the bats, he said.

Hatzofeh stresses that the figures are not final and that a more extensive survey with tracker dogs remains to be done. The authority will then analyze the data and decide whether to ask the turbine operators to take steps that could reduce the impact on the animals, such as shutting down the turbines when the wind speed is low, which is when bats are more active, and less electricity can be generated anyway.

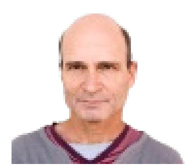
Afcon commented that it carries out monitoring in keeping with the agreement, and will continue to operate as required.

A bat killed by a wind turbine in Israel.Miriam Freund, National Parks and Nature Authority

Last Sunday, the Parks and Nature Authority and the Society for the Protection of Nature in Israel, together with four zoos that are involved in an eagle-breeding program, began a public campaign against the plan to build a large wind turbine farm in the Golan Heights, for fear of harm to the already seriously endangered vulture population there.

Zafrir Rinat

Haaretz Correspondent



Send me email alerts for new articles by Zafrir Rinat

Page 52-53 Bat vs turbines, mitigation is not affective and has major drawbacks.

Inf.EUROBATS.StC9-AC19.5

Action Plan for the Conservation of the Bat Species in the European Union 2014 - 2020

2nd DRAFT VERSION – 24/02/2014

EUROPEAN COMMISSION

EUROBATS

Action Plan for the Conservation of the Bat Species in the European Union 2014 - 2020

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COVER PHOTOS:

- Top-left corner: *Rhinolophus ferrumequinum* – L. Spanneut (Ecosphère)
- Bottom-left corner: *Nyctalus leislerii* – G. Marchais (Ecosphère)
- Top-right corner: *Pipistrellus pipistrellus* – L. Spanneut (Ecosphère)
- Bottom-right corner: *Nyctalus leislerii* – N. Flamand (Ecosphère)

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INTRODUCTION

European bats are a species-rich group widely distributed through the range of agricultural, forests and other habitats that form the landscapes of Europe. Serious declines in populations have occurred historically throughout Western Europe, particularly in the latter half of the twentieth century. Protection of bats and investment in their conservation has led to the stabilisation of population trends for some species more recently, but bats remain vulnerable to roost loss and habitat change in several EU Member states (MS). Some other species continue to decline.

Bats are an essential component of the great variety of natural and semi-natural ecosystems in the European Union. From an ecological perspective, this group is a good ecological indicator since bats respond to very slight changes in their environment. Such responses can be useful in revealing habitat fragmentation, ecosystem stress, intensification of agriculture or forestry as well as various human activities.

The European landscape has been and continues to be affected by intensive and varied human influences that have had widespread and sometimes devastating effects on bat populations. In addition, there are continued misunderstandings and prejudices arising from ignorance about bats and their lives and habits. As a result of these impacts, many species are considered threatened; some have even become extinct in a number of countries.

The aim of this EU Species Action Plan (SAP) for all bat species is to support the development of national or local action plans and conservation measures as appropriate[1].The objectives of this EU SAP are as follows:

- To provide baseline data about species status;
- To provide scientifically-based recommendations to those who can promote and support species conservation;
- To establish priorities in bat species conservation;
- To provide a common framework and focus for a wide range of stakeholders.

The information and proposed conservation actions presented in this EU SAP have been prepared in consultation with EUROBATS and a group of experts from all EU countries as well as through a review of available literature as in 2013. An attempt has been made in this EU SAP to summarize the literature most relevant to bats conservation. Ecology, distribution, status and threats are outlined.

Finally, the conservation actions proposed for the bat species are presented and recommendations are provided regarding stakeholder participation and the monitoring and review of this Plan.

Within the frame of this Multi-Species Action plan, a meeting with bats experts was held (18/11/2013) in order to analyze the threats facing the species, develop a conservation strategy and identify the most important actions.

This plan is intended to be implemented in all the EU MS unless an action plan is already implemented. For these states, amendments may be made when they will be reviewed.

[1] The EU Species Action Plans are not of a binding nature; species action plans are drafted and implemented at the discretion of MS.

1 - FOCUS SPECIES AND THEIR NATURAL HISTORY

1.1 - Focus species and their IUCN Red list status

Bats (order Chiroptera) are the only mammals that can fly. There are 45 species in the European Union from 5 families and 12 genera as presented in Table 1. The International Union for the Conservation of Nature (IUCN) red list statuses were published in 2007 for terrestrial Europe and for EU (only 25 Member States then, 28 in 2013) (1), and the latest world statuses were extracted from www.iucnredlist.org.

Table 1 – European species and their conservation status

IUCN red list categories:

- *EN: endangered – Very high risk of extinction in the wild;*
- *VU: vulnerable – High risk of extinction in the wild;*
- *NT: near Threatened – Likely to become threatened in the near future;*
- *LC: Least Concern – Does not qualify for a more at risk category. Widespread and abundant taxa are included in this category;*
- *DD: Data Deficient – Inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status;*
- *N/A: not assessed.*

SPECIES		IUCN Red list status			HD[2] Annex IV	HD Annex II
		World	Europe	EU 25 terrestrial		
Rhinolophidae (Horseshoe bats)						
Blasius's horseshoe bat	*Rhinolophus blasii*	LC	VU	DD	x	x
Mediterranean horseshoe bat	*Rhinolophus euryale*	NT	VU	VU	x	x
Greater horseshoe bat	*Rhinolophus ferrumequinum*	LC	NT	NT	x	x
Lesser horseshoe bat	*Rhinolophus hipposideros*	LC	NT	NT	x	x
Mehely's horseshoe bat	*Rhinolophus mehelyi*	VU	VU	VU	x	x
Vespertilionidae (Evening bats)						
Western Barbastelle bat	*Barbastella barbastellus*	NT	VU	VU	x	x
Anatolian Serotine	*Eptesicus anatolicus*	N/A	N/A	N/A	x	
Northern bat	*Eptesicus nilssonii*	LC	LC	LC	x	
Isabelline Serotine bat	*Eptesicus isabellinus*	LC	N/A	N/A	x	
Common Serotine	*Eptesicus serotinus*	LC	LC	LC	x	
Savi's pipistrelle	*Hypsugo savii*	LC	LC	LC	x	
Alcathoe whiskered bat	*Myotis alcathoe*	DD	DD	DD	x	
Steppe whiskered bat	*Myotis aurascens*[3]	LC	LC	LC	x	
Bechstein's bat	*Myotis bechsteinii*	NT	VU	VU	x	x
Lesser mouse-eared bat	*Myotis blythii oxygnathus*	LC	NT	NT	x	x

[2] Annexes of the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. 1992 (Consolidated version 1. 1. 2007). http://ec.europa.eu/environment/nature/legislation/habitatsdirective

[3] Formerly in *Myotis mystacinus*, probably more studies needed (very poorly known), sometime questioned.

SPECIES		IUCN Red list status			HD[2] Annex IV	HD Annex II
		World	Europe	EU 25 terrestrial		
Brandt's bat	*Myotis brandtii*	LC	LC	LC	x	
Long-fingered bat	*Myotis capaccinii*	VU	VU	VU	x	x
Pond bat	*Myotis dasycneme*	NT	NT	NT	x	x
Daubenton's bat	*Myotis daubentonii*	LC	LC	LC	x	
Escalerai bat	*Myotis escalerai*[4]	N/A	N/A	N/A	x	
Geoffroy's bat	*Myotis emarginatus*	LC	LC	LC	x	x
Greater mouse-eared bat	*Myotis myotis*	LC	LC	LC	x	x
Whiskered bat	*Myotis mystacinus*	LC	LC	LC	x	
Natterer's bat	*Myotis nattereri*	LC	LC	LC	x	
Maghreb mouse-eared bat	*Myotis punicus*	NT	NT	NT	x	
Azorean bat	*Nyctalus azoreum*	EN	EN	EN	x	
Greater noctule bat	*Nyctalus lasiopterus*	NT	DD	DD	x	
Leisler's bat	*Nyctalus leisleri*	LC	LC	LC	x	
Common noctule	*Nyctalus noctula*	LC	LC	LC	x	
Kuhl's pipistrelle	*Pipistrellus kuhlii*	LC	LC	LC	x	
Hanaki's Dwarf Bat	*Pipistrellus hanaki*	DD	N/A	N/A	x	
Madeira pipistrelle	*Pipistrellus maderensis*	EN	EN	EN	x	
Nathusius's pipistrelle	*Pipistrellus nathusii*	LC	LC	LC	x	
Common pipistrelle	*Pipistrellus pipistrellus*	LC	LC	LC	x	
Pygmy pipistrelle	*Pipistrellus pygmaeus*	LC	LC	LC	x	
Brown long-eared bat	*Plecotus auritus*	LC	LC	LC	x	
Grey long-eared bat	*Plecotus austriacus*	LC	LC	LC	x	
Kolombatovic's Long-eared bat	*Plecotus kolombatovici*	LC	NT	NT	x	
Mountain long-eared bat	*Plecotus macrobullaris*	LC	NT	VU	x	
Sardinian long-eared bat	*Plecotus sardus*	VU	VU	VU	x	
Tenerife long-eared bat	*Plecotus teneriffae*	EN	EN	EN	x	
Parti-coloured bat	*Vespertilio murinus*	LC	LC	LC	x	
Miniopteridae						
Schreiber's bat	*Miniopterus schreibersii*	NT	NT	NT	x	x
Molossidae (Free-tailed bats)						
European free-tailed bat	*Tadarida teniotis*	LC	LC	LC	x	
Pteropodidae						
Egyptian fruit bat	*Rousettus aegyptiacus*	LC	N/A (EN?)	N/A (EN?)	x	x

[4] Formerly in *Myotis nattereri.*

1.2 - Natural history of bats

1.2.1 - Evolution and Biogeography

1.2.1.1 - Evolution

The earliest existing bat fossils are tens of millions years old, even though bats bones are very thin and fragile. It seems that the earliest fossil insect-eating bat found to date is 50 million years old and is very similar to the species of bats that exist today (2). The origins of insect-eating bats and fruits bat differs. The shape of the skulls and teeth, the neck vertebrae and the bones in the hands are very different (2).

1.2.1.2 - Biogeography

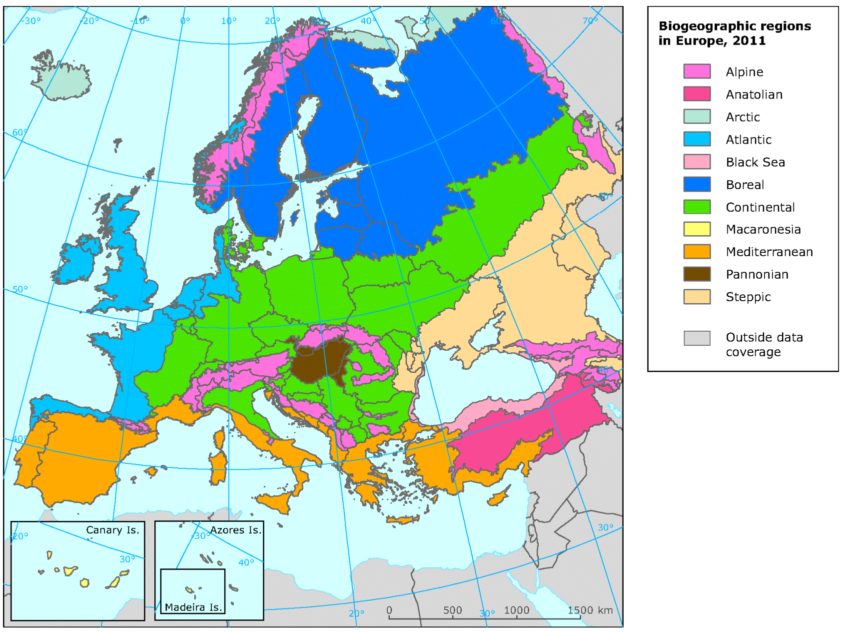
Flight gives bats the opportunity to go almost anywhere. Mountain ranges, seas or similar barriers that are obstacles to land-based mammals restrict them far less. This feature enables bats to reach new environments and after many generations, the survivors are gradually changed by the process of natural selection into new species (3). Bats are found in most terrestrial habitats, except in colder parts of the northern and southern hemispheres beyond the limit of tree growth or on some oceanic islands. The number of species increases towards the equator, where there is more food of more varied types than in temperate regions. Bats constitute the second most diverse mammal group in Europe (4). Three environmental characteristics (latitude, area and temperature) are the main predictors of bat species richness in Europe. These attributes act in an additive manner (5).

1.2.1.3 - Endemism

Each species is restricted in its range due to the ecological niche it has filled, governed by food supplies, temperature and roosting site availability. Some species have an extensive range, particularly those on large land masses. Other species, by contrast, have very small ranges. When they become geographically isolated over a very long period of time, bats evolve into new and unique species that can only be found in a single place – this is called endemism. Endemic species are especially likely to develop on biologically isolated areas such as islands. The endemic bat species of Europe are the Tenerife long-eared bat (*Plecotus teneriffae*), the Sardinian long-eared bat (*Plecotus sardus*), the Madeira's pipistrelle (*Pipistrellus maderensis*) and the Azorean bat (*Nyctalus azoreum*).

1.2.1.4 - EU Biogeographic regions

European bat species comprise several biogeographic groups with a widespread distribution in Europe (6), covering all the major biogeographic regions from the warmer Mediterranean to the colder Boreal and Alpine regions as shown in the map below.



Map 1 - Biogeographic regions in Europe (2011)

Using a spatial principal components analysis, the following plot was produced for 28 European bat species in which the three biogeographic groups can be distinguished (7). Four species were grouped in the Boreal biogeographic zone, 10 in the Temperate Humid Zone and 14 in the Mediterranean Zone (Fig. 1).

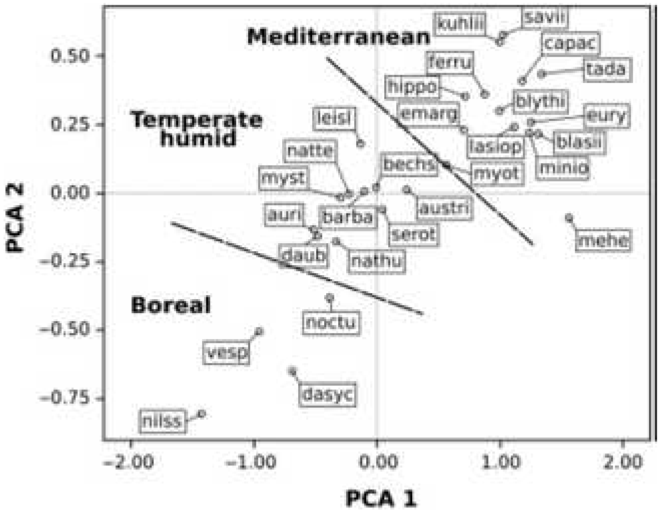


Figure 1 - Principal Components Analysis plot of the 28 bat species using three climatic variables (from (6)). The dashed lines separate each biogeographic group

Furthermore, there is a north-south gradient with the number of species increasing going southward (see chart 1 below).

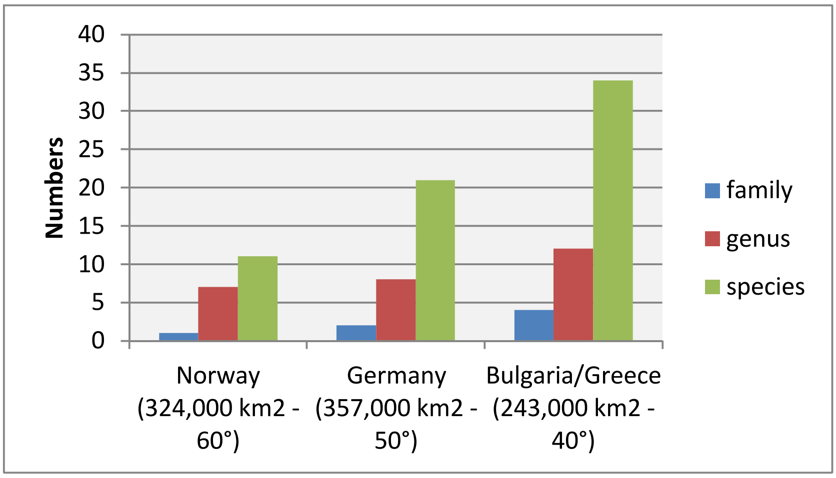


Figure 2 - Numbers of families, genera and species of European bats from north to south (from (7)).

1.2.1.5 - Influence of climate change

Biogeographic patterns exert a great influence on a species' response to climate change, with expected responses including range and population change (7). Bat species more associated with colder climates are most likely to be affected by current climate change prediction scenarios, while Mediterranean and Temperate groups may be more tolerant. However, the projections can vary considerably under different climate change scenarios (7).

1.2.2 - Life cycle

1.2.2.1 - General description from winter to autumn

In winter, the cold weather limits the numbers of active insects so there is little available food for insectivorous bats. Therefore, bats have developed a remarkable energy-saving strategy by hibernating – sleeping over a long period (many weeks) and cooling down their body temperature to approximately the same temperature as the surroundings. They also slow down their heart-beat and their breathing.

In spring time, as the ambient temperature rises up, they warm up their body to be able to fly and hunt for prey. While building up their reserves, they explore new areas and new roosting sites. The embryo of females, which have mated the previous autumn, starts to develop.

In summer, pregnant females gather together to give birth in maternity roosts – these are warm hidden and sheltered places. A female usually produces a single baby per year, but a few species, such as the ones belonging to the genera *Nyctalus* and *Pipistrellus* but also *Eptesicus,* occasionally produce twins. Males are usually not very active at this time of the year apart from feeding and exploring sites. Females spend several weeks weaning their babies which are born around June and July.

The juveniles may be able to fly out at one-month old only with the adults. By the end of summer, the offspring are almost independent but fly with the adults to learn the good feeding areas and roosting sites.

At the end of summer, the maternity colonies begin to move and split into smaller groups. Males become more active in courting females for mating. Some roosts are used for social gatherings called 'swarming sites' where up to a thousand bats seem to interact and build up various degrees of relationships with others.

By winter, the bats have sought out hibernation sites either individually or in small groups.

This is a general description (8). Close study of a single species will show up a number of variations in this basic pattern. Indeed, some species in warmer European countries may not hibernate and that a number of bats may be active during hibernation.

1.2.2.2 - Roosts

Bats do not make nests like birds but rather roost in a great variety of sites using overground structures like buildings, bridges, trees, or underground sites like caves, tunnels, mines, cellars - without bringing any kind of material. They often change site from one period of the year to another following the changes in weather and temperature patterns and to get closer to areas rich in prey. Being warm-blooded animals, they need to keep warm when they are resting or asleep during the active period (March to November in general). During winter, they need to find sheltered places with the right conditions of humidity and temperature as to be safe for hibernating over several months (8).

Depending on their functionality, the different types of roosts are classified as follow:

A HIBERNATION ROOSTS

These roosts are places where bats hide for safety when hibernating over winter because they are not capable to react from any danger (disturbance or predation) that may occur in the outdoors. Each species has its own requirements or habits, thus bats can be found in caves, mines, rock crevices, buildings but also in trees in winter.

B MATERNITY ROOSTS

These roosts are gatherings of female bats ready to give birth. Being together in numbers helps keeping the babies warm and safe. Males roost elsewhere (transitional roosts) most of the time; with some noticeable exceptions for *Plecotus* spp. bats, *Rhinolophus* spp. bats, *Miniopterus schreibersii*, *Myotis myotis*... These maternities or nurseries may contain many hundreds of females with their babies. Each species has its own requirements or habits, thus pregnant bats can be found in caves, mines, rock crevices and buildings or in trees.

C SWARMING SITES

These sites are roosts where a great number of bats gather in late summer for social interactions that are not fully understood to us. They were recently proposed as 'hot spots' for gene flow among populations – they seem to meet at swarming sites across colonies to start mating and, in addition, to renew information about suitable hibernacula (10). These roosts are usually found in caves, mines, tunnels or buildings, but also in deep forest areas and reed beds.

D TRANSITIONAL ROOSTS

These are all the other types of roosts where bats do not stay for long or have a special activity apart from resting. They may be used as an alternative for a better, but disturbed, roost or as a stopover while migrating or dispersing.

Table 2 below describes which species uses what type of roost at a certain period of the year.

Table 2 – The different roost types for the European species of bats
A: attics and other roofing spaces; B: buildings; C: caves and other underground sites (mines, bunkers); I: infrastructures (bridges, tunnels); T: trees; R: rock crevices or fissures; (A, B, C, I, T or R): means possible but not typical

SPECIES	Hibernation	Maternity	Transitional	Swarming
Rhinolophus blasii	C	C	C	
Rhinolophus euryale	C	C, A, (B), (I)	C, A, (B)	
Rhinolophus ferrumequinum	C	C, A, B	C, A, B	
Rhinolophus hipposideros	C	C, A, B, I	C, A, B, I, (T)	
Rhinolophus mehelyi	C	C	C	
Barbastella barbastellus	C, R, I, (T)	T, B, (R)	T, B, R	
Eptesicus anatolicus	R, B, (I)	B, R ?, (T)	B, R, I, (T)	
Eptesicus nilssonii	C, B, (R), (I)	B, (T), A	B, I, (T)	
Eptesicus isabellinus	B, R, I	B, R ?, (T)	B, I, (T)	
Eptesicus serotinus	B, I, (C)	B, A, I, (T)	B, (R), (T)	
Hypsugo savii	R, C	R, B	R, T, B, (I)	R, C
Myotis alcathoe	C, (T ?)	T	T, C	T, C
Myotis aurascens	C	R, I	R	R, C
Myotis bechsteinii	C, (T)	T, (B)	T	C
Myotis blythii oxygnathus	C	C, A, (I), (B)	C, A, I, (B)	C
Myotis brandtii	C, I	T, B	T, B	C, B
Myotis capaccinii	C, (B)	C	C, (I), (R)	C
Myotis dasycneme	C	B, A, (T)	B, T, C	B, C
Myotis daubentonii	C, I, (T)	I, T, C, B	I, T, B	C, I
Myotis escalerai	C	T, B, C	T, B, C	C, B
Myotis emarginatus	C	B, A, C, I	B, A, C, T, I	B, A, C
Myotis myotis	C, R	C, A, I, (B)	C, A, B, T, R	C, A
Myotis mystacinus	C	T, B, I	C, B, T	C, B
Myotis nattereri	C	T, B, (C), (I)	T, B, R, I, C	C, R
Myotis punicus	C	C, B,(I)	C, B, A, I	C, B, I
Nyctalus azoreum	T, R	T, B	T, R, B	
Nyctalus lasiopterus	T, R	T, (B)	T, R, I	
Nyctalus leisleri	T, R	T, (B)	T, R, I	
Nyctalus noctula	T, R, B, (C)	T, B	T, R, I, B	
Pipistrellus hanaki	B, R, C	T, B	T	C

SPECIES	Hibernation	Maternity	Transitional	Swarming
Pipistrellus kuhlii	B, R, (C)	B	B, T, R	B, C
Pipistrellus maderensis	B, R	B, A, R	B, A, R, I, T	B, A, R
Pipistrellus nathusii	T, R, (C)	T, B	T, B, R, I	T, B, R
Pipistrellus pipistrellus	B, C, I, (T)	B, T, A	B, T, A	B, A, C
Pipistrellus pygmaeus	B, T, C, I, (R)	T, B, A	B, T, A, I	B, A, C
Plecotus auritus	B, (C), (T)	T, B, A	B, T, A, I	
Plecotus austriacus	B, (C)	B, A, (C)	B, A, I	
Plecotus kolombatovici	C, R	B, A, I	R, B, C	
Plecotus macrobullaris	C, B	B, A	B, A	
Plecotus sardus	C, R, I	B	B, I, R	
Plecotus teneriffae	C, R	C, B, (R)	C, R, B	
Vespertilio murinus	R, B, I, (T)	B, A, R, (T)	B, R, (T)	
Miniopterus schreibersii	C	C, (A)	C, I, (B)	C, I, (B)
Tadarida teniotis	R, I	R, I	R, I, B, (T)	
Rousettus aegyptiacus	C	C, B, T	C, B, T	

1.2.3 - Foraging areas, commuting routes and ecological corridors

Bats are flying mammals which travel across the landscape using various features either natural or man-made, such as rivers, hedges, walls and bridges, to aid navigation and commuting to the principal foraging areas where they search for prey.

1.2.3.1 - Diet

A PREY ITEMS AND THEIR AVAILABILITY

In Europe, bats eat flies, moths, beetles, spiders and other insects (except *Nyctalus lasiopterus* which can hunt for small birds, *Rousettus aegyptiacus* which consumes large amounts of fruit such as wild dates, and *Myotis capaccinii* which can catch small fish). Each species is relatively specialised in the variety of insects it forages. For instance, moths are the bulk of the diet of *Miniopterus schreibersii* (9) throughout the year while the *Eptesicus serotinus* and *E. nilssonii* may hunt various types of swarming insects belonging to the Coleoptera, Lepidoptera, Hymenoptera and Heteroptera orders (10).

B HUNTING STRATEGIES

In Europe, bats forage at night to reduce competition with insectivorous birds. They emit calls in the dark and listen to the echoes of those calls that return from objects in their vicinity to avoid collisions and to catch insects. This capability is called echolocation or active sonar. All bats can also see; they are not blind (8).

Each species have developed their own strategy over millions of years to avoid competition and adapt to an ever-changing environment. Most species hunt in the air space from 0 to 30 m above ground level. Some species may fly and hunt higher especially in the *Nyctalus* genus. *Myotis daubentonii and M. dasycneme* are known to skim along the water surface of rivers and lakes, while *Tadarida teniotis*, the Noctule species (*Nyctalus* spp.*)* and the Serotine species *(Eptesicus/Vesperitilio* spp.) fly fast and high in the sky well clear of obstacles. Other species, such as the *Myotis bechsteinii*, favour dense deciduous woodland to glean insects from tree leaves, and *Myotis myotis* and *M. blythii oxygnathus* forages over pastures, steppes and meadows to catch beetles and grasshoppers off the ground (11).

A single bat may forage up to 20 different areas in a night to maximise its yield, especially the young mothers who need to feed their babies with their milk. A great variation occurs between species: certain species are used to forage not too far from their roosts like the *Rhinolophus* spp. bats and others do not hesitate to travel up to 25-30 km away from it for a rich meal like *Miniopterus schreibersii*.

C ROLE IN THE ECOSYSTEM

Bats are top predators. Although there are few studies on the degree to which bats control insect populations, in some regions they have been found to be highly effective in the control of agricultural pests, providing a major economic benefit to farmers[5]. *Rousettus aegyptiacus* also serves as a pollinator and seed disperser of many plants that are important to humans. Bat populations have the potential to be robust natural indicators of the health of our environment (12; 13). This is because bats are sensitive to pressures which affect other species and habitats (such as climate change, agricultural intensification, pesticides, land-use change) and also complement other taxonomic indicators by providing information on the night-time environment.

1.2.3.2 - Dispersal and Migration

A POPULATION DYNAMICS

Bats are small mammals but live a relatively long life compared to mice for instance - there are records of individuals of 20 and even more than 40 years old (14). Most of the species tend to have K-selected traits[6]: long life expectancy and the production of fewer offspring which often require extensive parental care until they mature.

A pregnant female will gather with other females to give birth a particular year but may not be able to do it every year for different reasons, and so it will live with her youngsters from previous years and other siblings. A male may be close to a particular group over winter but more solitary in summer. Therefore, a single bat may live in a variety of groups or families during its whole lifespan (8).

A typical situation is the gathering of a large number of individuals coming from the same local population (i.e. of close genetic distance) for hibernation in winter. These individuals will then split into smaller groups at spring time. Females and males live separately until autumn when they mate (11).

Particularities also occur: some species such as *Myotis bechsteinii* have very few exchanges between colonies. By studying the mitochondrial DNA of several maternity colonies it has been shown that all females share a common genotype (15).

In general, bats seem to have a typical population dynamic because the mortality rate is constant, independently of the age of adult individuals (10). In Europe, they have no major natural predators unlike many other animals since they are mostly active at night. A few are caught by opportunistic birds of prey (kestrel, sparrowhawk, owls) or other mammals (beech marten, weasel and stoat), but it is rather the domestic cat that has a significant impact on bat populations (16).

Thus, the small numbers of bats in a colony which reach sexual maturity and successfully rear a youngster each year makes long life essential if the population is to be maintained.

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[5] A two-year study on the diet of one individual of *Plecotus austriacus* at Mdina (Malta) resulted in 23 different species of moths, some of which are known to be pests on agricultural products (167).

[6] In ecology, the r/K selection theory relates to the selection of combinations of traits in an organism that trade off between quantity and quality of offspring. The terminology was coined by the ecologists Robert MacArthur and E. O. Wilson based on their work on island biogeography (165).

Table 3 - Different population parameters for 5 species from Central Europe (from (10)).

	Nyctalus noctula	*Pipistrellus pipistrellus*	*Pipistrellus nathusii*	*Myotis myotis*	*Myotis mystacinus*
Adult mortality (per annum)	0,44	0,31 - 0,37	0,32 - 0,34	0,21 - 0,24	0,19
Average life expectancy (in years)	1,7	2,1-2,6	2,4-2,7	3,6 - 4,2	4,6
Average recorded age for individuals at least 1-year old (in years)	2,2 - 2,3	2,7 - 2,9	2,6 - 2,9	3,9 - 4,0	4,5
Maximal recorded age (years)	12	16	14	25	23
Nativity rate required for maintain the population (per annum)	1,5 - 1,6	0,9 - 1,2	0,9 - 1,05	0,54 - 0,64	0,48

B MIGRATORY SPECIES

Many of the European species of bats perform seasonal long distance migrations and use geographically widely separate habitats during their life cycle. Some of them migrate over distances over 1,000 km long, e.g. all *Nyctalus* species and *Pipistrellus nathusii*.

Data on bat migrations in Europe were compiled in a book published in 2005 by the German Federal Agency for Nature Conservation (17). The terminology that describes the observed migrating behaviour of bats is still inconsistent. Fleming & Eby (2003) in (17) suggested defining migration as a seasonal, usually two-way, movement from one place or habitat to another to avoid unfavourable climatic conditions and/or to seek more favourable energetic conditions.

Dispersal usually involves movements away from an animal's place of birth – but not always (18). Because it is often difficult to distinguish between dispersal and incompletely documented migrations, the three widely established though artificial categories of spatial behaviour in bats – long distance, regional and sedentary, were provisionally adopted and are shown in Table 4 for all species. Data available indicate that most of the long-distance migratory bats move into a northeast-southwest direction, while the movements of regional migrants present a typical star-like pattern.

Population dynamics are slightly different for migratory species: young females are very faithful to their place of birth based in northern Europe; while males select their mating roosts in areas close to the migratory routes used by females and connecting summer maternity colonies and hibernation roosts based in southern Europe.

Migration is still understudied in bats and much less understood than for example in birds. It is technically challenging to study but advances in science and technology should lead to major knowledge advances in future.

Table 4 – Spatial behaviour of European bat species (from (17)).
"(x)": means possible but not typical.

SPECIES	Long-distance (> 100 km)	Regional (10-100 km)	Sedentary (<10 km)
Rhinolophus blasii			x
Rhinolophus euryale		(x)	x
Rhinolophus ferrumequinum		(x)	x
Rhinolophus hipposideros		(x)	x
Rhinolophus mehelyi		(x)	x
Barbastella barbastellus		(x)	x
Eptesicus anatolicus			
Eptesicus nilssonii		x	
Eptesicus isabellinus		(x)	x
Eptesicus serotinus		(x)	x
Hypsugo savii	(x)	x	
Myotis alcathoe			x
Myotis aurascens			x?
Myotis bechsteinii			x
Myotis blythii oxygnathus		x	
Myotis brandtii		x	
Myotis capaccinii		x	
Myotis dasycneme		x	
Myotis daubentonii		x	
Myotis escalerai			
Myotis emarginatus		(x)	x
Myotis myotis		x	
Myotis mystacinus		x	
Myotis nattereri		(x)	x
Myotis punicus		x	(x)
Nyctalus azoreum		x	
Nyctalus lasiopterus	x?	x	x
Nyctalus leisleri	x		
Nyctalus noctula	x		
Pipistrellus hanaki			x?
Pipistrellus kuhlii		(x)	x
Pipistrellus maderensis			x
Pipistrellus nathusii	x		
Pipistrellus pipistrellus	x?	x	
Pipistrellus pygmaeus	x	x	
Plecotus auritus			x
Plecotus austriacus			x
Plecotus kolombatovici			x
Plecotus macrobullaris			x
Plecotus sardus			x
Plecotus teneriffae			x
Vespertilio murinus	x	(x)	(x)
Miniopterus schreibersii	(x)	x	
Tadarida teniotis			x
Rousettus aegyptiacus			x

2 - BAT CONSERVATION IN EUROPE

2.1 - Conservation through the Habitats Directive and EU policies

The Birds Directive (BD)[7] and Habitats Directive (HD)[8] are the cornerstones of the EU's biodiversity policy (19). They enable all 28 EU Member States (MS) to work together within a common legislative framework to conserve Europe's most endangered and valuable species and habitats across their entire natural range within the EU, irrespective of political or administrative boundaries.

The overall objective of the HD is to maintain and restore to a favourable conservation status natural habitats and species of wild fauna and flora of Community interest. This directive does not cover every species of plant and animal in Europe (i.e. not all of the EU's biodiversity). Instead, they focus on a sub-set of around 2,000 (out of ca 100,000 or more species present in Europe) which are in need of protection to prevent their extinction. These are often referred to as species of Community interest or EU protected species.

All bat species found in Europe have been considered to be of Community interest:

- **14 bat species** are included in **Annex II** of the HD, and hence require site designation (Special Areas for Conservation) and special management measures aiming at conserving core areas for these species ;
- **All bat species** are included in the **Annex IV** of the HD. This means that they benefit from the general species protection provisions *across their entire natural range* and therefore also outside protected sites. The deterioration or destruction of breeding sites or resting places is prohibited all over Europe (apart from the implementation of the derogation system foreseen by article 16 of the HD).

The directive requires that MS do more than simply prevent the further deterioration of the listed species. They must also undertake positive management measures to ensure their populations are maintained and restored to a ***favourable conservation status*** throughout their natural range within the EU.

Favourable conservation status can be described as a situation where a species is prospering (extent/population) and has good prospects to do so in future as well. The fact that a species is not threatened (i.e. not faced by any direct extinction risk) does not necessarily mean that it is in favourable conservation status. The target of the directive is defined in positive terms, oriented towards a favourable situation, which needs to be defined, reached and maintained. It is therefore much more than just avoiding extinctions.

2.1.1 - The Natura 2000 network

A central element of the nature directives is that they require MS to designate sites for selected species and habitat types listed in the directives to be included into the Natura 2000 network. Once designated, these sites must be managed in a way that maintains or restores those species and habitats for which they have been designated in a good conservation condition.

There are 23,115 sites covering 602,000 km² that have been designated in 2013[9], and more than 700 new sites, including many caves (> 170), were designated for Croatia which has recently joined the EU.

At the end of 2010, around a third of sites designated in the framework of the HD were holding bat populations, including 4,015 sites designated for Annex II bat species (see table below). However, if foraging areas and commuting routes taken into consideration, the number of sites is greater (possibly most of the sites).

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[7] Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (http://ec.europa.eu/environment/nature/legislation/birdsdirective)

[8] Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (http://ec.europa.eu/environment/nature/legislation/habitatsdirective)

[9] http://ec.europa.eu/environment/nature/info/pubs/docs/nat2000newsl/nat35_en.pdf

Table 5 - Data from the Natura 2000 database (end of 2010, excluding Population category D)

Bat species included in the Annex II of the Habitats Directive		**Number of sites designated for the species at the end of 2010**
Blasius's horseshoe bat	*Rhinolophus blasii*	82
Mediterranean horseshoe bat	*Rhinolophus euryale*	524
Greater horseshoe bat	*Rhinolophus ferrumequinum*	1,475
Lesser horseshoe bat	*Rhinolophus hipposideros*	1,504
Mehely's horseshoe bat	*Rhinolophus mehelyi*	129
Western Barbastelle bat	*Barbastella barbastellus*	1,129
Bechstein's bat	*Myotis bechsteinii*	992
Lesser mouse-eared bat	*Myotis blythii*	551
Long-fingered bat	*Myotis capaccinii*	237
Pond bat	*Myotis dasycneme*	359
Geoffroy's bat	*Myotis emarginatus*	798
Greater mouse-eared bat	*Myotis myotis*	2,266
Schreiber's bat	*Miniopterus schreibersii*	744
Egyptian fruit bat	*Rousettus aegyptiacus*	26

These sites have to be managed and protected in accordance with the provisions of Article 6 of the HD. These provisions are briefly described hereby as they have a direct relevance for the conservation of bats. The first two paragraphs of Article 6 require MS to:

- establish the necessary conservation measures which correspond to the ecological requirements of the relevant bat species on the sites (Art 6.1);
- prevent any damaging activities that could significantly disturb the relevant bat species or deteriorate their habitats (Article 6.2).

To facilitate this task, MS are encouraged to develop **conservation objectives for each Natura 2000 site**. As a minimum, the conservation objective will be to maintain the conservation condition of bat species for which it was designated and not to allow this to deteriorate further. However, as the overall objective of the directive is for all bat species to reach a favourable conservation status, more ambitious conservation objectives may be set to improve the conservation condition of these species on a site. **Natura 2000 management plans,** where they exist, often outline the conservation objectives for the site and the measures needed to achieve these objectives.

Whereas Article 6(1) and 6(2) of the HD concern the day-to-day management and conservation of Natura 2000 sites, Articles 6(3) and 6(4) lay down the procedure to be followed when planning new developments that might have adverse effects to a Natura 2000 site.

Basically, it requires that any plan or project that is likely to have significant negative effect on a Natura 2000 site undergoes **an 'Appropriate Assessment'** to study these effects in detail and in view of the site's conservation objectives.

Depending on the findings of the appropriate assessment, the competent authority can either agree to the plan or project as it stands if it has ascertained that the project will not have adverse effects to the integrity of the site. Alternatively, depending on the degree of the identified impacts, the competent authority may require:

- the plan or project to be redesigned to prevent adverse effects on the Natura 2000 site;

- mitigation measures to be introduced to remove the negative effects; or certain conditions to be respected during the modification, upgrading and maintenance of the river ecosystems or the construction of associated infrastructures, again to remove the likelihood of negative effects;
- alternative less-damaging solutions to be explored instead.

In exceptional circumstances, a plan or project may still be approved in spite of it having an adverse effect on the integrity of one or more Natura 2000 sites provided the procedural safeguards laid down in the HD are followed (Article 6(4)). Thus, if it can be demonstrated that there is an absence of alternatives and the plan or project is considered to be necessary for ***imperative reasons of overriding public interest,*** then the project may still be approved provided adequate compensation measures are put in place to ensure that the overall coherence of the Natura 2000 network is protected.

2.1.2 - Species protection provisions

In addition to protecting core sites through the Natura 2000 network, the Habitat directive also requires that MS establish a general system of protection for species listed in Annex IV of the HD including all bat species found in Europe. These provisions apply both within and outside protected sites.

The exact terms are laid down in article 12 of the HD[10]. They require MS, amongst others things, to prohibit:

- the deliberate disturbance during breeding, rearing, hibernation and migration;
- the deterioration or destruction of breeding sites or resting places;

The number of derogations issued under article 16 of the HD is not precisely known but there are a number of them.

As some of the protected bat species are potentially vulnerable to long distance interferences with their habitats, these provisions must be taken into account when considering building traffic infrastructures or wind farms only a few kilometres around roosting sites or resting places.

However, the case of “accidental killing” has to be clarified. In view of the impact of roads and wind farms on bats (see below), it is difficult to determine whether the article 16 derogation system has to be applied or if the article 12.d) should be used. Referring to this article, MS shall establish a system to monitor the incidental capture and killing of the bat species listed in Annex IV. In the light of the available information reviewed, MS shall take further research or conservation measures as required to ensure that incidental capture and killing does not have a significant negative impact on the species concerned. It seems that these monitoring systems do not currently exist in most of the MS.

2.1.3 - EU biodiversity strategy

On the 3rd May 2011, the European Commission adopted a new strategy to halt the loss of biodiversity and improve the state of Europe’s species, habitats, ecosystems and the services they provide over the next decade. The EU Biodiversity strategy to 2020 includes a vision for 2050 and a 2020 headline target.

In addition, or in coherence with the new focus on ecosystem services, two specific targets will directly benefit to bat populations:

- The full implementation of the EU nature legislation (Actions: complete the establishment of the Natura 2000 Network and ensure good management; ensure adequate financing of Natura 2000 sites; increase stakeholder awareness and involvement and improve enforcement ; improve and streamline monitoring and reporting);

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[10] See the guidance document on the strict protection of animal species of Community interest under the Habitats Directive: http://ec.europa.eu/environment/nature/conservation/species/guidance/index_en.htm

- More sustainable agriculture and forestry (Actions: enhance direct payments for environmental public goods in the EU Common Agricultural Policy; better target Rural Development to biodiversity conservation; conserve Europe's agricultural genetic diversity; encourage forest holders to protect and enhance forest biodiversity; integrate biodiversity measures in forest management plans)

A set of biodiversity indicators will help to determine whether there has been an overall improvement in the state of Europe's biodiversity. Two of them will use available data on bats:

- A reduction in the number of species threatened with extinction;
- An increase in the number of species and habitats protected under EU nature legislation that is in favourable conservation status.

An analysis was prepared for 20 MS11 to compare the situation in terms of conservation status from the article 17 report for the period 2007-2013 per "trinomial"[12] Species/Biogeographic Area/Member State/Species (sp/BA/MS):

- 606 sp/BA/MS have a known status in 2013, including 193 with a favourable conservation status only
- On this data set, 327 BA/MS/sp are comparable between 2006 and 2013;
  - The situation was **stable for 213 sp/BA/MS** (including 72 still with a favourable status);
  - The situation has **improved for 53 sp/BA/MS** (including 26 now in favourable status);
  - The situation **was worst for 34 sp/BA/MS** (including 16 now in bad status);
  - For 6 sp/BA/MS, the species was not known in 2006, but is present in 2013 with a new conservation status;
- For 3 sp/BA/MS, the species was present in 2006 and is now absent in 2013 (temporarily?): *M. blythii* in the Mediterranean region of Malta, *N. noctula* in the Alpine region of Spain and *V. murinus* in the Atlantic region of Belgium ;
- The situation was unknown in 2006 and has been assessed in 2013 for 147 sp/BA/MS (including 10 for which the species is now considered as absent).

These figures have to be taken with caution because improvement or deterioration of conservation status may be related mostly to a better knowledge.

2.1.4 - Green infrastructures

On 5th May 2013, the European Commission published a new Strategy to promote the use of Green Infrastructure across Europe (20). Green Infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. The new Strategy calls for Green Infrastructure to be fully integrated into policies, and to become a standard part of spatial planning and territorial development.

The Natura 2000 Network forms the backbone of Europe's Green Infrastructure which will help reduce the fragmentation of the ecosystems, improving the connectivity between sites in the Natura 2000 Network and thus achieving the objectives of Article 10 of the HD.

In addition to designating core sites under the Natura 2000 Network, Article 10 of the HD also requires MS to endeavour to improve the ecological coherence of the network across the broader countryside by maintaining and, where appropriate, developing features of the landscape which are of major importance for wild fauna and flora, such as wildlife corridors or stepping stones which can be used during migration and dispersal.

Bats are very good indicators for this Green Infrastructure and the ecological network present in the countryside because most of them are using commuting routes between their roosts and their

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[11] It was not possible to include other MS (IE, SE, AT, SI, NL, DE) because of encrypted data. Greece is still in preparation at the date of 22/01/2014 and Croatia had no obligation in 2013.

[12] Trinomial = one species in one biogeographic area from one Member State (combinations - BA/MS/sp)

foraging areas, up to 40 km for some species (21). Landscape features such as hedges, rivers and cliffs are indeed particularly well used by bats.

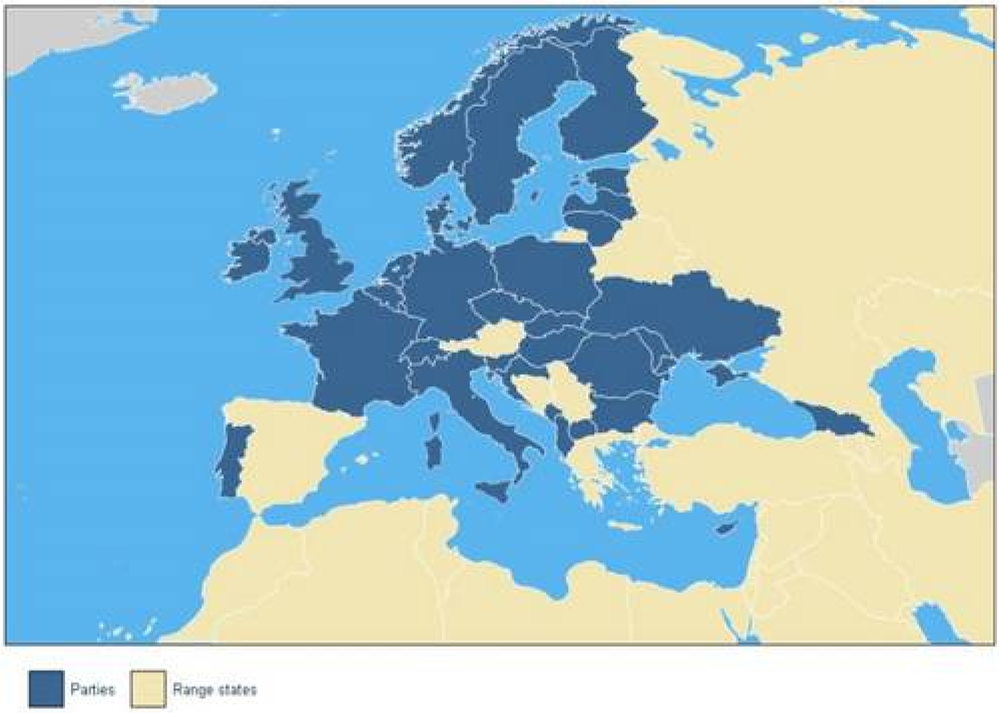
2.2 - UNEP/EUROBATS

The Convention on the Conservation of Migratory Species of Wild Animals (also known as CMS or Bonn Convention[13]) aims to conserve terrestrial, aquatic and avian migratory species throughout their range. It is an intergovernmental treaty concluded under the aegis of the United Nations Environment Programme (UNEP).

As the only global convention specialising in the conservation of migratory species, their habitats and migration routes, CMS complements and co-operates with a number of other international organisations, NGOs and partners in the media as well as in the corporate sector.

Migratory species threatened with extinction are listed on Appendix I of the Convention. However, none of the European bats are listed in this Annex. Migratory species that need or would significantly benefit from international co-operation are listed in Annex II of the Convention. For this reason, the Convention encourages the Range States to conclude global or regional Agreements. In this respect, CMS acts as a framework Convention. The Agreements may range from legally binding treaties (called Agreements) to less formal instruments, such as Memoranda of Understanding, and can be adapted to the requirements of particular regions. Such agreements have the great advantage that the Range States themselves decide on a tailored and structured action plan that includes the organization of joint research, monitoring activities and harmonisation of legislation.

Several Agreements have been concluded to date under the auspices of CMS including an Agreement on the Conservation of Populations of European Bats (EUROBATS[14]) dating from December 1991[15]. All the European bats are included in the Annex II of the CMS apart from *Rousettus aegyptiacus* which is however taken into consideration by EUROBATS.



Map 2 - Parties and Range States of the UNEP/EUROBATS Agreement

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[13] www.cms.int/index.html

[14] www.eurobats.org

[15] Apart from *Rousettus aegyptiacus*, all the European bats are included in the annex II of the CMS.

2.2.1 - The UNEP/EUROBATS Agreement

The Agreement on the Conservation of Populations of European Bats entered into force on 16th January 1994. As of December 2012, 35 of 63 Range States are Parties to the Agreement. In the EU, Austria, Greece and Spain are not parties but they may participate to common work.

The Bat Agreement aims to protect all the European bat species[16] - whether migratory or not - occurring in Europe and non-European Range States. The aim of EUROBATS is to conserve these bats through legislation, education, conservation measures and international co-operation amongst Agreement Parties and with those countries that have not yet joined.

EUROBATS sets up legal protection standards, while developing and promoting transboundary conservation and management strategies, research and public awareness across the Agreement area. It also assists in finding financial support for mainly cross-border oriented projects. EUROBATS has developed a wide-ranging Conservation and Management Plan, which is the key instrument for the implementation of the Agreement.

2.2.2 - Working within the framework of EUROBATS

2.2.2.1 - Meeting of Parties (MoP) and Secretariat

Since the first one in 1995, there are periodic Meetings of Parties (MoP) to this Agreement (in average every 3 years). This is the key governance place for any matter related to the Agreement. In 1995, during its first session, the MoP took the following key decisions:

- Establishment of a permanent **Secretariat** in Bonn in collocation with the CMS Secretariat ;
- Establishment of an **Advisory Committee,** which may establish working Groups, to provide expert advice and information to the Parties and the Secretariat;
- Adoption of priorities for Bat Conservation through the first **Conservation and Management Plan**.
- Proposal of guidelines for **national report** to the Parties;

Furthermore, since 2006 a **Standing Committee** was established to act on behalf of the MoP mainly with administrative matters, finance and representation.

The core functioning of the Agreement remains the same today but, as described below, the Conservation and Management plan is amended during the MoP.

The EUROBATS **Secretariat's** particular tasks are to:

- exchange information and co-ordinate international research and monitoring initiatives;
- arrange the Meetings of the Parties and the Advisory and Standing Committee meetings;
- stimulate proposals for improving the effectiveness of the Agreement, and attract more countries to participate in and join the Agreement;
- stimulate public awareness of the threats to European bat species and what can be done at all levels to prevent their numbers dwindling further.

2.2.2.2 - Advisory Committee and Intersessional Working Groups (IWG)

To advice the Parties and prepare technical resolutions for the MOP and the revision of the Conservation and Management Plan, there are regular (annual) meetings of the Advisory Committee. The work is prepared with working groups which organise meeting more or less regularly depending on the subjects. Even if they meet quite often during institutional meetings, they are named intersessional working groups (IWG).

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[16] www.eurobats.org/about_eurobats/protected_bat_species

In the ongoing quadriennium 2011-2014, there are 16 IWG[17] working on different bat conservation issues in order to fulfil the requirements of the last MoP resolutions including the 2011-2014 Conservation and Management Plan.

- 1. Conservation of Key Underground Sites
- 2. Bat Conservation and Sustainable Forest Management
- 3. Monitoring and Indicators
- 4. Monitoring of Daily and Seasonal Movements of Bats
- 5. Autecological Studies for Priority Species
- 6. Wind Turbines and Bat Populations
- 7. Light Pollution
- 8. Conservation and Management of Critical Feeding Areas and Commuting Routes
- 9. Man-made Purpose-built Bat Roosts
- 10. Impact of Roads and other Traffic Infrastructures on Bats
- 11. Lethal Fungal Infections
- 12. Implementation of the Agreement
- 13. Review of the Format of National Reports
- 14. Bat Rehabilitation
- 15. Bats and Insulation
- 16. Eurobats Projects Initiative Selection Working Group

The minutes and resolutions taken during the annual Advisory Meeting and documents produced by the IWGs are published on the EUROBATS website (www.eurobats.org) and on an extranet platform for members of the working groups. This published material was a key source for the preparation of this EU Action Plan and relevant information is presented in the corresponding chapters.

2.2.3 - Conservation and Management Plan

The fundamental obligations of the Agreement are described in its article III. To help apply article III and set up priorities, a **Conservation and Management Plan** is endorsed by the Parties during the MoP.

Some **resolutions** concerning conservation issues and priorities are also voted during the MoP to be integrated in the Conservation and Management Plan. MoP after MoP, the Conservation and Management Plan is updated and makes reference to past endorsed resolutions. It may also make reference to other official papers as those prepared by the Advisory committee.

The **current Conservation and Management Plan** was adopted in September 2010 for the period 2011-2014. Apart from institutional matters[18], it encompasses 7 main topics that will be better described in the conservation chapters further down in this document:

- Population survey and Monitoring (8 items)
- Roosts (2 items)
- Habitats (4 items)
- Promoting Public Awareness of Bats and their Conservation (3 items)
- Pesticides
- Diseases
- EUROBATS Projects Initiative (EPI)

Details of the outcome of each IWG can be consulted on the EUROBATS workspace website[19].

As foreseen in the article VI of the Agreement, each Party has a duty to provide regularly updated **National Reports** on the implementation of the Agreement. A number of non-party Range States also provide Eurobats with a national report. For the 6th Session of the meetings of the parties, 30 Parties provided national reports and 3 non-parties as well. Furthermore, some oral presentations also occur

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[17] http://workspace.eurobats.org/node/257

[18] Legal requirements & International co-operation

[19] http://workspace.eurobats.org/node/257

during the meeting. The two main parts of these reports concern the status of bats within the territory and the measures taken to implement the key article III of the Agreement.

In relation to the Conservation and Management Plan or to the work undertaken by the Advisory Committee and the IWGs, EUROBATS has already published several key documents dealing with various aspects of bat conservation. There are 3 main categories of publications:

- The EUROBATS Publication series that are sometimes reporting on the implementation of the EUROBATS Agreement in the Range States, and sometimes providing guidance on the best practices to protect bats and their habitats. It includes:
  - ✓ "*Conservation of Key Underground Sites*" (2010)
  - ✓ "*Guidelines for Surveillance and Monitoring of European Bats*" (2010)
  - ✓ "*Protection of overground roosts for bats*" (2nd edition, 2010)
  - ✓ "*Guidelines for consideration of bats in wind farm projects*" (2008)
  - ✓ "*Protecting and managing underground sites for bats*", (3rd edition, 2010)
- The EUROBATS Leaflets such as the one on "*Bats and Forestry*" published in 2009 after the work undertaken by the Advisory Committee and its IWG.
- Other specific publications prepared by partners :
  - ✓ "*Building Bat Friendly*" (Landschapsbeheer Flecoland, 2011)
  - ✓ "*Investigating the role of bats in emerging zoonoses - balancing ecology, conservation and public health interest*" (FAO, 2011)
  - ✓ "From *a Plattenbau block of flats into a tower for bats - a report with hints for planning*" (Institut für Tierökologie und Naturbildung, 2008).
  - ✓ "*Bats in Forests - Information and Recommendations for Forest Managers*", (Deutscher Verband für Landschaftspflege – DVL, 2001).

2.3 - NGOs and BatLife Europe

In 2003, the 4th EUROBATS Meeting of Parties recognized in its resolution n°4.11 the important role of Non-Governmental Organizations (NGOs) in bat conservation. Bats benefit highly from their voluntary monitoring and data collection work and their enormous and most successful efforts in raising public awareness. NGOs' expertise and activities represent a substantial contribution to the successful implementation of the EUROBATS Agreement and to bat conservation. There are tens of NGOs at national or local level, sometimes specialised or with a broader approach (mammals or fauna). The resolution encouraged activities of NGOs to collaborate in their activities and to share their experience in ways that have the potential to substantially improve transboundary co-operation and exchange of information as well as mutual assistance, including, where appropriate, the establishment of a pan-European umbrella organisation.

In 2006, the Bat Conservation Trust (BCT) UK was invited to establish BatLife Europe[20] and accepted. In 2010, BCT united with 5 other NGOs[21] to found BatLife Europe and invite others to join them.

BatLife Europe was launched as an international NGO in 2011 at the European Bat Research Symposium in Lithuania and currently (2013) has 33 partner NGOs in 30 countries and a part time secretariat based in London (currently in progress of registering as a UK charity).

BatLife Europe follows a membership model based on that of Birdlife International, which allows NGOs from across Europe and beyond to contribute. The trustees have decided that only national conservation NGOs should be able to become partners in BatLife Europe. However, other types of organisations such as state-owned museums and academic institutions can also work closely with BatLife Europe, as collaborating organisations.

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[20] www.batlife-europe.info

[21] The Dutch Mammal Society (DMS), Nature and Biodiversity Conservation Union (NABU), Romanian Bat Protection Association (RBPA), StiftungFledermaus and the French Society for Study of Mammals and their Protection (SFEPM).

BatLife Europe aims to conserve bats and their habitats and provide a stronger international voice for bat conservation in Europe by:

- Facilitating international communication and knowledge sharing
- Identifying European conservation priorities
- Developing pan-European projects
- Fundraising for international projects
- Developing best practice guidelines
- Assisting in capacity building
- Providing support and technical advice for EUROBATS initiatives
- Coordinating action in relation to special threats
- Collecting / managing data
- Assisting national bodies in developing / implementing national conservation plans /strategies
- Giving international status to national NGOs
- Providing international support for national matters of concern

BatLife Europe is active within the Eurobats Agreement and has been a partner in the development of the pan European bat indicator, BatLife Europe is also a member of the European Habitat's Forum, a partnership of over 20 environmental NGOs working together collaboratively at the European level, and is linking up with bat conservation networks in other continents to share knowledge and best practice.

In 2012, BatLife undertook a survey of the priorities and capacity building needs of its NGO members and 25 took part. The survey showed there is a big range of types and size of NGOs involved in bat conservation in Europe, some with staff, others entirely run by expert volunteers, and carrying out a range of activities from projects on bat research to conservation and education. Most NGOs are active in engaging people, carry out conservation activities, hold a database of bat records and monitor at population trends (to varying levels) and are engaged in some kind of political work. Some NGOs also carry out consultancy work or undertake practical work at roosts or nature reserves or by caring for injured bats or engage in fundraising. The survey identified the bigger barriers to bat conservation perceived by NGOs is lack of funding, followed by lack of people, the economic and political situation and lack of data. In terms of capacity building needs, the survey generated a large number of requests for help but also offers of help in sharing expertise in these areas:

- Engaging new members and volunteers
- Increasing public awareness about bat conservation
- Fundraising techniques
- Setting up a national bat monitoring programmes
- Storing and handling bat data
- Bat reserve/roost creation and management
- Lobbying for change
- Investigation of bat crime and persecution

BatLife Europe is now working to share knowledge and experience through sharing guidance and documents, by personal contacts and through twinning of NGOs and in due course aim to run capacity building workshops at existing international bat conservation and research events.

2.4 - Bat Action Plans

Many MS have monitoring programmes or site management plans including bat conservation objectives (e.g. for Natura 2000 sites). In addition, specific "Species Action Plans" or Conservation or Restoration Plans for species were also set up in a number of MS (national and/or regional level). These plans are be based on expert knowledge and implemented according to national specificities. They include specific measures or general ones as the adoption of measures (e.g. codes of best practice), to minimize damage to bats.

Some specific examples are presented below. Quite all the other MS are nevertheless implementing conservation actions concerning bats. National reports to EUROBATS present good illustration of the actions undertaken[22].

2.4.1 - National Action Plans

- Bat conservation action plans were included in the new Strategy and Action Plan for the Protection of Biological and Landscape Diversity of the Republic of **Croatia** from 2008, especially in regard to wind farms. However, management plan for bat species have not yet been prepared.
- **Estonia** has an Action Plan for the protection of bats. The first plan[23] covered the period 2005-2009. This plan identifies the main threats and important actions to improve the conservation status of bats. The compilation of a new action plan was contracted with NGO-organization after a successful public tender and is ongoing
- In **Finland**, a species action plan is considered for *Myotis nattereri*, as it is a species under strict protection.
- In **France**, after a first restoration plan implemented from 1999 to 2004 by the French Society for the Mammals Study and Protection (SFEPM), a new National Action Plan is currently implemented under the auspice of the French Ministry of Environment and with the support of a new legislation. This national action plan 2009-2013 involves numerous NGOs, local administrations and public bodies. 26 actions covers all aspects needed for bat conservation are included: protection and monitoring of roosts, forestry, transport infrastructures, wind energy, populations monitoring of all bat species present in the country, bat workers networking and raising public awareness…
- In **Germany** a Species Action Plan for the Lesser Horseshoe Bat has been drafted in 2013.
- In **Hungary**, the Minister for environment and water adopted a Species Protection Plan for *Nyctalus lasiopterus*.
- An "All-**Ireland** Species Action Plan – Bats" was published in 2008[24]. This Action Plan targets the maintenance of the populations of all bat species in Ireland and of their present range. It suggests a number of actions to be carried out in the interest of bat conservation by the lead agencies (NPWS, EHS, BCIreland, etc.). It also sums up all the current actions being carried out in favour of bats in Ireland.
- In **Lithuania**, a Ministerial order approved the project "*Preparation of Action Plans for Protection of Rare Species and Action Plans for the Control of Invasive Species*". This project includes three conservation plans for *Myotis dasycneme, Pipistrellus nathusii* and *Plecotus auritus*. Additional plans are also planned for other species.
- In **Luxembourg**, a five-year nature protection plan was established for bats in May 2007 by the Ministry of Environment. Three species are currently in the national nature protection plan and benefit from a species action plan since 2009[25]: *Barbastella barbastellus*, *Myotis emarginatus* & *Rhinolophus ferrumequinum*. Management targets are listed for each of these species, most of them for the conservation and restoration of habitats.
- In **Portugal**, a conservation plan for cave-dwelling species was published in 1992 (22).
- An action plan has been built in order to implement the EUROBATS agreement in **Sweden**. This action plan was published in 2006 under the name **"***Conservation and management of the bat fauna in Sweden - Action plan for implementation of the EUROBATS agreement*". It was written by a group of scientists and officials at Swedish Environmental Protection Agency (SEPA). In this report are discussed the following points:
    - ✓ importance of protection and management of important bat habitats

[22] http://www.eurobats.org/official_documents/national_reports

[23] http://envir.ee/498230

[24] www.npws.ie/publications/speciesactionplans/2008_Bat_SAP.pdf

[25] www.environnement.public.lu/conserv_nature/dossiers/Plans_d_actions/Plans_d_actions/index.html

- ✓ Implementation of available knowledge on bat ecology in several field activities
- ✓ Impact assessments

A central coordinator, a reference group of experts and contact persons at regional authorities were suggested. Other subjects are approached, such as public awareness, information circulation, organisation of the work, etc.

The necessity of creating species-specific recovery plans is also pointed out in Sweden. The first priority is to establish an action plan for *Barbastella barbastellus* and coordinate the efforts to protect and manage this species. Other action plans are likely to follow, probably for *Myotis bechsteinii* and *Myotis dasycneme* and perhaps one or two more species.

- In the **UK**, *Barbastella barbastellus*, *Myotis bechsteinii, Pipistrellus pygmaeus, Plecotus auritus, Nyctalus noctula, Rhinolophus ferrumequinum and R. hipposideros* benefit from Species Action Plan updated in December 2010 by the Joint Nature Conservation Committee (JNCC)[26], a statutory adviser to the UK Government. This was done for the priority species (most threatened and requiring conservation action) in the framework of the UK Biodiversity Action Plan. However, as a result of devolution, and new country-level and international drivers and requirements, much of the work previously carried out by the UK BAP is now focussed at a country-level.

2.4.2 - Other regional action plans

- In **Belgium**, the LIFE+ project "*Bat action, Action plan for three threatened bat species in Flanders*"[27] may be considered as a regional action for bats for the period 2006-2010. It was a major driving force for all kind of initiatives relating to bat conservation and bat management in Flanders (**Belgium**): land acquisitions, management plan, census, awareness campaigns. This project was a collaboration scheme between the Flemish Agency for Nature and Forest and the NGO Natuurpunt. It included three targeted bat species (*Myotis bechsteinii, Myotis dasycneme, Myotis emarginatus*) and aimed to achieve a substantial increase in numbers of bats. A species action plan is also implemented for *Rhinolophus hipposideros* in the Walloon region for the relict maternity colonies.
- In **Germany,** there are numerous bat actions planned at regional level and some of them could be considered as Species action Plan. In Bayern (and in Berlin), local species-assistance programmes for bats have been built to implement conservation measures on threatened species[28]. In Thuringia and Bavaria, there are Coordination agencies for bat conservation (since 1996) that supports and develops bat conservation programmes.
- In **Netherlands**, an action plan for bats was launched in 2006 by the province of Noord-Brabant, which is still currently running.
- In **Romania**, the Life+ Project "*Bat Conservation in Pădurea Craiului, Bihor and Trascău Mountains*" has been contracted in 2009 by the regional Environmental Protection Agency of Bihor. This project plans to implement conservation actions for bats on 16 Natura 2000 sites. Management plans for 7 bat species (*Myotis myotis, Myotis oxygnathus, Myotis bechsteinii, Barbastella barbastellus, Rhinolophus ferrumequinum, Rhinolophus hipposideros, Miniopterus schreibersii*) are to be established.
- In **Spain,** two specific Action Plans are in place in the Autonomic region "comunitat valenciana" on *Myotis capaccini* and *Rhinolophus mehelyi* respectively.

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26 http://jncc.defra.gov.uk/page-5170

27 www.natuurenbos.be/~/media/Files/Projecten/BatAction/laymans%20report.pdf

28 www.lfu.bayern.de/natur/artenhilfsprogramme_zoologie/fledermaeuse/index.htm

2.4.3 - Action Plans for the conservation of bats in Europe

- For conservation of *Rhinolophus ferrumequinum*, an Action Plan was prepared by R.D. Ransome, Anthony M. Hutson in 1999 (under the Bern Convention - Council of Europe). The Action Plan gives details about the status, ecology main threats of the greater horseshoe bat (23);
- The Action Plan for the Conservation of *Myotis dasycneme* in Europe was prepared by Herman Limpens, Peter Lina and Anthony Hutson in 1999 (Council of Europe). The document reflects the results of the surveys concerning the species ecology and conservation status at European level from that time (24).
- The Action Plan about Microchiropteran Bats includes a global status, survey and conservation actions of all bat species, complied by Anthony M. Hutson, Simon P. Mickleburgh, and Paul A. Racey (IUCN/SSC Chiroptera Specialist Group) in 2001 (25).

2.5 - EU and EUROBATS co-funded projects

There are many actions implemented for bat conservation by local NGOs with the support of local administration and sponsors. It is not the right place here to list them all. However EU or EUROBATS supported projects may well illustrate needs and possibilities.

The EUROBATS Project Initiative (EPI) was launched in August 2008 to provide appropriate funding for small to medium sized bat conservation projects (costs of up to 10,000 €). The following criteria are taken into account when assessing EPI projects (Details of each project are presented in Annexe 2):

- Predictable impact for bat conservation, in particular the implementation of the Conservation and Management Plan of the Agreement, other EUROBATS Resolutions, national conservation targets or public awareness,
- Degree of transboundary character,
- Contribution on the promotion of international cooperation of Parties and Range States,
- The ability of the project to provide innovative information and experience that can be shared with other parties and range states,
- Contribution on the education and motivation of newly established bat workers,
- European conservation concern of targeted species as defined by other EUROBATS Resolutions or the European Mammal Assessment,
- Envisioned outcomes of the project like publications, guidelines or follow-up programmes, educational outreach.

This approach focusing small projects does not exist as such in EU cofounded projects. However MS may use structural funds (Interreg) or EARDF funds (Leader) for small projects even if the competition is hard to access these funds. Annexe 2 lists the various projects (n=19) dedicated to bat conservation funded through European programmes. **Life** is the main financial tool used by these projects.

3 - SURVEILLANCE AND KNOWLEDGE ASSESSMENT

Good quality data are needed on the actual range of the species, on the size of colonies, populations and quality of habitats. The current conservation status of bats in the European Union means that information on changes in the distribution and abundance of bat species over time is still required. The size of population changes over years and has to be updated regularly (e.g. every 6 years as required by Art. 17 reporting). To help determining bat conservation status and preparing the article 17 reports, common methodologies or views on reference value and pressures are needed. Building capacity for monitoring in MS which do not currently have national monitoring schemes is needed.

In countries or regions with outdated or no data, basic surveys should start as soon as possible. In order to get comparable results, common standards for surveying need to be developed and agreed among countries (e.g. value given to acoustic data).

Population survey and monitoring is a key item of the EUROBATS Conservation and Management Plan and one the main activities of several IWGs aiming to develop common and transboundary approaches. The main results are publication of guidelines or recommendations and exchanges between experts and scientists to disseminate knowledge. There is a will, through pan-European observation frameworks, to identify national and European population trends, to better understand local and regional movements or to refine autecological data for representative key species.

The use of non invasive methods is preferred and two main guidelines were prepared by EUROBATS to reinforce ethical approaches in field studies:

- Guidelines for the Issue of Permits for the Capture and Study of Captured Wild Bats were issued in 2003[29] with some slight amendments later on.
- Guidelines on Ethics for Research and Field work practices were issued in 2010[30]

3.1 - Population survey

As stated in EUROBATS Publication series n°5, surveillance is defined as population surveys (range, abundance) over time, while monitoring is related to defined target involving species but also other factors surveillance.

3.1.1 - Surveillance methods

Preliminary general guidelines were published in 1998 ("Consistent monitoring methodologies"[31]) but the main current guidance document is the EUROBATS Publication series n°5 published in 2010: "**Guidelines for Surveillance and Monitoring of European Bats**". Guidelines should be reviewed regularly, every 3-5 years, to assess whether they need updating. The purpose of this manual is to recommend best practices to detect changes in distribution, range and abundance and provide long term population trends. The guidelines concentrates on the standardised methods required to produce indices of population change.

3.1.1.1 - Roosts counts

Surveillance activities are facilitated by the gregarious character of bats. Maternity and hibernation roosts are particularly useful for surveying numerous species. Counts of emerging bats or counts inside the roosts can be used for maternity roosts. At hibernation sites, the relationships between the number of bats seen and the number of bats present is not always clear because of numerous cracks and crevices in which bats may be hidden from view. The EUROBATS publication cites the example of a German cave in which about 300 individuals were visible when about 15,000 were present when counted with infrared detection

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[29] www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP4_Res.6_Issue_of_Permits.pdf

[30] www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP6_Record_Annex8_Res_6_5_Ethics.pdf

[31] www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP2_Res.2.pdf

Other summer or transitional roosts are also interesting but interpretation of data, especially quantitative, is more difficult when there are regular changes of roosts. It is much more difficult to count forest species, apart from the individuals using bat boxes (e.g. *Pipistrellus nathusii*) in forests with specific monitoring programmes.

In a greater urban area, there are many types of buildings (e. g. prefabricated houses) with structures as various gaps, cracks, vents of attic roofs and crevices that enable to roost some species of bats. In some countries these structures represent important hibernation sites of *Nyctalus noctula*. Because of the inaccessibility of this roost sites, it is possible only estimate number of individuals in cavities. Observation of bats flying out their roosts sites at each suitable building before they start to hibernate seems to be an effective method.

At late summer/autumn, swarming sites seem to play a key role in the yearly cycle of bats (which may be related to mating event, checking of hibernation sites, or training young...). Swarming sites attract thousands of individuals, and may also be roosts sites but not always.

3.1.1.2 - Away from roosts counts

Away from roosts counts use bat detectors or Automatic Recording Devices (ARDs), whereas walked surveys with handheld bat detectors, using line-transects and/or point-counts are utilised to monitor variation in abundance and activity between years. They are also used to study bat foraging areas or to identify commuting routes. This approach was proposed in Germany to fulfil the EC HD reporting requirements (26). Another approach is bat detector transects along roads using moving vehicles which provide statistically robust conclusions on population trends of common species along roadsides. Such a project is implemented at national level in France with 146 road sections monitored in 2008[32] through a partnership between scientists and volunteers.

Remote automated recording was not emphasised much by the EUROBATS publication. Noting the huge progress made during recent years concerning this technology and the development of classification tools[33], the guidelines could be updated to capture these new opportunities. New devices become available every year and some studies are now using batteries of ARDs. There are even new approaches concerning algorithms to use automatic data to monitor specific impacts as in the wind farms projects (27).

The capture of bats is not recommended for the purpose of surveillance unless less invasive bat detectors, ARDs and roosts counts methods are not adapted (e.g. to confirm reproductive status or for radio tagging projects). A good example may be provided by *Myotis bechsteinii* or *Myotis alcathoe* for which radio-tracking is generally needed to locate roosts. In addition, monitoring scheme for some countries include mist netting as the only applicable method for some bat species.

The EUROBATS Publication series n°5 are well designed to address long term surveillance with different scales of stratification relevant to surveillance obligations under the HD. However, this is not suitable for use in Environmental Impact Assessment (EIA) or to Article 6.3 on Appropriate Assessment because these involve short term studies and inappropriate sampling methods. Bat detector surveys in the countryside, using line-transect or point-count methods, should be analysed with the last scientist results in mind: e.g. a study based on 257 hours of listening in forests habitats (28) has shown that the exhaustiveness, in terms of number of bat species, was only rating at 65 % after 45 min. Therefore, data analysis and its transcription of impacts from EIAs is sometimes difficult to interpret both before the project authorisation and after during BACI protocols.

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[32] http://vigienature.mnhn.fr/chauves-souris

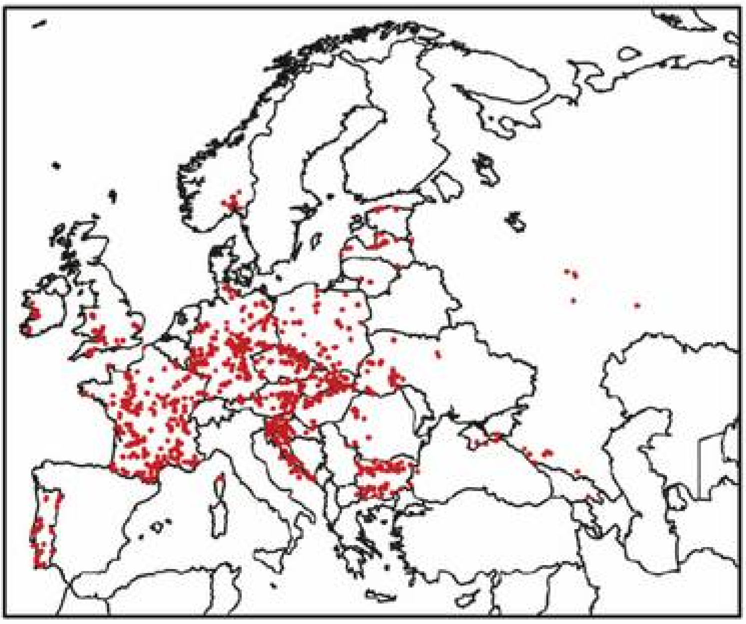
[33] As iBatsID, a free online tool developed by a network of European research worker, using ensembles of artificial neural networks to classify time-expanded recordings of bat echolocation calls from 34 European bat species https://sites.google.com/site/ibatsresources/iBatsID

3.1.2 - Data analysis and compilation for roosts

Because of the fidelity to the roosts and the gregarious nature of bats at roost sites, there is a great worth in compiling data from roosts counts to monitor their conservation status.

In 2010, EUROBATS collated a list of 1,487 internationally important underground sites for bats identified by Parties (1,402 for the EU). The current Conservation and Management plan envisaged to publish a new list in a suitable format accessible through the EUROBATS website.

It would be useful to analyse whether such sites are included within the Natura 2000 network (in the knowledge that some sites are may be important for Annex IV species only).



Map 3 - Underground sites important for bats in Europe as identified by EUROBATS Parties and Range States. The map shows the location of sites in the database at 1/11/06.

3.1.3 - Daily and seasonal movements - migration

The EUROBATS Conservation and Management Programme recommends collecting data on local and commuting movements among bat populations and identifying long distance migration routes. International-protection measures for bats are most important for those species which migrate furthest across Europe, crossing national boundaries. Possible dangers caused by barriers on the migratory routes of various species can then be identified and addressed by NGOs and MS. Furthermore, understanding migration is also important for understanding the potential spread of infections that can be harmful to bats and also to humans.

Among the transboundary approaches implemented by EUROBATS, a framework to study the status of *Pipistrellus nathusii* and especially its migration routes was launched in 1998 with specific recommendations including for banding. It seems that compilation of results was not specifically published apart from information presented in National reports and specific scientific papers or books published by scientists (17; 18).

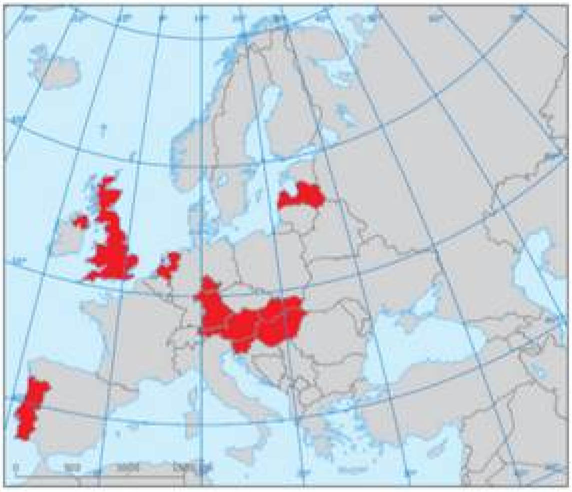
Today, the use of modern methods (e.g. genetics and isotope analysis) will supplement classical methods (e.g. banding) to identify long distance migration routes which cross national frontiers (29).

A EUROBATS IWG is currently tasked with the collection of migration data of species within the range of the Agreement. The data was to be obtained from published literature and other specialists. However, there is a need to collects data from 'grey literature' and from publications in several languages. A questionnaire on all species known to undertake seasonal movements is to be developed by EUROBATS and circulated among scientific focal points.

3.1.4 - Prototype pan European indicator

To improve the coordination of and streamline international biodiversity-related indicators, in line with the recommendation by Streamlining European Biodiversity Indicators (SEBI) 2010 to expand the suite of indicator taxa used to measure progress towards achieving biodiversity targets, EUROBATS seeks to develop indicators based on European bat monitoring data and conservation activities. This includes work towards the provision of standardised statistics in the national reports to EUROBATS.

The EUROBATS IWG on Monitoring and Indicators seeks to develop a bat indicator to summarize population trends at European scale. A first step towards this goal, developing a prototype indicator using hibernation data, has recently been possible through work commissioned by the European Environmental Agency (EEA) in 2011. This work has been published in the EEA technical report series[34] in early 2014.



The Bat Conservation Trust, the Dutch Mammal Society and Statistics Netherland led the work and established cooperation among 10 hibernation surveillance programmes in 9 countries.

The data contributing countries (see map 4) were UK, Netherlands, Bavaria and Thuringia (Germany), Austria, Hungary, Slovenia, Slovakia, Portugal and Latvia. The contributing hibernation surveillance schemes cover 6000 sites, 6 bio-geographic regions, 27 species and time series ranging from 6 to 26 years.

A **prototype** hibernating bat indicator, covering the period 1993-2011, incorporates data on 16 species from 10 schemes spread over 9 countries.

Overall, the species included in the prototype indicator appear to have increased by 43% at hibernation sites between 1993-2011, with a relatively stable trend since 2003. The apparent population increase of some species may reflect the impact of national and European conservation legislation, species and site protection, targeted conservation measures, the improvement of volunteers' skills to survey bats and widespread awareness-raising towards the public and professional sectors, particularly under the EUROBATS agreement. However, due to the **preliminary nature** of this prototype indicator, the early conclusion that bats have increased at hibernation sites should be **interpreted with caution** until the indicator can be expanded to cover a more representative range of European countries and species, and elements of the methodology to do with how sibling species are amalgamated be further refined. One species, *Plecotus austriacus,* shows a significant decline.

Map 4 - Data contributing countries for the prototype pan European indicator

[34] www.eea.europa.eu/publications/european-bat-population-trends-2013

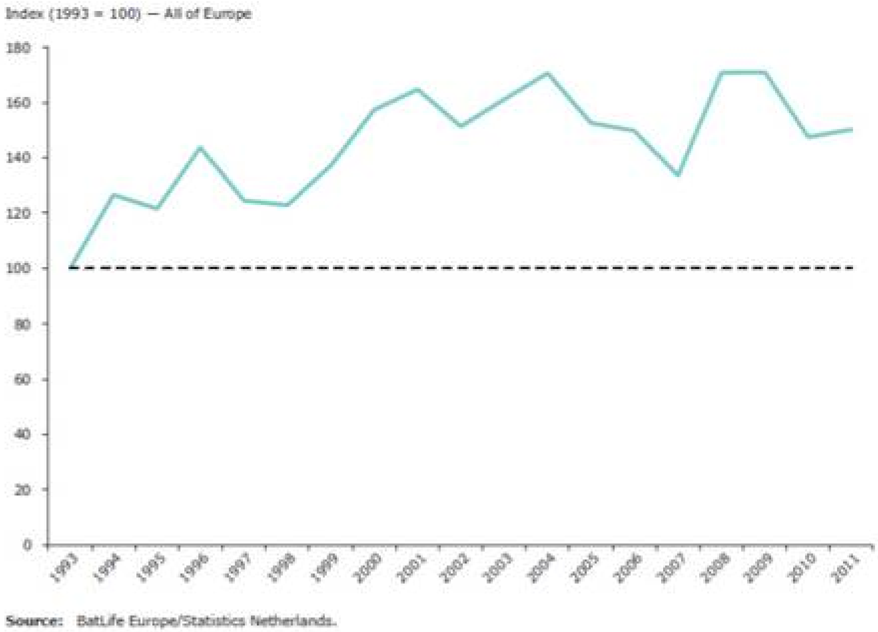


Figure 3 - The prototype European bat hibernating indicator (from (30))

Table 6 – Slope, error of slope and number of sites where the species occurred; trend of species and of the combined prototype European hibernating bat indicator

Species	Slope	Standard slope error	Number of sites	Trend classification
European hibernating bat indicator	**1.02**	(*) -		Increase
Rhinolophus euryale (Blasius, 1853)	1.08	0.03	37	Moderate increase
Rhinolophus ferrumequinum (Schreber, 1774)	1.04	0.01	272	Moderate increase
Rhinolophus hipposideros (Bechstein, 1800)	1.06	0.01	619	Moderate increase
Barbastella barbastellus (Schreber, 1774)	1.04	0.01	973	Moderate increase
Eptesicus nilssonii (Keyserling and Blasius, 1839)	1.03	0.02	309	Uncertain
Eptesicus serotinus (Schreber, 1774)	1.02	0.01	201	Stable
Myotis bechsteinii (Kuhl, 1817)	0.96	0.04	500	Uncertain
Myotis dasycneme (Boie, 1825)	1.00	0.01	230	Stable
Myotis daubentonii (Kuhl, 1817)	1.02	0.00	2 125	Moderate increase
Myotis emarginatus (Geoffroy, 1806)	1.08	0.02	111	Moderate increase
Myotis mystacinus/brandtii (Kuhl, 1879; Eversmann, 1845)	1.06	0.00	1 506	Strong increase
Myotis nattereri (Kuhl, 1817)	1.05	0.01	2 066	Moderate increase
Myotis myotis/(blythii) oxygnathus (Monticelli 1885)	1.02	0.00	1 748	Moderate increase
Plecotus auritus (Linnaeus, 1758)	0.99	0.01	3 655	Stable
Plecotus austriacus (Fischer, 1829)	0.91	0.03	399	Moderate decline
Miniopterus schreibersii (Kuhl, 1817)	1.00	0.01	44	Stable

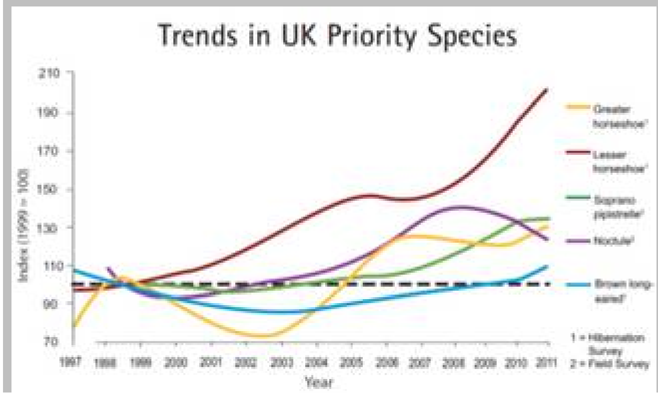
Note: (*) Trendspotter analyses differ from those of TRIM and do not result in standard errors of a slope.

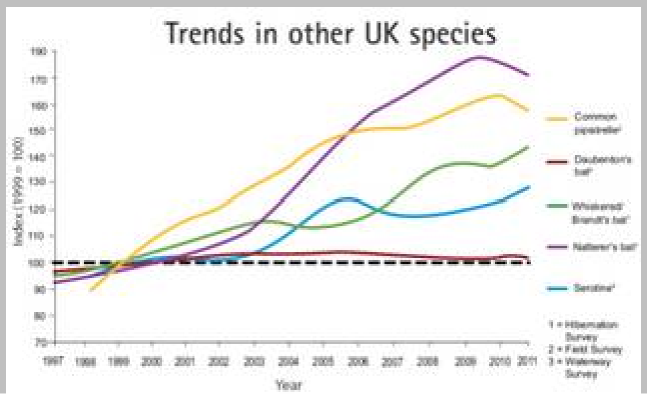
The future plan is to expand and update the indicator to incorporate data from at least 15 and ideally over 20 European countries at the earliest opportunity and to develop an additional trend line using data from maternity roosts. This is a realistic aim, given widespread pledges to participate from monitoring schemes in other countries, particularly from BatLife Europe partner organizations, but requires some funding to facilitate essential training in appropriate statistical techniques and coordination.

The working group would also like to develop a data sharing structure for census data to calculate pan-European and regional trends (which could be managed by BatLife Europe). This would also require specific funding.

National Bat Monitoring Programme in UK

Since 1996 more than 3,500 volunteers have taken part in surveys coordinated by Bat Conservation Trust (BCT) at over 6,800 roost or field sites around the UK. The data collected have already indicated population changes in some species but surveying needs to continue for many more years in order to ascertain whether these are long-term trends or simply short-term fluctuations. The figure above illustrates some of the results.





3.1.5 - Autecology / Population ecology- Specific action plan

In the framework of transboundary approaches implemented by EUROBATS, several species-focused approaches were developed

- In view of preparing an Action Plan for *Myotis dasycneme*, survey results have been collated in 1998/99. After all, the Action Plan for the Conservation of the Pond bat (*Myotis dasycneme*) in Europe was adopted by the Standing Committee of the Bern Convention (recommendation No. 73 on 3 December 1999) after consultation with EUROBATS. This action plan was published in 2000[35] (24).
- A working group on autecological studies has defined three priority species in 2004 (*Rhinolophus Euryale*, *Myotis capaccinii* and *Miniopterus schreibersii*) and a first state of the art was set up in 2006 and a more comprehensive one was prepared in 2010[36] (surveillance of populations and roosts, list of references and summaries, analysis of answers to the 2006 questionnaire).

3.2 - Gaps in biological knowledge

Good knowledge on bats ecology is needed to take the right decisions, address priorities and improve the management of priority areas. As in any action plan, filling the gaps in knowledge is a priority not only for biological and ecological aspects but also to assess the pressure of human activities.

- **Population ecology:**
  - ✓ The knowledge on regional meta-population is poor, even in countries with a long tradition on studying bats.
- **Behaviour:**
  - ✓ Several hypotheses have been produced to explain the gathering or swarming behaviour seen in late summer and autumn near cave or mine entrances. More research is required

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[35] Another one on *Rhinolophus ferrumequinum* was published at the same time (23). It seems that the results of both were never assessed.

[36] www.eurobats.org/sites/default/files/documents/pdf/Advisory_Committee/StC4_AC15_Doc_26_ReportIWG_PriorityySpecies.pdf

to fully explain the reasons of such phenomena (extension and importance in Southern Europe should be assessed).

- **Species knowledge:**
  - ✓ There is a strong lack of biological knowledge for the following species: *Myotis sclera*, *Myotis aurascens*, *Nyctalus azoreum*, *Plecotus kolombatovici, Nyctalus lasiopterus*.
  - ✓ Knowledge on cryptic species (*Pipistrellus*, *Myotis*...)
  - ✓ Why does *Nyctalus noctula* have a high nativity and mortality rate compared to the other species (10) ?
  - ✓ Natural wintering roost sites of *Nyctalus noctula*: Population size wintering in the structures of buildings (panel houses) in comparison with population size wintering in natural roost sites (tree or rock cavities);
  - ✓ For *Pipistrellus nathusii*, there is an urgent need of systematical studies about winter habitats of bats in the critical areas in coastal and mainland France, Italy, Slovenia, Croatia and the Balkans.
- **Migration:**
  - ✓ Migration mechanisms are still not well known and can have conservation implications (use of landscape features as spatial references, other environmental factors, memory or Earth magnetic field...);
  - ✓ Precise assessment of migration routes, including possible movements between Africa and Southern Europe ;
  - ✓ Lack of knowledge on migration pattern of *Pipistrellus pipistrellus*, *P. pygmaeus* and *Vespertilio murinus* in north-eastern part of species range ;
  - ✓ In spite of the study of *Pipistrellus nathusii* migration routes launched in 1998 by EUROBATS, migration is still not well understood. For instance, there is no detailed information about migration timing and important migration routes in east coast of Baltic Sea (Finland, Estonia, Latvia, Lithuania, and Poland). However, recent studies have provided evidence, that in some locations, *Pipistrellus nathusii* migration is very intensive and temporally concentrated. Recently, new wind farms have been erected and are planned in this coastal region without any intensive migration survey at all. There is also evidence that some species, which were thought to be mostly sedentary, are migrating distances greater than expected (e.g. *Eptesicus nilssonii*).
  - ✓ Do bats in the UK migrate?
  - ✓ Is there a migration through the Alps (because now wind farms are more and more planed in this area)?
- **Bats conservation:**
  - ✓ Impact of mortality due to human projects (wind farms, roads, insulation of buildings) on local bat population;
  - ✓ Role of compensation schemes and artificial roosts in population dynamics;
  - ✓ Effects of pesticides/biocides on bat survival / fitness (agricultural, forest and buildings);
  - ✓ Agriculture: impact of endectocides and farming practices.
  - ✓ Impact of building insulation on wintering and maternity roosts.
- **Bats and forestry:**
  - ✓ Assessment of direct mortality in bats due to forestry operations;
  - ✓ Evaluation on the density of “suitable” trees (e.g. dead trees for *Barbastella barbastellus*) to be left in order to sustain populations of forest species to provide foresters with appropriate guidelines to be put into practice rather than qualitative indications or “rules of thumb”;
  - ✓ Effects of forest fragmentation on movement / gene flow of forest bat species.

4 - THREATS AND CONSERVATION ISSUES

Many European bats are under threat and some have even become extinct in certain countries. The reasons for this are mainly:

- Loss of roosts and disturbances at roost sites;
- Habitat loss (commuting routes and foraging areas) and fragmentation;
- Mortality of individuals; and
- Prejudices against bats and misunderstandings arising from ignorance.

Bats are difficult to study (nocturnal, undetectable call for the human ear, hidden roost sites, lack of quantitative data, vulnerability to disturbance…) and there are strong gaps in knowledge that strongly hinder the assessment of the impacts especially at project level.

4.1 - Loss and disturbance of roosts

Bats make use of many different roosts, within a biological cycle. In Europe, the majority of bats hibernate in caves, buildings or in tree cavities to be protected from cold weather and predation. During other periods, some species prefer buildings or man-made structures, while others prefer caves or trees. But whatever the species, almost all of them use several roosts at a time. (31; 32; 33; 34; 35; 10).

Loss of roost, by destruction or by disturbance, has a significant impact on local populations. As explained by Bat Conservation Trust (36): "*Where there are limited alternative roosting opportunities locally, loss of a roost site would result in bats moving away perhaps to a site that is less suitable. In other cases there may be no suitable roosting sites nearby.*" Damage will be higher for maternity roosts as the "*loss of one maternity roost site may result in all the breeding females from an area being unable to rear young in that year, and possibly future years if there are no suitable alternative roosts nearby*" (36). Because of their reproduction strategy[37], the impact will be significant on local bat population.

It is possible to distinguish three main categories of roost sites:

- Underground sites: the word "*underground site*" is frequently reduced to natural caves. However all man-made structures that mimic the environmental conditions found in caves belong also to this category (37): abandoned mines, catacombs, tunnels, cellars, military installations and fortifications (war bunkers. …);
- Overground sites: generally man-made, they include bridges, castles, churches, houses, block of flats, stables and cowsheds, barns or even artificial roosts sites built for bats. Crevices in cliffs are also used;
- Tree dwelling sites: cavities, barks, cracks or even bat boxes established in forests.

4.1.1 - Underground sites

All man-made structures that mimic the environmental conditions found in caves belong to underground sites. This includes abandoned old mining systems and tunnels which share very similar conservation issues with caves. The case of cellars is slightly different because apart of airflow modifications, inhabitants have to accept to share their living space with bats (10). Unheated cellars in winter and/or heated cellars in summer may be used by *Rhinolophus ferrumequinum* and *R. hipposideros* bats and numerous questions on this case occur on the Internet.

Both humidity and temperature are buffered against rapid change in underground roost sites (37).This specific feature is fragile and modifications in airflow may alter the site value. Because of cave longevity, one single site can be used by many generations of bats. Thus, caves are long life roosts easily used by bats for hibernation and, in some places of EU, for maternity or transitional roosts. Bats are generally faithful to their roosts when they remain stable.

[37] Long-lived mammals but in general only one single baby per year in case of successful reproduction.

Since 1998, a EUROBATS IWG is working on underground sites, because they were defined as very important for the conservation of bats populations. A list of internationally important underground sites for bats was produced by EUROBATS experts in 2010 (1.487 sites) and is published on the EUROBAT Website. Currently, a review process in on the way and experts are working on criteria by biogeographic zones. Within the current list, 78.3 % of the important underground sites are composed of caves, mines, quarries or tunnels. However some EU countries are not included in this database as Spain or Greece.

The conservation of underground sites is done through legal protection and/or site management. Numerous legislation or regulation exist within MS, all of them being compatibles with the Article 6.1 of the HD which asks for establishing the necessary conservation measures at Natura 2000 sites. Preliminary guidance is provided in the EUROBATS Publication Series n°2 for restrictions within sites with site grading and conservation code examples (37).

4.1.1.1 - Issues

The two main issues to be considered for underground sites management are:

- Ecological modifications of cave features ;
- Excessive disturbance at underground sites;

A ECOLOGICAL MODIFICATIONS OF CAVE FEATURES

Many caves or subterranean sites have been closed for security reasons or concern over legal liability (37) and became unusable by bats. Other sites have been reused as storage sites, mushrooms cultures… or reopened for their original use. A cave may also be totally modified or even inundated with hard consequences on meta-populations.

The necessary ecological conditions for bats hibernating can be disturbed by preservation works and gating or grilling in an inappropriate way. The installation of an unfitted grille can modify airflows; then the inner temperature can increase or the humidity can vary, hence the desertion of the cave by bats (37; 38; 39; 40). An unfitted grille can also become an obstacle for some species as *Miniopterus schreibersii* (41; 37) or, in breeding season, *Rhinolophus euryale, R. mehelyi, Myotis myotis, M. blythii* (37) which are intolerant to any grilles.

The EUROBATS Publication Series n°2 provides advice and numerous examples concerning physical protection measures of caves (37).

B EXCESSIVE DISTURBANCE

Even if bats can tolerate a small amount of disturbance, important or regular ones can trigger desertion or mortality (37; 38; 42). Many people may visit caves: speleologists, inexperienced tourists, local people who can dump (toxic) wastes, light a fire or intentionally kill bats as it was reported in one French cave, where people used hibernating bats as paintball targets (43). EUROBATS highlights the fact that the increasing use of a growing number of sites outdoor leisure centres, adventure holiday groups and unregulated tourism is a cause for concern as members such parties generally have a poor understanding of the impact of humans on these sites (37).

Excessive disturbance can be illustrated with the case of the Bulgarian Devetashka cave, one of the most important bat caves in Europe. In 2011, after the filming of the movie “Expendables 2” with star movie actors, the bat population in the cave has been reduced to around a ¼ (8,000 bats hibernating compared to 30,000 the year before). Numerous bats have come out of hibernation much earlier than usual and dead bats seem to occur. The impact will remain for a long period because a bridge was built which now provides now easy access to the cave entrance attracting visitors.

“Mineral mines” state companies systematically apply a total closure (by demolition or filling of entrance sections) of the old abandoned mines in the mining areas (e. g. in Slovakia). They follow mining law about protection and utilisation of mineral richness to eliminate consequences of mining activities, because the most of old abandoned mines are dangerous to residents.

4.1.1.2 - Bat-friendly management of artificial underground sites

To take part in an appropriate management of underground sites, local authorities have to be made aware of bat needs (raising awareness). The priority is to develop and support strict protection of the sites of international importance within the Natura 2000 network and to include other sites of international importance lacking in this EU network.

Habitat conservation measures can only be implemented if bat requirements in underground roosts are correctly taken into consideration as in the examples below.

There are thousands of military installations from the 20th century which are now unoccupied in the EU: war bunkers, pillboxes and blockhouses, others fortified buildings or even older military fortifications. In some areas, this creates a key network of artificial sites for bats. One of the first LIFE project dedicated to bats was the "*Transboundary program for the protection of bats in Western Central Europe*" (LIFE95 NAT/D/000045) implemented in Belgium, Germany, France, Luxemburg.

The project secured a total of 143 sites and indirectly 22 other ones. This work includes purchase and lease of several forts, blockhouses or other military buildings as powder storage blocks. All sites were subsequently managed for the bats' benefit (bat-doors, grills and other devices).

In Germany, around 22.000 bunkers were built between 1936 and 1940 between Bale and Kleve to form the Western Wall. After the war most of the fortifications were blown up by the occupying powers, and then became largely forgotten. The undestroyed and partially destroyed bunker systems have evolved over the decades into valuable habitats and place in the densely populated and intensively cultivated cultural landscape. In the bunker ruins of the Western Wall numerous bats were detected with at least 10 species of bats using bunkers including *Myotis dasycneme*, *Myotis myotis*, *Pipistrellus spp*., *Eptesicus serotinus*... The NGO Bund is committed to the preservation of the remaining residues and the further improvement of the ecological network along this Western Wall strip[38].

In Poland, an extensive subterranean system of defences, often referred to as the Miedzyrzecz fortifications (Ostwall), were built for German troops from 1933 through to the end of the second world war in 1945[39]. Today, sections of this underground bunker complex serve as perhaps the most important winter hibernation roost in Europe, for at least 12 species of bats. True bat numbers are almost impossible to ascertain because the entire system cannot be investigated thoroughly. However, most researchers agree that the number of bats present here during the winter months number between 20,000 and 30,000. Many of these bats are rare or endangered species such as the *Barbastella barbastellus* and *Myotis myotis*. The bats travel from as far away as western Germany, the Czech Republic and throughout Poland to this unique hibernation roost in October each year.

In the UK, several local NGOs are converting pillboxes from the World War II into bat hibernacula with sometimes good results for species e.g. *Plecotus auritus* or *Myotis nattereri*. The gun ports are bricked up, leaving just a single small entrance for bats to fly through and bat bricks are cemented to the ceiling. Finally, a steel door is fitted to each pill box and secured with a padlock to prevent disturbance to any bats that might use the sites[40]. The EUROBATS Publication Series n°2 provides examples of this conversion (37).

Slovakia is a state rich in mineral resources. There are many mining areas with thousands of old mines. It means a great potential for occurrence of bat populations in the underground roost sites (e. g. *Rhinolophus euryale* or *Miniopterus schreibersii* maternity colonies). The method of their protection is based on cooperation with the Mineral Mines State Company to ensure maintenance of them. A

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[38] www.gruenerwallimwesten.de

[39] http://polandpoland.com/nietoperek_bats.html

[40] www.essex-batgroup.org.uk/reports.html

good example[41] can be construction of protective walls around dangerous entrances to the old mines which will solve the threat of entry or fall and retains access for the bats.

A new option is developed today with mitigation and biodiversity offsets: totally artificial underground buildings are built specifically for bats. This was done in the context of the construction of large reservoirs in north-east Portugal where two artificial galleries were built in 1995 and 2005. Good results occurred in the first one for *Myotis myotis*, *Rhinolophus mehelyi* and *Miniopterus schreibersii*. More recently, a motorway company built two artificial concrete bat shelters along the motorway A89 in France in the framework a partnership with a local NGO (see also chapter on overground sites) However time is needed to assess the results of this kind of project. Furthermore there is today no clue that they could shelter thousands of bats as it is the case in some natural caves.

4.1.2 - Overground roosts in buildings

Man-made overground structures regularly used by bats across Europe include bridges, castles, churches, houses, blocks of flats, stables and cowsheds, barns or even artificial roosts sites built for bats. These roosts can be found in such buildings all year round. In late spring, maternity roosts are formed in the roofs of buildings to take advantage of the heat provided by the sun. This is because breeding females seek warm areas during this phase in their life-cycle to minimise the energy cost of maintaining a high body temperature. In winter, bats of most species have been recorded hibernating in various parts of buildings such as inside cavity walls, around window frames, under ridge tiles and in cooler areas with stable temperatures such as cellars and basements.

A high percentage of the bat fauna rely on roosts in buildings in northern European countries, compared to the percentage seen in the southern countries (44). A survey carried out by Eurobats showed that in Europe, for their roosts:

- At least 33 species depend on castles and fortifications;
- At least 32 species depend on church, buildings and houses;
- 27 species depend on stables;
- 23 species depend on bridges.

However, there is a true diversity within MS, may be related to differences in construction (barns, bridges...) with all over EU churches and houses being key places. Some species such as *Rhinolophus hipposideros* shows a great variability in its roost choice across Europe (44): churches are highly important in Austria, Slovenia and Slovakia and are of medium importance in neighbouring Hungary, Czech Republic, Germany and France.

4.1.2.1 - Issues

A PROBLEMS CAUSED BY BATS ROOSTING IN BUILDINGS

On occasion, bats roosting in buildings can cause a number of nuisances that have to be taken into consideration for bat conservation (44):

- A serious smell of bats or the noise from the roost can keep family members awake;
- Droppings, over a protracted period of time, may cause pitting, long-term staining and etching to porous materials such as painted wall surfaces, wooden monuments and stone sculptures;
- Bat urine (which is 70% urea) is chemically aggressive and therefore of even greater conservation concern. It can cause spotting and etching of wooden, metal and painted surfaces;
- The presence of these protected species requires consideration when planning work such as remedial timber treatment or reroofing for repair or refurbishment in a private house or other buildings.

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41 www.netopiere.sk/aktuality/2013/10/15/Grafity_v_lesoch_Revuckej_vrchoviny_upozornuju_na_vyskyt_netopiero

B POISONING BY TIMBER TREATMENT DURING RENOVATION OF BUILDINGS

Bat populations are very sensitive to chemicals because of their long lifetime and their low reproductive rate. Species roosting in roofs are exposed to frame treatment products. Because of their large naked wings, bats are more exposed than other species of mammals. They also ingest directly these chemical substances by licking their wing membranes and their fur or by grooming others members of the colony. Some substances can also be transmitted by lactation.

A recent study (45) compiled data on different toxics substances. Three mains types of chemical substances are used to treat wood:

- Chlorinates (organochlorine pesticides, DDT, dieldrine, lindane, chlordane): they cause severe and chronic poisoning, by storage in brain entailing death. Other effects are known on reproduction and fertility. These substances can increase bat metabolism, and can induce death by precocious exhaustion of fat reserves. Chlorinates are stocked in fat, then they can be mobilised to the brain during hibernation, or they can be transmitted by lactation to juveniles by lactation which are more sensitive than adults. These substances are persistent in the environment, and studies show that recent bat corpses can present a high level of forbidden toxic substances since 40 years.

- Pyrethrinoide pesticides (cypermetrine and permethrine): these products present a lower toxicity for mammals but are still neurotoxins. They can affect reproduction (more abnormal spermatozoids, decrease of weight of juveniles at birth, increase of prenatal death, delay of growth…). These substances can be lethal, but it seems that they don't have noticeable effects in doses of normal use.
- Metals and metalloids (TBTO, Boron salt and Zinc): these products are concentrated in different organs. The accumulation rate depends on species, age and sex of animals. They can also be transferred to the juveniles by lactation and by placental transfer. Some scientists have noticed a significant mortality with TBTO use, but not with Bore salt or Zinc salt (46) (45).

Because of these toxic effects, a large number of these types of chemicals are not permitted anymore for use in many countries because of the hazard to human health.

Treatment should take place at a time when no bats are present. In most situations, where bats are only present seasonally, this is fairly straightforward. Certain species, however, may be present in buildings all year round and there is no ideal solution in these cases (44). The local Bat Conservation Organisation may provide some help.

Tree species which don't need much treatment are sweet chestnut, oak, arch, Douglas pine. A number of fungicides and insecticides available on the market have been granted the European Ecolabel[42] due to their less toxic chemical composition (47).

C BUILDING INSULATION

Bats roost in cavity walls during all seasons. There are currently many European level and national initiatives to encourage building insulation to reduce carbon footprint. Although in theory, as part of these schemes, protected species should be surveyed for and their needs taken into account, in practice this rarely happens. Insulation schemes are damaging and destroying bat roosts in cavity walls in buildings, and at times killing whole roosts of bats where they become entombed within the cavity when the insulation is injected.

Another problem is breathable roofing membranes (BRMs) which have become widely used in buildings in recurrent years. Although originally designed for use as part of a continuous breathable/airtight barrier, they are also used in conventional ventilated buildings. There are a wide range of breathable membranes available but it has become apparent, through research undertaken at the University of Reading (UK)[43], that most of these membranes are detrimental to bats.

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[42] http://ec.europa.eu/environment/ecolabel/index_en.htm

[43] http://www.bats.org.uk/data/files/Entanglement_StaceyWaring.pdf

The issue is widespread across Europe:

- In Slovakia and Poland, some of the worst examples come from apartment blocks being upgraded, especially insulation of accessible roof voids that encouraged swift and bat occupation in apartment blocks. Financial support for insulation has been gained from the EU through program "Jessica";
- In the Netherlands, a 2013 workshop on urban bat ecology highlighted many problems with post-build isolation of wall cavities;
- In the UK, there are many examples of cases where insulation and refurbishment of buildings have had a similar impact on bats.

4.1.2.2 - Renovation works and mitigation measures

There are many examples from throughout Europe to show how bats need not be impacted during building works. Indeed, with some careful planning, the status of bats in a building can often be enhanced during such operations. Equally, it has been shown that if bat expertise is involved from the early planning stages of a restoration project, and a flexible approach is taken to the scheduling of the works, the bats can be satisfactorily accommodated throughout the project at little or no additional cost and without compromising the aims of the works.

Table 7 - Optimal period for carrying out works

Bat usage of site	Optimal period for carrying out works (some variation between species, and geographical regions)
Maternity	1 October – 1 April
Summer (not a proven maternity site)	1 September – 1 May
Hibernation	1 May – 1 October
Mating / swarming	1 November – 1 August

A BUILDINGS OF CULTURAL HERITAGE

UNESCO's Convention Concerning the Protection of the World Cultural and Natural Heritage[44], signed in Paris in 1972, recognised the dual need for protection of both natural and built heritage elements. However, conflicts arising between these two objectives have their origin in two opposite issues: either restoration / renovation works are planned for the building that will impact on the bats, or the bats themselves are causing a disturbance or damage within the building (44). Stakeholders of both side need to exchange at technical level to find appropriate solutions.

Lots of cultural heritage buildings tend to be illuminated at night with some impacts for certain species such as *Rhinolophus* and *Myotis spp*. Lighting can limit bat colonies installation or can disturb the schedules of exit and by the way increase prey availability at the beginning of the night (48).

Some public buildings, particularly churches, are closed to avoid settlement by pigeons. Belfries are fenced by wire netting and the access for bats is forgotten. When there is an established colony, bats can be trapped in these belfries and die.

A specific issue with some older buildings is the existence of lead based paints on girders or other metal structures. Bats can develop lead poisoning by ingesting flakes of this paint during grooming. Such a situation arose in the Château de Trévarez in north-west France. The chateau contained a

[44] Further information on this agreement can be found at http://portal.unesco.org/culture/en/ev.php-URL_ID=8453&URL_DO=DO_TOPIC&URL_SECTION=201.html

nursery roost of 300 *Rhinolophus ferrumequinum*. Lead and pentachlorophenol poisoning was found to be the cause of high juvenile mortality at the site and in this case it was decided that the best solution was to build a new roost for the bats (49).

Case study: Ratková Church, Slovakia (44)

The loft of the Lutheran church in the village of Ratková, Slovakia, is occupied by a nursery colony of *Myotis myotis* and *Myotis blythii* in summer. The colony was discovered in 1992 and is the biggest colony of this type known in Slovakia, with up to 5,000 individuals present. A thick layer of bat guano had accumulated below the colony over the years; in places the layer of guano exceeded 1 m. The weight of the guano was about 10 tonnes, giving rise to concerns about the ceiling of the church.

On 3 - 4 December 2004, the loft of the church was cleaned with the help of the employees of the Muránska Planina National Park and Slovak Bat Conservation Society (SON) members. The guano was bagged and distributed to members of the local community as fertiliser. The colony continues to thrive and the ceiling of the church is no longer threatened with collapse. See SON website for further details of this work: http://www.netopiere.sk/aktuality/2004/12/03/cistenie-kostola-v-ratkovej.

Case study: Grad na Goričkem, Slovenia (44)**.**

Grad na Goričkem lies in northeastern Slovenia, close to Austria and Hungary. It is a castle of cultural heritage importance dating from the middle ages. When plans were developed to transform the castle into a visitor centre for cross-border landscape parks, it provided an opportunity to improve the roosting habitat of the castle's bats. Bats were first discovered in the castle in 1999. Intensive research followed on the composition of the bat fauna, seasonal dynamics of species and the microclimates of the areas being used by bats. Volunteer involvement was also important in developing an understanding of the importance of the building for bats. Conservation work was then undertaken to protect the bats from disturbance. Funding was provided by the State and also through an INTERREG IIIA project (Conservation of amphibians and bats in the Alpine & Adriatic region).

Ten bat species (one third of all Slovenian species) were found to use the site; the cellars provide hibernation sites for *Rhinolophus hipposideros*, *Myotis myotis*, *Barbastella barbastellus* and even occasionally for *Myotis bechsteinii*. *M. myotis* use the cellars as mating quarters as well. Up to 100 *Miniopterus schreibersii* have been recorded in the castle, making it one of the biggest known roosts for this species in the north-western part of the Pannonian basin. *R. hipposideros* also forms a small nursery group in the attic of the castle. As underground habitats are generally rare in the region, the cellars are thought to be an important swarming site for bats in the wider area. The building works required the complete demolition and reconstruction of parts of the castle used by bats. On the basis of the research, mitigation measures were recommended during the renovation, including the designation of part of the cellars as a bat roost. Extensive discussion took place between nature conservation and cultural heritage officers to agree the position and size of a new entrance for bats (Figure 16). Follow up monitoring is now required to ensure that the conservation measures are effective, but it seems that the conservation efforts to date have been successful. For further details of this work see (50).

B BARNS AND ATTICS

As detailed in EUROBATS Publication Series (44), old barns play a locally important role as roosts for some bat species and provide their own challenges when it comes to accommodating bats during renovation or restoration works. A study in the UK has shown that many old timber-framed barns, some dating back several centuries, are now being converted into dwellings. Briggs (51; 52) found that the vast majority (77%) of converted barns have not maintained their bat species and she questions whether barns with bats should ever be converted. She looked at how bats could best be accommodated in these conversions and provides details of mitigation measures that should be built into future barn conversion designs (Species specific design, light pollution, timing of the works...).

The same issue exist for attics that are transformed in rooms when old houses are rearranged (53).

C BRIDGES

Bridges are known to be of particular importance for at least 13 species of bats across Europe (44). For example, out of 328 inspected bridges in Austria, 30% were used by bats (54). A survey of 200 known bridge roosts of *Myotis daubentonii* in Ireland showed that 75% were occupied by 1-5 bats and only 5% held 20 or more bats (55). Individual bats will use crevices as small as 50 mm deep and 12 mm wide, but larger groups require bigger, deeper roosting sites. Large, concrete motorway bridges with big interiors can provide shelters for many bats (e.g. one of the biggest known maternity roosts of *Rhinolophus hipposideros* in Austria is found in such a bridge). In Southern Spain, there are also modern bridges which support colonies of several thousand *P. pygmaeus* or hundreds of *E. isabellinus*

Old bridges, often made of stone, are subject to different types of disturbance and require different forms of maintenance or restoration works (redo joints, roughcast...). Crevices-dwelling species are very concerned by this issue. Some guidance documents provide helpful advice on how to accommodate bats in both old and new structures[45]. Again, careful timing of the works is a determining factor as well as preserving individual roosting spaces wherever possible.

D MODERN BUILDINGS

All types of modern buildings (houses, flats, offices…) may be colonized by a number of species of bats, since they provide roosting opportunities which are becoming less and less available in more natural habitats. These modern buildings are often subject to renovation, reroofing, thermal insulation in the attic or elsewhere, or even demolition works at shorter periods than the buildings of cultural heritage. Simon et al. (56) provide detailed information on the construction of artificial roosts within buildings. Mitchell-Jones (57) and Schofield (58) provide extensive advice on the design and construction of roosts in dwellings. For other practical examples of mitigation measures and alternative roosts see Reiter & Zahn (59).

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[45] See the leaflet produced by SFEPM that can be downloaded from www.sfepm.org/NuitChauveSouris/images2/Savoirplus/plaqponts.pdf.

Case study: Morcegário, Portugal (44)

In 2000, bats were discovered during the environmental impact study for the destruction of a 15-storey building in Portugal. Up to 100 *Tadarida teniotis* and some *Eptesicus serotinus* and *Pipistrellus pygmaeus* were hiding in crevices below concrete plates covering the walls.

Detailed monitoring showed that bats were present in all seasons and favoured walls with higher sun exposure. Bats were present at various heights, but were most abundant above 21 m, where temperatures were warmest. 75% of the bats were found inside crevices less than 3 cm wide.

Old and new Tadarida roosts, Portugal. © M. Carapuço © J. Palmeirim

The developer built a new roost in 2003, 150 m from the original. It was designed, in consultation with the statutory nature conservation organisation, to replicate the original building, although it is only 12 m high. In order to ensure that the thermal characteristics of the crevices were replicated the concrete plates of the original building were re-used. Follow-up monitoring confirmed that the thermal behaviour of the new roost was quite similar to the original one. To encourage colonization of the new roost, 50 bats were captured and released there when it was finished. The old building was knocked down in 2005. In 2006, 22 *Tadarida teniotis*, 12 *Eptesicus serotinus* and 4 *Pipistrellus pygmaeus* were recorded in the new roost. In 2007, the maximum numbers seen were 11 *Tadarida teniotis*, 11 *Eptesicus serotinus* and 7 *Pipistrellus pygmaeus*. Monitoring of the new roost is continuing.

Case study: Prefabricated panel houses and blocks of flats, Slovakia

Efforts for the procedure in conservation of bats and other protected species applied in Slovakia:

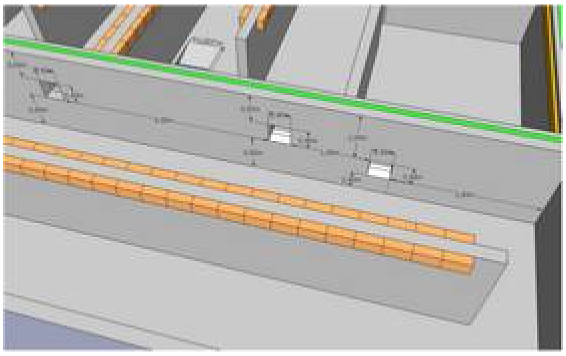
During planning of thermal insulation of blocks of flats the investor asks for an expert´s statement on occurrence of protected species from the State Nature Conservancy or a specialist with relevant experience listed in the List of Experts for elaboration of expertise. This appraisal will become a part of the project documentation similar to other obligatory parts of the design (like from fire-fighters etc.). In the statement the expert proposes protective measures which will be necessary during construction works (e.g. evacuation of bats from rifts between panels) and proposes the extent of compensation measures for loss of roosts as a consequence of insulation of the building (it can be done in different ways – if the situation permits keeping of used roosts or installation of artificial bat houses on the building façade or directly to the insulation)[46]. These works are covered by investor (or after agreement by the construction company). - Photos © D. Lobbova

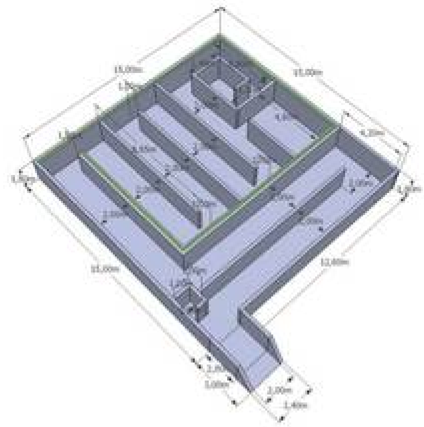
[46] www.bat-man.sk/netopiere/eshop/1-1-Budky-pre-netopiere/1-2-Polystyrenove

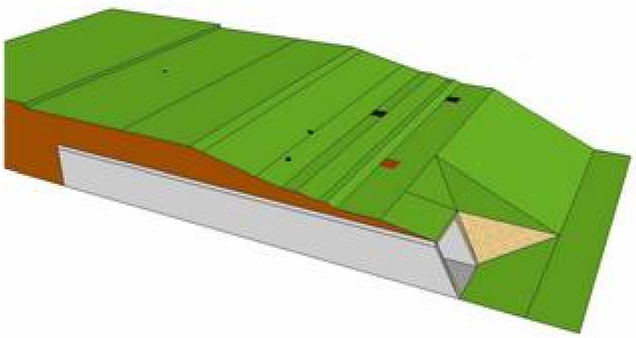
E ARTIFICIAL BAT HOUSES AS MITIGATION OR COMPENSATION MEASURES

Creation of new roosts – bat bricks or boxes - can be incorporated into bridges and buildings to replace lost crevices. This is done locally e.g. in relation with large infrastructure projects where this kind of measure become compulsory in the framework of compensation scheme or biodiversity offset projects. Some private or public bodies are building bat boxes for gardens, walls or other support and numerous NGOs or commercial catalogs are selling this equipment. However this is mainly proposed for some species (e.g. *Pipistrellus*) and transitional roosts.

In some cases artificial large bat houses are now proposed as it is already the case since many years in North America[47]. Such large bat houses have been proposed in some Environmental impact assessment studies as compensation measures and feasibility studies are now published (60). In some large projects, artificial bat houses imitating caves are proposed even in forest as in the figure below.







Different views of a proposed artificial roost in the forest of Belles-Forêts (France). This project is undertaken since 2012 by a public French company in the railway sector (RFF) in the framework of a compensation scheme (views extracted from the call for tender for the building operation published in 2012).

4.1.3 - Tree roosts

Trees are often used by bats as roosts with some species specialising in forest habitats (e.g. *Myotis bechsteinii*). They can use lots of different cavities: cracks, woodpecker tree holes, etc. Nevertheless, they prefer old and living deciduous trees (or more precisely indigenous trees which can be resinous in mountains) or forests with some great trunks and dead or broken trees. They also prefer a cavity high up into the trunk, a thin opening and tree cavities which are close to each other. Aged or ancient forests with enough dead wood are more often used by bats (35; 61). Also, orchards and isolated trees in hedges or in urban areas may also offer good roosting opportunities. Habitat requirements for each tree-dwelling species are detailed in (62; 63; 64).

In the town of Strasbourg (France), seven old plane trees were felled down in January 2013 as a measure for a new urban development project. In one of them, there was the second most important known tree-dwelling of *Nyctalus noctula* in Europe: 488 animals were found hibernating in the big internal cavity of the plane tree.

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[47] www.batmanagement.com/Ordering/condos/batcondo.html

Unfortunately, 24 of them died on the day of the felling; 464 were cared for by a local NGO and the animals were released in March-April. 118 to 145 were released at a time from the roof of the building next to the lost hibernacula. These releases were screened with infrared camera and few individuals were radio-tracked. This study allowed finding 4 other tree roosts distant from 1.8 to 14 km. All of these trees were found in old and big trees more than 100 years old (65; 66; 67).

The case of forest tree-dwelling is developed within the chapter on forestry practices (4.2.3). Roosting opportunities found in forested areas can be preserved by conserving standing dead trees, old and big trees and trees with holes in all forestry operations (around 7-10 roosting trees per ha is recommended (63)). Clusters of old trees are particularly valuable. In Germany, the conservation programs from Berlin, Hesse and Rhenanie-Wetsphalie include good practices regarding the conservation of 5 to 10 old trees per ha and their marking (64).

The importance of tree-dwelling bats in the rural countryside (isolated trees, hedges...) is not well known because tree-dwelling are very difficult to find and studies are scarce. However, bat will benefit from the next CAP reform as some areas of ecological interest will have to be conserved within the farmers' estate.

Logging in areas with high potential for roosting bats should be carried out outside the breeding season (mid-may to the end of July, or August in northern countries) but also outside the hibernating season (December to March included).

The conservation value of bat boxes (for certain forest species) is limited to areas without old trees, where natural bat roosts are missing. In such areas bat boxes can be helpful for bats to survive until such time when trees become old enough to have holes and crevices. However, bat boxes should only be used if it is ensured that somebody cares for them for many years. Bat boxes should not be used in old-growth forests and core areas of nature reserves or national parks (62).

4.2 - Commuting and foraging in fragmented landscapes

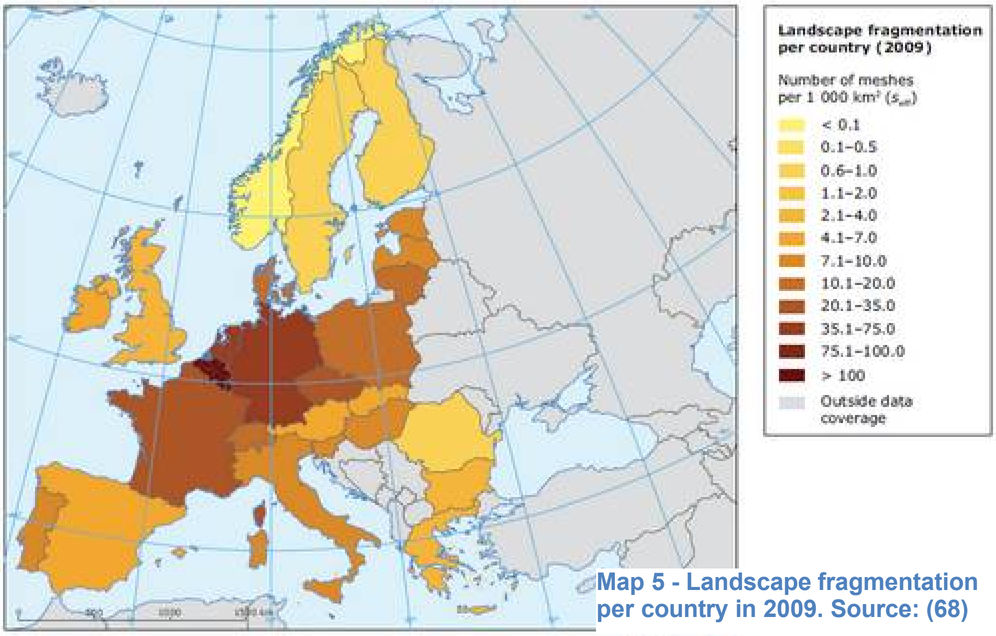
To reach their foraging sites or sheltered places, most species are following commuting routes using various features either natural (rivers) or man-made (hedges, walls, bridges). Certain species tend to forage not too far from their roosts like *Rhinolophus spp*. while others do not hesitate to travel 40 km and even more away from it for a rich meal like *Miniopterus schreibersii* and *Myotis capaccinii*. All the species are covering long distances every night and a single bat may forage up to 20 different areas in a night to maximise its yield. This means that both foraging areas and commuting routes are key features for the conservation of bats and the scale to be used is the landscape one.

A EUROBATS IWG is currently working on guidelines concerning conservation and management of critical feeding areas and commuting routes. Apart from species accounts, it includes a chapter on landscape structure and changes in it and a more detailed chapter dealing with e.g. different habitat types. Concerning examples of successful habitat management cases, however it was noted during the work that there are not that many cases where habitats had been managed and the outcomes monitored and reported. Rather, many cases include suggested or implemented management measures but no monitoring on the effects of these actions.

4.2.1 - Land planning and fragmentation

Commuting routes play a key role in conservation of bat populations as foraging areas are sometimes far away from roosting sites. Bats are thus very sensitive to landscape fragmentation by both infrastructures and disappearance of habitat diversity. Furthermore, landscape fragmentation increases the risk of populations of becoming locally extinct as isolated populations are more vulnerable to natural stress factors such as natural disturbances (e.g. weather conditions, fires, diseases (68)).

In 2011, the European Environment Agency has published a report in association with the Swiss Federal Office for the Environment (FOEN) specifically addressing the issue of landscape fragmentation in Europe (68). A European map of fragmentation has been produced and many highly fragmented regions are located in Belgium, the Netherlands, Denmark, Germany, France, Poland and the Czech Republic.



Map 5 - Landscape fragmentation per country in 2009. Source: (68)

Note: Landscape fragmentation was calculated using fragmentation geometry FG-B2.

High fragmentation mostly occurs in the vicinity of large urban areas and along major transportation corridors. Many more new transportation infrastructure projects were planned after 2009, in particular in Eastern Europe. As a consequence, fragmentation of landscapes is still rising.

However, the fast pace of road development by far exceeds our increase in understanding the effects on the environment and biodiversity, which makes appropriate adaptive management impossible. This results in a lack of accountability for the majority of uncertain effects and effects that become manifest years after the construction of new transportation infrastructure due to the long response times of wildlife populations (68).

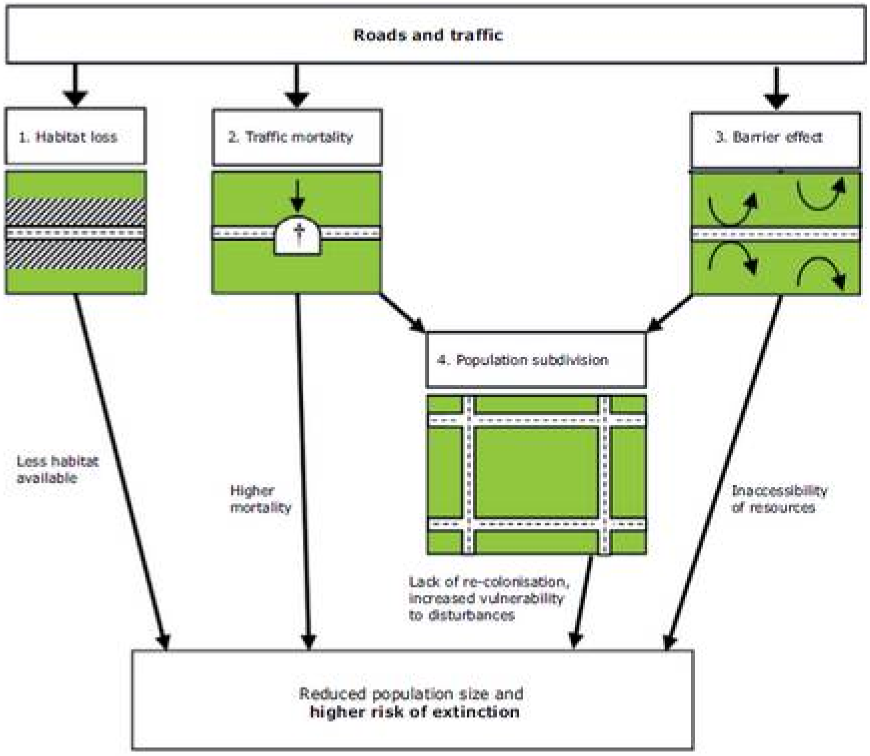


Figure 4 - The four main effects of transportation infrastructure on wildlife populations. ***Source: from Jaeger et al., 2005b in*** **(68)*.***

While single alterations are easily visible and assessed as 'not significant', their cumulative effects over longer periods of time are much more difficult to observe. Thus, single landscape alterations are easily marginalised and their cumulative impacts are underestimated. This has been called the 'pitfall of marginalisation'. Only after several decades can the full extent of the alterations and the resulting degradation of the landscape be properly evaluated (68)).

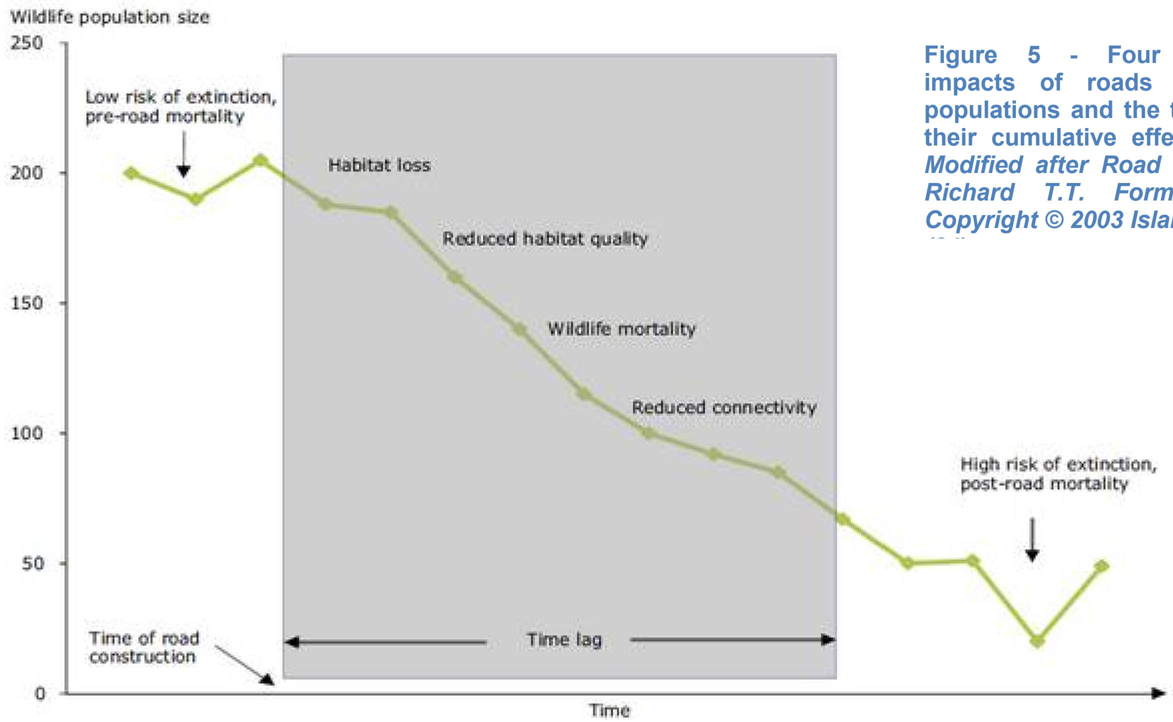


Figure 5 - Four ecological impacts of roads on animal populations and the time lag for their cumulative effect. *Source: Modified after Road Ecology by Richard T.T. Forman et al. Copyright © 2003 Island Press. In*

The 2011 report of the EEA on landscape fragmentation in Europe made the following recommendations with regard to biodiversity that are worthwhile for bats:

- "[...] We recommend drawing up guiding concepts for the landscapes in Europe (together with the MS) that include the identification of regionally and nationally important unfragmented areas and priority areas for defragmentation. To make these guiding concepts more tangible, it is desirable to adopt appropriate benchmarks or targets for the degree of landscape fragmentation. For example, the German government and the German Conference of Environmental Ministers claimed as an important goal a 'trend reversal in landscape fragmentation and urban sprawl' in Germany (Bundesminister des Innern, 1985; LANA, 1995). To achieve this goal, the German Advisory Council on the Environment (SRU) (1994: 128; 253) recommended the development and implementation of limits and orientation values for changes in landscape structure over time. Waterstraat et al. (1996) recommended the protection of large unfragmented low-traffic areas in Germany. More recently, the German Federal Environment Agency suggested that region-specific limits to control landscape fragmentation should be introduced (Penn-Bressel, 2005) [...]".
- "[...] Appropriate objectives and measures should be elaborated that are made binding for European and national offices and should state what measures should be taken and where and how they should be implemented, in connection with ongoing EU initiatives for a green infrastructure48. A process of Europe-wide documentation and coordination is recommended to produce an overview of measures at the European level and to enable regional strengths and shortcomings to be recognised more easily. This work could build on the achievements of the previous EU COST 341 Action (Luell et al., 2003) and the Infra Eco Network Europe (IENE) (http://www.iene.info) [...]".
- "[...] Further research should also address the question of how current transportation systems can be improved to keep landscapes unfragmented. The identification of thresholds of landscape fragmentation is a particularly important task [...].

4.2.2 - Agricultural practices

Apart from using hedgerows as commuting routes, bats regularly forage in crop fields and meadows. This is especially the case on edges between meadows or crop fields and wooded structures or water courses. Pasture may play a key role as a foraging habitat for some species (*Eptesicus serotinus, Rhinolophus ferrumequinum, Rhinolophus hipposideros, Myotis myotis, Myotis blythii oxygnathus, Myotis nattereri, Plecotus austriacus*).

Removal of hedgerows, loss of foraging areas (meadows, ponds), and reduction in insect prey with the increased use of pesticides will impact bat populations. Agricultural intensification is suspected to be a major cause of the decline in many European bat populations (13). It has partly driven bat populations of central Europe near to the extinction, and Mediterranean populations have strongly declined in intensively farmed areas (10).

4.2.2.1 - Changes in farming practices

While farmland covers 45% (180 million hectares) of the EU-25 (69), intensively managed agricultural landscapes have become increasingly monotonous in some areas. After World War II, increased size of fields, mechanisation, loss of traditional rotations management and the subsidised intensification of agriculture led to the loss of semi-natural habitats. However, patches and networks of natural elements are essential for increasing connectivity within the landscape (70; 71). Intensification leads to the degradation of hedgerows, conversion of crops to large monoculture fields, draining of pastures, ponds and other wetland, loss of crop rotation, conversion of pastures to arable land and conversion of woodland to farmland. (69).

These changes lead to a decrease in non-crop habitats such as hedgerows, groves, field margins, unmown grass strips, ponds and orchards (72), which are essential habitats for bats (flight paths,

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[48] http://ec.europa.eu/environment/nature/ecosystems/

foraging sites, insect source) (13). Moreover, a number of bats are likely to have suffered from destruction of roost sites in groves and hedgerows.

Even though bats do not feed during the day, the European Grassland Butterfly Indicator 1990-2011 (73) efficiently demonstrates the influence of these changes on potential prey. 17 butterfly species are assessed including 7 widespread and 10 specialist species. Out of the 17 species, 8 have declined in Europe, 23 have remained stable, 1 has increased and for 6 species the situation is uncertain. No doubt that the situation is more or less the same for bat preys such as moths. The reasons involve intensification leading to uniform grasslands which are almost sterile for biodiversity, and abandoned land as unmanaged meadows are naturally replaced by scrub and woodland.

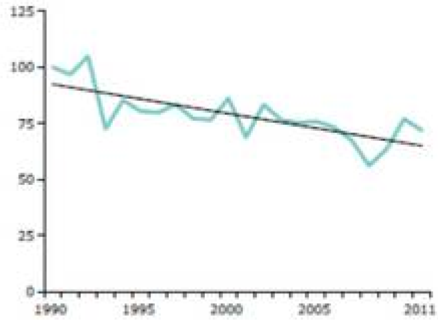

Figure 6 - European Grassland Butterfly Indicator 1990-2011(from (73))

Linear landscape elements may be of prime importance for bats and provide them with more protection against wind, but also foraging habitat with higher prey densities than in open areas. Isolated trees, tree lines or hedgerows are landscape elements for both commuting (certain bat species are reluctant to fly in open habitats) and foraging.

In a recent Swiss study (71), bat activity was 1.4–2.8 times higher around landscape elements compared to open and unstructured control areas. This indicates that bats significantly prefer landscape elements over open habitat. This study corroborates previous findings that open habitats seem to be less attractive to bats for foraging, apart for cattle grazed pastures according to another British study (74). The shape of landscape elements (linear vs. patchy) is much less crucial for bats than the area covered by vegetation structure. Higher bat activity around structural elements suggests that the presence of a single isolated tree to a highly connected hedgerow or forest may benefit bats. Authors highlight the importance of connectivity for bat communities in farmland-dominated landscapes and claim that fragmentation is a major threat to bat populations.

Another UK recent study (75) has demonstrated that the effect of boundary loss on most bats was very strong in both crops and grasslands, but the larger species of bat (*Nyctalus*/*Eptesicus* spp., mostly identified as *Nyctalus noctula*) showed no sensitivity to boundary loss.

From 2000 to 2006, 22 % of semi-natural habitats loss was due to the conversion from natural land to farmland (76). The common agriculture policy (CAP) instruments have been created in order to slow down that trend. It includes the concept of eco-conditionality, which sets up a number of conditions under which farmers can get direct payments from CAP's first pillar (77). In order to get those, farmers must fulfil good agricultural and environmental conditions (GAEC), which include the implementation of field margins, the maintenance of set-aside and/or cultivated land, the grassland management and the upkeep of landscape features (hedges, ditches, woodland edges, etc.) (78). Reintroduction of structural elements should also be planned in the framework of agri-environment schemes which compensate farmers for loss of income or extra work due to measures they take to improve biodiversity.

4.2.2.2 - Pesticides and chemicals

The use of pesticides and chemicals is also an important threat to bats. It reduces food supply by eliminating insects and can poison birds and mammals that feed on them (69). However, a study in UK (75) has demonstrated that bats were relatively insensitive to increased agrochemical inputs and the switch from hay to silage, but more strongly sensitive to boundary loss (hedgerows, tree lines...). Authors nonetheless stipulate that they cannot comment on possible toxicological effects.

Pesticides can also accumulate in insects and then concentrate to lethal levels in bats. Such pesticides used for agriculture and forestry are known to kill (79). Furthermore, the impact on prey populations may be high as it was demonstrated for endectocides.

Endectocides (avermectins and milbemycins) are drugs used on livestock to control parasites (80). Ivermectin is an antihelminthic from the avermectin family, which is massively used (it was the most sold veterinary drug in 1996) (81). Many coprophagous invertebrates are negatively affected by avermectins or other antihelminthics coming from livestock dung (Beynon, 2012; Vickery et al, 2001 in (82)). These drugs can kill adult insects or larvae, impair reproduction of these insects, delay their development or cause malformations. In Europe, such antiparasitic drugs are used for livestock in at least 16 range states. The bat species most likely to be affected by this lack of food are *Rhinolophus* spp., *Eptesicus serotinus*, *Nyctalus* spp., *Myotis myotis, Myotis blythii*, *Myotis punicus* and some *Pipistrellus* spp.

A recent German study (83) showed that by following the toxicity-exposure ratio approaches of the current pesticide risk assessment, no acute dietary risk was found for all recorded bat species. However, a potential reproductive risk for bat species that include foliage-dwelling arthropods in their diet was indicated. The results emphasize the importance of adequately evaluating the risks of pesticides to bats, which, compared to other mammals, are potentially more sensitive due to their ecological traits.

There is an example from Rajec in central Slovakia on death of an attic colony of Myotis myotis caused most probably by using of chemicals in agriculture (possibly neonikotinoids) because females did not return back from the foraging site to the roost to their young ones[49].

Contrary to agriculture intensification, organic farming excludes the use of chemicals (synthetic fertilizers, pesticides, growth regulators and livestock feed additives). Organic farmland habitats have a higher quality and higher overall insect abundance, and key insect families important to bats are more common on organic farms than on conventional farms. As a consequence, bats seem to prefer organic farms over conventional farms for both foraging and general movements (13).

4.2.3 - Forestry practices

4.2.3.1 - Forests - Key habitats

As highlighted by the EUROBATS leaflet, forests of all types ranging from the dry Mediterranean forests to the boreal conifer forests are used by bats because they will seek out particular features, such as ponds or streams, clearings or forest edges, where insects tend to be most abundant.

The species for which forest habitats is vital, for both roosting opportunities and foraging areas, include two annex II species (*Myotis bechsteinii* & *Barbastella barbastellus*), and several annex IV species (*Pipistrellus nathusii, Myotis nattereri, Myotis brandtii*…). However, forests are also key habitats for *Nyctalus* spp., *Plecotus auritus* and *Myotis daubentonii*, and provide the favoured foraging areas for e.g. *Myotis myotis, Myotis emarginatus*, *Eptesicus nilssonii*, *Vespertilio murinus* and the *Rhinolophus* spp.

Specialised books on the ecology and conservation of bats in forested areas (64; 63) highlight the need of more research for these species in order to better understand their ecological requirements in view of a more sensitive management. There are links between management options and the related use of forest by bats such as partial thinning of the canopy which increases the light intensity and thus promote undergrowth which in turn is good for gleaning species like *Myotis bechsteinii and Plecotus auritus*. On the contrary, the development of dense canopy which eventually increases space between trees is the preferred foraging area of *Myotis myotis*.

4.2.3.2 - Forestry issues

Overall in Europe, most of the forested areas are managed for commercial purposes with limited consideration for the protection of bats. The main issues are the following (64; 63):

- Cutting trees during the hibernating season (winter), and thinning in summer (breeding season);
- The age of the trees are limited to its optimum in terms of quality of wood (80 years for the spruce and 120 years for the beech), hence there is usually a low number of trees with bat roosting opportunities (cavities, cracks, holes…);

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[49] www.netopiere.sk/aktuality/2013/08/19/Rozsiahly_uhyn_v_kolonii_netopiera_obycajneho_v_Rajci

- An increase in coniferous plantations and other exotic species (e.g. the Douglas pine tree and the Japanese larch tree), which are unfavourable to most of bats;
- The impoverishment in insect diversity due to a limited number of tree species present in forest (monoculture) causes decreases in prey availability for bats;
- The sudden loss of foraging areas used for years when clear-cut harvesting on large areas;
- The use of pesticides which also reduces prey availability and possibly affect the bats themselves;
- The fragmentation of large forested split into smaller plots bordered with tracks and roads, and disturbance and mortality caused by the vehicle traffic at night;
- Classic harvesting techniques can be harmful to surrounding trees, while modern techniques using cranes allow to avoid damaging valuable trees for roosting bats;
- Structural and functional relationships between unmanaged and managed forests (they may act as sources and sinks respectively (84).

4.2.3.3 - Reducing the impacts of forestry practices

A EUROBATS Working Group was launched in 2004 and a leaflet on good practice guidance for bat-friendly forestry in Europe, “Bats and Forestry”, was published in 2004[50]. Apart from landscape planning advices related to fragmentation and corridors, 11 good practices for forestry operations where proposed as follow:

- Preserve and increase roosting sites by conserving standing dead trees, old and big trees and trees with holes in all forestry operations (logging, thinning and cleaning). Groups of old trees are particularly valuable;
- Wherever possible try to increase variation in tree species and forest structure. Use native species wherever possible;
- Conserve deciduous trees in coniferous forests. Deciduous trees produce food and roosting sites;
- Increase food production for bats by conserving important habitats: wet forests, riparian habitats, gaps and forest edge zones;
- Limit the use of pesticides in forests;
- Avoid drainage of forest land. Creating new small wetlands and ponds within the forest benefits the bats. Flooding and storms can create dead trees and a variable forest structure;
- Semi-open pastures are sometimes important habitats. Nowadays grazing is often abandoned and these areas are allowed to re-grow or are planted with trees. It is important to conserve some areas with semi-open structure and high abundance of flowering plants. Do not cover the whole landscape with monoculture plantations;
- Grazing and browsing by cattle or other large herbivores creates a variable semi-open forest which is a good foraging habitat for bats. However, too much grazing can remove the whole under storey;
- Avoid creating large clear-cuts;
- Identify the next generation of trees for bats and leave these during harvesting;
- Avoid cutting through any trees close to holes; there may be bats roosting inside.

The public body in charge of nature conservation in England (previously English Nature, now Natural England) has published several guidance documents on the good practice management of woodlands for bats (62), including one specifically targeted on Bechstein’s bat and the Barbastelle bat (85).

Another technical guide on this topic was also published by the Conservatoire des Espaces Naturels Rhône-Alpes[51] from France (86).

[50] www.eurobats.org/publications/eurobats_leaflets

[51] www.cen-rhonealpes.fr/index.php/editiontech

Excerpt of a booklet on "*Woodland management advice for Bechstein's bat and barbastelle bat*" (85).

"[…] In dedicated plantation woodlands, Bechstein's bat colonies may exist for periods but they are neither stable nor sustainable in the longer term with current commercial woodland practice. Colonies rely heavily on semi-mature or mature canopy to forage in and a continuous supply of suitable roost trees into the distant future. This requires linked canopy cover with under storey over an area of about 50 hectares with further areas going into canopy decline and others not yet in canopy closure or in sapling stage. The current trend in forestry practice towards a wider remit of wildlife and recreation as well as timber production gives some scope for management practice to improve matters. A forestry timber extraction policy that follows the slow removal of prime individual trees on a continuous basis, rather than clear fell, will avoid sudden crashes in colony population sizes by maintaining adequate canopy cover for foraging.

Improvements in plantation management should include:
1. Creating non-intervention strips along all watercourses within the woodlands. This should include all the small floodplains and steep banks along the woodland streams.
2. Harvesting hardwood trees in plantations only when unavoidable and then by selected felling only, done on a slow continuing basis cutting only the best sound mature timber at appropriate times of the year.
3. Monitoring stands of trees used as nest sites by woodpeckers and leaving these stands as non-intervention until their natural decay.
4. Creating a series of suitable areas within which Green Woodpeckers can forage for ants. These areas should be over and above the woodland area required by the bats to forage in.
5. Ensuring, by new planting if necessary, that all hardwood blocks in nursery colony areas have deciduous woodland connections.
6. Leaving not only hollow trees but the immediate stand of trees around them together with the under storey during any felling operations

4.2.4 - Light pollution

Following the results of a EUROBATS IWG in 2008[52], light pollution might influence species through habitat disturbance, changing of behaviour, and in some cases on survival if intervening with crucial steps in the life cycles of species. In particular for bats, at least three main areas can be identified having a possible influence on populations:

- (In)direct effects on maternity colonies, hibernation sites and roosts;
- Effects on commuting e.g. barrier function of lit roads and fragmentation of the night landscape;
- Interaction with feeding activity, including prey distribution and intra-bat species competition;
- Higher risk to become a prey to the predator by illuminated roost sites.

Only few species (*Pipistrellus pipistrellus, P. Pygmaeus, P. kuhlii, Hypsugo savii, Eptesicus spp., Plecotus spp.* and *Nyctalus spp.*) seem to take advantage of the aggregation of insects to the UV-component of light sources for foraging (although may be adversely affected by illumination of roost entrances).

Observations of repeated predation of bats by diurnal raptors in urban areas (roosts present in blocks of flats) were made in Slovakia (Kladecik J., pers. comm.). The street lights allow to the Common Kestrel to adapt its foraging ability on bats during the evening.

52 www.eurobats.org/sites/default/files/documents/pdf/Advisory_Committee/AC13_Doc_13_IWGLightPollutionReport.pdf

Longer term effects were also shown by an Italian study (87): street light boosting in Italy may have acted as an evolutionary pressure on cranial size of *P kuhlii*, which has increased since 1940's-1950s possibly to catch larger prey concentrated near street lamps.

The Bat Conservation Trust, in partnership with Arup, will soon host a symposium on the topic of Artificial Light and Wildlife (to be held in London on the 20-21 March 2014). The symposium will bring together the lighting industry (manufacturers, installers, designers, and planners), local authorities, ecological consultants and academics, to discuss the current state of scientific knowledge of the ecological impacts of lighting and the needs of practitioners. Although talks will be on a range of wildlife the emphasis will be on bats and associated invertebrates.

4.3 - Infrastructures and mortality

4.3.1 - Traffic infrastructures

Linear infrastructures (particularly roads, motorways, railways...) have different impacts on bat populations, both during their construction and their use. They are generally negative ones; however some infrastructure may have a role for commuting routes (canals, bridges…).

4.3.1.1 - Issues

A HABITAT DESTRUCTION BY TRAFFIC INFRASTRUCTURES

The construction phase may lead to the destruction of roosts (buildings, caves or tree-dwelling). In this case, there is a strong adverse impact if these roosts are maternity or hibernation roosts (e.g. *Nyctalus noctula*). The impact is less adverse for transitional roosts if precautions are taken to avoid mortality of individuals. Roosts destruction can also occur when a bridge have to be reshaped, widened or maintained (reinforcement, joints), and roosting animals can be trapped (88).

Construction phase will also induce destruction of habitats which can be used by bats for foraging. In addition to the land take for the infrastructure itself, works require additional areas for compound sites and temporary storage areas, building engines circulation ways. It may represent a large area which becomes unfavourable for bats (88). To give an idea, a motorway may block around 3 ha per kilometre. The pollution of wet zones via the run off waters loaded in hydrocarbons, heavy metals... can also induce a decrease of insects productions and hence a loss of interest for foraging (88).

B HABITAT FRAGMENTATION BY TRAFFIC INFRASTRUCTURES

New linear infrastructures will intercept many flyways and make them unusable by bats. Older infrastructures have the same effect but bats may have found new strategies for using local territories. Every type of flyways can be concerned: hedgerows, forests edges, rivers, forests canopy or alley, tree alignments... Zurcher *et al*. (89) explained that 60 % of bats crossing road turn back when a vehicle arrives. The different habitats used within a year by bats (breeding roosts, mating sites, hibernacula, foraging sites ...) will be affected because of a lack of accessibility.

However some species can cross roads more easily than other, depending on their ecology: *Nyctalus* species generally fly high and are less dependent from landscape features. This is not the case for other species as *Rhinolophus* or *Plecotus spp.* (90; 91; 92).

A study by Kerth *et al* (91) demonstrated that motorways can restrict habitat accessibility for bats but the effect seems to depend on the species' foraging ecology and wing morphology. Motorways seem to have stronger barrier effects on bats that forage close to surfaces than on bats that forage in open space. Using radio-telemetry, mist netting, and mark-recapture data the authors investigated the effects of a motorway with heavy traffic on the habitat use of two threatened forest-living bats. They have compared *Barbastella barbastellus*, which forage in open space, to *Myotis bechsteinii*, which glean prey from the vegetation. Five of six radio-tracked barbastelle bats crossed the motorway during foraging and roost switching, flying through underpasses and directly over the motorway. In contrast, only three of 34 radio-tracked Bechstein's bats crossed the motorway during foraging, all three using an underpass. Bechstein's bats, unlike barbastelle bats, never crossed the motorway during roost switching.

C BAT MORTALITY

Direct destruction can occur by casualties with traffic (93; 94; 95). Some studies show that all kind of species are concerned (95; 96; 90; 93; 94; 97) although not to the same extent. The following table illustrate this issue with some results gathered during monitoring surveys carried out along roads.

Table 8 - Case studies of bat mortality due to traffic

References	Country	Context	Mortality
Bickmore 2003 (98)	Wales	A477 and A487 in 2001 and 2002	16 carcasses (10 in 2001 and 6 in 2002 on the A487 - nothing on the A477).
Choquène, 2006 (93)	France	7 Km of a 2 x 2 lanes in 1997	30 carcasses - 3 species.
		27 Km of the RN27 (2 x 2 lanes)	87 carcasses in 3 years (31 in 1997; 42 in 1998 and 14 in 1999) - 9 species.
		Few Km of a 2 x 2 lanes	12 carcasses in 4 consecutive days in August.
Capo *et al.*, 2006 (94)	France	On a 2 x 2 lanes near a hibernacula	104 carcasses (17 in 1998; 41 in 1999; 23 in 2001 and 23 in 2002). Mortality pick in May and August-September.
Graisler *et al.* 2009 (95)	Czech Republic	Two roads R5204 (3.5 Km) and R5205 (4.5 Km)	119 carcasses in 2007 - 11-12 species. Mortality pick in July-August and September-October.
Lesinski, 2008 (96)	Poland	1 km of highway (2 x 2 lanes)	52 carcasses in 2.5 years (2 in 2004; 28 in 2005 and 19 in 2006).
Lesinski, 2007 (90)	Poland	8 km of a 2 x 2 lanes - 1994-2000	112 carcasses - 11 species. Death pick in August-September. Different mortality pick according to the species.
Lesinski *et al.*, 2011 (97)	Poland	16.6 km of a 2 x 1 lanes in the National Park Kampinos in 2008 and 2009	61 carcasses - 7 species. 2 mortality picks: July-August and October.

Lesinski (90) specified that young-of-the-year seems more sensitive to accidental killing than adults. Some differences appear also depending on the surrounding landscape (96; 97; 95) which can lead bats on road. He noticed that there are more carcasses at a junction between road and forest edges or with trees alley (90; 96). He also showed that casualties depend on the landscape surrounding with a higher rate of mortality in building areas and in forests (97).

Different studies report three mortality peaks during the year:

- At the end of hibernation (98), when adults need to intensively forage in order to build up energy supplies;
- At the end of summer, when young-of-the-year begin to fly and are in dispersal phase (97; 90),
- September to October, when bat populations are at their peak numbers, seeking to mate and to build up fat reserves for hibernation (97).

Poisoning by pollution via the run-off waters from roads loaded with hydrocarbons, heavy metals... may have an impact on bats through food chains (88). However, this requires more research studies as it may only concern a few individuals.

D DISTURBANCE

Noises, vibrations and light due to the construction phase of the infrastructure can induce disturbance of bat populations. Bat roosts can be located near a building site (old trees, bridge, buildings...). These disturbances can trigger the desertion of these roosts (98). Disturbance can also occur on flyways: bats tend to avoid built areas, especially because of work lights (99), and can make unapproachable different habitats. It had been shown that bats, even species able to hunt around street lights, avoid lights when commuting along flyways.

Berthinussen & Altringham (100) have shown a clear avoidance of major roads by bats: the bats activity and the number of species are three times more important at 1,600 m far from the road than at its direct edges. Schaub *et al.* (101) wanted to test the reaction of gleaning bats when they have to forage in noisy areas. These species can use the sound emitted by their prey in order to catch them

(102). They observed foraging behaviour of *Myotis myotis* in different compartments: three noisy ambiances and a silent one. It appeared that there was a clear noise effect through the time spent in each compartment. Noise affects the hunting success of bats and so they tend to avoid noisy compartment. This experience shows that bats tend to desert foraging areas close to important source of noises, like major roads.

4.3.1.2 - Mitigation measures for traffic infrastructures

A CURRENT KNOWLEDGE

Different studies show that bats can cross a road or a railway using sheltered passages. The use of tunnels as flyways, when they are not too far from the original flyways, has already been demonstrated (103).

Better ways to mitigate fragmentation by different sheltered passages have been compiled recently (92). Results showed that bats use more frequently underpasses and river bridges than overpasses (regularly proposed for bigger mammals like deer). In this study, 93.6 % of bats were crossing via underpasses and 98 % via river bridges whilst only 50 % were using overpasses. They have also noticed that underpasses and river bridges are not so efficient if bats can stay in higher canopy as the height of the road verge tends to induce bat to increase the height of their flight.

In another study (104), it was demonstrated that if an underpass allows bats to cross without changing their direction or their flight height, they are the ones preferably used (96 % of crossings); remaining cases concerned direct crossing over the road. They have also seen that gantries seem to be ineffective.

The height of underpasses is a key feature for bat crossing whilst the length seems to be a non significant element (105).

Several reviews and reports have been drafted, in which solutions and good practices have been compiled and summarized (98; 99; 88).

B GOOD PRACTICES AND EXPERIMENTAL PROJECTS

- In **Ireland**, the National Roads Authority (NRA) has established guidelines and procedures that focus on the impacts on bats during the construction of new national road schemes[53]. These can also be adopted for road realignment and bridge maintenance programmes.

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[53] www.nra.ie/environment

Innovative palliative measures for the A7 motorway (Spain)

The motorway A7 in Alcoi (Spain) was recently constructed next to an important bat shelter. Different mitigation strategies were assayed there. A sector of the motorway was entirely covered with a net of 20 cm of aperture size to avoid bat collisions. The preliminary results showed that the net can effectively block the access to the road to bats. The net is combined with overpasses and underpasses. The preliminary results showed that underpasses are preferred to overpasses by commuting bats.

Photo 1 - Detail of the net that covers the A7 in the vicinity of the bat shelter (© J. Juste)

Photo 2 - Overpass details (© J. Juste)

Innovative bat bridge for the A89 motorway (France)

In southern France, an innovative approach is currently being tested on a new motorway. However, data are still missing in order to assess the effective use of these group-specific overpasses by bats. On the A89, the specific overpass is only a part of a comprehensive project including the erection of artificial galleries, the monitoring of tree roosting, the development of specific bat roosts in the structures… The overpass itself was an experimental project with a specific structure being also safe in terms of security, easy to manage, and attractive for both bats and the human eye!

Photo 3 – Bat bridge of the A89 in France (© ASF)

A EUROBATS Working Group was launched a few years ago to look into methods to minimise the impact of roads and other infrastructures. Its objectives include:

- the collection and review of the different studies, scientific literature and impact assessment reports available on bat mortality, habitat fragmentation relating to roads, railways, etc;
- the collection and review of technical documents on the approach to road building and landscape management which seek to minimise impacts when constructing new infrastructures; and

- the production of general guidelines to raise awareness on the impact of traffic infrastructures on bats and provide some advice for assessing mortality, fragmentation of habitats and others impacts on bats.

4.3.2 - Wind energy development

The Eurobats published in 2008 the "*Guidelines for consideration of bats in wind farm projects*" Guidelines for assessing potential impacts of wind farms on bats was worked out by the IWG of Eurobats and adopted by Meeting of Parties in 2006. Then, the guidelines were updated with new data from recent literature and published (106). However, knowledge is rapidly increasing on this issue and new measures to reduce the impacts are proposed.

As part of the implementation of the Kyoto Protocol, the interest of renewable energy sources has resulted in the European Union promoting wind energy through the energy-climate package and this is now is one of the three main regions of wind installations in the world.

4.3.2.1 - Issues

Although development of renewable energy sources is generally considered environmentally friendly, wind power development has been associated with the deaths of bats. While many studies have long since shown the impact of wind turbines on birds, mortalities of bats are really documented since 1996. It was in 1999 that the American and European studies begin to mention potentials impacts on bats corroborated by corpses discovered under and near wind turbines. Two causes of bat deaths have been documented: collision with blades and barotraumas that involves tissue damage to air-containing structures caused by rapid air pressure reduction near moving turbine blades (107; 108; 109).

Today monitoring studies of bats mortality are required at wind energy facilities. Several monitoring methods continue to be developed in Europe and mortality rates can be corrected thanks to tests determining the search efficiency, the predation rate and the surface correction. Data processing can cause statistical difficulties because mortality rates are expressed with or without the use of bias correction. Moreover, results are very variable depending on the calculation methods used to remove bias (sometimes differences of several tens). Also bat mortality is very different depending on the site related to the habitat type. All of this generates very different results. The following table summarizes some number of bats fatalities identified for various European studies.

Table 9 – Number of bats fatalities identified for various European studies

References	Country	Context	Mortality results	Bats killed/ turbine/year	
				Unadjusted numbers	***Corrected numbers***
ABIES, 2009 (110)	France	28 turbines - 4,5 months	30 fatalities	-	1,07
AVES Environnement, 2009 (111)	France	9 turbines -1 year	103 fatalities	11,44	79,3
Behr O. & Helversen O., 2005 (112)	Germany	4 turbines - 1 year	31 fatalities	7,75	31,5
Brinkmann R., 2004 (113)	Germany	16 turbines - 1 year	40 fatalities	2,5	20,9
		8 turbines -1 year	10 fatalities	1,25	11,8
Georgiakakis P. et al., 2012 (114)	Greece	88 turbines -1 year	181 fatalities	2,08	-
Leuzinger et al.,2008 (115)	Switzerland	5 turbines - 4,5 months	2 fatalities	-	8,2

Bat fatalities at wind turbines in Europe have been compiled since 2002 by Tobias Dürr from the Ornithological Station of the State Office for Environment, Health and Consumer Protection of the Land Brandenburg, Germany[54]. Most of the data come from Germany, Spain, France and Portugal. The figures are dependent of the data providers and do not stem from standardized studies, but there are only ones available to date. The most impacted species are *Pipistrellus* spp., *Nyctalus* spp. and *Eptesicus* spp. All the available data is in the Appendices section.

Recently, indirect monitoring techniques were developed, such as methods for estimating mortality calculated with the acoustic activity and statistical models. Many questions remain unanswered about if collisions occur fortuitously or if bats are attracted to wind turbines. Yet several characteristics of the wind turbine could influence the mortality of bats like the diameter of the rotor, the size tower, the ground clearance and the blade tip speed which can exceed 300 km/h. Other parameters increasing bat mortality like meteorological and time factors have been demonstrated (116).

4.3.2.1 - Mitigation measures

Minimizing these fatalities is critically important to both bat conservation and public acceptance of wind-energy development. Currently, only curtailment, the act cutting-out the generator from the grid when bat activity is high, has demonstrated effective reductions of bat fatalities (117; 118). Techniques using automated systems based on models incorporating variables in addition to wind speed (time of night, bat activity…) and meteorological data have been developed (119). When risky periods for bats (high bat activity) are detected, turbines are stopped automatically.

Although these measures showed a significant reduction of the mortality, this technique requires a lot of time for data collection and the many consecutive starts and stops can cause an abnormally wear of the wind turbine.

Easier methods like the increasing cut-in speed and feathering blades by slowing rotor speed up to the turbine manufacturer's cut-in speed yields substantial reductions in fatality of bats. The cut-in speed is the wind speed at which the generator is connected to the grid and producing electricity. The manufacturer's set cut-in speed for most contemporary turbines is between 3.0 and 4.0 m/s. The principle of this measure to reduce the risk of bat mortality is increasing the cut-in speed. The turbine's computer system (referred to as the Supervisory Control and Data Acquisitions or SCADA system) is programmed to a cut-in speed higher than the manufacturer's set speed. The turbines are set to remain almost completely stopped until the increased cut-in speed is reached over some average number of minutes (usually 5-10 min). Several studies have shown that raising turbine cut-in speeds from the manufactured speed by 1.5-3.0 m/s results in significant reductions in bat fatalities compared to normally operating turbines. Most of them have shown a 50 % reduction in mortality of bats when the cut-in speed was delayed by 1.5 m/s. The lost power for this operational mitigation is generally lower than 1 % of total annual power output. However, altering turbine operations, even on a limited basis, potentially poses operational and financial difficulties for some project operators. At wind speeds below operational cut-in speeds, turbines are generally "freewheeling". Even though turbines are not producing any electricity while freewheeling, they still may rotate at high speeds that are lethal to bats. Thus, altering turbine operations to eliminate blade movement at or below normal cut-in speed also may reduce bat fatalities without raising cut-in speeds. Normally operating turbine blades are angled perpendicular to the wind at all times. The feathering is adjusting the angle of the rotor blade parallel to the wind, or turning the whole unit out of the wind, to slow or stop blade rotation. The advantage of the feathering turbine blades is that it could be implemented at many facilities with those turbine models that have SCADA systems capable of relatively easy programming.

At last, studies have tested the effectiveness of ultrasonic acoustic deterrent for reducing bat fatalities at wind energy facilities (120). They proved that the emission of ultrasonic broadband can affect the behaviour of bats directly by discouraging to approach the sound source, or indirectly by reducing the hunting time spent near the turbine because insects are repulsed by ultrasounds.

The farmers that host turbines are told they can still farm under and around these turbines. I do not think they understand the full implications of "farming" under these machines. The deterrence used to mitigate bat deaths would further compound the simple issue of insect populations and their relationship with crop yields.

[54] Die Staatliche Vogelschutzwarte des Landesamtes für Umwelt, Gesundheit und Verbraucherschutz Brandenburg (www.lugv.brandenburg.de/cms/detail.php/bb1.c.312579.de)

However, this mitigation measure has some limitations. Deterrence by ultrasound is limited by distance (efficiency up to 15 meters) and weather conditions like humidity. Further effectiveness is different between bat species. Future studies must also evaluate cost-effectiveness of deterrents in relation to curtailment strategies to allow a cost-benefit analysis and mitigating bat fatalities.

Regarding the micro-wind turbines for local energy production, they may also potentially have significant impacts on bats if they are erected in close proximity to a roost or commuting route of these animals. A British study[55] carried out in 2010 on 20 different sites located in Scotland and England showed that bat activity (dominated by *Pipistrellus pipistrellus*) was 50 % lower near the micro-win turbine (1-5 m) compare to bat activity recorded at a further distance (20-25 m). Besides, a guidance document[56] has been published in May 2010 by the Malta Environment and Planning Authority. This document includes considerations of related impacts to bats and their minimisation.

Case study: Estimating bat (and bird) mortality occurring at wind energy turbines from covariates and carcass searches using mixture models (121)

Two approaches have been employed to assess collision rates: carcass searches and surveys of animals prone to collisions with wind turbines. The authors combined carcass search data with animal density indices in a mixture model to investigate collision rates. In a simulation study, they showed that the collision rates estimated by their model were at least as precise as conventional estimates based solely on carcass search data. Furthermore, if certain conditions are met, the model can be used to predict the collision rate from density indices alone, without data from carcass searches. This can reduce the time and effort required to estimate collision rates. They applied the model to bat carcass search data obtained at 30 wind turbines in 15 wind facilities in Germany. They used acoustic bat activity and wind speed as predictors for the collision rate. The model estimates correlated well with conventional estimators. Their model can thus be used to predict the average collision rate. It enables an analysis of the effect of parameters such as rotor diameter or turbine type on the collision rate. The model can also be used in turbine-specific curtailment algorithms that predict the collision rate and reduce this rate with a minimal loss of energy production.

year	number of turbines (I)	number of nights	number of recordings	number of carcasses found	average carcass detection probability	Average wind speed in m/s (SD)
2007	12	473	2187	22	0.58	5.2 (1.9)
2008	18	1225	16263	35	0.61	5.5 (1.8)

doi:10.1371/journal.pone.0067997.t001

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55 Park K., University of Stirling. "*Integrating applied ecology & planning policy: the case of micro-turbines & wildlife conservation*" (Presentation at a conference on Renewable Energy and Biodiversity Impacts, 7-8 November 2012, Cardiff).

56 "*Planning Guidance for Micro-Wind Turbines*" (www.mepa.org.mt/file.aspx?f=4983)

4.4 - Infectious diseases

4.4.1 - Infections affecting bats

Many different infectious agents have been found in bats (reviewed in (122)). However only very few of them has been shown to affect bat health or to be effectively transmitted to humans from bats.

4.4.1.1 - White-nose syndrome

White-nose syndrome (WNS) is a disease affecting hibernating bats. A newly cold adapted soil fungus, *Pseudogymnoascus destructans* (*Pd*) previously known as *Geomyces destructans* (123), has been demonstrated to cause this disease which was first documented in New York in the winter of 2006-2007.

Named for the white fungus that appears on the muzzle and other body parts of hibernating bats, WNS is associated with extensive mortality of bats in eastern North America: in some hibernacula, 90 to 100 % of bats have died. Bats with WNS exhibit uncharacteristic behaviour during cold winter months, including flying outside in the day and clustering near the entrances of hibernacula57.

In response to WNS in North America, researchers in Europe initiated a surveillance effort during the winter of 2008–09 for WNS-like fungal infections among hibernating populations of bats. *Pd* in Europe was previously reported in a single hibernating bat which was sampled in Périgueux (France) during March 2009 (124). Despite laboratory confirmation that bats obtained in Germany, Switzerland, Austria and Hungary were colonised by *Pd,* deaths were not observed at collection sites. Although the mechanism(s) by which hibernating bats died because of infection with *Pd* in North America is not yet fully understood. Bat species in Europe may exhibit greater resistance or respond differently to infection by this fungus than their counterparts in North America.

A more recent study seems to demonstrate that altered torpor-arousal cycles underlie mortality from WNS and provide direct evidence that *Pd* is a novel pathogen to North America from Europe (i.e. accidental introduction by tourists visiting caves). (125).

A resolution "*Guidelines for the Prevention, Detection and Control of lethal fungal Infections in Bats*" was adopted by the Parties of EUROBATS[58] to encourage monitoring of this issue and to raise awareness on this subject (NGOs, operators of tourist caves in Europe, laboratories …).

4.4.1.2 - Mass mortality on *Miniopterus schreibersii* - Lloviu virus as putative cause

In 2002, mass mortality on several populations of *M. schreibersii* was observed. It started in May in France and moving south to end on southern Iberian Peninsula in July. France, Spain and Portugal were affected by the event (126). Other bat species sharing roosts with *M. schreibersii* were not affected. Subsequent investigation revealed interstitial pneumonia as the cause of the death.

High loads of a new filovirus related to Ebola and Marburg viruses called the Lloviu virus was found in several organs of the affected bats including lungs. The Lloviu virus has been proposed as a new genus (Cuevavirus) within the family Filoviridae. Intensive search of the virus in affected populations of *M. schreibersii*, as well as in many other bat species from Spain has not succeeded on detecting the virus again. Consequently, the origin of the virus remains unknown. According to the extreme pathogenicity observed and to the absence of the virus in other populations of *M. schreibersii* than the affected ones by this particular mass-mortality event, punctual cross species from an unknown source resulting in a self-limited outbreak without further adaptation to the new host remains as the most likely hypothesis.

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[57] http://whitenosesyndrome.org/about-white-nose-syndrome

[58] www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP6_Record_Annex9_Res_6_6_GuidelinesFungalInfections.pdf

4.4.1.3 - Other infectious agents

In Europe, research is predominantly focused on European virus, but first indications of bat-pathogenic bacteria isolated from deceased bats in Germany and Great Britain has been found (127; 128; 129; 130).

Bats attacked by cats are likely to succumb to bacterial infection even if non-fatal injuries were present since various bacteria can be transmitted via bites. This relation has been proven for *Pasteurella multocida* infections in European bat species (128; 127; 131). On the other hand, bats already debilitated by disease are more vulnerable. Consequently, bats may also act as vectors for zoonotic pathogens, as domestic cats could pass these infectious agents on to humans. Such cross-species transmission events from bats to domestic animals are well documented (132; 133).

Ectoparasites (mites, fleas, and ticks) and endoparasits (helminth parasites and different protozoan) can also affect bats.

Impact of diseases and infectious agents on bats in Germany (134)**.**

Alongside to trauma-associated mortality and undefined mortality cases, disease aspects represented one third of mortality causes in 486 investigated bats of 19 European Vespertilionidae species. By comparing pathology and bacteriology results, the authors were able to detect 22 different bacterial species (families *Pasteurellaceae*, *Enterobacteriaceae*, *Steptococcaceae*) that were clearly associated with disease in bats. There was a strong association between cat predation and bacterial infections in bats as almost one half of bats (44 %) caught by cats were affected by bacterial disease.

Ectoparasites were noted in 14 % of bats. Microscopic examination of organ tissues revealed endoparasitic infection in 29 % of investigated bats, involving different protozoan (families *Eimeriidae* and *Sarcocystidae*) and helminth parasites (trematodes, cestodes, and nematodes). Helminthes were predominantly found in the gastro-intestinal tract of the bats, while in some animals, granulomatous organ lesions were associated with larval migration of nematode species. Large bats like *N. noctula*, *E. serotinus* and *V. murinus* revealed higher endoparasite prevalence compared to individuals of medium-sized or small Vespertilionidae species. At least 12 % of all bats had died due to bacterial, viral and parasitic infections. They also found clear seasonal and individual variations in disease prevalence and infection rates, indicating an increased susceptibility to infectious agents in female bats and juveniles during the maternity season.

4.4.2 - Negative public opinion of bats as carriers of viruses

The occurrence of viruses in certain European bat species has been confirmed in several MS. The negative public opinions on potential health risks may influence bat conservation with actions reducing their conservation status (individual killing, roosts destruction...). The media and the general public is a key concern for this issue.

4.4.2.1 - Rabies

The occurrence of Lyssaviruses (European Bat Lyssaviruses or EBLVs) in certain European bat species has been confirmed in several MS. These viruses have an extremely rare incidence in humans or other non-bat wild and domestic mammals; and none of these viruses seems to be a threat to bat populations.

EBLVs might be under-reported as prevalence is routinely reported only in countries that have a regular surveillance programme. Bat rabies reporting is historically based on passive surveillance made on bats in circumstances like dead, injury or diseases.

These circumstances facilitate contact with humans. Consequently, anthropic species and their associated viruses are overrepresented while bat species restricted to the wilderness are underrepresented and their associated viruses are rarely detected or even remain unknown.

The following current situation, known from passive surveillance only, is detailed in the Annexe 4.

A resolution was adopted by EUROBATS in 2006[59] including recommendations such as:

- Establishment of national bat rabies surveillance network in close collaboration with bat specialists,
- Supporting education efforts that reflect the best scientific advice available regarding the human health risks associated with bat rabies,
- Supporting efforts to avoid overreaction to incidental bat bite exposures and to develop policies for determining the fate of bats involved in contact incidents with humans (and domestic animals such as cats);
- Ensuring that reasonable advice on precautions to avoid infection is available and implemented, including for the maintenance of colonies in buildings where rabies-positive bats have been recorded.

Protocols based on recommendations of the EU Med-Vet-Net working group (*Rabies Bulletin Europe*, 2005(4): 3.1) were proposed.

4.4.2.2 - Other viruses

Viruses from most families relevant for human health have been found in bats. However, only some of them have been proved to have a relevant role in public health. Several seminal studies have recently implicated bats as sources of important RNA viruses of humans and livestock (122; 135; 136), including:

- coronaviruses (CoVs, human pneumonia, severe acute respiratory syndrome as SARS virus and the recently described MERS virus (137));
- filoviruses (viral hemoragic fever as Ebola and Marburg viruses (138));
- henipaviruses causing severe respiratory disease as hendra virus or severe encephalitis as Nipah virus, which are naturally harboured by Pteropid fruit bats in Asia and perhaps Africa (no current occurrence in the EU); and
- orthoreoviruses (diarrhea) (139; 140; 141)

It has been shown that bats harbour a great diversity of viruses of families such as Rhabdoviridae, Coronaviridae, Paramyxoviridae or Astroviridae that are considered as putative ancestors of members of these families infecting other mammals, including humans. However, a recent study found that bat hepadanvisuses may have been ancestral sources of primate hepadnaviruses including the Hepatitis B virus (142).

DNA viruses, including herpesviruses and adenoviruses (AdVs), have also been detected in bats, although with less clear implications regarding the role of bats as sources of infection for other mammals (143; 144; 136).

Most bat viruses transmitted to humans are carried by tropical fruit bats (filoviruses, henipaviruses) with no current emergence in the EU. But the predominant hosts of mammalian CoVs, including those related to the agent of Severe Acute Respiratory Syndrome (SARS), are insectivorous bats that are not restricted to tropical climates (145). The presence of SARS-related CoV in Europe has recently been demonstrated (136). Coronaviruses related with the Middle East Respiratory Syndrome (MERS) has been also found in Europe recently (146)

Knowledge is currently lacking on the ecology of bat-borne viruses in bat reservoirs (136). However, the Food and Agriculture Organisation of the United Nations has published in 2011 a document investigating the role of bats in emerging zoonoses worldwide (147). It shows that the advance of molecular tools and increased scientific activities in this field will uncover many more new bat viruses in the near future. Bat populations are more and more under stress, foraging and behavioural patterns are altered, niches expand, and livestock and humans come into closer contact than ever. The involvement of veterinarians and other wildlife specialists has highlighted the role that they can play in the surveillance, control and prevention of emerging zoonoses.

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59 www.eurobats.org/sites/default/files/documents/pdf/Meeting_of_Parties/MoP5_Record_Annex5_Res5_2_bat_rabies.pdf

4.5 - Misunderstandings and myths

4.5.1 - Ignorance

Simply because they are active only at night and difficult to observe and understand, bats rank among our planet's most misunderstood and intensely persecuted mammals.

A good description of ignorance on bats in accordance to time line was made by Arthur & Lemaire in 2009 (148) and is briefly summarised below. The first descriptions of bats were made according to the knowledge and superstitions of the moment. It was firstly described as a viviparous bird, according to Pliny the Elder (23-79) and then as a flying mouse by Albertus Magnus (1200-1280). Although bats aroused curiosity among their first observers, they have been suffering from man's misunderstandings. Back in time, several myths on bats led people to fear them and to try to eradicate them. They were considered as vampires sucking blood from sleeping animals. They were suspected to transmit scabies and to tangle into hair. Individuals were captured and nailed to doors or dived in molten lead (148).

From the 19th century to nowadays, this perception has now changed gradually thanks to naturalist observations and the wish to take out any negative popular belief on bats. Bats were considered as mammals for the first time in the second half of the 19th century (11). At the beginning of the 20th century, they were finally described as auxiliaries to agriculture by feeding on pest insects and started to be protected. However, since pesticides are used to control pest insects, bats' part in crop protection has been minimised (148). Nowadays, some prejudices against bats remain today. Bats are still believed by some to be dirty rodents and full of germs, or even ugly "little monsters". They would be feeding on human blood (while only 1 out of 1,200 bat species known worldwide feed on cattle blood and 2 others on bird blood). Intentional damages or destructions still occur as bats are sometimes unwanted in buildings because of the noise they make and their bad smell. Thus, colonies can be sprayed with chemicals, smoked out with suffer, shot, etc (148).

4.5.2 - Educational programs

Stakeholders, local authorities, land owners, buildings owners, farmers, foresters and other land users are key players in the conservation of bats. They need to be provided with all relevant information concerning the species ecology and the required management of their habitat. It is also very important to provide information to general public and to improve the public relation with bats. The following initiatives play an essential role in targeting this issue.

- Local bat groups

Many local bat groups in all European countries run events at night or during the day to raise public awareness on the issues that bats face nowadays. Nationwide NGOs assist them through the provision of communication materials.

- European/International bat night

The Bat Night, which is organised by EUROBATS, takes place every year since 1997 in more than 30 countries on the last weekend of August[60]. Nature conservation agencies and NGOs from across Europe pass on information to the public about the way bats live and their needs with presentations, exhibitions and bat walks, often offering the opportunity to listen to bat sounds with the support of ultrasound technology. From 2012, it was renamed the "International Bat Night" in order to be in phase with similar events taking place in other continents.

- Year of the bats in 2011-12

In 2011-12, The Convention on Migratory Species (CMS) and The Agreement on the Conservation of Populations of European Bats (EUROBATS) have joined together to celebrate the Year of the Bat. It enabled to attract the attention of the media and thus numerous members of the general public were invited to join in at a local event near where they live. It also helped in increasing data gathered by amateur naturalists with the aim of publishing regional distribution maps.

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[60] www.eurobats.org/international_bat_night

5 - FRAMEWORK FOR FUTURE ACTIONS

5.1 - Vision and overall goal

In the 2011 EC Communication "Our life insurance, our natural capital: an EU biodiversity strategy to 2020" (COM 244 final), the target 1 specifies:

"To halt the deterioration in the status of all species and habitats covered by EU nature legislation and achieve a significant and measurable improvement in their status so that, by 2020, compared to current assessments: (i) 100% more habitat assessments and 50% more species assessments under the Habitats Directive show an improved conservation status".

In reference to this policy the vision of this EU bat species Action Plan is:

To halt the deterioration of the status of all EU bat species

The overall goal of this action plan is:

To achieve a significant and measurable improvement in bat conservation status, so that 50% more species assessments under the HD show an improved conservation status by 2020 compared to current "inadequate" or "bad" assessments.

Waiting for the results of the current assessment of 2013 bat conservation status (analysis of article 17 reports) it is impossible to size this overall goal at this stage. However on a set of 606 assessed "trinomials"[61], there are 413 ones with an "inadequate" or "bad" assessment. To fulfil this overall goal, this means an improvement for more than 200 "trinomials"!

5.2 - Goal targets

The goal targets were defined on the basis of the issues identified in the first part of this report.

n°	Issues	Goal targets
1	Old or local or single species action plans in 16 MS and lack of action plans in 12 other MS (see 2.4) does not offer the right framework for bat conservation.	Multi/single bat species action plans published in all the EU Member States
2	Gaps in biological knowledge were identified (see 3.2)	Knowledge improved for the identified gaps
3	Lack of capacity or common understanding or common tools to get an EU overview on bat conservation status	Capacity building sufficiently developed with common approaches to assess population trends and bat conservation statutes
4	Lack of knowledge and involvement of local authorities and private landowners to correctly protect underground roosts	Decline of bat underground roosts stopped within Natura 2000 sites and the Eurobats Important Underground Sites.

[61] Trinomial = one species in one biogeographic area from one Member State (combinations - BA/MS/sp)

5	Lack of knowledge and involvement of local authorities and private landowners to correctly protect overground roosts	A European campaign launched on a shared approach between European building insulation schemes and European bat conservation policies
6	Lack of knowledge and involvement of local authorities and private landowners to correctly protect overground roosts	Technical solutions for bat conservation implemented in all key overground roosts especially within Natura 2000 sites
7	Lack of EIA/AA, or poor quality concerning bats, for building renovation, roads, or railways wind farms projects	Quality of bat studies in the framework of AAs and EIAs improved
8	Large mortality in quite all wind farms due to the lack of mitigation measures to reduce risks	Mitigation measures applied in all new wind farm projects and old wind farms revised within Natura 2000 sites
9	Large mortality along roads not designed in relation with local bat issues	A brochure on mitigation measures for road projects is published and a system to monitor road killing is developed in at least 14 MS
10	Fragmentation through transportation infrastructures, disappearance of hedgerows or habitat degradation is affecting commuting roads and bat key habitats	Any initiative to reduce fragmentation of EU landscape is supported and a bat indicator is developed to measure fragmentation
11	Forest are key habitats for bats but forest management does not take enough into consideration bat needs	A common scheme/strategy is developed between Eurobats, Forest Europe and EC to better integrate bat conservation within forest management policies/practices
12	Bad use of endectocides (antihelminthics) lead to insects mortality and reduce preys of some bat species	Define the best protocol possible concerning the use of antihelminthics
13	Conservation objectives hindered by a negative opinion against bats related to the risk of transmission of rabies and viruses to human and domestic animals	Public health, environmental authorities and conservation NGOs correctly informed on risks associated with viruses carried by bats
14	Fears due to misunderstandings and lack of knowledge on the life of bats	Key stakeholders correctly informed on bat requirements and action possibilities to conserve them

5.4 - Actions

Legends for the time scale in the tables below:

- ***Ongoing**: currently being implemented and should continue,*
- ***Immediate**: action should be completed in 1 year;*
- ***Short:** action completed in 3 years (2014 – 2017);*
- ***Medium**: completed in 6 years (2014-2020);*
- ***Long**: completed in more than 6 years;*

Legend for priorities in tables below:

- ***Priorities**: high, moderate, low*

Goal target 1: Multi/single bat species action plans published in all the EU Member States						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
1.1	Distribute this EU Action Plan and promote its implementation among all EU MS.	EU level	high	immediate	European Commission, (Eurobats, Batlife Europe)	Done before 2015
1.2	Prepare and implement National (Regional) multi-bats action plan	All MS	high	medium	National authorities, Conservation agencies, NGOs	Number of MS where such action plans have been adopted
1.3	Identify all appropriate EU funding resources for the activities outlined in the Action Plan, ensuring that all relevant organizations, institutions and individuals are aware of such opportunities	All MS	moderate	short	European Commission, National authorities	Already done for Natura 2000 Done before 2017 for Annex IV species
1.4	Assess the current EU multi-bats action plan in 6 years	EU level	high	long	European Commission (Eurobats)	Done before June 2021

Goal target 2: Knowledge improved for the identified gaps (see also other targets)						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
2.1	Launch conservation programmes on the Endangered species that are not in a favourable status in the EC (biology, habitat requirements, range): *Nyctalus azoreum, Pipistrellus maderensis, Roussettus aegyptiacus...*	CY, PT	high	medium	National authorities, Eurobats, Conservation agencies, Research institutions, NGOs	Number of species with actions undertaken
2.2	Promote research on the following issues: - Knowledge on regional meta-population - Migration mechanisms and precise assessment of migration routes, including possible movements between Africa and Europe - Knowledge on cryptic species (*Pipistrellus, Myotis*...) - Effects of pesticides/biocides on bat survival / fitness - Role of compensation schemes and artificial roosts in population dynamics;	All MS	moderate	medium	National authorities, Conservation agencies, Research institutions, Eurobats	Number of publications/reports concerning these issues

Goal target 3: Capacity building sufficiently developed with common approaches to assess population trends and bat conservation statutes						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
3.1	In the framework of article 17 reports, define a common understanding for reference value concerning bats and appreciation of pressure from human activities	all MS	high	medium	European Commission, EEA, national authorities, Conservation agencies	A report published
3.2	Development of the prototype pan European bat population indicator based on existing data (hibernacula counts, statistical package TRIM used for national trends, combination by a central statistical team to create pan European trends).	More than 15 MS	high	short	EEA, Eurobats, Batlife Europe, Conservation agencies, NGO's	A new report published by EEA before 2017
3.3	Development of the same kind of pan European population indicator based on maternity roosts.	At least 5 MS	moderate	medium	EEA, Eurobats, Batlife Europe, Conservation agencies, NGO's	A report published before 2020
3.4	Develop capacity building for monitoring in countries which do not currently have national monitoring schemes.	To be determined	high	medium	National authorities, Batlife Europe, NGOs	Number of new countries participating in European bat population indicators

Goal target 4: Decline of bat underground roosts stopped within Natura 2000 sites and the Eurobats Important Underground Sites						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
4.1	Review and update the list of Eurobats important underground sites for bats and the criteria for assessing them.	all MS	high	medium	Eurobats, national authorities, Conservation agencies, NGOs	A list published before 2020
4.2	Ensure that all the underground sites of international importance are within the Natura 2000 network. This could be mandatory when it concerns the Annex II species.	EU level	high	immediate	European Commission, Eurobats, national authorities	An assessment carried out before end of 2015
4.3	Ensure that all the underground sites within the Natura 2000 network have adapted closure systems and are safe from excessive disturbance	all MS	high	medium	European Commission, national authorities, Conservation agencies, NGOs	Assessment done within the next article 17 reports (2020)
4.4	Define a strategy to conserve underground sites at the national level in relation with the needs of species to be in a favourable conservation status.	all MS	high	medium	National authorities, Conservation agencies, NGOs	Chapter included within the National/Regional action plans
4.5	Ensure implementation of compensation measures in case of destruction of roosting sites in order to maintain the species conservation status.	all MS	moderate	medium	European Commission, Eurobats, national authorities, Conservation agencies, research institutions, NGOs	Assessment based on national derogation reports and/or article 6.4 schemes

Goal target 5 : A European campaign launched on a shared approach between European building insulation schemes and European bat conservation policies						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
5.1	DG Environment to liaise with other EU departments encouraging insulation, to make sure the needs of protected species are taken into account (e.g. programme Jessica)	EU level	high	short	European Commission	Key contacts identified and a meeting organised
5.2	Ensure EU and national policies promoting building insulation (in new and existing buildings) include the need to survey for the presence of bats and take account of their needs by including space for bat roosts	All MS	high	medium	Conservation agencies, NGOs, site managers, land owners and users	An assessment conducted for 2020
5.3	Launch an EU campaign on bat conservation within building insulation programmes	EU level	high	short	European Commission, Eurobats, Batlife Europe	A brochure published before 2017

Goal target 6: Technical solutions for bat conservation implemented in all key overground roosts especially within Natura 2000 sites						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
6.1	Ensure appropriate management on all Natura 2000 overground roosting sites with regular bat occurrence	all MS	high	medium	National authorities, Conservation agencies, NGOs, owners	Assessment done within the next article 17 reports (2020)
6.2	Ensure appropriate management on all other overground roosting sites with regular bat occurrence for priority species (to be determined nationally)	all MS	moderate	medium	National authorities, Conservation agencies, NGOs, owners	An assessment conducted for 2020
6.3	Define the best protocol possible concerning timber treatment during renovation of buildings, compile guidance documents already produced in a single web page with a summary on good practices	EU level	moderate	short	European Commission, Eurobats, Batlife Europe	A web page produced at the end of 2017
6.4	Management of problems caused by bats in cultural heritage roosting sites: compile guidance documents already produced in single web page with a summary on good practices.	EU level	moderate	short	European Commission, Eurobats, Batlife Europe	A web page produced at the end of 2017
6.5	Bridge restoration: compile guidance documents already produced in a single web page with a summary on good practices.	EU level	moderate	short	European Commission, Eurobats, Batlife Europe	A web page produced at the end of 2017
6.6	Biodiversity offset by building bat houses: compile and assess "experimental" designs in view of producing guidelines.	All MS	moderate	short	Eurobats, Batlife Europe, conservation agencies, NGOs	Guidelines published at the end of 2017
6.7	Define the best protocol possible concerning precaution in tree cutting in rural and urban areas, compile guidance documents already produced in a single web page with a summary on good practices.	All MS	moderate	short	Conservation agencies, NGOs	A web page produced at the end of 2017

Goal target 7 : Quality of bat studies in the framework of AAs, or EIAs or derogation procedures (art.12) improved						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
	Update the EC guidance document on Natura 2000 and wind farms to include bats conservation issues (especially mitigation measures).	EU level	high	short	European Commission	New EC guidance published before 2017
	Develop guidelines for assessing impacts of wind turbines on bat population	All MS	high	medium	Eurobats, National authorities, Conservation agencies, NGOs	A report published for 2020
	Develop guidelines for assessing impacts of roads on bat population	All MS	high	medium	Eurobats, National authorities, Conservation agencies, NGOs	A report published for 2020
	Develop guidelines for AAs (HD Art.6.3) for projects such as sky beamers or installation of any kind of large spotlights	All MS	moderate	medium	National authorities, Conservation agencies	A brochure or a web page published for 2020

Goal target 8 : Mitigation measures applied in all new wind farm projects and old wind farms revised within Natura 2000 sites						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
8.1	Organise a technical seminar on the impacts of wind farms on bats and develop guidelines for assessing impacts of wind turbines on bat populations	All MS	high	short	Batlife europe, National authorities, Conservation agencies, NGOs	A seminar organised before 2016 and a report published for 2017
8.2	Develop guidelines for the design of new wind turbines taking into consideration the ecological requirements of bat populations (mitigation measures)	EU level	high	medium	European commission, Eurobats, batlife Europe	Guidelines published or a web page produced at the end of 2020
8.3	Promote research supported by EU or national authorities on the impact of mortality due to wind farms on local bat meta-populations or European cross-border populations	All MS	moderate	long	EEA, Batlife Europe, Conservation agencies, Research institutions	Number of publications/reports concerning this issue
8.4	Produce a pilot register/data base to collect mortality cases (HD, art 12d)	EU level	high	medium	EEA, National authorities, Conservation agencies, NGOs	A report published by EEA before 2020

Goal target 9 : a brochure on mitigation measures for road projects is published and a system to monitor road killing is developed in at least 14 MS						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
9.1	Organise a technical seminar on the impacts of roads on bats and develop guidelines for assessing impacts of roads on bat populations	All MS	high	short	Batlife europe, National authorities, Conservation agencies, NGOs	A seminar organised before 2016 and a report published for 2017
9.2	Produce European technical guidance to help local authorities and stakeholders to minimise negative impacts during the planning and construction phases of new transportation infrastructures.	EU level	high	medium	European Commission, Eurobats, Batlife europe	Guidelines published or a web page produced at the end of 2020
9.3	Address the question of how current transportation systems can be improved to enhance the ecological coherence of the Natura 2000 network in relation with HD art.10. This includes works on the infrastructure transparency for bats (underpass and overpass, mitigation to reduce mortality) and actions to restore connectivity across existing infrastructures systems (by building tunnels and wildlife bridges) on the basis of national priorities.	All MS	moderate	medium	National authorities, Conservation agencies, NGOs	Assessment done within the next article 17 reports (2020)
9.4	Produce a pilot register/data base to collect mortality cases (HD, art 12d)	EU level	high	medium	European Commission, EEA, Topic centre	A report published by EEA before 2020
9.5	Promote research supported by EU or national support on the impact of mortality due to roads on local bat meta-populations or European cross-border populations	All MS	moderate	long	EEA, Batlife Europe, Conservation agencies, Research institutions	Number of publications/reports concerning this issue

Goal target 10: Any initiative to reduce fragmentation of EU landscape is supported and a bat indicator is developed to measure fragmentation						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
10.1	Support the recommendation made by EEA on landscape fragmentation in Europe: *"[...] We recommend drawing up guiding concepts for the landscapes in Europe (together with the MS) that include the identification of regionally and nationally important unfragmented areas and priority areas for defragmentation. To make these guiding concepts more tangible, it is desirable to adopt appropriate benchmarks or targets for the degree of landscape fragmentation. [...]".* *"[...] Appropriate objectives and measures should be elaborated that are made binding for European and national offices and should state what measures should be taken and where and how they should be implemented, in connection with ongoing EU initiatives for a green infrastructure. A process of Europe-wide documentation and coordination is recommended to produce an overview of measures at the European level and to enable regional strengths and shortcomings to be recognised more easily. [...]".*	EU level	high	immediate	European commission	A support given by Habitats Committee before end of 2015
10.2	Develop a prototype indicator on bats and fragmentation	EU level	moderate	medium	European Commission, Eurobats, EEA, Batlife Europe	A report published by EEA before 2020
10.3	To enhance the ecological coherence of the Natura 2000 network in relation with HD art.10, improve connectivity between bat populations by creating line corridors and stepping stones with appropriate habitat and its management, especially in areas with fragmented populations (e.g. connection of forest fragments with hedgerows and tree lines)	all MS	high	medium-long	National authorities, Conservation agencies, NGOs	Assessment done within the next article 17 reports (2020)

Goal target 11 : a common scheme/strategy is developed between Eurobats, Forest Europe and EC to better integrate bat conservation within forest management policies/practices						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
11.1	Integrate bat conservation issue in the guidance document on forest and Natura 2000 (under preparation)	EU level	high	short	European Commission and Habitat committee	Forest guidance document published with bat issues
11.2	Promote research work on the relationship between bat communities and forest types in the next research and innovation programmes supported by the EU: Assessment of direct mortality in bats due to forestry operations, evaluation on the density of "suitable" trees (e.g. dead trees) to be left in order to sustain populations of forest species, effects of forest fragmentation on dispersal / gene flow of forest bat species.	All MS	moderate	long	European Commission, EEA, Batlife Europe, Conservation agencies, Research institutions	Number of publications/reports concerning this issue
11.3	In relation with the new EARDF or LIFE funding possibilities, implementing agreements regarding forest management with forest owners in important key Natura 2000 sites for vulnerable tree-roosting bats.	All MS	moderate	medium	National and regional authorities, NGOs	Number of projects co-financed
11.4	Encourage MS to promote training and awareness for forest managers and forest workers in order to improve bat conservation with the help of their own national guidance relevant to their bat communities, forest ecosystems and forest management practices.	All MS	moderate	medium	National/regional conservation and forest authorities, conservation agencies, NGOs	An assessment conducted for 2020
11.5	Produce European technical guidance to help local forests authorities and stakeholders to combine forestry with bat conservation in intensively managed forests or in key bat forest habitats	EU level	high	medium	European Commission, Eurobats, Batlife europe	Guidelines published or a web page produced at the end of 2020

Goal target 12: Define the best protocol possible concerning the use of antihelminthics						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
12.1	Define the best protocol possible concerning the use of antihelminthics, compile guidance documents already produced in a single web page with a summary on good practices	EU level	moderate	short	European Commission, Eurobats, Batlife Europe	A web page produced at the end of 2017

Goal target 13: Public health, environmental authorities and conservation NGOs correctly informed on risks associated with viruses carried by bats						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
13.1	Support education efforts that reflect the best scientific advice available regarding the human health risks associated with bat rabies and support efforts to avoid overreaction to incidental bat bite exposures and to develop policies for determining the fate of bats involved in contact incidents with humans (and domestic animals such as cats).	All MS	moderate	medium	Eurobats, National authorities, Conservation agencies, NGOs	An assessment conducted for 2020
13.2	Ensure that the bat conservation and speleogy societies are aware of the threat associated with the fungal infection known as White Nose Syndrome in North America and encourage liaison between them. Encourage surveillance for the presence of fungal infections in bats. Identify laboratories with facilities to identify skin fungi and refer any such fungi found on bats for identification.	All MS	moderate	medium	National authorities, Conservation agencies, Research institutions, NGOs	An assessment conducted for 2020
13.3	Ensure that reasonable advice on precautions to avoid infection is available and implemented (e.g., rabies compulsory vaccination for people regularly handling bats) including for the maintenance of colonies in buildings where rabies-positive bats have been recorded.	All MS	moderate	medium	National authorities, Conservation agencies, Research institutions, NGOs	An assessment conducted for 2020

Goal target 14: Key stakeholders correctly informed on bat requirements and action possibilities to conserve them						
No.	**Action**	**MS**	**Priority**	**Time scale**	**Responsible organizations**	**Indicator**
14.1	Continue the event “International Bat Night” on an annual basis	All MS	high	Ongoing	Eurobats, NGOs	See Eurobats
14.2	Draft and publish on the web a list of FAQ concerning solutions to problems arising from the discovery of colonies in private properties (public: owners)	All MS	high	Medium	Conservation agencies, NGOs	An assessment conducted for 2020
14.3	Training workshops, informative seminars, factsheets, etc., to involve volunteers into conservation work (e.g. monitoring of colonies, acoustic monitoring…).	All MS	moderate	long	Batlife Europe, NGOs	An assessment conducted for 2020
14.4	Compilation of a list of scientific publications on the effectiveness and value of rehabilitation for bats and a list of handbooks and papers on bat rehabilitation and care in captivity; development of guidelines for protocols for accepting animals into captivity.	All MS	moderate	medium	Eurobats, Batlife Europe, Conservation agencies, NGOs	Guidelines published by Batlife Europe for 2020

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Study: Wind Turbines Could Make This Endangered Bat Go Extinct

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Andrew Follett | Energy and Science Reporter

Wind turbines are killing endangered bats much faster than anybody thought, according to a new University of California study that warns hoary bats could go extinct if nothing is done.

The new study found the endangered hoary bat populations could decline by 90 percent in the next 50 years as more wind turbines are built. The study's results suggest building wind turbines poses a substantial threat to migratory bats in North America.

Hoary bats were listed under the Endangered Species Act in 1970, and are Hawaii's only native land mammal. Population estimates of the bats for all islands range from a few hundred to a few thousand, according to the U.S. Fish and Wildlife Service (FWS). The research was supported by FWS and the U.S. Forest Service.

"This new study is a clear warning signal that action is needed before the hoary bat population plummets and needs heroic measures to prevent its extinction," Jamie Rappaport Clark, president of the environmental group Defenders of Wildlife which was not involved in the study, said in a statement. "Defenders of Wildlife will work with the wind energy industry and other conservation partners over the next year to tackle this issue, so that these dire predictions never become reality.

Hawaii's five major wind turbine farms are killing endangered bats about three times faster than anyone predicted.

Wind farms killed more bats in the last 6.4 years than experts expected the turbines to kill over two decades. The wind farms have killed 146 endangered Hawaiian hoary bats out of the 187 they are permitted to kill by 2030. The same turbines have also killed roughly 50 nene, an endangered goose and Hawaii's state bird.

Wind farms kill an estimated 573,000 birds each year, as well as 888,000 bats, according to a 2013 peer-reviewed study published in Wildlife Society Bulletin. Wind farms are projected to kill 1.4 million birds annually by 2030. A single solar power plant in California killed an estimated 3,500 birds in just the plant's first year of operation.

Wind farms in North Carolina were forced to pay a $1 million fine for killing 14 eagles and 149 other birds in 2013. An Oregon-based wind power company was fined $2.5 million for killing 38 eagles in 2015. Modern wind turbines create a powerful vortex that literally sucks eagles and other birds into them.

To put those numbers in perspective, the 2010 British Petroleum Gulf of Mexico oil spill only killed an estimated 800,000 birds, for which the company was fined $100 million. In the last five years, America's wind turbines killed more than three times as many birds as the BP oil spill did.

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Review Article

Ecological and Economic Importance of Bats (Order Chiroptera)

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Abstract
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Abstract

Order Chiroptera is the second most diverse and abundant order of mammals with great physiological and ecological diversity. They play important ecological roles as prey and predator, arthropod suppression, seed dispersal, pollination, material and nutrient distribution, and recycle. They have great advantage and disadvantage in economic terms. The economic benefits obtained from bats include biological pest control, plant pollination, seed dispersal, guano mining, bush meat and medicine, aesthetic and bat watching tourism, and education and research. Even though bats are among gentle animals providing many positive ecological and economic benefits, few species have

negative effects. They cause damage on human, livestock, agricultural crops, building, and infrastructure. They also cause airplane strike, disease transmission, and contamination, and bite humans during self-defense. Bat populations appear to be declining presumably in response to human induced environmental stresses like habitat destruction and fragmentation, disturbance to caves, depletion of food resources, overhunting for bush meat and persecution, increased use of pesticides, infectious disease, and wind energy turbine. As bats are among the most overlooked in spite of their economical and ecological importance, their conservation is mandatory.

1. Introduction

The order Chiroptera is the second most diverse among mammalian orders, which exhibits great physiological and ecological diversity [1]. They form one of the largest nonhuman aggregations and the most abundant groups of mammals when measured in numbers of individuals [2]. They evolved before 52 million years ago and diversified into more than 1,232 extant species [3]. They are small, with adult masses ranging from 2 g to 1 kg; although most living bats weigh less than 50 g as adults [4]. They have evolved into an incredibly rich diversity of roosting and feeding habits. Many species of bats roost during the day time in foliage, caves, rock crevices, hollows of trees, beneath exfoliating bark, and different man-made structures [2]. During night, they become active and forage on diverse food items like insects, nectar, fruits, seeds, frogs, fish, small mammals, and even blood [3].

The forelimb of a bat is modified into a wing with elongated finger bones joined together by a thin and large (85% of the total body surface area) membrane with rich blood flow [5]. Their wing is an unusual structure in mammals enabling for active unique powered flight. Skin covering the wings of bats not only constitutes a load-bearing area that enables flying but also performs multiple functions like providing a protective barrier against microbes and parasites, gas exchange, thermoregulation, water control, trapping of insects, and food manipulation and for swimming [6]. The powerful flight of bats plays the most important role for their widespread distribution and diversity. This helps in the occurrence of bats in all continents except Antarctica, some Polar Regions, and some isolated oceanic islands. It has also contributed a lot for their extraordinary feeding and roosting habits, reproductive strategies, and social behaviors [2].

Although all bats do not echolocate, in general echolocation is considered as one of the major characteristics of bats. Even if the role of echolocation for plant-visiting bats is not clear, they use wide range (10–200 kHz) of ultrasonic frequencies during foraging. The availability of commercially produced bat detectors contributed a lot in linking data of echolocation with the biology of bats [3].

Bats are an essential natural resource that play great role in providing many ecological and economic services [7]. However, the determination of the ecological and economic values provided by bats is extremely challenging except from the studies on ecosystem services provided directly to the production of goods and services consumed by humans [3, 7].

2. Ecological Importance of Bats

Bats have long been postulated to play important ecological roles in prey and predator, arthropod suppression, seed dispersal, pollination, material and nutrient distribution, and recycle [3].

2.1. As Predators

Bats have diverse patterns of feeding in which some select among available prey while others are generalist predators, feeding on a wide diversity of taxonomic groups. They also opportunistically consume appropriately sized prey depending on availability within a preferred habitat [8]. Their prey size can vary from 1 mm (midges and mosquitoes) to as large as 50 mm long (beetles and large moths) based on the species of bat [8, 9].

Remains of 12 orders or classes of prey belonging to 18 taxonomic families of insects were reported in the diet of bats [10]. The prey items include Acari, Arachnida, Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Isoptera, Lepidoptera, Neuroptera, Orthoptera, and Trichoptera. They also predate on frogs, fish, small mammals, and even blood of mammals and birds [3]. Some species also eat unusual prey items such as scorpions and spiders [11]. Bats exhibit high species diversity with multiple species forage sympatrically to avoid competition. A resource partition is possible through the use of diverse mechanism like difference in wing shape, body size, and sensory cues [12].

Obtaining accurate estimates of the amount of prey consumed by bats is challenging. However, its amount and type are confirmed as it varies with prey availability, time during night, species, sex, age, and the reproductive status of bats [13, 14]. Variety of approaches like direct observation [15], comparison of pre- and postflight body mass [14], and fecal sample analysis [16] have been used to estimate the amount and type of prey consumed by bats. Results of studies carried out on insectivorous bats indicated that they consume more than 25% of their body mass of insects each night [17]. At the peak night of lactation, a 7.9 g little brown bat (*Myotis lucifugus*) needs to consume 9.9 g of insects which is over 100% of its body mass [18]. At peak lactation, a female Brazilian free-tailed bat (*Tadarida brasiliensis)* consumes insects up to 70% of the body mass each night. It frequently selects nutrient-rich abdomen of moths while discarding the wings, head, and appendages, which greatly increases feeding efficiency and the quantity of insects consumed [14]. This can indicate that maternity colony of one million Brazilian free-tailed bats weighing 12 g each could prey up to 8.4 metric tons of insects in a single night. These studies hint at the immense capability of insect consumption and the potential role of bats in the suppression of arthropod populations [3]. Based on fecal sample analyses, a colony of 300 evening bats (*Nycticeius humeralis*) and 150 big brown bats in Indiana was estimated to consume 6.3 and 1.3 million insects per year, respectively [16, 19].

In this way, an estimated 99% of potential crop pests are limited by natural ecosystems of which some fraction can be attributed to predation by bats [7]. Predation of bats can have direct effects on herbivore communities and indirect effects on plant communities through both density mediated (consumption) and trait-mediated (behavioral) interactions and for nature balance [20].

2.2. Prey for Vertebrates

Although there are relatively few observations of animals feeding on bats, a number of vertebrate predators like fish, amphibians, birds, reptiles, and mammals prey on bats throughout the world [21, 22]. The main bat predators are owls, hawks, falcons, snakes, and mammals such as raccoons, ringtails, and opossums. In some countries like New Zealand, forest-floor dweller bats are frequently predated by the introduced rats, feral cats, and weasel [23]. The larger phyllostomid bats (*Vampyrum spectrum*, *Chrotopterus auritus*, and *Phyllostomus hastatus*) are known to eat smaller bats [24].

Bats generally comprise a relatively small proportion of the diet of most predators. Bats represented only 0.003% of the diet of small falcons and hawks and 0.036% of the diet of owls in Great Britain [21]. Although diurnal raptors feed on bats during twilight hours in some parts of the world [25], nocturnal predation by owls is the most significant predation pressure on bats in temperate regions [21].

Most of the bats are predated on roosting or when they emerge from roosts although sometimes predated during foraging or flying. Large concentrations of bats at roost sites and the relatively predictable patterns of their emergence from roosts, provide significant opportunities for predators to prey on bats [25]. However, strategies like low dependability to roost sites, selection of time, and patterns of emergence from roosts and nocturnal activity are used to minimize the risk of predation [21].

2.3. Hosts for Parasite

Numerous haematophagous ectoparasites live such as bat fleas (Ischnopsyllidae), bat flies (Nycteribiidae), bat mites (Spinturnicidae), and bugs (Cimicidae) on the skin surface and in the fur of bats. These obligate ectoparasites are specialized to their hosts [26]. The skin and hair morphology play important roles in affecting the parasite's life style in terms of adaptation, feeding, movement and egg laying resulted in morphological adaptations with coevolution of both species [5].

The hair density as well as surface structures of bat hairs and the distribution of mast cells are very important for the host defense against parasite infestation. Although the hair density of bats primarily provides protection against unfavorable microclimatic conditions, it also serves as passive antiparasitic defense. The high hair density prohibits infestation by large parasites. However, dense fur in some parts of the host's body may provide a suitable shelter for specialized small parasites [5].

2.4. Pollination

In addition to insect suppression through predation, some bat species primarily the two families of bats (Pteropodidae in the Old World and Phyllostomidae in the New World) play important roles in plant pollination [3]. Although bat pollination is relatively uncommon when compared with bird or insect pollination, it involves an impressive number of economically and ecologically important plants [27]. Particularly, beyond the economic value of plant pollination and seed dispersal services, plant-visiting bats provide important ecological services by facilitating the reproductive success and the recruitment of new seedlings [3]. Many of these plants are among the most important species in terms of biomass in their habitats. For instance, bat-pollinated columnar cacti and agaves are dominant vegetation elements in arid and semiarid habitats of the New World [3].

Bat pollination occurs in more than 528 species of 67 families and 28 orders of angiosperms worldwide [28]. Pteropodid bats are known to pollinate flowers of about 168 species of 100 genera and 41 families and phyllostomid bats pollinate flowers of about 360 species of 159 genera and 44 families [28]. As feeding on nectar and pollen requires relatively specialized morphology (e.g., elongated snout and tongue), relatively few members of these families are obligate pollinators. Unlike predation, which is an antagonistic population interaction, pollination, and seed dispersal are mutualistic population interactions in which plants provide a nutritional reward (nectar, pollen, and fruit pulp) for a beneficial service [3].

2.5. Seed Dispersal

Seed dispersal is a major way in which animals contribute for ecosystem succession by depositing seeds from one area to another [29]. As 50–90% of tropical trees and shrubs produce fleshy fruits adapted for consumption by vertebrates, the role played by frugivorous bats in dispersing these seeds is tremendous [30].

Countless tropical trees and understory shrubs are adapted for seed dispersal by animals, primarily by bats and birds. Particularly, night-foraging fruit bats are more compliant than birds by covering long distances each night, defecating in flight, and scattering far more seeds across cleared areas [31]. Unlike most seed dispersal by vertebrates that dispersed close to parent plants with only 100–1,000 m away, the seeds dispersed by frugivorous bats were relatively far away (1-2 km) [31]. Furthermore, the flying fox migration for more than 1,000 km across the central belt of the African continent helps to scatter huge numbers of seeds along the way. Unlike birds, bats tend to defecate or spit out seeds during flight and hence facilitate seed dispersal in clear-cut strips [32]. In addition to their tendency to defecate seeds in flight, many bats use one or more feeding roosts each night where they deposit the vast majority of seeds ingested far away from fruiting plants.

Many bat-dispersed seeds are from hardy pioneer plants, the first to grow in the hot, dry conditions of clearings with up to 95% chance of germination. As these plants grow, they provide shelter that helps other, more delicate plants to grow [33]. Fruit-eating bats play an extremely important role in forest regeneration. Tropical frugivorous bats also facilitate tropical forest regeneration and help to maintain species diversity by introducing seeds from outside disturbed areas, whereas the neotropics frugivorous bats play important role in the early stages of forest succession [32].

The dispersed seeds of palms and figs by bats are also common in many tropical forests. Because they are also eaten by many birds and mammals, figs often act as keystone species in tropical forests [34].

2.6. Soil Fertility and Nutrient Distribution

Bats play an important ecological role in soil fertility and nutrient distribution due to their relatively high mobility and the use of different habitats for roosting and foraging, which facilitates nutrient transfer within ecosystems [35, 36]. However, the suspected importance of nutrient transfer by bats in overall ecosystem function is probably relatively low when compared with microhabitat conditions [36]. For soil fertility and nutrient distribution, bat guano has a great ecological potential as bats sprinkle it over the landscape throughout the night. Thus, bats contribute a lot in nutrient redistribution, from nutrient-rich sources (e.g., lakes and rivers) to nutrient-poor regions (e.g., arid or upland landscapes) [35]. For instance, a colony of one million Brazilian free-tailed bats (*T. brasiliensis*) in Texas can contribute to 22 kg of nitrogen in the form of guano.

Bat guano in turn supports a great diversity of organisms including arthropods, fungi, bacteria, and lichens that represent different trophic levels [37]. The diversity of organisms living on guano differs depending on the species and their diet. For example, guano from insectivorous bats is typically inhabited by mites, pseudoscorpions, beetles, thrips, moths, and flies, whereas the guano of frugivorous bats is inhabited by spiders, mites, isopods, millipedes, centipedes, springtails, barklice, true bugs, and beetles [38]. As bats regularly or occasionally roost in caves, bat guano provides the primary organic input to cave ecosystems, which are inherently devoid of primary productivity. They provide essential organic input that supports assemblages of different endemic cave flora and fauna. For example, cave-dwelling salamander and fish populations and invertebrate communities are also highly dependent upon nutrients from bat guano. However, little consideration has been given to the role of bats in supporting entire cave ecosystems [39].

2.7. Bioindicators

The earth is now subject to climate change and habitat deterioration on a large scale. Monitoring of climate change and habitat loss alone is insufficient to understand the effects of these factors on complex biological communities [40]. Ecosystems are geographically variable and inherently complex whereas responses to anthropogenic changes are in a nonlinear and scale dependent manner. Thus, a broad-scale network of monitoring that captures local, regional, and global components of the earth's biota is critical for understanding and forecasting responses to climate change and habitat conversion [2]. It is therefore important to identify bioindicator taxa that show measurable responses to climate change and habitat loss and that reflect wider-scale impacts on biodiversity [2].

There are three types of bioindicators (biodiversity, ecological, and environmental indicators) [41]. Biodiversity indicators capture responses of a range of taxa and reflect components of biological diversity such as species richness and species diversity. Ecological indicators consist of taxa or assemblages that are sensitive to identified environmental stress factors that demonstrate the effect of those stress factors on biota. Environmental indicators respond in predictable ways to specific environmental disturbances [41].

Biodiversity indicator species have characteristics that can be used as an index of attributes (e.g., presence/absence, population density, and relative abundance) of other species comprising the biota of interest [42]. Thus, these species collectively must have characteristics that make them easily identifiable (stable taxonomy), easy to sample, and show graded responses to habitat degradation that correlate with the responses of other taxa [43]. In addition, as environmental degradation can occur over a variety of scales, monitoring the impacts of such threats through indicator species requires the species that have broad geographic ranges. Bats, as volant taxa, fulfill this criterion better than most other taxa [2].

Bats are excellent ecological indicators of habitat quality. They have enormous potential as bioindicators to both disturbance and the existence of contaminants due to a combination of their size, mobility, longevity, taxonomic stability, observable short and long term effects, trends of populations, and their distribution around the globe [2, 4, 44].

Bat populations are affected by a wide range of stressors that affect many other taxa. In particular, changes in bat numbers or activity can be related to climate change (including extremes of drought, heat, cold, precipitation, cyclone, and sea level rise), deterioration of water quality, agricultural intensification, loss and fragmentation of habitats, fatalities at wind turbines, disease, pesticide use, and overhunting [2]. The magnitude of changes around the globe is quite variable as is the nature of the human activities that alter and fragment landscapes differs from one place to another [45]. As insectivorous bats occupy high trophic levels, they are sensitive to accumulations of pesticides and other toxins, and changes in their abundance may reflect changes in populations of arthropod prey species [1]. High fatalities observed in bats associated with diseases, may provide an early warning of environmental links among contamination, disease prevalence, and mortality. Increased environmental stress can suppress the immune systems of bats and other animals and thus one might predict that the increased prevalence of diseases is a consequence of altered environments [2].

3. Economic Importance of Bats

3.1. Biological Pest Control

Among the estimated 1,232 extant bat species, over two-thirds are either obligate or facultative insectivorous mammals. They consume nocturnal and crepuscular species of insects from different habitats as such forests, grasslands, agricultural landscapes, aquatic, and wetland habitats [3].

Various species of prominent insect pests have been found in the diet of bats based on identification of insect fragments in fecal samples and stomach contents. They consume enormous quantities of insect pests that cost farmers and foresters billions of dollars annually [46]. These insects include, June beetles (Scarabidae), click beetles (Elateridae), leafhoppers (Cicadelidae), plant hoppers (Delphacidae), the spotted cucumber beetle (Chrysomelidae), the Asiatic oak weevil (Curculionidae), and the green stinkbug (Pentatomidae) [3].

Mexican free-tailed bats (*T. brasiliensis*) feed an estimated one million kilogram of the most costly agricultural pest insects (corn earworm moth) each night [47]. One bat can eat 20 female corn earworm moths in a night and each moth can lay as many as 500 eggs, potentially producing 10,000 crop-damaging caterpillars [46]. About 150 big brown bats also consume enough adult cucumber beetles in one summer to prevent egg-laying that could produce 33 million root-worm larvae and contributing in prevention of agricultural pests damage [16]. Thus, the death of one million bats from the disease called white nose syndrome indicates 660–1,320 metric tons of insects are no longer being consumed each year in affected areas [36]. Millions of Brazilian free-tailed bats each evening consume a wide variety of prey items (12 orders, 35 families) of about 14,000 kg agricultural pests [48, 49]. Based on the dietary composition (minimum number of the total insects per guano pellet), number of specific agricultural pest species in each pellet, and the number of active foraging days per year, a colony of 150 big brown bats (*Eptesicus fuscus*) in the midwestern United States annually consume approximately 600,000 cucumber beetles, 194,000 June beetles, 158,000 leafhoppers, and 335,000 stinkbugs, which are severe crop pests [16].

Bats are just one of several groups of animals that naturally prey upon mosquitoes. A Florida colony of 30,000 southeastern myotis (*Myotis austroriparius*) eats 50 tons of insects annually, including more than 15 tons of mosquitoes [8]. It is also known that northern long-eared bats (*Myotis septentrionalis*) suppress mosquito populations through direct predation [50].

The estimation of the economic importance of bats in agricultural systems is challenging [36]. A common challenge in the study of the use of bats as pest control is the lack of basic ecological information regarding foraging behavior and diet for many species of bats. For example, traditional dietary analyses through fecal or stomach contents have only identified arthropod fragments to the ordinal or familial level, rather than to species [9, 17] and in cases where species identification is possible, it has typically been restricted to hard-bodied insects although recent novel molecular techniques have allowed detection and species identification of both hard and soft bodied insects [51, 52]. However, the value of pest suppression services provided by bats ranges from $12 to $173 per 0.405 ha in Texas [48]. In USA, the estimate value of bats as a result of reduced costs of pesticide applications due to insect pest suppression by bat predation is in the range of $3.7–$53 billion per year excluding the costs of impacts of pesticides on ecosystems [36].

3.2. Pollination

As pollinators, tropical bats provide invaluable support to many local and national economies [33]. Large-scale cash crops that are originally pollinated or dispersed by bats include wild bananas, mangos, breadfruits, agave, durians, and petai of which durians and petai currently rely on bats for pollination

[7]. Durian, a wildly popular fruit worth more than $230 million per year in southeast Asia, opens its flower at dusk and relies almost exclusively on fruit bats for pollination [7].

Except the "ornamental" bananas with upright flowers that are pollinated by birds, all the rest, including the ancestors of edible bananas, that have horizontal or drooping flowers are pollinated primarily by bats [33]. Their adaptations for bat pollination include nocturnal flowering, a strong and characteristic odor that attracts bats, plus abundant and accessible nectar and pollen. The coevolution of bananas and bats over 50 million years also resulted in adaptations for effective seed dispersal even if other mammals like monkeys feed on fruits and disperse seeds [33]. Although bats are no longer needed to pollinate flowers or disperse the seeds of edible bananas, the ecological services bats provide for their wild relatives are important for conserving its genetic diversity [3].

Agave macroacantha is extremely dependent on nocturnal pollinators for its reproductive success of which bats are especially important for its successful pollination [53]. Some of these pollinators (bats) are migratory, and have been reported to be steadily declining. A continuing decline in the populations of pollinators may hamper the successful sexual reproduction of the plant host and may put its survival under risk [53].

The Mahwa tree or honey tree (*Madhuca indica*) is pollinated by bats. These pollination services highlight one of the highly valued ecosystem services provided by plant-visiting bats both culturally and economically. The timber of this tree is used for making farm cart wheels in India. The flowers are used as food and for preparing a distilled spirit and its sun-dried fruits for human consumption and the oil extracted from flowers and seeds as ingredients for soaps, candles, cosmetics, lubricants, and medicines [54].

Similarly, there are 289 Old World tropical plant species that rely on pollination and seed dispersal services by bats for their propagation [7]. These plants, in turn, contribute to the production of 448 bat-dependent products in a variety of categories such as timber and other wood products (23%); food, drinks and fresh fruit (19%); medicine (15%); dye, fiber, animal fodder, fuel wood, ornamental plants, and others (43%). However, because bat-provided services represent one input within a multi-input production process, only a portion of the total value of the end product can be attributed to bats [7].

The pollination services of bats for 100 food crops by combining the pollination dependence ratios with regional crop production and its prices was determined [55]. Of these, 46 crops depended to some degree on animal pollinators (6 essentially dependent, 13 highly dependent, 13 moderately dependent, and 14 slightly dependent) accounting for 39% of world production value.

Based on the crop production and animal-dependent pollination, the total economic value of bats in global pollination services is estimated to be $200 billion, representing 9.5% of the value of world food crop production in 2005 [55].

3.3. Seed Dispersal

Bats are crucial to the survival of the world's tropical forests. Enormous expanses of rain forest are cleared every year for logging, agriculture, ranching, and other uses. Fruit-eating bats are uniquely suited for dispersing the seeds of "pioneer plants" from which a diverse and healthy forest can reemerge [33]. Thus, the economic value contributed by bats in maintaining forests is tremendous. For instance, the economic value estimate for seed dispersal services provided by bats to the regeneration of giant oak is $212,000 for seeding acorns and $945,000 for planting saplings [56]. The tropical almond tree, *Terminalia catappa*, is one of the bat-dispersed trees with many human uses like shade, fuel-wood, edible nuts, timber, and tannin (extracted from the bark, leaves, roots, and the fruit shell). The large leaves are also used as wrapping material and have also many medicinal uses, including diaphoretic, anti-indigestion, antidysentery and headache [33].

3.4. Guano Mining

Guano from bats has long been mined from caves for use as fertilizer on agricultural crops due to its high concentrations of limiting nutrients like nitrogen and phosphorous [57]. It provides some of the world's finest natural fertilizers [58]. About 950 bat guano products show a market demand for the product. Prices for bat guano organic fertilizer varied from $1.25 to $12.00 per 0.5 kg depending on the size of the package (larger packages have lower unit prices) and the mix of its ingredients [3]. The Mexican free-tailed bat guano has been extracted for fertilizer in thousands of tons from Bracken Cave in Texas alone with the current retail sales ranging from $2.86 to $12.10 per kilogram [58]. In some places, guano harvesting is carried out on a sustainable basis, especially in caves where bats normally migrate elsewhere for a part of their life each year. The bacteria extracted from bat guano have also been used by some companies to improve detergents and other products of great value to humans [58].

3.5. Bush Meat and Medicine

Bats have also long been used for food and medicine [59]. They provide a direct source of human food in many countries [60]. Several anecdotal price information of bat bush meat ranges from $2.50 to $3.50 per bat in Malaysia and $0.43–$10 per bat in Jakarta. Bat bush meat has the highest nutrient (high protein, vitamin and mineral composition) with lowest cost per kg [7, 61, 62]. Several studies have reported on the overhunting of bat for bush meat indicating a need for further conservation [61].

The anticoagulant compound called salivary plasminogen activator (DSPA) found in the saliva of the common vampire bat is used to treat strokes. Unlike alternative medicines, it can be administered even much later after a stroke has occurred and still be effective [63]. Physicians used bats to treat ailments of patients ranging from baldness to paralysis [60, 63].

3.6. Aesthetic and Bat Watching Tourism

Wildlife watching is simply an activity that involves watching wildlife to identify and observe their behavior and appreciate their beauty. It differs from other forms of wildlife-based activities like hunting and fishing [49]. Although perhaps not as widely practiced as bird watching, bat watching is currently growing as a recreational activity [49]. Similar to other wildlife watching tourism, it also generates income in the form of entrance and permit fees, personal payments to the guides, drivers and scouts and payment for accommodation, and other services [49].

The majority of bat watching takes place at cave entrances where bats emergence can be viewed. For this purpose, the charge ranges from $5 to $12 per visitor. For instance, the Congress Avenue Bridge, which is the home to the largest urban bat colony of approximately 1.5 million Mexican free-tailed bats (*T. brasiliensis*) in USA is visited by 200–1,500 visitors per evening with the value of $3 million per year. The spectacular flock emergence of bats from their roost from March to November, to feed and migrate south during the winter months serves as tourist attraction [49, 64].

3.7. Education and Research

Although extremely difficult to quantify, it is important to recognize the extraordinary value of bats to ancient and contemporary traditions and science. The current study of bat echolocation and locomotion has provided inspiration for novel technological advances in biomedical ultrasound, sensors for autonomous systems, and wireless communication and BATMAVs (bat-like motorized aerial vehicles) [65, 66].

Bats contributed a lot to the field of biomimetics, which is the science of modeling cutting-edge technologies based on natural forms [65]. The anticlotting chemicals in the saliva of bats are also currently being investigated as potential anticoagulant for people who are at high risk of blood clots and strokes. In addition, the development of sonar for ships and ultrasound was partly inspired from echolocation that bats use as navigation system to find and follow their prey at night without crashing on trees, buildings, or other obstructions [65, 66].

Particularly, a unique feature of bats that provides potential for future application is their flying ability by their own power. The aerodynamic range of bats includes changing flight direction by turning 180 degrees within just three wing beats while flying at full tilt. They are such quick flyers because of the quickness of their wings that are structured to fold during flight, similar to the way that a human hand folds. Also, their wings are draped by stretchy skin and are powered by special muscles. Ongoing research about the structure of bat wings and the mechanics of bat flight may ultimately lead to the development of technologies that improve the maneuver ability of airplanes [22].

3.8. Bats as Pests

Although bats are grouped among the world's gentlest animals that provide many positive ecological and economic benefits, few of them are considered as pests. They may cause damage on human, livestock, agricultural crops, airplane strike, building, and infrastructure infestation, and rarely become aggressive or bite humans during self-defense [58]. For instance, frugivorous bats that feed on some economically important fruits result in greater loss.

Three species of vampire bats that occur in the New World are major pests feeding mainly on the blood of livestock (cattle, equines, goats, sheep, and pigs), poultry and occasionally humans. They are also responsible in transmitting rabies. Populations of vampire bats have increased sharply in areas of Latin America where European livestock have been introduced [67]. Wounds caused by vampire bats may also be vulnerable to secondary infections [1].

Bat strikes to airplane have been responsible for loss of human lives and damage to materials worldwide resulting in loss of billions of dollars annually [68, 69]. For example, 821 bat strikes were reported in the USA Air Force during 1997–2007 [70] and 327 from 91 airports during 1996–2006 in Australia [71]. From less than 1% of the bat-strike reported in USA, a cumulative damage is more than $825,000 of which more than half is attributable to 5 bat-strike incidents [70]. This high damage is accredited to high body weight (up to 1 kg like flying foxes) and unlike birds, they possess none pneumatized solid and heavy bones. It results in a greater and more concentrated impact force of strike and a greater capacity to perforate an aircraft than bird strikes [69]. Australian flying foxes roost gregariously and emerge from roosts in flocks, which may include thousands of flying foxes, thus the increasing risk of multiple simultaneous strikes. Their major damage to aircraft includes breaking of windscreen, perforation of aircraft skin, and ingestion into engine [71].

Building and house infestation by bat constitutes a serious public health problem [72]. They spoil food and make ceilings, walls, and floors dirty with the accumulation of guano and urine [72]. Besides, they cause discomfort to humans by their distressing noise, offensive odors, and attraction of coprophagous insects. Potential health hazards may result from chitinous remains of finely chewed insects in guano, attack of ectoparasites, drinking water contamination by urine and feces [72].

3.9. Disease Transition and Contamination

Bats are hosts to a range of zoonotic and potentially zoonotic pathogens. They differ from other disease reservoirs because of their unique and diverse lifestyles, including their ability to fly, often highly gregarious social structures, long life spans, and low fecundity rates [73]. They represent a potential epidemiologic of several diseases that can be fatal to humans, including rabies, Ebola, leptospirosis, histoplasmosis, and pseudotuberculosis [72, 74].

Bats are reservoirs of several pathogens, whose spread may be related to physiological stress associated with habitat loss or alteration [75]. The recent die-offs of bats presenting with white nose syndrome may relate to increased levels of environmental stress that render them to be susceptible to fungal infection and viral infections like Henipaviruses, European bat lyssaviruses, rabies, and Ebola virus [74].

Human activities that increase exposure to bats will likely increase the opportunity for infections [73]. Like bird droppings, bat guano can contain a potentially infectious fungus *Histoplasma capsulatum* that causes lung infection known as histoplasmosis [58].

Bat populations appear to be declining presumably in response to human induced environmental stresses like habitat destruction and fragmentation, disturbance to caves, depletion of food resources, overhunting for bush meat and persecution, increased use of pesticides, infectious disease, and wind energy turbine. As bats are among the most overlooked in spite of their economical and ecological importance, their conservation is mandatory.

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CorrespondenceBarotrauma is a significant cause of bat fatalities at wind turbines

1.

Tables (1)

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Summary

Bird fatalities at some wind energy facilities around the world have been documented for decades, but the issue of bat fatalities at such facilities — primarily involving migratory species during autumn migration — has been raised relatively recently 1, 2. Given that echolocating bats detect moving objects better than stationary ones [3], their relatively high fatality rate is perplexing, and numerous explanations have been proposed [1]. The decompression hypothesis proposes that bats are killed by barotrauma caused by rapid air-pressure reduction near moving turbine blades 1, 4, 5. Barotrauma involves tissue damage to air-containing structures caused by rapid or excessive pressure change; pulmonary barotrauma is lung damage due to expansion of air in the lungs that is not accommodated by exhalation. We report here the first evidence that barotrauma is the cause of death in a high proportion of bats found at wind energy facilities. We found that 90% of bat fatalities involved internal haemorrhaging consistent with barotrauma, and that direct contact with turbine blades only accounted for about half of the fatalities. Air pressure change at turbine blades is an undetectable hazard and helps explain high bat fatality rates. We suggest that one reason why there are fewer bird than bat fatalities is that the unique respiratory anatomy of birds is less susceptible to barotrauma than that of mammals.

Main Text

As with any airfoil, moving wind-turbine blades create zones of low pressure as the air flows over them. Animals entering these low pressure areas may suffer barotrauma. To test the decompression hypothesis, we collected hoary (*Lasiurus cinereus*) and silver-haired bats (*Lasionycteris noctivagans)* killed at a wind energy facility in south-western Alberta, Canada, and examined them for external and internal injuries.

Of 188 bats killed at turbines the previous night, 87 had no external injury that would have been fatal, for example broken wings or lacerations (Table 1). Of 75 fresh bats we necropsied in the field, 32 had obvious external injuries, but 69 had haemorrhaging in the thoracic and/or abdominal cavities (Table 1). Twenty-six (34%) individuals had internal haemorrhaging and external injuries, whereas 43 (57%) had internal haemorrhaging but no external injuries. Only six (8%) bats had an external injury but no internal haemorrhaging.

Table 1. Injuries observed in bats killed at wind turbines in south-western Alberta, Canada.

	L. cinereus	***L. noctivagans***	***Other species***	***Total***
No external injury	38% (103)	55% (77)	75% (8)	46% (188)
Internal haemorrhage	90% (48)	96% (26)	100% (1)	92% (75)
Pulmonary lesions	100% (6)	100% (8)	100% (3)	100% (17)

Internal haemorrhage was detected by visual examination of dissected carcasses, while pulmonary lesions were detected using stained histological sections. Numbers in parentheses are sample sizes.

Among 18 carcasses examined with a dissecting microscope, ten had traumatic injuries. Eleven bats had a haemothorax, seven of which could not be explained by a traumatic event. Ten bats had small bullae — air-filled bubbles caused by rupture of alveolar walls — visible on the lung surface (Figure 1A). All 17 bats examined histologically had lesions in the lungs consistent with barotrauma (Table 1), with pulmonary haemorrhage, congestion, edema, lung collapse and bullae being present in various proportions (Figure 1). In 15 (88%), the main lesion was pulmonary haemorrhage, which in most cases was most severe around the bronchi and large vessels.

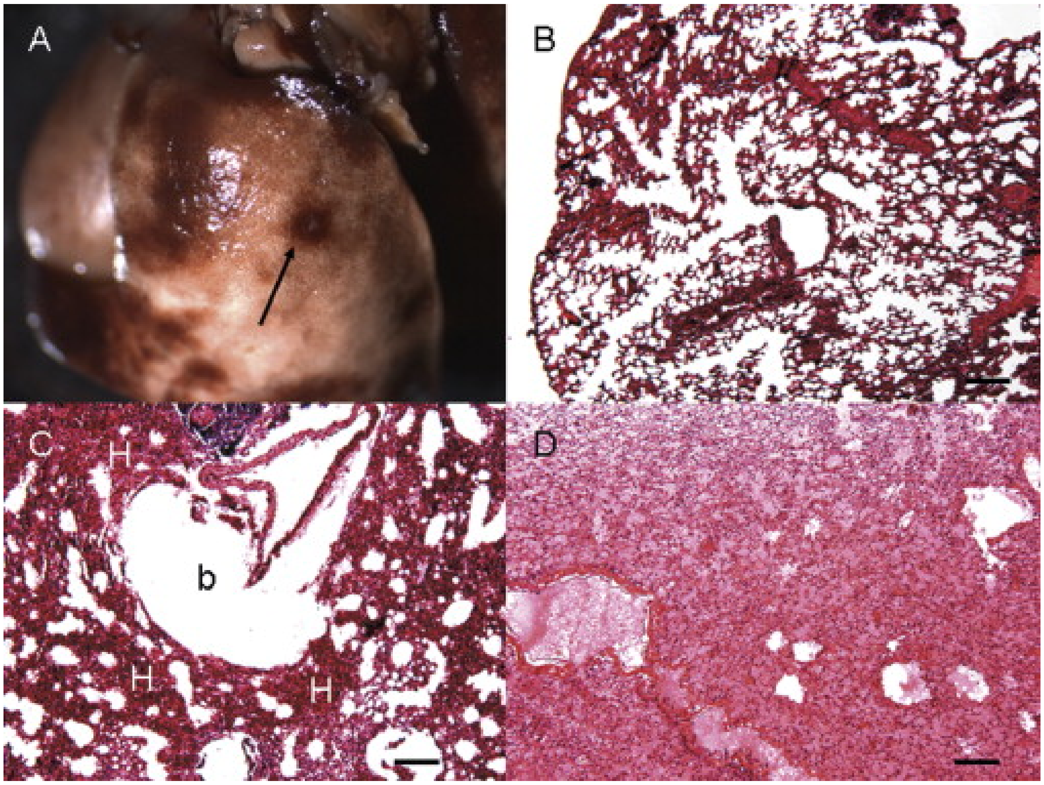

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Figure 1. Pulmonary barotrauma in bats killed at wind turbines.

(A) Formalin-fixed *L. noctivagans* lung with multifocal hemorrhages and a ruptured bulla with hemorrhagic border (arrow). Histological sections of bat lungs stained with hematoxylin and eosin (100X). (B) Normal lung of an *L. noctivagans*. (C) Lung of *Eptesicus fuscus* found dead at a wind turbine with no traumatic injury. There is extensive pulmonary hemorrhage (H), congestion, and bullae (b). (D) Lung of *L. cinereus* found dead at a wind turbine with a fracture of the distal ulna and radius. 90% of the alveoli and airways are filled with edema. Bar = 100 µm.

Although the pressure reduction required to cause the type of internal injuries we observed in bats is unknown, pressure differences as small as 4.4 kPa are lethal to Norway rats (*Rattus norvegicus*) [6]. The greatest pressure differential at wind turbines occurs in the blade-tip vortices which, as with airplane wings, are shed downwind from the tips of the moving blades [7]. The pressure drop in the vortex increases with tip speed, which in modern turbines turning at top speed varies from 55 to 80 m/s. This results in pressure drops in the range of 5–10 kPa (P. Moriarty, personal communication), levels sufficient to cause serious damage to various mammals [6].

Barotrauma helps explain the high fatality rates of bats at some wind energy facilities. Even if echolocation allows bats to detect and avoid turbine blades, they may be incapacitated or killed by internal injuries caused by rapid pressure reductions they can not detect.

Birds are also killed at wind turbines, but at most wind energy facilities fewer birds than bats are killed [8], and barotrauma has not been suggested as a cause of bird fatalities. This may be explained partly by differences in the respiratory anatomy and susceptibility to barotrauma of birds and bats. Bats have large lungs and hearts, high blood oxygen-carrying capacity, and blood-gas barriers thinner than those of terrestrial mammals [9]. These flight adaptations suggest that bats are particularly susceptible to barotrauma. Although birds have even thinner blood-gas barriers, they have compact, rigid lungs with unidirectional ventilation and a cross-current blood-gas relationship, as opposed to mammals which have large pliable lungs with the blood-gas relationship in a uniform pool in the pulmonary alveoli 9, 10. In addition, the pulmonary capillaries of birds are exceptionally strong compared to those of mammals, and do not change as much in diameter when exposed to extreme pressure changes [10]. Bats' large pliable lungs expand when exposed to a sudden drop in pressure, causing tissue damage, whereas birds' compact, rigid lungs do not.

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Supplemental Data

Document S1. Supplemental Experimental Procedures.

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Subject: Wind Farms Want Permission To Kill More Bats — A Lot More

Wind Farms Want Permission To Kill More Bats — A Lot More

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In a “conservation conundrum,” projects to produce more clean energy are a threat to Hawaii’s only native land mammal.

Wind turbines are proving to be more of a menace than expected to opeapea — endangered Hawaiian hoary bats, the islands’ only native land mammal.

As a result, three wind energy farms are requesting increases in the amount of bats they are allowed to “take.”

“Take,” according to the Endangered Species Act, includes harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing or collecting the animals.

In 2012, the farms received federal and state permits that allowed them to take a designated number of the bats. Two of permits were supposed to be in effect for 20 years, the third for 25. Combined, they were allowed to take 92 during those periods, but they have already exceeded that number.

It's unknown how many endangered Hawaiian hoary bats are left in the islands.

Forest and Kim Starr

Now the three wind farms —Kawailoa Wind Power on Oahu, and Auwahi Wind and Kaheawa Wind Power II on Maui — are looking to amend their existing incidental take permits to increase the amount of bats they are allowed to take. Pakini Nui Wind Farm, which has been operating since 2007 on the Big Island, is applying for a first-time permit.

Each wind energy project submitted its own take request, but if all are approved, the original limit of 92 would increase to 483.

All four projects have submitted drafts of their amended incidental take permits accompanied with revised habitat conservation plans to the U.S. Fish and Wildlife Service.

Kawailoa received its original incidental take permit from Fish and Wildlife in December 2011 and its incidental take license from the Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife in January 2012. Both were supposed to last for 20 years and the project was authorized to take 60 bats within that time. Now it's requesting permission to take an additional 162 bats through 2031.

Auwahi Wind received both its permit and license in February 2012 and was allowed to take 21 bats. The project is requesting permission to take an additional 176 through 2037. Kaheawa Wind Power II also received approval from state and federal agencies in 2012 to take 11 bats and is requesting permission to take 27 more by 2032.

Pakini Nui has been in the process of applying for a new 20-year permit since 2016. It would allow the wind farm to take 26 bats.

Environmental attorney Maxx Phillips, who represents Keep the North Shore Country, said Pakini Nui has been able to operate without a permit or license because no one has brought legal action.

While Hawaiian hoary bats are not the only flying creatures threatened by wind turbines, they are more difficult to monitor and track than endangered birds like the uau (Hawaiian petrel) and the nene (Hawaiian goose).

"Hawaiian hoary bats are more difficult than some of the (other endangered species) because it's a lot more difficult to understand how large the populations are and what the impacts of losing X number of individual bats to wind farms, what that's really going to do to a population in the long run," said Dr. Loyal Mehrhoff, Endangered Species Recovery Director at the Center for Biological Diversity.

Unlike other bats, the opeapea don't congregate in caves, but instead nest in trees. It's unknown how many hoary bats are left in the islands.

In order for the wind energy projects' proposed amendments to be approved, the Endangered Species Act requires that each submit a habitat conservation plan for approval to both the U.S. Fish and Wildlife Service and the Hawaii Division of Forestry and Wildlife.

The plans outline what measures the wind farms will take to minimize adverse effects and show that the species will be "better off with the project than without," Phillips said.

Hawaii wind energy projects pose a greater threat to the endangered Hawaiian hoary bat population than was originally expected.

PF Bentley/Civil Beat

Kawailoa, for example, is testing pre-commercial technology that uses ultrasonic sound to deter bats from flying near rotor-swept areas. Kawailoa has also been turning off the turbines during low wind speed conditions because bats are more likely to collide with structures at low wind speeds.

"We are very proud to make this contribution, the contribution of the project to the renewable energy goals that Hawaii has," said Brita Woeck, environmental compliance manager for Kawailoa Wind. "But we want to be able to do so in a way that minimizes impacts to the environment and specifically to bats."

Fish and Wildlife is reviewing the plans submitted by each project and has announced its intent to draft a programmatic environmental statement under the National Environmental Policy Act.

The programmatic approach, which differs from the usual process of creating an environmental impact statement for each project, will result in a comprehensive document that includes information from all four wind projects' habitat conservation plans. The impacts of the projects on the endangered species will be analyzed cumulatively, but decisions regarding the take number requested will be addressed separately.

A public scoping period began June 1 and ended July 2. Three public meetings were held in June on Hawaii, Maui, and Oahu, where concerned community members could ask questions of Fish and Wildlife, which hosted the meetings, and consultants who have been hired to represent each project.

Phillips attended the June 21 meeting at Sunset Beach Recreation Center and said 20 to 30 community members were there, including representatives from organizations like the Center for Biological Diversity and Malama Pupukea-Waimea.

Fish and Wildlife supervisory biologist Darren LeBlanc said the agency received comments from about 23 people during the scoping period.

One of the comments came from North Shore resident Chris Bruns, who suggested shutting down all wind farm turbines at night until preventive measures are put in place to protect the bats or until each project presents plans to somehow mitigate the take.

LeBlanc said all farms will continue to operate while their amended plans are under consideration since they applied for permit amendments prior to exceeding their original take numbers.

Fish and Wildlife is not concerned about the need to increase the take of Hawaiian hoary bats because the original estimates "probably weren't correct to begin with, but they were based on what we knew at the time," Leblanc said.

"This whole process is about following the best science," said Holly Richards, public affairs officer for Fish and Wildlife. "So, the original permits were issued with the best available estimates and as we get more data and as our science evolves, we better understand those populations."

Wind energy projects contribute to Hawaii's goal of operating on 100 percent clean energy by 2045. According to the 2017 Renewable Portfolio Standard Status Report listed in a document by the Hawaii State Energy Office, wind energy contributes 21 percent to the state's total renewable energy portfolio and makes up 5.8 percent of Hawaii's overall energy use.

"It's a conservation conundrum," said Phillips. "We want green energy, but are we willing to do that at the extinction of our only native land mammal?"

Fish and Wildlife officials anticipate the draft of the programmatic environmental statement and each wind energy project's habitat conservation plan will be available for public review and commentary by the end of this year.

LeBlanc and Richards said they anticipate that it will be an additional six months after that before permitting decisions are made.

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Prestin and high frequency hearing in mammals

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Abstract

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Recent evidence indicates that the evolution of ultrasonic hearing in echolocating bats and cetaceans has involved adaptive amino acid replacements in the cochlear gene *prestin*. A substantial number of these changes have occurred in parallel in both groups, suggesting that particular amino acid residues might confer greater auditory sensitivity to high frequencies. Here we review some of these findings, and consider whether similar signatures of *prestin* protein sequence evolution also occur in mammals that possess high frequency hearing for passive localization and conversely, whether this gene has undergone less change in mammals that lack high frequency hearing.

Key words: ultrasonic hearing, cochlea, convergent evolution, amino acid replacements

Prestin in echolocating mammals

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Prestin encodes a motor protein expressed in the outer hair cells (OHCs) of the basilar membrane (BM) in the cochlea, where it is thought to boost the BM's vibratory response to incoming sound waves.[1] It is this so-called "cochlear amplifier" that give mammals their remarkable auditory sensitivity as well as their narrow frequency tuning and dynamic range.[2] We and others have reported several lines of evidence that link substitutions in the cochlear gene prestin to the evolution of ultrasonic (>20 kHz) hearing in echolocating mammals. Briefly, unrelated lineages of echolocating bats,[3] and also bats and echolocating cetaceans,[4,5] have undergone numerous parallel amino acid replacements in the prestin gene, some of which are common to both cases of convergence.[6] Strikingly, these replacements are sufficiently abundant to cause conflicts between the true species tree and phylogenetic reconstructions based on prestin, in which some echolocators are seen to group together in the same clade.[4,5]

Parallel substitutions could occur by chance, and conflicts between gene-tree and species-trees could reflect long-branch attraction or gene duplications, however, there is good evidence that convergence between bat and cetacean prestin has been driven by adaptive evolution. The strength of positive selection at sites along the dolphin prestin gene correlates with these sites' support for the grouping of dolphins with bats,[5] while bursts of positive selection have also been identified on the branch leading to bats with constant frequency echolocation (horseshoe and leaf-nosed bats),[3] the ancestral branch of all toothed whales and the ancestral branch of dolphins plus beaked whales.[6]

Apart from particular sites under convergent and/or adaptive change, the overall level of protein sequence evolution appears to be linked to high hearing frequency. Within clades of bats and cetaceans, the number of amino acid substitutions counted along the evolutionary path leading to each taxon was found to correlate with its frequency of maximum auditory sensitivity, though this relationship disappears in bats after phylogenetic correction possibly due to a lack of taxonomic coverage.[6] Given all of these recent findings from echolocating taxa, it is tempting to speculate that there might be particular amino acid residues in prestin that confer greater auditory sensitivity to high frequencies in mammals.

Prestin in non-echolocating mammals

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Echolocating bats and whales typically have the most sensitive hearing at high frequencies, using ultrasound for hunting, obstacle avoidance and orientation in space. Yet a much greater range of mammals can also perceive frequencies in the ultrasonic range.[7] Numerous small species including rodents, shrews and tree shrews, as well as larger taxa such as cats, seals, cows and dogs, are all known to be able to hear frequencies beyond the upper limit of human hearing.[8] Although these taxa mostly receive and process ultrasound solely for passive localization, some also produce ultrasonic vocalizations for communication,[9] and there is mounting evidence that a number of small insectivorous mammals can echolocate to some degree[10] (although we classify these as non-echolocators here, to avoid confusion). At the other end of the spectrum, species such as human, non-human primates, elephants and sloths are generally considered to have poor high frequency hearing (e.g. ref. [8]).

To test whether observed signatures of prestin evolution in echolocators also occur in other mammals with ultrasonic hearing, but to a lesser extent in mammals without ultrasonic hearing, we obtained and aligned all available mammal prestin sequences that contained over 90% of the coding region. This new alignment contained 51 sequences, including eleven new species from eight orders. An unconstrained Maximum-Likelihood phylogenetic tree based on this extended dataset recovered the previously reported monophyly of echolocating whales and bats, but contained no further instances of convergence or conflicts with the known species tree (figure not shown).

We derived prestin ancestral states for all nodes from the constrained species topology using the software CODEML, and traced substitutions leading to each taxon (**Fig. 1A**). The number of amino acid substitutions varied widely among taxa, from just 13 in elephant to 59 in the pika. In the latter, more than 30 changes were inferred to have occurred since the split from the rabbit. High numbers of changes (>30) were also detected in all of the small rodents included (rat, mouse and gerbil), compared with both the primates (including human) that had around 22 changes each, and the other large mammals that had 23 each. Changes that were convergent with those seen in echolocators were distributed relatively evenly across all branches, and showed no obvious association with any particular taxa (**Fig. 1A**).

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Figure 1

(A) *Prestin* amino acid substitutions mapped onto the evolutionary path for each taxon. Red amino acid substitutions are convergent with one or more lineages of echolocating bat, blue substitutions are convergent with one or more lineages of echolocating whale and green are convergent with both of these groups. Changes along the pika branch are shown by an asterisk. Names and sequence details of echolocating taxa, cow, pig, horse, dog, cat, human, rabbit, gerbil, mouse and rat are listed in ref. [6]. Other mammal sequences were obtained from GenBank (giant panda XM_002928662, opossum XM_001371300 and platypus XM_001507913, with the latter two used as outgroups) or from Ensembl using BLAT. (B) Number of *prestin* amino acid substitutions versus estimated frequency of peak hearing sensitivity for mammals for which audiogram data were available (listed in ref. [6] and refs. [12—24]). Note that the elephant's hearing data is based on the Indian elephant, whereas the gene sequence is from the African elephant. Red and black circles represent echolocating and non-echolocating bats, respectively, and blue and black squares are echolocating and non echolocating baleen whales, respectively. Non-echolocating mammals are shown as black triangles. Species for which auditory data were not available are listed on the right-hand axis..

A plot of counts of substitutions against corresponding estimated frequencies of optimal hearing revealed a significant positive relationship ($R = 0.7$, $P < 0.0001$). However, following phylogenetic correction by regressing pairwise differences in hearing frequency and substitutions, this trend was no longer significant ($R = 0.04$, NS, independent contrasts). Prestin sequences from more species are needed to determine whether this lack of effect is real, or reflects uneven taxonomic coverage. Regardless, it is clear that during their evolution echolocating bats and cetaceans have typically undergone many more changes in this gene than have Old World fruit bats, baleen whales and other non-echolocating mammals (**Fig 1B**). Of the five species for which no hearing data were available, the larger mammals showed similarly low numbers of changes as their sister taxa. On the other hand, the pika was a dramatic outlier, having undergone similar levels of change to echolocating bats, and thus making a potentially interesting candidate for an audiogram study.

Combining data from non-echolocating mammals to the results of our earlier studies of bats and dolphins adds some support to the idea that the tempo of change in Prestin correlates positively with the evolution of ultrasonic hearing in mammals. Alternative explanations for lineage-specific differences in molecular evolution due to variation in effective population sizes[11] are unlikely to account for higher numbers of substitutions in groups as diverse as bats, rodents and cetaceans. Yet the mechanism by which observed amino acid replacements in prestin might promote auditory sensitivity to high frequencies in echolocating and other taxa is not known. One possibility is that they result in conformational changes of the prestin protein, which in turn alter the shape and stiffness of the OHCs thereby allowing them to vibrate faster. For a given point along the BM, such upward tuning of OHC vibrations would allow closer matching to the frequencies of the ultrasonic echoes used by bats and cetaceans.[2] Alternatively, the prestin protein in echolocating mammals might be adapted to facilitate transmission of vibrations to neural excitation, a pathway that has been shown to be impaired in prestin -/- mice.[2]

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Notes

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Commun Integr Biol

ECOLOGICAL AND ECONOMIC IMPORTANCE OF BATS

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Abstract

Abandoned mines now serve as important year-round sanctuaries for bats. Many of North America's largest remaining bat populations roost in mines. These include more than half of the continent's 45 bat species and some of the largest populations of endangered bats. Bats have lost countless traditional roosts in caves and old tree hollows and many have gradually moved into abandoned mines, which can provide similar environments. Mine closures without first surveying for bats can have potentially serious ecological and economic consequences. Bats are primary predators of night-flying insects, and many such insects rank among North America's most costly agricultural and forest pests. These include cucumber, potato, and snout beetles; corn-earworm, cotton-bollworm, and grain moths; leafhoppers; and mosquitoes. A single little brown bat (*Myotis lucifugus*) can catch more than 1,200 mosquito-sized insects in an hour. A mine roosting colony of just 150 big brown bats (*Eptesicus fuscus*) can eat sufficient cucumber beetles each summer to protect farmers from 33 million of these beetles' root worm larvae, pests that cost American farmers an estimated billion dollars annually. And a colony of Mexican free-tailed bats (*Tadarida brasiliensis*) living in the old Orient Mine consumes nearly two tons of insects nightly, largely crop-consuming moths. In the western states, pallid bats (*Antrozous pallidus*) benefit ranchers by consuming large quantities of grasshoppers and crickets. Lesser and greater long-nosed bats (*Leptonycteris curasoae* and *L. nivalis*) and long-tongued bats (*Choeronycteris mexicana*) are believed to be important pollinators for some 60 species of agave plants and serve as both pollinators and seed dispersers for dozens of species of columnar cacti, including organ pipe and saguaro, which rank among the southwestern deserts' most familiar and ecologically important plants. Despite their critical role in our environment and economy, available evidence suggests that millions of bats have already been lost during abandoned mine safety closures or renewed mining in historic districts. These actions could endanger even currently abundant species, forcing the need for Federal listing at considerable taxpayer expense. The loss of bats can increase our reliance on chemical pesticides (which often threaten both environmental and human health), jeopardize whole ecosystems of other plants and animals, and harm human economies. The cost of surveying and protecting key mine roosts is small compared to the benefits provided by these valuable night-flying allies.

Introduction

Bats are one of the most important, yet least understood, groups of animals in the world. Across North America, bats play a vital role in both natural and managed ecosystems. Bats are key predators of night-flying insects that cost American farmers and foresters a billion dollars annually, and they are pollinators of several keystone desert plants in the American southwest and Mexico. Despite their importance, bats are often persecuted both intentionally and unintentionally, and their numbers continue to decline from habitat loss, environmental toxins, and disturbance at key roost sites. Bats currently represent the most imperiled order of land mammals in the United States and Canada.

Due to disturbance of bats' traditional roosts in caves and tree hollows, abandoned and inactive underground mines have now become refuges of last resort for more than half of the 45 bat species found in the United States and Canada, including some of the largest remaining populations. As thousands of abandoned mines are being reclaimed, available evidence suggests that millions of bats have been inadvertently buried or have lost crucial habitats. Closure of abandoned mines without first evaluating their importance to bats is perhaps the single greatest threat to many North American bat populations.

The Role of Bats in Ecosystem Management

Bats are primary predators of vast numbers of insects that fly at night, including many that rank among North America's most costly agricultural and forest pests. Just a partial list of the insects these bats consume includes cucumber, potato, and snout beetles; corn-borer, corn earworm, cutworm, and grain moths; leafhoppers; and mosquitoes. Just one of the little brown bats that hibernate in Michigan's Millie Hill Mine can catch 1,200 mosquito-sized insects in an hour. Bats are just one of several groups of animals that naturally prey upon mosquitoes. Although not the only insect consumed, from 77.4 to 84.6 percent of little brown bats living in the northern U.S. and Canada eat mosquitoes (Anthony and Kunz, 1977; Fascione, et. al., 1991). A Florida colony of 30,000 southeastern myotis (*Myotis austroriparius*) eats 50 tons of insects annually, including more than 15 tons of mosquitoes (Zinn and Humphrey, 1981). The loss of bats increases our reliance upon chemical pesticides that typically cause more long-term problems than they solve. Chemical poisons often kill natural mosquito predators more effectively than mosquitoes. Over time, predators such as fish, insects, and bats die out while mosquitoes develop resistance, multiplying in ever larger numbers in a losing battle often referred to as "the pesticide treadmill."

Mexican free-tailed bats, like those living in the famed Carlsbad Caverns and Bracken Cave, eat incredible numbers of insects nightly and just one colony living in Colorado's old Orient Mine consumes nearly two tons of insects nightly. In Texas' largest bat caves alone, up to 1,000 tons (2 million pounds) of insects, primarily moths, are eaten each night by Mexican free-tailed bats. U.S. Department of Agriculture research shows that in early June, billions of corn earworm moths (America's number-one agricultural pest) emerge from agricultural regions of Mexico, flying at high altitudes into the U.S. on prevailing winds—often traveling more than 250 miles a night. Days later, the moth's peak egg-laying occurs on corn, cotton, and other crops in agricultural regions of Texas. Their destructive larvae, which have fattened on the crops for about three weeks, give rise to the next generation of moths that emerge and continue a northward "hopscotch," infesting crops through much of central North America.

Doppler radar studies confirm that Mexican free-tailed bats fly at altitudes from 600 to 10,000 feet or more above the ground, sharing the same winds as moths, in the season when bats have their greatest energy needs (McCracken, 1996). To prove that bats prey upon this prime agricultural pest, fecal pellets were collected as bats returned to a Texas bat cave. In mid-June, moths comprise about 96 percent of the diet of these bats (Whitaker, et. al., 1996). Using DNA markers it was confirmed that corn earworm moths were the species being consumed (McCracken, 1996). Further proof came when bat detectors were affixed to weather balloons floating freely with the moths, recording bat calls and feeding buzzes to corroborate that free-tailed bats are indeed flying and feeding at the same altitudes and locations as the moth migrations (*ibid.*). The regional impact these bats are having on corn earworm moths is staggering.

Mexican free-tailed bats are also known as "guano bats" for the enormous quantities of droppings they produce. From 1903 to 1923, at least 100,000 tons were removed from Carlsbad Caverns alone and sold to fruit growers in California (Tuttle, 1994). Railroad officials estimated that, early this century, they annually transported 65 carloads at 30,000 pounds each from Texas, making bat guano the State's largest mineral export before oil (*ibid.*). Guano extraction for use as a natural fertilizer is still being extensively used in developing countries and is making a comeback with organic gardeners. Free-tailed bats have supported several American war efforts since gun powder's most valuable ingredient, saltpeter, is made from guano. And a single ounce of guano contains billions of bacteria useful in detoxifying industrial wastes, producing natural insecticides, improving detergents, and converting waste byproducts into alcohol.

Another common North American species, the big brown bat, specializes on beetles and true bugs, including cucumber beetles, May beetles or June bugs, green and brown stinkbugs, and leafhoppers. In one summer season the 150 bats of an average Midwestern maternity colony can conservatively eat 38,000 cucumber beetles, 16,000 June bugs, 19,000 stinkbugs, and 50,000 leafhoppers (Whitaker, 1995). By eating 38,000 adult cucumber beetles in a season, these bats control about 33 million of these beetles' rootworm larvae (*ibid.*). Both cucumber beetle adults and larvae attack crops, costing U.S. farmers about one billion dollars annually, with the larvae doing considerable damage—they can reduce corn productivity 10 to 13 percent and force farmers to spray $15 to $25 in insecticides per acre (Whitaker, 1993). Adult June bugs defoliate trees and their larvae (grubworms) feed on the roots of grasses and other plants. Stinkbugs are often pests in orchards and on soybeans. Leafhoppers are serious pests of many plants since they feed on the sap, rendering the plant vulnerable to various plant diseases and reducing the plant's productivity. In one study, these four bugs collectively totaled 37.8 percent of the food eaten by 184 big brown bats from various parts of Indiana (*ibid.*). At certain times and places, however, they often total nearly 100 percent of the diet of big brown bats.

With the growing agricultural emphasis on biological control and integrated pest management, more and more farmers are using bats as a weapon in the war against insect pests. Instead of eradicating bat colonies from their farmhouses and barns, farmers are exploring ways of attracting bats to their fields. Many farmers are living with their bat allies and even encouraging their colonization by constructing artificial habitats. In addition to consuming insect pests, it is suggested that bats protect crops from pests by "chasing" away insects with their echolocation calls. Researchers saw a 50 percent reduction in damage to corn plots by corn borers when they broadcast bat-like ultrasound over test plots (Belton and Kempster, 1962).

North American bats are boosting local economies by encouraging tourism at renowned locations like Carlsbad Caverns and Austin's Congress Avenue Bridge. In Austin, just one decade ago, citizens petitioned for the bridge's bat colony to be eradicated. In 1999, Bat Conservation International (BCI) initiated a study which showed that the Congress Avenue Bridge bat colony generates nearly $8 million in tourism revenue each year (Ryser and Popovici, 2000). More than 100,000 people watch the bat emergence annually, including many who specifically travel to Austin to view the bats, spending millions on lodging, transportation, food services, and entertainment.

Bats are also key pollinators of many familiar desert plants. The endangered lesser and greater long-nosed bats, and Mexican long-tongued bat, serve as both pollinators and seed dispersers for dozens of columnar cacti species including organ pipe, and saguaro, and are important pollinators for some 60 species of agave plants. Agaves have been closely associated with man since the beginning of civilized America as a food item, a fermented beverage, and a fiber source. Today, tequila, made from distilled agave juices, is by far the best known Mexican liquor, and its rising popularity in international markets contributes to a multi-million dollar industry. Yet agave propagation, in the absence of bats, falls to 1/3000th of normal (Howell, 1980; Fleming, 1991). The bat-plant association is so strong that the disappearance of one would threaten the survival of the other.

In addition to consumptive uses, cacti rank among the southwestern desert's most ecologically important plants (Howell, 1980). Bees, moths, lizards, hummingbirds, woodpeckers, orioles, finches, sparrows and field mice all depend on plants pollinated by bats for food and shelter, and are affected indirectly by the loss of bat pollinators and subsequent decrease in plant populations, such that entire ecosystems are damaged.

Habitat destruction is likely the major factor affecting pollinating bats and contributing to their endangered or "at risk" status. Their specialized nectar diet and disappearance of their food plants could explain population declines. The fragile bat-plant relationship is magnified in the case of the long-nosed bats because of their migratory habits. These bats depend not only on the plants in a given region, but on a continuous supply of food along their migratory routes. The destruction of habitat in Mexico, for example, could have severe effects, through the bats, on the plant communities in Arizona. Mexican cattlemen, in misguided attempts to control numbers of vampire bats (*Desmodus rotundus*), have also indiscriminately destroyed countless colonies of highly beneficial bats, including pollinators.

In tropical ecosystems, bats play a critical role in seed dispersal and pollination. And because loss of rain forest habitats is one of the most serious environmental problems today, the loss of bats can have serious environmental and economic consequences. In one recent West African study, bats were shown to be far more effective seed dispersers than birds. Because most bats prefer to carry fruit away from the tree before eating, apparently to avoid predators, they cross cleared areas and sometimes travel up to 50 km or more in a single night. In Africa, up to 95 percent of forest regrowth on cleared land comes from seeds dropped by bats (Tuttle, 1983). In contrast, birds and other animals drop seeds mostly beneath existing trees.

Bats also are the primary pollinators of numerous tropical plants. More than 130 genera of trees and shrubs are already known to rely on bats for pollination, and many more such relationships await discovery (*ibid.*). Recent studies demonstrate that seed dispersal activities of bats can be critical to reforestation of clear-cut areas, and that many of the tropics' most economically important plants depend on bats for propagation. The nearly endless list of valuable products from these plants includes many grocery store fruits such as peaches, bananas, and avocados, as well as kapok and hemp fibers for surgical bandages, life preservers, and rope, latex for chewing gum, prized lumber for furniture and crafts, beads for jewelry, and carob for candy. The harvest of Durian fruits in Southeast Asia and iroko timber in West Africa accounts for annual sales of over 100 million dollars. The former requires bats for pollination and the latter for seed dispersal.

In the Old World, exaggerated reports of crop damage from fruit bats have led to bat killings. Farmers are alarmed by the sight of large bats eating fruit that ripens prematurely or that is missed during picking. Because fruit bats prefer strong-smelling, ripe fruits, commercial crops that are picked green for shipping are seldom damaged. Birds and rats are not so picky, leaving their depredations to be blamed on the more conspicuous bats. As a consequence, large colonies of big flying fox bats are being destroyed. In the Old World and throughout the South Pacific Islands, bats are considered a delicacy and are over harvested for human food, folk medicine and even aphrodisiacs. Many populations of large flying fox bats are seriously threatened. On Guam, bat dinners may sell for $25 a plate, and in West Africa, bats are so valuable that two poachers working together can make $1,000 in a single day.

The Importance of Mines to Bats

Although caves are numerous in some regions, most are now too frequently disturbed by humans to permit bat use. In addition, bat populations have lost countless traditional roosts in old tree hollows due to logging. Over the past 100 or more years, displaced bats have gradually moved into abandoned mines, which often provide microclimates similar to caves. In regions where natural caves do not occur, mines represent new “super habitats” that have concentrated colonial bat populations formerly distributed in smaller numbers across the landscape (Brown and Berry, 1991).

Mines are key to the life history of bats and are critical for many purposes such as rearing young in the summer, winter hibernation, gathering for social activities (such as courtship and mating), and night roosting (places where bats temporarily rest to digest their prey between foraging bouts). Mines also serve as crucial rest stops between spring and fall migration. Abandoned mines are often the only suitable shelters left midway between summer and winter roosts. Without these protected resting places, migratory mortality could increase tremendously. Although mines are utilized for many reasons, their use as bat maternity and hibernation sites is essential to the survival of several North American species. The microclimate, most importantly the temperature, determines whether bats will use a particular mine. Warm sites are selected for maternity roosts, while cold sites are chosen for hibernation.

Bats that roost in smaller groups typically require temperatures between 70 and 90EF for maternity use. Big-eared bat (*Corynorhinus* spp.) maternity roosts have sometimes been recorded in colder sites where ambient temperatures are as low as 60EF. Approximately one-quarter of the bat species in the United States and Canada are believed to hibernate almost exclusively in old mines or caves (Tuttle and Taylor, 1994). Suitable hibernation sites for bats in all regions must protect bats from freezing, and for most species, should provide stable temperatures throughout the winter above the freezing point but below 50EF. Some desert dwelling bats may be an exception and often hibernate in mines with temperatures up to 58EF (Brown, pers. com., 1997).

While any abandoned mine may be important to bats, the larger, more complex and dangerous mines, with multiple entrances, often harbor the most significant populations. This is because large and complex mines offer bats a measure of security no longer found in caves. The complexity and associated airflow of these mines provides a range of internal temperatures suitable for bats (Altenbach, 1995). These complex sites are most often found on private mining industry lands.

Of the more than 8,000 mines surveyed by researchers in Arizona, California, Colorado, New Mexico, Oregon, and Washington, approximately 45 to 75 percent showed signs of use by bats, with an average of 10 percent containing important bat colonies. From the Great Lakes Region north and eastward in the United States and Canada, up to 70 percent of open, unflooded subsurface mines having sufficient volume to protect bats from freezing, may be used by hibernating bat populations.

Abandoned Mine Closures: Effects on Bats

In the last decade alone, thousands of abandoned mines have been permanently closed by backfilling, capping, blasting, or other method, and until recently few were first evaluated for their importance to bats. Available evidence suggests that millions of bats have already been lost, or their roosts destroyed. Bats now have few alternatives to abandoned mines, and are so instinctively committed to certain sites that they often cannot change roosts in the time allowed by current rates of mine closure (Altenbach, pers. com., 1996). Due to their colonial nature, many bat species are especially vulnerable to mine closures, and hundreds of thousands of bats can be lost in a single closure.

Little brown bats are among North America's most abundant bat species. However, in the northern United States and Canada, these bats rely almost exclusively upon abandoned mines for hibernation sites. If a mine is closed during winter months (trapping the bats inside), a multi-state region can be affected. This is due to the fact that little brown bats travel from summer colonies that may be thousands of miles away to hibernate in mines. Closure of mines without first checking for bats could drastically reduce bat numbers, needlessly endangering many species.

In the western United States, Townsend's big-eared bats (*Corynorhinus townsendii*) are particularly dependent on abandoned mines (Altenbach, 1995). The largest known populations, numbering up to 10,000, have been found in deep, complex workings, however, even shallow or simple workings will often be used by small groups of up to several hundred. Endangered Indiana bats (*Myotis sodalis*) and southwestern cave myotis (*M. velifer brevis*) have been found in mines in numbers approaching 100,000. Similarly, the largest known hibernating populations of the southeastern big-eared bat (*Corynorhinus rafinesquii*), a candidate for the endangered species list, live in abandoned iron and copper mines in small groups ranging from a few dozen to more than 500.

All of the known remaining nursery roosts of the endangered lesser long-nosed bat in the United States are found in mines. In California, all winter roosts and all but one maternity colony of California leaf-nosed bats (*Macrotus californicus*) are found in abandoned mines (Brown, pers. com., 1997). Many other bat species rely heavily on mines for hibernation, even though they may congregate in smaller colonies throughout a greater number of abandoned mines. Table 1 provides a list of North American bats known to use mines (Tuttle and Taylor, 1994).

Many examples underscore the magnitude of potential bat losses from abandoned mine closures. More than 50,000 little brown bats were temporarily entombed in a western Wisconsin mine closure before biologists were able to have the mine reopened. The old Neda Mine in Iron Ridge, Wisconsin, was threatened with closure before being acquired by a local University. It is now home to nearly half a million little brown bats, as well as large populations of big brown bats, eastern pipistrelles (*Pipistrellus subflavus*), and northern long-eared myotis (*Myotis septentrionalis*).

The largest hibernating population ever recorded of another species in decline, western big-eared bats (*Corynorhinus townsendii pallescens*), was destroyed in a New Mexico mine shaft when vandals set old timbers on fire (Altenbach, pers. com., 1996). In New Jersey, the State's largest population of hibernating bats was inadvertently trapped in the Hibernia Mine when it was capped in 1989. These bats would also have died had biologists not convinced state authorities to reopen the entrance immediately. Likewise, the Canoe Creek State Park limestone mine in Pennsylvania was reopened in time to save its bats and now shelters a population of endangered Indian bats and the largest hibernating bat population in that state.

In December 1992, an estimated three quarters of a million little and big brown bats were found in the Millie Hill Mine in Iron Mountain, Michigan. It was slated to be backfilled the following spring. Instead, BCI convinced the town to close the mine with a large steel cage, protecting the bats and human safety (Tuttle and Taylor, 1994). These bats comprise the second largest hibernating bat population ever discovered in North America. A local mine inspector from Iron Mountain, Michigan, reported that of the 12 mines closed prior to 1993, some contained significantly large bat populations, perhaps even more than were saved in the Millie Hill Mine.

Mine and cave roosting bats are exceptionally vulnerable to human disturbance in their nursery and hibernation caves. Entire populations can be destroyed in single incidents, emphasizing the need for public education and protection of critical sites. Requiring up to an hour or more to arouse from hibernation, bats cannot quickly fly away from danger, and in any event cannot survive outside of their roost in winter. Helpless, thousands at a time have been intentionally killed by vandals. Many more die as a result of inadvertent disturbance by mine or cave explorers who do not realize the dire consequences of their actions. When hibernating, bats must conserve energy until spring when insects are once again abundant. A single disturbance can cost a bat over 60 days of stored fat reserves (Thomas, et. al., 1990). Excessive disturbances can cause the bat to burn up all its fat reserves and perish.

Large colonies of bats are at risk as well. Mexican free-tailed bats have declined at Carlsbad Caverns from over 8 million to just a few hundred thousand. Likewise, the bats at Eagle Creek Cave in Arizona that once numbered between 25 and 50 million have declined by 99.9 percent to just under 30,000 (Tuttle, 1991).

Pesticide poisoning can also affect bats in many ways. By reducing non-target insects, bats are unable to find adequate sources of insect prey. Bats also can ingest sub-lethal doses of pesticides, which become stored in their fat reserves. During times of stress, such as hibernation or migration, when large stores of fats are released, pesticides are released too, sometimes at lethal levels.

Because bats are consuming vast quantities of insect pests, the general health of entire ecosystems are compromised in the absence of bats. How many bats can we lose before their numbers become too few to survive and service our ecosystems? When humans modify ecosystems for natural resource production such as timber, minerals, or agriculture, maintaining habitat for bats will not only ensure the survival of these important wildlife species, but will also benefit the sustainable production of natural resource products.

The North American Bats and Mines Project

BCI and the United States Bureau of Land Management founded the North American Bats and Mines Project (NABMP) in 1993 to address conservation issues facing mine-roosting bats. The purpose of the NABMP is to eliminate the loss of bats during abandoned mine-land reclamation, while still protecting human safety. The NABMP has five primary objectives: (1) to educate natural resource managers and the public on the importance of mines for bats; (2) to train wildlife and mine-land managers on mine assessment and closure methods that protect both bats and people; (3) to assist agencies and industry in protecting and enhancing bat roosts in abandoned mines; (4) to provide leadership and coordination among Federal, State, and private agencies and the mining industry, thus minimizing bat losses; and (5) to aid with active research and monitoring efforts. By establishing and achieving these goals, BCI and its agency partners will ensure that bat conservation measures are incorporated into the planning and operating procedures of agencies and organizations responsible for mine-land management and wildlife conservation. To date, we have already provided funding and technical support to protect critical habitats for more than 2 million mine roosting bats, hosted 18 bats and mines workshops, distributed 20,000 copies of our resource publication, *Bats and Mines*, and translated this publication into Spanish for our Latin American Partners. As we continue to learn about our vital and fascinating bat species, we are better suited to manage for their long-term survival.

Table 1. North American bats that use mines for maternity and/or hibernation sites.

Species	Colony Sizes	Range	Use Time
Ghost-faced bat *Mormoops megalophylla*	Dozens to hundreds	AZ & TX	Year-round
California leaf-nosed bat *Macrotus californicus*	Dozens to over a thousand	AZ, southern CA & NV	Year-round
Mexican long-tongued bat *Choeronycteris mexicana*	A dozen or fewer	AZ, southern CA & NM	Summer
Lesser long-nosed bat *Leptonycteris curasoae**	Hundreds to thousands	AZ & NM	Summer
Greater long-nosed bat *Leptonycteris nivalis**	Hundreds to thousands	TX & NM	Summer
Southeastern myotis *Myotis austroriparius*	Hundreds to thousands	Southeastern U.S.	Year-round
California myotis *Myotis californicus*	Up to a hundred	Western U.S.	Year-round
Western small-footed myotis, *Myotis ciliolabrum*	Up to hundreds	Western U.S.	Year-round
Long-eared myotis *Myotis evotis*	Dozens	Western U.S.	Year-round
Gray bat *Myotis grisescens**	Hundreds to 50,000 or more	Southeastern U.S.	Year-round
Small-footed myotis *Myotis leibii*	Dozens	Eastern U.S.	Winter
Little brown bat *Myotis lucifugus lucifugus*	Hundreds to a million or more	Northern U.S.	Year-round
Arizona myotis *M. l. occultus*	Hundreds	Southwestern U.S.	Year-round
Northern long-eared myotis *Myotis septentrionalis*	Hundreds to thousands	Eastern U.S.	Winter
Indiana bat *Myotis sodalis**	Hundreds to 100,000 or more	Eastern U.S.	Winter

Table 1. (Cont.) North American bats that use mines for maternity and/or hibernation sites.

Species	Colony Sizes	Range	Use Time
Fringed myotis *Myotis thysanodes*	Dozens to hundreds	Western U.S.	Year-round
Cave myotis *Myotis velifer*	Hundreds to 100,000 or more	Southwestern U.S.	Year-round
Long-legged myotis *Myotis volans*	Hundreds	Western U.S.	Year-round
Yuma myotis *Myotis yumanensis*	Hundreds to thousands	Western U.S.	Year-round
Western pipistrelle *Pipistrellus hesperus*	Dozens	Western U.S.	Year-round
Eastern pipistrelle *Pipistrellus subflavus*	Dozens to thousands	Eastern U.S.	Winter
Big brown bat *Eptesicus fuscus*	Dozens to hundreds	North America	Year-round
Allen's lappet-browed bat *Idionycteris phyllotis*	Dozens to about two hundred	Mostly AZ, also parts of NV & CO	Year-round
Southeastern big-eared bat *Corynorhinus rafinesquii*	Dozens to several hundred	Southeastern U.S.	Year-round
Pacific big-eared bat *C. townsendii townsendii*	Dozens to hundreds	Western U.S.	Year-round
Ozark big-eared bat *C. t. ingens**	Dozens to hundreds	Ozark Mountains	Year-round
Western big-eared bat *C. t. pallescens*	Dozens to thousands	Western U.S.	Year-round
Virginia big-eared bat *C. t. virginianus**	Dozens to thousands	KY, VA & WV	Year-round
Pallid bat *Antrozous pallidus*	Dozens to hundreds	Western U.S.	Year-round
Mexican free-tailed bat *Tadarida brasiliensis*	Hundreds of thousands	Southwestern U.S., north to OR	Mainly summer, some year-round

* Endangered

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Role of bats in our ecosystems (ecosystem services)

The majority of bats eat night-flying insects, including many agricultural pests. As the primary predators of night-flying insects bats play a significant role in controlling insect populations. Estimates from studies show that some bats eat more than 70% of their weight in insects each night and some pregnant females at 100% of their body weight (that's a lot of insects!). Another way of looking at it, taken from an example on the Bat Conservation International website, is that: *"A single little brown bat can eat up to 1,000 mosquito-sized insects in a single hour."* Leading to speculation about their role in controlling mosquitoes – which may reduce the spread of malaria. De Hoop cave is the largest known roost in South Africa with an estimated 300,000 bats congregating there each year. Due to the large numbers of bats eating insects in the area (an estimated 100 tons every year) the farmers are believed to be saving thousands of rands on insecticides each year.
New research, carried out by Professor Peter Taylor (University of Venda, SA) and colleagues, found that bats foraging around macadamia farms were eat stinkbugs - a major agricultural pest. The researchers collected bat droppings, from bats caught on farmland, that were then sent to the University of Copenhagen in Denmark for genetic analysis. The preliminary results show that stinkbugs remains were identified in the droppings of four of five species; namely the Egyptian slit-faced bat, mops free-tailed bat, little free-tailed bats, African pipistrelle bat and the yellow house bat.

With ecosystem services receiving little attention until relatively recently we are just beginning to understand the impact of population declines and extinctions.

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Bracken Cave, in Texas, has the largest known (insectivorous) bat roost in the world. In fact it is the largest congregation of mammals anywhere in the world! Mexican free-tailed bats congregate here in numbers estimated to be over 20 million to have their young. These bats primarily eat corn ear worm and cotton bollworm moths, which are agricultural pest species that cause millions of dollars in damage to crops each year (as reported by Bat Conservation International).

"*Production of at least one third of the world's food, including 87 of the 113 leading food crops, depends on pollination carried out by insects, bats and birds. This ecosystem service is worth over USD200 billion per year.*" (source: IUCN - Securing the web of life, June 2012).
About a third of bats are fruit or nectar feeding, and in the process they pollinate numerous plants and disperse seeds. Kasanka National Park in Zambia has the largest known fruit bat roost on earth! Impressively, an estimated five to eight million straw-coloured fruit bats migrate

to Kasanka National Park between October and the end of December each year for what is now considered to be the biggest migration in Africa! Yes, our furry alies even beat the magnificent Great Serengeti migration.

Fruit and nectar feeding bats pollinate many plants, including an estimated 450 commercial plants used by us. Foods such as bananas, peaches, guavas, mangoes, avocado, figs, dates, papaya, almonds, cashew nuts, vanilla and other products such as tequila (from the agave plant), carob and many more. In the tropics many plants are pollinated by bats, attracted to their strong scent at night and bats are important seed dispersers for many tree species. Fruit bats pollinate the legendary baobab tree – these iconic trees have cultural and aesthetic value. Baobabs are affectionately known as the 'upside down tree' or the 'tree of life' - for good reason, these trees provide shelter, water and food people as well as other animals.

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Ultrasonic noise emissions from wind turbines: Potential effects on bat species

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ABSTRACT

The impact that wind turbines have on the environment, particularly with respect to wildlife such as bat species, has generated increasing concern over the last decade. Although the harnessing of wind power is becoming much more widespread as a clean, renewable energy resource, the increasing global turbine mortality rates for bats are thought to be significantly detrimental to susceptible species. Much research is still needed to fully understand the ways in which turbines affect bats, since they rely on echolocation and audible cues to hunt and navigate, therefore having a unique acoustic perspective of objects in their vicinity. Here we present an overview of what is currently known regarding ultrasonic emissions from operational wind turbine structures, including noise generated from the gearing mechanism, rotor, or through blade defects, and how such noise may be perceptible to some bat species in the local turbine habitat.

INTRODUCTION

Wind energy is the fastest growing global energy technology, with a yearly growth rate of around 30–40 % (BWEA, 2001; EWEA, 2009). Wind power is seen as a clean, environmentally friendly renewable energy source; although wind turbines have undergone rapid development over the last 30 years (Twidell, 2003), it is only relatively recently that their impact on wildlife has been brought to scientific and public attention. This is perhaps due to their increasingly widespread deployment over a wider range of habitats than ever before, through increasing demand for 'greener' energy production. The phenomenon of wildlife-turbine mortality initially asserted itself with incidents of bird strike at early experimental large-scale turbine installations in the 1980's (Erickson *et al*., 2002). It was not until early 2000 that bat-strike at wind plants began to be noticed during ground carcass surveys, with many hundreds of bat carcasses turning up, at some plants outnumbering bird carcasses by almost 7:1 (Kerns & Kerlinger, 2004). Further study over the last decade has revealed that the phenomenon of bat-turbine mortality is widespread throughout the US, Europe and other countries world-wide. The causality behind bat interactions at wind turbine installations still remains largely unclear, and it is widely recognized that much more study is required to investigate the underlying factors. However, it is recognised that direct blade-strike mortality may not be the only issue for bat populations in the vicinity of wind turbines.

Rather than a visual system, insectivorous bats rely on echolocation, producing high-frequency (ultrasonic) pulses of sound and interpreting reflected echoes to navigate and hunt. It is not yet clearly understood whether operational wind turbine rotors produce significant levels of ultrasonic emission that could be detected by bats, or potentially interfere with echolocation during bat-turbine interactions. This paper provides a brief overview of the current knowledge surrounding noise emissions from wind turbines, and the potential effects on local bat species.

ULTRASONIC NOISE EMISSIONS FROM WIND TURBINES

Operational turbines are known to produce variable levels of human-audible noise (<20 kHz) from the blades and nacelle. Although turbine noise is predominantly low frequency with almost all acoustic contribution at 65 dB SPL from frequencies below 2 kHz (Dooling, 2002), it seems feasible there could also be an ultrasonic component (Johnson & Kunz, 2004). To date, there have been very few investigations into the ultrasonic emissions of different makes of turbine. Due to the nature of ultrasound being increasingly attenuated with distance, high-frequency sound emissions from turbines can be difficult to assess, particularly at large-scale installations. Some studies have been unable to detect any ultrasonic noise produced by active turbines, although it is possible that the distance between the turbine blades and ground level was large enough to prevent detection by the equipment used at the time (Johnson & Kunz, 2004). Schröder (1997) investigated the ultrasonic emissions of 47 turbines (19 types) in Germany, using a ‘Pettersson D980’ bat detector, at ground level, between the base to 100 m away. Many turbines were found to emit ultrasound at around 20–50 kHz, although levels were not provided. Although the turbines in this study ranged from 10–92 m tall, there did not appear to be a correlation between ultrasonic emission and turbine size, and the precise source of the ultrasonic noise could not be identified. A similar study by Szewczak & Arnett (2006) examined the ultrasonic emission components of 7 types of turbine at wind plants around the US, as measured by a ‘Pettersson D240x’ bat detector at ground level. In contrast with Schröder’s findings, Szewczak & Arnett found most turbines contributed little, if any, ultrasound above ambient noise level. There therefore appears to be no ‘standard’ type of ultrasound emission between different makes of turbine, with some structures emitting no ultrasound while others may emit significant levels of ultrasonic noise.

Potential sources of ultrasonic noise production

According to Twidell (2003), although low-frequency noise can be generated from the turbine’s blades passing the tower and perturbing the wind, high-frequency noise may be primarily generated by the blade tips. Some blades are known to ‘whistle’ due to slight defects in the blade (Dooling, 2002), or previous damage. The rotational frequency of the rotor, and its harmonics, can produce unwanted vibrations (Twidell, 2003), which could play a part in ultrasonic emission. The internal machinery housed in and around the turbine’s nacelle is also reportedly a generic source of noise, and while Szewczak & Arnett (2006) found the electronic machinery of some turbine models to generate ultrasonic noise, in most cases this was not detectable more than 10 m from the nacelle. Such studies have noted that other sources of ultrasonic emissions from the turbines need further investigation.

EXAMPLE TURBINE NOISE MEASUREMENTS

Microturbine sound field measurement

Previous work by the authors (Long, 2011) assessed the ultrasonic noise emissions from a microturbine model (rotor diameter 0.91 m) previously linked with bat mortality. Measurements were taken with a high-frequency calibrated microphone (assessed frequency range 45–55 kHz), in an anechoic chamber, in 10° increments around the operational rotor (0.6 m from the hub). The microturbine was found not to produce appreciable ultrasonic noise above the undistorted noise floor of the microphone (see Fig. 1).

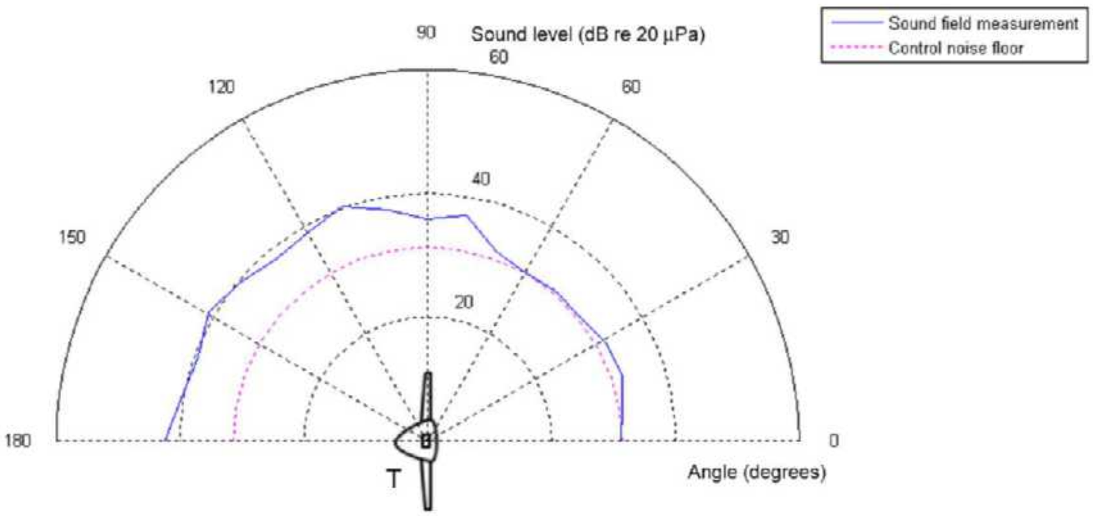

Figure 1: Polar sound map of microturbine sound field in the ultrasonic region between 45–55 kHz, as measured by calibrated ultrasonic microphone at a distance of 0.6 m. Solid line indicates the noise measurement, dotted line the control noise floor level for the microphone, while ‘T’ denotes the location of the microturbine.

It was therefore concluded that this particular model of microturbine did not contribute a high level of ultrasonic noise to the environment in the range of 45–55 kHz. In addition, sonograms of the ultrasonic frequency band recorded (20–100 kHz) revealed no other ultrasonic contribution in this range.

Unusual turbine blade fault emission

As noted by Dooling (2002), minor blade structural discrepancies/faults can cause operational rotors to ‘whistle’, either in the human-audible or ultrasonic range. An interesting example of this was recorded from a 20 kW turbine (rotor diameter 11 m) by the authors (Long, 2011), using a calibrated high-frequency microphone (assessed frequency range 2 Hz–100 kHz). Ultrasonic FM sweeps were produced by the turbine, between around 22–30 kHz and lasting about 140 ms (see Fig. 2).

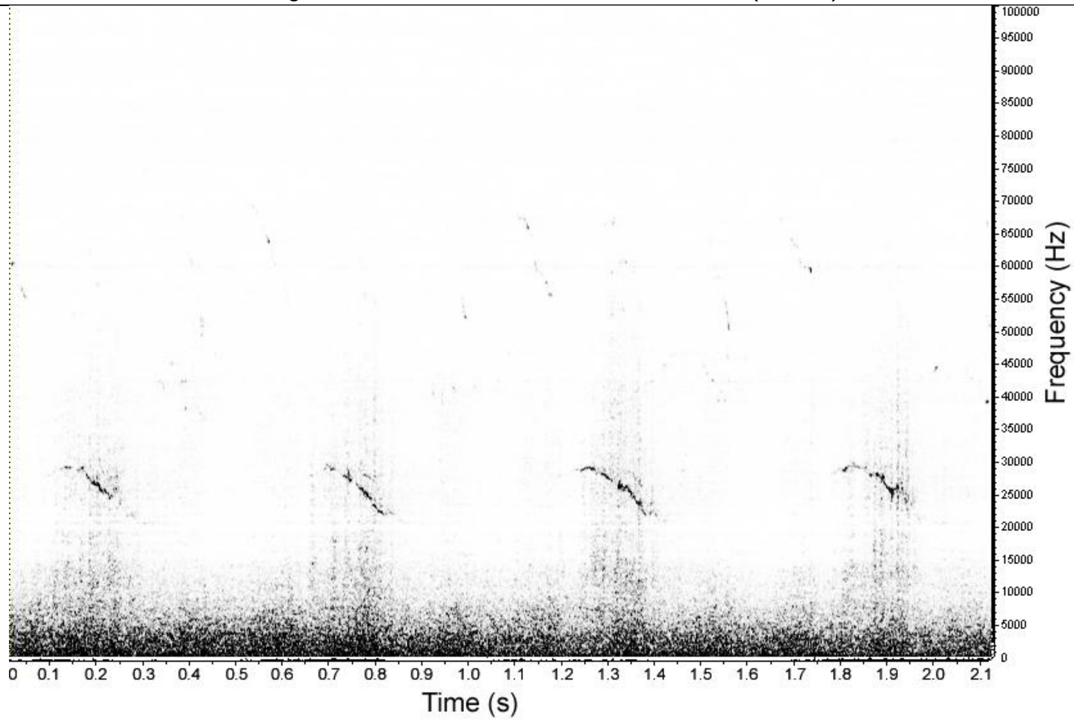

Figure 2: Acoustic emission spectral FFT profile from a 20 kW turbine with blade fault, recorded at 200 kS s^{-1} at the turbine base, one metre above ground level (hub height 13 m). Hanning window, FFT length 1024 bands, 75 % overlap, 40 % linear energy scaling.

By analyzing video footage of the moving blades, these FM sweeps were confirmed to correlate with the passage of one of the turbine's three blades. The owners of the turbine reported that there was one damaged/defective blade that had previously been repaired, but not replaced. Fig. 3 highlights the overall amplitude difference between sound emission from the turbine and a control background noise measurement taken in the same location while the turbine was not operational, over the frequency range of the emitted sweep (22–30 kHz).

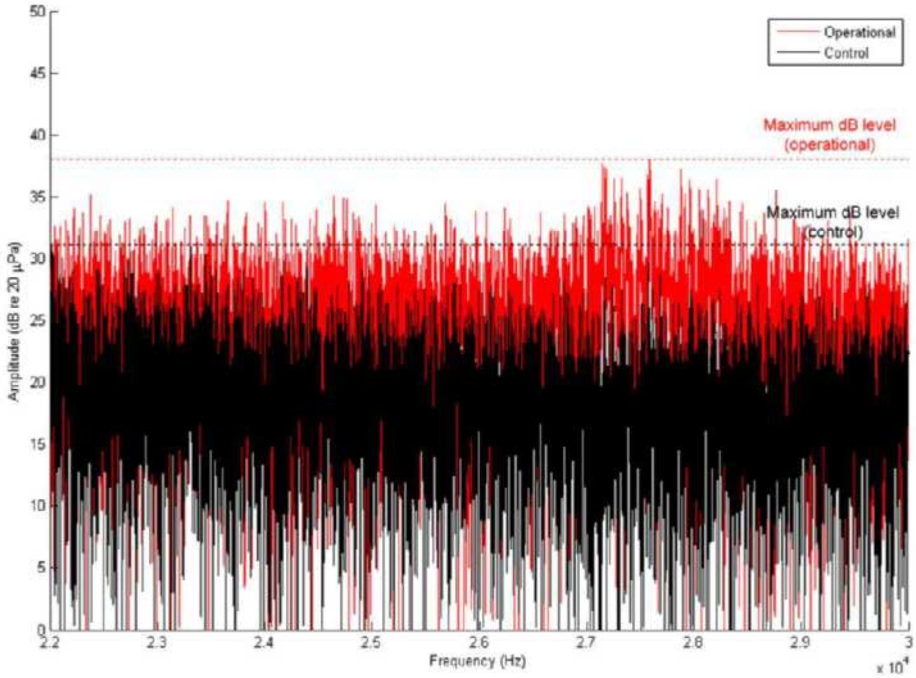

Figure 3: DFT trace of the recorded amplitude data comparing a control measurement to that taken during turbine operation, between 22–30 kHz (DFT calculated using MATLAB's FFT algorithm, sampled at 200 kS s^{-1}, FFT length 262144 bands). Red and black dotted lines indicate maximum dB levels for the operational and control recordings, respectively. Data taken from 600 ms samples of original recordings (one complete blade sweep cycle).

POTENTIAL EFFECTS OF TURBINE NOISE ON LOCAL BAT SPECIES

Because bats rely heavily on using and interpreting ultrasound in their environment, potential disruption to their normal behavior patterns due to ultrasound disturbance must be investigated further. It might be speculated that ultrasonic noise emitted in the vicinity of the turbine rotor could potentially 'jam' the ultrasonic emissions of a bat, making it difficult for them to navigate and hunt effectively. Studies in the US have even attempted to deter bats from certain areas by emitting high-intensity broad-band ultrasound, in attempts to 'jam' the bats' echolocation calls (Szewczak & Arnett, 2007). The aim was to deploy these devices around turbines, but this method may also compromise the bats' already reduced capacity to interpret their own echoes from moving blades, and avoid them (Long *et al*., 2010). It has even been suggested that ultrasonic noise itself is attractive to bats (Johnson & Kunz, 2004), or at least attracts the curiosity of bats (Arnett *et al*., 2005), although investigations by Ahlén (2004) to this effect have demonstrated negative results and this hypothesis remains largely unverified (Arnett *et al*., 2005).

The majority of turbines in Schröder's study were found to produce ultrasound, typically between 20–50 kHz, which correlates well with frequencies used by European bat species for echolocation (although the sound intensity, and the relationship with bat mortality, were not investigated). Some turbines have a digital anemometer on top of the turbine rotor housing, and these have been found (in some cases) to emit ultrasound themselves in the region of 38 kHz (Arnett *et al*., 2005), well within the frequency range found to be used by bat species observed in the areas of the study. Arnett and colleagues disabled some of these anemometers and found that there was no effect on the bat mortality rate. The conclusion was reached that these emissions were too readily attenuated to have any effect on the bats present; however the intensity of the emissions from these devices was not measured.

Microturbine sound field assessment by Long (2011) revealed ultrasound levels only slightly above ambient noise (25–40 dB re 20 μPa). Experimental work by Griffin *et al*. (1960) concluded that sounds produced by small insects of 25–30 dB re 20 μPa at 15 cm were unlikely to be detectable by a bat over 50 cm away, so it seems unlikely that the similar noise level produced by this turbine could be acting as an acoustic lure or masking echolocation. Although this particular microturbine model had been previously linked to bat deaths, it seems unlikely that ultrasound emission played any critical role.

With regard to the ultrasonic noise produced by blade defect, although the predominant ultrasound emissions between 22–30 kHz may be below the detectable range of some of the more common UK bat species, serotine (*Eptesicus serotinus*), Leisler's (*Nyctalus leisleri*) and noctule (*Nyctalus noctula*) bats all echolocate at the lower end of the ultrasonic spectrum, within this range, and may therefore be able to detect this particular turbine's acoustic emission. While the peak amplitude of the emission over this range was over 5 dB re 20 μPa louder than the ambient background noise, the peak was less than 40 dB re 20 μPa in total as measured directly underneath the blades (12 m to hub), and degraded such that it was not discernible above background noise over 20 m away from the source. This can be compared with the relative sound levels produced by the same operational turbine within the human audible range (up to 20 kHz), with a peak of 96 dB re 20 μPa in the <1 kHz zone, as measured at the turbine's base. It is therefore conceivable that some bats could detect the ultrasonic emissions from this particular turbine which are caused by a blade fault. However, bats in the locality of the turbine may not be able to detect such emissions unless they were in the immediate vicinity, for example within a radius of 10 m, due to the low amplitude of the ultrasound emission and high attenuation.

The impact of ultrasonic emissions on bats is thought by some to be limited, particularly during the summer and during migration (Rodrigues *et al*., 2006), however this theory remains untested and the way bats react to turbine-produced ultrasound remains unknown (Bach & Rahmel, 2004; Bach, 2001). Some observations suggest that serotines actually avoid locations where ultrasonic emissions occur, but other bats (such as pipistrelles (*Pipistrellus* spp.)) do not (Bach, 2001). It is possible that serotines are able to use ultrasound produced by turbines as an 'acoustic landmark' and use this for orientation or avoidance (after Jensen *et al*., 2005). Dooling (2002) has also hypothesised that turbine-generated noise may help birds (and possibly bats) to better detect and avoid these blades. It is therefore possible that different bat species might detect and utilize ultrasonic noise from turbines in different ways, and that ultrasound emissions may therefore have a variable impact on each species in the locality.

CONCLUSIONS

Ultrasonic emissions from wind turbines appear to be highly variable and not well investigated. Current research has revealed some turbines do generate ultrasound, either inherently through design or components, or acquired as a result of blade defects. Analysis of this noise has identified the possibility that the ultrasound emissions of such turbines could be perceptible by some bat species, although little is currently known on the long-term effects of ultrasound emission on bat behavior or local bat populations. Existing research suggests that ultrasonic noise produced by wind turbines may have variable effects depending on bat species, something that must be investigated in more detail in order to obtain further insight into potential effects on local bat ecology.

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Important

batcon.org/why-bats/bats-are/bats-are-important

Bats Are Important

The Earth without bats would be a very different and much poorer place. More than 1,300 species of bats around the world are playing ecological roles that are vital to the health of natural ecosystems and human economies.

Many of the more than 1,300 bat species consume vast amounts of insects, including some of the most damaging agricultural pests. Others pollinate many valuable plants, ensuring the production of fruits that support local economies, as well as diverse animal populations. Fruit-eating bats in the tropics disperse seeds that are critical to restoring cleared or damaged rainforests. Even bat droppings (called guano) are valuable as a rich natural fertilizer. Guano is a major natural resource worldwide, and, when mined responsibly with bats in mind, it can provide significant economic benefits for landowners and local communities.

Bats are often considered “keystone species” that are essential to some tropical and desert ecosystems. Without bats’ pollination and seed-dispersing services, local ecosystems could gradually collapse as plants fail to provide food and cover for wildlife species near the base of the food chain. Consider the great baobab tree of the East African savannah. It is so critical to the survival of so many wild species that it is often called the “African Tree of Life.” Yet it depends almost exclusively on bats for pollination. Without bats, the Tree of Life could die out, threatening one of our planet’s richest ecosystems.

Pest control

Insectivorous bats are primary predators of night-flying insects, and many very damaging pests are on their menu. Pregnant or nursing mothers of some bat species will consume up to their body weight in insects each night.

The millions of Mexican free-tailed bats at BCI’s Bracken Cave in Central Texas eat tons of insects each summer night. And a favorite target in the United States and Mexico is an especially damaging pest called the corn earworm moth (aka cotton bollworm, tomato fruitworm, etc.) that attacks a host of commercial plants from artichokes to watermelons. Worldwide crop damage from this moth is estimated at more than $1 billion a year, and research in 2006 concluded that freetails save cotton farmers in south-central Texas more than $740,000 annually. Throughout the United States, scientists estimate, bats are worth more than $3.7 billion a year in reduced crop damage and pesticide use. And that, of course, means fewer pesticides enter the ecosystem.

Learn more - Bats Worth Over $1 Billion to Corn Industry

Pollinators

From deserts to rainforests, nectar-feeding bats are critical pollinators for a wide variety of plants of great economic and ecological value. In North American deserts, giant cacti and agave depend on bats for pollination, while tropical bats pollinate incredible numbers of plants.

Most flowering plants cannot produce seeds and fruit without pollination – the process of moving pollen grains from the male part of the flower (the stamen) to the female part (the pistil). This process also improves the genetic diversity of cross-pollinated plants. Bats that drink the sweet nectar inside flowers pick up a dusting of pollen and move it along to other flowers as they feed.

A few of the commercial products that depend on bat pollinators for wild or cultivated varieties include: bananas, peaches, durian, cloves, carob, balsa wood, and agave. Find out more - six fast fact about pollinating bats!

Seed dispersers

Vast expanses of the world’s rainforest are cleared every year for logging, agriculture, ranching and other uses. And fruit-eating bats are key players in restoring those vital forests. Bats are so effective at dispersing seeds into ravaged forestlands that they’ve been called the “farmers of the tropics.”

Regenerating clear-cut forests is a complex natural process, one that requires seed-scattering by birds, primates and other animals as well as bats. But birds are wary of crossing large, open spaces where flying predators can attack, so they typically drop seeds directly beneath their perches. Night-foraging fruit bats, on the other hand, often cover large distances each night, and they are quite willing to cross clearings and typically defecate in flight, scattering far more seeds than birds across cleared areas.

And many of the bat-dispersed seeds are from hardy pioneer plants, the first to grow in the hot, dry conditions of clearings. As these plants grow, they provide the shelter that lets other, more delicate plants take root. Seeds dropped by bats can account for up to 95 percent of the first new growth. The pioneer plants also offer cover and perches for birds and primates, so they can add still more, different seeds to the mix that can lead eventually to a renewed forest. Bats have been reported dispersing the seeds of avocado, dates, figs, and cashews - among many others.

Further Reading

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Bat

Bats are mammals of the order **Chiroptera**;[a] with their forelimbs adapted as wings, they are the only mammals naturally capable of true and sustained flight. Bats are more manoeuvrable than birds, flying with their very long spread-out digits covered with a thin membrane or patagium. The smallest bat, and arguably the smallest extant mammal, is Kitti's hog-nosed bat, which is 29–34 mm (1.14–1.34 in) in length, 15 cm (5.91 in) across the wings and 2–2.6 g (0.07–0.09 oz) in mass. The largest bats are the flying foxes and the giant golden-crowned flying fox, *Acerodon jubatus*, which can weigh 1.6 kg (4 lb) and have a wingspan of 1.7 m (5 ft 7 in).

The second largest order of mammals, bats comprise about 20% of all classified mammal species worldwide, with over 1,200 species. These were traditionally divided into two suborders: the largely fruit-eating megabats, and the echolocating microbats. But more recent evidence has supported dividing the order into Yinpterochiroptera and Yangochiroptera, with megabats as members of the former along with several species of microbats. Many bats are insectivores, and most of the rest are frugivores (fruit-eaters). A few species feed on animals other than insects; for example, the vampire bats feed on blood. Most bats are nocturnal, and many roost in caves or other refuges; it is uncertain whether bats have these behaviours to escape predators. Bats are present throughout the world, with the exception of extremely cold regions. They are important in their ecosystems for pollinating flowers and dispersing seeds; many tropical plants depend entirely on bats for these services.

Bats provide humans with some benefits, at the cost of some threats. Bat dung has been mined as guano from caves and used as fertiliser. Bats consume insect pests, reducing the need for pesticides. They are sometimes numerous enough to serve as tourist attractions, and are used as food across Asia and the Pacific Rim. They are natural reservoirs of many pathogens, such as rabies; and since they are highly mobile, social, and long-lived, they can readily spread disease. In many cultures, bats are popularly associated with darkness, malevolence, witchcraft, vampires, and death.

Bat

Temporal range: Eocene – Present

PreЄ Є O S D C P T J K PgN

Scientific classification

Kingdom:	Animalia
Phylum:	Chordata
Class:	Mammalia
Clade:	Scrotifera
Order:	**Chiroptera** Blumenbach, 1779

Suborders

(traditional):

- Megachiroptera
- Microchiroptera

(recent):

- Yinpterochiroptera
- Yangochiroptera

Contents

Worldwide distribution of bat species

Etymology

An older English name for bats is flittermouse, which matches their name in other Germanic languages (for example German *Fledermaus* and Swedish *fladdermus*), related to the fluttering of wings. Middle English had *bakke*, most likely cognate with Old Swedish *natbakka* ("night-bat"), which may have undergone a shift from *-k-* to *-t-* (to Modern English *bat*) influenced by Latin *blatta*, "moth, nocturnal insect". The word "bat" was probably first used in the early 1570s.[2][3] The name "Chiroptera" derives from Ancient Greek: χείρ – *cheir*, "hand"[4] and πτερόν – *pteron*, "wing".[1][5]

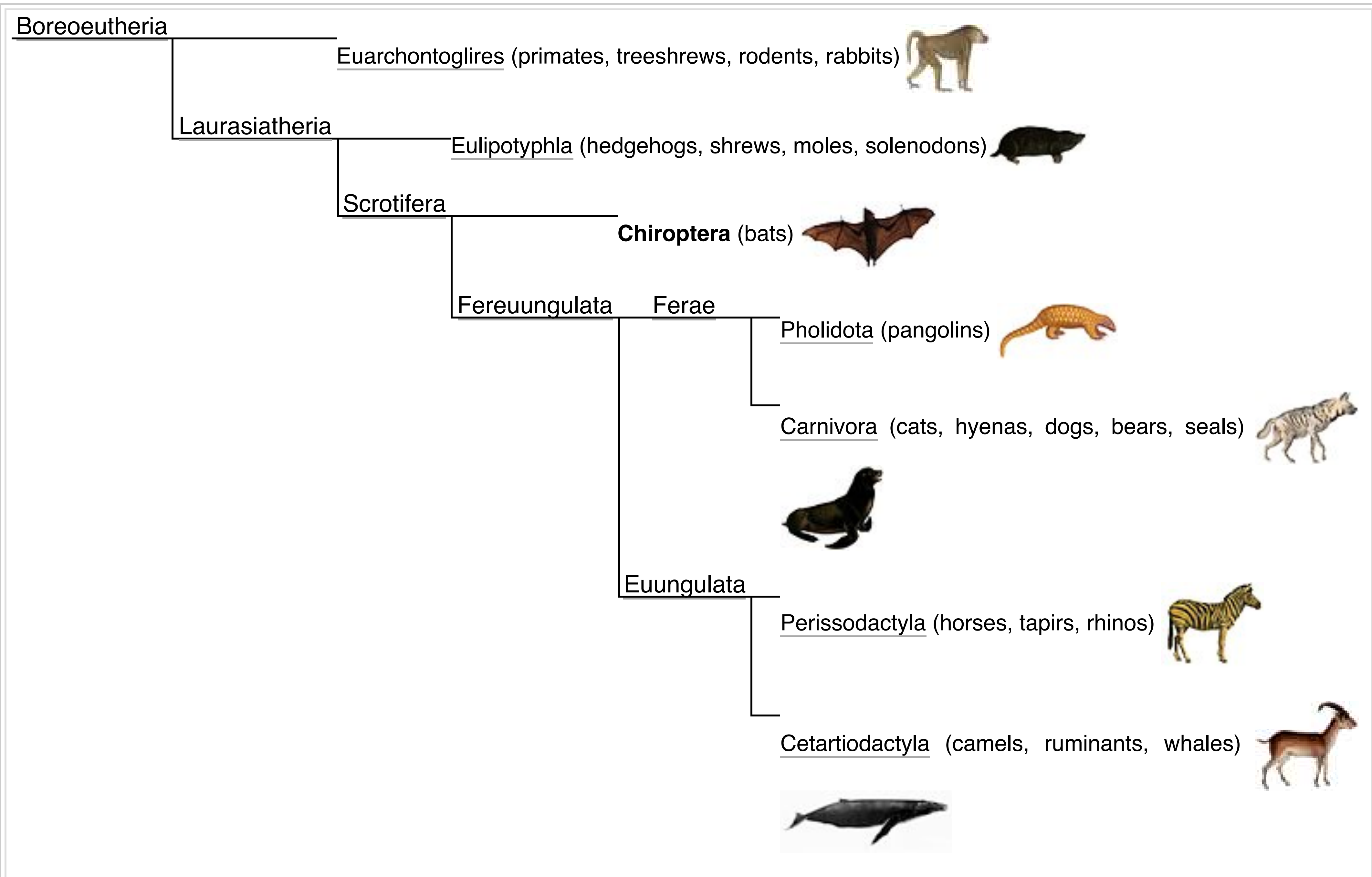
Phylogeny and taxonomy

Evolution

The delicate skeletons of bats do not fossilise well, and it is estimated that only 12% of bat genera that lived have been found in the fossil record.[6] Most of the oldest known bat fossils were already very similar to modern microbats, such as *Archaeopteropus* (32 million years ago).[7] The extinct bats *Palaeochiropteryx tupaiodon* (48 million years ago) and *Hassianycteris kumari* (55 million years ago) are the first fossil mammals whose colouration has been discovered: both were reddish-brown.[8][9]

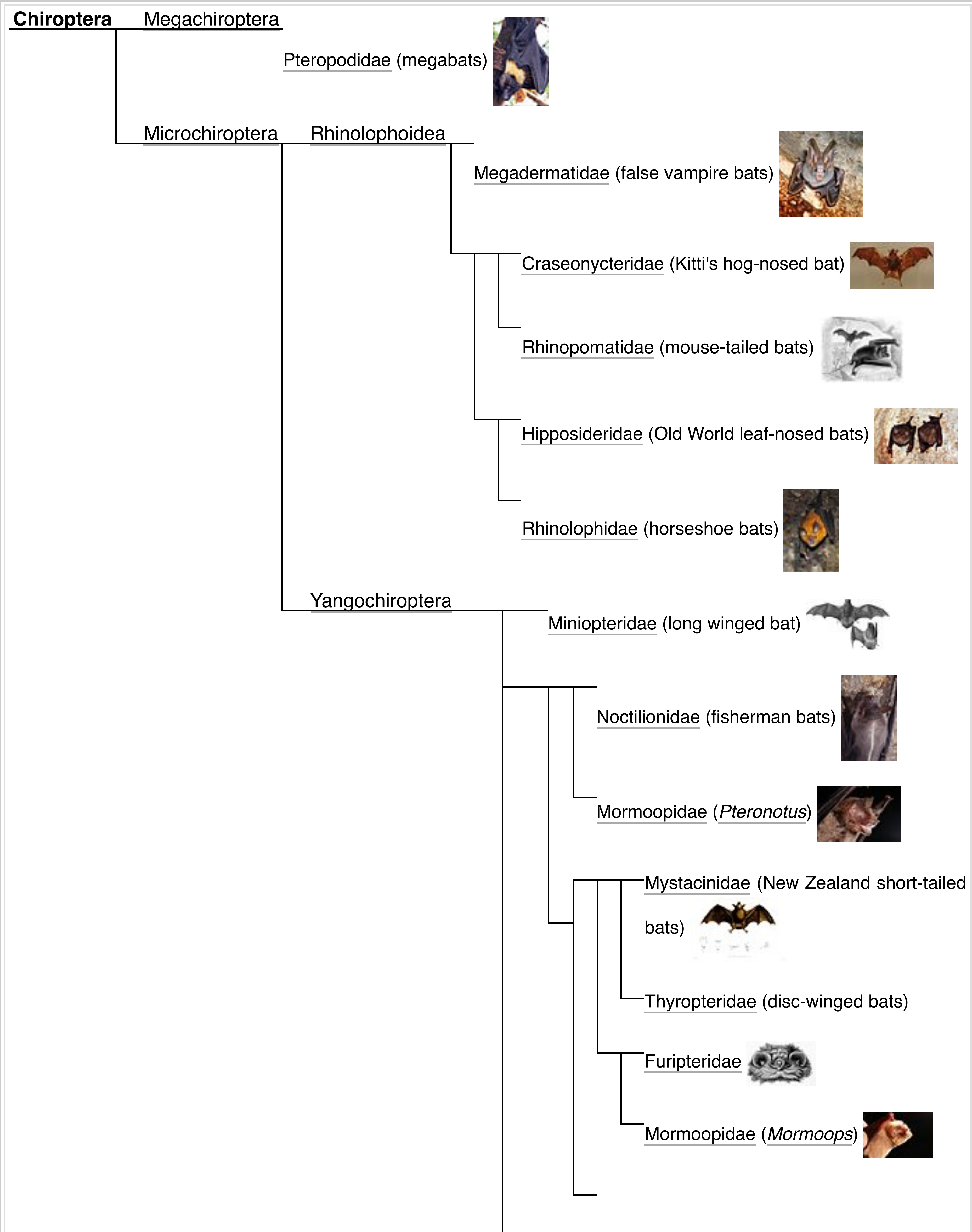
Bats were formerly grouped in the superorder Archonta, along with the treeshrews (Scandentia), colugos (Dermoptera), and primates.[10] Modern genetic evidence now places bats in the superorder Laurasiatheria, with its sister taxon as Fereuungulata, which includes carnivorans, pangolins, odd-toed ungulates, even-toed ungulates, and cetaceans.[11][12][13][14][15] One study places Chiroptera as a sister taxon to odd-toed ungulates (Perissodactyla).[16]

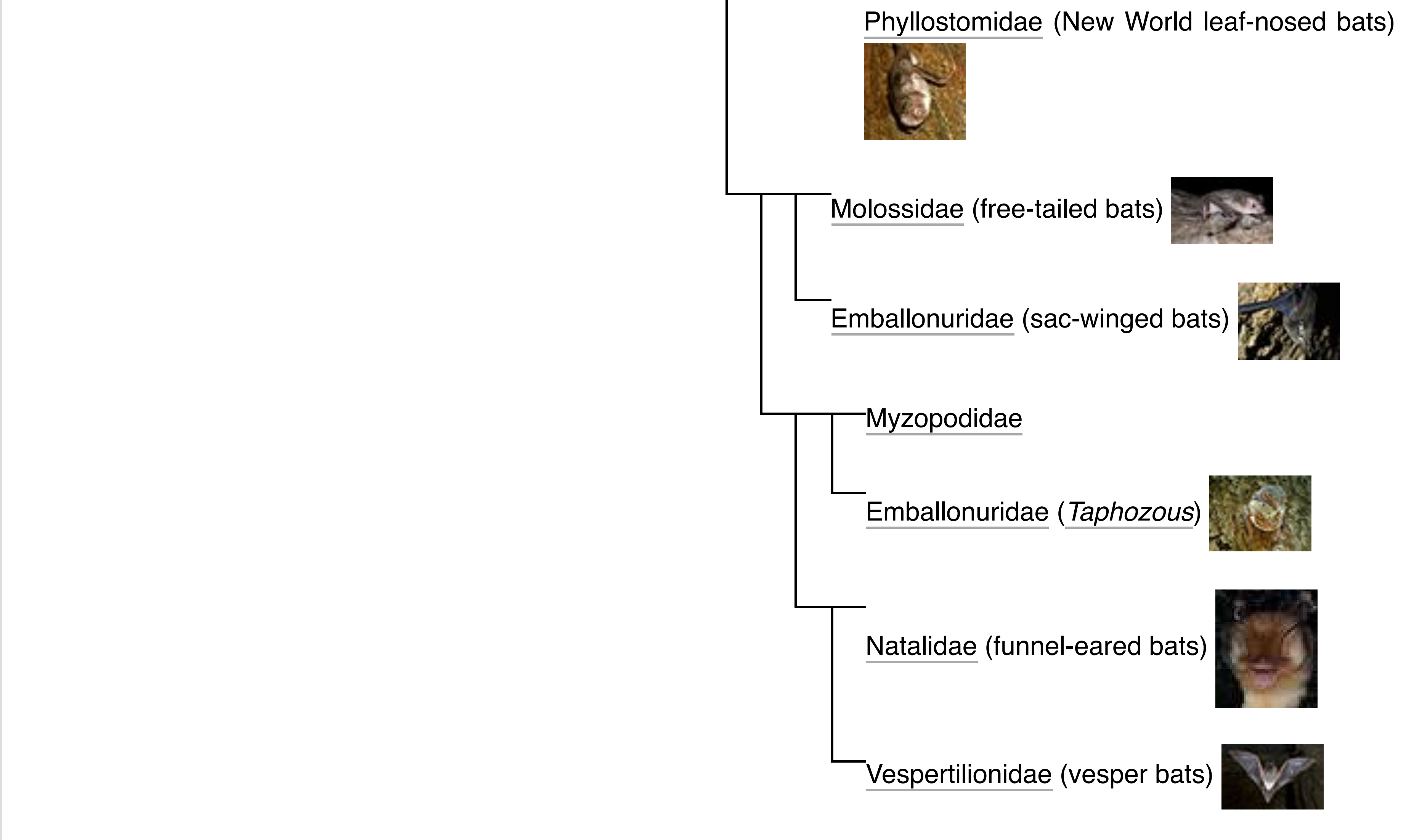
The early Eocene fossil microchiropteran *Icaronycteris*, from the Green River Formation



Phylogenetic tree showing Chiroptera within Laurasiatheria, with Fereuungulata as its sister taxon according to a 2013 study[15]

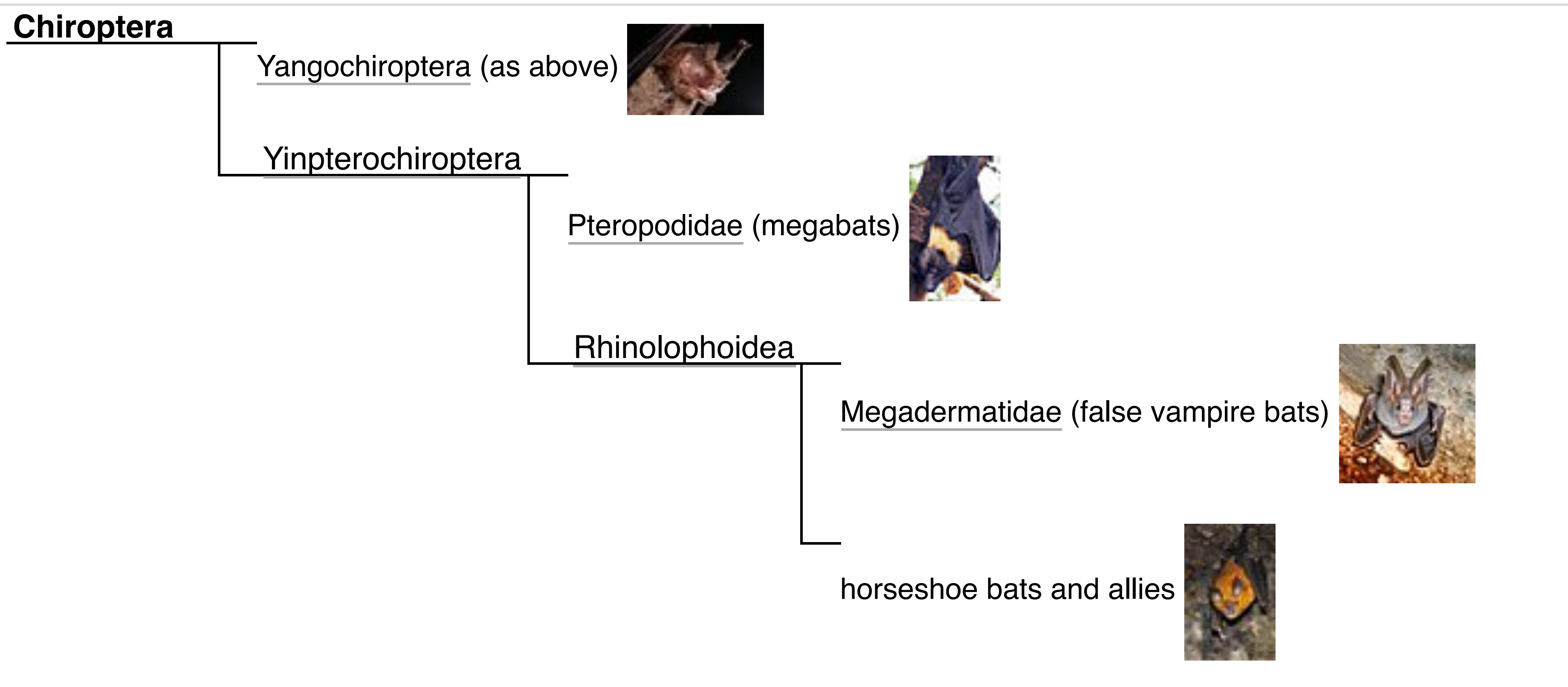
The phylogenetic relationships of the different groups of bats have been the subject of much debate. The traditional subdivision into Megachiroptera and Microchiroptera reflected the view that these groups of bats had evolved independently of each other for a long time, from a common ancestor already capable of flight. This hypothesis recognised differences between microbats and megabats and acknowledged that flight has only evolved once in mammals. Most molecular biological evidence supports the view that bats form a natural or monophyletic group.[7]





Internal relationships of the Chiroptera, divided into the traditional megabat and microbat clades, according to a 2011 study[17]

Genetic evidence indicates that megabats originated during the early Eocene, and belong within the four major lines of microbats.[15] Two new suborders have been proposed; Yinpterochiroptera includes the Pteropodidae, or megabat family, as well as the families Rhinolophidae, Hipposideridae, Craseonycteridae, Megadermatidae, and Rhinopomatidae.[18] Yangochiroptera includes the other families of bats (all of which use laryngeal echolocation), a conclusion supported by a 2005 DNA study.[18] A 2013 phylogenomic study supported the two new proposed suborders.[15]



Internal relationships of the Chiroptera, with the megabats subsumed within Yinpterochiroptera, according to a 2013 study[15]

In the 1980s, a hypothesis based on morphological evidence stated the Megachiroptera evolved flight separately from the Microchiroptera. The flying primate hypothesis proposed that, when adaptations to flight are removed, the Megachiroptera are allied to primates by anatomical features not shared with Microchiroptera. For example, the brains of megabats have advanced characteristics. Although recent genetic studies strongly support the monophyly of bats,[7] debate continues about the meaning of the genetic and morphological evidence.[19]

The 2003 discovery of an early fossil bat from the 52 million year old Green River Formation, *Onychonycteris finneyi*, indicates that flight evolved before echolocative abilities.[20][21] *Onychonycteris* had claws on all five of its fingers, whereas modern bats have at most two claws on two digits of each hand. It also had longer hind legs and shorter forearms, similar to climbing mammals that hang under branches, such as sloths and gibbons. This palm-sized bat had short, broad wings, suggesting that it could not fly as fast or as far as later bat species. Instead of flapping its wings continuously while flying, *Onychonycteris* probably alternated between flaps and glides in the air.[7] This suggests that this bat did not fly as much as modern bats, but flew from tree to tree and spent most of its time climbing or hanging on branches.[22] The distinctive features of the *Onychonycteris* fossil also support the hypothesis that mammalian flight most likely evolved in arboreal locomotors, rather than terrestrial runners. This model of flight development, commonly known as the "trees-down" theory, holds that bats first flew by taking advantage of height and gravity to drop down on to prey, rather than running fast enough for a ground-level take off.[23][24]


Giant golden-crowned flying fox, *Acerodon jubatus*

The molecular phylogeny is controversial, as it points to microbats not having a unique common ancestry, which implies that some seemingly unlikely transformations occurred. The first is that laryngeal echolocation evolved twice in bats, once in Yangochiroptera and once in the rhinolophoids.[25] The second is that laryngeal echolocation had a single origin in Chiroptera, was subsequently lost in the family Pteropodidae (all megabats), and later evolved as a system of tongue-clicking in the genus *Rousettus*.[26] Analyses of the sequence of the vocalization gene *FoxP2* were inconclusive on whether laryngeal echolocation was lost in the pteropodids or gained in the echolocating lineages.[27] Echolocation probably first derived in bats from communicative calls. The Eocene bats *Icaronycteris* (52 million years ago) and *Palaeochiropteryx* had cranial adaptations suggesting an ability to detect ultrasound. This may have been used at first mainly to forage on the ground for insects and map out their surroundings in their gliding phase, or for communicative purposes. After the adaptation of flight was established, it may have been refined to target flying prey by echolocation.[22] Bats may have evolved echolocation through a shared common ancestor, in which case it was then lost in the Old World megabats, only to be regained in the horseshoe bats; or, echolocation evolved independently in both the Yinpterochiroptera and Yangochiroptera lineages.[28] Analyses of the hearing gene *Prestin* seem to favour the idea that echolocation developed independently at least twice, rather than being lost secondarily in the pteropodids.[29]

Classification

Bats are placental mammals. After rodents, they are the largest order, making up about 20% of mammal species.[30] In 1758, Carl Linnaeus classified the seven bat species he knew of in the genus *Vespertilio* in the order Primates. Around twenty years later, the German naturalist Johann Friedrich Blumenbach gave them their own order, Chiroptera.[31] Since then, the number of described species has risen to over 1,200, traditionally classified as two suborders: Megachiroptera (megabats), and Microchiroptera (microbats/echolocating bats).[32] Not all megabats are larger than microbats.[33] Several characteristics distinguish the two groups. Microbats use echolocation for navigation and finding prey, but megabats apart from those in the genus *Rousettus* do not, relying instead on their eyesight.[34] Accordingly, megabats have a well-developed visual cortex and good visual acuity.[32] Megabats have a claw on the second finger of the forelimb.[35][36] The external ears of microbats do not close to form a ring; the edges are separated from each other at the base of the ear.[36] Megabats eat fruit, nectar, or pollen, while most microbats eat insects; others feed on fruit, nectar, pollen, fish, frogs, small mammals, or blood.[32]

The following classification from Agnarsson and colleagues in 2011 reflects the traditional division into megabat and microbat suborders.[17]

- Order Chiroptera[17]
  - Suborder Megachiroptera
    - Family Pteropodidae
  - Suborder Microchiroptera
    - Yangochiroptera (unranked)

- Family Emballonuridae
- Family Furipteridae
- Family Miniopteridae
- Family Molossidae
- Family Mormoopidae
- Family Mystacinidae
- Family Myzopodidae
- Family Natalidae
- Family Noctilionidae
- Family Phyllostomidae
- Family Thyropteridae
- Family Vespertilionidae
- Rhinolophoidea (unranked)
  - Family Craseonycteridae
  - Family Hipposideridae
  - Family Megadermatidae
  - Family Rhinolophidae
  - Family Rhinopomatidae

Anatomy and physiology

"Chiroptera" from Ernst Haeckel's *Kunstformen der Natur*, 1904

Skull and dentition

The head and teeth shape of bats can vary by species. In general, megabats have longer snouts, larger eye sockets and smaller ears, giving them a more dog-like appearance, which is the source of their nickname of "flying foxes".[37] Among microbats, longer snouts are associated with nectar-feeding.[38] while vampire bats have reduced snouts to accommodate large incisors and canines.[39]

A preserved megabat showing how the skeleton fits inside its skin

Small insect-eating bats can have as many as 38 teeth, while vampire bats have only 20. Bats that feed on hard-shelled insects have fewer but larger teeth with longer canines and more robust lower jaws than species that prey on softer bodied insects. In nectar-feeding bats, the canines are long while the cheek-teeth are reduced. In fruit-eating bats, the cusps of the cheek teeth are adapted for crushing.[38] These feeding behaviors are true for both megabats and microbats. The upper incisors of vampire bats lack enamel, which keeps them razor-sharp.[39] The bite force of small bats is generated through mechanical advantage, allowing them to bite through the hardened armour of insects or the skin of fruit.[40]

Wings and flight

Bats are the only mammals capable of sustained flight, as opposed to gliding, as in the flying squirrel.[41] The fastest bat, the Mexican free-tailed bat (*Tadarida brasiliensis*), can achieve a ground speed of 160 kilometres per hour (99 mph).[42]

The finger bones of bats are much more flexible than those of other mammals, owing to their flattened cross-section and to low levels of calcium near their tips. The elongation of bat digits, a key feature required for wing development, is due to the upregulation of bone morphogenetic proteins (Bmps). During embryonic development, the gene controlling Bmp signalling, *Bmp2*, is subjected to increased expression in bat forelimbs—resulting in the extension of the manual digits. This crucial genetic alteration helps create the specialised limbs required for powered flight. The relative proportion of extant bat forelimb digits compared with those of Eocene fossil bats have no significant differences, suggesting that bat wing morphology has been conserved for over 50 million years.[43] During flight, the bones undergo bending and shearing stress; the bending stresses felt are smaller than in terrestrial mammals, but the shearing stress is larger. The wing bones of bats have a slightly lower breaking stress point than those of birds.[44]

As in other mammals, and unlike in birds, the radius is the main component of the forearm. Bats have five elongated digits, which all radiate around the wrist. The thumb points forward and supports the leading edge of the wing, and the other digits support the tension held in the wing membrane. The second and third digits go along the wing tip, allowing the wing to be pulled forward against aerodynamic drag, without having to be thick as in pterosaur wings. The fourth and fifth digits go from the wrist to the trailing edge, and repel the bending force caused by air pushing up against the stiff membrane.[45] Due to their flexible joints, bats are more manoeuvrable and more dexterous than gliding mammals.[46]

The wings of bats are much thinner and consist of more bones than the wings of birds, allowing bats to manoeuvre more accurately than the latter, and fly with more lift and less drag.[47] By folding the wings in toward their bodies on the upstroke, they save 35 percent energy during flight.[48] The membranes are delicate, tearing easily,[49] but can regrow, and small tears heal quickly.[49][50] The surface of the wings is equipped with touch-sensitive receptors on small bumps called Merkel cells, also found on human fingertips. These sensitive areas are different in bats, as each bump has a tiny hair in the centre, making it even more sensitive and allowing the bat to detect and adapt to changing airflow; the primary use is to judge the most efficient speed to fly at, and possibly also to avoid stalls.[51] Insectivorous bats may also use tactile hairs to help perform complex manoeuvres to capture prey in flight.[46]

Wing membranes (patagia) of Townsend's big-eared bat, *Corynorhinus townsendii*

The patagium is the wing membrane; it is stretched between the arm and finger bones, and down the side of the body to the hind limbs and tail. This skin membrane consists of connective tissue, elastic fibres, nerves, muscles, and blood vessels. The muscles keep the membrane taut during flight.[52] The extent to which the tail of a bat is attached to a patagium can vary by species, with some having completely free tails or even no tails.[38] The skin on the body of the bat, which has one layer of epidermis and dermis, as well as hair follicles, sweat glands and a fatty subcutaneous layer, is very different from the skin of the wing membrane. The patagium is an extremely thin double layer of epidermis; these layers are separated by a connective tissue centre, rich with collagen and elastic fibres. The membrane has no hair follicles or sweat glands, except between the fingers.[51][53] For bat embryos, apoptosis (cell death) only affects the hindlimbs, while the forelimbs retain webbing between the digits that forms into the wing membranes.[54] Unlike birds, whose stiff wings deliver bending and torsional stress to the shoulders, bats have a flexible wing membrane that can only resist tension. To achieve flight, a bat exerts force inwards at the points where the membrane meets the skeleton, so that an opposing force balances it on the wing edges perpendicular to the wing surface. This adaptation does not permit bats to reduce their wingspans, unlike birds, which can partly fold their wings in flight, radically reducing the wing span and area for the upstroke and for gliding. Hence bats cannot travel over long distances as birds can.[45]

Nectar- and pollen-eating bats can hover, in a similar way to hummingbirds. The sharp leading edges of the wings can create vortices, which provide lift. The vortex may be stabilised by the animal changing its wing curvatures.[55]

Roosting adaptations

When not flying, bats hang upside down from their feet, a posture known as roosting.[56] The femurs are attached at the hips in a way that allows them to bend outward and upward in flight. The ankle joint can flex to allow the trailing edge of the wings to bend downwards. This does not permit many movements other than hanging or clambering up trees.[45] Most megabats roost with the head tucked towards the belly, whereas most microbats roost with the neck curled towards the back. This difference is reflected in the structure of the cervical or neck vertebrae in the two groups, which are clearly distinct.[56] Tendons allow bats to lock their feet closed when hanging from a roost. Muscular power is needed to let go, but not to grasp a perch or when holding on.[57]

Internal systems

Bats have an efficient circulatory system. They seem to make use of particularly strong venomotion, a rhythmic contraction of venous wall muscles. In most mammals, the walls of the veins provide mainly passive resistance, maintaining their shape as deoxygenated blood flows through them, but in bats they appear to actively support blood flow back to the heart with this pumping action.[58][59] Since their bodies are relatively small and lightweight, bats are not at risk of blood flow rushing to their heads when roosting.[60]

Group of megabats roosting

Bats possess a highly adapted respiratory system to cope with the demands of powered flight, an energetically taxing activity that requires a large continuous throughput of oxygen. In bats, the relative alveolar surface area and pulmonary capillary blood volume are larger than in most other small quadrupedal mammals.[61] Because of the restraints of the mammalian lungs, bats cannot maintain high-altitude flight.[45]

It takes a lot of energy and an efficient circulatory system to work the flight muscles of bats. Energy supply to the muscles engaged in flight require about double the amount compared to the muscles that do not use flight as a means of mammalian locomotion. In parallel to energy consumption, blood oxygen levels of flying animals are twice as much as those of their terrestrially locomoting mammals. As the blood supply controls the amount of oxygen supplied throughout the body, the circulatory system must respond accordingly. Therefore, compared to a terrestrial mammal of the same relative size, the bat's heart can be up to three times larger, and pump more blood.[63] Cardiac output is directly derived from heart rate and stroke volume of the blood;[64] an active microbat can reach a heart rate of 1000 beats per minute.[65]

The wings are highly vascularized membranes, the larger blood vessels visible against the light.[62]

With its extremely thin membranous tissue, a bat's wing can significantly contribute to the organism's total gas exchange efficiency.[53] Because of the high energy demand of flight, the bat's body meets those demands by exchanging gas through the patagium of the wing. When the bat has its wings spread it allows for an increase in surface area to volume ratio. The surface area of the wings is about 85% of the total body surface area, suggesting the possibility of a useful degree of gas exchange.[53] The subcutaneous vessels in the membrane lie very close to the surface and allow for the diffusion of oxygen and carbon dioxide.[66]

The digestive system of bats has varying adaptations depending on the species of bat and its diet. As in other flying animals, food is processed quickly and effectively to keep up with the energy demand. Insectivorous bats may have certain digestive enzymes to better process insects, such as chitinase to break down chitin, which is a large component of insects.[67] Vampire bats, probably due to their diet of blood, are the only vertebrates that do not have the enzyme maltase, which breaks down malt sugar, in their intestinal tract. Nectivorous and frugivorous bats have more maltase and sucrase enzymes than insectivorous, to cope with the higher sugar contents of their diet.[68]

The adaptations of the kidneys of bats vary with their diets. Carnivorous and vampire bats consume large amounts of protein and can output concentrated urine; their kidneys have a thin cortex and long renal papillae. Frugivorous bats lack that ability and have kidneys adapted for electrolyte-retention due to their low-electrolyte diet; their kidneys accordingly have a thick cortex and very short conical papillae.[68][69]

Bats have higher metabolic rates associated with flying, which lead to an increased respiratory water loss. Their large wings are composed of the highly vascularized membranes, increasing the surface area, and leading to cutaneous evaporative water loss.[62] Water helps maintain their ionic balance in their blood, thermoregulation system, and removal of wastes and toxins from the body via urine. They are also susceptible to blood urea poisoning if they do not receive enough fluid.[70]

The structure of the uterine system in female bats can vary by species, with some having two uterine horns while others have a single mainline chamber.[71]

Senses

Echolocation

Pipistrellus pulses

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Recording of *Pipistrellus pipistrellus* bat time-expanded echolocation calls and social call.

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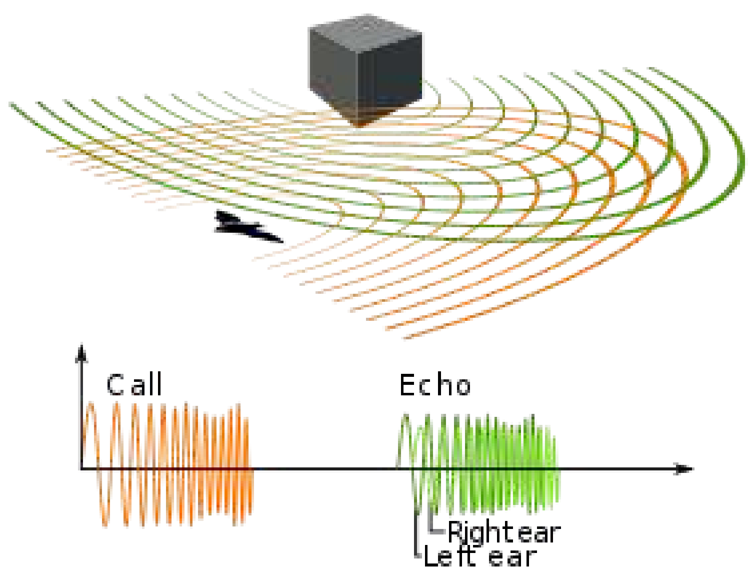
Microbats and a few megabats emit ultrasonic sounds to produce echoes. By comparing the outgoing pulse with the returning echoes, the brain and auditory nervous system can produce detailed images of the bat's surroundings. This allows bats to detect, localise, and classify their prey in darkness. Bat calls are some of the loudest airborne animal sounds, and can range in intensity from 60 to 140 decibels.[72][73] Microbats use their larynx to create ultrasound, and emit it through the mouth and sometimes the nose. The latter is most pronounced in the horseshoe bats (*Rhinolophus* spp.). Microbat calls range in frequency from 14,000 to well over 100,000 Hz, extending well beyond the range of human hearing (between 20 and 20,000 Hz).[74] Various groups of bats have evolved fleshy extensions around and above the nostrils, known as nose-leaves, which play a role in sound transmission.[75]



Principle of bat echolocation: orange is the call and green is the echo

In low-duty cycle echolocation, bats can separate their calls and returning echoes by time. They have to time their short calls to finish before echoes return. Bats contract their middle ear muscles when emitting a call, so they can avoid deafening themselves. The time interval between the call and echo allows them to relax these muscles, so they can hear the returning echo.[76] The delay of the returning echoes allows the bat to estimate the range to their prey.[74]

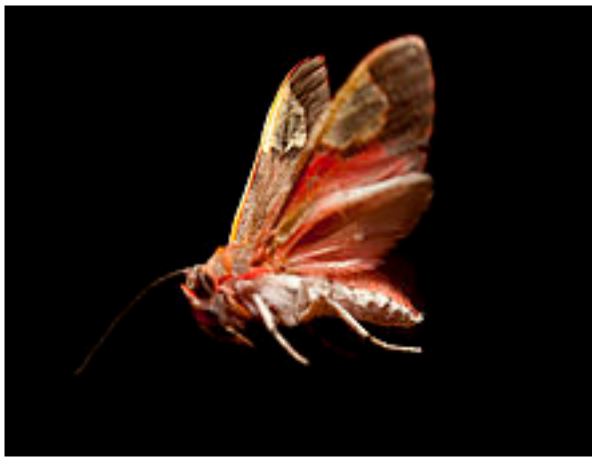
In high-duty cycle echolocation, bats emit a continuous call and separate pulse and echo in frequency. The ears of these bats are sharply tuned to a specific frequency range. They emit calls outside this range to avoid deafening themselves. They then receive echoes back at the finely tuned frequency range by taking advantage of the Doppler shift of their motion in flight. The Doppler shift of the returning echoes yields information relating to the motion and location of the bat's prey. These bats must deal with changes in the Doppler shift due to changes in their flight speed. They have adapted to change their pulse emission frequency in relation to their flight speed so echoes still return in the optimal hearing range.[77]

In addition to echolocating prey, bat ears are sensitive to the fluttering of moth wings, the sounds produced by tymbalate insects, and the movement of ground-dwelling prey, such as centipedes and earwigs. The complex geometry of ridges on the inner surface of bat ears helps to sharply focus echolocation signals, and to passively listen for any other sound produced by the prey. These ridges can be regarded as the acoustic equivalent of a Fresnel lens, and exist in a large variety of unrelated animals, such as the aye-aye, lesser galago, bat-eared fox, mouse lemur, and others.[78][79][80] Bats can estimate the elevation of their target using the interference patterns from the echoes reflecting from the tragus, a flap of skin in the external ear.[74]

By repeated scanning, bats can mentally construct an accurate image of the environment in which they are moving and of their prey.[83] Some species of moth have exploited this, such as the tiger moths, which produces aposematic ultrasound signals to warn bats that they are chemically protected and therefore distasteful.[81][82] Moth species including the tiger moth can produce signals to jam bat echolocation. Many moth species have a hearing organ called a tympanum, which responds to an incoming bat signal by causing the moth's flight muscles to twitch erratically, sending the moth into random evasive manoeuvres.[84][85][86]

Vision

The eyes of most microbat species are small and poorly developed, leading to poor visual acuity, but no species is blind.[87] Most microbats have mesopic vision, meaning that they can only detect light in low levels, whereas other mammals have photopic vision, which allows colour vision. Microbats may use their vision for orientation and while travelling between their roosting grounds and feeding grounds, as echolocation is only effective over short distances. Some species can detect ultraviolet (UV). As the bodies of some microbats have distinct coloration, they may be able to discriminate colours.[41][88][89][90]


The tiger moth (*Bertholdia trigona*) can jam bat echolocation[81][82]

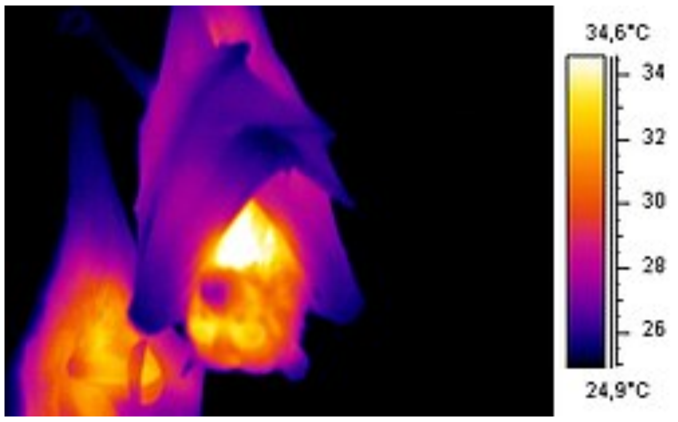
Megabat species often have eyesight as good as, if not better than, human vision. Their eyesight is adapted to both night and daylight vision, including some colour vision.[90]

Magnetoreception

Microbats make use of magnetoreception, in that they have a high sensitivity to the Earth's magnetic field, as birds do. Microbats use a polarity-based compass, meaning that they differentiate north from south, unlike birds, which use the strength of the magnetic field to differentiate latitudes, which may be used in long-distance travel. The mechanism is unknown but may involve magnetite particles.[91][92]

Thermoregulation

Most bats are homeothermic (having a stable body temperature), the exception being the vesper bats (Vespertilionidae), the horseshoe bats (Rhinolophidae), the free-tailed bats (Molossidae), and the bent-winged bats (Miniopteridae), which extensively use heterothermy (where body temperature can vary).[93] Compared to other mammals, bats have a high thermal conductivity. The wings are filled with blood vessels, and lose body heat when extended. At rest, they may wrap their wings around themselves to trap a layer of warm air. Smaller bats generally have a higher metabolic rate than larger bats, and so need to consume more food in order to maintain homeothermy.[94]



Thermographic image of a bat using trapped air as insulation

Bats may avoid flying during the day to prevent overheating in the sun, since their dark wing-membranes absorb solar radiation. Bats may not be able to dissipate heat if the ambient temperature is too high;[95] they use saliva to cool themselves in extreme conditions.[45] Among megabats, the flying fox *Pteropus hypomelanus* uses saliva and wing-fanning to cool itself while roosting during the hottest part of the day.[96] Among microbats, the Yuma myotis (*Myotis yumanensis*), the Mexican free-tailed bat and the pallid bat (*Antrozous pallidus*) cope with temperatures up to 45 Celsius by panting, salivating and licking their fur to promote evaporative cooling; this is sufficient to dissipate twice their metabolic heat production.[97]

Bats also possess a system of sphincter valves on the arterial side of the vascular network that runs along the edge of their wings. When fully open, these allow oxygenated blood to flow through the capillary network across the wing membrane; when contracted, they shunt flow directly to the veins, bypassing the wing capillaries. This allows bats to control how much heat is exchanged through the flight membrane, allowing them to release heat during flight. Many other mammals use the capillary network in oversized ears for the same purpose.[98]

Torpor

Torpor, a state of decreased activity where the body temperature and metabolism decreases, is especially useful for microbats, as they use a large amount of energy while active, depend upon an unreliable food source, and have a limited ability to store fat. They generally drop their body temperature in this state to 6–30 °C (43–86 °F), and may reduce their energy expenditure by 50 to 99%. Around 97% of all microbats use torpor.[99] Tropical bats may use it to avoid predation, by reducing the amount of time spent on foraging and thus reducing the chance of being caught by a predator.[100] Megabats were generally believed to be homeothermic, but three species of small megabats, with a mass of about 50 grams (1.8 oz), have been known to use torpor: the common blossom bat (*Syconycteris australis*), the long-tongued nectar bat (*Macroglossus minimus*), and the eastern tube-nosed bat (*Nyctimene robinsoni*). Torpid states last longer in the summer for megabats than in the winter.[101]

A tricoloured bat (*Perimyotis subflavus*) in torpor

During hibernation, bats enter a torpid state and decrease their body temperature for 99.6% of their hibernation period; even during periods of arousal, when they return their body temperature to normal, they sometimes enter a shallow torpid state, known as "heterothermic arousal".[102] Some bats become dormant during higher temperatures to keep cool in the summer months.[103]

Heterothermic bats during long migrations may fly at night and go into a torpid state roosting in the daytime. Unlike migratory birds, which fly during the day and feed during the night, nocturnal bats have a conflict between travelling and eating. The energy saved reduces their need to feed, and also decreases the duration of migration, which may prevent them from spending too much time in unfamiliar places, and decrease predation. In some species, pregnant individuals may not use torpor.[104][105]

Size

The smallest bat is Kitti's hog-nosed bat (*Craseonycteris thonglongyai*), which is 29–34 millimetres (1.1–1.3 in) long with a 15 centimetres (5.9 in) wingspan and weighs 2–2.6 grams (0.071–0.092 oz).[106][107] It is also arguably the smallest extant species of mammal, next to the Etruscan shrew.[108] The largest bats are a few species of *Pteropus* megabats and the giant golden-crowned flying fox, (*Acerodon jubatus*), which can weigh 1.6 kilograms (3.5 lb) with a wingspan of 1.7 metres (5.6 ft).[109] Larger bats tend to use lower frequencies and smaller bats higher for echolocation; high-frequency echolocation is better at detecting smaller prey. Small prey may be absent in the diets of large bats as they are unable to detect them.[110] The adaptations of a particular bat species can directly influence what kinds of prey are available to it.[111]

Ecology

Tent-making bats (*Uroderma bilobatum*) in Costa Rica

Flight has enabled bats to become one of the most widely distributed groups of mammals.[112] Apart from the high Arctic, the Antarctic and a few isolated oceanic islands, bats exist in almost every habitat on Earth.[113] Tropical areas tend to have more species than temperate ones.[114] Different species select different habitats during different seasons, ranging from seasides to mountains and deserts, but they require suitable roosts. Bat roosts can be found in hollows, crevices, foliage, and even human-made structures, and include "tents" the bats construct with leaves.[115] Megabats generally roost in trees.[116] Most microbats are nocturnal[117] and megabats are typically diurnal or crepuscular.[118][119]

In temperate areas, some microbats migrate hundreds of kilometres to winter hibernation dens;[120] others pass into torpor in cold weather, rousing and feeding when warm weather allows insects to be active.[121] Others retreat to caves for winter and hibernate for as much as six months.[121] Microbats rarely fly in rain; it interferes with their echolocation, and they are unable to hunt.[122] A few species such as the New Zealand short-tailed bat and the common vampire bat are agile on the ground.[123]

Food and feeding

Mexican long-tongued bat (*Choeronycteris mexicana*) drinking from a cactus

Different bat species have different diets, including insects, nectar, pollen, fruit and even vertebrates.[124] Megabats are mostly fruit, nectar and pollen eaters.[118] Due to their small size, high-metabolism and rapid burning of energy through flight, bats must consume large amounts of food for their size. Insectivorous bats may eat over 120 percent of their body weight, while frugivorous bats may eat over twice their weight.[125] They can travel significant distances each night, exceptionally as much as 38.5 kilometres (23.9 mi) in the spotted bat (*Euderma maculatum*), in search of food.[126] Bats use a variety of hunting strategies.[110] Bats get most of their water from the food they eat; many species also drink from water sources like lakes and streams, flying over the surface and dipping their tongues into the water.[127]

The Chiroptera as a whole are in the process of losing the ability to synthesise vitamin C.[128] In a test of 34 bat species from six major families, including major insect- and fruit-eating bat families, all were found to have lost the ability to synthesise it, and this loss may derive from a common bat ancestor, as a single mutation.[129][b] At least two species of bat, the frugivorous bat (*Rousettus leschenaultii*) and the insectivorous bat (*Hipposideros armiger*), have retained their ability to produce vitamin C.[130]

Insects

Most microbats, especially in temperate areas, prey on insects.[124] The diet of an insectivorous bat may span many species,[131] including flies, mosquitos, beetles, moths, grasshoppers, crickets, termites, bees, wasps, mayflies and caddisflies.[38][132] Large numbers of Mexican free-tailed bats (*Tadarida brasiliensis*) fly hundreds of metres above the ground in central Texas to feed on migrating moths.[133] Species that hunt insects in flight, like the little brown bat (*Myotis lucifugus*), may catch an insect in mid-air with the mouth, and eat it in the air or use their tail membranes or wings to scoop up the insect and carry it to the mouth.[134][135] The bat may also take the insect back to its roost and eat it there.[136] Slower moving bat species such as the brown long-eared bat (*Plecotus auritus*) and many horseshoe bat species, may take or glean insects from vegetation or hunt them from perches.[38] Insectivorous bats living at high latitudes have to consume prey with higher energetic value than tropical bats.[137]

Fruit and nectar

An Egyptian fruit bat (*Rousettus aegyptiacus*) carrying a fig

Fruit eating, or frugivory, is found in both major suborders. Bats prefer ripe fruit, pulling it off the trees with their teeth. They fly back to their roosts to eat the fruit, sucking out the juice and spitting the seeds and pulp out onto the ground. This helps disperse the seeds of these fruit trees, which may take root and grow where the bats have left them, and many species of plants depend on bats for seed dispersal.[138][139] The Jamaican fruit bat (*Artibeus jamaicensis*) has been recorded carrying fruits weighing 3–14 g (0.11–0.49 oz) or even as much as 50 g (1.8 oz).[140]

Nectar-eating bats have acquired specialised adaptations. These bats possess long muzzles and long, extensible tongues covered in fine bristles that aid them in feeding on particular flowers and plants.[139][141] The tube-lipped nectar bat (*Anoura fistulata*) has the longest tongue of any mammal relative to its body size. This is beneficial to them in terms of pollination and feeding. Their long, narrow tongues can reach deep into the long cup shape of some flowers. When the tongue retracts, it coils up inside the rib cage.[141] Because of these features, nectar-feeding bats cannot easily turn to other food sources in times of scarcity, making them more prone to extinction than other types of bat.[142][143] Nectar feeding also aids a variety of plants, since these bats serve as pollinators, as pollen gets attached to their fur while they are feeding. Around 500 species of flowering plant rely on bat pollination and thus tend to open their flowers at night.[139] Many rainforest plants depend on bat pollination.[144]

Vertebrates

Some bats prey on other vertebrates, such as fish, frogs, lizards, birds and mammals.[38][146] The fringe-lipped bat (*Trachops cirrhosus,*) for example, is skilled at catching frogs. These bats locate large groups of frogs by tracking their mating calls, then plucking them from the surface of the water with their sharp canine teeth.[147] The greater noctule bat can catch birds in flight.[145] Some species, like the greater bulldog bat (*Noctilio leporinus*) hunt fish. They use echolocation to detect small ripples on the water's surface, swoop down and use specially enlarged claws on their hind feet to grab the fish, then take their prey to a feeding roost and consume it.[148] At least two species of bat are known to feed on other bats: the spectral bat (*Vampyrum spectrum*), and the ghost bat (*Macroderma gigas*).[149]

The greater noctule bat (*Nyctalus lasiopterus*) uses its large teeth to catch birds.[145]

Blood

A few species, specifically the common, white-winged, and hairy-legged vampire bats, only feed on animal blood (hematophagy). The common vampire bat typically feeds on large mammals such as cattle; the hairy-legged and white-winged vampires feed on birds.[150] Vampire bats target sleeping prey and can detect deep breathing.[151] Heat sensors in the nose help them to detect blood vessels near the surface of the skin.[152] They pierce the animal's skin with their teeth, biting away a small flap,[153] and lap up the blood with their tongues, which have lateral grooves adapted to this purpose.[154] The blood is kept from clotting by an anticoagulant in the saliva.[153]

The common vampire bat (*Desmodus rotundus*) feeds on blood (hematophagy).

Predators, parasites, and diseases

Bats are subject to predation from birds of prey, such as owls, hawks, and falcons, and at roosts from terrestrial predators able to climb, such as cats.[155] Twenty species of tropical New World snakes are known to capture bats, often waiting at the entrances of refuges, such as caves, for bats to fly past.[156] J. Rydell and J. R. Speakman argue that bats evolved nocturnality during the early and middle Eocene period to avoid predators.[155] The evidence is thought by some zoologists to be equivocal so far.[157]

Among ectoparasites, bats carry fleas and mites, as well as specific parasites such as bat bugs and bat flies (Nycteribiidae and Streblidae).[158][159] Bats are among the few non-aquatic mammalian orders that do not host lice, possibly due to competition from more specialised parasites that occupy the same niche.[159]

A little brown bat with white nose syndrome

White nose syndrome is a condition associated with the deaths of millions of bats in the Eastern United States and Canada.[160] The disease is named after a white fungus, *Pseudogymnoascus destructans*, found growing on the muzzles, ears, and wings of afflicted bats. The fungus is mostly spread from bat to bat, and causes the disease.[161] The fungus was first discovered in central New York State in 2006 and spread quickly to the entire Eastern US north of Florida; mortality rates of 90–100% have been observed in most affected caves.[162] New England and the mid-Atlantic states have, since 2006, witnessed entire species completely extirpated and others with numbers that have gone from the hundreds of thousands, even millions, to a few hundred or less.[163] Nova Scotia, Quebec, Ontario, and New Brunswick have witnessed identical die offs, with the Canadian government making preparations to protect all remaining bat populations in its territory.[164] Scientific evidence suggests that longer winters where the fungus has a longer period to infect bats result in greater mortality.[165][166][167] In 2014, the infection crossed the Mississippi River,[168] and in 2017, it was found on bats in Texas.[169]

Bats are natural reservoirs for a large number of zoonotic pathogens,[170] including rabies, endemic in many bat populations,[171][172][173] histoplasmosis both directly and in guano,[174] Nipah and Hendra viruses,[175][176] and possibly the ebola virus.[177][178] Their high mobility, broad distribution, long life spans, substantial sympatry (range overlap) of species, and social behaviour make bats favourable hosts and vectors of disease. Compared to rodents, bats carry more zoonotic viruses per species, and each virus is shared with more species.[179] They seem to be highly resistant to many of the pathogens they carry, suggesting a degree of adaptation to their immune systems.[179][180][181] Their interactions with livestock and pets, including predation by vampire bats, accidental encounters, and the scavenging of bat carcasses, compound the risk of zoonotic transmission.[172] Bats are implicated in the emergence of severe acute respiratory syndrome (SARS) in China, since they serve as natural hosts for Coronaviruses, several from a single cave in Yunnan, one of which developed into the SARS virus.[174][182][183]

Social behaviour

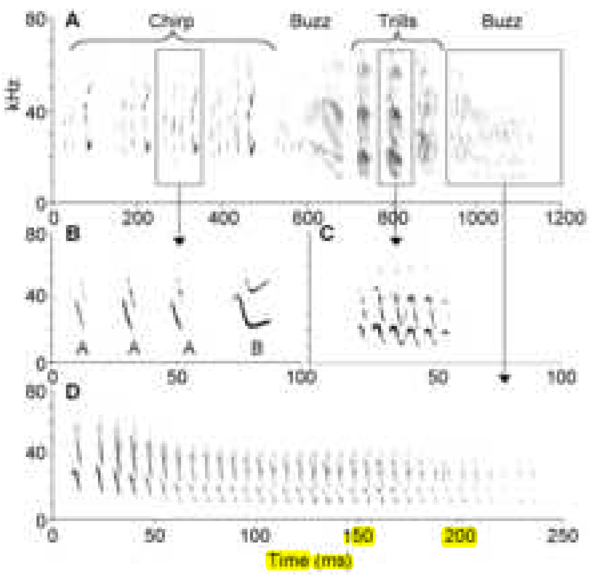
Social structure

Bracken Bat Cave, home to 20 million Mexican free-tailed bats

Some bats lead solitary lives, while others live in colonies of more than a million.[184] Living in large colonies lessens the risk to an individual of predation.[38] Temperate bat species may swarm at hibernation sites as autumn approaches. This may serve to introduce young to hibernation sites, signal reproduction in adults and allow adults to breed with those from other groups.[185]

Several species have a fission-fusion social structure, where large numbers of bats congregate in one roosting area, along with breaking up and mixing of subgroups. Within these societies, bats are able to maintain long term relationships.[186] Some of these relationships consist of matrilineally related females and their dependent offspring.[187] Food sharing and mutual grooming may occur in certain species, such as the common vampire bat (*Desmodus rotundus*), and these strengthen social bonds.[188][189]

Communication



Acoustics of the songs of Mexican free-tailed bats[190]

Bats are among the most vocal of mammals and produce calls to attract mates, find roost partners and defend resources. These calls are typically low-frequency and can travel long distances.[38][191] Mexican free-tailed bats are one of the few species to "sing" like birds. Males sing to attract females. Songs have three phrases: chirps, trills and buzzes, the former having "A" and "B" syllables. Bat songs are highly stereotypical but with variation in syllable number, phrase order, and phrase repetitions between individuals.[190] Among greater spear-nosed bats (*Phyllostomus hastatus*), females produce loud, broadband calls among their roost mates to form group cohesion. Calls differ between roosting groups and may arise from vocal learning.[192]

In a study on captive Egyptian fruit bats, 70% of the directed calls could be identified by the researchers as to which individual bat made it, and 60% could be categorised into four contexts: squabbling over food, jostling over position in their sleeping cluster, protesting over mating attempts and arguing when perched in close proximity to each other. The animals made slightly different sounds when communicating with different individual bats, especially those of the opposite sex.[193] In the highly sexually dimorphic hammer-headed bat (*Hypsignathus monstrosus*), males produce deep, resonating, monotonous calls to attract females. Bats in flight make vocal signals for traffic control. Greater bulldog bats honk when on a collision course with each other.[191]

Bats also communicate by other means. Male little yellow-shouldered bats (*Sturnira lilium*) have shoulder glands that produce a spicy odour during the breeding season. Like many other species, they have hair specialised for retaining and dispersing secretions. Such hair forms a conspicuous collar around the necks of the some Old World megabat males. Male greater sac-winged bats (*Saccopteryx bilineata*) have sacs in their wings in which they mix body secretions like saliva and urine to create a perfume that they sprinkle on roost sites, a behaviour known as "salting". Salting may be accompanied by singing.[191]

Reproduction and life history

Group of polygynous vampire bats

Strategies

Most bat species are polygynous, where males mate with multiple females. Male pipistrelle, noctule and vampire bats may claim and defend resources that attract females, such as roost sites, and mate with those females. Males unable to claim a site are forced to live on the periphery where they have less reproductive success.[194][38] Promiscuity, where both sexes mate with multiple partners, exists in species like the Mexican free-tailed bat and the little brown bat.[195][196] There appears to be bias towards certain males among females in these bats.[38] In a few species, such as the yellow-winged bat and spectral bat, adult males and females form monogamous pairs.[38][197] Lek mating, where males aggregate and compete for female choice through display, is rare in bats[198] but occurs in the hammerheaded bat.[199]

Mating

For temperate living bats, mating takes place in late summer and early autumn.[200] Tropical bats may mate during the dry season.[201] After copulation, the male may leave behind a mating plug to block the sperm of other males and thus ensure his paternity. In hibernating species, males are known to mate with females in torpor.[38] Female bats use a variety of strategies to control the timing of pregnancy and the birth of young, to make delivery coincide with maximum food ability and other ecological factors. Females of some species have delayed fertilisation, in which sperm is stored in the reproductive tract for several months after mating. Mating occurs in the autumn but fertilisation does not occur until the following spring. Other species exhibit delayed implantation, in which the egg is fertilised after mating, but remains free in the reproductive tract until external conditions become favourable for giving birth and caring for the offspring.[202] In another strategy, fertilisation and implantation both occur, but development of the foetus is delayed until good conditions prevail. During the delayed development the mother keeps the fertilised egg alive with nutrients. This process can go on for a long period, because of the advanced gas exchange system.[203]

Life cycle

For temperate living bats, births typically take place in May or June in the northern hemisphere; births in the southern hemisphere occur in November and December. Tropical species give birth at the beginning of the rainy season.[204] In most bat species, females carry and give birth to a single pup per litter.[205] At birth, a bat pup can be up to 40 percent of the mother's weight,[38] and the pelvic girdle of the female can expand during birth as the two halves are connected by a flexible ligament.[206] Females typically give birth in a head-up or horizontal position, using gravity to make birthing easier. The young emerges rear-first, possibly to prevent the wings from getting tangled, and the female cradles it in her wing and tail membranes. In many species, females give birth and raise their young in maternity colonies and may assist each other in birthing.[207][208][206]

Newborn common pipistrelle, *Pipistrellus pipistrellus*

Most of the care for a young bat comes from the mother. In monogamous species, the father plays a role. Allo-suckling, where a female suckles another mother's young, occurs in several species. This may serve to increase colony size in species where females return to their natal colony to breed.[38] A young bat's ability to fly coincides with the development of an adult body and forelimb length. For the little brown bat, this occurs about eighteen days after birth. Weaning of young for most species takes place in under eighty days. The common vampire bat nurses its offspring beyond that and young vampire bats achieve independence later in life than other species. This is probably due to the species' blood-based diet, which is difficult to obtain on a nightly basis.[209]

Life expectancy

The maximum lifespan of bats is three-and-a-half times longer than other mammals of similar size. Five species have been recorded to live over 30 years in the wild: the brown long-eared bat (*Plecotus auritus*), the little brown bat *(Myotis lucifugus)*, Brandt's bat (*Myotis brandti*), the lesser mouse-eared bat (*Myotis blythii*) and the greater horseshoe bat (*Rhinolophus ferrumequinum*). One hypothesis consistent with the rate-of-living theory links this to the fact that they slow down their metabolic rate while hibernating; bats that hibernate, on average, have a longer lifespan than bats that do not.[210][211] Another hypothesis is that flying has reduced their mortality rate, which would also be true for birds and gliding mammals. Bat species that give birth to multiple pups generally have a shorter lifespan than species that give birth to only a single pup. Cave-roosting species may have a longer lifespan than non-roosting species because of the decreased predation in caves. A male Brandt's bat was recaptured in the wild after 41 years, making it the oldest known bat.[211][212]

Interactions with humans

Conservation

Groups such as the Bat Conservation International[213] aim to increase awareness of bats' ecological roles and the environmental threats they face. In the United Kingdom, all bats are protected under the Wildlife and Countryside Acts, and disturbing a bat or its roost can be punished with a heavy fine.[214] In Sarawak, Malaysia, "all bats"[215] are protected under the Wildlife Protection Ordinance 1998,[215] but species such as the hairless bat (*Cheiromeles torquatus)* are still eaten by the local communities.[216] Humans have caused the extinction of several species of bat in modern history, the most recent being the Christmas Island pipistrelle (*Pipistrellus murrayi*), which was declared extinct in 2009.[217]

Bat roost in San Antonio, Texas, 1915

Many people put up bat houses to attract bats.[218] The 1991 University of Florida bat house is the largest occupied artificial roost in the world, with around 400,000 residents.[219] In Britain, thickwalled and partly underground World War II pillboxes have been converted to make roosts for bats,[220][221] and purpose-built bat houses are occasionally built to mitigate damage to habitat from road or other developments.[222][223] Cave gates are sometimes installed to limit human entry into caves with sensitive or endangered bat species. The gates are designed not to limit the airflow, and thus to maintain the cave's micro-ecosystem.[224]

Bats are eaten in countries across Asia and the Pacific Rim. In some cases, such as in Guam, flying foxes have become endangered through being hunted for food.[225] There is evidence that wind turbines create sufficient barotrauma (pressure damage) to kill bats.[226] Bats have typical mammalian lungs, which are thought to be more sensitive to sudden air pressure changes than the lungs of birds, making them more liable to fatal rupture.[227][228][229][230][231] Bats may be attracted to turbines, perhaps seeking roosts, increasing the death rate.[227] Acoustic deterrents may help to reduce bat mortality at wind farms.[232]

Cultural significance

In many cultures, including in Europe, bats are associated with darkness, death, witchcraft, and malevolence.[233] Because bats are mammals, yet can fly, they are liminal beings in many traditions.[234] Among Native Americans such as the Creek, Cherokee and Apache, the bat is a trickster spirit. In Tanzania, a winged batlike creature known as Popobawa is believed to be a shapeshifting evil spirit that assaults and sodomises its victims.[235] In Aztec mythology, bats symbolised the land of the dead, destruction, and decay.[236][237][238] An East Nigerian tale tells that the bat developed its nocturnal habits after causing the death of his partner, the bush-rat, and now hides by day to avoid arrest.[239]

Francisco Goya, *The Sleep of Reason Produces Monsters*, 1797

More positive depictions of bats exist in some cultures. In China, bats have been associated with happiness, joy and good fortune. Five bats are used to symbolise the "Five Blessings": longevity, wealth, health, love of virtue and peaceful death.[240] The bat is sacred in Tonga and is often considered the physical manifestation of a separable soul.[241] In the Zapotec civilisation of Mesoamerica, the bat god presided over corn and fertility.[242]


Zapotec bat god, Oaxaca, 350–500 AD

The Weird Sisters in Shakespeare's *Macbeth* used the fur of a bat in their brew.[243] In Western culture, the bat is often a symbol of the night and its foreboding nature. The bat is a primary animal associated with fictional characters of the night, both villainous vampires, such as Count Dracula and before him *Varney the Vampire*,[244] and heroes, such as Batman.[245] Kenneth Oppel's Silverwing novels narrate the adventures of a young bat,[246] based on the silver-haired bat of North America.[247]

The bat is sometimes used as a heraldic symbol in Spain and France, appearing in the coats of arms of the towns of Valencia, Palma de Mallorca, Fraga, Albacete, and Montchauvet.[248][249][250] Three US states have an official state bat. Texas and Oklahoma are represented by the Mexican free-tailed bat, while Virginia is represented by the Virginia big-eared bat (*Corynorhinus townsendii virginianus*).[251]

Economics

Insectivorous bats in particular are especially helpful to farmers, as they control populations of agricultural pests and reduce the need to use pesticides. It has been estimated that bats save the agricultural industry of the United States anywhere from $3.7 billion to $53 billion per year in pesticides and damage to crops. This also prevents the overuse of pesticides, which can pollute the surrounding environment, and may lead to resistance in future generations of insects.[252]

Bat dung, a type of guano, is rich in nitrates and is mined from caves for use as fertiliser.[253] During the US Civil War, saltpetre was collected from caves to make gunpowder; it used to be thought that this was bat guano, but most of the nitrate comes from nitrifying bacteria.[254]

The Congress Avenue Bridge in Austin, Texas is the summer home to North America's largest urban bat colony, an estimated 1,500,000 Mexican free-tailed bats. About 100,000 tourists a year visit the bridge at twilight to watch the bats leave the roost.[255]

See also

- Bat detector

Notes

a. Pronounced /kaɪˈrɒptərə/; from the Ancient Greek: χείρ – *cheir*, "hand" and πτερόν – *pteron*, "wing".[1]

b. Earlier reports that only fruit bats were deficient were based on smaller samples.[130]

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External links

- Data related to Chiroptera at Wikispecies
- UK Bat Conservation Trust (http://www.bats.org.uk/pages/about_bats.html)

- Tree of Life (http://tolweb.org/tree?group=Chiroptera&contgroup=Eutheria)
- Microbat Vision (http://www.fladdermus.net/thesis.htm)
- The DSP Behind Bat Echolocation (http://www.hscott.net/the-dsp-behind-bat-echolocation/) – Analysis of several kinds of bat echolocation

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David Lassman I dlassman@newyorkupstate.com

Eeek! Meet New York's 6 cave bats and 3 tree bats

Repulsive to many and feared by others, bats are amazing beneficial animals that have an undeserved reputation, according state wildlife experts. They are the only flying mammal, consuming 20-50 percent of their weight in insects each night. New York has nine bats -- six are cave dwellers; three live in trees. We'll start with six cave dwellers. White-nose syndrome is a devasting, fungal diseaseresponsible for mass mortalities in hibernating North American cave bats.

Don Pfritzer

Little Brown Bat

The most common bat in the state, little browns are the ones people see most often. The fur is uniformly dark brown and glossy on the back and upper parts with slightly paler, greyish fur underneath. They frequently occupy buildings during the summer, but also live in crevices and under loose bark in trees. The bat has 38 teeth, all of which, including molars, are relatively sharp and prominent to enable grasping hard-bodied insects in flight.

National Park Service

Big Brown Bat

The largest of the state's cave bats, big brown bats weigh two to three times more than other cave bats with a wingspan of nearly 13 inches. They are identified by their large size, dark ears and face and glossy light to dark brown fur. It is one of the state's most common summer bats. Most tolerant of cold temperatures and low humidity they winter near the entrance to caves and mines, and are the only to winter in buildings.

Andrew King, U.S. Fish and Wildlife Service

Indiana Bat

Indianas are an endangered species. These small bats are vulnerable because they live in high concentrations in few places,making them highly susceptible to white-nose syndrome. Roosting in clusters of 300 to 400 per square foot, half of the Indianas in the northeast winter in just one N.Y. mine. Indiana bats lose 10 to 30 days worth of their limited fat reserves during every spontaneous arousal from their hibernating sleep caused by human disturbance. Multiple disturbances during a cold winter can cause mortality.

Cal Butchkowski / Pennsylvania Game Commission

Small-Footed Bat

The state's smallest bat, the small-footed bat weighs less than a nickel. It can be identified by its small size, jet-black "raccoon" face and mask and wings, long glossy fur and tiny feet, according to the DEC. During the summer, they roost and raise their young in accumulations of rocks, cliff faces, road cuts and concrete bridges. Many reside in just two mines in the Adirondack region. They feed primarily on flying insects such as beetles, mosquitoes, moths and flies and are capable of filling their stomachs within an hour of eating.

Larisa Bishop-Boros

Eastern Pipistelle

A healthy, hiberating Eastern Pipistrella. This tiny bat, also called the tricolored bat, is distinguished from other cave bats by its reddish forearms and fur that is black at the base, yellowish-orange in the middle and brown at the tips. They eat small insects. When the pipistrelles capture food they use the tail or wing membranes to restrain their prey. Some insects are even captured by their tail membrane. It forms a pouch and the bat bends its head in to grab the insect with its teeth.

Mnolf photo

Northern Long-Eared Bat

The northern long-eared bat is protected as a threatened species under both federal and New York State Endangered Species law. The current population for this formerly common bat is approximately one percent of its previous size, making it the species most severely impacted by white=-nose syndrome.

U.S. Geological Survey

Red Bat

The red bat is one of the state's three tree bats. As the names suggests, tree bats live year-round in trees. They are more colorful than the generally brownish cave bats. Tree bats have full furred tail membranes which they can curl up around their bodies like a blanket, The female red bats are noticeably grayer and larger than the reddish-orange males. Moths form the majority of this bat's diet, but they also dine on beetles, flies and other insects.

Larisa Bishop-Boros

Hoary Bat

The largest of the state's bats, hoary bats live in trees and have wingspans that measure up to 16 inches. More of a northern species, they are most common in the Adirondacks. They roost on branches, hiding among leaves. It prefers woodland, mainly coniferous forests, but hunts over open areas or lakes. It hunts alone and its main food source is moths. In this photo, the bat is being examined by a scientist. The inner forearm was marked with black marker to provide re-capture data.

Larisa Bishop-Boros

Silver-Haired Bat

The, silver-haired bat is the last of three tree bats. As its name implies, is has silvery tipped hairs on its nearly black body. It prefers more northern habitats, roosting under loose bark or in tree cavities. This species will forage low, over both still and running water, and also in forest openings. These medium-sized bats are slow, but maneuverable flyers that typically detect prey (soft-bodied insects such as moths, spiders and harvestmen), a short distance away.