Proceedings of the International Symposium on the Importance of Bats as Bioindicators

Programme, Abstracts and List of participants

Proceedings of the International Symposium on the Importance of Bats as Bioindicators

2012

Carles Flaquer, Xavier Puig-Montserrat (eds.)

There is growing alarm and a great degree of uncertainty among scientists and governments over the possible catastrophic effects of climate change, combined with the destruction and degradation of natural habitats and the high present rates of biodiversity loss. Given the complexity of ecosystems and their biological communities, it is not easy to directly assess the health of natural environments and how it changes over time. Scientists therefore use particular taxa that show measurable responses to these changes as indicators of the state and quality of the environment. These "bioindicators" should ideally reflect the responses of a wide range of taxa and thus inform about the functionality of the whole ecosystem.

While insects, birds and aquatic macroinvertebrates are common bioindicator groups, comparatively much less work has been done on the use of bats as bioindicators. However, several studies suggest that bats' great taxonomic, ecological and trophic diversity, high sensitivity to temperature changes and to habitat deterioration, geographic ubiquity and good population numbers could indeed make them excellent indicators of environmental change.

For bats to be useful bioindicators, bat monitoring programs should be cost-efficient, reliable and sufficiently standardized to allow large-scale studies and comparison of results over time and between geographical areas. Fortunately, new technologies such as acoustic monitoring and advances in data storage and sharing are developing rapidly in the context of bat monitoring.

We believe it is therefore an ideal time to compile and integrate current developments on bats as bioindicators of environmental change, to contrast experiences on bat monitoring worldwide and to open up new ideas for developing more successful bat monitoring schemes. With this goal in mind, this symposium brings together international experts in climate change, bioindication and biomonitoring. While the main focus of the Symposium is on bats, discussions benefit from experiences made by monitoring programs of other taxa, such as insects and birds. More than serving as a simple exchange of ideas, the Symposium has encouraged contributors to participate in the production of a joint publication to summarize the state of the art regarding bats and bioindication and discuss the pros, cons and future perspectives of current and projected bat monitoring programs.

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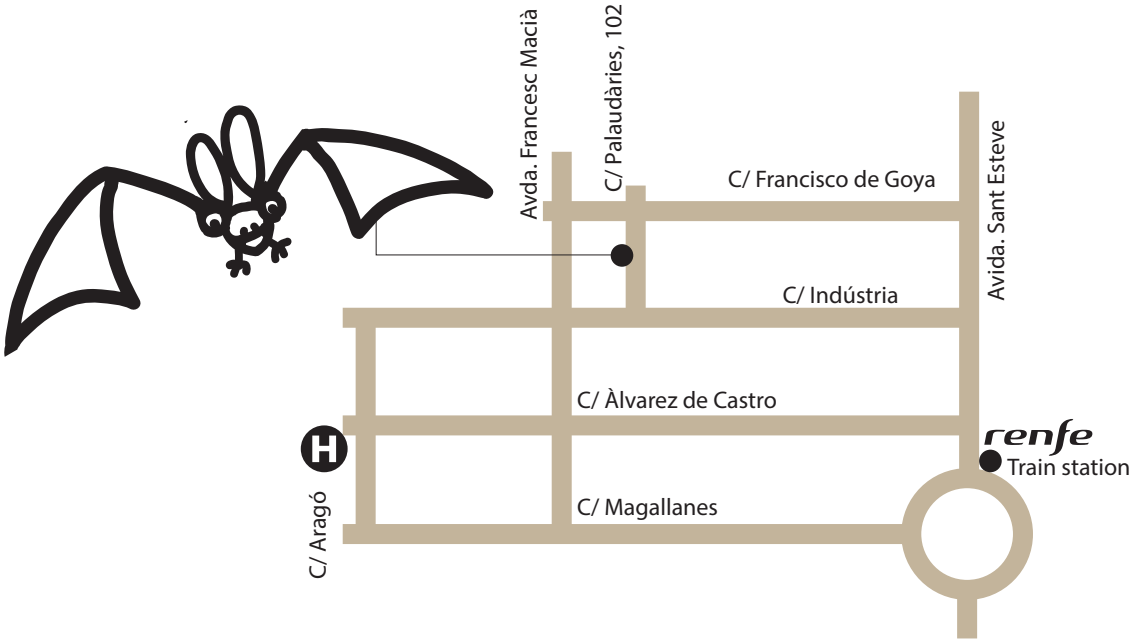


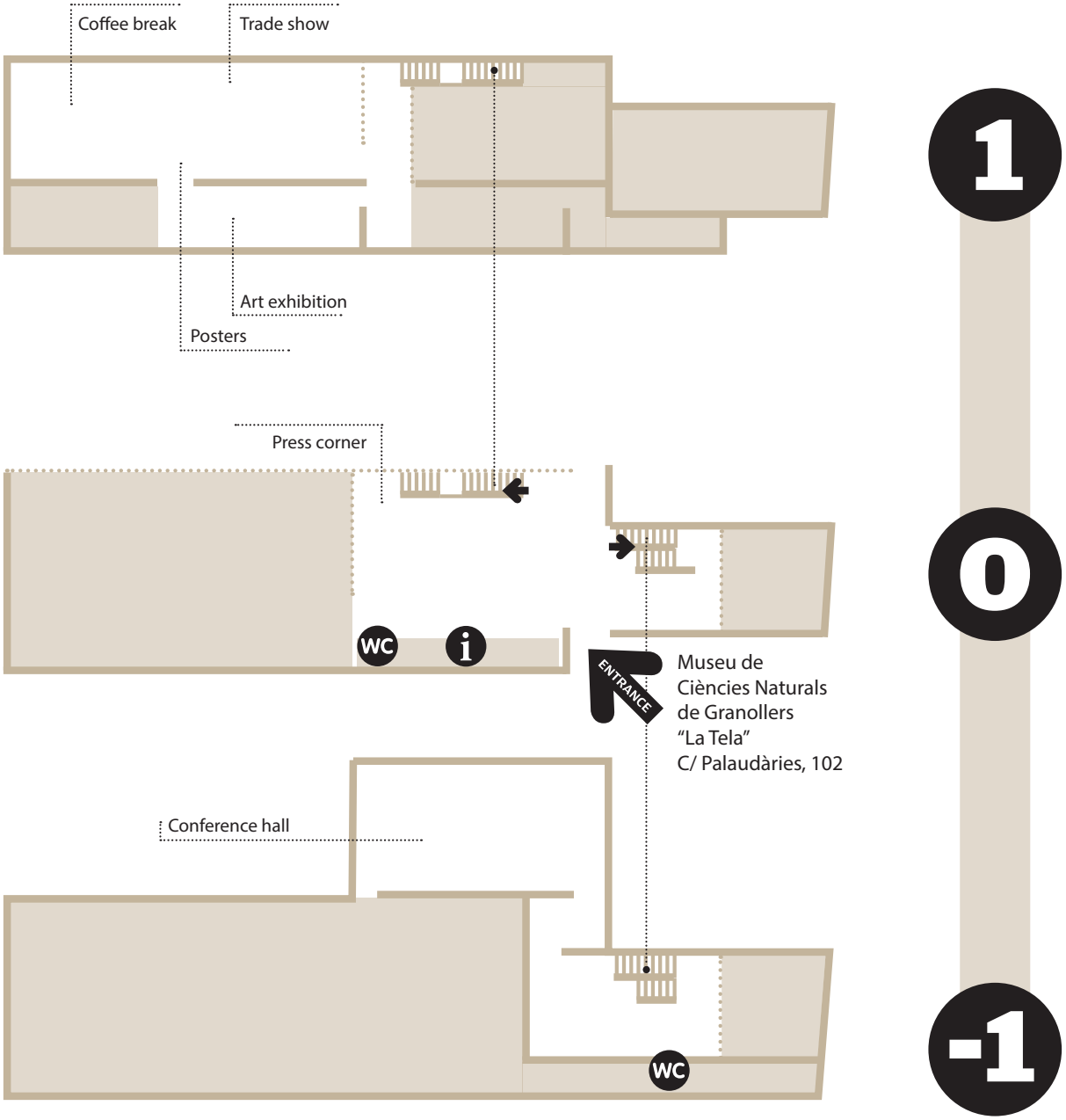
Information

Aparthotel Atenea Vallès
C/ Magallanes/Aragó s/n
08400 Granollers
Telephone (34) 938 794 820

Museu de Granollers de Ciències Naturals "La Tela"
Avinguda Francesc Macià, 51
08402 Granollers

Xavi Puig (+34 649 798 748) and
Carles Flaquer (+34 609 726 981)

Venue map


Coffee break
Trade show
Art exhibition
Posters
Press corner
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de Granollers
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Programme

Wednesday 5th December 2012

16:00 Opening of registration desk

16:15 Poster set up

18:00 Inaugural talk by
Mr. Andreu Carreras Puigdelliura (*Envirnomental Representative for Barcelona's Province Council*),
Mrs. Marta Subirà (*Catalan Government Director of Environmental Policies*),
Mr. Josep Mayoral *(Mayor of Granollers)* and
Mrs. Alba Barnusell (*Councilor of Culture for Granollers' council*).

18:30 Plenary: Bioindicators and climate change in a global perspective
Dr. Michael Willig. *Director of the Center for Environmental Sciences and Engineering. University of Connecticut (USA)*

19:30 Catalan wine and cheese tasting

Thursday 6th December 2012

Session 1: Monitoring programs and characteristics of global bioindicators
Chairman Dr. Michael Willig. *Director of the Center for Environmental Sciences and Engineering. University of Connecticut (USA)*

9:00 Tropical bats: suitable candidates for long-term monitoring?
Dr. Christoph F. J. Meyer. *Centro de Biologia Ambiental, Universidade de Lisboa (Portugal)*

9:45 The use of radars to monitor migration strategies of moths
Dr. Jason Chapman. *Rothamsted Research Station (UK)*

10:30 Coffee break and posters session

11:30 Assessing the effects of climatic change on the phenology of butterflies
Dr. Constantí Stefanescu. *Museum of Natural Science of Granollers (Catalonia, Spain)*

12:00 Bird monitoring at a continental scale: climatic debts
Dr. Sergi Herrando. *Catalan Institute of Ornithology (Catalonia, Spain)*

12:30 Roundtable 1: Requirements for global bioindicators and monitoring networks
Speakers of this session and chairman

13:30 Symposium lunch - Atenea Hotel (included)

Session 2: Bat Monitoring

Chairman Dr. Javier Juste. *Spanish Scientific Council (CSIC). Doñana Biological Station (Spain), SECEMU (Spain) & IUCN Bat Specialist Group.*

15:45 Monitoring bats in caves: the impact of white-nouse syndrom on hibernating bats
Dr. Winifred F. Frick. *Research Scientist, University of California, Santa Cruz (USA)*

16:30 Bat monitoring programes in the UK: achievements and perspectives
Dr. Karen Haysom. *Director of Conservation. Bat Conservation Trust (UK)*

17:15 Calculating a European bat indicator: following birds and butterflies
Dr. Tom van der Meij. *CBS Natuurstatistieken (Netherlands)*

17:30 Coffee break and posters session

17:45 How to analyse your bat data with Trim and Birdstats
(and contribute to a European bat indicator). Training course.
Dr. Tom van der Meij. *CBS Natuurstatistieken (Netherlands)*

18:45 Roundtable 2: Large scale bat monitoring programmes and policies
Speakers of this session and chairman

20:00 End of the day

20:30 Symposium dinner (optional)

Friday 7th December 2012

Session 3: Effects of environmental degradation on bats

Chairman Dr. Christoph F. J. Meyer. *Centro de Biologia Ambiental, Universidade de Lisboa (Portugal)*

9:00 Using spatial modelling to study the impact of
climate change on the distributions of bats
Dr. Hugo Rebelo. *Bat Ecology and Bioacoustics. University of Bristol (UK)*

9:45 Forest degradation and bats
Dr. Danilo Russo. *Facoltà di Agraria, Università degli Studi di Napoli Federico II (Italy)*

10:30 Coffee break and posters session

11:00 The impacts of extreme events on biodiversity – lessons from die-offs in flying-foxes
Dr. Justin A. Welbergen. *Centre for Tropical Biodiversity and Climate Change, James Cook University (Australia) & Department of Zoology, University of Cambridge (UK)*

11:30 Bats and toxic pollutants
Dr. Jan Zukal. *Institute of Vertebrate Biology, Academy of Sciences of the Czech Republic (Czech Republic)*

12:00 Bats as bioindicators: from genes to ecology
Dr. Gareth Jones. *Bat Ecology and Bioacoustics Lab. University of Bristol (UK)*

12:30 Conference closure roundtable: Basis to create a global bat monitoring program
All chairmen and speakers

14:00 Farewell lunch - Atenea Hotel (optional)

Organization Committee

Carles Flaquer
Museum of Sciencies of Granollers (Catalonia, Spain) &
SECEMU (Spanish Society for the Conservation and Study of Bats)

Xavier Puig
Galanthus Association (Catalonia, Spain) &
SECEMU (Spanish Society for the Conservation and Study of Bats)

Adrià López-Baucells
Museum of Sciencies of Granollers (Catalonia, Spain)

Lídia Freixas
Museum of Sciencies of Granollers (Catalonia, Spain)

Montserrat Subirana
Symposium Secretariat (Catalonia, Spain)

Ana Popa Lisseanu
National Research Council of Spain (CSIC). Doñana Biological Station (Spain)

Antoni Arrizabalaga
Museum of Sciencies of Granollers (Catalonia, Spain)

Scientific committee

Carlos Ibáñez
Spanish Scientific Council (CSIC). Doñana Biological Station (Spain)

Christoph F. J. Meyer
Centro de Biologia Ambiental, Universidade de Lisboa (Portugal)

Danilo Ruso
Facoltà di Agraria, Università degli Studi di Napoli Federico II (Italy)

Gareth Jones
Bat Ecology and Bioacustics Lab. Bristol University (UK)

Hugo Rebelo
Bat Ecology and Bioacustics Lab. University of Bristol (UK)

Javier Juste
Spanish Scientific Council (CSIC). Doñana Biological Station (Spain) &
IUCN Bat Specialist Group

Josep Peñuelas
National Research Council of Spain (CSIC). Director of the CREAF-CEAB-CSIC
Global Ecology Unit located at CREAF (Center for Ecological Research and Forestry Applications)-
Universitat Autònoma de Barcelona (Catalonia, Spain)

Joxera Aihartza
University of the Basque Country. Euskal Herriko Unibertsitatea (Basque Country)

Justin A Welbergen
Centre for Tropical Biodiversity and Climate Change, James Cook University (Australia)
& Department of Zoology, University of Cambridge (UK)

Karen Haysom
Bat Consevation Trust (UK)

Luis F. Aguirre
Centro de Biodiversidad y Genética. Facultad de Ciencias y Tecnología.
Universidad Mayor de San Simon (Bolivia)

Marie-Jo Duborg-Sauvage
Société Française pour l'Etude et la Protection des Mammifères (France)

Martí Boada
Department of Geography and at the Institute of Environmental Science and
Technology (ICTA) of the Autonomous University of Barcelona (Catalonia, Spain)

Michael Willig
Center for Environmental Sciences & Engineering & Professor in the Department of
Ecology & Evolutionary Biology. University of Connecticut (USA)

Winifred F. Frick
Research Scientist, University of California, Santa Cruz (USA)

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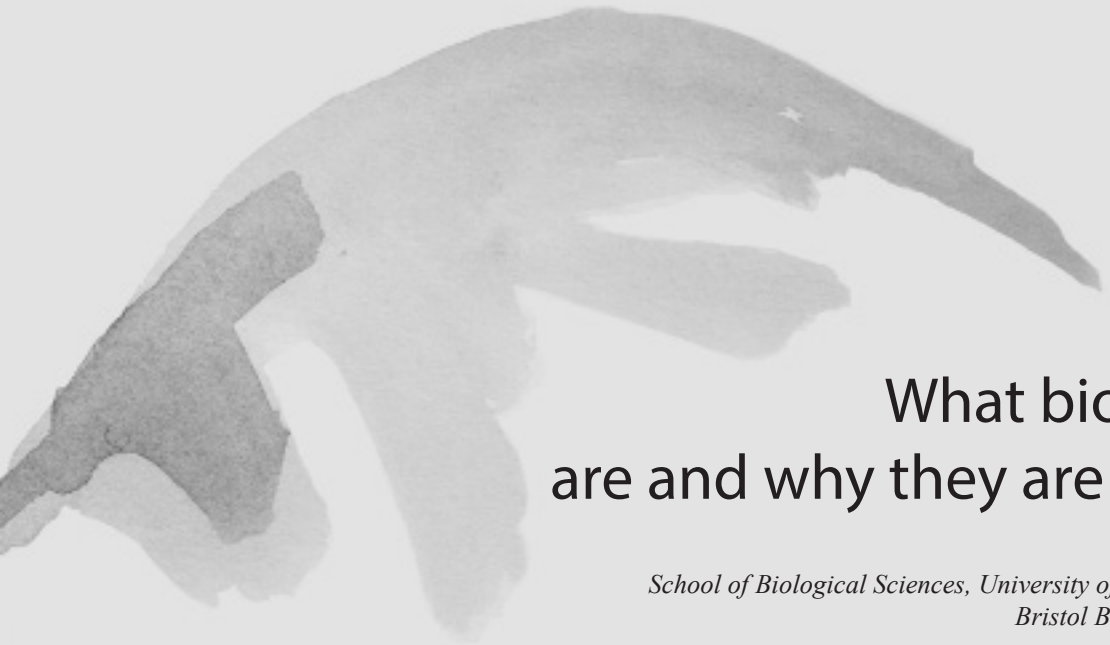
Granollers, Catalonia 2012

autor: salvadorvinyes



Introduction

What bioindicators are and why they are important

Gareth Jones
School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, United Kingdom

A Bat Monitoring Network for Global Change in the Anthropocene: Now or Never

Michael R. Willig
Center for Environmental Sciences & Engineering and Department of Ecology & Evolutionary Biology University of Connecticut Storrs, CT 06269, USA

What bioindicators are and why they are important

Gareth Jones
School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, United Kingdom

Are environmental conditions on Earth improving or getting worse? How can we use changes in the physiological or behavioural state, distribution, abundance, and population genetics of organisms to better inform us about the causes of environmental change? Answers to these questions are of fundamental importance to conservation biologists. Moreover, biodiversity is important not just in its own right, but also because our economies and health depend on it. Biological indicators of environmental change are therefore helpful for measuring the 'quality of life' in a broader context. Below I outline how changes in the biological characteristics of animals and plants known as 'bioindicators' can inform us about the nature and severity of environmental change. I'll conclude by summarising why bats show characteristics that make them potentially valuable bioindicators.

What is a bioindicator? Bioindicators can broadly be defined as 'biota that are developed as indicators of the quality of the environment, the biotic component, or humans within an ecosystem' (Burger 2006). A widely-used illustration of a bioindicator is the canary, used to detect carbon monoxide and methane in mines because of the birds' high sensitivity to these dangerous gases. In this example the canaries gave early warnings of conditions that may eventually become lethal for humans. This is not the only role for a bioindicator – in general bioindicators are used to assess changes in environmental quality over time.

Although recent technological advances allow more refined and precise measurement of potential ecological stressors, measuring changes in the stressor levels themselves tells us nothing about their impacts. For example, extensive and co-ordinated measurements of temperature allow a better understanding of the trajectory and speed of climate warming, and satellite imaging allow us to measure habitat loss and fragmentation, but what are the consequences of these changes for biodiversity and ecosystem services? Combining data on environmental change gathered by more and more sophisticated technology with monitoring the responses of animals sensitive to these changes provides exciting and vital scientific challenges at present.

Animals and plants are adapted to a limited suite of biological and physical conditions, and exposure to environmental change may expose them to conditions outside of their comfort zone. If these conditions are detrimental for fitness they will impact negatively on a range of biological processes from physiology through to the organism's distribution and population size, which will in turn affect the genetic structure of populations. Consequently environmental deterioration is expected to result in physiological stress, reduced population sizes, shifts in distribution to more suitable areas and probably a loss of genetic diversity. Under severe environmental stress, extinction may occur. Hence the attributes measured in bioindicator taxa to understand environmental change can be proximate or population-level measures.

Bioindicators are therefore important for evaluating environmental quality. They can be thought of as having three major functions – monitoring environmental change such as physical or chemical alterations, monitoring ecological processes, and monitoring biodiversity more generally (Holt & Miller 2011). The Earth is currently subjected to intense pressures largely associated with a rapidly expanding population. Key aspects of global change include climate change and habitat degradation. Linking the stressor of interest to changes in the abundance of bioindicators is important: often if a taxon is affected by a large number of stressors simultaneously, identifying the cause(s) of population change can be problematic. Monitoring programmes therefore need to focus on impacts that can be linked to graded levels of the stressor of interest, with other stressors kept as constant as possible.

What makes a good bioindicator species? To some extent this depends on the stressor of interest, but some general characteristics are important. The ease with which individuals can be sampled and populations can be monitored, widespread distributions that show a range of exposures to the stressor, taxonomic stability,

and fulfilment of key ecosystem services are desirable features. Taxa at high trophic levels can sometimes reflect changes in the abundance of taxa they feed on, and may be affected by accumulations of pollutants that have less marked effects on prey. The effects of stressors can be identified with more confidence when a range of organisms with different evolutionary histories respond to a stressor in similar ways. Indeed, a suite of bioindicator species can also be used to inform policy. The UK government uses monitoring of bioindicator species (including 6 bat species monitored under the Bat Conservation Trust's National Bat Monitoring Programme) to quantify progress towards governmental targets of halting biodiversity loss to meet targets under the Convention on Biological Diversity.

Of course, studying all of the potential range of stresses in a wide range of organisms is not feasible. Bioindicators that reflect broad assemblage, community or ecosystem responses can be especially informative of likely widespread impacts. Hence 'biodiversity indicator species' are sometimes used as an index of the presence, population density, or relative abundance of species other than the biota of interest, assuming that all taxa of interest share specific attributes that are affected by the environmental stressor of interest in similar ways. By this logic, the effects of stressors on biodiversity can sometimes be evaluated more generally by using particular taxa that act as shortcuts for biodiversity evaluation (Moreno et al. 2007).

The diversity of feeding habits in bats, together with their almost global distribution, and their roles in important ecosystem services such as pollination, seed dispersal and their potential for controlling insect pests makes them excellent candidates as bioindicators (Jones et al. 2009). Moreover it is becoming increasingly feasible to identify and survey echolocating species remotely, a useful feature in monitoring programmes. Bats are reservoirs of a range of zoonoses that can spillover to humans especially when habitats are degraded, making bats also useful bioindicators of disease risk for us. Because the physiology, ecology and life-histories of bats make them respond to major impacts of global change such as climate warming and habitat degradation they can be used to assess impacts from a broad range of environmental factors. Now that monitoring methods are producing statistically robust measures of changes in population size and are beginning to become standardised over wide geographic areas the monitoring of bats to evaluate environmental quality is becoming increasingly relevant and important. The future for bats as bioindicators looks promising.

References

- **Burger J** (2006) Bioindicators: types, development, and use in ecological assessment and research. Environmental Bioindicators 1: 22-39
- **Holt EA** and Miller SW (2011) Bioindicators: using organisms to measure environmental impacts. Nature Education Knowledge 3(10): 8
- **Jones G**, Jacobs DS, Kunz TH, Willig MR, Racey PA (2009) Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8: 93-115
- **Moreno CE**, Sánchez-Rojas G, Pineda E, Escobar F (2007) Shortcuts for biodiversity evaluation: a review of terminology and recommendations for the use of target groups. International Journal of Environmental Health 1: 71-86

A Bat Monitoring Network for Global Change in the Anthropocene: Now or Never

Michael R. Willig
Center for Environmental Sciences & Engineering and Department of Ecology & Evolutionary Biology University of Connecticut Storrs, CT 06269, USA

The Biodiversity Crisis

At local, regional, and global scales, biodiversity and the services that it provides to people are being threatened by anthropogenically induced factors such as climate change, land use change, invasive species, and the interactions among them. Moreover, the distribution of negative effects on biodiversity from such global change drivers will not be homogeneous throughout all regions of the planet, and many areas that currently harbor high biodiversity will likely suffer disproportionately higher rates of habitat loss and fragmentation, as well as continued degradation in the coming decades of this century.

Humans have a long history of modifying natural landscapes and converting them to uses (e.g., croplands, pastures, urban areas, industrial developments) that serve the welfare of society, at least in the short term. Nonetheless, the extent of land use modification has become so pervasive and severe that some have come to recognize the last few hundred years, especially those associated with the industrial revolution and the mechanization of agriculture, as the Anthropocene (Steffan et al. 2003; Zalasiewicz et al. 2010). Similarly, recognition of the emerging dominance of anthropogenically modified landscapes -- anthromes -- suggests the ubiquitous nature of human-dominated landscapes that have emerged over the last few centuries (Ellis and Ramankutty, 2008; Ellis et al. 2010). We now live in a world in which wildlands occupy less than a quarter of the area of terrestrial biomes (Figure 1) and are in rapid decline.

Throughout much of the world, human populations continue to increase, as does the per capita use of resources. By 2050, the size of the human population is projected increase by 2.3 billion individuals (UNDESSA 2007). For global food production to meet this demand, it must increase by 70% (FAO, 2010). Although some of this required increase in production will be attained by cultivating crops with higher yields, including use of genetically modified organisms, a substantial portion of the required increase will necessitate the conversion of natural areas to agricultural lands. For energy supplies to meet the demands of a burgeoning human population, energy production must increase by 100% (Sheffield, 1999), with a substantial quantity potentially associated with biofuel production, causing additional reduction in the extent of natural areas or diminishing the allocation of arable land to food production. In general, the effects of decreasing the amount of habitat and increasing the fragmentation of habitat are clear from theoretical and empirical perspectives (Pimm and Raven, 2000; Barbault and Sastrapradja, 1995): population sizes decrease and species go extinct.

Climate change and increasing climate variability will alter the geographic distribution of critical environmental factors (e.g., temperature, precipitation), as well as the frequency, intensity, and scale of disturbances (e.g., cyclonic storms, droughts), all of which affect the distribution and abundance of organisms (Parmesan et al., 2000), as well as the interactions among them (Gilman et al., 2010). By some estimates, climate change alone could contribute to the extinction of approximately 25% of the species in some groups of organisms, such as vertebrates and plants (Malcolm et al., 2006). In part, this may occur because new combinations of environmental characteristics may emerge more rapidly than will the ability of some species to adapt to them. Alternatively, no-analog communities (i.e., novel combinations of species compared to current communities) will develop in which biotic interactions may enhance extinction rates (Williams and Jackson, 2008). Moreover, species occupying high elevation habitats, especially those in the Tropics, which have heretofore been buffered from the effects of humans because of their inaccessibility and ruggedness, may be particularly vulnerable to extinctions as current high-elevation habitats will shrink in extent and the species that are high elevation specialists will suffer higher extinction rates than their low elevation counterparts (Colwell et al., 2008). Currently, such mountainous areas enjoy particularly high species richness and are inhabited, especially at higher elevations, by micro-spatial species (i.e., those with small geographic distributions), which are characterized

by high extinction probabilities (Andelman and Willig, 2003). Taken together, these factors strongly suggest that the world's biota will become increasingly subjected to threats — direct and indirect — associated with human activities. Consequently, the biodiversity crisis will likely become even more severe in the future, and may represent one of the most important long-term threats to human welfare, via effects on ecosystem services, that must be confronted by society in the 21st Century.

Biological Indicators and Bats

Effective biological indicators should reflect the responses of a range of taxa beyond the indicator taxon, and should do so at the level of populations and communities. Additionally, these indicators should herald alterations in ecosystem function and associated services derived by humans. Importantly, the members of the indicator taxon should be responsive to the kinds of environmental changes or stresses that are anticipated in the future, and should be able to capture successes in response to management, conservation, and policy initiatives. Finally, biological indicators should be relatively easy to monitor over space and time.

The taxonomy of the bats is well understood, and the group is species rich and cosmopolitan in distribution. The slow reproductive rate of bats (fecundity of no more than 1-3 young per year per female) enhances the likelihood that changes in abundance in response to stressors can be quite rapid, thereby acting as an early indicator for other taxa (i.e., enhanced mortality cannot be easily overcome because of limits established by fecundity). Moreover, bats are relatively easy to capture via mist netting, and advances in technologies associated with acoustic monitoring (Sherwin et al. 2000; Russo et al. 2003; Duchamp et al. 2006) and weather surveillance radars (Kelly et al., 2012) promise to revolutionize the capacity to accurately assess bat activity patterns (phenology) in a species-specific manner over relatively broad spatial extents using comparable approaches (e.g., Horn and Kunz, 2008; Kunz et al. 2008).

Bats occupy a variety of ecological niches, consuming a broad array of resources (e.g., fruits, nectar, invertebrates, terrestrial vertebrates, fish, and blood) and affecting the structure of food webs within terrestrial and aquatic communities. As a result, bats can directly or indirectly reflect the abundance and distribution of many other species (e.g., plants and insects), as well as the flow of energy or the cycling of nutrients within and among ecosystems. In addition, bats perform a suite of critical ecosystem functions (e.g., pollination, seed dispersal, insect population regulation) that are directly linked to services that enhance human welfare (e.g., commercial fruit production, insect pest control). Equally important, bats perform important roles in facilitating succession or enhancing recovery from natural and human-induced disturbances (contributing indirectly to carbon sequestration). Finally, bats respond to a variety of disturbances such as those associated with habitat conversion, habitat loss and fragmentation, hunting, urbanization, and pollution, and do so at multiple spatial scales (Jones et al., 2009).

Because of their sensitivity at multiple spatial scales to a broad range of disturbances and stressors, bats may constitute an effective biodiversity indicator whose monitoring is both accurate and cost-effective. Indeed, the responses of bats to global change drivers recommends them for consideration in the implementation of local, regional, or global networks of biological indicators (Jones et al., 2009).

CLIMATE CHANGE.--Bat mortality is associated with climatic extremes such as temperature maxima or minima and precipitation maxima or minima (e.g., Bourne and Hamilton-Smith, 2007; Welbergen et al. 2008; Jones et al., 2009). Because many bats in temperate environs hibernate, they are particularly sensitive to increasing temperatures associated with global warming (Humphries et al., 2002). Similarly, roosts of some bat species are susceptible to sea level rise (McWilliam, 1982), a particularly severe problem for island populations. Moreover, bat populations and communities are affected by disturbance regimes associated with cyclonic storms or droughts (Willig and McGinley, 1999) whose frequency, intensity, and scale are projected to be modified as a result of global change. Finally, bat mortality is affected by renewable energy technologies such as wind turbines (Johnson et al., 2003; Kunz et al. 2008; Voigt et al. 2012), which likely will become more abundant and widespread as humans attempt to curb carbon emissions associated with dependence on fossil fuels.

LAND USE CHANGE.--Bat populations, functional groups, and communities respond to the conversion of forests to other land uses (Fenton et al. 2009). For example, the abundances of 8 species of frugivorous bat differed among closed canopy forest, early successional forest,

and cultivated fields in Amazonian Peru (Willig et al. 2007). In addition, temporal activity patterns of 5 species of frugivore differed between agricultural fields and intact or successional forest, but no differences occurred between successional and closed canopy forest. Bats also respond to variation in landscape structure (number, sizes, and juxtaposition of forest patches) associated with human activities and do so in guild-specific and scale-dependent fashion (e.g., Schulze et al. 2000; Gorresen and Willig, 2004; Gorresen et al., 2005; Klingbeil and Willig, 2009; Klingbeil and Willig, 2010). There is similarly strong evidence that bats respond to urbanization (e.g., Kunz and Reynolds, 2003), agricultural intensification (e.g., Stebbings, 1988; Wickramasinghe et al., 2003), and pollution (e.g., Jeffries, 1972; Clark et al. 1978; Racey and Swift, 1986).

Biodiversity Monitoring Network

In a broad review of the current understanding of bat biology, Jones et al. (2009) convincingly argued that it is time to "capture the night" (carpe noctem) and utilize the full potential of bats as global sentinels for change. I reiterate that suggestion and provide a number of criteria for consideration in initiating, implementing, and maintaining a global network for bats as biological indicators.

Network design should be sufficiently flexible so as to capture global and continental responses to drivers of change, as well as to capture regional and local responses to drivers of change (i.e., drivers of change at the local scale can be quite different from drivers of change at regional or global scales). The balance of interest between these scales should be determined by the overarching question or questions that motivate the network.

The global network can be distributed and federated in nature (i.e., a network of networks). This will likely arise because of funding realities associated with the political nature of national priorities for science. Nonetheless, a set of minimum characteristics associated with the overarching goal of capturing change at a global scale should be considered for inclusion.

To ensure a high likelihood of being able to answer specific questions about biodiversity and global change scenarios, careful consideration of sampling design and its efficacy in light of estimates of variability should precede selection of sampling sites or implementation of sampling protocols (Andelman and Willig 2004).

Multidisciplinary participation in network design by scientists with expertise in conservation, ecology, population biology, biogeography, systematics, land use change, climate change, and statistics or modeling would enhance the likelihood of success and the long-term value of the network.

Recent success in creating an "open-source network" should be considered in the absence of substantial international, national or private funding (see Adler et al. [2011] and Stokstad [2011] for a possible mechanism).

Partnerships with and expansion of citizen science programs that focus on bats (e.g., iBat) as well as other taxa can provide valuable data for informing conservation action and biodiversity science (Walters et al. 2012). The full potential of these activities may be enhanced considerably by embracing modern communication (e.g., mobile phones and global positioning devices) and cyberinfrastructure advances (e.g., cycle scavenging, crowd sourcing, cognitive surplus, and human computation). The education and outreach potential of these activities are considerable, and provide a mechanism for affecting the issues that the public considers when balancing natural resource issues with other concerns.

A combination of approaches for sampling bats should be developed, including conventional approaches (use of mist nets or harp nets), acoustic monitoring, and radar surveillance.

Information management is critical to the long-term success of any network, especially if integration and synthesis is a requirement. Care should be taken to provide adequate metadata for collected data, especially as it relates to effort (spatial and temporal domains) and systematics.

Monitoring should be conducted in collaboration with the IUCN Bat Specialist Group. This would guarantee that current scientifically validated conservation status is included in monitoring activities and that collected data about bats as biological indicators can be used to clarify the conservation status of species listed as "Data Deficient", thereby improving the "Red List" process (see Lacher et al., 2012) .

Generally, results from network activities should be freely available to the scientific and professional community.

In conclusion, framing a vision for the network will require a careful consideration of data quantity and quality, tradeoffs associated with the scales at which questions will be answered, models for quantifying biotic change and enhancing predictive understanding, and the quantitative tools that will be used to inform

conservation action and policy. Given the magnitude of the biodiversity crises, and the nature of threats that promise to exacerbate it in the near future, the time is literally now or never for mobilizing the scientific community to adopt a multi-scale global network based on bats as biological indicators.

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References

- **Adler**, P.B., et al. 2011. Productivity is a poor predictor of plant species richness. Science 333:1750-1753.
- **Andelman**, S.J., and M.R. Willig. 2003. Present patterns and future prospects for biodiversity in the Western Hemisphere. *Ecology Letters* 6:818-824.
- **Andelman**, S.J., and M.R. Willig. 2004. Networks by design: A revolution in ecology. Science 305:1565-1566.
- **Barbault**, R., and S.D. Sastrapradja. 1995. Generation, maintenance and loss of biodiversity. Pp. 193-274, in W.H. Heywood (Ed.), Global Biodiversity Assessment, Cambridge University Press, Cambridge.
- **Bourne**, S., and E. Hamilton-Smith. 2007. Miniopterus schreibersii bassanii and climate change. Australasian Bat Society Newsletter 28:67-69.
- **Colwell**, R.K., G. Brehm, C.L. Cardelus, A.C. Gilman, and J.T. Longino. 2008. Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. Science 322:258-261.
- **Daszak**, P., A.A. Cunningham, and A.D. Hyatt. 2000. Emerging infectious diseases of wildlife--threats to biodiversity and human health. Science 287:443-449.
- **Duchamp**, J.E., M. Yates, R.-M. Muzika, and R.K. Swihart. 2006. Estimating probabilities of detection for bat echolocation calls: an application of the double-observer method. Wildlife Society Bulletin 34:408-412.
- **Ellis**, E.C., and N. Ramankutty. 2008. Putting people in the map: anthropogenic biomes of the world. Frontiers in Ecology and the Environment 6:439-447.
- **Ellis**, E.C., K.K. Goldewijk, S. Siebert, D. Lightman, and N. Ramankutty. 2010. Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography 19:589-606.
- **FAO**. 2010. How to feed the world in 2050. Food and Agriculture Organization of the United Nations, Rome, Italy.
- **Fenton,** M.B., M. Davison, T.H. Kunz, G.F. McCracken, P.A. Racey, M.D. Tuttle, and A.P. Dodson. 2006. Linking bats to emerging diseases. Science 311:1098-1099.
- **Gilman**, S.E., M.C. Urban, J. Tewksbury, G.W. Gilchrist, and R.D. Holt. 2010. A framework for community interactions under climate change. Trends in Ecology and Evolution 25:325-331.
- **Gorresen**, P.M., and M R. Willig. 2004. Landscape responses of bats to habitat fragmentation in Atlantic forest of Paraguay. Journal of Mammalogy 85:688-697.
- **Gorresen**, P.M., M.R. Willig, and R.E. Strauss. 2005. Multivariate analysis of scale-dependent associations between bats and landscape structure. Ecological Applications 15:2126-2136.
- **Horn**, J.W., and T.H. Kunz. 2008. Analyzing NEXRAD Doppler radar images to assess nightly dispersal patterns and population trends in Brazilian free-tailed bats (Tadarida brasiliensis). Integrative and Comparative Biology 48:24-39.
- **Humphries**, M.M., D.W. Thomas, and J.R. Speakman. 2002. Climate-mediated energetic constraints on the distribution of hibernating mammals. Nature 418:313-316.
- **Johnson**, G.D., W.P. Erickson, M.D. Strickland, M.F. Shepherd, D.A. Shepherd, and S.A. Sarappo. 2003. Mortality of bats a large-scale wind power development at Buffalo Ridge, Minnesota. The American Midland Naturalist 150:332-342.
- **Jones**, G., D.S. Jacobs, T.H. Kunz, M.R. Willig, and P.A. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8:93-115.
- **Kelly**, J., J. Shipley, P. Chilson, K. Howard, W. Frick, and T. Kunz. 2012. Quantifying animal phenology in the aerosphere at continental scale using NEXRAD weather radars. Ecosphere 3:6.
- **Klingbeil**, B.T., and M.R. Willig. 2009. Guild-specific responses of bats to landscape composition and configuration in fragmented Amazonian rainforest. Journal of Applied Ecology 46:203-213.
- **Klingbeil**, B.T., and M.R. Willig. 2010. Seasonal differences in population-, ensemble- and community-level responses of bats to landscape structure in Amazonia. Oikos 119:1654-1664.
- **Kunz**, T.H., and D.S. Reynolds. 2003. Bat colonies in building. Pp. 91-102, in T.J. O'shea and M.A. Bogan (eds.), Monitoring trends in bat

populations of the United States and territories: problems and prospects. U.S. Geological Survey, Biological Resources Division, Information and Technology Report02003-003. Washington, DC

- **Kunz**, T.H., E.B. Arnett, W.P. Erickson, A.R. Hoar, G.D. Johnson, R.P. Larkin, M.D. Strickland, R.W. Thresher, and M.D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315-324.
- **Kunz**, T.H., S.A. Gauthreaux, N.I. Hristov, J.W. Horn, G. Jones, E.K.V. Kalko, R.P. Larkin, G.F. McCracken, S.M. Swartz, R.B. Srygley, R. Dudley, J.K. Westbrook, and M. Wikelski. 2008. Aeroecology: probing and modeling the aerosphere. Integrative and Comparative Biology 48:1-11.
- **Lacher**, T.E., Jr., L. Boitani, and G.A.B. da Fonseca. 2012. The IUCN global assessments: partnerships, collaboration and data sharing for biodiversity science and policy. Conservation Letters 5:327-333.
- **Malcolm**, J., L. Canran, R.P. Neilson, L. Hansen, and L. Hannah. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology 20:538-548.
- **McWilliam**, A.N. 1982. Adaptive responses to seasonality in four species of Microchiroptera in coastal Kenya. Unpublished Ph.D. Dissertation, University of Aberdeen.
- **Parmesan**, C., T.L. Root, and M.R. Willig. 2000. Impacts of extreme weather and climate on terrestrial biota. Bulletin of the American Meteorological Society 81:443-450.
- **Pimm**, S.L., and P. Raven. 2000. Biodiversity: extinction by numbers. Nature 403:843–845.
- **Racey**, P.A., and S.M. Swift. 1986. Residual effects of remedial timber treatments on bats. Biological Conservation 35:205-214.
- **Russo**, D.R., and G. Jones. 2003. Use of foraging habitats by bats in a Mediterranean area determined by acoustic surveys: conservation implications. Ecography 26:197-209.
- **Schuze**, M.D., N.E. Seavy, and D.F. Whitacre. 2000. A comparison of the phyllostomid bat assemblages in undisturbed neotropical forest and in forest fragments of a slash-and-burn farming mosaic in Petan, Guatemala. Biotropica 32:174-184.
- **Sheffield**, J. 1999. World population and energy demand growth: the potential role of fusion energy in an efficient world. Philosophical Transactions of the Royal Society of London A 357:377-395.
- **Sherwin**, R.E., W.L. Gannon, and S. Haymond. 2000. The efficacy of acoustic techniques to infer differential use of habitat by bats. Acta Chiropterologica 2:145-153.
- **Stebbings**, R.E. 1988. Conservation of European Bats. Christopher Helm, London.
- **Steffen**, W., P.J. Crutzen, and J.R. McNeill. 2003. The Anthropocene: are humans now overwhelming the great forces of nature? AMBIO 36:614-621.
- **Stokstad**, E. 2011. Open-source ecology takes root across the world. Science 334:308-309
- **United Nations**, Department of Economic and Social Affairs, Population Division (UNDESSA). 2007. World population prospects: The 2006 revision. Working Paper No. ESA/P/WP.202.
- **Voigt**, C.C., A.G. Popa-Lisseanu, I. Niermann, and S. Kramer-Schadt. 2012. The catchment area of wind farms for European bats: a plea for international regulations. Biological Conservation 153:80-86.
- **Welbergen**, J.A., S.M. Klose, N. Markus, and P. Eby. 2008. Climate change and the effects of temperature extremes in Australian flying foxes. Proceedings of the Royal Society, Series B 275:419-425.
- **Wickramasinghe**, L.P., S. Harris, G. Jones, and N.V. Jennings. 2004. Bat activity and species richness on organic and conventional farms: impact of agricultural intensification. Journal or Applied Ecology 40:984-993.
- **Williams**, J.W., and S.T. Jackson. 2008. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment 5:475-482.
- **Walters**, C.L., R. Freeman, A. Collen, C. Dietz, M.B. Fenton, G. Jones, M.K. Obrist, S.J. Puechmaille, T. Sattler, B.M. Siemers, S. Parsons, and K.E. Jones. 2012. A continental scale tool for acoustic identification of European bats. Journal of Applied Ecology 49:1064-1074.
- **Willig**, M.R., and M.A. McGinley. 1999. The response of animals to disturbance and their roles in patch generation. Pp. 633-657 in L.R. Walker (Ed.), Ecosystems of Disturbed Ground. Elsevier Science, Amsterdam, The Netherlands.
- **Willig**, M.R., S.J. Presley, C.P. Bloch, C.L. Hice, S.P. Yanoviak, M.M. Diaz, L.A. Chauca, V. Pacheco, and S.C. Weaver. 2007. Phyllostomid bats of lowland Amazonia: Effects of habitat alteration on abundance. Biotropica 39:737-746.
- **Zalasiewicz**, J., M. Williams, W. Steffen, and P. Crutzen. 2010. The new world of the Anthropocene. Environmental Science and Technology 44:2228-2231.

Figure 1.--*Global maps of the anthropogenic biomes of the world for 1700, 1800, 1900, and 2000. The sequence illustrates 300 years of increasing intensity and pervasiveness of human modified landscapes (modified from Ellis et al., 2010). Numbers indicate general categories: Dense settlements--urban settlements (11) and mixed settlements (12); Villages--rice villages (21); irrigated villages (22); rain-fed villages (23); and pastoral villages (24); Croplands--residential irrigated croplands (31), residential rain-fed croplands (32), populated croplands (33), and remote croplands (34); Rangelands--residential rangelands (41), populated rangelands (42), and remote rangelands (43); Seminatural areas--residential woodlands (51), populated woodlands (52), remote woodlands (53), and inhabited treeless and barren lands (54); and Wildlands--wild woodlands (61), and wild treeless and barren lands (62).*

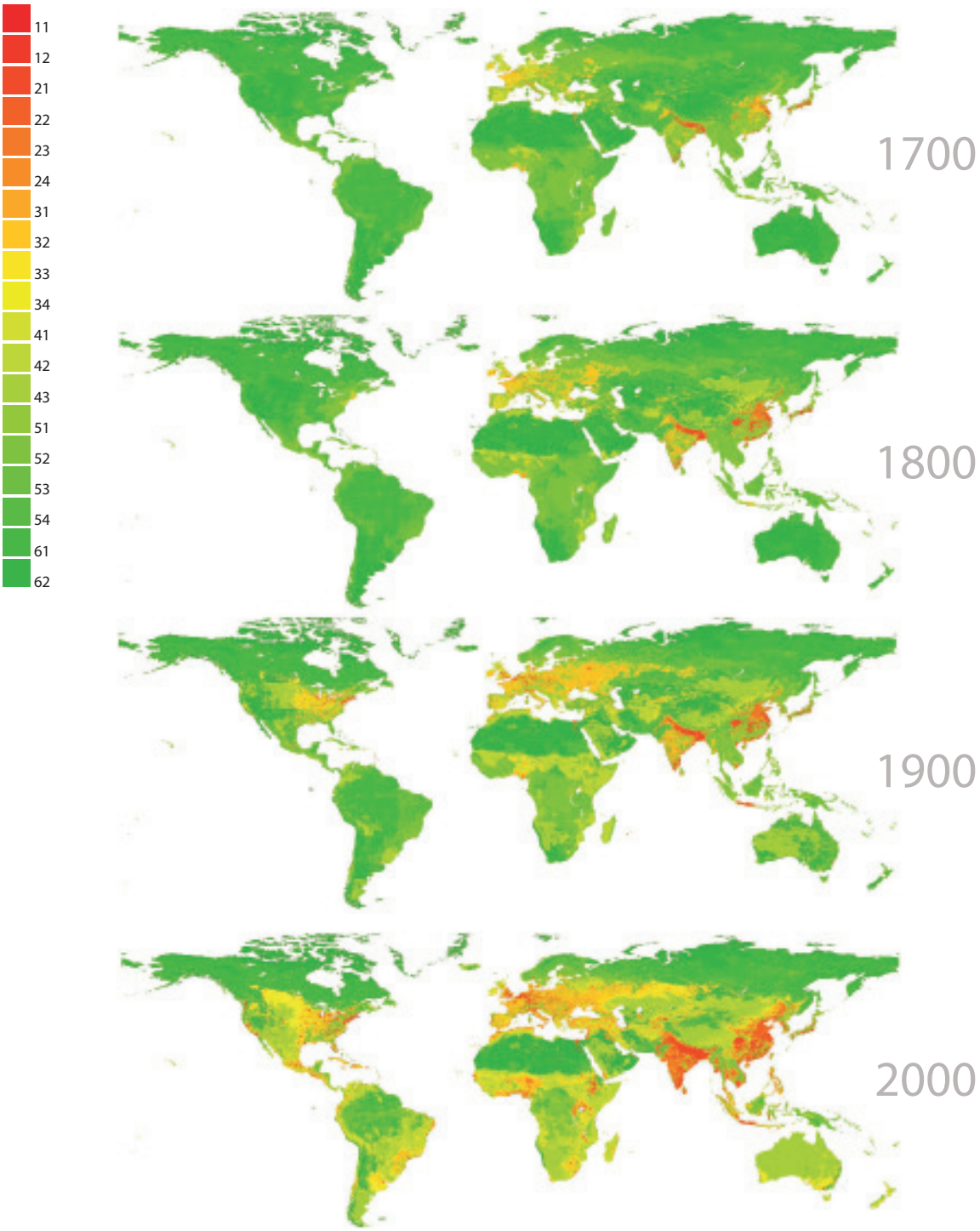


Photo: Justin Welbergen

Monitoring programs and characteristics
of global bioindicators

Tropical bats: suitable candidates for long-term monitoring?

Christoph F.J. Meyer
Centro de Biologia Ambiental, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

The use of radars to monitor migration strategies of moths

Jason W. Chapman
Department of AgroEcology, Rothamsted Research, Harpenden, Hertfordshire AL5 2JQ, United Kingdom

Responses of butterflies and birds to climate change in the Mediterranean region

Constantí Stefanescu
Museu de Ciències Naturals de Granollers, Francesc Macià 51, 08402 Granollers & CREAF, 08193 Cerdanyola del Vallès, Catalonia, Spain
Sergi Herrando
Institut Català d'Ornitologia, Girona 168, 08037 Barcelona, Catalonia, Spain

Tropical bats: suitable candidates for long-term monitoring?

Christoph F.J. Meyer
Centro de Biologia Ambiental, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal

Introduction

The latitudinal gradient in bat species richness parallels that of mammals in general; it is in tropical regions where bats attain their highest taxonomic and functional diversity. Bats are dominant components of animal assemblages in tropical forests as they are often the most species-rich and abundant mammals at the local level and exhibit a high degree of ecological diversity. Tropical bats provide crucial ecosystem services with respect to flower pollination and seed dispersal, and as control agents of arthropod prey populations [1]. In tropical forests, frugivorous bats may be the sole or principal dispersers of numerous plant species, and their activities facilitate secondary succession and forest regeneration by dispersing seeds of many pioneer plants [2,3]. Forest-dwelling animalivorous bats have been attributed great potential to serve as indicators of the integrity of tropical forests as they are sensitive and respond to anthropogenic habitat fragmentation and disturbance [4,5,6,7].

Despite the growing recognition of the potential of bats as bioindicators and the need for establishing a global network for bat monitoring [8], existing programs to date are largely limited to temperate regions. Examples include efforts, mostly at the local scale, of monitoring populations of certain bat species in the United States [9] or, on a national level, the United Kingdom's National Bat Monitoring Program [10]. More recently launched programs such as the Indicator Bats Program (iBats, http://www.ibats.org.uk), which aims to monitor bats globally using acoustic techniques, so far also mostly operates in the temperate zone, although pilot projects are underway for expanding into tropical countries. While a variety of taxa such as terrestrial mammals, birds, and plants are currently being targeted as part of established long-term monitoring programs in the tropics such as the Tropical Ecology, Assessment and Monitoring (TEAM) network (www.teamnetwork.org), similar long-term monitoring programs for tropical bats are currently lacking.

In light of both the alarming rate at which habitat for bats in tropical countries continues to be destroyed as a result of human activities and the importance of this group as providers of crucial ecosystem services in tropical ecosystems, it seems logical to evaluate whether tropical bats make suitable monitoring targets.

Here, I summarize the main findings of an assessment of the potential suitability of tropical bats for long-term monitoring [11,12,13], which was based on a synthesis of a large number of datasets provided by colleagues, and which evolved from a workshop hosted by the TEAM network.

In order to provide reliable results, monitoring programs require sampling schemes that are statistically sound, guaranteeing that change can indeed be detected with a high level of confidence. Apart from statistical considerations, selection of indicator taxa for monitoring purposes also has to take into account the practical feasibility and cost-effectiveness with which a particular taxon can be surveyed and our assessment hence focused on both of these aspects.

Can tropical bat monitoring programs reliably detect trends in species richness?

Species richness is not only the most widely used biodiversity metric but also an important state variable in biological monitoring programs [14]. Studies investigating spatial or temporal trends in species richness are generally confronted with the problem of imperfect and variable species detectability [15]. Tropical bat assemblages are highly diverse, making it particularly challenging to estimate their richness since all species present at a particular site and time will likely not be recorded during a survey (e.g. owing to species rarity, methodological sampling bias). Temporal or spatial comparisons of species richness may therefore be biased if simply based on raw counts of species. Thus, tropical bat monitoring requires knowledge about species detectability and how it varies over temporal (e.g. seasons, sampling years) or spatial scales (e.g. sampling localities).

Using data from a suite of Old and New World bat assemblages, we estimated mean species detectability for each dataset as the mean proportion of species detected for each site-year combination (mean species inventory completeness) and, at the individual species level, modeled detectability as the probability of detecting a particular species during two successive surveys [12].

Across datasets, the mean proportion of species detected was estimated at 0.76, implying that, on average, roughly 25% of the species estimated to be present in a particular sampling plot were missed during all visits to that plot. Trophic group was a strong determinant of mean inventory completeness, with generally lower estimates for animalivorous (animal-eating) compared to phytophagous (plant-eating) bats. For phytophagous species, the mean proportion of species detected was influenced by the number of surveys and season, whereas the number of surveys and sampling method (ground- or canopy-level mist nets, harp traps, acoustic sampling) most strongly affected estimates of detectability for animalivorous bats. Species-specific detectability averaged 0.4 and was highly heterogeneous across the suite of 232 species examined (range of estimates: 0.03-0.84). Estimates of species-level detectability were found to be sensitive to various external factors such as location, season, or sampling method.

These results indicate that using raw species counts as a proxy for species richness in a tropical bat monitoring program could often lead to erroneous inferences, highlighting the need for employing appropriate statistical models that properly account for variation in detectability when comparing species richness over time and when making regional comparisons. With some species having characteristically low detection probabilities (such as most gleaning animalivores or nectarivores) and a limited number of repeat visits per sampling site, estimation-based approaches to monitoring are essential as they allow formal detectability corrections in species richness comparisons.

Can temporal trends in population abundance be reliably monitored?

The detection of temporal patterns in population abundance is an issue central to most monitoring programs. Monitoring programs designed to assess changes in population levels over time should generally ensure sufficient statistical power for reliable trend detection, however, many programs simply neglect this fundamental issue [16]. In the context of population monitoring, statistical power characterizes the probability that a monitoring program will detect a trend in population abundance when such a trend has indeed occurred or is occurring.

We used power simulations to determine the necessary sampling effort required to detect population trends and to identify appropriate survey techniques and sampling designs for monitoring tropical bat species [13]. For a suite of different species, estimates of the initial magnitude and variance in relative abundance at a particular sampling site from nine different data sets were used as input for the power simulations. Additionally, we assessed statistical power at the functional level, pooling species by bat ensemble (frugivores, nectarivores, gleaning animalivores, aerial insectivores). The analysis focused on the trade-offs between number of sampling sites, sampling frequency within and between years, and duration of the monitoring program. Specifically, we estimated power for 10 and 20 years of surveys performed annually or biennially along one, three, or five sampling plots and involving two, three, or four repeat surveys per plot per year.

Despite pronounced temporal variation in abundance of most tropical bat species, power simulations suggested that long-term monitoring programs ($\geq$ 20 years) can detect population declines of 5% per year or more with adequate statistical power ($\geq$ 0.9). However, shorter programs ($\leq$ 10 years) typically have insufficient power for reliable trend detection.

Overall, our analyses demonstrate that a monitoring program extending over 20 years with four surveys conducted biennially on five plots per monitoring site would have the potential for detecting a 5% annual change in abundance for a suite of bat species from different bat ensembles. The likelihood of reaching an appropriate power level ($\geq$ 0.9) was influenced by initial species abundance and the magnitude of count variation, emphasizing that detailed population monitoring should focus on the more common species in an assemblage and those which show little variation in abundance.

Undersampling in tropical bat monitoring surveys and its effects on biodiversity patterns

The monetary cost and time allocation necessary to survey a given taxon are two of the main constraints faced in monitoring programs [17]. Achieving maximum sampling completeness in biodiversity surveys or monitoring programs is usually cost-ineffective due to the large number of rare species encountered in tropical assemblages and this also applies to speciose tropical bat assemblages.

Unlike for a variety of other taxa [18], for tropical bats the consequences of undersampling,

i.e. missing subsets of species from the full species pool, for capturing richness and compositional patterns across sites have not been systematically assessed. Sampling only a subset of species, e.g. by excluding rarer species that would be time-intensive to survey, could considerably reduce the cost of a monitoring program (requiring, for instance, fewer visits per sampling site) and is therefore of relevance in the context of evaluating the practical feasibility and cost-effectiveness of a tropical bat monitoring program.

For a suite of empirical datasets we assessed the magnitude of correlations for bat species richness and species composition, respectively, between each complete dataset that included all species sampled versus species subsets with different numbers of species deleted either at random, or according to their rarity in the respective assemblage [11].

For species richness, correlations between random subsets and full datasets were strong with moderate (ca. 25%) species loss. Bias associated with information loss was greater for species composition; on average ca. 85% of species in random subsets had to be retained to adequately capture among-site variation. For non-random subsets, removing only the rarest species (on average 15% of the full dataset) yielded strong correlations (median $r > 0.95$) for both species richness and composition. Eliminating greater proportions of rare species typically resulted in weaker correlations and large variation in the magnitude of observed correlations among datasets.

Species subsets that comprise about 85% of the full set may therefore be considered reliable surrogates, capable of adequately revealing patterns of species richness and temporal or spatial turnover in tropical bat assemblages.

Conclusions

Our analyses indicate that temporal changes in species abundance can be assessed with an adequate level of statistical power for a range of tropical bat species from different functional groups, provided monitoring data are collected over a sufficiently long time span (15-20 years). In this context, a biennial sampling scheme would allow for reliable trend detection while at the same time minimizing survey costs. Selection of target species should be based on reasonably high abundance and low variability in abundance measures, as well as on important ecological functions. Although many tropical bat species exhibit pronounced temporal variation in abundance, power simulations indicate that high imprecision in abundance estimates can in many cases be counterbalanced by increasing the time frame of a monitoring program. Comparatively low temporal variation in abundance measures and high species detectability suggest that aerial insectivorous bats constitute a suitable target group for monitoring and technological advances now make acoustic sampling increasingly time- and cost-efficient.

An important consideration is that data from tropical bat montoring surveys will have to properly take into account differences in species detectability and the fact that detectability often varies in relation to external factors (e.g. among localities). This necessitates the application of adequate statistical modeling techniques at the data analysis stage to correct raw species counts so as to avoid the detection of spurious patterns and to enable valid inferences about change.

Patterns of spatial turnover in tropical bat assemblages are apparently to a large extent driven by common species and our analyses demonstrate that in many cases survey effort could be reduced to a certain extent with little loss of information for detecting ecological patterns, highlighting the potential for tropical bat monitoring protocols to be effectively streamlined.

Recent studies suggest that the indicator potential and surrogacy value of single taxa is usually poor [19,20] and that tropical biodiversity surveys should aim to include as many different taxa as possible under given financial and logistical constraints. In this regard, our assessment overall suggests that bats have the potential to make an important contribution to existing monitoring efforts in the tropics.

References

- **1.** Kunz T H, de Torrez EB, Bauer D, Lobova T, Fleming TH (2011) Ecosystem services provided by bats. Annals of the New York Academy of Sciences 1223: 1-38.
- **2.** Lobova TA, Geiselman CK, Mori SA (2009) Seed dispersal by bats in the Neotropics. New York: New York Botanical Garden Press. 492 p.
- **3.** Kelm DH, Wiesner KR, von Helversen O (2008) Effects of artificial roosts for frugivorous bats on seed dispersal in a Neotropical forest pasture mosaic. Conservation Biology 22: 733-741.
- **4.** Medellín RA, Equihua M, Amin MA (2000) Bat diversity and abundance as indicators of disturbance in Neotropical rainforests. Conservation Biology 14: 1666-1675.
- **5.** Struebig MJ, Kingston T, Zubaid A, Mohd-Adnan A, Rossiter SJ (2008) Conservation

value of forest fragments to Palaeotropical bats. Biological Conservation 141: 2112-2126.
- **6.** Meyer CFJ, Fründ J, Pineda Lizano W, Kalko EKV (2008) Ecological correlates of vulnerability to fragmentation in Neotropical bats. Journal of Applied Ecology 45: 381-391.
- **7.** Presley SJ, Willig MR, Wunderle Jr. JM, Nélio-Saldanho L (2008) Effects of reduced-impact logging and forest physiognomy on bat populations of lowland Amazonian forest. Journal of Applied Ecology 45: 14-25.
- **8.** Jones G, Jacobs DS, Kunz TH, Willig MR, Racey PA (2009) Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8: 93-115.
- **9.** O'Shea TJ, Bogan MA (2003) Monitoring Trends in Bat Populations of the United States and Territories: Problems and Prospects. Biological Resources Division, Information and Technology Report, USGS/BRD/ITR–2003-0003: U. S. Geological Survey. 274 p.
- **10.** Walsh AL, Catto CMC, Hutson TM, Langton S, Racey PA (2003) The United Kingdom Bat Monitoring Programme: Turning conservation goals into tangible results. In: O'Shea TJ, Bogan MA, editors. Monitoring Trends in Bat Populations of the United States and Territories: Problems and Prospects. Biological Resources Division, Information and Technology Report, USGS/BRD/ITR–2003-0003: U. S. Geological Survey. pp. 103-118.
- **11.** Meyer CFJ, Aguiar LMS, Aguirre LF, Baumgarten J, Clarke FM, et al. (in prep.) Undersampling in tropical bat surveys: effects on emerging biodiversity patterns.
- **12.** Meyer CFJ, Aguiar LMS, Aguirre LF, Baumgarten J, Clarke FM, et al. (2011) Accounting for detectability improves estimates of species richness in tropical bat surveys. Journal of Applied Ecology 48: 777-787.
- **13.** Meyer CFJ, Aguiar LMS, Aguirre LF, Baumgarten J, Clarke FM, et al. (2010) Long-term monitoring of tropical bats for anthropogenic impact assessment: gauging the statistical power to detect population change. Biological Conservation 143: 2797-2807.
- **14.** Yoccoz NG, Nichols JD, Boulinier T (2001) Monitoring of biodiversity in space and time. Trends in Ecology and Evolution 16: 446-453.
- **15.** Kéry M, Schmid BR (2008) Imperfect detection and its consequences for monitoring for conservation. Community Ecology 9: 207-216.
- **16.** Marsh DM, Trenham PC (2008) Current trends in plant and animal population monitoring. Conservation Biology 22: 647-655.
- **17.** Gardner TA, Barlow J, Araujo IS, Avila-Pires TC, Bonaldo AB, et al. (2008) The cost effectiveness of biodiversity surveys in tropical forests. Ecology Letters 11: 139-150.
- **18.** Vellend M, Lilley PL, Starzomski BM (2008) Using subsets of species in biodiversity surveys. Journal of Applied Ecology 45: 161-169.
- **19.** Larsen FW, Bladt J, Balmford A, Rahbek C (2012) Birds as biodiversity surrogates: will supplementing birds with other taxa improve effectiveness? Journal of Applied Ecology 49: 349-356.
- **20.** Kessler M, Abrahamczyk S, Bos M, Buchori D, Putra DD, et al. (2011) Cost-effectiveness of plant and animal biodiversity indicators in tropical forest and agroforest habitats. Journal of Applied Ecology 48: 330-339.

The use of radars to monitor migration strategies of moths

Dr. Jason W. Chapman
Department of AgroEcology, Rothamsted Research, Harpenden, Hertfordshire AL5 2JQ, United Kingdom

Countless billions of adult insects migrate by flight in the temperate regions of the world (Holland et al 2006). Some species undertake seasonal back-and-fore movements between low and high latitude regions to exploit the temporary breeding resources found in temperate zones during the summer (in a similar manner to well-known bird migrants). Other species carry out more local dispersive movements to find new patches of habitat as their current patch deteriorates. Some of these migrations require movements over hundreds or even thousands of kilometres, and as insects are generally short-lived in the adult stage (typically a matter of a few weeks) and relatively slow-flying (compared to birds), it may seem surprising that they are capable of such long-distance journeys. Most insect migrants get around this problem by migrating at considerable heights above the ground (anywhere between 200 m and 2 km above ground level), where they can exploit fast-moving airstreams for long-range transport. For example, if insects that migrate at night ascend into the low-level jet that frequently occurs at altitudes of between 300 m and 800 m, they can regularly be transported at speeds of 50 km per hour or more, and hence if they fly for 6 hours they will easily travel 300 km in a single flight. It is important to note here that the insect must continue to actively flap its wings during these flights otherwise they will very quickly fall out of the atmosphere. The journeys are therefore not completely passive as the insects must continually fly, but it is true that the great majority of the energy for the journey is provided by the wind. It follows therefore that the speed and direction of the journey will be determined by the wind in which the insect flies, but that the insect can control its take-off, flight altitude and descent.

The great majority of insect migration therefore takes place hundreds of metres above the ground, way beyond visual range and more-or-less invisible to researchers unless special measures are taken to sample them. This was first done in the 1930s and 1940s in the UK and USA, by attaching nets either to mobile aircraft or 'fixed platforms' high in the sky (such as tall towers or tethered kites and balloons). From these and more recent aerial trapping surveys, it is clear that a wide variety and huge abundance of insects are using high-altitude winds to travel (see Chapman et al 2004 for a recent summary). However, in order to carry out systematic and long-term studies of insect migration and flight behaviour, a method that is less labour-intensive and less destructive is required. The answer was provided by radars, which have been known to be capable of detecting migrating birds and insects almost as long as they have been in existence. The first dedicated radar entomology studies were carried out in the 1960s, so there is a long history of using this technique and we have learnt a great deal about insect migration from their use (see Chapman et al 2011).

Since 1999, Rothamsted Research in the UK has been carrying out continuous monitoring of high-altitude insect migration with two dedicated entomological radars based in southern England. These radars have narrow vertically-pointing beams that 'illuminate' an approximately 30 m wide column of the atmosphere above them. As objects pass through the beam, they return a complex signal that contains information about their altitude, shape and size, their alignment (flight heading), and their speed and direction of movement relative to the ground. These signals are analysed, and an algorithm is used to firstly separate insects from non-insects, and then to categorise the insects based on their size and shape characteristics. The radars are setup to record all individual insects that pass through the beam between heights of 150 m and 1200 m above the ground, both day and night, throughout the entire year. The radars may typically detect several thousand insects a day during warm weather, and our combined database from the two radars over the 13 years they have been running includes information on the flight characteristics, biomass and aerial density of approximately 10 million individuals. This database can be used to investigate many aspects of the migration ecology of high-flying insects, and has produced a wealth of new findings (see Chapman et al 2011 for a summary). One of the most striking findings was the sheer abundance of migrating insects, and I shall provide two examples that give an idea of the numbers involved. Some years ago, I used radar and aerial sampling data to estimate that during a typical summer month, approximately 3.6 billion (3,600,000,000) individual insects will migrate through each 1 km_ 'window' of the atmosphere

above southern England (Chapman et al 2003). More recently, my studies of moth migration (see below) estimated that up to 250 million adult silver Y moths (Autographa gamma) may invade the UK from continental Europe each spring (Chapman et al 2012). As the period of monitoring continues, the radar data will increasingly be of value for long-term studies of trends in the intensity, phenology (timing), biomass and biodiversity of populations of high-altitude migrating insects in the UK, and the relationship between these trends and environmental changes. In this article I shall provide a summary of my research into the migration strategies of nocturnal moths, as these are the best-studied group and are of relevance to bats as they provide an important food source for some species.

Several species of large moth ('macro-moths') regularly migrate between winter-breeding regions around the Mediterranean Basin and summer-breeding regions at higher latitudes in central and northern Europe. In the UK, the silver Y moth (Autographa gamma, see figure 1) is by the far the commonest species of large migrant moth, and the rest of this article will focus on this species.

Figure 1 shows that numbers of this species reaching the UK vary greatly from year-to-year, with large invasions typically every 3 or 4 years followed by leaner years when numbers may be only 10–15% of those found in invasions. Radar data indicate that very few individuals of other large moth species fly at radar-detectable heights (>150 m) in any year, and so the great majority of the high-flying nocturnal large insects is due to the annual invasions of this one species of moth.

The migrating moths are not spread evenly throughout the vertical profile of the nocturnal atmosphere, but are usually concentrated in narrow altitudinal layers (typically 100–150 m deep) that may occur anywhere between 300–800 m above the ground. Figure 2 shows such a layer of nocturnal insects (mostly silver Y moths), that arose from a dense take-off at dusk, and which continued to fly until about 01.00 GMT at an altitude of about 600 m. It is clear that on many nights, the biomass of nocturnal insects is not evenly spread but concentrated into discrete areas of the atmosphere. These layers vary in altitude from night-to-night, and tend to be associated with the presence of warm, fast-moving airstreams. This is beneficial to the insects for two reasons: firstly, because insects are cold-blooded and therefore restricted by air temperature, flying in the warmest zones will increase the number of opportunities for migration; secondly, by flying in the fastest moving airstreams, the insects will maximise their transport distance. Concentration of the insects into these discrete layers obviously has implications for any aerial predators, such as bats, which will need to focus their foraging activity at the right altitude otherwise they will encounter very few insects.

Flying at the altitude of the fastest winds is only beneficial if the selected airstreams are blowing towards a seasonally-favourable direction, i.e. towards the north in the spring and towards the south in the autumn. This suggests that the moths should attempt to select favourable tailwinds for their migratory flights in the spring and autumn, otherwise they will be transported in the wrong direction and will very likely die. Examination of radar data from the spring and autumn migration periods of the mass invasion years (2000, 2003 and 2006) indicated that the migrating A. gamma moths do exactly this. Spring migrations are restricted to nights with southerly winds which will transport the moths towards the north, while autumn migrants show a seasonal reversal and only migrate on nights with northerly winds that aid their transport towards the south. Thus the moths not only migrate at the most favourable altitudes, but they also select nights with the most favourable winds, to gain the maximum amount of tailwind assistance. Careful examination of the radar data also demonstrated that the migrating moths have another method for improving their migration pathways – they actively fly along the preferred migration direction, so that they travel faster than the wind (and thus travel further), and also partially correct for any drifting off course due to winds which are not perfectly aligned with the direction they wish to travel (Chapman et al 2008a, 2008b). These rather surprising findings indicate that the moths have an internal compass, although this remains to be verified in the laboratory.

To examine the effect of the flight behaviours on their migration trajectory, I collaborated with scientists at the UK Met Office to model their movements. Using a particle trajectory simulation, but including the moths' flight characteristics (such as flying at the altitude of the fastest winds, and flying in the preferred seasonal direction), we were able to show that flight behaviour was very important. In comparison to passively-transported particles, the simulated moth trajectories travelled 50% further on average (300 km per night rather than 200 km per night) and were 20° closer to the preferred migration direction than passive

particles (Chapman et al 2010). The results of this study indicated that the moths were not at the 'mercy of the wind', but rather had evolved sophisticated strategies to utilise the wind in a very efficient manner. My most recent work provides compelling evidence that these annual migrations to high-latitude summer-breeding regions are highly beneficial for the silver Y moth (Chapman et al 2012). Using a combination of radar data and ground-level trapping, my colleagues and I were able to show that on average every spring immigrant to the UK will produce four adult moths in the autumn, and that all of these moths attempt a return migration back to the southerly winter-breeding regions. This fourfold population increase over the summer indicates that significant reproductive benefits are gained by individuals that engage in long-range migration, but if the majority of the migrants perish on the return journey this benefit will not be realised. However, trajectory simulations and population dynamic modelling showed that mortality along the migration route was likely to be small (approximately 30%), and thus the reproductive gains would be carried over into the next generation. These results demonstrate how long-range migration, which may seem a very costly and risky strategy, can evolve and actually turn out to be very successful (Chapman et al 2012).

The enormous 'bioflow' of insect migrants through the atmosphere obviously has huge implications for the health of ecosystems and human populations (Drake & Gatehouse 1995). Some of the insect migrants carry out essential ecosystem services, such as pollinating flowers, controlling insect pests and providing food for insectivorous organisms including dragonflies, birds and bats. On the other hand, many migrant insects are pests, either causing direct damage to crops, or transmitting diseases between crops, livestock or humans. It is therefore important to monitor the intensity and timing of insect migration through the atmosphere, and radars are the most appropriate tools to do so. The Rothamsted radars have not been running long enough to enable any long-term trends in migration activity or timing to be detected yet, but as they continue to collect data they will become an ever more valuable resource. The data they collect will also be of great interest to those studying trends in insectivorous organisms, particularly those that engage in aerial hunting for actively flying insects, for example swifts and swallows during the day, and insectivorous bats at night. Information on the timing, intensity and altitude of major movements of nocturnal insects will be invaluable in understanding the foraging activity of aerially-hunting birds and bats (McCraken et al 2008; Boyles et al 2011), and so greater cooperation between entomologists and those studying vertebrates will reap dividends.

References

- **Boyles JG**, Cryan PM, McCracken GF, Kunz TH (2011). Economic importance of bats in agriculture. Science 332: 42–3.
- **Chapman JW**, Bell JR, Burgin LE, Reynolds DR, Pettersson LB, Hill JK, Bonsall MB, Thomas JA (2012). Seasonal migration to high latitudes results in major reproductive benefits in an insect. Proc. Natl. Acad. Sci. USA 109: 14924–9.
- **Chapman JW**, Drake VA, Reynolds DR (2011). Recent insights from radar studies of insect flight. Annu. Rev. Entomol. 56: 337–56.
- **Chapman JW**, Nesbit RL, Burgin LE, Reynolds DR, Smith AD, Middleton DR, Hill JK (2010). Flight orientation behaviors promote optimal migration trajectories in high-flying insects. Science 327: 682–5.
- **Chapman JW**, Reynolds DR, Hill JK, Sivell D, Smith AD, Woiwod IP (2008a). A seasonal switch in compass orientation in a high-flying migratory moth. Curr. Biol. 18: R908–9.
- **Chapman JW**, Reynolds DR, Mouritsen H, Hill JK, Riley JR, Sivell D, Smith AD, Woiwod IP (2008b). Wind selection and drift compensation optimize migratory pathways in a high-flying moth. Curr. Biol. 18: 514–8.
- **Chapman JW**, Reynolds DR, Smith AD (2003). Vertical-looking radar: A new tool for monitoring high-altitude insect migration. Bioscience 53: 503–11.
- **Chapman JW**, Reynolds DR, Smith AD, Smith ET, Woiwod IP (2004). An aerial netting study of insects migrating at high-altitude over England. Bull. Entomol. Res. 94: 123–36.
- **Drake VA**, Gatehouse AG, eds. (1995). Insect Migration: Tracking Resources Through Space and Time. Cambridge, UK: Cambridge University Press.
- **Holland RA,** Wikelski M, Wilcove DS (2006) How and why do insects migrate? Science 313: 794–6.
- **McCraken GF**, Gillam EH, Westbrook JK, Lee YF, Jensen ML, Balsley BB (2008). Brazilian free-tailed bats (Tadarida braziliensis: Molossidae, Chiroptera) at high altitude: links to migratory insect populations. Integ. Comp. Biol. 48: 107–18.

Figure 1 *Annual spring influxes of A. gamma into the UK (numbers of moths per 1 km_ 'window' of the atmosphere) detected by radars in southern England.*

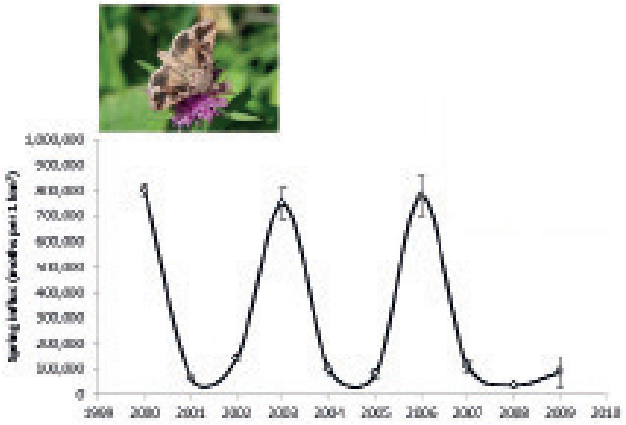
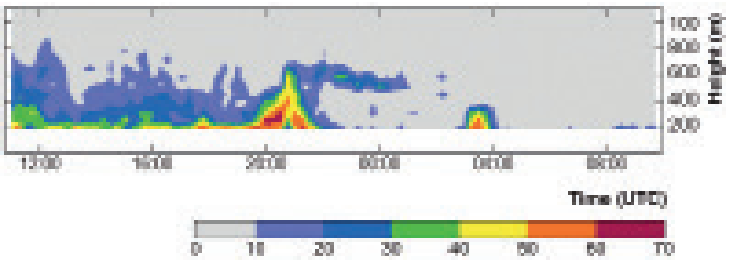


Figure 2 *Time/height plot of insects recorded by an entomological radar in southern England. The plot shows that a layer of nocturnal migrants arose from an intense dusk take-off and continued to fly at about 600 m until after midnight. The coloured scale bar refers to the numbers of insects present at each altitude (figure taken from Chapman et al 2011).*



Responses of butterflies and birds to climate change in the Mediterranean region

Constantí Stefanescu
Museu de Ciències Naturals de Granollers, Francesc Macià 51, 08402 Granollers & CREAF, 08193 Cerdanyola del Vallès,Catalonia, Spain
Sergi Herrando
Institut Català d'Ornitologia, Girona 168, 08037 Barcelona, Catalonia, Spain

Introduction

Butterflies and birds have long been recognised as useful bioindicators for environmental change and, more particularly, for climate change (Parmesan 2003, Møller et al. 2010). In recent years, evidence has accumulated indicating that both of these groups are responding to climate change in various different ways. In this paper we summarise some of the main conclusions reached after two decades of research in this field, with a special focus on the Mediterranean region and on our own studies. We start first by considering how global warming is affecting the phenology of butterflies and birds and discuss the impacts that these changes can have on ecosystem functioning. We then move a step further and, using data from European monitoring programmes, we examine some of the intriguing results originating from a joint analysis of changes in the composition of butterfly and bird communities at continental scale. Most of our research is based on the analysis of data from long-term monitoring programmes, which provide comprehensive information at both spatial and temporal scales. Two such schemes have been running in Catalonia over the last two decades: the Catalan Butterfly Monitoring Scheme (CBMS) and the Catalan Common Bird Survey (SOCC). In both programmes, a large number of volunteers systematically collect field observations of butterfly and bird populations, which are ideal for tracking changes in both groups in response to climate change.

Phenological changes due to climate warming

It has been predicted that advances in the emergence time and flight period of insects will occur as climate warming speeds up developmental times of immature stages (Peñuelas & Filella 2001). This prediction has been confirmed by CBMS data from one site

in the period 1988–2002, where we found that all butterfly species had advanced their first appearance dates and that eight out of 19 species had significantly advanced their mean flight dates. These changes parallel an increase of 1–1.5ºC in mean February, March and June temperatures at the study site. Similar trends were found for several other insect species (e.g. one aphid, two beetles, one bee and one butterfly) at another Catalan site after analysis of a much longer temporal dataset (1943–2003: Gordo & Sanz 2005). In recent years, many other studies from diverse regions have confirmed this phenological trend for butterflies, which is now recognised as a well-established pattern (see, for example, Roy & Sparks 2000, Forister & Shapiro 2003).

Phenological responses by birds to climate warming have also been reported by researchers and include an advance in the breeding period (e.g. Crick et al. 1997) and a general pattern of earlier arrival by migratory species (e.g. Rubolini et al. 2007, Lehikoinen & Sparks 2010). This trend towards earlier arrival has been confirmed in the Iberian Peninsula for a number of different species (Gordo & Sanz 2006).

These reported phenological changes may have important population consequences if they create mismatches in predator-prey interactions. This is likely to occur since Lepidopteran larvae represent the main feeding resource for many insectivorous birds, especially during the breeding period. Long-term data for insects and birds co-occurring at a site reveal stronger phenological advances in the former (e.g. Gordo & Sanz 2005), suggesting that mismatching may indeed be a common outcome of climate warming. Indeed, this tendency has been detected by several long-term studies carried out in the Netherlands that analyzed over two decades of climate warming the breeding success of the Pied Flycatcher, Ficedula hypoleuca, and three species of Tits, Parus spp., in relation to the availability of caterpillars (Both et al. 2006, 2009).

Unfortunately, it is very difficult at present to generalize on the basis of the above-mentioned results given the paucity of other similar studies and the apparent complexity of the phenological responses shown by both butterflies and birds. Although a phenological advance is a common response in both these taxa, the most comprehensive analyses for both groups have revealed that substantial differences between species exist in the degree of responses. For example, in birds arrival dates have advanced more in short-distance than in long-distance migrants (Rubolini et al. 2007), while for butterflies those species that feed on trees and shrubs in the larval stage have had more notable phenological advances than those feeding on herbs (Altermatt 2010).

The consequences at population level of mismatching associated with climate change are beginning to be understood. Saino et al. (2011) have recently found in the Baltic countries that the ecological mismatch in the arrival of migrant birds is related to their population trends, whereby the species with the longest delay in arrival dates are those that have undergone the greatest population declines in recent decades. As this study indicates, extensive datasets provided by monitoring programmes such as the CBMS and SOCC, which reflect long-term population trends by gathering phenological data for many sites and co-occurring species, will be extraordinarily useful in the future. For instance, they offer excellent opportunities to further explore the consequences of temporal mismatching across trophic levels, which has been recently highlighted as the most likely cause for species extinction due to climate change (Cahill et al. 2012).

Climatic debt in butterflies and birds

In addition to changes in phenology, climate change has profound effects on the distribution of species (Parmesan 2006, Møller et al. 2010). Poleward shifts to track temperature changes have been reported in many groups (Hickling et al. 2006) including European butterflies (Parmesan et al. 1999) and birds (La Sorte & Thompson 2007). These movements will predictably lead to changes in the structure of communities, which will increasingly become dominated by species adapted to higher temperatures.

To test this hypothesis, Devictor et al. (2012) used butterfly and bird data from various European monitoring programmes collected over the last two decades. Their analysis was based on 9,490 and 2,130 sample sites for birds and butterflies, respectively, from seven countries or regions (Finland, Sweden, UK, the Netherlands, France, Czech Republic, and Catalonia). Based on earlier work by these authors (Devictor et al. 2008), each sample site was characterized for each year from 1990 to 2008 with a Community Temperature Index (CTI), which reflects the relative composition of high- versus low-temperature dwellers in local communities and is a simple way of measuring the rate of change in community composition in response to climate change. As a previous step,

each species is characterized by a temperature index (STI), estimated as the average temperature found throughout the species' range. The CTI is then calculated for a given site and season as the average of the STI of the species present weighted according to these species' abundances in that season.

We would expect a spatial gradient in the CTI, with communities from lower latitudes dominated by species with higher STI values – and therefore with higher average CTI values – than communities from higher latitudes. This prediction was confirmed with a linear trend for both butterflies and birds: butterfly communities showed a decrease of $1.47 \pm 0.08 \times 10^{-3}$ ºC loss of CTI km^{-1}, while birds showed a decrease of $1.26 \pm 0.01 \times 10^{-3}$ ºC loss of CTI km^{-1} when moving northwards (Fig. 1a).

Likewise, under the assumption of climate warming, we would expect a temporal trend in the CTI at a given site: as temperatures increase, communities would become progressively dominated by high-temperature dwellers, resulting in an increase of CTI over time. Data from monitoring programmes accumulated over two decades confirm this hypothesis: from 1990 to 2008, CTIs increased steadily following the linear relationships $9.3 \pm 0.5 \times 10^{-3}$ ºC yr-1 for butterflies and 2.6 ± 0.19 x 10-3 ºC yr^{-1} for birds (Fig. 1b). During the same period, the temperature also increased steeply (5.50 ± 0.61 x 10-2 ºC yr^{-1}).

Using the spatial gradients shown in Fig. 1a, it is possible to translate temporal trends in temperatures and CTIs into spatial trends. For temperature, the increase recorded from 1990 to 2008 was equivalent to a northward shift in temperatures of 249 ± 27 km, while the CTIs increases corresponded to northward shifts of 114 ± 9 km for butterflies and 37 ± 3 km for birds. The difference between the spatial shift in temperature and in CTI is known as the climatic debt: although species move in the expected direction, they do not adjust their abundances according to the northward shift of the climates that suit them. In the case of butterflies, a climatic debt of 135 km has been detected, while in birds the debt was of 212 km.

The study by Devictor et al. (2012) not only revealed the existence of climatic debts, but also showed remarkable differences in the strength of responses to climate warming in butterflies and birds. This again suggests that some predator-prey interactions may be disrupted, with unpredictable consequences at ecosystem level.

Differences between countries and the Mediterranean paradox

The results reported above depict the general pattern occurring at European scale. The same analysis was then repeated for each country to look for variability at a finer level. This intra-European analysis showed positive and highly significant temporal trends in the CTI for every dataset with the exception of Catalonia, where the slope was positive but non-significant in the case of birds, and even negative (but non-significant) in the case of butterflies. In other words, this new analysis showed that a well-established pattern in the temperate and northern countries does not hold for the only Mediterranean region included in this study. Surprisingly, in this area, butterfly and bird communities are not becoming increasingly dominated by high-temperature dwellers.

However, the reasons for this conflicting result became apparent once a different indicator of climate change, which considers not only temperature but also water availability, was used for this region. This indicator, originally developed for European birds by Gregory et al. (2009) on the basis of long-term population data from monitoring programmes, measures divergence in population trends by comparing species predicted by climatic envelope models to be favourably affected by climatic change (i.e. it enables them to expand their geographical range) with those adversely affected (i.e. it causes them to contract their geographical range). Models were fitted using combinations of a set of variables representing each of the three principal climatic constraints upon the distribution of organisms in Europe, i.e. winter cold, growing season warmth and water availability, under three projected general circulation climatic models (GMC).

When the climatic indicator of Gregory et al. (2009) is calculated for Catalan bird populations using the SOCC dataset, a significant increase between 2002-2011 occurs that confirms the expected response of Catalan bird communities to climatic change (Fig. 2a). The same procedure was then applied to the CBMS dataset, using the predictions of changes in distribution provided by the climatic risk atlas of European butterflies (Settele et al. 2008) and, as for birds, the climatic indicator increased significantly in the period 1994–2011 (Fig. 2b).

We believe that the reliability of this climatic indicator in Catalonia for both butterflies and birds stems from the fact that both water availability and temperature are taken into account to predict species' responses to climatic

change. Firstly, several studies have shown that while higher latitude ecosystems are typically limited by temperature, lower latitude and continental ecosystems are mainly limited by drought. In Catalonia, for example, butterfly diversity is highly positively correlated to water availability (Stefanescu et al. 2011). Secondly, both observational data and regional climate change simulations have consistently predicted an increase in the impact of droughts and heat waves in the Mediterranean region in the coming decades (Giorgi & Lionello 2008). The negative effects of droughts are starting to become apparent for those species whose distributions are concentrated in the most arid habitats, as predicted by climatic envelope models. It should be noted that in many cases the species with the highest STIs are precisely those that are expected to show the greatest declines (for butterflies we found a highly significant negative relationship between CTI and expected change in the distribution range, as predicted by climatic envelope models). This particular relationship means that in the Mediterranean region an increase in CTI due to climate change is not the predicted outcome of climatic change in butterfly and bird communities, as indeed is confirmed by the empirical data from the CBMS and SOCC programmes.

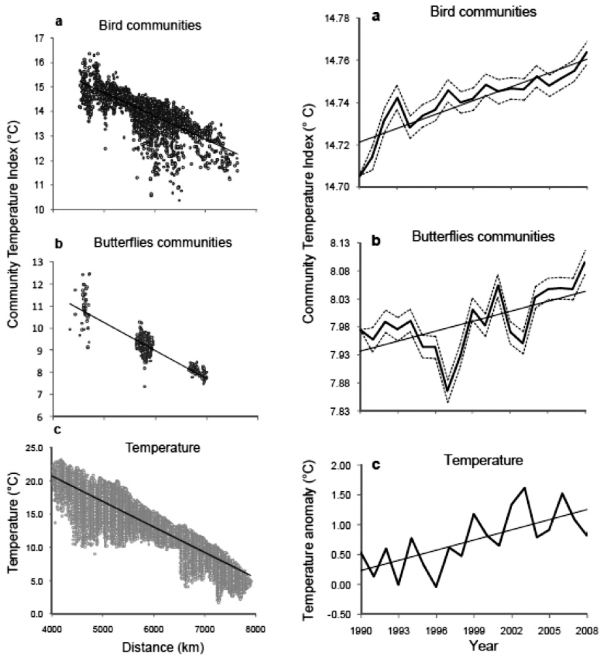
References

- **Altermatt**, F. (2010) Tell me what you eat and I'll tell you when you fly: diet can predict phenological changes in response to climate change. Ecol. Lett. 13: 1475-1484.
- **Both**, C., Bouwhuis, S., Lessells, C.M. & Visser, M.E. (2006) Climate change and population declines in a long-distance migratory bird. Nature 441: 81-83.
- **Both**, C., van Asch, M., Bijlsma, R.G., van den Burg, A. & Visser, M.E. (2009) Climate change and unequal phenological changes across four trophic levels: constraints or adaptations? J. Anim. Ecol. 78: 73-83.
- **Cahill**, A.E., Aiello-Lammens, M.E., Fisher-Reid, M.C., Hua, X., Karanewsky, C.J., Ryu, H.Y., Sbeglia, G.C., Spagnolo, F., Waldron, J.B., Warsi, O. & Wiens, J.J. (2012) How does climate change cause extinction? Proc. R. Soc. B. (published in early view. Doi:10.1098/rspb.2012.1890).
- **Crick**, H.Q.P., Dudley, C., Glue, D.E. & Thomson, D.L. (1997) UK birds are laying eggs earlier. Nature 388: 526.
- **Devictor**, V., Julliard, R., Couvet, D. & Jiguet, F. (2008) Birds are tracking climate warming, but not fast enough. Proc. R. Soc. B. 275: 2743-2748.
- **Devictor**, V., van Swaay, C., Brereton, T., Brotons, L., Chamberlain, D., Heliölä, J., Herrando, S., Julliard, R., Kuussaari, M., Lindström, A., Reif , J., Roy, D.B., Schweiger, O., Settele, J., Stefanescu, C., van Strien, A. van, Turnhout, C., Vermouzek, Z., DeVries, M.W., Wynhoff, I. & Jiguet, F. (2012) Differences in the climatic debts of birds and butterflies at a continental scale. Nature Clim. Change, 2: 121-124.
- **Forister**, M.L. & Shapiro, A.M. (2003) Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biol. 9: 1130-1135.
- **Giorgi**, F. & Lionello, P. (2008) Climate change projections for the Mediterranean region. Glob Planet Change 63: 90-104.
- **Gordo**, O. & Sanz, J.J. (2005) Phenology and climate change: a long-term study in a Mediterranean locality. Oecologia 146: 484-495.
- **Gordo**, O. & Sanz, J.J. (2006) Climate change and bird phenology: a long-term study in the Iberain peninsula. Global Change Biol. 12: 1993-2004.
- **Gregory**, R.D., Willis, S.G., Jiguet, F., Vorisek, P., Klvanová, A., van Strien, A., Huntley, B., Collingham, Y.C., Couvet, D. & green, R.E. (2009) An indicator of the impact of climatic change on European bird populations. PLoS ONE, 4(3): e4678.
- **Hickling**, R., Roy, D. B., Hill, J. K., Fox, R. & Thomas, C. D. (2006) The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biol. 12, 450–455.
- **La Sorte**, F.A. & Thompson. F.R. (2007) Poleward shifts in winter ranges of North American birds. Ecology 88:1803–1812.
- **Lehikoinen**, F. & Sparks, T.H. (2010) Changes in migration. In: Effects of climate change on birds (Moller, A.P., Fiedler, W. & Berthold, P., Eds), pp. 89-112. Oxford University Press, Oxford.
- **Møller**, A.P, Fiedler, W. & Berthold, P. (2010). Effects of climate change on birds. Oxford University Press, Oxford.
- **Parmesan**, C. (2003) Butterflies as bioindicators of climate change impacts. In: Evolution and ecology taking flight: butterflies as model systems (Boggs, C., Watt, W.B. & Ehrlich, P.R., Eds), pp. 541-560. Chicago University Press, Chicago-
- **Parmesan**, C. (2006) Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37: 637-669.
- **Parmesan**, C., Ryrholm, N., Stefanescu, C., Hill, J.K., Thomas, C.D., Descimon, H., Huntley, B., Kaila, L., Kullberg, J., Tammaru, T., Tennent, W.J., Thomas, J.A. & Warren, M.S. (1999) Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399: 579-583.
- **Peñuelas**, J. & Filella, I. (2001) Responses to a

warming world. Science 294: 793-795.

- **Roy**, D.B. & Sparks, T.H. (2000) Phenology of British butterflies and climate change. Global Change Biol. 6: 407-416.
- **Rubolini**, D., Moller, A.P., Rainio, K. & Lehikoinen, F. (2007) Intraspecific consistency and geographic variability in tmeporal trends of spring migration phenology among European bird species. Clim. Res. 35: 135-146.
- **Saino**, N., Ambrosini, R., Rubolini, D., von Hardenberg, J, Provenzale, A, Hüppop, K., Hüppop, O., Lehikoinen, A., Lehikoinen, E., Rainio, K., Romano, M. & Sokolov, L. (2011). Climate warming, ecological mismatch at arrival and population decline in migratory birds. Proc. R. Soc. B. 278: 835-842.
- **Settele**, J., Kudrna, O., Harpke, A., Kühn, I., van Swaay, C., Verovnik, R., Warren, M., Wiemers, M., Hanspach, J., Hickler, T., Kühn, E., van Halder, I., Veling, K., Vliegenthart, A., Winhoff, I. & Schweiger, O. (2008) Climatic risk atlas of European butterflies. Pensoft, Sofia-Moscow.
- **Stefanescu**, C., Carnicer, J. & Peñuelas, J. (2011) Determinants of species richness in generalist and specialist Mediterranean butterfly: the negative synergistic forces of climate and habitat change. Ecography 34: 353-363.
- **Stefanescu**, C., Peñuelas, J. & Filella, I. (2003) Effects of climatic change on the phenology of butterflies in the northwest Mediterranean Basin. Global Change Biol. 9: 1494-1506.

Fig. 1. *(A) Spatial trends of CTI (birds and butterflies) and temperature in Europe. For birds and butterflies each point represents the CTI for a given sample monitored in 2005. Temperature is the average of March-September temperatures corresponding to the breeding season of both birds and butterflies. Distance (x-axis) is calculated from the southern border (Catalonia) of the studied region. (B) Temporal trend in CTI (birds and butterflies) and temperature in Europe in the period 1990–2008. Temperature anomalies are calculated as the departure from the average during the base period 1961–1990 (based on Devictor et al. 2012).*



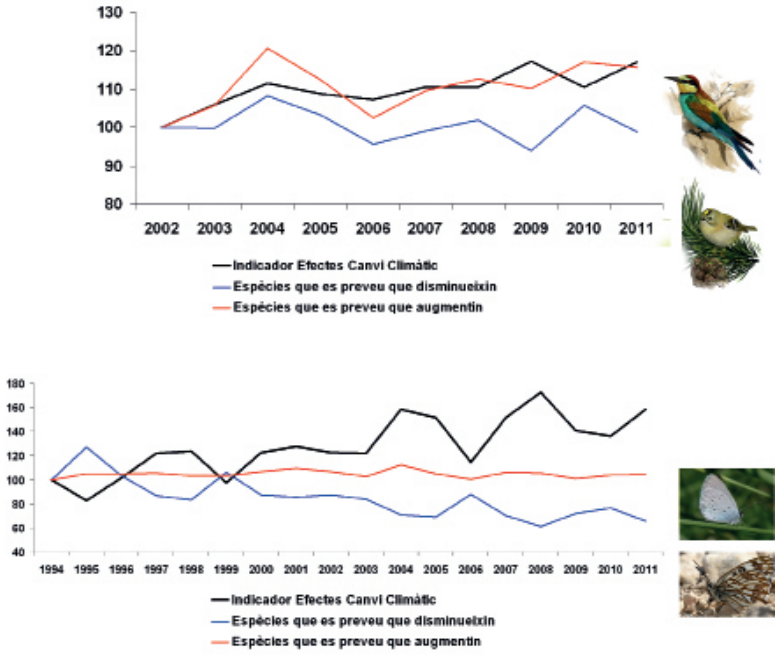


Fig. 2. *Indices of the impact of climate change on Catalan populations of (A) birds (period 2002-2011) and (B) butterflies (period 1994-2011). The indices are set to 100 at the start of the recording period. The red line shows the weighted composite trend of species that under projected climatic change are expected from the climatic envelope models to increase their geographical range in Europe; the blue line shows the trend of species whose ranges are expected to contract. The black line is the Climatic Impact Indicator, which is the ratio between the index for species whose potential geographical range is expected to expand and the index for species whose potential geographical range is expected to contract due to climatic change. Trends of the Climatic Impact Indicator are significantly positive for both birds and butterflies.*

Photo: Ryan Von Linden

Bat Monitoring

Monitoring bats in caves and mines: the impact of white-nose syndrome on hibernating bats

Winifred F. Frick
Department of Ecology and Evolutionary Biology, University of California Santa Cruz. USA

Bat monitoring programmes in the UK: achievements and perspectives

Karen A. Haysom, Kate E. Barlow, Philip A. Briggs, & Steve D. Langton
Bat Conservation Trust, Quadrant House, 250 Kennington Lane, London, SE11 5RD, UK.

Large scale bat monitoring programmes and policies

Marie-Jo Dubourg-Savage
Société Française pour l'Etude et la Protection des Mammifères (SFEPM) France

Calculating a European bat indicator: following birds and butterflies

Tom van der Meij
Statistics Netherlands

Monitoring bats in caves and mines: the impact of white-nose syndrome on hibernating bats

Winifred F. Frick
Department of Ecology and Evolutionary Biology, University of California Santa Cruz. USA

White-nose syndrome (WNS) is an emerging infectious disease that affects hibernating bats in North America and has caused massive declines in bat populations in eastern North America in the past five years (Frick et al. 2010, Langwig et al. 2012). The United States Fish and Wildlife Service has estimated that WNS has killed upwards of 5-6 million bats in North America since 2007. The disease is confirmed in 21 US states and 4 Canadian provinces and has spread over 1500 km from where it was first detected in upstate New York. The mass mortality caused by this novel disease raises serious concern about the impacts on bat populations and has sparked an international collaborative effort to monitor hibernating bat populations and assess the impacts of WNS.

In 2007, biologists at the New York Department of Environment and Conservation noticed unusually large numbers of dead bats at hibernacula, the caves and mines where bats hibernate, while conducting routine winter monitoring of hibernating bat aggregations. Bats were seen flying out into the snow and bats had an unusual white powdery substance on their faces and wings, which had never before been seen. This was the first evidence of White-Nose Syndrome, a disease we now know is caused by a cold-loving fungus named *Geomyces destructans*. The first evidence of the fungus growing on bats in North America is from a photograph taken by a caver at Howe Cavern near Albany, New York in 2006.

The fungus *Geomyces destructans* was previously not described by science (Gargas et al. 2009), but belongs in a group of mostly cold-tolerant environmental fungi (Blehert 2012). *Geomyces destructans* grows only at cold temperatures (below 20° Celsius) and therefore only affects bats during hibernation when bats are in torpor (Verant et al. 2012). Laboratory infection trials have confirmed that *Geomyces destructans* is the causative agent of White-Nose Syndrome (Lorch et al. 2011, Warnecke et al. 2012). The disease is characterized by presence of cutaneous infection of cupping epidermal lesions where fungal hyphae invade the connective skin tissues (Meteyer et al. 2009). Although the mechanisms leading to mortality are still being researched (Cryan et al. 2010, Willis et al. 2011), it is apparent that infected bats have altered patterns of arousal during hibernation that often leads to starvation and death (Reeder et al. 2012).

Hibernating bat species aggregate in caves and mines during winter to escape the cold winter months. During hibernation, bats use bouts of torpor interrupted by infrequent arousals (Speakman et al. 2003). During torpor, bats are typically at ambient temperatures just above freezing and have compromised immune function (Bouma et al. 2010). Once bats arouse in spring, they appear capable of clearing infections of *Geomyces destructans* and healing wing lesions relatively rapidly (Fuller et al. 2011). Bats from multiple species often aggregate in the same cave or mine, however, there are differences among species in preferences for microclimatic roosting conditions, such as temperature and humidity. There are also species differences in terms of propensity to hibernate in clusters (Barbour and Davis 1969). Microclimatic preferences as well as propensity for clustering behavior appear to affect the severity of population declines caused by WNS (Langwig et al. 2012).

During summer months females must stay metabolically active and form species-specific maternity colonies to give birth and raise young. Maternity colonies are usually located in areas separate from the hibernacula and can occur in natural structures such as trees as well as human-made structures (e.g. attics, barns). During summer, male bats can use daily torpor and typically roost solitarily or in small bachelor groups. WNS infection does not appear to readily occur during summer months, but research on the seasonality of WNS infection is on-going.

There is no evidence that the fungus existed in North America prior to 2006. Semi-annual monitoring of bats at winter hibernacula has been conducted at caves and mines in the northeastern United States dating back to the early 1980s, often by researchers taking photographs to count bats in hibernating clusters. Review of these archived photographs showed no evidence of bats with typical white fungal infections on the face or wings (A. Hicks, personal communication). In contrast, the fungus appears to be quite common on hibernating bats throughout Europe, but

without any signs of mass mortality associated with its presence on bats (Puechmaille et al. 2011). Furthermore, mounting genetic evidence suggests that the fungus likely originated in Europe and was only recently introduced in North America (J. Foster, personal communication). There is no consensus on how the fungus was introduced to North America, but it first appeared at a highly visited commercial cave and it is quite plausible that a cave tourist accidentally introduced it. Other plausible scenarios include a bat stowed away in a shipping bunker, as Albany, New York is a shipping port. Given that bats are incapable of unaided trans-atlantic movements, human trade or travel is highly implicated in the introduction of this pathogenic fungus to North America.

Geomyces destructans is well-distributed throughout Europe and has been confirmed on bats in at least eight countries spanning the European continent (Puechmaille et al. 2011). Photographic evidence suggests that *G. destructans* is also present in four additional countries (Puechmaille et al. 2011). There is some evidence from the Czech Republic that fungal infections on European bat species can cause skin lesions diagnostic of WNS (Pikula et al. 2012). However, there is no evidence to date that WNS causes mass mortality in any species in Europe (Puechmaille et al. 2011). Legal restrictions on collecting whole bat specimens for histopathological analysis (necessary for confirmation of skin lesions) as well as restrictions on less invasive sampling, such as swab sampling, which requires handling bats during hibernation, have limited the ability of researchers to conduct comparable studies of infection status in Europe and North America.

In North America, presence of the disease is determined by histopathological examination to determine presence of characteristic cupping skin lesions (Meteyer et al. 2009). In the USA, biologists from state natural resource agencies conduct winter monitoring of bats and collect whole bat specimens of individuals suspected to have WNS from visual signs of fungus on a bat or other clinical field signs, such as aberrant winter behavior or high mortality. These specimens are sent to the National Wildlife Health Center for diagnostic confirmation by histopathology. A similar process is followed in Canada and a database of US and Canadian records by county or district is maintained and made publicly available by the United States Geological Service (http://www.nwhc.usgs.gov/disease_information/white-nose_syndrome/).

There have been several genetic-based diagnostic tests developed to provide ability to determine presence of the fungal pathogen on bats without specimen collection. A swab sample can be taken in the field by rubbing a sterile swab on the wing and muzzle of the bat and then analyzed by either a quantitative PCR (qPCR) or standard PCR technique to determine presence of fungal DNA (Chaturvedi et al. 2010, Muller et al. 2012). This non-invasive sampling method provides the ability to determine whether an individual is infected without killing a bat and is being used by researchers to determine the fraction of individuals infected at selected sites across the United States. Understanding the prevalence of infection among individuals and across species is necessary to answer some basic questions about the transmission of *Geomyces destructans* in the wild and to help monitor the impacts and spread of the pathogen.

The routine monitoring efforts to count bats in the caves and mines where bats aggregate during winter was pivotal in the early detection of WNS and quantifying its significant impact on bat populations (Frick et al. 2010, Langwig et al. 2012). Winter monitoring of bats in the USA is primarily conducted by biologists employed by state natural resource agencies and databases of counts of bats are maintained by these state agencies. One of the reasons why state biologists count bats during winter is to adhere to federal recovery plans for monitoring population trends for two bat species listed on the federal endangered species list (*Myotis sodalis* and *Myotis grisescens*). Both of these species have been listed as federally endangered since the inception of the Endangered Species Act in 1973 and federal recovery plans mandate that aggregations at winter hibernacula listed as priority sites be counted every two years. Efforts vary by states, but counts of non-listed species that occur at sites with *Myotis sodalis* and *Myotis grisescens* are often conducted at the same time, although this is done at the discretion of state biologists and not required by federal or state law. Therefore, there is wide variety in the monitoring efforts and quality of databases on wintering populations of bats in the United States. Counting bats at winter hibernacula is recognized as the primary means to determine population trends and status for the two species protected by US federal law. Due to concerns that entry into hibernacula may cause disturbance to hibernating bats, the United States Fish and Wildlife Service requires that monitoring counts for *Myotis sodalis* and *Myotis grisescens* be conducted on a biennual

basis (every other year). However, there has been no analysis to date that indicates that annual monitoring visits results in population declines at sites that have been monitored on an annual basis in some states and monitoring every year greatly improves ability to estimate accurate population trends.

In general, monitoring bats at hibernacula has many advantages for population monitoring of bats because species that use hibernacula are aggregated in localities where it is physically possible to count individuals. These census counts if conducted annually can be used to estimate population growth and determine population trends (Morris and Doak 2002). Consistency in count methods and reducing observer error is necessary to ensure data quality. In addition, efforts should be made to minimize disturbance of bats during counts, such as using photographic methods which reduces the overall time underground (Meretsky et al. 2010). Hibernacula counts may offer the only means for assessing population trends for species that roost in small, cryptic roost localities during summer (e.g. *Myotis sodalis*). However, counts at hibernacula are obviously limited to those species that aggregate in caves and mines during winter and currently has limited potential in certain regions of the USA where there are very few known hibernacula and most species are not known to aggregate in caves and mines during winter (western USA). Furthermore, for assessing overall population sizes and regional trends, it is not known what proportion of hibernacula are known in a given region.

In 1994, the United States Geological Service (USGS) started a project to compile existing published counts from both winter and summer roosts of bats from 1855-2001 and created a printed and online database of counts called the Bat Population Database (BPD) (O'Shea and Bogan 2003). The BPD was created as a central repository for monitoring counts, but after its initial creation in the early 2000s received little institutional support. With the advent of WNS, there has been renewed interest and the BPD is currently being updated to provide an accessible database to store information on the spread of WNS as well as count data at both hibernacula and maternity roosts. Creation of an accessible central repository for colony counts of bats at summer and winter roosts will be instrumental in analyzing population trends for bats over time and across large geographic regions. There are some issues with data sharing in these types of online repositories. Most notably, many roost sites are located on private land and there is concern over sharing locality information to protect landowner privacy as well as protect bats. By using data sharing agreements many of these concerns can be addressed so that relevant information can be used by the broader scientific and conservation community.

The significant impact of WNS on bats has triggered an effort to create a national bat monitoring program in the USA. A workshop was held in April 2012 to "Develop Methods for Monitoring and Modeling Bat Populations and Responses to White-Nose Syndrome". This workshop convened expert bat biologists and bio-statisticians to develop a working plan for implementing a national bat monitoring program. The workshop report recommended a program that would involve both colony counts at summer and winter roosts, spatial distribution sampling using techniques such as acoustic monitoring and mist-net captures, and focused mark-recapture studies to estimate vital rates for demographic modeling of target species. There was a strong emphasis on designing a probabalistic sampling frame to enable a relevant and appropriate scope of inference. The implementation of the recommendations by this workshop panel will depend in large part on institutional support and funding to create an organized effort to carry out the recommendations. Currently, there is no institutional structure or funding in place, however there are several successful models of monitoring programs similar in scale and scope for birds in the USA (e.g. the Breeding Bird Survey).

The severe impact of WNS on bat populations in North America has been a catalyst for focused energy and attention on monitoring bat populations and the importance of bats to ecosystems (Boyles et al. 2011). Population declines have been severe (upwards of 70%) in the northeastern USA and the pathogen continues to spread into new regions each year. A coordinated monitoring program is necessary for assessing impacts and improving understanding of the disease, especially as it moves into new regions.

References

- **Barbour**, R., and W. Davis. 1969. Bats of America. The University Press of Kentucky, Lexington, KY, USA.
- **Blehert**, D. S. 2012. Fungal Disease and the Developing Story of Bat White-nose Syndrome. PLOS Pathogens 8:e1002779.
- **Bouma**, H. R., H. V. Carey, and F. G. M.

Kroese. 2010. Hibernation: the immune system at rest? Journal of Leukocyte Biology 88:619–624.
- **Boyles**, J. G., P. M. Cryan, G. F. McCracken, and T. H. Kunz. 2011. Economic Importance of Bats. Science (New York, N.Y.) 332:41–42.
- **Chaturvedi**, V., D. J. Springer, M. J. Behr, R. Ramani, X. Li, M. K. Peck, P. Ren, D. J. Bopp, B. Wood, W. A. Samsonoff, C. M. Butchkoski, A. C. Hicks, W. B. Stone, R. J. Rudd, and S. Chaturvedi. 2010. Morphological and Molecular Characterizations of Psychrophilic FungusGeomyces destructansfrom New York Bats with White Nose Syndrome (WNS). PLoS ONE 5:e10783.
- **Cryan**, P. M., C. U. Meteyer, J. G. Boyles, and D. S. Blehert. 2010. Wing pathology of white-nose syndrome in bats suggests life-threatening disruption of physiology. BMC biology 8:135.
- **Frick**, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchkoski, and T. H. Kunz. 2010. An Emerging Disease Causes Regional Population Collapse of a Common North American Bat Species. Science (New York, N.Y.) 329:679–682.
- **Fuller**, N. W., J. D. Reichard, M. L. Nabhan, S. R. Fellows, L. C. Pepin, and T. H. Kunz. 2011. Free-Ranging Little Brown Myotis (Myotis lucifugus) Heal from Wing Damage Associated with White-Nose Syndrome. EcoHealth 8:154–162.
- **Gargas**, A., M. T. Trest, M. Christensen, T. J. Volk, and D. S. Bleher. 2009. Geomyces desctructanssp. nov. associated with bat white-nose syndrome. Mycotaxon 108:147–154.
- **Langwig**, K. E., W. F. Frick, J. T. Bried, A. C. Hicks, T. H. Kunz, and A. M. Kilpatrick. 2012. Sociality, density-dependence and microclimates determine the persistence of populations suffering from a novel fungal disease, white-nose syndrome. Ecology Letters 15:1050–1057.
- **Lorch**, J. M., C. U. Meteyer, M. J. Behr, J. G. Boyles, P. M. Cryan, A. C. Hicks, A. E. Ballmann, J. T. H. Coleman, D. N. Redell, D. M. Reeder, and D. S. Blehert. 2011. Experimental infection of bats with Geomyces destructans causes white-nose syndrome. Nature 480:376–378.
- **Meretsky**, V. J., V. B. JR, T. C. Carter, R. Clawson, R. R. Currie, T. A. Hemberger, C. J. Herzog, A. C. Hicks, J. A. Kath, and J. R. Macgregor. 2010. Digital Photography Improves Consistency and Accuracy of Bat Counts in Hibernacula. Journal of Wildlife Management 74:166–173.
- **Meteyer**, C. U., E. L. Buckles, D. S. Blehert, A. C. Hicks, D. E. Green, V. Shearn-Bochsler, N. J. Thomas, A. Gargas, and M. J. Behr. 2009. Histopathologic Criteria to Confirm White-nose Syndrome in Bats. Journal of Veterinary Diagnostic Investigation 21:411–414.
- **Morris**, W. F., and D. F. Doak. 2002. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer Associates, Inc., Sunderland, MA, USA.
- **Muller**, L. K., J. M. Lorch, D. L. Lindner, M. O'Connor, A. Gargas, and D. S. Blehert. 2012. Bat white-nose syndrome: A real-time TaqMan polymerase chain reaction test targeting the intergenic spacer region of Geomyces destructans. Mycologia 10.3852/12-242.
- **O'Shea**, T. J., and M. A. Bogan. 2003. Monitoring trends in bat populations of the United States and Territories: Problems and prospects. (T. J. O'Shea and M. A. Bogan, Eds.). U.S. Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR-2003-003.
- **Pikula,** J., H. Bandouchova, L. Novotny, C. U. Meteyer, J. Zukal, N. R. Irwin, J. Zima, and N. Martínková. 2012. Histopathology confirms white-nose syndrome in bats in Europe. Journal of Wildlife Diseases 48:207–211.
- **Puechmaille**, S. J., G. Wibbelt, V. Korn, H. Fuller, F. Forget, K. M hldorfer, A. Kurth, W. Bogdanowicz, C. Borel, and T. Bosch. 2011. Pan-European Distribution of White-Nose Syndrome Fungus (Geomyces destructans) Not Associated with Mass Mortality. PLoS ONE 6:e19167.
- **Reeder**, D., C. L. Frank, G. G. Turner, and C. U. Meteyer. 2012. PLOS ONE: Frequent Arousal from Hibernation Linked to Severity of Infection and Mortality in Bats with White-Nose Syndrome. PLoS ONE 7:e38920.
- **Speakman**, J. R., D. W. Thomas, T. H. Kunz, and M. B. Fenton. 2003. Physiological ecology and energetics of bats. Pages 430–492 in T. H. Kunz and M. B. Fenton, editors. Bat Ecology. University of Chicago Press, Chicago.
- **Verant**, M. L., J. G. Boyles, W. Waldrep, G. Wibbelt, and D. S. Blehert. 2012. Temperature-Dependent Growth of Geomyces destructans, the Fungus That Causes Bat White-Nose Syndrome. PLoS ONE 7:e46280.
- **Warnecke**, L., J. M. Turner, T. K. Bollinger, J. M. Lorch, V. Misra, P. M. Cryan, G. Wibbelt, D. S. Blehert, and C. K. R. Willis. 2012. Inoculation of bats with European Geomyces destructans supports the novel pathogen hypothesis for the origin of white-nose syndrome. Proceedings of the National Academy of Sciences 109:6999–7003.
- **Willis**, C. K. R., A. K. Menzies, J. G. Boyles, and M. S. Wojciechowski. 2011. Evaporative Water Loss Is a Plausible Explanation for Mortality of Bats from White-Nose Syndrome. Integrative and Comparative Biology 51:364–373.

Bat monitoring programmes in the UK: achievements and perspectives

Karen A. Haysom, Kate E. Barlow,
Philip A. Briggs, & Steve D. Langton
Bat Conservation Trust, Quadrant House, 250 Kennington Lane, London, SE11 5RD, UK.

Summary

The National Bat Monitoring Programme (NBMP) is the UK's principal tool for assessing population change in bats, and was established in 1996 to provide early warning of species declines and evidence to support conservation action and government reporting obligations. The NBMP is an integrated programme of volunteer-based surveys, producing population trends for 11 of the UK's 17 breeding species. This paper outlines the development of the programme, the survey and data analysis methods used, support of the volunteer network, and how results are reported. Finally, we show how the data have been used in research and discuss major achievements and future challenges.

Introduction

In the UK, as in much of western Europe, populations of many bat species are considered to have undergone severe declines during the latter half of the twentieth century, due to pressures such as land-use change, agricultural intensification, toxic timber treatment in buildings and the deliberate or accidental loss of roosts (Haysom et al. 2010). During the period of most rapid population change however, bats were an understudied taxon, and documented evidence of declines in abundance and, for some species, range contraction comes from a small number of experts (e.g. Racey & Stebbings 1972, Stebbings 1988, Ransome 1989). Bat conservationists lacked a fundamental tool, a robust, standardised, national, surveillance programme, capable of detecting the early signals of species decline so important for triggering appropriate conservation action. A national surveillance programme was also needed by the UK government to measure and report progress against targets set in the national biodiversity strategy and European level directives and agreements.

The UK's National Bat Monitoring Programme (NBMP) was first established by the Bat Conservation Trust (BCT) in 1996 (Bat Conservation Trust 2001). It began as a five-year research project funded by the Department of the Environment, Transport and the Regions (DETR) to develop, test and implement methods for monitoring eight target species using a network of trained volunteer surveyors. Since 2001, NBMP has continued as a partnership between BCT and Joint Nature Conservation Committee (JNCC), and in 2012 the partnership expanded to include two further government agencies, Countryside Council for Wales (CCW) and the Department for Environment, Food and Rural Affairs (Defra). The NBMP is now the UK's longest running purpose-built mammal surveillance programme, delivering statistically robust population trends for 11 of the 17 bat species known to breed in the UK. The NBMP owes its success to the time contributed generously by hundreds of volunteer surveyors. Since the start of the programme, more than 5800 sites have been surveyed in total across all core surveys (Figure 1). The number of volunteer surveyors has increased substantially since the programme was established (Figure 2); more than 1000 surveyors now return data from over 2000 sites in a typical year.

Survey methods

The overall aim of the NBMP is to run annual and periodic monitoring of bats to determine the population status of individual species and deliver a range of information and reporting needs for UK and country biodiversity strategies, and obligations under the EU Habitats Directive. NBMP is an integrated programme incorporating four core surveys (Table 1). For the majority of species in the programme, bats are surveyed in more than one stage of their annual life-cycle by different surveys e.g. R. hipposideros is monitored by both the Colony Count and Hibernation Survey. These core surveys collect quantitative data on counts of individuals or "bat passes" heard on a bat detector, from which population trends are calculated. The Colony Count and Hibernation Surveys take place at sites selected by the surveyors, but the two detector surveys take place at allocated sites within a 10km radius of the surveyor's home. For the Field Survey the sites are allocated from a randomly generated list of grid references stratified by land-use type, while for the Waterway Survey sites are selected randomly from a list of locations previously surveyed as part of the Environment Agency's River Habitat Survey (Raven et al. 1998).

In addition to these national core surveys, the NBMP team administer several other survey activities including the Sunset /Sunrise survey,

an engagement survey available to everyone, including those with no previous experience and a distribution survey for P. nathusii focused on large lakes. Another example, the first large-scale systematic distribution survey for Myotis bechsteinii, was a catching survey that demanded very high levels of skill, and operated between 2008 and 2011. The overall ethos of the NBMP is an inclusive, integrated framework of surveys, open to volunteers with a broad range of abilities, underpinned by a strategic training plan to enable volunteer development and ensure the continuity of site coverage at a national scale.

Data analyses

The key outputs from the NBMP are annual population trend estimates for the species monitored. To deduce long-term population trends for each individual species, General Additive Models (GAMs) are used to fit a smooth line to each dataset according to Fewster et al. (2000). Annual fluctuations and extreme outliers can have an unacceptably large impact on the first and last years of GAM trends, and to counteract this potential problem, the year 1999 has generally been used as the baseline. The estimate for the most recent year is regarded as provisional. Various factors including the model of bat detector used, temperature on the night of the survey, or the duration of the survey, have the potential to influence the yearly means. Their impact is investigated first through generalised linear mixed models (GLMMs), and those that are statistically significant are subsequently included in GAMs as covariates.

For the majority of species, which are surveyed by two methods, two separate trends are produced and reported. This approach was taken during the development of the programme to provide information on the veracity of individual surveys but has been retained in the longer term in recognition that species are vulnerable to different pressures at different phases of the life cycle, and that complementary information can be derived by running two surveys in parallel (BCT 2001). Different potential biases are relevant to different techniques so, where both trends are in close agreement, a high level of confidence in the interpretation of the results is obtained.

Maintaining a network of surveyors

The NBMP was originally designed to detect population trends at UK level, and power analyses conducted as part of its development estimated that a minimum core of 30-40 sites where the species is present should be surveyed in each year to maintain the ability of each species survey to detect changes effectively (BCT 2001). Volunteer recruitment, retention and adequate skills are therefore vital components of the successful operation of NBMP. For optimising statistical power, maintaining continuity of both the site and its surveyor in a survey is also an important aim.

Geographical gaps in survey coverage are reviewed each year as part of the training strategy. Free or low-cost bat detector workshops are made available to prospective volunteers in areas with low densities of surveyors, and on request to local bat groups to provide training for volunteers to develop the skills required for the Field and Waterway Surveys. The longest running training workshop, Using your Ears, teaches surveyors to use heterodyne bat detectors to identify five species of bats in the field. Approximately 26% of training course attendees participate in the programme and return data at least once after attending a workshop, a figure that appears to compare well with the training courses for other biodiversity surveillance schemes in the UK. Turnover of surveyors at sites may be high, however, and training must therefore be available across the country to ensure new surveyors are brought into the programme and to refresh the skills and enthusiasm of existing volunteers. The number of training workshops that can be delivered each year has been increased by training and supporting a network of volunteer trainers across the UK, making it possible to run 26 bat detector workshops in 2011.

More recently, training courses that focus on how to undertake a specific survey have achieved greater success in getting trainees to participate in the surveys and return data. Online survey tutorials have been developed to supplement and reinforce these survey-specific workshops, incorporating video clips to build surveyor confidence in implementing all elements of the survey from setting out the survey route, to using equipment to identify the target species in the field and completing the survey form.

Outputs and communication of results

The principal output of the programme is an annual technical report which includes a detailed account of the latest population trends, and is now produced as an online report http://www.bats.org.uk/pages/nbmp_annual_report.html. In this report we provide general information on the distribution, legal and conservation status of each species, the surveys used to assess its population

trend and population trend graphs displayed for the UK, or at country or regional levels where sufficient data permit. The outputs from this report are of direct use to government agency technical experts and conservation practitioners; results have contributed to reporting against the UK biodiversity strategy, the UK annual report to the EUROBATS agreement, and in Article 17 reporting rounds.

Since 2004, a short summary report, the State of the UK's Bats has been targeted at policymakers and the public. This provides an overview of results, and profiles of individual surveys or research work based on NBMP data. The report style is intended to be accessible to a wide readership, and trends are displayed without technical statistical detail (Figure 3). The publication of this report is often accompanied by a press release to increase the profile of the programme and the underlying conservation messages.

A further development for the wide-reaching communication of bat population trend information has been the development and adoption of a UK biodiversity indicator based on NBMP data. Biodiversity indicators are simple summary statistics to communicate core messages to policy makers and the public. Bat populations are considered highly relevant as indicators of the health of the environment, since they are responsive to a wide range of pressures that also affect other taxa (Jones et al. 2009). The UK government has a suite of biodiversity indicators, official statistics that are published each May to report against national targets on the state of the environment, and delivery of biodiversity strategy (JNCC 2012). An index of populations of widespread bat species has been developed, from the combined trends of six widespread species. The 17% increase in this index since 2000 is presented with contextual information outlining the previous major declines of many species.

Supporting additional evidence needs

Although the primary purpose of establishing the NBMP was to enable the detection of population change, with particular emphasis on the provision of an IUCN style red and amber alert system (BCT 2001), other types of information are needed by conservationists for developing strategy and to address reporting obligations. These include information on species range and distribution, coarse and fine-scale habitat associations and the pressures driving population change. Individual stakeholders such as the UK's constituent country agencies may have additional needs such as a requirement for data at a range of nested scales (e.g. UK, country, regional, local) and information to support decisions on the current and future management of protected sites or the wider countryside. Other stakeholders in NBMP information include voluntary local bat-groups. In relation to distribution data, species records are mobilised on an annual cycle to the UK's National Biodiversity Network (NBN), from which they become available for purposes such as informing planning or the allocation of Agri-Environment Scheme payments, and reporting on Article 17 and biodiversity strategies. Local bat groups can receive distribution data on request. The principle of sharing data is important as a model for encouraging general data exchange, since in the UK there are many privately held sources of species data, which are not all available for supporting conservation.

To extend the use of NBMP data, past and on-going research collaborations have been used to model species habitat associations, and to seek to understand better the factors that influence population change. Through GIS-based modelling approaches, Boughey et al. (2011a) defined more clearly the associations between P. pipistrellus and P.pygmaeus and linear features. This examination of NBMP Field Survey data at a national scale showed that use by P. pygmaeus was related to tree density within the hedgerow and closeness to woodland, and is one of the few studies in the UK that has demonstrated the additional value of hedgerow trees within a boundary to biodiversity. A similar approach to comparing habitat composition surrounding summer roosts of six bat species surveyed by the NBMP Colony Counts with random locations not known to be roosts has quantified relationships with broadleaved woodland proximity and extent (Boughey et al. 2011b). Ninety percent of roosts of P. pipistrellus, P. pygmaeus, R. hipposideros, E. serotinus and M. nattereri occurred within 440m of woodland, significantly closer than expected by chance.

Since the start of the survey, the allocation of sites for the Waterway survey has been matched to stretches of waterway in the Environment Agency River Habitat Survey (RHS) which collects data on a large number of aquatic chemical and biodiversity features and describes the surrounding riparian vegetation (Raven et al. 1998). This has enabled predictive models of the occurrence of Daubenton's bat to be developed and tested (Langton et. al. 2010). Daubenton's bat

activity was higher on larger waterways close to extensive woodland, and was significantly related to aquatic macro-invertebrate diversity.

Achievements and future challenges

Bat surveillance presents obvious challenges, such as the need to survey at night, the difficulty of identifying species, and the need to purchase specialist equipment. Despite these difficulties, we have established a successful programme that generates population trends for more than half the UK's bat species. More than 3000 people have participated in the programme since it began, and the training provided will also have bolstered bat conservation at a local scale by improving the skill-set of volunteer bat-workers. Volunteer-based monitoring schemes also play an important role in connecting people with their natural environment. It is powerful to relate to policy-makers that people care sufficiently about bats to contribute more than 45000 hours in 2011 to their surveillance in the UK. These statistics are supplied to the UK government indicator on volunteer time spent in conservation (JNCC 2012).

The NBMP collaborates on the development of approaches to make bat monitoring more accessible and effective. The Indicator Bats Program iBats (Jones et al. 2011), a Zoological Society of London (ZSL) and BCT project to establish car-based monitoring exemplifies this, and has been used in the UK and internationally for rapid generation of bat species record data in areas where few volunteer surveyors or bat specialists are available. Volunteers drive transects at a standardized speed, in vehicles fitted with a time expansion bat detector connected to a digital recording device and a GPS system. Each bat call recorded is geo-referenced automatically and species are identified by sonogram analysis. Since very large numbers of bat calls are accumulated, a central challenge has been to develop an automated identification system to standardise the interpretation of call data (Walters et al. 2012). Since much of the process from data collection, through data upload and identification is automated, the volunteers who participate in the survey do not have to be skilled in bat identification.

Being able to report species trends at a range of scales is important. The UK biodiversity strategy is now devolved to the four component countries, and with this comes the need to measure progress against the strategies at country level. Currently trends can be produced for 11 species at UK and England level, but sparser volunteer coverage gives insufficient power to report trends for most individual species in Scotland, Wales, or Northern Ireland. Further investment in volunteer training and support is needed in these countries. It would also be strategically useful, and aid the interpretation of data and our understanding of the drivers of trends, to achieve sufficient power to deduce habitat specific trends. However, despite the integrated nature of the programme, NBMP does not cover all UK species. One group, the woodland specialists, remains particularly elusive due to the technical challenges of detecting species that have quiet echolocation calls and separating the Myotis group to species. On-going research is investigating how to generate an approach for the long-term national surveillance of woodland species by volunteer surveyors.

A further challenge is ensuring the continued modernisation and improvement of the programme whilst maintaining consistency of data collection over a long-time period. It is the experience of long term surveillance programmes for many taxa that after a protocol has been established with the best available techniques, surveillance methods improve, but the protocol cannot be continually changed where the objective is to identify change over long periods of time. This is particularly an issue for surveillance using bat detectors as new models become available, including technologies that facilitate more accurate and or more standardised recording. BCT is exploring how to integrate new technologies into the programme in the future while maintaining the integrity of historic data. Similarly improvements are being made to the process of data collection, with online data entry systems in development to improve the volunteer experience and make the process of data capture more efficient.

Finally it remains important for bat conservation that the outputs of monitoring are communicated to wide audiences and become of mainstream interest, not only nationally but internationally, able to measure progress against wider-scale commitments such as the European Biodiversity Strategy. However, although there are a large number of separate national and regional species monitoring efforts across Europe (Haysom 2008) there has been relatively little opportunity for communication between the different scheme organisers since there is no equivalent of the European Bird Census Council (EBCC) (EBCC 2012) or co-ordinated framework such as the Pan European Common Bird Monitoring Scheme

(PECBMS). Important steps towards this were taken with the launch in 2011 of BatLife Europe (BatLife Europe 2011), a pan European NGO and the commissioning by European Environment Agency (EEA) of a prototype biodiversity indicator to represent trends in the populations of European bats (Haysom et al. 2011). In this project, NBMP hibernation data were brought together with similar data from ten schemes from nine other European countries. The process of building the indicator was based on methods developed by Statistics Netherlands for birds and butterflies, with individual countries using the statistical programme TRIM to generate national species trends which were aggregated to form European species trends and then a combined index. It is hoped that the European indicator will be rapidly expanded and refined to represent at least fifteen countries and provide national schemes like those of the UK with a further context against which to interpret population change.

Acknowledgements

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References

- **Bat** Conservation Trust. (2001). The UK's National Bat Monitoring Programme — Final report 2001. DEFRA Publications, PB 5958A, Bat Conservation Trust, London.
- **BatLife** Europe (2011) (http://www.batlife-europe.info/ . Accessed October 2012.
- **Bat** Conservation Trust. (2012) National Bat Monitoring Programme Annual Report 2011. http://www.bats.org.uk/pages/nbmp_annual_report.html
- **Bat** Conservation Trust (2012). The State of the UK's Bats. National Bat Monitoring Programme Population Trends 2012. Bat Conservation Trust, London. http://www.bats.org.uk/publications_download.php/1182/NBMP_Summary_2012_web.pdf.
- **Boughey**, K.L., Lake I.R., Haysom, K.A., Dolman, P.M. (2011a). Improving the biodiversity benefits of hedgerows: how physical characteristics and the proximity of foraging habitat affect the use of linear features by bats. Biological Conservation, 144, 1790-1798.
- **Boughey**, K.L., Lake, I.R., Haysom, K.A. & Dolman, P.M. (2011b) Effects of landscape-scale broadleaved woodland configuration and extent on roost location for six bat species across the UK. Biological Conservation, 144, 2300–2310.
- **EBCC** 2012. What is the European Bird Census Council http://www.ebcc.info/what.html . Accessed October 2012.
- **Fewster**, R.M., Buckland, S.T., Siriwardena, G.M., Baillie, S.R. & Wilson, J.D (2000). Analysis of population trends for farmland birds using generalized additive models. Ecology, 81, 1970-1984.
- **Haysom**, K.A. (2008). "Streamlining European 2010 Biodiversity Indicators (SEBI 2010)": Developing a methodology for using bats as indicator species; and testing the usability of GBIF data for use in 2010 biodiversity indicators. Contract EEA/BSS/07/008. Report to European Environment Agency.
- **Haysom**, K.A., Jones, G., Merrett, Racey, P.A. (2010). Bats. In: Silent Summer: The State of Wildlife in Britain and Ireland. (Ed. Maclean, N.), p259-280. Cambridge University Press.
- **Haysom**, K., Dekker, J. Russ, J. van der Meij, T. & van Strien, A. (In review). Support for a project on 'Streamlining European Biodiversity Indicators (SEBI)': Development of a prototype indicator of European bat population trends. European Environment Agency Technical Report Series. European Environment Agency, Copenhagen.
- **Jones**, G., Jacobs, D.S., Kunz, T.H., Willig, M. R. & Racey, P.A. (2009). Carpe noctem: the importance of bats as bioindicators. Endangered Species Research, 8, 93-115.
- **Jones**, K.E., Russ, J.A., Bashta, A-T., Bilhari, Z., Catto, C., Cs_sz, I., Gorbachev, A., Gy_rfi, P., Hughes, A., Ivashkiv, I. , Koryagina, N., Kurali, A., Langton, S., Maltby, A., Margiean, G., Pandourski, I., Parsons, S., Prokofev, I., Szodoray-Paradi, A., Szodoray-Paradi, F., Tilova, E., Walters, C., Weatherill, A. & Zavarzin, O. (2011). Indicator Bats Program: a system for the global acoustic monitoring of bats. In: Biodiversity monitoring and conservation: bridging the gaps between global commitment and local action (Eds. Collen, B, P. et al.). Blackwell Press, London.
- **JNCC** (2012). UK Biodiversity Indicators in Your Pocket (BIYP). http://jncc.defra.gov.uk/page-4229 . Updated 29.05.12
- **Langton**, S.D., Briggs, P.A., Haysom, K.A. (2010). Daubenton's bat distribution along rivers-developing and testing a predictive model. Aquatic Conservation: Marine and Freshwater Ecosystems, 20, S45-S54.
- **Racey**, P.A. & Stebbings, R.E. (1972). Bats in Britain – a status report. Oryx, 11, 319-327.

- **Raven**, P.J., Holmes N.T.H., Dawson F.H., Everard M. (1998). Quality assessment using River Habitat Survey data. Aquatic Conservation: Marine and Freshwater Ecosystems, 8, 477–499.
- **Ransome**, R.D. (1989). Population changes of Greater Horseshoe bats studied near Bristol over the past twenty-six years. Biological Journal of the Linnean Society, 38, 71-82.
- **Stebbings**, R.E. (1988). Conservation of European Bats, London, Christopher Helm.
- **Walters**, C.L., Freeman, R., Collen, A., Dietz, C., Brock Fenton, M., Jones, G., Obrist, M.K., Puechmaille, S.J., Sattler, T., Siemers, B.M., Parsons, S. & Jones, K.E. (2012). A continental-scale tool for acoustic identification of European bats. Journal of Applied Ecology, doi: 10.1111/j.1365-2664.2012.02182.x.

Figures

Fig. 1. *Distribution of sites surveyed by National Bat Monitoring Programme since 1996.*

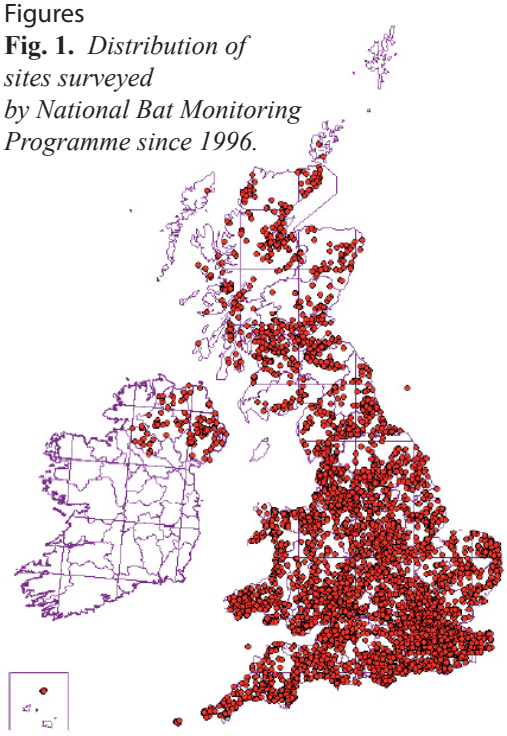

Fig. 2. *Annual volunteer surveyor participation in the National Bat Monitoring Programme.*

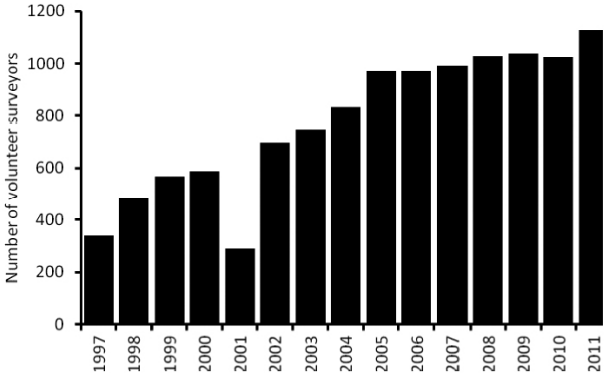

Fig. 3 *Population trends of bat species surveyed in the National Bat Monitoring Programme i) Species listed as priorities (UK BAP species) in the UK Biodiversity Action Plan. ii) All other species.*

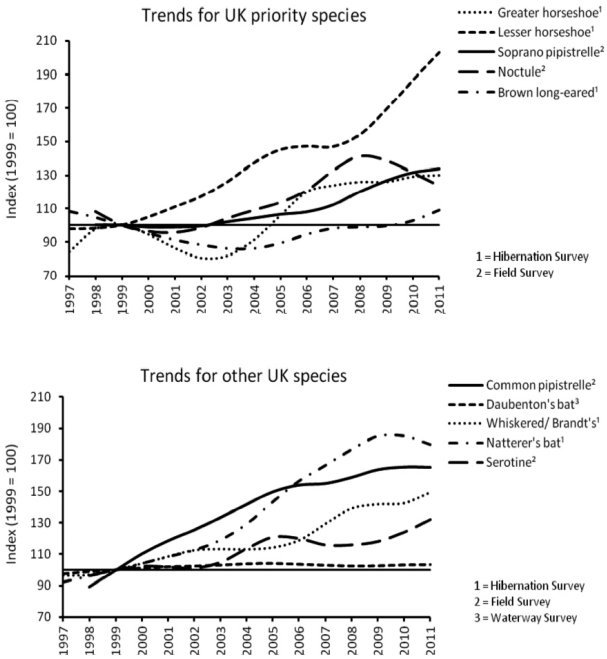

Table 1. *Summary information on the National Bat Monitoring Programme (NBMP) core surveys.*

Survey Name	Method	Species covered
Colony Count (to be renamed Roost Count in 2013)	*Emergence counts at summer roosts*	*Pipistrellus pipistrellus, P. pygmaeus, Plecotus auritus, Eptesicus serotinus, Myotis nattereri, Rhinolophus ferrumequinum, R. hipposideros,*
Field Survey	*Bat detector survey incorporating points and transects*	*Nyctalus noctula, E. serotinus, P. pipistrellus, P. pygmaeus*
Waterway Survey	*Bat detector survey at points on transect*	*Myotis daubentonii*
Hibernation Survey	*Counts of animals hibernating in natural and man-made winter roosts*	*Rhinolophus ferrumequinum, R. hipposideros, M. daubentonii, M. nattereri, M. mystacinus / brandtii, P. auritus*

Large scale bat monitoring programmes and policies

Marie-Jo Dubourg-Savage
Société Française pour l'Etude et la Protection des Mammifères (SFEPM). France

The dramatic decline of cave-dwelling and forest bat populations in the mid 1950s was the incentive for the protection of bats in Europe. Amongst several international conventions signed by most European states, it is worth mentioning the CMS (Convention on the Conservation of Migratory Species of Wild Animals) and its specific Agreement on the Conservation of Populations of European Bats, called EUROBATS. As the geographic range of European bats extends to some countries in North Africa and the Middle East, the states concerned have been invited to join the Agreement to fulfil the efforts of conservation.

In the European Community, the Directive 92/43/EEC on the Conservation of Natural and Semi-natural Habitats and of Wild Flora and Fauna is also an important tool for the conservation of bats as it aims to set up a network of protected areas (Natura 2000 sites). It boosted the research on bats through species inventory and also developed public awareness of the importance of this group of fauna.

The need for cooperation

EUROBATS Intersessional Working Groups (IWGs) stressed the necessity of developing European cooperation regarding both research on bats and tools for the protection of bats. Some countries have years of experience in these fields (some on scientific research, others focussing more on conservation) and could share their knowledge with countries just starting to take account of bats in their policies.

The issues of global warming, emerging zoonoses, newly discovered bat species and bat migration highlight the importance of working together at European level and the requirement for surveillance and monitoring programmes of bat populations.

Two examples will show the importance of international cooperation:

In spring 2002 *Miniopterus schreibersii* went through a massive die-off in Portugal, Spain and France. Apparently Italian populations were not concerned but France lost about 10 000 Schreiber's bats in a few weeks (Roué & Némoz 2002). In 2011 the discovery in Miniopterus schreibersii of a new filovirus called LLOV put forward the hypothesis that this virus could have caused the 2002 massive mortality (Negredo et al. 2011).

More recently, from 2006 onwards, 5.7 million bats died from White Nose Syndrome in 21 U.S. states and in 4 Canadian provinces (Source: BCI 23/08/2012). The origin of these deaths goes back to a European fungus Geomyces destructans possibly brought by accident to the USA. Some bats have been observed in Europe with evidence of this fungus, but only some cases of mortality have been recorded so far (Puechmaille et al. 2011) and therefore we cannot speak of a "syndrome" in Europe.

EUROBATS guidelines

EUROBATS has published various guidelines on underground roosts, on wind turbines and on overground roosts. The most recent of these publications, "Guidelines for Surveillance and Monitoring of European Bats", gives the latest information compiled by EUROBATS experts and is summarized here.

These guidelines present basic information on setting up surveillance and monitoring schemes. For example, how to assess occurrence and abundance of species, frequency of data collection, size of the survey area, choice of species to survey, sensitivity and power of the planned survey and its biases. They also show how to collect, manage, validate, store and analyse data. Different methods of surveillance are described: bat counts at hibernation and maternity roosts, at swarming sites and emergence counts. Their pros and cons are listed as well as their suitability according to species. Ultrasonic detecting surveys are dealt with to assess foraging activity or commuting of bats, using walked transects, point counts, car transects or by automatic recording of calls. Examples of a national monitoring programme are given for most methods. Each bat species occurring in Europe is presented with its distribution map and the recommended methods for its monitoring are listed.

Finally some countries have reported their own monitoring programmes and the methods used for particular species.

Some large scale monitoring programmes

It is worth mentioning some projects that rely on European cooperation, either for monitoring

and identify trends in bat populations or for research with conservation as the final goal.

● Pan-European Monitoring of Bats in Underground Sites (PEMBUS)

This programme was initiated by EUROBATS and its Advisory Committee charged the Bat Conservation Trust (UK) with carrying out a feasibility study.

The main aim of this project was to set up a system for regularly providing population indices for bat species, based on hibernation counts at important and less important underground sites.

This project would have been a framework for managing information at European level and would have provided qualitative information about a certain number of sites in Europe. It would have delivered training in all monitoring methods in line with Eurobats guidelines. It was due to be managed and coordinated by a new structure that had not been created then: BatLife Europe. The feasibility study lasted 6 months but it was not possible to find the funds necessary to start with the project (Guziak & Battersby 2008). However, PEMBUS is still on BatLife agenda.

● Indicator Bats Programme (iBats)

A partnership between the Zoological Society of London and the Bat Conservation Trust in cooperation with some national NGO's, iBats uses bat detector car surveys for monitoring some of the most common species. The aim of this partnership is to track changes in bat biodiversity. Many protocols and free software can be downloaded from the website http://www.ibats.org.uk.

Car survey programmes are also performed in Ireland, France and in many countries from Central and Eastern Europe.

● Development of a prototype indicator of European bat populations trends

This project is a follow-up of the iBats programme and is a partnership between the Bat Conservation Trust, the Dutch Mammal Society, Statistics Netherlands and BatLife Europe. Its aim is to develop an indicator to evaluate the trends of bat populations. Ten organisations from Austria, Germany (2), Hungary, Latvia, the Netherlands, Portugal, Slovakia, Slovenia and the United Kingdom have contributed to the prototype indicator that has been submitted to the European Environment Agency (Haysom et al. 2012).

● European Bat Migration Project

In 2008 the Leibniz Institut for Zoo and Wildlife Research (IZW) in Berlin started a project on European bat migration using stable isotopes in the fur of long distance migrating female bats. Information has been collected from isotopes in the fur of bat species resident in Europe, together with isotopes from migrating bats, and from museum specimens of bats found dead during migration. Using this information it should be possible to produce a map of migration patterns across Europe to explain the different migrating strategies of species and identify regions and habitats that are essential for the conservation of the species concerned (Popa-Lisseanu et al. 2012). In 2012 the project is focussing on *Pipistrellus nathusii*, a species that pays a high toll to wind energy on its migration routes. This isotopic approach of bat migration could also help identify the origin of some sub-populations of the Greater Noctule Bat.

● European co-operative research needed for *Nyctalus lasiopterus*

The Greater Noctule Bat *Nyctalus lasiopterus* is one of the rarest bat species in Europe and one for which very few ecological data are available except in Southern Spain (Popa-Lisseanu, 2007). While males are quite well widespread in Southern Europe, reproduction only seems to be documented in four countries: Spain, Hungary, France and Ukraine.

Research on the ecology and behaviour of this species is urgently needed as its migration status is not even confirmed and in France, for example, at least three individuals were killed by wind turbines before the discovery of their roosts. Classified as Near Threatened (NT) by the IUCN, assessment of Greater Noctule distribution, surveillance and monitoring of the known roosts and scientific research should be a priority and this implies cooperation at European level.

References
- **Battersby** J. (comp.) (2010). Guidelines for Surveillance and Monitoring of European Bats. EUROBATS Publication Series N° 5. UNEP/ EUROBATS Secretariat, Bonn, Germany, 95 pp.
- **Guziak** R. & Battersby J. (2008). The Pan European Monitoring of Bats in Underground Sites: A Feasibility Study. Bat Conservation Trust, 37 pp.
- **Haysom** K., Dekker J., Russ, Jon, van der Mej T. & van Strien A. (2012). Development of a prototype indicator of European bat population trends. Draft report to the European Environment Agency, 62pp.
- **Negredo** A, Palacios G, Vázquez-Morón S, González F, Dopazo H, et al. (2011). Discovery of an Ebolavirus-Like Filovirus in Europe. PLoS Pathog 7(10): e1002304. doi:10.1371/journal.ppat.1002304
- **Popa-Lisseanu** A.G. (2007). Roosting behaviour, foraging ecology ans the enigmatic dietary habits of the aerial-hawking bat Nyctalus ladiopterus. PhD Thesis. Universidad de Sevilla. Sevilla, Spain
- **Popa-Lisseanu** A.G., Sörgel K, Luckner A., Wassenaar L.I., Ibáñez C, Kramer-Schadt S., Ciechanowski M., Görföl T., Niermann I., Beuneux G., Mys_ajek R.W., Juste J., Fonderflick J., Kelm D.H., & Voigt C.C. (2012) A Triple-Isotope Approach to Predict the Breeding Origins of European Bats. PLoS ONE 7(1): e30388. doi:10.1371/journal.pone.0030388
- **Puechmaille** S.J., Wibbelt G., Korn V., Fuller H., Forget F., et al. (2011). Pan-European Distribution of White-Nose Syndrome Fungus (Geomyces destructans) Not Associated with Mass Mortality. PLoS ONE 6(4): e19167. doi:10.1371/journal.pone.0019167
- **Roué** S.Y. & Némoz M. (2002). Mortalité exceptionnelle du Minioptère de Schreibers en France lors de l'année 2002. Bilan national. SFEPM, Paris, 28 pp.

Calculating a European bat indicator: following birds and butterflies

Tom van der Meij
Statistics Netherlands

Summary

In 2011 the European Environmental Agency supported a project to establish a first prototype for the European Bat Indicator. The British Bat Conservation Trust executed this project in cooperation with the Dutch Mammal Society and Statistics Netherlands. Nine counties participated in the making of this indicator, based on bat counts in hibernacula and statistical methods and procedures designed by Statistics Netherlands.

After birds and butterflies, bats are now the third species group for which a European indicator is being developed. Just like with the birds and butterflies the development of this indicator stimulates the international cooperation between non-governmental organizations, helps building methodological and analytical capacity and stimulates public and political awareness of the importance of biodiversity and protection of the species in concern.

Introduction

In the European Union wildlife is protected by – among others - the Habitats Directive (HD) and Bird Directive (BD). Both directives are accepted and ratified in all member states and each member state is obliged to report regularly about the favorable conservation status of its protected species. Unlike other EU policy areas like economic affairs or agriculture, there is no long tradition to integrate information for flora and fauna on the level of the EU as a whole. Moreover, in most member states collecting data about protected species depends heavily on volunteers and non-governmental organizations (NGO's). Despite the obliged character of the reports for the Birds and Habitats Directives, governmental support is usually low and often not structural. Supporting integration of information on the level of individual countries to information on a higher level is not a national obligation and does not have a high priority for the EU administration. As a result European indicators for flora and fauna are scarce.

NGO's in many countries organized wildlife counts even before the Birds and Habitats Directives came into force. Due to differences in culture, tradition and income, the size and strength of the NGO's was and still is different from country to country. Unique for the situation

in the Netherlands was that NGO's received early support by the governmental bureau of Statistics Netherlands for their monitoring activities. Because of this cooperation, Statistics Netherlands became acquainted with and searched for solutions for typical statistical problems of wildlife monitoring: missing data and poor representativeness. As a result a tailor made program was built to cope with these problems and to ease the statistical analysis of wildlife count data. The first release of this program, called TRIM (TRends and Indices for Monitoring data, Pannekoek & Van Strien, 2001), was in the early nineties. It analyses time series of counts, using Loglineair Poisson regression (a form of generalized linear modeling), estimates missing values and produces yearly time totals, indices, trends and standard errors. In order to cope with under- or oversampling of regions or plot types TRIM was also made capable of using weight factors per plot. To make it more convenient for internal use on different scales in the Netherlands a special version of TRIM was produced with a multi-stage approach to calculating trends. Precisely this version offered a unique opportunity for combining national trends and indices to a European level.

The development of the
European Farmland Bird indicator

In the eighties a plan arose in international meetings of bird-NGO's to calculate European trends and indices. This was impossible at that time because it required a combined database with basic counts data of all participating countries, under the condition that all count data would be comparable with respect to the population size they represent. At that time this was not feasible because monitoring methods were not standardized and NGO's were very reluctant to share their basic data. Basic data is generally regarded as 'capital' of the NGO's that should not be given away.

TRIM however, offered a solution to both problems. TRIM is able to collate trends and indices by using standardized output of previous TRIM runs (time totals and standard errors) instead of basic data. In other words: if individual countries only provide standardized TRIM output, calculation of combined trends is possible. Furthermore, the incomparability of data can - to a certain extent - be solved by using weights factors in TRIM, based on (estimates of) population sizes in countries. European trends and indices are then within reach when all countries use TRIM to provide standard output, when they are willing to share this output and when population sizes are available to weigh the output of countries relative to each other.

In 1998 a pilot was performed to test whether a framework could be built to perform the combination of TRIM output and to see if this would result in credible European trends for bird species. Trends were calculated for five farmland species in seven countries over a period of 20 years. The results of this first pilot were compared to other methods of trend calculating and proved to be very promising (Van Strien et al., 2001). In the follow up of this project more countries joined in, more species were taken into consideration and several levels of combining trends were introduced. In an additional and final step, a single indicator for birds was calculated by taking the geometric averages of the European indices of individual species (Gregory et al., 2005, Van Strien et al., 2011).

The work on the European bird indicators not only stimulated more countries to join in, but it also helped developing capacity for monitoring and trend calculation in many countries. Whereas the first pilot indicator in 1998 was based on input from seven countries, nowadays the indicator is based on the input of more than 25 countries.

Another positive effect was that considerable political attention was given to the results. It fitted perfectly in the framework of the Streamlining European Biodiversity Indicators (SEBI) process. In less than ten years after the first pilot this resulted in the establishment of the Farmland Bird Indicator as the first official integrated European wildlife indicator, adopted by EU regulation (Gregory et al., 2008).

Offspring of the EU bird indicator

In the slipstream of the EU bird indicator projects, international conferences and workshops were organized, statistical and methodological training of European NGO's was provided and a European support centre was initialized. To support individual countries and NGO's in using TRIM an MS Access application was built to ease and standardize analyzing bird and other wildlife count data with TRIM. Together with TRIM this application, BirdStats, is freely available on the internet (www.EBCC.info/trim.html).

Stimulated by the success of the European bird indicators several NGO's involved in butterfly monitoring in Europe, started the same process to establish a European butterfly indicator. Again, Statistics Netherlands built the analytical framework, did the first analyses and combined trends on different levels into a European butterfly indicator for grasslands (Van Swaay, 2009).

The latest offspring was in 2011, when the European Environmental Agency financed a project to built a first prototype of a European bat indicator. The work was carried out by the British Bat Conservation Trust (BCT), the Dutch Mammal Society (MS) and again Statistics Netherlands provided essential support.

Composing the prototype European bat indicator

For the composition of the prototype EU bat indicator counts in hibernacula from nine countries, 16 species and 19 years were used (Haysom et al., 2011). Data represents a total of around 6000 sites, approximately 2300 of which are monitored yearly by a network of more than 760 volunteers. Countries involved are shown in figure 2.

Before combining the indices to the European level, national results were combined into four regions: Atlantic, boreal, continental and Mediterranean, followed by combining these regions into European trends and indices. In all levels of combining, estimation of missing values and comparing with population sizes took place. Estimation of missing values is necessary for indices that are not biased by missing data. By doing this on every level, estimation of missing values in every country is based on other results in this country only and estimation of missing data in a region is based on other results within the region.

In order to be able to compensate for different sample sizes in the participating countries weighting is necessary. The time totals output for each country represent the populations of each country and ideally the relative population sizes per country would be used as weight factors to compensate for unequal sampling. Unfortunately, population sizes per country for bat species are not known or highly unreliable. To be able to weigh between countries the relative distribution area of bat species per country were used as an estimate for population size.

Resulting European bat indices and bat indicator

On a European level, 9 species monitored in hibernacula showed a positive trend (Haysom et al., 2011). Only *Plecotus austriacus* showed a moderate decline (Table 1). For two species, *Myotis bechsteinii* and Eptesicus nilssonii, no European species trend could be determined, probably due to high between-year variation. Four species' populations appear stable.

The resulting prototype of the hibernating bat indicator showed a positive trend for bats as a group (figure 2). Due to the preliminary nature of this prototype indicator, the early conclusion that bats have increased at hibernation sites, should be interpreted with great caution until the indicator can be expanded to cover a more representative range of European countries and species, and elements of the methodology need to be further refined. One of these refinements concerns the crude weighting procedure that was applied. Due to the tight time schedule of the project, using readily available distribution areas was practically the only option. Another refinement may come from incorporating other monitoring methods than hibernacula counts only. The indicator is based on less than 40% of all European species. To represent a broader spectrum of European species, would require more countries to join in and data from methods e.g. summer roosts or point and transect counts with bat detectors. Inclusion of such data in the framework of the indicator is not a technical problem, but some prudence is necessary to be able to cope with ecological and other peculiarities of bat monitoring. More countries may also refine the geographic regions classification that was used.

Although only in the first stage of its development, the making of the bats indicator already stimulated the international cooperation between national bat NGO's, and helped building methodological and analytical capacity in some countries. Further development of the indicator will improve its credibility and impact on public and political awareness of the importance of biodiversity in general and bats as part of it. Achieving this is a step forward in the protection of the European bats.

Acknowledgements

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References

- **Gregory**, R.D., van Strien A.J., Vorisek P., Gmelig Meyling A.W., Noble D.G., Foppen R.P.B. et Gibbons D.W. (2005): Developing indicators for European birds. Philosophical Transactions of the Royal Society B 360: 269-288.
- **Gregory**, R.D., Vorisek, P., Noble, D.G., Van Strien, A., Klvanova, A., Eaton, M., Meyling A.W.G., Joys, A., Foppen, R.P.B., Burfield, I.J. (2008): The generation and use of bird population indicators in Europe. Bird Conservation International 18: S223-S244 (DOI: 10.1017/S0959270908000312).
- **Haysom**, Karen, Jasja Dekker, Jon Russ, Tom van der Meij & Arco van Strien (2011). Support for a project on 'Streamlining European Biodiversity Indicators (SEBI)': Development of a prototype indicator of European bat population trends. Bat Conservation Trust.
- **Pannekoek**, J. & A.J. van Strien, 2001. TRIM3 Manual. Trends and Indices for Monitoring Data. Researsch paper No. 0102. Statistics Netherlands Voorburg, The Netherlands
- **Van Strien,** A.J., Pannekoek, J. et Gibbons, D.W. (2001): Indexing European bird population trends using results of national monitoring schemes: a trial of a new method. Bird Study 48: 200-213.
- **Van Strien**, A.J., Soldaat, L.L., Gregory, R.D.

(2011): Desirable mathematical properties of indicators for biodiversity change. Ecological Indicators 14: 202-208.

- **Van Swaay**, C.A.M., Van Strien, A.J., Harpke, A., Fontaine, B., Stefanescu, C., Roy, D., Maes, D., Kühn, E., Õunap, E., Regan, E., _vitra, G., Heliölä, J., Settele, J., Warren, M.S., Plattner, M., Kuussaari, M., Cornish, N., Garcia Pereira, P., Leopold, P., Feldmann, R., Jullard, R., Verovnik, R., Popov, S., Brereton, T., Gmelig Meyling, A., Collins, S. (2010). The European Butterfly Indicator for Grassland species 1990-2009. Report VS2010.010, De Vlinderstichting, Wageningen

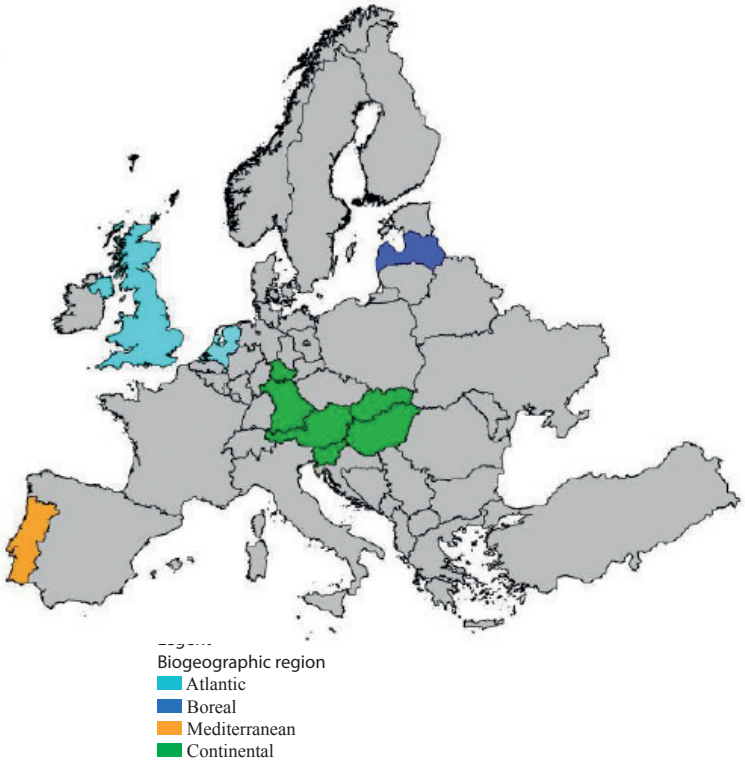


Figure 1. *Bio-geographical grouping of countries contributing to the prototype European hibernating bat indicator*

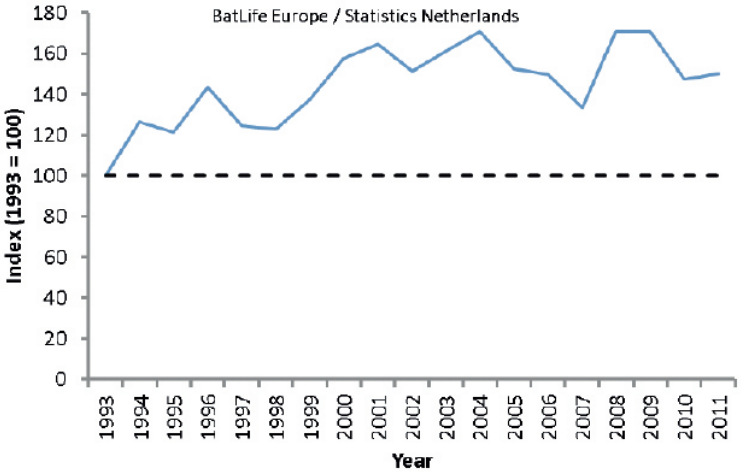


Figure 2. *The prototype of the European hibernating bat indicator*

Table 1. *Slope, number of sites the species occurred in, and trend of species for the combined countries.*

Species	Slope	Error of slope	Number of sites	Trend
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 & 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	2125	Moderate increase
Myotis emarginatus (Geoffroy, 1806)	1.08	0.02	111	Moderate increase
Myotis mystacinus/brandtii	1.06	0.00	1506	Strong increase
Myotis nattereri (Kuhl, 1817)	1.05	0.01	2066	Moderate increase
Myotis myotis/blythii (oxygnathus)	1.02	0.00	1748	Moderate increase
Plecotus auritus (Linnaeus, 1758)	0.99	0.01	3655	Stable
Plecotus austriacus (Fischer, 1829)	0.91	0.03	399	Moderate decline
Miniopterus schreibersii (Kuhl, 1817)	1.00	0.01	44	Stable

Photo: Xavier Puig-Montserrat

Effects of environmental degradation on bats

Using spatial modelling to study the impact of climate change on the distributions of bats

Hugo Rebelo[1,2], Francisco Amorim[1] & Gareth Jones[2]
[1] *CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, 11, 4485-661 Vairão, Portugal*
[2] *School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, United Kingdom*

Bats and forest degradation

Danilo Russo
Laboratorio di Ecologia Applicata, Dipartimento Ar.Bo.Pa.Ve., Facoltà di Agraria, Università degli Studi di Napoli Federico II, via Università 100, I-80055 Portici (Italy)
School of Biological Sciences, University of Bristol, Woodland Road, BS8 1UG, Bristol (U.K.)

The impacts of extreme events on biodiversity – lessons from die-offs in flying-foxes

Justin A. Welbergen
Centre for Tropical Biodiversity and Climate Change, James Cook University, Townsville, Australia 4811
Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, UK

Bats and toxic pollutants

Jan Zukal[1], Jiri Pikula[2] & Hana Bandouchova[2]
[1] *Institute of Vertebrate Biology AS CR v.v.i., Brno, the Czech Republic*
[2] *University of Veterinary and Pharmaceutical Sciences, Brno, the Czech Republic*

Using spatial modeling to study the impact of climate change on the distributions of bats

Hugo Rebelo[1,2], Francisco Amorim[1]
& Gareth Jones[2]
[1] CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, Campus Agrário de Vairão, R. Padre Armando Quintas, 11, 4485-661 Vairão, Portugal
[2] School of Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, United Kingdom

Bats as bioindicators of climate change

Climate change is currently one of the main priorities in the political, social and biodiversity conservation agenda. The warming of the climate system is now unequivocal. Eleven years between 1995-2006 rank amongst the warmest years since 1850 (when the instrumental record of temperature commenced). In addition a widespread melting of snow and ice together with an average rising of global sea level is apparent (Bernstein et al. 2007). The increase in greenhouse gases has been linked to current climate change. There is increasing evidence that human activities have been mainly responsible for the increases in greenhouse gases concentrations since the 1750s and levels now far exceed values found in the past hundreds of thousands of years (Loulerge et al. 2008).

The biological effects of climate change are already visible, with plants flowering earlier than usual (Cleland et al. 2007) and polewards range shifts of insects (Wilson and Maclean 2011) and birds (Gregory et al. 2009) just to mention a few examples. The consequences for the viability of populations suffering such rapid alterations to their environments are still unclear and will probably vary among species. However, it is expected that throughout the 21st century global biodiversity will continue to decline irrespective of the severity of the climate change scenarios predicted (Pereira et al. 2010) although for the more extreme warming scenarios higher levels of extinction are expected. Bats are no exception to this pattern. It is expected that bats will also show range shifts, contractions in their distributions and probably reductions in genetic variation in their populations (Rebelo et al. 2010). However, little is known about the effect of climate change on hibernation, gestation and other factors associated with bats' life cycles. That said, the knowledge gap associated with bat's responses to climate change does not hamper their use as bioindicators of ecosystem alterations. There are several characteristics that qualify bats for this purpose: their populations can be monitored, changes in the populations can be measured, bats are widely distributed (Jones et al. 2009), their physiology responds to local climatic conditions and several species have high mobility and potential to colonise new suitable areas. Therefore, the monitoring of bat populations could provide information regarding the effects of climate change on species distributions, phenology and physiology. Their wide distribution also allows measurement of these effects at very large scales.

How to study and predict the effects of climate change?

Whenever local conditions change outside a species' ecological niche, individuals will either move towards suitable areas or extinction is probable (Thomas et al. 2004). Therefore, through the monitoring of bat populations it will be possible to detect range shifts of species or population changes. Several countries have already established monitoring networks and programmes. The continuation and expansion of these programmes to other countries and regions would be ideal for the establishment of a comprehensive global detection network of changes in biodiversity.

In parallel, studies with the goal of predicting the effect of climate change have been dominated by distribution studies. The use of species distribution modelling techniques under climate change scenarios has become popular (Pereira et al. 2010).

The usefulness of species distribution models

Over the last decade, species distribution models (SDM) have become very popular tools in a wide scope of studies of biogeography, ecology and conservation biology. Conceptually SDMs try to establish relationships between species presence at sites and a set of environmental and/or spatial characteristics of the sites (Hirzel and Le Lay 2008). Their rationale is based on Hutchinson's (1958) concept that an ecological niche is a subset of the environmental values where a species can occur. Hutchinson viewed an ecological niche as a "hypervolume" in multidimensional ecological space, determined by a species' requirements to reproduce and survive. There are two major forms of SDM techniques:

mechanistic and correlative modelling. Mechanistic modelling relies on physiological information to determine the potential area a species might occupy. The lack of physiological information for several taxa has somehow limited the use of these types of algorithms. On the other hand, correlative modelling techniques have been widely used. There are several techniques available, some of which were shown to produce very accurate predictions regarding current distributions (Elith et al. 2006) even with small datasets (Rebelo and Jones 2010). Moreover, SDM also allows conclusions to be made about which ecological factors delimit a species' distribution, hence providing insight into which factors conservation actions should focus on. The choice of which SDM technique to employ clearly depends on the type of dataset considered, for example presence/absence data or presence-only are available. Absences are usually unreliable in the case of bats due to their elusive and nocturnal behaviour associated with low detectability for a number of species.

Like any methodology SDM has its limitations. In short, SDMs are more accurate with specialist than generalist species. The latter require more ecogeographic data in order to cover the full niche breadth. Also, the choice of which variables should be considered is of utmost importance for SDMs. For robust predictions it is necessary that ecologically meaningful variables are considered, otherwise weak relations between models and presence data are expected.

Several SDM techniques have already proven powerful in predicting current species distributions, yet their ability to extrapolate models to different geographic regions or time epochs is still very much debated and a few assumptions must be considered. First, the presence dataset must cover the whole species' niche. Failing to do so would induce underpredictions, i.e. models would fail to detect some areas where the species might occur. Additionally, it is assumed that species under study show niche conservatism – their ecological niche changes little over time. Niche conservatism implies that a species will occupy similar environmental conditions irrespective of geographical area or time epoch considered.

The ability of SDMs to extrapolate under climate change scenarios

There are several possible ways in which to test for the existence of niche conservatism. One of the most popular methods is through a phylogeographic perspective comparing results from molecular analyses and SDMs projected into the past, most frequently to the Last Glacial Maximum (LGM ,21-18 kyr before present). Molecular analyses allow determination of which populations occurred in glacial refugia (areas where species persisted through the ice ages) and how populations are structured within the refugium. This is accomplished by the delimitation of the most genetically diverse populations and also the source populations for the post-glacial colonisation (where older haplotypes occur). In addition, the projection of current distribution models into the past (hindcasting) permits determination of areas where species could have persisted. If the ecological niche has not changed considerably over time then predictions on the location of glacial refugia generated by both SDM and molecular analyses should match. As an example of this approach, the phylogeography of barbastelles *Barbastella barbastellus* was studied by sequencing two mitochondrial DNA fragments (cytochrome b and D-loop) from 115 individuals covering most of the species' European range (Rebelo et al. 2012). In parallel, palaeo-distribution models were calculated for the LGM. Both methods yielded similar results by delimiting the occurrence of barbastelles during the LGM to the southern European peninsulas of Iberia, Italy and the Balkans (Fig. 1). Moreover, the existence of two possible populations in Iberia was also confirmed, while for Italy and the Balkans large scale population movements probably occurred between the glacial and inter-glacial periods. This could explain the loss of genetic variability in those areas. Regarding post-glacial colonisation routes, Italian populations seemed to have contributed the most for the establishment of new populations in the U.K. while Balkan populations probably colonised eastern and central Europe. In conclusion, at least for barbastelles the niche conservatism hypothesis was supported. New studies also seem to support this hypothesis for other bat species (Buckley et al. 2010) and hence niche conservatism may occur widely in bats.

The existence of niche conservatism in a species supports the extrapolation of models from the current distribution to other time epochs, including future climate change scenarios. It is expected that these species will occupy areas with similar conditions to those experienced where they currently occur.

Impact of climate change on European bats

Europe has a very complex distribution of different biogeographic zones, ranging from the warmest Mediterranean region in the south to the Boreal conditions in the high latitudes and altitudes. Therefore, it is expected that bat species associated with those regions may react differently to predicted climate change. Rebelo et al. 2010 analysed the potential effect of different climate change scenarios on 28 European bat species. First, species were pooled into three biogeographic groups: Mediterranean, Temperate and Boreal. Then Maximum Entropy modelling (Elith et al. 2011) was employed to determine potential species distributions under four climate change scenarios (ranging from the most extreme A1FI, A2, B2 to the least severe, B1). Range shifts typically occurred towards higher, cooler latitudes. Of special concern, Boreal species will probably be highly affected by climate change with the large-scale disappearance of suitable areas in Europe, which is associated with the impossibility of moving further north due to the lack of physical space. Their range contraction is predicted to be extensive and the few suitable new potential areas of occurrence show little overlap with the species' current distribution. Likewise, for Temperate species severe range contraction is also expected under the most severe climate change models but not of the magnitude predicted for Boreal taxa. As expected, the Mediterranean species were the less affected by the predicted warming, showing species-specific responses. For some taxa range contractions are predicted while for others an expansion towards northern latitudes is expected. Nevertheless, for the majority of these species it is predicted a severe contraction on their current range, namely in the Mediterranean region.

Consequently, the spatial pattern of species richness in Europe is predicted to show major changes (Fig. 2). Major extinctions are predicted for southern Europe while the U.K. and Fenno-Scandinavia are expected harbour high levels of biodiversity by the end of the century. This situation is likely to occur irrespective of the climate change scenario though the scenario A1FI (scenario characterised by the intensive use of fossil fuel with rapid economic growth) is clearly the most damaging. The loss of species in southern Europe is of concern because these areas were probably the glacial refugia for the majority of the European bats. It is highly likely that areas of high genetic diversity will be lost with unknown consequences for the species survival. Only through continued monitoring of the bat populations will it be possible to detect the effects of climate change and future viability of those populations.

Designing a bat monitoring network sensitive to climate change

In 2010 a study was commissioned for northern Portugal to design a bat monitoring network sensitive to potential climate change – SIMBioN network. Within the project's philosophy, it was anticipated that monitoring should be carried out by volunteers, non-governmental organisations, staff working in protected areas and local associations. Moreover, the monitoring network should be directed to bat species that are associated (for at least a part of their life cycle) with priority habitats for conservation, especially mature native woodland (usually dominated by oaks). Moreover, monitored species should be relatively easy to identify through acoustic analysis and should have high detectability in cluttered environments such as woodlands. Consequently seven species were chosen for the monitoring program, namely *Pipistrellus kuhlii, Eptesicus serotinus, Nyctalus leisleri, Barbastella barbastellus, Myotis daubentonii, Hypsugo savii* and *Tadarida teniotis*. The main aim of this project was to delimit which areas may suffer greatest turnover in species richness between the present and the future as predicted under climate change scenarios. The distribution models obtained were calculated from partial species distributions, hence it was highly likely that the whole ecological niche of each species was not covered. However, it was never intended to produce accurate predictions on the future species distribution. Instead, bat distribution data was employed to determine which areas in the region are more sensitive to likely changes in species richness due to climate change.

Prior to this study, the available data for bat distributions were scarce and biased (mainly located in protected areas). To overcome this, SDMs were calculated to guide acoustic sampling in the region to fill potential distribution gaps. 44 acoustic transects were made and with subsequent data new SDMs were calculated for the current distribution and then projected into two climate change scenarios: A2a and B2a (both scenarios simulate a world where economic growth varies among world regions' though scenario B includes some environmental concerns that are absent in the A scenario). By overlapping current and future models it was then possible to identify which areas will potentially have greatest

species turnover (gain or loss in the number of species) under the specified climate change scenarios.

The challenge was then to propose the location of acoustic monitoring stations without knowing how much sampling effort was going to be dedicated because volunteer commitment was unknown. So, the final step of this study consisted on the development of three networks designed for different scenarios of volunteer commitment (Fig. 3). The choice of the siting of the monitoring stations was done with the aid of the conservation planning software Marxan (Ball et al. 2009), considering SDMs for the present and for the climate change scenarios.

To sum up, this study illustrates other possible applications of SDMs considering climate change and conservation.

Key messages

Like all methodologies SDMs have limitations. As long as researchers are aware of these constraints, the possible outcomes from SDMs projected to future climate change scenarios provide valuable information for conservation practitioners, evolutionists and decision-makers. SDMs predict potential areas of occurrence under a number of climate change scenarios, hence it is possible to highlight which areas are expected to play important roles for bat conservation in the future. Additionally, SDMs can determine which ecological factors are currently limiting species distributions. This information is also of high valuable for conservation and management.

Climate change forecasting and spatial modelling are fast growing fields. It is expected that new advances will permit further improvements in the accuracy of predicting future distributions.

References

- **Ball IR**, Possingham HP, Watts M (2009) Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.
- **Bernstein** N, Bosch P, Canziani O, Chen Z, Christ R, Davidson O, Hare W, Huq S, Karoly D, Kattsov V, Kundzewicz Z, Liu J, Lohmann U, Manning M, Matsuno T, Menne B, Metz B, Mirza M, Nicholls N, Nurse L, Pachauri R, Palutikof J, Parry M, Qin D, Ravindranath N, Reisinger A, Ren J, Riahi K, Rosenzweig C, Rusticucci M, Schneider S, Sokona Y, Solomon S, Stott P, Stouffer R, Sugiyama T, Swart R, Tirpak D, Vogel C, Yohe G (2007) Climate change 2007: synthesis report. 26-73
- **Buckley** LB, Davies TJ, Ackerly DD, Kraft NJB, Harrison SP, Anacker BL, Cornell HV, Damschen EI, Grytnes J-A, Hawkins BA, McCain CM, Stephens PR, Wiens JJ (2010) Phylogeny, niche conservatism and the latitudinal diversity gradient in mammals. Proceedings of the Royal Society B 277:2131-2138
- **Cleland** EE, Chuine I, Menzel A, Mooney HA, Schwartz MD (2007) Shifting plant phenology in response to global change. Trends in Ecology and Evolution 22:357-365
- **Elith** J, Graham CH, Anderson RP, Dudik M, Ferrier S, Guisan A, Hijmans RJ, Huettman F, Leathwick JR, Lehmann A, Li J, Lohmann LG, Loiselle BA, Manion G, Moritz C, Nakamura M, Nakazawa Y, Overton JM, Peterson AT, Phillips SJ, Richardson K, Scachetti-Pereira R, Schapire RE, Soberón J, Williams S, Wisz MS, Zimmermann NE (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129-151
- **Elith** J, Phillips SJ, Hastie T, Dudik M, Chee YE, Yates CJ (2011) A statistical explanation of Maxent for ecologists. Diversity and Distributions 17:43-57
- **Gregory** RD, Willis SG, Jiguet F, Vorisek P, Klvanová A, van Strien A, Huntley B, Collingham YC, Couvet D, Green RE (2009) An indicator of the impact of climate change on European bird populations. PLoS One 4:e4678. doi:10.1371/journal.pone.0004678
- **Hirzel** AH and Le Lay G (2008) Habitat suitability modelling and niche theory. Journal of Applied Ecology 45:1372-1381
- Hutchinson GE (1958) Concluding remarks. Cold Spring Harbor Sympsia on Quantitative Biology 22:415-427
- **Jones** G, Jacobs DS, Kunz TH, Willig MR, Racey PA (2009) Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8:93-115
- **Loulerge** L, Schilt A, Spahni R, Masson-Delmotte V, Blunier T, Lemieux B, Barnola J-M, Raynaud D, Stocker TF, Chappellaz J (2008) Orbital and millennial-scale features of atmospheric CH4 over the past 800,000 years. Nature 453:383-386
- **Pereira** HM, Leadley PW, Proença V, Alkemade R, Scharlemann JPW, Fernandez-Manjarrés JF, Araújo MB, Balvanera P, Biggs R, Cheung WWL, Chini L, Cooper HD, Gilman EL, Guénette S, Hurtt GC, Huntington HP, Mace GM, Oberdoff T, Revenga C, Rodrigues P, Scholes RJ, Sumaila UR, Walpole M (2010) Scenarios for global biodiversity in the 21st century. Science 330:1496-1501
- **Rebelo** H and Jones G (2010) Ground validation

of presence-only modelling with rare species: a case study on barbastelles Barbastella barbastellus (Chiroptera: Vespertilionidae). Journal of Applied Ecology 47:410-420

- **Rebelo** H, Froufe E, Brito JC, Russo D, Cistrone L, Ferrand N, Jones G (2012) Postglacial colonization of Europe by the barbastelle bat: agreement between molecular data and past predictive modelling. Molecular Ecology 21:2761-2774
- **Rebelo** H, Tarroso P, Jones G (2010) Predicted impact of climate change on European bats in relation to their biogeographic patterns. Global Change Biology 16:561-576
- **Thomas** CD, Cameron A, Green R, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427:145-148
- **Wilson** RJ and Maclean IMD (2011) Recent evidence for the climate change threat to Lepidoptera and other insects. Journal of Insect Conservation 15:259-268

Figure 2 - Difference between present species richness and projections for 2090–2100 for climate change scenarios (a) A1FI, (b) A2, (c) B1 and (d) B2. From Rebelo et al. (2010), reproduced with permission from John Wiley & Sons Inc.

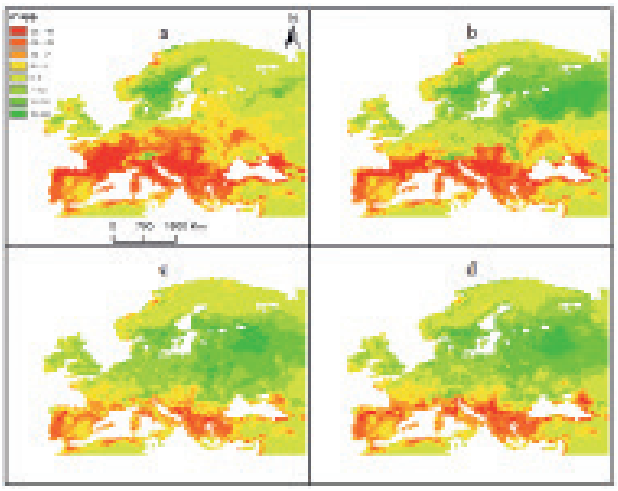


Figure 3 – Example of a proposed monitoring working taking into consideration the turnover of species richness for two climate change scenarios: A2a (left) and B2a (right).

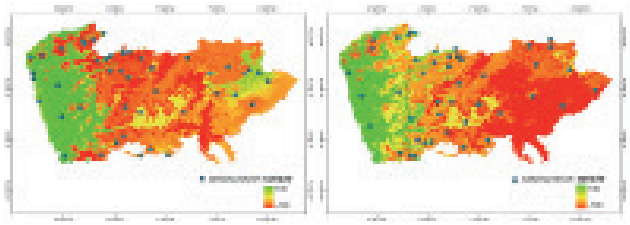
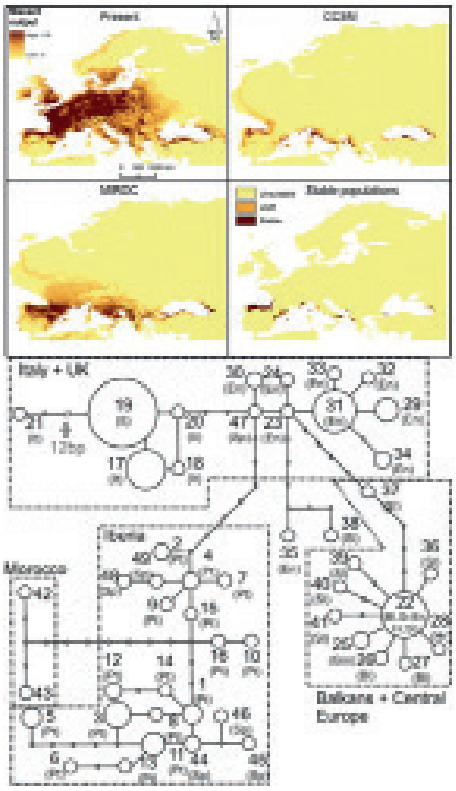


Figure 1 – Above: three Maxent models and a reclassified map of the potential distribution of *Barbastella barbastellus*. One for the present conditions; two for the last glacial maximum (LGM) employing two different general circulation models (Community Climate System Model and Model for Interdisciplinary Research on Climate); and a reclassified map indicating areas where suitable conditions subsisted in the LGM alone and in both glacial and interglacial periods (here called stable). This latter map was obtained from overlaying the present and both LGM models. Below: concatenated (cytochrome b and D-loop) minimum spanning network based on 1437 bp for 115 barbastelle specimens. Clades are delimited by the dashed boxes. The dots connecting the network represent missing or unsampled haplotypes. Circles represent haplotypes, and their size is proportional to the number of specimens; for more information on haplotype designation see Rebelo et al. (2012). Sample origin: Bl, Bulgaria; En, England; Gm, Germany; Gr, Greece; Hr, Hungary; Italy, It; Pt, Portugal; Sl, Slovenia; Sp, Spain. From Rebelo et al. (2012), reproduced with permission from Blackwell Publishing Ltd.



Bats and forest degradation

Danilo Russo
Laboratorio di Ecologia Applicata, Dipartimento Ar.Bo.Pa.Ve., Facoltà di Agraria, Università degli Studi di Napoli Federico II, via Università 100, I-80055 Portici (Italy)
School of Biological Sciences, University of Bristol, Woodland Road, BS8 1UG, Bristol (U.K.)

1. Introduction

Forests have represented a major evolutionary set for bats since these mammals' very first origins, so not surprisingly such ecosystems still play a crucial role in bat natural history. Bats use forests for two main reasons: roosting (Barclay & Kurta 2007) and foraging (Patriquin & Barclay 2003). Forest loss or alteration may therefore affect such vital activities and lead to a decline of bat populations. Bats are long-lived, slowly reproducing mammals (Altringham 2011). Therefore, they are especially vulnerable and put at risk by the loss or alteration of key habitats. This is especially concerning since bats are important contributors to global mammal diversity and provide key ecosystem services, such as the control of insect pests in agricultural or forest landscapes, having crucial consequences for human economy and health (Boyles et al. 2011; Kunz et al. 2011). Preserving bat habitats, including forests, is the most effective strategy for bat conservation (Anonymous 2005). To better understand why managing forests sustainably is important, and which forest features should be addressed by management, I will first briefly cover the ecological relationships existing between bats and forests. I will then review the human-driven factors affecting bats in forests and provide a general picture of forest management for bats. I will finally review the bats and forests topics that have so far received little attention by scientists whose better understanding would be of great value to implement effective forest management for bats. My considerations will regard echolocating bats in temperate regions, with special reference to the European situation.

1.1. Bats roosting in forests

Bats spend over half of their life roosting, so roost features may crucially influence their survival and reproduction. Many bat species select tree cavities for roosting for at least part of their life cycle (Barclay & Kurta 2007). Roosts are selected according to a range of characteristics observed at different spatial scales (Russo et al. 2004). Roost types chosen may differ according to the season as well as in relation with individual features and physiological conditions (sex, age class, reproductive phase, etc.). Roost microclimate is clearly important in influencing the energetic costs of the various life cycle stages including hibernation, pregnancy and lactation. The roosting environment's features also influence predation risk, parasite load, behavioural interactions and energy spent for commuting to foraging sites (e.g. Russo et al. 2004; Barclay & Kurta 2007; Russo et al. 2007). Roost selection typically relies on parameters recognized on multiple spatial scalea such as location, structure and aspect. Because old and dead trees are richer in cavities suitable for roosting, they may be particularly important for bats. Different bat species, or even different populations or individuals from the same species, may select varying roost-tree types or tree cavities. Cavity types commonly used by tree-roosting bats in temperate areas include rot cavities, mechanical breaks such as vertical splits, woodpecker holes or spaces beneath defoliating bark (Figure 1).

Tree-roosting bats often switch between roosts. Roost switching has been proposed to be a response to avoid predators or disturbance, disrupt parasite life cycles, select specific microclimate requirements, get closer to feeding sites, maintain social relationships between small groups of individuals spread over large forest areas, and record the exact location and state of alternate roosts (Lewis 1995; Kerth & König 1999; Willis & Brigham 2004; Russo et al. 2005; Popa-Lisseanu et al. 2008). Practically, all such hypotheses – perhaps except the supposed optimisation of distance to feeding sites – have received some observational or experimental support from studies of different species. Roost switching may have evolved in different bat species as a response to a range of converging selective pressures typical of forest roosting environments (Russo et al. 2005). Apart from the remote or proximate factors responsible for roost switching, the practical implication of this behaviour is that to support even a small population of bats scattered over a forest area, large numbers of suitable trees are needed (Russo et al. 2005).

1.2. Bats foraging in forests

Echolocating bats find their way in the dark and detect prey targets thanks to a sophisticated "biosonar". Echolocation call structure tells a lot about the habitats used by a certain bat species (Schnitzler et al. 2003). Likewise, wing shape differs across bat species according to the habitats they exploit (Norberg 1990). Both echolocation and wing design of many species are clearly adapted to perform best in forest.

Bats find a variety of food items in forests. The occurrence of different "microhabitats", i.e. small-scale habitat structures, within forests makes coexistence of several species in the same area possible with little or no competition for food. Some species, such as pipistrelle bats, are flexible foragers though they are especially adapted to hunt insects on the wing and forage along forest edges or within small clearings. Others - Ca. 30% of echolocating bats (Russo et al. 2007) – may glean prey from substrates (foliage, leaf litter, etc.) or very close to them. The cluttered structure of forest interior or leaf litter makes prey detection an especially difficult task. To solve it, some bats still rely on echolocation and either use broad-band echolocation calls, offering high discrimination performances (Siemers & Schnitzler 2004), or rely on the detection of subtle "acoustic glints". The latter are given by variations in call intensity or frequency encoded in the returning echo which reveal the presence of suitable prey moving against a structurally complex background (Neuweiler 1989). Rhinolophid bats often use a peculiar forest-adapted foraging strategy called perch hunting (Jones & Rayner 1989). They hang from a perch to scan their surroundings for moving prey. When the latter is detected, they make short pursuit flights to catch it and return to a perch to dismember and ingest it.

Besides echolocation, for the detection and localisation of substrate-lying prey several bat species also employ other mechanisms such as passive listening (listening for prey generated sounds), vision and olfaction. Passive listening is a major strategy among nocturnal vertebrates relying mostly on hearing to capture relatively immobile prey in cluttered microhabitats (e.g. Russo et al. 2007).

Forests often include further bat foraging habitats. Small ponds and rivers in forests are typically insect-rich habitats and offer further foraging opportunities to several bat species. Overall, preserving a variety of habitat structures in forest landscapes, i.e. forest heterogeneity, is a crucial approach to host a diverse community of foraging bats (Anonymous 2005).

2. Forest loss or alteration

Given the great value of forest to bats, deforestation clearly represents a specially serious threat to conservation of these mammals. Many bat species are strictly associated with forests and may not survive its disappearance. Large forest areas, or at least networks of forest patches connected by either continuous or discontinuous (stepping stones) ecological corridors, may be needed to promote gene flow and support viable bat populations. Habitat fragmentation may thus significantly influence bats (Grindal and Brigham 1998) even if the corresponding habitat loss is minimal. Landscape connectivity, i.e. the continuity of suitable habitats, may sometimes be promoted by linear habitats such as hedgerow networks in agricultural landscapes. Maintaining or creating woodland patches, even in densely inhabited areas such as cities (e.g. parks), and supporting landscape connectivity by promoting the occurrence of connecting features may help sustain forest bat populations on a regional scale.

Compared to forest loss, forest alteration or degradation is a subtler process whose occurrence, magnitude, or impact may go unnoticed since it may not show as a reduction in forest surface, or may even occur as forest expands. For our scopes, by "forest degradation" we mean the detrimental effects on biodiversity and associated ecosystem services mainly determined by human activities such as overexploitation, overgrazing or large-scale, recurrent fires. Abiotic or biotic environmental disturbance factors may also lead to forest degradation, such as parasites, diseases or catastrophic weather events. Degradation typically consists of a decrease in biomass, structural alteration, qualitative or quantitative changes in tree species assemblages and soil degradation. Because forest degradation implies a large-scale loss of habitat suitability for many forest specialist organisms and occurs practically in all continents, it is a major part of the global change process currently threatening biodiversity worldwide.

Forestry have impacts on bat activity at various spatial scales (Grindal & Brigham 1999). Intensive forestry often causes alteration of bat roosting habitat. As we have seen, bats often roost in tree cavities which generally occur in defective, moribund or dead trees. In managed forests, concerns over forest safety, fire risk, productivity and pest species make the removal of dead or defective trees a common forestry practice. Thus, even if commercial forestry is carried out as selective logging, preserving the overall forest

cover (i.e. the extent of available habitat) may still result in a considerable loss in the availability of defective or standing dead trees. Trees are logged well before completion of their natural cycle, a practice which, along with deliberate removal of dead trees, contributes to reducing the availability of the latter by affecting the natural forest turnover (Russo et al. 2010).

Intensive forest management, including practices such as coppice or reforestation for soil protection or timber production, may result in a structurally homogeneous forest unsuitable for bat foraging. Coppiced woodlands may simply be too densely covered with small-diameter trees for being crossed by bats. Besides, coppice management often implies clearing continuous, large areas of woodland which interrupts habitat connectivity and may affect bat commuting. Afforestation or reforestation may also lead to forest areas unsuitable to bats. Artificial plantations, often made with non-native tree species (e.g. eucalyptus or alien pine trees in Mediterranean areas) may support little or no insect food and are unsuitable to many bat species (Russo et al. 2002; 2005). On the other hand, some forms of traditional woodland management or tree cultivations may be important for bats. For example, the threatened *Rhinolophus mehelyi* in Spain has been found to forage preferentially in 'dehesas', a semi-natural oak savannah (Russo et al. 2005); grazed oak forest remnants (Figure 2) offer vital habitat to the little known, and perhaps endemic, *Pipistrellus hanaki* on Crete (P. Georgiakakis & D. Russo, unpublished data); and traditional olive groves buffer some bat species from the effects of deforestation in many Mediterranean landscapes (Russo et al. 2002; Davy et al. 2007). Such examples are part of the broader, well recognized role of traditional farmland for biodiversity preservation. Abandoned agricultural land, encroached on by woody vegetation, may not evolve to vegetation stages suitable for bats. In many areas of Mediterranean Europe, abandoned land is often colonised by homogeneous scrubland which has little value to foraging or roosting bats and is highly exposed to the risk of large-scale fires. The latter may easily affect surrounding forest areas and lead to further habitat loss besides determining direct mortality.

3. Forest management for bat preservation

From my brief analysis of habitat features important to bats and the above review of factors affecting forest "quality" for these mammals it should now be clear that forest preservation and sustainable management are indispensable for bat conservation. It is obvious that maintaining large patches of unmanaged forest on a regional scale is a first crucial step to sustain forest bat populations. However, since most temperate forests are nowadays exploited, adopting appropriate conservation strategies in managed forests is perhaps even more important. Too often foresters lack both technical skills needed to manage forests sustainably and awareness about the issue of bat conservation in such habitats. Therefore, regrettably many countries appear far from developing effective conservation strategies and still rely on classical, unsustainable forestry. Recent work by our research group on a sensitive forest bat (*Barbastella barbastellus*; Figure 3) has shown that harvested areas are still of conservation value and are not irreversibly inhospitable even for a bat largely depending on standing dead trees (Russo et al. 2007). Such areas are subject to colonization attempts by this bat, so especially when buffering unmanaged stands used by several tree-dwelling species, they should receive appropriate conservation attention.

Covering specific forest management strategies would be well beyond the scopes of this brief paper given the extremely wide range of forest types and forestry practices occurring in the different geographic regions even restricting the analysis to the sole Europe. Basic forest management principles to preserve bats, also offering a way to carry out environmental compensation for harvesting (see e.g. Anonymous 2005), may include designating small groups of suitable trees (i.e. trees bearing suitable roosting cavities), or even single ones some hundred m apart to favour colonization and movement across the territory and connecting more effectively optimal reproduction areas. Snags, used by certain bats such as *B. barbastellus*, may be deliberately created by girdling, injecting or inoculating large stems (Russo et al. 2010). Bat boxes may also help bats to colonize managed forest but they deteriorate over a few years so their usefulness is restricted to a short time.

Landscape management of forest areas should address the maintenance of structural diversity by adopting ad hoc harvesting, prolonging rotations and when possible converting coppice into harvested mature forest. This approach plays a major role to meet roosting or foraging requirements of several bat species, overall sustaining a diverse bat community.

Direct bat mortality associated with logging

operations is a largely neglected issue. Logging often occurs during key periods such as breeding, rearing, hibernation or migration, potentially implying strong disturbance to bat life cycle and high risk of casualties. In the EU, the EC/92/43 Habitats Directive prohibits deliberate disturbance of Annex IV species (including bats) even outside Special Areas of Conservation (SACs). According to law, forestry plans should be scheduled to take the impact on bats into account, but to my best knowledge this is seldom done in many EU countries. If direct mortality is not taken into account, making managed forests more attractive to bats may turn them into a deadly ecological trap.

4. Gaps in scientific knowledge

Some key-issues concerning the interaction between forestry and bats are poorly known yet understanding them would offer a way to greatly improve forest management for bats. The following list highlights some of them.

How many suitable trees are needed? Research is needed on the relationship between roost availability and population size. Providing foresters with management guidelines for bat conservation may be difficult since quantitative information is needed yet this is not always available. For instance, deciding on the minimum numbers of "bat-trees" (i.e. trees suitable for roosting) to be retained in a managed woodland patch too often relies on little scientific evidence. This is all the more difficult when quantitative guidelines addressing the whole bat community, rather than selected species, are needed.

Effects of management on reproduction. Another aspect deserving attention is the effect of different management intensities on bats' reproductive success. Even sensitive bat species may occur in intensively logged forests but this tells little on whether such habitats are really important to them rather than representing sinks in a metapopulation dynamics, i.e. suboptimal areas where a net loss of individuals takes place.

Bat casualties due to logging. Direct mortality due to logging operations is another largely neglected issue whose knowledge would be crucial to plan safer forestry practices, select the time of year when logging is least harmful to bats, etc.

Occurrence of forest bats in non-forest habitats. Even forest specialist bats may occur in non-forest habitats but this issue has so far been largely neglected. For example, ongoing research on *B. barbastellus* in Italy has revealed its presence in clay badlands or on rocky islands where little or no suitable trees are available, showing that these bats may exploit rock crevices and persist in apparently unsuitable areas provided their key food – moths – is available. Such so far overlooked situations may be especially important to support gene flow between otherwise isolated forest bat populations.

BATS AS BIOINDICATORS OF FOREST MANAGEMENT.

Bats have been highlighted as effective ecological indicators (Jones et al 2009). Few studies have addressed the usefulness of bats as environmental indicators of forest management. Exploring the relationships between the diversity of bat communities and forestry intensity may have useful practical applications i.e. lead to a better understanding of what happens to forest biological diversity when a new management regime is applied. However, forests are complex environments whose biodiversity patterns are the results of a large set of interacting variables, management being only one of them. Finding a way to address the effects of such variables separately is certainly challenging. Selecting single bat species as environmental indicators would be much more difficult, and the few studies so far published call for prudence. The mere observation of a "forest specialist" bat in a given forest area does not suffice to regard the latter as characterised by a high environmental quality. In fact that species may roost there with very low numbers, originate from other far away forest sites or reveal unsuspected plasticity – see e.g. the above-mentioned occurrence of forest bats in non-forest habitats. On the other hand, the occurrence of standing dead wood in temperate forests is typical of habitats characterized by a diverse bat community: this feature may represent an effective surrogate for overall bat richness to carry out large-scale analysis of bat habitat suitability or designate reserves.

References

- **Altringham** J (2011) Bats: from Evolution to Conservation. 2nd edition. Oxford University Press, Oxford, UK
- **Anonymous** (2005) Woodland management for bats. Forestry Commission for England and Wales, Bat Conservation Trust, Countryside Council for Wales and English Nature, UK
- **Barclay** RMR, Kurta A (2007) Ecology and behavior of bats roosting in tree cavities and under bark. In: Lacki MJ, Hayes JP, Kurta A (eds) Bats in Forests. Conservation and

Management. The John Hopkins University Press, Baltimore, pp 17–59
- **Boyles**, JG, Cryan PM, McCracken GF and Kunz TH (2011) Economic importance of bats in agriculture. Science 332: 41-42
- **Davy** CM, Russo D, Fenton MB (2007) Use of native woodlands and traditional olive groves by foraging bats on a Mediterranean island: consequences for conservation. J Zool (Lond) 273: 397-405
- **Grindal** SD, Brigham RM (1998) Effects of small scale habitat fragmentation on activity by insectivorous bats. J Wildl Manage 62: 996–1003
- **Grindal** SD, Brigham RM (1999) Impacts of forest harvesting on habitat use by foraging insectivorous bats at different spatial scales. EcoScience 6: 25–34
- **Hayes** JP, Loeb SC (2007) The influences of forest management on bats in North America. In: Lacki MJ, Hayes JP, Kurta A (eds) Bats in Forests. Conservation and Management. The John Hopkins University Press, Baltimore, pp 207–235
- **Jones** G, Rayner JMV (1989) Foraging behavior and echolocation of wild horseshoe bats Rhinolophus ferrumequinum and Rhinolophus hipposideros (Chiroptera, Rhinolophidae). Behavioral Ecology and Sociobiology 25: 183–19
- **Jones** G, Jacobs DS, Kunz, TH et al (2009) Carpe noctem: the importance of bats as bioindicators. Endang Spec Res doi 10.3354/esr00182
- **Kerth** G, König B (1999) Fission, fusion and nonrandom associations in female Bechstein's bats (Myotis bechsteinii). Behaviour 136: 1187–1202
- **Kunz** TH, de Torrez Braun E, Bauer DM, Lobova TA and Fleming TH (2011) Ecosystem Services provided by bats, in "The Year in Ecology and Conservation," eds, R.A. Ostfeld and W.H. Schlesinger. Special issue, Ann NY Acad Sci 1223: 1-38
- **Lewis** SE (1995) Roost fidelity in bats: a review. J Mammal 76: 481–496
- **Neuweiler** G (1989) Foraging ecology and audition in echolocating bats. Trends Ecol Evol 6: 160–66
- **Norberg** UM (1990) Vertebrate flight: mechanics, physiology, morphology, ecology and evolution. Springer-Verlag
- **Patriquin** K, Barclay RMR (2003) Foraging of bats in cleared, thinned and unharvested boreal forest. J Appl Ecol 40: 646–647
- **Popa-Lisseanu** AG , Bontadina F, Mora O et al (2008) Highly structured fission–fusion societies in an aerial-hawking, carnivorous bat. Anim Behav 75:471–482
- **Russo** D, Jones G, Migliozzi A (2002) Habitat selection by the Mediterranean horseshoe bat, Rhinolophus euryale (Chiroptera: Rhinolophidae) in a rural area of southern Italy and implications for conservation. Biol Conserv 107: 71-81
- **Russo** D, Almenar D, Aihartza J, Goiti U, Salsamendi E, Garin I (2005) Habitat selection in sympatric Rhinolophus mehelyi and R. euryale (Chiroptera: Rhinolophidae). J Zool (Lond) 266: 327-332
- **Russo** D, Cistrone L, Jones G (2005) Spatial and temporal patterns of roost use by tree-dwelling barbastelle bats, Barbastella barbastellus. Ecography 28: 769-776
- **Russo** D, Cistrone L, Jones G (2007) Emergence time in forest bats: the influence of canopy closure. Acta Oecol 31: 119-126
- **Russo** D, Cistrone L, Jones G et al (2004) Roost selection by barbastelle bats (Barbastella barbastellus, Chiroptera: Vespertilionidae) in beech woodlands of central Italy: consequences for conservation. Biol Conserv 117: 73–81
- **Russo** D, Jones G, Arlettaz R (2007) Echolocation and passive listening by foraging mouse-eared bats Myotis myotis and M. blythii. J Exp Biol 210: 166-176
- **Russo** D, Cistrone L, Garonna, AP, Jones, G (2010) Reconsidering the importance of harvested forests for the conservation of tree-dwelling bats. Biodiversity and Conservation 9: 2501-2515
- **Schnitzler** HU, Moss CF, Denzinger A (2003) From spatial orientation to food acquisition in echolocating bats. Trends Ecol Evol 18, 386e394.
- **Siemers** BM, Schnitzler HU (2004) Echolocation signals reflect niche differentiation in five sympatric congeneric bat species. Nature 429: 657–661.
- **Willis** CKR, Brigham RM (2004) Roost switching, roost sharing and social cohesion: forest-dwelling big brown bats, Eptesicus fuscus, conform to the fission-fusion model. Anim Behav 68: 495–505

Figure legends

Figure 1. *Bats such as Barbastella barbastellus often roost in dead trees beneath defoliating bark. (Photo courtesy of Luca Cistrone).*

Figure 2. *Relic oak forests on the island of Crete (Greece) are vital to the little known Hanak's dwarf bat Pipistrellus hanaki (Danilo Russo)*

Figure 3. *A typical forest vespertilionid bat, the barbastelle bat Barbastella barbastellus (Photo courtesy of Luca Cistrone).*

The impacts of extreme events on biodiversity – lessons from die-offs in flying-foxes

Justin A. Welbergen
Centre for Tropical Biodiversity and Climate Change, James Cook University, Townsville, Australia 4811
Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, UK

Introduction

Over the past 100 years, the global average temperature has increased by approximately 0.74 ± 0.18 oC (mean ± SE) and is projected to continue to rise at a rapid rate (IPCC 2007). Current conservative projections are that global average temperatures will increase by 1.7 °C to 4.0 °C by the end of this century (IPCC 2007). The inevitable anthropogenic changes in the world's mean state of climate are significant for natural systems as they affect population abundance, species distributions and invasions; potentially resulting in significant levels of extinction among the world's plants and animals (Parmesan and Yohe 2003, Thomas et al. 2004). However, it is now becoming widely acknowledged that extreme climate events may be much more important than gradual increases in climatic means and will continue to gain significance as drivers of ecological responses to climatic change (e.g., Kapos et al. 2008).

'Extreme events' are extremes of atmospheric weather and climate variables, such as temperature extremes, precipitation extremes, and cyclones; as well as from more climatologically-derived events, such as fires, dust storms, landslides, and extreme sea levels (Parmesan et al. 2000, Parmesan 2006). There is strong evidence that changes in the regimes of temperature extremes have already occurred, but the evidence is less strong for extreme precipitation and cyclone activity (Seneviratne et al. 2012). It is virtually certain that there will be further increases in extreme heat events, and changes in extreme precipitation and cyclone activity are likely (Seneviratne et al. 2012). The potential negative consequences of extreme events for natural systems have only recently come into focus, and thus we do not have a coherent understanding of how biological systems respond to extremes, which severely restricts our ability to project the impacts of such events (Parmesan 2006).

Temperature extremes are fundamental expressions of climate change due to their direct link with increased heat content of the atmosphere. Changes in extreme temperature events are arguably the principle way in

which people, animals and plants will strongly experience climate change (IPCC 2007). Species that live close to their maximum thermal tolerances, such as tropical taxa, may be particularly at risk because small changes in thermal regimes could have disproportionally large impacts (Tewksbury et al. 2008). Temperature extremes are important to biodiversity conservation, not only because of their direct impacts on organismal health but also because of their indirect effects on the frequency and intensity of droughts and wildfires. Extreme heat events are already occurring more frequently than in the 1960s (Zwiers et al. 2010) and are of increasing concern now that climate models predict a dramatic increase in their frequency, intensity and duration (Meehl and Tebaldi 2004).

Temperature extremes can cause widespread mortality of organisms, as evidenced by the 2003 heat wave in Europe that resulted in more than 15,000 human fatalities in France alone (WHO 2003); however, little is known about the kinds of effects that temperature extremes have on natural systems. Below, I will summarise our work on the impacts of extreme temperature events on flying-foxes, the first such study on non-human vertebrate. This study shows that extreme events can cause selective die-offs with profound ecological implications, and highlights the need for a comprehensive suite of bioindicators to monitor and manage the impacts of such events.

Impacts of extreme temperature events on flying-foxes

On 12 January 2002, we documented a mass mortality event that perhaps featured among the most dramatic natural die-offs witnessed in nature. That day, weather stations in northern New South Wales, Australia, recorded maximum temperatures of 43.4 oC (up to 16.5 oC higher than expected), and we recorded how this extreme event decimated flying-foxes in the area (Welbergen et al. 2008). At the time we were working in a mixed-species colony (camp) containing more than 30,000 grey-headed (*Pteropus poliocephalus*) and black flying-foxes (*P. alecto*) roosting among canopy trees (Welbergen 2005). The same extreme temperature event affected 8 other colonies located along a 250-kilometre stretch of NSW coastline, killing over 3,500 individuals in total. This event revealed that extreme events can profoundly impact on behaviour and demography, and differentially affect species (Welbergen et al. 2008).

Mortality was higher among young and adult females (young: 23-49%; females: 10-15%; males: <3%), which is in keeping with the lower thermoregulatory capacity of young flying-foxes (e.g. Bartholomew et al. 1964). In addition, adult females may be more sensitive than adult males because lactation may result in the elevation of basal metabolic rate and increased thermoregulatory needs (Brody 1974). This interpretation is supported by recent behavioural observations by Snoyman et al (in press) that show that in summer nursing mothers spend a greater proportion of their time engaging in thermoregulatory behaviours than any other demographic category. The higher sensitivities of dependent young and adult females indicate that temperature extremes can disproportionately affect recruitment and the effective breeding population (two key parameters for conservation). Especially in species such as flying-foxes that have a very low natural capacity for increase (McIlwee and Martin 2002), these effects are expected to exacerbate the impacts of temperature extremes on population persistence.

The black flying-fox was more affected than the grey-headed flying-fox (10-13% and <1%, respectively), suggesting that the black flying-fox has a lower physiological tolerance to high temperatures. This may seem counterintuitive given the distributions of the species: the grey-headed flying-fox is endemic to coastal south-eastern Australia where it extends into higher latitudes than any other Pteropus species; whereas the range of the black flying-fox is much more tropical extending from Papua New Guinea and Indonesia to northern Australia (Mickleburgh et al. 1992). However, while average temperatures are higher in tropical Australia, maximum temperatures are much higher at mid-latitudes (e.g. Dury 1972), suggesting that the more temperate grey-headed flying-fox has a pre-adaptive advantage over the tropical black flying-fox in coping with temperature extremes.

Conservative estimates suggest that at least 40,000 flying-foxes have died during 25 similar events in Australia in the last two decades alone (Welbergen et al. 2008). In those cases where mixed-species colonies were affected, the black flying-fox suffered substantially higher mortality than the grey-headed flying-fox (Welbergen et al. 2008), again suggesting that the black flying-fox is more sensitive to these events than the grey-headed flying-fox. However, overall about 80% of the casualties involved grey-headed flying-foxes because the majority of extreme heat events occur south of the black flying-fox's distribution limit. Given that the most recent nation-wide survey figures have put the grey-headed flying-fox population at around 320,000 - 400,000 individuals (Eby and Lunney 2002), it is clear that extreme temperature events represent a major cause of extrinsic mortality for the species (see also Tidemann & Nelson 2011).

The majority of reported die-off events are from the last two decades. This suggests that die-off events have recently become more common, although recent events are more likely to have been reported given the increased urbanisation

of flying-foxes and greater environmental awareness. However, the die-offs are consistently associated with temperatures >42 oC (Welbergen et al. 2008) and the probability that such extreme temperatures occur along the east-coast of Australia has increased significantly since the 1970s (Hughes 2003). Specifically, the annual frequency of temperatures >42 oC within the grey-headed flying-fox range is now about 2.5 times greater than it was in 1970 (Welbergen, unpublished data), clearly indicating a recent increase in the exposure to extreme temperature events. On average, more than 5 percent of all grey-headed flying-fox colonies are currently subjected to temperatures of >42 oC annually (Welbergen, unpublished data). Assuming an average life-expectancy of 7.1 years (Tidemann and Nelson 2011) and free movement of individuals across the range (e.g. Roberts et al. 2012), this suggests that the lifetime probability that an individual grey-headed flying-fox will encounter temperatures greater than 42 oC is currently at least 35 percent. Climate change means that this level of exposure will only increase in the future so that die-offs will become more frequent and widespread.

Interestingly, the black flying-fox has been expanding southwards in eastern Australia, into the range of the grey-headed flying-fox. Before 1920, the black flying-fox was not recorded further south than 23°S (near Rockhampton) but by 2007 the species was breeding at 34°S (in Sydney) and in 2010 the first individual was recorded at 37°S (Melbourne), a range expansion that is too fast to be explained by historical shifts in mean climate (Roberts et al. 2012). As temperature extremes increase in severity with latitude in eastern Australia (Welbergen et al. 2008), the southern range expansion exposes the black flying-fox to increasing temperature extremes, thereby providing an window into the future under climate change.

Broader implications of the impacts on flying-foxes

The impacts of temperature extremes on the behaviour and demography of flying-foxes demonstrate that the ultimate ecological consequences of extreme events can be unexpected and complex. In particular, they show that sensitivity to temperature extremes can vary within and between species, and therefore extreme events can alter demography, population dynamics, and interspecific interactions.

There is considerable variation within and between species in their capacity to tolerate extreme temperatures, but we know little about how such variation will interact with the effects of climate change (e.g., Boyles et al. 2011, Huey et al. 2012). Flying-foxes show a predictable sequence of thermoregulatory behaviours in response to extreme temperature events (i.e. wing-fanning, shade-seeking, panting and saliva-spreading, respectively; Welbergen et al. 2008), and the thermal thresholds for these behaviours vary between species (Bartholomew et al. 1964). However, it is unknown whether flying-foxes can adjust their behaviour in response to recent or anticipated experiences with extreme temperature events. Information on such thermal acclimatization ability is generally lacking, and a better understanding of how species differ in their capacity to modify their thermal tolerances is important for managing and predicting impacts of temperature extremes on biodiversity.

The greater sensitivity of dependent young and adult females shows that extreme events can affect some demographic units more strongly than others. The disproportionate impacts on recruitment and the effective breeding population are expected to affect population growth and dynamics, and reduce the species' resilience to these and other events. At present there is little information on how such demographic effects may determine the persistence of populations in the face of climate change, and research in this area is clearly needed (e.g., Isaac 2008).

The asymmetric sensitivities of the black flying-fox and the grey-headed flying-fox to temperature extremes show that extreme events can influence the dynamics between closely interacting species. There is tentative evidence that the southwards expanding black flying-fox is more competitive and this may in part be responsible for the current decline of the grey-headed flying-fox (e.g., Lunney et al. 2008). Therefore, the different impacts on the two species provide an example of how climate change may influence the connectedness in ecosystems by affecting competitive interactions. These kinds of dynamics are likely to complicate further predictions of ecological responses to climate change (Walther et al. 2002, Root et al. 2003).

Monitoring the impacts of extreme events – bioindicators

There is a growing need for biodindicators to monitor the impacts of climate change, including the effects of extreme events. Bats have recently been highlighted as having enormous potential as bioindicators because they are widely distributed, their taxonomy is well-defined, impacts and trends in their populations can be assessed with relative ease, and they are sensitive to a range of stressors that also affect many other taxa (Jones et al. 2009).

Flying-foxes have features that potentially make them useful bioindicators. For example, they are important pollinators and seed dispersers for a number of ecologically and economically important plants, and play keystone roles in structuring forest communities (e.g. Fujita and

Tuttle 1991). Therefore, they reflect the health of the ecosystems in which they occur. They are also highly visible biodiversity components and are easily monitored. Among flying-foxes, the grey-headed flying-fox is probably the most intensively studied species – baseline ecological data have largely been established and its life-history is well known (e.g., Nelson 1965, McWilliam 1986, Parry-Jones and Augee 1991, Eby 1996, Welbergen 2005, 2010, 2011). The species is threatened by several stressors, including destruction of foraging habitat and roosts, killing of animals in orchards; and consequently it is considered Vulnerable at state, federal and international levels (Duncan et al. 1999, Eby et al. 1999, Tidemann 2003, Lunney et al. 2008). The species is clearly affected by extreme heat events (above) and would be an excellent indicator of heat stress in more cryptic fauna where impacts are more difficult to assess.

The monitoring of impacts of extreme events will likely require multiple bioindicator species and flying-foxes could form part of a more extensive suite. This is because extreme events are geographically variable and will likely affect a multitude of interacting species that vary in their respective tolerances to such events. This highlights the need for a broad-scale monitoring network that captures local, regional and global components of the earth's biota (Jones et al. 2009). This network will be critical for understanding and predicting responses to extreme events, and for the conservation and sustainable management of our natural resources in the face of climate change.

Predicting the impacts of extreme events – vulnerability analyses

Careful documentation of responses of bioindicators to extreme events will inform analyses that aim to predict the vulnerability of the world's biodiversity to climate change. Vulnerability analyses incorporate information on the degree to which organisms are subjected to climate change ('exposure') and their ability to respond to that change ('sensitivity') (Williams et al. 2008). Such analyses are playing an increasingly important role in informing governments of the seriousness of the climate change threat and in facilitating conservation management. Quantifying and integrating the parameters that contribute to vulnerability to extremes is a difficult analytical exercise. However, flying-foxes allow for easy examinations of exposure and sensitivity to temperature extremes, at both individual and population-wide levels of organization, making them potential model species for analyses that incorporate both shifts in climatic means and changes in regimes of extremes. Our current research aims to quantify the vulnerability of flying-foxes to extreme temperature events and map the future impacts on the species. It is our hope that this will form the basis for a generalized framework for assessing the impacts of extreme events on natural systems and help the development of informed management strategies that preserve biodiversity in the face of extreme events.

Conclusion

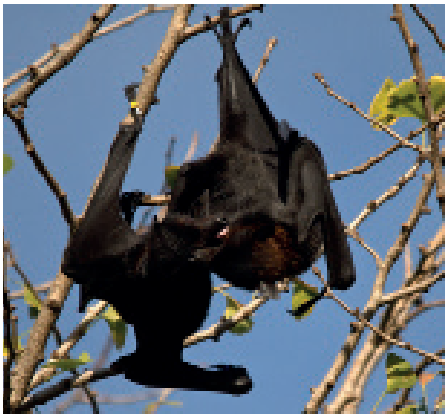
There is no doubt that extreme events will have an increasingly important impact on the structure of ecosystems and the sustainability of animal populations in a wide range of taxa (e.g., Parmesan et al. 2000); however, our knowledge of how biological systems respond to these events is limited. Examining the impacts of temperature extremes on flying-foxes shows that extreme events can cause selective die-offs with unexpected and complex ecological consequences. The keystone roles that flying-foxes play as seed dispersers and pollinators suggest that these bats could be useful bioindicators, but a broader suite of species is clearly needed to monitor the biological impacts of extreme events. Such indicator species will be particularly useful for analyses of the vulnerability of the world's biodiversity, and will help enhance our ability to predict ecological responses to climate change.

References

- **Bartholomew**, G. A., P. Leitner, and J. E. Nelson. 1964. Body temperature oxygen consumption and heart rate in three species of Australian flying foxes. Physiological Zoology 37:179-198.
- **Boyles**, J. G., F. Seebacher, B. Smit, and A. E. McKechnie. 2011. Adaptive thermoregulation in endotherms may alter responses to climate change. Integrative and Comparative Biology 51:676-690.
- **Brody**, S. 1974. Bioenergetics and growth: with special reference to the efficiency complex in domestic animals. Hafner: Collier Macmillan, New York; London.
- **Duncan**, A., G. B. Baker, and N. Montgomery. 1999. The action plan for Australian bats. Environment Australia, Canberra.
- **Dury**, G. H. 1972. High temperature extremes in Australia. Annals of the Association of American Geographers 62:388-400.
- **Eby**, P. 1996. Interactions between the grey-headed flying-fox, Pteropus poliocephalus (Chiroptera: Pteropodidae) and its diet plants - seasonal movements and seed dispersal. Ph.D. University of New England, Armidale.
- **Eby**, P. and D. Lunney. 2002. Managing the grey-headed flying fox, Pteropus poliocephalus as a threatened species: a context for the debate. Pages 1-15 in P. Eby and D. Lunney, editors. Managing the grey-headed flying fox Pteropus poliocephalus as a threatened species in NSW. Royal Zoological Society of New South Wales,

Mosman.
- **Eby**, P., G. Richards, L. Collins, and K. Parry-Jones. 1999. The distribution, abundance and vulnerability to population reduction of a nomadic nectarivore, the grey-headed flying fox, Pteropus poliocephalus, in New South Wales, during a period of resource concentration. Australian Zoologist 31:240-255.
- **Fujita**, M. S. and M. D. Tuttle. 1991. Flying-foxes (Chiroptera: Pteropodidae): threatened animals of key ecological and economic importance. Conservation Biology 5: 455-463.
- **Huey**, R. B., M. R. Kearney, A. Krockenberger, J. A. M. Holtum, M. Jess, and S. E. Williams. 2012. Predicting organismal vulnerability to climate warming: roles of behaviour, physiology and adaptation. Philosophical Transactions of the Royal Society B: Biological Sciences 367:1665-1679.
- **Hughes**, L. 2003. Climate change and Australia: trends, projections and impacts. Austral Ecology 28:423–443.
- **IPCC**, editor. 2007. Climate change 2007: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
- **Isaac**, J. L. 2008. Effects of climate change on life history: implications for extinction risk of mammals. Endangered Species Research 7:115-123.
- **Jones**, G., D. S. Jacobs, T. H. Kunz, M. R. Willig, and P. A. Racey. 2009. Carpe noctem: the importance of bats as bioindicators. Endangered Species Research 8:93-115.
- **Kapos**, V., J. P. W. Scharlemann, A. Campbell, A. Chenery, and B. Dickson. 2008. Impacts of Climate Change on Biodiversity: A review of the recent scientific literature. UNEP World Conservation Monitoring Centre.
- **Lunney**, D., G. Richards, and C. Dickman. 2008. Pteropus poliocephalus.in IUCN, editor. Red List of Threatened Species.
- **McIlwee**, A. P. and L. Martin. 2002. On the intrinsic capacity for increase of Australian flying-foxes (Pteropus spp., Megachiroptera). Australian Zoologist 32:76-100.
- **McWilliam**, A. N. 1986. The feeding ecology of Pteropus in northern New South Wales, Australia. Myotis 23:201-208.
- **Meehl**, G. A. and C. Tebaldi. 2004. More Intense, more frequent, and longer lasting heat waves in the 21st century. Science 305:994-997.
- **Mickleburgh**, S. P., A. M. Hutson, and P. A. Racey. 1992. Old world fruit bats: an action plan for their conservation. I.U.C.N/S.S.C., Gland, Switserland.
- **Nelson**, J. E. W. 1965. Movements of Australian flying foxes (Pteropodidae: Megachiroptera). Australian Journal of Zoology 13:53-73.
- **Parmesan**, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology Evolution and Systematics 37:637-669.
- **Parmesan**, C., T. L. Root, and M. R. Willig. 2000. Impacts of extreme weather and climate on terrestrial biota. Bulletin of the American Meteorological Society 81:443-450.
- **Parmesan**, C. and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.
- **Parry-Jones**, K. and M. L. Augee. 1991. Food selection by grey-headed flying foxes (Pteropus poliocephalus) occupying a summer colony site near Gosford, New-South-Wales. Wildlife Research:111-124.
- **Roberts**, B. J., C. P. Catterall, P. Eby, and J. Kanowski. 2012. Latitudinal range shifts in Australian flying-foxes: A re-evaluation. Austral Ecology 37:12-22.
- **Root**, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig, and J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. Nature 421:57-60.
- **Seneviratne**, S. I., N. Nicholls, D. Easterling, C. M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang. 2012. Changes in climate extremes and their impacts on the natural physical environment. In: Managing the risks of extreme events and

Figure 1. *Black flying-foxes, P. alecto (above) Grey-headed flying-foxes, Pteropus poliocephalus (below)*



disasters to advance climate change adaptation. Cambridge, UK.
- **Snoyman**, S., J. Munich, and C. Brown. in press. Nursing females are more prone to heat stress: Demography matters when managing flying-foxes for climate change. Applied Animal Behaviour Science.
- **Tewksbury**, J. J., R. B. Huey, and C. A. Deutsch. 2008. Putting the heat on tropical animals. Science 320:1296-1297.
- **Thomas**, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, and L. Hannah. 2004. Extinction risk from climate change. Nature:145-147.
- **Tidemann**, C. R. 2003. Displacement of a flying fox camp using sound. Ecological Management and Restoration 4:5-7.
- **Tidemann**, C. R. and J. E. Nelson. 2011. Life expectancy, causes of death and movements of the grey-headed flying-fox (Pteropus poliocephalus) inferred from banding. Acta Chiropterologica 13:419-429.
- **Walther**, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature:389-395.
- **Welbergen**, J. A. 2005. The social organisation of the grey-headed flying-fox. Ph.D thesis. University of Cambridge.
- **Welbergen**, J. A. 2010. Growth, bimaturation, and sexual size dimorphism in wild gray-headed flying foxes (Pteropus poliocephalus). Journal of Mammalogy 91:38-47.
- **Welbergen**, J. A. 2011. Fit females and fat polygynous males: seasonal body mass changes in the grey-headed flying fox. Oecologia 165:629-637.
- **Welbergen**, J. A., S. M. Klose, N. Markus, and P. Eby. 2008. Climate change and the effects of temperature extremes on Australian flying-foxes. Proceedings of the Royal Society B-Biological Sciences 275:419-425.
- **WHO**. 2003. WHO briefing note for the fifty-third session of the WHO Regional Committee for Europe. Vienna, Austria.
- **Williams**, S. E., L. P. Shoo, J. L. Isaac, A. A. Hoffmann, and G. Langham. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biol 6:2621-2626.
- **Zwiers**, F. W., X. Zhang, and Y. Feng. 2010. Anthropogenic influence on long return period daily temperature extremes at regional scales. Journal of Climate 24:881-892.

Bats and toxic pollutants

Jan Zukal[1], Jiri Pikula[2] and Hana Bandouchova[2]
[1] Institute of Vertebrate Biology AS CR v.v.i., Brno, the Czech Republic
[2] University of Veterinary and Pharmaceutical Sciences, Brno, the Czech Republic

Bats today face a number of major threats, with habitat disturbance and loss of roost sites (through deforestation and reconstruction of buildings) some of the more obvious. Less recognised or documented, however, are the detrimental effects due to toxicant exposure, which can be just as important but only become obvious once bat populations have started to decline. Toxicants come from a variety of sources, both natural and artificial, with agricultural and industrial chemicals some of the best known.

Like other wild animal taxa, bats are capable of indicating environmental quality. Rapid declines in the bat populations of many countries, however, have resulted in the classification of 24% of species as threatened and 21% as near threatened (Mickleburgh et al. 2002). Strict world-wide protection and conservation of most bat species prevents their use in standardised monitoring programmes for environmental contaminants, such as those undertaken with game animals. Further, the nocturnal and reclusive nature of these mammals makes recognition of die-offs more difficult than in other wild animals.

The study of bat toxicology, therefore, must be a multidisciplinary procedure with investigations based on analytical chemistry, biochemistry, statistical and mathematical modelling, and biological and ecological studies of the various species, including pathological and behavioural studies (Rattner 2009).

Toxic pollutants

Although humans have lived on earth for tens of thousands of years, it is only during the last two centuries that dramatic changes in the use of natural resources and energy, with resultant changes in economic systems, have led to exponential growth in the human population. One of the most important human impacts on natural processes and living organisms began with the increase in extraction, refining and processing of fossil fuels for the petrochemical industry at the beginning of the 20th century. Since that time, chemical compounds have contaminated all parts

of environment, and pollution by toxic elements continues to increase to the present day.

Many different types of contaminants are now present in the environment, ranging from synthetic chemicals (which would not be present in the environment without human intervention) to increased levels of trace metals that are required for life (Melancon 2003). These can be classified under various criteria, including origin, effect, property or degradability. Concerns range from possible harmful effects on flora and fauna (e.g. changes in growth rate, hormonal changes, immune system damage, or carcinogenicity) to possible harm caused to humans from consuming contaminated organisms. Notable chemical contaminants include four main groups: 1) heavy metals, 2) persistent organic pollutants, 3) environmentally persistent pharmaceutical pollutants, and 4) volatile organic compounds. To date, only the first two groups have been studied in any detail in bats.

Heavy metals

Heavy metals occur naturally in the environment and, therefore, there is always a natural background concentration in soils, rocks, sediments, water and in living organisms, with concentrations varying greatly. Anthropogenic pollution results in higher concentrations of these metals relative to the normal background values. Municipal and industrial waste and fossil fuels are especially likely to contain heavy metals.

The eleven elements of highest concern within the European Community are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin and thallium. All are hazardous to health or the environment, with lead, mercury, arsenic and cadmium among the most hazardous.

Persistent organic pollutants

Persistent organic pollutants are organic compounds of natural or anthropogenic origin that resist photolytic, chemical and/or biological degradation (UNEP, 1999). They are semi-volatile, allowing them to be transported long distances from their original source via water and the atmosphere, meaning that they can reach regions where they have never been used or produced. Persistent organic pollutants are toxic, chemically stable and tend to concentrate in living organisms through the process of bioaccumulation due to their high lipid solubility. As fish, predatory birds and mammals (including bats and humans) are high up in the food chain, they accumulate the greatest concentrations, mainly in fatty tissues. Almost all of these chemicals are produced by humans through industrial processing; natural sources being very scarce.

Three main groups are differentiated: 1) pesticides (e.g. DDT and its analogues, HCH compounds, cyclodienes, toxaphene and compounds with caged structures), 2) industrial chemicals (e.g. PCBs and hexabromobiphenyl), and 3) by-products (e.g. dioxin, furan and PAHs). Persistent organic pollutants are used in industrial processes and the production of a wide range of products (e.g. solvents and pharmaceuticals). Others are still widely used as pesticides (Jones & de Voogt 1999). Persistent organic pollutants are of high concern as some have been identified as carcinogenic, mutagenic and teratogenic, and many are recognised as exerting sub-lethal effects.

Bats as bioindicators

Bats are among the most diverse and widespread mammal species on Earth. Approximately 1,200 chiropteran species are known and they are found on all continents (except Antarctica) inhabiting a wide variety of ecological niches (Nowak 1994). Bats also display a high number of roosting and feeding specialisations and play key functional roles in ecosystems, acting as plant pollinators, seed dispersers and predators of insects, including harmful forest and agricultural pests (Kunz et al. 2011). Most bat species are listed under the International Union for the Conservation of Nature's Red List of Threatened Species (IUCN 2010) and are of global conservation concern (Micklenburg et al. 2002).

In light of their diversity and importance, bats have enormous potential as biodiversity, ecological and environmental indicators. Jones et al. (2009) summarised a number of general parameters that make bats ideal indicators of human-induced climate change and habitat quality (Tab. 1). Insectivorous bats in particular have been used in wildlife toxicology studies as they have a number of characteristics that make them suitable for use as indicators of general environmental conditions (Tab. 2).

Insectivorous bat species are the primary consumers of nocturnal insects and food composition, and subsequent exposure to environmental pollution, is influenced by the habitats that different bat species use for insect foraging (e.g. aquatic, aquatic and terrestrial, or terrestrial only) as well as the environmental conditions at the sites the bats were collected

from. Aquatic habitats (e.g. rivers, lakes and canals) are favoured as they often attract a rich supply of insects, though emerging aquatic insects may provide contaminant subsidies. Some species have adapted well to urban environments and can be found feeding (e.g. around streetlamps) within major agglomerations with high contaminant pollution (Gaisler et al. 1998).

Like other insectivorous mammals and birds, bats receive higher contaminant residues in their diets than herbivores due to food chain build-up. Moreover, the high metabolic rate of bats (bats consume 40–100% of their body mass each night) connected with flight (several km per night) and their associated small size demands greater rates of food intake than less active or larger mammals. Greater food intake thus increases the amount of contaminant available for concentration in fat.

Bats tend to have low reproductive rates and long life spans of up to 30 years (Racey & Entwistle 2000). Bats, therefore, may be subject to long-term accumulation of toxic contaminants and large concentrated doses of lipophilic contaminants may be transferred to offspring in milk. Moreover, bats are at risk of contaminant residue mobilisation as fat is absorbed and energy utilised during hibernation (Thomas et al. 1990).

Monitoring toxic contaminants in bats

There have been a number of reports published on the adverse effects of natural toxins on bats, including a description of mass mortality associated with a cyanobacterial bloom (Pybus et al. 1986) and negative physiological effects on flight performance and echolocation following ethanol ingestion by fruit bats (Sánchez et al. 2010). Reports on the effects of anthropogenic pollutants on Holarctic bats, however, are far more frequent (O'Shea & Johnson 2009). The results of these studies, which have used a variety of methods, all strongly implicate bioaccumulation of insecticides and other pollutants as contributing to the recent decline in bats.

In Europe, for example, Luftl et al. (2003) and Walker et al. (2007), have used standard residue analysis to assess heavy metals in the livers and kidneys of dead or debilitated bats in Austria and Britain, respectively. In the Czech Republic, Pikula et al. (2010) have confirmed the susceptibility of vespertilionid bats to the toxic heavy metals lead and cadmium and provided data on the essential element zinc. They also examined responses of bats foraging over aquatic, aquatic and terrestrial, and terrestrial habitats to heavy metals through evaluation of the metal-binding protein metallothionein. In southern Brazil, Zocche et al. (2010) have observed adverse effects of exposure to heavy metals in a coal mining area, using the Comet assay to assess DNA damage in blood cells of insectivorous bats.

An important recent study on the effects and responses of toxic contaminants has highlighted high intestinal permeability as a means for passive absorption through cell walls in bats (Caviedes-Vidal et al. 2008). While this is a less selective system for nutrient absorption than the more common carrier-mediated system, it may compensate the bat for its relatively less intestinal tissue. Paracellular absorption, however, also allows toxins to be readily absorbed from plant and animal material through the intestinal lumen and, therefore, increases the susceptibility of bats to toxins in the diet.

The wide use of organophosphate-based pesticides in agriculture makes exposure of humans and animals unavoidable and can result in both acute effects and chronic damage to the nervous system (Stephens et al. 1995). Sub-lethal exposure to pesticides over longer periods, however, can also be an important source of adverse effects. While detoxification via cytochrome P450 enzyme systems can ameliorate such effects, this uses energy that may then be lacking for other functions.

Monitoring and evaluation of bat activity represents an alternative approach to examining the responses of bats to environmental pollution. For example, significant differences have been observed in both bat diversity and activity between areas of mixed coniferous forest exposed to different degrees of air pollution (Rachwald et al. 2004); while Vaughan et al. (1996) have shown how a decline in river water quality affects the foraging behaviour of Pipistrellus pipistrellus and Myotis spp. bats, with both overall activity and foraging activity reduced downstream of a sewage output.

Other methods include mark-recapture techniques, used by Frick et al. (2007) to obtain data on the effects of a major pesticide spill on annual survival and population growth of Myotis yumanensis in the USA; and comparing foraging activity at sites of pesticide application with data on insect contamination to estimate exposure of bats to pesticides (Stahlschmidt and Bruhl 2012).

One problem that many of these studies face is the fact that, under environmental conditions, bats can be exposed to multiple stressors at the same time, including natural toxins, anthropogenic pollutants and infectious agents.

Given that contaminants frequently occur as mixtures in nature, ecotoxicology must also take into account possible synergistic effects between pesticides and natural stressors (Relyea & Hoverman 2006) and chronic, low-level exposure (Sanderson & Solomon 2009) with additive or jointly independent actions (Kortenkamp et al. 2007). Further, a number of epizootic infectious diseases have been noted as more severe in areas contaminated by environmental pollutants, demonstrating the possibility of population level effects associated with contaminant-induced immunosuppression.

Perspectives and advice for future bat studies

In many instances, human risk assessments do not adequately protect other biota. There is no doubt, therefore, that it will be necessary to study both classical and new environmental pollutants in bats in the future. The main purpose of these studies must be to assess the potential risk of toxicants for bats in order to enhance their future protection. As such, researchers should bear in mind the following advice:

1. All studies should comply with national and international nature conservation legislation and laws for the protection of animals against cruelty;

2. The 3Rs method should be used whenever possible (i.e. Replacement, Refinement and Reduction);

3. If experimental work is necessary to evaluate responses of bats to toxicants, consider using bats from wildlife rehabilitation centres. These may have been permanently handicapped and, therefore, cannot be returned to the wild;

4. When planning collection of bats from the wild, power analysis should be conducted to estimate the sample size providing sufficient statistical power and significance;

5. Always use non-destructive and non-invasive sampling procedures;

6. If possible, make use of samples collected from natural die-off, i.e. specimens found dead or moribund;

7. Obtain samples from bats originally delivered for different analyses, such as rabies or white-nose syndrome testing;

8. Do not discard bat cadavers after obtaining samples for your particular study, they may be useful for future studies;

9. Cooperate with specialists from different fields in order to obtain the widest range of analysis and views;

10. Employ progressive analytical techniques and modern instrumentation with the lowest detection limits;

11. Employ techniques allowing analysis of very small samples;

12. Increase passive collection of data and samples for contaminant analysis and its effects during other projects;

13. Identify exposure biomarkers and correlate levels with toxin content in tissue, thereby allowing non-destructive intra-vital diagnoses;

14. When handling bats, bear in mind that they may be reservoirs for zoonotic agents;

15. Encourage further detailed ecotoxicological investigations into this interesting mammalian group.

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References

- **Caviedes-Vidal,** E., Karasov, W.H., Chediack, J.G., Fasulo, V., Cruz-Neto, A.P., Otani, L., 2008: Paracellular Absorption: A Bat Breaks the Mammal Paradigm. PLoS ONE, 3: e1425.
- **Frick**, W.F., Rainey, W.E., Pierson, E.D., 2007: Potential Effects of Environmental Contamination on Yuma Myotis Demography and Population Growth. Ecological Applications, 17: 1213 – 1222.
- **Gaisler**, J., Zukal, J., Rehak, Z., Homolka, M., 1998: Habitat preference and flight activity of bats in a city. J Zool, 244: 439 – 445.
- **International** Union for the Conservation of Nature, 2010: IUCN Red List of Threatened Species, version 2010.3.
- **Jones**, G., Jacobs, D.S., Kunz, T.H., Willig, M.R., Racey, P.A., 2009: Carpe noctem: the importance of bats as bioindicators. Endang Species Res, 8: 93 – 115.
- **Jones**, K,C., de Voogt, P., 1999: Persistent organic pollutants (POPS); state of the science. Environmental Pollution, 100: 209 – 221.
- **Kortenkamp**, A., Faust, M., Scholze, M., Backhaus, T., 2007: Low-level exposure to multiple chemicals: reason for human health concerns? Environ Health Persp, 115 (Suppl 1): 106 – 114.
- **Kunz**, T.H., de Torrez, E.B., Bauer, D., Lobova, T., Fleming, T. H., 2011: Ecosystem services provided by bats. Ann N Y Acad Sci, 1223: 1 – 38.
- **Luftl**, S., Freitag, B., Deutz, A., Tataruch, F., 2003: Concentrations of Heavy Metals in European Bats (Microchiroptera). Fresenius Environmental Bulletin, 12: 353 – 358.
- **Mickleburgh**, S. P., Hutson, A.M., Racey, P.A., 2002: A review of the global conservation status of bats. Oryx, 36: 18 – 34.
- **Melancon**, M.J., 2003: Bioindicators of Contaminant Exposure and Effect in Aquatic and Terrestrial Monitoring. In: Hoffman D.J., et al. (eds.), Handbook of Ecotoxicology. 2nd edition. Lewis Publishers, USA, pp. 257 – 278.
- **Mickleburgh**, S.P., Hutson, A.M., Racey, P.A., 2002: A review of the global conservation status of bats. Oryx, 36: 18 – 34.

- **Nowak**, R.W., (ed.), 1994: Walker's bats of the world. Johns Hopkins University Press, Baltimore, MD, 287 pp.
- **O'Shea**, T.J., Johnson, J.J., 2009: Environmental contaminants and bats: investigating exposure and effects. In: Kunz, T.H., Parsons, S., (eds.), Ecological and behavioral methods for the study of bats, 2nd edn. Johns Hopkins University Press, Baltimore, pp. 500 – 528.
- **Pikula**, J., Zukal, J., Adam, V., Bandouchova, H., Beklova, M., Hajkova, P., Horakova, J., Kizek, R., Valentikova, L., 2010: Heavy metals and metallothionein in vespertilionid bats foraging over aquatic habitats in the Czech Republic. Environmental Toxicology and Chemistry, 29: 501 – 506.
- **Pybus**, M.J., Hobson, D.P., Onderka, D.K., 1986: Mass mortality of bats due to probable blue-green algal toxicity. J Wildl Dis, 22: 449 – 450.
- **Rachwald**, A., Wodecka, K., Malzahn, E., Kluzinski, L., 2004: Bat Activity in Coniferous Forest Areas Land the Impact of Air Pollution. Mammalia, 68: 445 – 453.
- **Racey**, P.A., Entwistle, A.C., 2000: Life history and reproductive strategies of bats. In: Crighton, E.G., Krutzsch, P.H. (eds.), Reproductive biology of bats. Academic Press, New York, pp. 363 – 414.
- **Rattner**, B.A., 2009: History of wildlife toxicology. Ecotoxicology, 18: 773 – 783.
- **Relyea**, R., Hoverman, J., 2006: Assessing the ecology in ecotoxicology: a review and synthesis in freshwater systems. Ecol Lett, 9: 1157 – 1171.
- **Sánchez**, F., Melcón, M., Korine, C., Pinshow, B. (2010): Ethanol ingestion affects flight performance and echolocation in Egyptian fruit bats. Behavioural Processes, 84: 555 –558.
- **Sanderson**, H., Solomon, K., 2009: Contaminants of emerging concern challenge ecotoxicology. Environ Toxicol Chem, 28: 1359 – 1360.
- **Stahlschmidt**, P., Bruhl, C.A., 2012: Bats at risk? Bat activity and insecticide residue analysis of food items in an apple orchard. Environmental Toxicology and Chemistry, 31: 1556 – 1563.
- **Stephens**, R., Spurgeon, A., Calvert, I.A., Beach, J., Levy, L.S., Berry, H., Harrington, J.M., 1995: Neuropsychological effects of long-term exposure to organophosphates in sheep dip. Lancet, 345: 1135 – 1139.
- **Thomas**, D.W., Dorais, M., Bergeron, J.M., 1990: Winter energy budgets and cost of arousals for hibernating little brown bats, Myotis lucifugus. J Mammal, 71: 475 – 479.
- **UNEP**, 1999: Inventory of information sources on chemicals Persistent Organic Pollutants. 141 pp.
- **Vaughan**, N., Jones, G., Harris, S., 1996: Effects of sewage effluent on the activity of bats (Chiroptera: Vespertilionidae) foraging along rivers. Biological Conservation, 78: 337 – 343.
- **Walker**, L.A., Simpson, V.R., Rockett, L., Wienburg, C.L., Shore, R.F., 2007: Heavy Metal Contamination in Bats in Britain. Environmental Pollution, 148: 483 – 490.
- **Zocche**, J.J., Leffa, D.D., Damiani, A.P., Carvalho, F., Mendonça, R.A, dos Santos, C.E.I., Boufleur, L.A, Dias, J.F., de Andrade, V.M., 2010: Heavy metals and DNA damage in blood cells of insectivore bats in coal mining areas of Catarinense coal basin, Brazil. Environmental Research Volume, 110: 684 – 691.

Table. 1. *Criteria that make bats excellent indicators (reproduced from Jones et al. 2009).*

• Relatively stable taxonomy
• Can be sampled at several levels (e.g. population, feeding rates of individuals)
• Wide geographic range
• Graded responses to habitat degradation correlated with responses of other taxa (e.g. insects)
• Rich trophic diversity
• Slow reproductive rate, meaning that population declines can be rapid
• Perform key ecosystem services (e.g. pollination, fruit dispersal, arthropod control)
• Reservoirs of a wide range of emerging infectious diseases whose epidemiology may reflect environmental stress

Table 2. *List of characteristics that make insectivorous bats important as environmental indicators.*

Parameter		Importance for bio-indication
Long lifespan	=	*Long-term accumulation*
Obligate insectivores	=	*High in the trophic chain*
Variety of feeding habitats	=	*Diversity of contaminants sources*
Active flight	=	*Long-range coverage*
Synanthropy	=	*Human and industrial impact*
High metabolic rate	=	*Accumulation of contaminants*
Hibernation	=	*Mobilisation of residues within a short period*

autor: salvadorvinyes

Abstracts posters

LONG-TERM BAT SURVEYS IN A TROPICAL CLOUD FOREST AND RECENT EFFECTS OF DEFORESTATION ON BAT ASSEMBLAGES

M. Arzúa and K. Bohn
Operation Wallacea. Carretera de Castilla, 15403, Ferrol, Spain

Cusuco National Park is located in the Merendón Mountain Range, state of Cortés, Honduras. Since 2006, bats have been mist-netted in the buffer zone and the core zone of Cusuco and there is a database of the bat assemblage in the area, previous surveys were made since 2004.

Bat surveys were conducted between June and August each year by Operation Wallacea scientists in 4 survey camps within the buffer zone and the core zone of the park with similar sampling efforts among sites. Deforestation has significantly reduced, some areas especially in the west side of the park.

A total of 3221 individuals were captured and identified in Cusuco, comprising 59 species from 5 families. Phyllostomidae was the most abundant and diverse family, they have a wide range of dietary and roosting habits and thus a large number of species for monitoring long term effects of habitat degradation, weather variation, and anthropogenic disturbance on biodiversity. Differences on some species composition of Phyllostomidae subfamilies are detected.

BATS AS POLLUTION INDICATORS: HEAVY METAL STUDIES IN ITALY

D. Scaravelli, P. Priori and A. Zaccaroni
STERNA e Museo Ornitologico F. Foschi. Via Pedriali 12, 47121, Forli, Italy

The exposure to and the potential effect on wildlife health status of heavy metals have been clearly proved since long time. Despite the fact that bats, being among the common vertebrates in agricultural and urban areas, can potentially accumulate high amounts of pollutants, little work has been done in order to assess contaminants body burden in these species. Present work reports about the evaluation of heavy metals excretion with faeces in *Myotis myotis* from a reproductive colony located in Gargazzone, Val Venosta (BZ). Heavy metals profiles in M. myotis present high As, Cr, Pb and Fe. There are few references regarding monitoring of guano and heavy metals. Our results are indicative of exposure to Hg at non toxic levels. For bats living in a contaminated area, level of As were comparable to those observed in Eptesicus fuscus by O'Shea et al., (2000). So, a potential intoxication can be considered, even if no study have been performed to assess toxic thresholds in bats. A certain concern raise from obtained results, as a high, unexpected exposure to Pb, As and Cd was observed.

The real meaning of such levels needs further evaluation, by comparing levels in guano and in bat tissues. The use of intensive orchard and deciduous shrub forests by this populations implicate a strong possible effect of management of lands in charge the ecosystem of pollutants. Bat can be considered in this way a very important bio-sentinel and use in the assessment of human impact. Differences among colony in Southern Tyrol can be evaluated in future to understand the level of pollutants in the province as well as to assess the potential role in conservation of greater Myotis.

TEMPORAL PATTERN OF ACTIVITY OF THE ONLY CAVE NURSERY COLONY OF THE GREATER MOUSE-EARED BAT, *MYOTIS MYOTIS* IN THE AREA OF THE CZECH REPUBLIC

L. Falkova and Z. Rehak
Department of Botany and Zoology, Faculty of Science,
Masaryk University. Kotlarska 2, 61137, Brno, Czech Republic

In Central Europe, the Greater mouse-eared bat Myotis myotis usually forms nursery colonies in attics while in the Mediterranean nurseries are commonly situated in caves. The cave Rotunda is a part of the Hranice Karst (Moravia, Czech Republic) and is the only underground nursery colony of M. myotis in the Czech Republic. It is one of the northernmost cave roosts of nursery colony of *M. myotis* in Europe. Internal microclima of the cave is stable all year long compared to the usual summer roosts in attics. The cave Rotunda is only accessible with diving equipment. The only possibility of monitoring the colony is by using recording equipment. *M. myotis* colony was studied in 2010 – 2012. The research was focused on seasonal and overnight changes in activity, forming and disintegration of the nursery colony. Videorecordings were acquired by a IR videocamera system placed in front of the only flying passage from the cave. The overnight flying in/out activity of bats was recorded fortnightly from May to October. The length of the night was limited by the time of astronomical sunset and sunrise. The highest number and flight activity of bats were observed from the middle of July to the middle of August due to juveniles fledged. In spring and autumn the bat activity and size of the colony were lower. In these periods the activity was more influenced by climate conditions.

BATS ACTIVITY IN UNCUT AND PARTIALLY CUT BEECH-FIR FORESTS IN CROATIA

I. Pavlinić and M. Đaković
[1]*Croatian Natural History Museum, Demetrova 1, 10000 Zagreb, Croatia.*
[2]*Centre for Nature Research and Conservation-Fokus, Demetrova 1, 10000 Zagreb, Croatia*

We made walking transects in beech-fir forests in Croatia in the period from June 2005 to September 2005 and compared uncut with partially cut ones.

Our study took place in the area of Plitvice National Park (_orkova bay) and the partially cut forest in the immediate vicinity (Vrhovine) and in the Medvednica Nature Park at three locations of which one is partially cut (_upljak) and two are not (Markov Travnik, Stara Pila). All localities are between 600-800 m.a.s.l. To examine bat activity along selected transects we used the Pettersson D1000X Ultrasound Detector. Data was later processed by programs for sound analysis BatSound and Raven. Data was statistically analyzed using ANOVA and Tukey's HSD for unequal N. Results showed no statistically significant difference in bat activity and species composition except in July when the partially cut forests have greater activity than the uncut. We detected eleven categories of bats of which nine are determined to the species level and two to the group level (sp. and *Myotis sp.). Myotis sp., P. pipistrellus* and group sp. had the most registered passes per kilometer. In the uncut forest we detected all eleven categories; the predominant were *Myotis sp.* and *N. noctula.* In the partially cut forest we detected nine categories, predominant were *P. pipistrellus* and *E. serotinus* (with no *N. noctula, P. pygmaeus*). The species composition shows no qualitative and quantitative differences between the two types of forest management; respectively at some periods partially cut type has greater bat activity than the uncut. A possible explanation is that this way of management increases edge effect respectively increasing the number and diversity of insects. The negative side of the partially cut type that is not considered in this study is that availability of the hollows in the old trees is reduced.

RAINFALL AND TEMPERATURE INFLUENCE ON THE REPRODUCTION OF *MOLOSSUS RUFUS* (CHIROPTERA, MOLOSSIDAE) IN CIANORTE, PARANÁ, SOUTH OF BRAZIL

M. A. Marques, H. Ortêncio Filho, D. D. Gonçalves and E. A. Kashiwaqui
Universidade Paranaense. Estrada Cristal 83 A, 87225-000, Japurá, Brazil

The presence of bats in different ecosystems can serve as a parameter for the identification of biological processes involving the loss or transformation of natural habitats, and some species are considered as indicators of environmental change. Studies about chiropteran reproduction may contribute to understanding the strategies developed by these animals to overcome changes in the environment. The present study aimed to investigate the time pattern of the reproductive status of *Molossus rufus,* in the city of Cianorte, Paraná, South of Brazil and associate it to rainfall and temperature, between October 2010 and September 2011. The study was conducted in urban and rural properties located near the Cinturão Verde Municipal Park. Mist nets were placed at points of exit of the animals. In order to obtain information on the reproductive status of the bats, the analysis of the secondary sexual characteristics was performed. For data analysis, the Spearman's rank correlation (R) was applied at a significance level of 5%. 165 animals of the species *M. rufus* were captured, 63% females and 37% males. The highest number of captures occurred in September 2011 (32.15%) and August 2012 (30.30%). Pubescent females were more abundant than pregnant ones. Both of them were positively correlated significantly (R = 0.60), being frequent in the months of August and September. Pubescent males were not observed only in June, February, October and November of 2010. Among males there was no correlation, however, pubescent males were positively correlated (R = 0.72) with females in the same reproductive state, since they were also frequent in the months of August and September. These data suggest that the bats studied showed polyestry, concentrated to reproduction in the drier months, indicating that rainfall coupled with temperature has a direct influence on the reproductive patterns of these animals.

IS FORAGING GREATER HORSESHOE BAT PREDICTABLE IN THE CAMARGUE AREA ?

D. Lyx, C. Azam, J. Fonderflick, D. Quekenborn and E. Cosson
Groupe Chiroptères de Provence. Rue Villeneuve, 04230, Saint-Etienne-les-Orgues, France

The Camargue delta is currently one of the area showing the largest populations of greater horseshoe bats in the provencal region. Until 2005, no colonies were listed within the area. Then, the delta has been regularly explored and 6 nursery colonies have been discovered, totalising more than 600 individuals. In order to understand population requirements and to protect roosts and habitats, several radiotracking studies have been conducted on the species. Univariate analysis showed specific areas preferences associated with characteristic habitat types. We are now planning to test if multivariate analysis based on the ENFA (Ecological Niche Factor Analysis) could (1) highlight specific environmental factors which could explain foraging sites' distribution; (2) allow the development of a landscape diagnosis modelisation dedicated to the greater horseshoe bat. Once validated, the model could help conservation managers to focus on relevant protection measures and in some cases avoid resorting to heavy and costly radiotracking studies.

MONITORING SCHEMES REVEAL IMPACTS OF STREET LIGHTING ON BATS

N. Roche, T. Aughney, S. Langton, N. Kingston, D. Lynn and F. Marnell
Bat Conservation Ireland. Ulex House, Drumheel, Lisduff, Virginia, Cavan, Ireland

Despite much anecdotal evidence regarding the impacts of street lighting on Irish bats, no comprehensive studies have been carried out to-date. Using data collected from two bat monitoring schemes – a car-based driven method, and a foot-based waterways survey, we analysed the impacts of street lights on activity levels or presence of four Irish bat species. For driven transects we categorised street lamp types into white (mercury vapour), yellow (high pressure sodium) and orange (low pressure sodium). Orange lights were most frequently recorded across the island and white lights were the least common. We found that activity levels of Leisler's bat *(Nyctalus leisleri)* along roads were significantly positively impacted by the presence of yellow and white street lights. This fits with predictions based on the species' fast flight style and medium body size and findings of other researchers. We found no significant impact, positive or negative, on activity of the two most common species of pipistrelle (*Pipistrellus pipistrellus* and *P. pygmaeus*) recorded by the car-based scheme. This contrasts with findings in other countries, where these species have been positively associated with lit roads. We hypothesise that vegetation cover along lit stretches is another factor that may impact pipistrelle activity and this needs further study. For Daubenton's bats we found that it was 9% less likely to occur at waterway survey spots if street lights (colour not noted) were present, fitting with predictions regarding *Myotis spp.*

DIVERGENT RESPONSE OF BATS AND INSECTS TO LAND USE AND SOIL TYPES IN AGRICULTURAL GRASSLAND SYSTEMS

J.T. Treitler, O. Heim, E.K.V. Kalko and K. Jung
Institute of Experimental Ecology. Albert Einstein Allee 11, 89069, Ulm, Germany

Expansion and intensification of agriculture are two of the most important factors for land transformation. In such agricultural areas natural factors (e.g., soil) interact with anthropogenic land use (e.g., fertilization), thus affecting patterns of biodiversity and interrelations between different taxa and associated ecosystem services. An important interaction is the predator-prey relationship between bats and insects.

We investigated this specific relation on fifty differently managed grassland plots in the Schorfheide-Chorin in Germany by assessing occurrence, activity and species composition of bats by using acoustic monitoring. Simultaneously, we captured insects with a flight interception trap to determine abundance and composition of insect orders. To explore diversity patterns across hierarchical scales (local to landscape level) we applied hierarchical partitioning; non-metric multidimensional scaling was used to investigate differences in composition of bats and insects, and for an evaluation how environmental variables influence activity of bats, we utilized generalized linear models.

Our results indicate that bats and insects in agricultural managed grassland systems are driven by differing mechanisms. Diversity patterns and composition of insect orders were mainly affected by local environmental factors such as soil and land use type. In contrast, diversity pattern and species composition of bats were predominantly influenced by local fluctuations of insects and very likely by the landscape matrix surrounding the grassland sites. The activity of bats is to a great extent affected by insects and thus to a certain extent by local environmental factors in the grassland.

In conclusion, our results show that bats and insects are affected differently by land use management. While insects are directly affected by local factors, bats are indirectly influenced by land use through its effects on the insects. This study shows that bats are indeed important bioindicators, but conservation and management implementations should additionally take interactions with different taxa of the ecosystem into account.

BATS AS INDICATORS OF RIPARIAN FORESTS CONSERVATION: COMPARATIVE COST-EFFICIENCY WITH OTHER ZOOLOGICAL GROUPS

J. Camprodon and D. Guixé
Biodiversity Department. Forest Sciences Center of Catalonia (CTFC).
Ctra. de St. Llorenç de Morunys a Port del Comte, km 2, 25280 Solsona Catalonia

We studied the use of bats as indicators of riparian forest structure in the Alt Ter River (Catalonia) in 2009-2010. Bat activity was evaluated on 7 sites using quantitative echolocation methods (Pettersson D980 detector and Song Meter SM2 automatic system) and was complemented by capture sessions. The results were compared with other indicator organisms (birds, small mammals and carnivores) sampled on the same study sites. The selection of forest variables at plot and landscape levels was obtained by RDA analyses as an exploratory approach, followed by the use of linear models.

We found 9 species of bats with conventional echolocation detector sampling and capture sessions. There was a significantly higher frequency of forest bat specialists in structurally more complex riparian forests. In contrast, the frequency of generalist species increased in the most degraded forests. This lack of adjustment is attributed to high heterogeneity of riparian habitat and the sampling limitations. Nevertheless, the forest-specialized bats selected two plot variables: high cover of trees (> 16 m) and native woody vegetation.

Echolocation conventional samples can clarify the fine selection of forest variables by bats, but have some limitations to use as a fine indicator of the changes in the habitat, because of the large field effort and subsequent determination of species to achieve consistent results. However, it may be suitable for monitoring long-term population trends. Captures complement acoustic data, but require a very large sampling effort. The standardized use of forest bats as indicators must be a compromise between the effectiveness and the cost of field sampling and analysis. The automatic system may be the most effective and most promising method in the near future.

The best indicator of the structure of riparian forest was the bird community, because it is a very sensitive group to environmental changes, is diversified, simple and cheap to monitor. Bats and small mammals are defined as two complementary bioindicators, with a higher cost-efficiency effort. However, these groups report additional and complementary information to the birds, at the stand and landscape level.

SPECIES RICHNESS AND EDGE EFFECTS ON BAT COMMUNITIES FROM PEROBAS BIOLOGICAL RESERVE, PARANÁ, SOUTH BRAZIL

J .R. R. Silva, H Ortêncio Filho, T. E. Lacher Junior and C. A. O. Magalhães Júnior
Universidade Estadual de Maringá. Avenida Reitor Zeferino Vaz, s/n Jardim Universitário
Cep 87360-000, Goioerê, Paraná, Brazil

Habitat fragmentation, characterized by a continuing decrease in native vegetative by habitat conversion, creates the formation of habitat mosaics and contact between forest and deforested zones, denominated edges. Previous researches have shown a reduction in bat diversity as a consequence of this process. The aim of this study was to investigate the influence of edge effects upon the composition of bat species from Perobas Biological Reserve, Paraná, southern Brazil. Sixteen mist nets were set in the forest edges and 16 set in the forest fragments, generating a capture effort of 43,520 m2h. During the period of study, 170 individuals were captured, belonging to 13 species. Data were analyzed by means of contingency tables, student's t-test ($P < 0,05$) and descriptive statistics. A higher number of species was registered in the forest (n=11), compared to the edge (n=09). *Artibeus lituratus* and *Sturnira lilium* were the most frequent captured species, mainly in the forest. *Eptesicus furinalis* and *Molossops neglectus* were sampled exclusively in the edge, *A. fimbriatus, A. obscurus, A. planirostris* and *Lasiurus blossevillii* only in the forest and *Carollia perspicillata, Pygoderma bilabiatum, E. brasiliensis, Myotis nigricans, M. ruber* in both sites. Although edges have reduced overall richness, some bats specialize in those more open habitats and some level of edge adds to regional species richness.

LONG-TERM BAT MONITORING PROGRAMMES IN LATVIA

G. Pētersons[1] , V. Vintulis[2], J. Šuba[2]
[1]Faculty of Veterinary Medicine, Latvia University of Agriculture, Kr. Helmana 8, LV-3004 Jelgava, Latvia
[2]Faculty of Biology, Latvian University, Kronvalda bulv. 4, LV-1010 Riga, Latvia

Three monitoring programmes of bats are conducted in Latvia: 1) counting the hibernating bats in underground sites (started in 1992); 2) counting the migrating Nathusius' bats *Pipistrellus nathusii* (1993) and 3) counting the pond bats *Myotis dasycneme* in the Natura 2000 sites (2008).

The annual census of hibernating bats covers about 80 caves and 50 cellars or fortifications that are visited by local bat experts and volunters once every winter. On average, 1700 bats of 8 species are recorded annually. The trends calculated for 20-year period by TRIM are stable for the northern bat *Eptesicus nilssonii,* the pond bat *Myotis dasycneme* and the Natterer's bat *Myotis nattereri,* indicate moderate increase in the Daubenton's bat *Myotis daubentonii* and strong increase in the Brandt's bat *Myotis brandtii.* The only species with declining trend is the brown long-eared bat *Plecotus auritus.*

Annual acoustic survey of migrating Nathusius'bats by ultrasound detectors is conducted at the Pape Ornithological Research Centre located at the eastern coast of the Baltic Sea (SW Latvia) between 10th August and 10th September. Number of bat passes is registered every night in three sessions at four spots is used as an index of bat activity during the autumn migration period. During the last 20 years, the total number of bat passes per season indicates possible increase in the population size of the Nathusius' bats within the north-eastern part of its distribution range.

The monitoring program of the pond bats is implemented in 10 Natura 2000 sites. Every site is visited by the bat experts and volunteers once in two years. In 8 territories, the monitoring program includes counts of adult females during the evening emergence form nursery roosts in buildings (n = 11). In two other territories, presence or absence of the pond bats is recorded within potential foraging habitats.

MONITORING OF CAVE-DWELLING BATS IN THE COMUNIDAD VALENCIANA REGION. SPAIN. PERIOD 2003-2011

M.A. Monsalve[1], A.J. Castelló[2], A. Alcocer[2], F. Cervera[1], B. Sarzo[1], M.A. Bartolomé[1], M. Vilalta[1], A. Pradillo[1], J.V. Bataller[1] and D. Almenar[2]
[1]Equipo de Seguimiento de Fauna – VAERSA. Conselleria de Infraestructuras, Territorio y Medio Ambiente
[2]CADEC, Taller de Gestión Ambiental S.L. Spain

Since 2003 an annual monitoring of several species has been developed: *Rhinolophus mehelyi* (2 roosts), *Rhinolophus euryale* (7), *Myotis capaccinii* (13), *Myotis myotis/blythii* group (9) and *Miniopterus schreibersii* (12). In this paper we describe the trends for each species from 2003 to 2011.

Counts were made at the caves entrances through video recording with infrared light and ultrasound detector. Films were made at nightfall, starting when the first bat left the roost, and during 60 minutes. Colonies were recorded each year in the breeding season, from early May to late July, and similar dates were selected for yearly replications in each locality. Data used to estimate trends were calculated with the software TRIM 3.53 which covers the gaps appearing in the matrix locality/year.

Recorded data indicate that *Miniopterus schreibersii* and *Myotis capaccinii* populations are stable (15,000 spec. and 2,000 spec. respectively).

Data collected in the last two years for Rhinolophus euryale and *Myotis myotis/blythii* group show a recovery of populations. Until 2009 the populations had an average annual reduction of 4% for *R.euryale* and 6% for *M.myotis/blythii* group (with a minimum recorded that year of about 450 spec. and 2,000 spec. respectively). However in recent years the counts have increased to the same numbers to those reported in beginning of the period (1,500 spec. of *R.euryale* and 5.000 spec. of *M.myotis/blythii* group).

After 10 years of conservation actions the only species that has a clearly unfavorable situation is *Rhinolophus mehelyi* (current estimate is less than 50 spec.) which maintains a marked reduction of approximately 10% per year.

NON-INVASIVE MONITORING OF STRESS HORMONES IN *EPTESICUS ISABELLINUS*

D. H. Kelm, A. G. P.-Lisseanu, M. Dehnhard and C. Ibáñez
Avd. Américo Vespucio s/n - Isla de la Cartuja. Estación Biológica Doñana (CSIC), Sevilla. Spain.

Environmental and social stress may directly correlate to decreased survival rates in wildlife. Hence, stress hormone analysis can be a useful tool to highlight environmental stress and deduce on the individual and population level fitness. Regarding stress hormone research, non-invasive sampling techniques, such as fecal sampling, may be advantageous, but have not been used in bats before. In bats, a principal factor inducing stress may be colony size. To test the applicability of fecal stress hormone analysis in bats we studied the influence of colony size on stress in five colonies of *Eptesicus isabellinus* with varying size and survival rates in Andalusia, Spain. First, we validated the hormonal analysis with an ACTH challenge, comparing blood stress hormone levels and fecal stress hormone metabolites in consecutively collected fecal samples. We identified corticosterone and cortisol and their derivates in blood and feces and verified the increase of fecal stress hormones after inducing physiological stress with ACTH. The baseline and maximum blood cortisol levels, at 6.5 ng ml-1 and 46.2 ng ml-1 respectively, were low compared to other bat species studied before. Baseline fecal cortisol was at 224 ± 198 ng g-1 and did not increase within 1.5 h after capture. We did not find a difference in fecal baseline cortisol levels between colonies (22 ± 5 individuals sampled per colony), despite significantly varying colony size and survival rates between colonies, nor a correlation between biometric variables, such as forearm length, and fecal cortisol. We argue that analysis of fecal stress hormones indeed allows non-invasive studies of stress in bats, however care needs to be taken when deducing on relations between hormonal stress and environmental factors.

ROOSTING BEHAVIOUR OF THE INDIAN FLYING FOX, *PTEROPUS GIGANTEUS*: A BIOINDICATOR OF WETLAND ECOSYSTEM.

S. Suthakar Isaac
Research Department of Zoology, St.John's College,
Palayamkottai 627 002. Tamilnadu, India

Roosting behaviour and distribution of the Indian flying fox, *Pteropus giganteus* was investigated in three districts of the South Tamilnadu, India during the years 2004 and 2012. About 41 roosting sites were located in the study area and the total count of P. giganteus was around 22,000 in 2004 and 34,000 in 2012. The total number of roost trees also has been increased from 87 to 188 during the study period. A majority of the roosting sites of *P. giganteus* were located in wetland ecosystem. Evidently, 90% roosts (37 trees) were located on the bank of rivers, canal, and freshwater ponds. The remaining 10% roosts (4 trees) were located on the cultivated agricultural land, and near residential area. Among 15 species of roosting trees, 7 are commonly used (80.60%) and other 8 species are less frequently used (19.40%). The commonly used tree species are *Terminalia arjuna* (34.40%), *Bassia latifolia* (18.81%), *Ficus bengalensis* (9.13%), *Cassia siamea* (6.98%), *Termarindus indica* (4.83%), *Ficus religiosia* (4.30%), and *Mangifera indica* (2.15%). It is concluded that *P. giganteus* prefers to roost in trees near water bodies in wetland ecosystems, where a microclimatic condition of high humidity and low temperature prevail. Therefore, this species can be considered as a bioindicator of wetland ecosystem of tropical plains.

FUNCTIONAL IMPACTS OF GLOBAL WARMING ON THE PREY DETECTION ABILITY OF ECHOLOCATING BATS

J. Luo[1,2], K. Koselj[1], S. Zsebők[1,3], B. M. Siemers[1] and H. R. Goerlitz[1]
[1] Max Planck Institute for Ornithology, Sensory Ecology Group, Eberhard-Gwinner-Straße, 82319 Seewiesen, Germany.
[2] Jilin Key Laboratory of Animal Resource Conservation and Utilization, Northeast Normal University, 130024 Changchun, China.
[3] MTA-ELTE-MTM Ecology Research Group, Ludovika tér 2, 1083 Budapest, Hungary

Climate change impacts the biogeography and phenology of plants and animals, yet the underlying mechanisms are little known. Here we present a functional link between rising temperature and the foraging efficiency of echolocating bats. The maximum distance over which bats can detect prey is determined by sound attenuation. Sound attenuation is especially pronounced for high frequencies, such as bat echolocation, and is a non-linear function of both call frequency and ambient temperature. Hence, the prey detection ability and foraging efficiency of bats is susceptible to global temperature rise through climate change. Using projected temperature rises of the 21st century, we modelled this effect for the entire range of bat echolocation call frequencies and for climate zones around the globe. Depending on call frequency, prey detection ability will both decrease and increase. Within local species assemblages, species calling above a crossover frequency will lose and species emitting lower frequencies will gain foraging efficiency, causing a shift in competitive balance, whose magnitude and crossover frequency depend on the local climatic conditions. Global warming thus affects the foraging efficiency of individual bats directly and species interactions such as competition and predator-prey dynamics indirectly.

WHAT DO BIOINDICATORS (BIO)INDICATE?

M. Napal, I. Garin, J. Aihartza
University of the Basque Country. UPV/EHU. Dpto. Zoología y Biología Celular Animal. B. Sarriena s/n. ES-48940 Leioa. Basque Country

Bechstein's bat (*Myotis bechsteinii*, Kuhl 1817) has several attributes making it a good bioindicator. The species is strictly dependent on forests – with preference for mature to aged woods, providing a range of suitable roosts -. Moreover, some features hindering its ability to colonize new areas enhance its susceptibility to forest loss and transformation, namely extreme phylopatry, sedentary habits and low demographic rates.

We characterized the autoecology of the species in several localities in the Atlantic domain of the Iberian Peninsula. Based on the presence of the species, we would have predicted those forests harbouring apparently healthy colonies to be high-quality habitats. However, some evidences coming from the ecological characterization challenge this interpretation (e.g. comparative long commuting distances, pathways crossing the highway, unusual foraging habitats and choice of seemingly unsuitable roosting cavities). Actually, this locality is among the most modified by human activity, including industry, electric lines and ongoing forestry with allochthonous species – Q. rubra.

In this locality, the presence of *M. bechsteinii* could well be evocating the ghost of past habitat suitability, rather than current favourable conditions. We claim that habitat quality should not be directly inferred from the presence of bioindicators without further verification of their behaviour and population trends.

WEATHER AND GEOGRAPHIC EFFECTS ON REPRODUCTIVE PHENOLOGY OF *RHINOLOPHUS FERRUMEQUINUM, RHINOLOPHUS EURYALE* AND *MYOTIS EMARGINATUS* IN GALICIA (NW SPAIN). IMPLICATIONS FOR A MONITORING PROGRAMME.

F. Arcos, E. Rego and R. Salvadores
Arcea Xestión de Recursos Naturais S.L. C/. Velázquez Moreno nº9 planta 3, oficina 05. 36201 Vigo, Pontevedra, Spain

According to the Habitat Directive (92/43/EEC), member States of the European Union must develop a monitoring programme of the species included on its II, IV and V Annexes, to establish the evolution of their populations and to determine their conservation status over time. All the European bat species are included in those Annexes and at present a monitoring programme should be in operation in all the European countries.

The census of adults and young linked to maternity roosts is one of the options for bat monitoring. However, these counts have methodological difficulties, because before putting in practice a monitoring programme to obtain comparable counts for trend estimation in a cost-effective way, it is necessary to determine the geographic and interannual variability of reproductive phenology and occupation of the colonies.

In the Autonomous Region of Galicia, the bat monitoring programme is still in its initial stages. Until now it has been focussed on the documentation of the variability of the occupation dynamics and the reproductive phenology of a selection of maternity roosts of three bats species: the Greater Horseshoe Bat (*Rhinolophus ferrumequinum)*, the Mediterranean Horseshoe Bat *(Rhinolophus euryale*) and the Geoffroy's Bat (*Myotis emarginatus).*

In 2011 we visited three times four maternity roosts between June 24th and July 14th to obtain infrared video recordings of young creches after the emergence of the adults. The counts were therefore done in the laboratory. Additionally, one of the roosts was also monitored between 2010 and 2012.

Preliminary results show the existence of geographic differences on the date of maximun young counts inside breeding roosts, which seems to be conditioned by the climatic regime of the surroundings of the roost. Therefore, the ones which are under the influence of very dry temperate and warm climatic regimes show peak counts a week earlier than the ones which are under wet and very wet warm regimes. Also, in years with a high level of montly accumulated precipitations between April and July, we have registered a week's delay in birth peaks.

According to the information obtained, we recommend a monitoring programme of the breeding performance of the species mentioned above in Galicia, based on four weekly counts carried out between the third week of June and the second week of July. The counts have the objective of identifying the peak concentration of young at the roost and to determine the date when the 50% of annual births occur.

PATTERNS OF *HYPSUGO SAVII* (MAMMALIA: CHIROPTERA:VESPERTILIONIDAE) RANGE CHANGES IN THE FRAME OF THE PANNONIAN BASIN AND THE CARPATHIANS

M. Uhrin, E. Miková, M. Rendoš, B. Lehotská, R.Lehotský, P. Estók, Š. Danko, S. Bücs, C. Jére, I. Csősz, L. Barti, F.Szodoray-Parádi & I. Pocora
University of Pavol Jozef Šafárik in Košice, Slovak Republic

During last years, range expansion of *H. savii* in western and central Europe was observed. It was usually discussed as a consequence of global climate change. All available data on *H. savii* occurrence from the Pannonian lowlands and the Carpathians mountain range are analysed in the paper. Data were obtained by field studies (using standard methods of bat research, e.g. roosts inspections, mist nettings, echolocation calls detectoring) in the respective regions complemented by data gathered by surveying of available literature. Almost two hundred species records were altogether gathered from Slovakia, Hungary and Romania. It seems to be clear, that since 90ies the species undergone progressive range change. During this period, the species became rather common bat in the Pannonian lowlands with preference to large cities. Later, the species was more often recorded also in the frame of Carpathian mountain range in both types of typical habitats, large cities (e.g. Bratislav a, Miskolc, Michalovce, etc.) and stony habitats (e.g. Turda Gorge, Intregalde Gorge). Course and patterns of range change in the region is discussed with emphasis also to possibilities of detecting such changes in bats.

BAT MONITORING IN SLOVAKIA: CONCEPTION AND REALITY

M. Uhrin, M. Ceľuch, P. Kaňuch & E. Miková
Institute of Biology and Ecology, Faculty of Science. P. J. Šafárik University, Moyzesova 11, SK-04001 Košice, Slovak Republic

Since Slovakia in 2004 entered European Union, necessity of nature monitoring as obligation related to Natura 2000 network rapidly increased. Slovak Bat Conservation Society in cooperation with

State Nature Conservancy prepared proposal for bat monitoring in the country, whose included several research methods covered all ecologically different bat species occurring in Slovakia. The system included census of nursery colonies, reaching roost holes in trees, counting of emerging bats, mist-nettings, bat-detectoring on fixed transects, and winter census. All proposed methods were combined to monitor habitat quality and species and/or habitat threats. The evaluation of the current state of several monitoring methods is presented and dicussed in the presentation. Only one method, hibernacula censuses, was wide applied in Slovakia (more than 300 winter roost are annually censused since 1980). Using other methods depends on financiall support from both, government and non-govern ment organisation.Monitoring of species dependent on urban habitats (as common noctule and pipistrelle) is cruccial today. This species are strongly impacted today because of massive insulation of buildings.

THE INFLUENCE OF WATER QUALITY ON DAUBENTON'S BAT ACTIVITY ON IRISH RIVERS

Aughney, T.[1], Roche, N. [1], Langton, S. [2], Marnell, F. [3] and Lynn, D[3]
[1] Bat Conservation Ireland, Ulex House, Drumheel, Lisduff, Virginia, County Cavan, Ireland.
[2] Statistical Consultancy, North Yorkshire, UK.
[3] National Parks and Wildlife Service, Department of Heritage, Arts and Gaeltacht, 7 Ely Place, Dublin 2, Ireland.

Bat population trends provide an indication of ecosystem health. Using the monitoring methodology developed by Bat Conservation Trust (BCT), UK, The Daubenton's Bat Waterway Survey was introduced throughout the Republic of Ireland and Northern Ireland in 2006 by Bat Conservation Ireland and was jointly funded by the National Parks and Wildlife Service (NPWS) (RoI) and the Northern Ireland Environment Agency (NIEA). Overall, 422 waterway sites have been surveyed at least once over the six years of the scheme providing an excellent, robust dataset on the distribution of Daubenton's bats across the island.

An array of variables was tested to determine the influence of such on the Daubenton's bat activity. One such parameter included water quality data. The Daubenton's bat is a specialist of freshwater habitats feeding on insects taken from the surface of waterbodies and therefore it is likely to be affected by changes in water quality and may, therefore, be a potentially valuable indicator of water quality. The selection of waterway sites for the All Ireland Daubenton's Bat Waterway Monitoring Scheme, where possible, corresponded to current water quality sampling sites monitored by the Environmental Protection Agency, Republic of Ireland and the Water Management Unit, NIEA, Northern Ireland. The biological water quality index for All Ireland Daubenton's Bat Waterway Monitoring Scheme waterway sites has been collated to investigate if there is any impact of water quality on the level of Daubenton's bat activity on waterways across Ireland.

Testing of the relationships was carried out by adding the water quality variables to the binomial GLMM for the proportion of spots with bats (but with data at the survey level) using only 2006-2011 water quality data. By far the strongest relationship is with biological water quality (Q value). A total of 214 waterway sites with biological data were included in the dataset and the majority of the waterway sites in this dataset had a Q4 value. The linear relationship (using the numerical values in column QValueID of the 'abbreviations' sheet) is highly significant ((F=12.27 with 1 and 165 d.f., P=0.001) and there is a quadratic relationship of borderline significance (F=2.12 with 1 and 142 d.f., P=0.148). Observed and predicted means for the relationship between presence of Daubenton's bats and the Q values shows a difference which is quite striking, with around 20% fewer spots having bats for a Q value of 3 (poor) compared to a waterway with a Q value of 4 (good). It should however be noted that there is some spatial clustering of the Q values, with more good quality rivers in the West, so there is some risk of the effects being confounded with other geographic differences.

last name	first name	registration email	country
Adams	Nathan	nathan178adams@gmail.com	Malta
Aguirre	Luis F.	laguirre@fcyt.umss.edu.bo	Bolivia
Aihartza Azurtza	Joxerra	joxerra.aihartza@ehu.es	Basque Country
Arcos	Francisco	farcos@arcea.net	Spain
Arrizabalaga Blanch	Toni	m.granollers.cn@diba.es	Catalonia, Spain
Arzúa	Manuel	manuarz@yahoo.es	Spain
Aughney	Tina	info@batconservationireland.org	Ireland
Baños Villalba	Adrián	adrianbvsg@gmail.com	Spain
Barreiro	Sílvia	sbarreiro@plecotus.com	Portugal
Barthe-Pla	Emilie	emilie.barthe@cg66.fr	France
Boada	Martí	Marti.Boada@uab.cat	Catalonia, Spain
Castelló Monsoriu	Antonio José	aterrodom@gmail.com	Spain
Celuch	Martin	martin.celuch@gmail.com	Slovak Republic
Chapman	Jason	jason.chapman@rothamsted.ac.uk	United Kingdom
Đaković	Maja	Maja.Dakovic@hpm.hr	Croatia
Duborg-Savage	Marie-Jo	chirosavage@gmail.com	France
Falkova	Lenka	l.falkova@mail.muni.cz	Czech Republic
Flaquer	Carles	cflaquer@ajuntament.granollers.cat	Catalonia, Spain
Freixas Mora	Lídia	lidia.freixas@yahoo.es	Catalonia, Spain
Frick	Winifred F.	wfrick@batresearch.org	USA
Guixé Corominas	David	david.guixe@ctfc.cat	Catalonia, Spain
Haysom	Karen	KHaysom@bats.org.uk	United Kingdom
Hermida	Roberto J.	robertox.hermida@gmail.com	Spain
Herrando	Sergi	ornitologia@ornitologia.org	Catalonia, Spain
Ibáñez Ulargui	Carlos	ibanez@ebd.csic.es	Spain
Imbeau	Louis	louis.imbeau@uqat.ca	Canada
Isaac	Sundararaj Suthakar	isaacsuthakar@yahoo.com	India
Jones	Gareth	Gareth.Jones@bristol.ac.uk	United Kingdom
Julien	Jean-Francois	jfjulien@mnhn.fr	France
Juste Ballesta	Javier	juste@ebd.csic.es	Spain
Karanouh	Rena	rena.karanouh@gmail.com	Lebanon
Kelleher	Conor	conorkelleher@eircom.net	Ireland
López Baucells	Adrià	adria.baucells@gmail.com	Catalonia, Spain
López Gallego	Zeltia	zeltia.lopez.gallego@gmail.com	Spain
Luo	Jinhong	jluo@orn.mpg.de	Germany
Marques	Marcelo Aparecido	marcelomarques@unipar.br	Brazil
Mendes	Eduardo	edu.mendes@ua.pt	Portugal
Meyer	Christoph F. J.	cmeyer@fc.ul.pt	Portugal
Miková	Edita	editamikova@gmail.com	Slovak Republic
Monsalve Dolz	Miguel Ángel	miguelangel.monsalve@gmail.com	Spain
Napal	María	maria.napal@ehu.es	Basque Country

Institution
Centro de Biodiversidad y Genética. Facultad de Ciencias y Tecnología. Universidad Mayor de San Simon
University of the Basque Country
ARCEA Xestión de Recursos Naturais S.L.
Museu de Ciències Naturals de Granollers
Operation Wallacea
Bat Conservation Ireland
Estación Biológica de Doñana (CSIC)
Plecotus - Estudos Ambientais, Unip. Lda
Conseil Général des Pyrénées-Orientales
Department of Geography and Institute of Environmental Science and Technology of the University of Barcelona
Slovak Bat Conservation Society
Rothamsted Research Station
Centre for Nature Research and Conservation-Fokus
SFEPM
Department of Botany and Zoology, Faculty of Science, Masaryk University
Museu de Ciències Naturals de Granollers
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University of California, Santa Cruz
Centre Tecnològic Forestal de Catalunya
Bat Conservation Trust
Drosera
Catalan Institute of Ornithology
Estación Biológica de Doñana (CSIC)
Ubiversité du Québec en Abitibi-Témiscamingue
St.John's College,
Bat Ecology and Bioacoustics Lab. University of Bristol
C.N.R.S. and Museum National d'Histoire Naturelle
Estación Biológica de Doñana (CSIC)
American University of Beirut
Bat Conservation Ireland
Museu de Ciències Naturals de Granollers
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Centro de Biologia Ambiental, Universidade de Lisboa
University of Pavol Jozef Šafárik in Košice
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UPV/EHU

last name	first name	registration email	country
Nardone	Valentina	valentina.nardone@hotmail.it	Italy
Neves Ferreira Lino	Ana Catarina	ana.lino@ua.pt	Portugal
Nicolas Francisco	Olga	olga.nicolas@gmail.com	Catalonia, Spain
Obon	Elena	elena.obon@gencat.cat	Catalonia, Spain
Ortêncio Filho	Henrique	henfilhobat@gmail.com	Brazil
Pastor Beviá	David	david.pastor@ebd.csic.es	Spain
Pavlinić	Igor	Igor.Pavlinic@hpm.hr	Croatia
Peña	Marcela	march16085@yahoo.com	Costa Rica
Peñuelas	Josep	josep.penuelas@uab.cat	Catalonia, Spain
Pētersons	Gunārs	Gunars.Petersons@llu.lv	Letonia
Piccioli Cappelli	Mattia	mattiapiccioli@libero.it	Italy
Pinto	Nuno	nmlpinto@ua.pt	Portugal
Popa Lisseanu	Ana	anapopa@izw-berlin.de	Spain
Priori	Pamela	pamela.priori@gmail.com	Italy
Puig Montserrat	Xavier	xavierpuigm@gmail.com	Catalonia, Spain
Quekenborn	Delphine	delphine.quekenborn@gcprovence.org	France
Rebelo	Hugo	hugo_reb@sapo.pt	United Kingdom
Riccucci	Marco	marco.riccucci@gmail.com	Italy
Rocha	Ricardo	ricardo.nature@gmail.com	Portugal
Roche	Niamh	niamhr@batconservationireland.org	Ireland
Russo	Danilo	danrusso@unina.it	Italy
Salicini	Irene	irene@ebd.csic.es	Spain
Sánchez Navarro	Sonia	sonia_san_na@hotmail.com	Spain
Santos Fernández	Ledicia	ginkgo-gz@hotmail.com	Spain
Savage	Ralph David	bats.dsavage@gmail.com	France
Silva	Bruno	bsilva@plecotus.com	Portugal
Spada	Martina	martina@ngi.it	Italy
Stefanescu	Constantí	canliro@gmail.com	Catalonia, Spain
Stone	Emma	emma.stone@bristol.ac.uk	United Kingdom
Subirana	Montserrat	msubiranam@uoc.edu	Catalonia, Spain
Torre Corominas	Ignasi	ignasitorre@gmail.com	Catalonia, Spain
Treitler	Julia	juliatreitler@gmail.com	Germany
Turini	Mariella	mturini3@gmail.com	Italy
Uhrin	Marcel	marcel.uhrin@gmail.com	Slovak Republic
van der Meij	Tom	tvdmeij.bioland@xs4all.nl	Netherlands
Vilà	Anna	avilaesc@gmail.com	Catalonia, Spain
Wawrocka	Kamila	kamila.freeme@gmail.com	Czech Republic
Welbergen	Justin A.	justin.welbergen@jcu.edu.au	Australia
Willig	Michael	michael.willig@uconn.edu	USA
Zeilstra	Ilja	izeilstra@yahoo.co.uk	Netherlands
Zukal	Jan	zukal@ivb.cz	Czech Republic

Institution
Faculty of Agriculture, Università degli Studi di Napoli Federico II
Universidade de Aveiro
Centre de Fauna Vallcalent
Centre de Fauna Salvatge de Torreferrussa
Universidade Estadual de Maringá
Estación Biológica de Doñana (CSIC)
Croatian Natural History Museum, Department of Zoology
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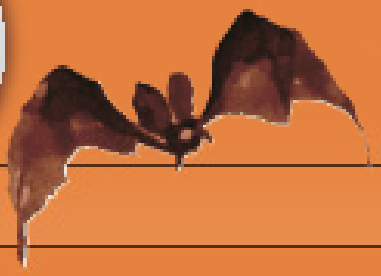

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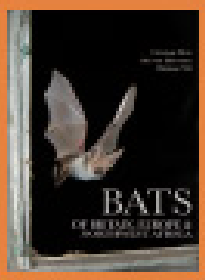

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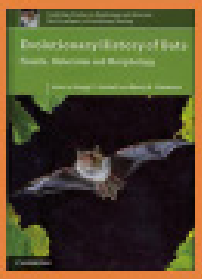

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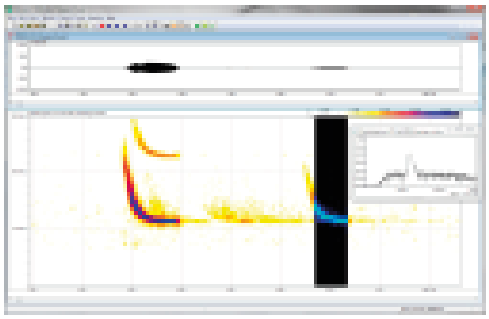

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