Advances in avian tracking and remote sensing: methods and applications

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Tracking long distance migratory birds for conservation

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Knowledge of the areas that long-distance migrants use throughout their annual cycle remains relatively poor. The rapid increase in the use of small tracking devices is now revolutionising our understanding of this and providing information that is vital for their conservation. We present data from a number of studies of declining land-bird migrants and endangered shorebirds to demonstrate how conservation efforts can be directed and more efficiently targeted by tracking work.

In the case of endangered shorebirds, the breeding grounds and/or stopover areas of entire taxa may be completely unknown and thus unprotected. Obtaining this information whilst managing risks to tiny populations is a major challenge. In the case of long-distance migratory land-birds, knowledge is accumulating through studies of individual species and populations but stopover and wintering areas that are important for multiple breeding populations and species have yet to be identified. The challenge here is to bring together individual tracking studies to identify critical areas for migratory birds at different stages of their annual cycle – we outline the need for a multi-user database where datasets can be deposited and analyses undertaken to identify these critical areas for migrant birds.

Phil Atkinson is head of the international research team at BTO. The team focuses on migrant birds and on understanding whether factors outside the UK could be responsible for the catastrophic declines recently observed in many species of Afro-Palearctic migrant birds.

What are the limits of monitoring behaviour with accelerometry? Examples from foraging and flight behavioural studies

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Bio-logging technology enables us to monitor locations, behaviour, and physiology of animals throughout their daily routines and annual cycles at ever more detail. Movement ecology experiences an explosive increase of data for a wide range of species and research questions. However, analysing these new types and large volumes of data is not trivial. Interpreting accelerometer data doesn't seem very intuitive.

Although machine learning has shown to be a useful methodology to classify animal behaviour based on tri-axial accelerometer data, there is no standard procedure or workflow that always provides good results. The deployment of the tag, the annotation of data, the design and selection of the right data features, and the machine learning methodology all affect the quality of the classification model. We will discuss 1) the effects of tag attachment methods in relation to the movement of the tag and the behaviour that we try to monitor, 2) the relation between the movement of a sensor and the characteristic features of the recorded data and their importance in the classification process, 3) the duration of a measurement required for identifying a certain behaviour, the segmentation, and the number of measurements needed for obtaining the classification model, and 4) the necessity of "ground truth" of behaviour.

We will show examples of our research and discuss opportunities and limitations of assessing annual time budgets, measuring intake rates, and understanding flight strategies of birds in relation to landscape and atmospheric properties.

Willem Bouten has a multi-disciplinary background. He was educated as a soil chemist, did his PhD on forest hydrology and meteorology and leads, since 2004, the Computational Geo-Ecology research group. With his group he promotes and facilitates big-data and computationally intensive ecological research, what we call “e-Ecology” (technology enhanced ecology), among others applied to bird movement ecology.

Processing, archiving, and analysing avian movement data on Movebank

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Data on movements of individual birds have been collected for over a century, and have been central to our understanding of bird migration. As the volume and accuracy of avian tracking data have increased, so have the opportunities to move beyond descriptive studies to address hypothesis-driven questions, compare across populations, and quantify relationships between animals and their environment. The animal tracking database Movebank (movebank.org) offers free tools to support such studies while allowing researchers to retain data ownership and access control. Several features on Movebank provide unique tools for working with avian tracking data. First, it allows live feeds for incoming GSM data as well as collecting and filtering data from Argos. Second, Movebank supports archiving of data from archival geolocators—allowing storage of raw light-level data, derived locations, and documentation of how location estimates were made—and is integrated with TAGS, a new open-source tool for processing light-level data. Third, Movebank's Env-DATA System enables users to browse and link their tracking data to thousands of variables from global environmental datasets, including MODIS products, weather models, and human and physical geography datasets. The Env-DATA System annotates tracking data with these environmental variables by accessing and interpolating the source datasets to create value estimates linked to each animal location. Taken together, these tools allow researchers significantly to reduce the time and technical skill required to integrate and reanalyze tracking data, document and improve methods for location estimation using light-level data, and incorporate external environmental data. We will illustrate how Movebank can be used in a movement ecology context using tracking data of White storks.

Andrea Flack completed her PhD at the University of Oxford and is currently a Postdoctoral Researcher at the Max Planck Institute for Ornithology in Germany. Her research mainly focuses on migration and social navigation in white storks. She studies the ontogeny of migration routes, the energy cost of migration and the extent to which cultural transmission shapes migratory behaviour.

Ethical and welfare considerations of tagging wild birds in Britain and Ireland

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The British Trust for Ornithology (BTO) operates the bird ringing scheme in Britain and Ireland. It supervises the training and licensing of ringers, who must hold a BTO permit to capture wild birds and ring them with BTO rings. The BTO training and licensing system has long included the issuing of endorsements for particular species groups or to use various capture methods that require specialist training. For over thirty years the BTO has operated an additional system, involving an independent advisory group, for regulating the attachment of tags and other devices to wild birds . Originally called the Unconventional Methods Technical Panel and dealing almost entirely with VHF radio tags, it has evolved to cover a much wider range of devices and techniques, including satellite PTTs, GPS tags, PIT tags and archival data-loggers, and is now called the BTO Special Methods Technical Panel (SMTP). SMTP has six unpaid members, who are not BTO staff, including people with practical expertise in tag design, performance and attachment methods and knowledge of the scientific and conservation value of tagging studies and a veterinarian. The Panel assesses applications to deploy tracking and telemetry devices and some other kinds of marks, offers advice, and recommends to BTO licensing staff whether approval should be issued or not. It also scrutinises annual report forms required to be submitted by all licensed users of tags and submits an annual report, summarising of tagging activities and highlighting issues needing attention, to the BTO's Ringing Committee and the UK Government's Home Office. The Panel covers all tag deployments where BTO rings are also used, in Britain, Ireland and the UK Overseas Territories. In this presentation, I will describe the mode of operation of the Panel and its role in identifying and disseminating best practice in this rapidly changing field.

Rhys Green is Honorary Professor of Conservation Science in the Department of Zoology, University of Cambridge and Principal Research Biologist at RSPB. He has been a member of the BTO's Special Methods Technical Panel and its predecessors since its foundation and its current Chair.

Tracking the smallest migrants using geolocators – a new chapter in bird migration research or more of the same?

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Tracking individual birds has meant a revolution for the study of bird migration. Tracking studies have for example revealed exact routes individual birds take, how they organise their travels (e.g. where and how often they make a stopover), and how they are influenced by environmental conditions such as wind. Initially, tracking devices were large, thus naturally tracking research focussed on larger species such as large waterfowl, storks and large raptors. Although tracking devices gradually got smaller over time, the 'holy grail of bird migration research' tracking even the smallest migrants, small passerine birds, remained beyond reach, despite the fact that small migrants are the most numerous, both in terms of number of species as in number of individuals. This however changed by the introduction of the minute geolocators, which has allowed to track migrants down to 10g. Consequently the number of tracking studies on small passerine birds exploded, and currently an astonishing number of geolocator tracking papers has been published. After this first eruption of geolocator studies it is time to ask the question what advancements in our understanding of bird migration this has really given us? Have we really learned something new, i.e. do small passerines migrate differently compared to lager species as raptors, as optimal migration theory has always suggested? Or do we just see more of the same? These are the questions I aim to cover in my talk.

Raymond Klaassen has been interested in birds since he was be able to raise a pair of binoculars, and despite a half-hearted attempt to pursue a career in entomology (in order to keep birds as a hobby), he became a keen ornithologist. After a PhD on the foraging movement of Bewick's Swans (which actually included tracking individual swans by making triangulations from the shore) he moved to Lund University in Sweden for his postdoc on bird migration. He arrived in Lund at exactly the right time as they just had obtained the first detailed GPS-tracks of Ospreys. Moreover, during the extended postdoc in Lund the geolocator era started, and Klaassen was privileged to work with this new technique in a whole suite of species. Klaassen is renowned for his original analysis of tracking data, often opening new perspectives on bird migration. Currently Klaassen is back in The Netherlands where he apart from bird migration is studying local behaviour using state-of-the-art GPS-tracking technology.

Video loggers and proximity loggers: tracking technologies at the cutting-edge of field ornithology

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New Caledonian crows *Corvus moneduloides* use tools for extracting arthropod prey from deadwood and vegetation, exhibiting a remarkable degree of behavioural sophistication. Despite considerable research interest, the species' biology remains poorly understood, not least because of the difficulty of observing free-ranging crows in their forest habitats. In the context of a long-term field study, my team has pioneered two bio-logging technologies that provide detailed data on, respectively, subjects' foraging ecology and behaviour (video loggers), and their social encounters (proximity loggers). Video loggers afford a crow's-eye view of natural, undisturbed behaviour. Tail-mounted units (ca. 13 g) record ca. 70-90 min of high-quality video footage over several days, following a custom-programmed duty-cycle, and are recovered after drop-off using a small, integrated VHF radio beacon. Using this self-developed technology, we have gained intimate insights into New Caledonian crow biology, discovering a range of novel tool behaviours and producing first estimates of activity budgets. Proximity loggers enable fully automated, near real-time collection of association data for entire crow populations, at unprecedented spatio-temporal resolutions. Harness-mounted transceiver tags (ca. 10 g) communicate with tags on other subjects (to record the proximity and duration of social encounters), and with fixed receiver stations (to enable spatial tracking of birds, and remote data transfer), forming a powerful *ad-hoc* wireless sensor network. During a 19-day period, we recorded time-ordered association data for 33 crows, and explored through landscape-level experimental manipulations how social-network dynamics track the availability of tool-derived prey. Video- and proximity-logging has provided valuable data for our crow project, and promises exciting insights into the biology of a wide range of other avian study systems that are difficult to observe through conventional field-ornithological techniques.

Christian Rutz is a Reader in Biology at the University of St Andrews. He has wide-ranging interests in evolutionary ecology, animal cognition and conservation science. Following doctoral research on urban-breeding northern goshawks, he launched his field project on New Caledonian crows in 2005, which nowadays involves research in seven different study sites across the island, including three colour-marked populations. His pioneering use of video loggers (2007, *Science*) and proximity loggers (2012, *Current Biology*) for field-ornithological research has been recognised with a string of academic awards, including the Hans Loehrl Prize of the German Ornithologists' Union (2014), the Isambard

Kingdom Brunel Award of the British Science Association (2014), and the Marsh Award for Innovative Ornithology of the British Trust for Ornithology (2013). Christian is Associate Editor of *IBIS* and *Animal Biotelemetry*, and co-organised the 4th International Bio-Logging Symposium in Strasbourg, France (2015). He is Co-Chair of the Committee that is currently preparing the launch of the International Bio-Logging Society, which will promote global efforts to advance our understanding of wildlife biology, and our ability to implement effective conservation measures, through the ethical use of bio-logging and bio-telemetry technologies.

Use of tracking in the study of orientation in free-living birds

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Billions of migratory birds each year cross desert and sea to find suitable winter grounds. Based on an innate spatiotemporal migratory orientation programme, inexperienced juveniles manage this task without guidance. Experienced birds are capable of returning to previously visited sites after having travelled thousands of kilometres. Most of our knowledge of the orientation programme are based on the study of orientation and navigation in the laboratory. However, the orientation decisions and travels take place in a far more complex setting in the wild extending vast distances and involving considerable variation in conditions experienced. For a full understanding of the demanding task of finding species-specific wintering grounds, the outcome of orientation decisions needs to be studied in free-flying birds too. Such study of the ultimate fate of orientation choices has been hampered by difficulties in following the long-distance travels of migratory birds. The recent miniaturisation of tracking devices has seen an emerging research programme investigating the migratory orientation programme as it unfolds in the wild. This includes using conventional radio telemetry to study shorter free-flying distances in the field and satellite transmitters carried by the smallest long-distance, solitary, nocturnal migrants. These technologies allow for additionally studying long-term effects of orientation decisions and potentially manipulations. Here, I present a suite of studies of free-flying birds from orientation in manipulated songbirds tracked with conventional radio telemetry to satellite tracking of common cuckoos, a nest parasite ideal for the study of innate migratory orientation.

Kasper Thorup is Associate Professor in Ornithology and Head of Copenhagen Bird Ringing Centre at Center for Macroecology, Evolution and Climate, Natural History Museum of Denmark, University of Copenhagen. His main research interests are in the ecology and evolution of bird migration, but he also works on the conservation ecology in general. His primary research focus is on the migration programme in long-distance migratory birds, involving both behavioural and ecological studies and how the programme influences their life history. He conducts field research on a variety of bird species with a focus on tracking bird movements in the wild.

Long-term tracking systems for birds, should we use a soft touch?

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Animal tags attached externally have greatly advanced our understanding of bird ecology and behaviour. However, one major drawback of such technology is that it can negatively impact the tagged birds. Despite an apparent wealth of disparate information on device effects on birds, there has been no systematic study of how best to attach and deploy such tags. The aim of my research has been to quantify the extent to which externally-attached packages can compromise bird well-being and seeks to formalize a package that can be used over long-term and long-distance, with defined and acceptable effects. It began with an assessment of the factors most likely to affect birds when they are equipped with external devices according to device mass, size, shape and placement. Important outcomes are certainly that device design and position must be considered on a case by case basis due to the divergence in impact between the bird groups.

In addition, how these external tags should be attached remains controversial and problematic. Current methods include feather attachment systems such as glue, tape or feather clamps, which are only suitable for periods of days or weeks, or harnesses, which may be used for months or years. Typically, harnesses are made of material robust enough to withstand both bird attention and environmental stress which may, however, lead to an unacceptable impact on the bird carriers. We present the concept and trials for a new approach to harness design using a highly elastic, soft, hypoallergenic material which can be moulded into any form and size. Although this new method may not be suitable for all bird species, for others it may represent a unique minimal-impact system for long-term tracking.

Sylvie Vandenabeele is a biologist and ecologist whose research focuses on both fundamental and applied aspects of the biology of birds including their behaviour, physiology, ecology as well as welfare using remote-sensing technology. More specifically, during her PhD at Swansea University and with the support of the RSPCA and other collaborators like the Max Plank Institute for Ornithology, she has been looking at the effects of tracking and logging devices on birds. The ultimate goal is to develop minimal-impact methods for the monitoring of birds over long-time/distance. These methods should have applications in many areas from blue-skies research through to conservation.

Mastering migration: high-resolution and life-long tracking reveal how individual birds learn to exploit atmospheric currents for long-distance migration

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Migrating birds must cope with highly dynamic weather conditions throughout their seasonal journeys. To understand how migrants ensure a successful and timely completion of their journeys through the atmospheric boundary layer it is necessary to track individual migrants throughout their entire annual cycle. Such tracking studies have enabled the description of migration patterns in a wide range of species. However, comparatively few studies have tried to unravel the role of atmospheric processes in the development of migration patterns between different species, populations and individual birds.

In this presentation we report on past and ongoing research into the weather-dependent migration strategies of thermal-soaring European Honey Buzzards *Pernis apivorus*. By comparing high-resolution flight behaviour measurements with predictions from optimal migration theory we show that on average across an entire flyway Honey Buzzards glide slower between thermals than they should to minimize the duration of migration. They do this mostly in areas with poor thermal convection in order to avoid energetically costly flapping flight. However, we argue they also glide slower than expected for time-optimal migration because they best increase migration speed by catching a tailwind during most of their journeys. We further argue that Honey Buzzards which use the east-Atlantic flyway use different migration routes between autumn and spring because they anticipate on predictable wind regimes within this flyway. To determine how adult Honey Buzzards are capable of such complex migratory behaviour we used satellite transmitters to determine lifelong development of individual migration patterns from fledging into adulthood. Preliminary results indicate that Honey Buzzards learn complex migration routes through a mixture of individual experience and social learning.

Our results help to piece together recently emerging contrasting evidence about the degree of individual consistency and flexibility in avian migration strategies. In so doing, this presentation will

help demonstrate the value of novel avian tracking methods to answer long outstanding questions about bird migration.

Wouter Vansteelant completed his Ph.D. on the influence of weather on adult Honey Buzzard migration strategies at the University of Amsterdam (2011-2015). Since 2008 he played a critical role in the development of raptor migration surveys and conservation projects at Batumi Raptor Count. Wouter is also secretary of the Migrant Landbird Study Group.

New technology for birds, new questions for scientists

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The capriciousness of birds, with their extraordinary mobility and general disaffection for humans has made them challenging to study. Fortunately, the silicon age has now given us far more than just clever mobile phones. The solid-state revolution is allowing scientists to use animal-attached tags to examine things like the movements, behaviours and energy expenditures of birds in great detail, even when they are in impossible places such as high above mountain ranges, hundreds of metres below the sea surface or operating in a thick forest at the dead of night. However, while this new age of sensors and seemingly infinite on-board memory has huge potential, it brings its own problems. These include difficult decisions about what we should record and why, and how much information we should gather and analyse before we feel we can make a reasonable stab at hypotheses. This talk will showcase the value of some new sensors deployed in archival tags systems on birds but also consider how the way we examine the data will profoundly affect the way we formulate the way forward.

Rory Wilson works in the Swansea Lab for Animal Movement at Swansea University in Wales. He specialises in the conception and production of animal-attached tags for understanding aspects of the behavioural ecology of wild animals, notably penguins, something he has been doing for over 30 years. Today he works as part of an eclectic team consisting of physicists, mathematicians, electronics engineers and computer scientists, all concerned with maximizing the value and impact of tag-derived data from animals while minimizing the impact of the tags on the animals themselves.