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From individuals to flyways: the future of marking birds for conservation

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The broad agenda for bird and biodiversity conservation, together with wider environmental issues such as global environmental change and disease control, will continue to set the context and priorities for research based on marked birds. We outline the ways in which the British Trust for Ornithology (BTO) Ringing Scheme will address these issues and how it will contribute to all six science themes of the BTO Strategy. New technologies for tracking birds will continue to increase in importance, facilitating novel study designs that require fewer birds to be marked and will lead to rapid increases in knowledge complementing more traditional bird ringing. Continental and flyway mechanisms for rapid collation, sharing and analysis of data will become the norm. The power of analysis and modelling techniques will continue to grow, facilitating integrated analyses of multiple data sets. The scientific progress achieved through large-scale bird ringing over the last 100 years has been critically dependent on thousands of highly skilled and dedicated volunteers, whose efforts will be equally important in the future. Maintaining their enthusiasm and support at a time of unprecedented changes in technology and study designs will be a key challenge for bird-marking schemes during the first half of the 21st century.

Since the first birds were marked with individually identifiable rings by Hans Christian Cornelius Mortensen in Vibørg, Denmark, in 1899, bird ringing has become a vital research tool that contributes greatly to our understanding of bird populations and to their conservation. Bird marking underpins most of our knowledge of bird behaviour, ecology and evolution and has been used to demonstrate, for example, the action of natural selection (Grant & Grant 2008), the costs and benefits of group foraging (Sansom *et al* 2008) and the fact that, contrary to expectations, extra-pair paternity is widespread in birds (Griffith *et al* 2002). Such questions are not only of academic interest but also add greatly to our understanding of population processes and bird conservation. Thus, for example, understanding how individual birds vary in foraging ability enables us to predict the consequences of fisheries management policy for their conservation (Goss-Custard *et al* 2004).

At larger scales, bird marking contributes to our understanding of population processes by providing measures of survival, productivity and dispersal (Baillie 2001). This allows identification of the demographic and environmental mechanisms responsible for population changes (Peach *et al* 1999, Freeman *et al* 2007) and supports conservation actions and adaptive management (Nichols *et al* 2007). Bird-marking has also revealed the routes that birds take on migration, demonstrating how these vary between and within populations and over time (Wernham *et al* 2002, Bearhop *et al* 2005). In addition it can provide estimates of numbers of individuals making use of particular stopover sites (Gillings *et al* 2009). In the future, bird marking will continue to be fundamental to developing our understanding of birds, their populations, and their conservation. In this paper we review some of the key opportunities and challenges that will need to be addressed by large-scale bird-marking programmes over the next 10–20 years, particularly in the context of the British and Irish Ringing Scheme.

CONSERVATION CONTEXT

The aim of most research based on bird marking is to address applied questions. Because much of the work is funded through government agencies, legislative and other components of national and regional conservation policy have a strong influence on the research programme (Boobyer 1999). Over the last 10 years there has been increased international emphasis on halting biodiversity loss, particularly as a result of the 1993 Convention on Biological Diversity (CBD), with its target set in 2002 to achieve a significant reduction in the rate of biodiversity loss by 2010. The EU has adopted the more stringent target of halting biodiversity loss on this timescale. There

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is also increased emphasis on the value of the natural environment in providing goods and services that are of value to the human population (ecosystem services), including cultural services. These ideas stem largely from the CBD and the Millennium Ecosystem Assessment completed in 2005.

Thus bird conservation needs to be concerned not only with the conservation of populations and communities, but also with demonstrating the wider value of such biodiversity. Within the UK there is a clearly structured process for the conservation of species and habitats through Biodiversity Action Plans implemented at local and national scales. In 2002, the UK Government Department for Environment, Food and Rural Affairs (Defra) adopted a target to reverse declines in farmland birds by 2020. This has provided a framework underpinning much research and conservation activity within the wider countryside, with the main delivery being via agri-environment schemes. Bird species conservation priorities are strongly influenced by the UK Birds of Conservation Concern List; the latest revision (Eaton *et al* 2009) highlights declines in long-distance migrants, with Cuckoo *Cuculus canorus*, Tree Pipit *Anthus trivialis*, Yellow Wagtail *Motacilla flava flavissima* and Wood Warbler *Phylloscopus sibilatrix* all being red-listed. Research based on bird marking will be crucial for understanding the causes of these declines and identifying potential solutions.

Wider environmental concerns are also highly influential in determining the environmental research agenda. Global climate change is now widely recognised as a massive threat both to the future well-being of human populations and to biodiversity. Disease transmission has also become a key international concern with implications for ornithological research. In particular, concerns about the rapid spread of Highly Pathogenic Avian Influenza have led to increased research on waterbird movements and there is likely to be an ongoing demand for further research on disease ecology.

BIRD MARKING AND THE BTO STRATEGY 2009–14

The BTO aims to deliver a coherent programme of applied research on bird populations by focusing on six interrelated science themes. Ringing will make a key contribution to each of these themes, building on the previous scientific strategy of the BTO Ringing Scheme (Baillie *et al* 1999).

Monitoring distribution and abundance

The BTO will continue to develop its role in monitoring the distributions and abundances of birds in the UK, working closely with colleagues in the European Bird Census Council (EBCC) and the European Union for Bird Ringing (EURING) to provide a European perspective. For some species, notably Reed *Acrocephalus scirpaceus* and Sedge Warblers *A. schoenobaenus*, constant-effort ringing sites provide the best index of abundance as they operate in the main habitats used by these species. Ringing can also elucidate the mechanisms by which populations increase in range by quantifying patterns of dispersal, as in the case of Cetti's Warbler *Cettia cetti* (Robinson *et al* 2007). Information on trends in abundance and demography gathered through ringing will feed into the reporting of data on population performance (Baillie *et al* 2009).

Population dynamics and modelling

The BTO will continue to develop its Integrated Population Monitoring programme (Baillie 2001, Baillie & Schaub 2009), giving particular attention to strengthening systematic projects that provide robust demographic information, including Constant Effort Sites (CES), Retrapping Adults for Survival (RAS) and the integration of ringing and nest recording on the same sites. A European Constant Effort Sites scheme will be developed, building on the existing network and collaborations already established through EURING. Developing analytical techniques that integrate ringing data with data from census and nest record schemes is a key research goal over the next few years. A particular applied focus of these demographic studies will be to understand the causes of declines in the abundance of Afro–Palaearctic migrants. Exciting questions that will receive increasing attention include large-scale spatial variation in population dynamics (Royle & Dorazio 2008) and seasonal variation in vital rates. The research programme will also make more use of information collected when birds are caught for ringing to improve understanding of the ways in which body condition, behaviour, individual performance and life histories contribute to population processes.

Multi-scale habitat studies

This research theme is concerned with the factors that determine the abundance and distribution of terrestrial birds at a range of spatial scales from individual territories to landscapes. Much of this work will focus on the analysis of bird–habitat relationships and on exploring how birds depend on and contribute to ecosystems. However, there is an increasing need to understand how birds move within landscapes to exploit the available food resources, using both radio tracking and more conventional mark–recapture approaches (Calladine *et al* 2006). To develop mechanistic models of how birds use landscapes we need to understand how productivity and survival within habitat patches, and movements between them, shape the dynamics of metapopulations.

Climate change

Many birds are breeding earlier as a result of climate change (Crick & Sparks 1999). There is increasing evidence that, for at least some species, this may result in a mismatch between the time when young are in the nest and peak prey availability, leading to reduced breeding success and population declines (Both *et al* 2006, Møller *et al* 2008). Demographic data from ringing and other components of the BTO's Integrated Population Monitoring programme will be important for testing these ideas across a wide range of UK bird populations. Migration routes are also expected to change in relation to climate, and bird marking will measure these changes. Improved models for predicting the effects of climate and habitat change on bird populations are urgently required. Such models will need to consider spatial variation in demographic processes and the consequences of dispersal and migration.

Migration and the ecology of migrants

Marking of birds has a key role to play in understanding the ecology of migratory species, particularly in the context of recent widespread declines in Afro–Palaearctic migrants. An immediate aim of research on these declines will be to identify wintering and stopover areas using a combination of tracking techniques and field surveys. This will provide a basis for investigating how ecological changes in wintering and stopover areas influence the size of breeding populations. The role of stopover sites in migrant ecology has important implications for bird conservation. Developments in mark–recapture methods are allowing stopover duration, numbers of individuals using particular sites and individual condition to be quantified, providing insights into conservation requirements for site networks (Frederiksen *et al* 2001, Gillings *et al* 2009). There is substantial scope to involve volunteer ringers in planned studies to address these issues, building on novel mark–recapture approaches and the success of initiatives such as the EURING Swallow Project (Rubolini *et al* 2002).

Wetland, coastal and marine ecology

Many of the principles that apply to other groups, such as the need to understand migration and population dynamics, also apply to waterbirds and seabirds (Atkinson *et al* 2003, Gunnarsson *et al* 2005, Crespin *et al* 2006). Estuarine bird populations face many threats to their fragile habitats, particularly as a result of increased interest in tidal and wind power as a source of renewable energy. Colour-ringing studies have shown that estuarine habitat loss can lead to reductions in population size through increased mortality (Burton *et al* 2006) and further research on turnover and local survival is being developed to address these issues.

Seabirds present a unique set of problems because most of their time is spent away from land, making it difficult to study their ecology by direct observation. Long-term ringing programmes for seabirds have provided important links between breeding colonies and feeding and wintering areas, as well as data on survival rates. Most seabirds are reasonably large-bodied, so the wider deployment of tracking devices to identify key foraging areas is a priority for future research (Guilford *et al* 2009). This is particularly important given the programme currently being undertaken in the UK to identify candidate marine protected areas.

FUTURE DEVELOPMENTS IN BIRD MARKING

New technologies and study designs

Technology is increasingly playing a role in the study of bird movements (*eg* Fiedler 2009, Guilford *et al* 2009, Strandberg 2009) and a variety of devices are now available to store or transmit data from individuals. A major limitation of such tags is still their weight, which has, so far, limited their application to large-bodied species. However, continued technological developments will bring down the weight of such tags and increase the range of species that can be tracked or monitored and the quantity and accuracy of data collected. Technological developments are also allowing much greater use of intrinsic markers, such as stable isotopes, trace elements, blood chemicals and even DNA, all of which can yield information about where birds have been and their body condition (Coiffait *et al* 2009). However, effective use of such intrinsic markers is likely to be restricted to particular situations.

These new technologies should not be viewed as alternatives to conventional ringing and colour marking. Rather all of these new and conventional techniques provide a toolbox from which researchers can draw in order to address specific questions (Fiedler 2009). There is an urgent need for more work to inform this decision-making process and to develop quantitative approaches that will allow different types of data to be combined. Combining data from new and conventional movement studies, as well as incorporating count data (Royle & Rubenstein 2004), has considerable potential to offer new insights into movement patterns.

To date, the main emphasis of work using both new tracking technologies and intrinsic markers has been to determine population origins, movements and migration patterns, although some tracking studies have also investigated behaviour (Sharp 2009) and physiology. However, there is enormous potential to start to apply some of these techniques to large-scale population studies, particularly using relatively cheap methods such as passive integrated transponders (PIT tags: Becker & Wendeln 1997, Fiedler 2009). There is also potential to use new tracking technologies to study parts of the life cycle that

are less amenable to conventional marking methods. For example, studies of post-fledging survival based on radio tracking could be embedded within population studies based on conventional ringing.

These possibilities open up exciting new options for study designs. Experience of recovery and recapture studies has taught us that the best way to improve the quantity of information from such work is to increase the re-encounter rate. From projects such as CES and RAS we also know that standardising the recapture effort often allows us to make much better use of the data because we can fit models where the within-site recapture rate does not vary between years (Peach *et al* 1995). Thus an advantage of using new tracking technologies to study population dynamics is the high re-encounter rates that can be achieved within suitable study systems. However, while such studies may give high-quality data on return rates to specific sites there will also be a need for information on those individuals that move elsewhere. Thus we envisage studies where a small number of sites collecting high-quality data on return rates based on new technologies are embedded in a wider ringing programme. We can also anticipate studies where a small proportion of the population is marked with sophisticated tracking devices but a much higher number are followed using conventional ringing or colour marking. Indeed a number of such studies are already under way. A key challenge for ringing centres over the next five years will be to conduct pilot studies that explore how selected novel tracking technologies can be deployed most effectively to enhance large-scale programmes based on conventional ringing and colour marking.

Management and sharing of data and information

A major theme of the Ringing Scheme's scientific strategy has been to increase the computerisation of ringing data, both to allow variation in reporting rates to be incorporated within ring-recovery models and to provide access to data from individual captures, such as the age and sex composition of the catch, morphometrics, body condition and moult. For current data this aim has now been largely achieved, with over 95% of ringing and recapture data being submitted electronically within the British and Irish Scheme. Many other ringing schemes have made similar progress. This is thanks to a fantastic effort by volunteer ringers and the volunteer programmers who have supported them. However, while most current data are being captured, large amounts of historical data remain to be computerised.

Some colour marking and tracking data are held in the national database, but there is an urgent need to make such data more comprehensive. A few large colour-marking projects have developed their own web-based systems to collate colour-mark resightings (*eg* www.geese.org) but such systems are not available for many colour-marking projects. Where data from colour-marking and tracking studies are not lodged in national or international databases, there is a danger that they will be lost as individual researchers and research groups may move and change interests over time.

The new tracking technologies that are now coming on stream pose many new challenges for the design of computer systems to handle the resulting data. Tracking devices can generate large numbers of location records each day, combined with information both about the state of the bird and the environment in which it is located. Developing effective and generic systems to handle such data efficiently will be a significant challenge. The Movebank initiative (www.movebank.org) being developed for a range of organisms including birds looks set to offer good new opportunities and tools in this area.

The increasing demand for continent- and flyway-wide analyses means that data from many countries need to be accessible from a single location, implemented either as a single large database or as a distributed database. The EURING databank (www.euring.org/data_and_codes) already provides such facilities for European ring recoveries and work is in progress to extend it to include morphometrics and data from key projects such as European Constant Effort Sites. Over the next 20 years it will be essential to extend the EURING databank so that it incorporates a high proportion of the data generated through bird marking, working closely with programmes such as the African Bird Ringing Scheme (AFRING) and Movebank. This can only be achieved through a high level of co-operation between individual ringing schemes and research groups.

A further objective is to improve the delivery of applied information on migration routes and how they are changing, building on the success of the on-line Migration Mapping Tool (Atkinson *et al* 2007). There may also be some scope to develop improved analytical methods that account for geographical variation in recovery probabilities (Thorup & Conn 2009). EURING has ambitious plans to develop an on-line European Migration Atlas based on further development of this technology.

Analysis and reporting

While some types of data from bird marking can still be addressed using relatively simple analytical techniques, the design of effective large-scale marking studies and the analysis of the results are increasingly dependent on an array of sophisticated statistical methods. Indeed the bird-ringing community has been instrumental in promoting the development of mark–recapture–recovery methods, particularly through the EURING Analytical Conferences

and their associated proceedings volumes (Senar *et al* 2004, Thomson *et al* 2009). Work on population dynamics is increasingly moving towards integrated analyses of multiple data sets (Brooks *et al* 2004, Freeman *et al* 2007, Baillie & Schaub 2009) which have become much more tractable with the wider availability of Bayesian techniques (Royle & Dorazio 2008). While most of this work has revolved around the estimation and modelling of demographic parameters, there is increasing interest in the development of more sophisticated methods for analysing recovery patterns and movement data (Hofer *et al* 2006, Atkinson *et al* 2007, Clark *et al* 2009).

Refereed publication will continue to be the primary means of reporting the results of research based on bird marking. Much routine reporting of trends and movement patterns is now being published on-line (*eg* Baillie *et al* 2009) and we expect this trend to continue. We anticipate the development of further on-line tools which both report observed patterns and allow users to explore the consequences of alternative scenarios and policy options. The Migration Mapping Tool (Atkinson *et al* 2007) provides a simple example of what is possible here. Two versions of the tool were developed to provide policy users from the UK and the EU with information about bird movements that could pose a risk of spreading Highly Pathogenic Avian Influenza. Users can select a region of interest and then obtain maps and information on movements between there and the locations of any possible outbreaks. We expect future developments of on-line tools providing predictions of changes in ranges, abundances and migration patterns that are likely to occur as a result of predicted climate and habitat changes. The integration of marking data with other types of information will be essential for any such modelling effort.

Ringers now have good tools for managing data and submitting results to national ringing schemes. Such tools will continue to evolve to incorporate new types of data, share recoveries and recaptures more easily and facilitate the generation of reports. Although most volunteer ringers may find it difficult to use and understand the vast array of sophisticated techniques that are available to analyse data from bird marking, their situation is similar to that of many professional ornithologists who often work in collaboration with specialist statisticians and modellers. While a core of basic biological studies that can be analysed and published by volunteer and professional ornithologists will remain, many projects will require more sophisticated analysis. We see two ways to address this issue. The first is to extend the already productive collaborations that take place between ornithologists and ecological modellers, and to create better mechanisms for initiating such collaborations. The second is the development of on-line tools for analysis and retrieval of information about study populations that would allow users to focus on the interpretation of results based on their ornithological knowledge and study design, without having to be deeply involved in the modelling process.

The role of volunteer bird markers

For the foreseeable future, many large-scale and long-term studies will continue to be based largely around conventional ringing and colour marking, with programmes being dependent on the field skills of many thousands of highly trained volunteers. In the longer term we envisage a much greater integration of new technologies (Fiedler 2009, Coiffait *et al* 2009) with conventional marking techniques, with multiple methods often being incorporated within a single study. We also envisage some of the developing techniques becoming much cheaper than they are at present, allowing the tracking of substantial numbers of individuals within large-scale and long-term studies.

The next 20 years will be an exciting time to be a volunteer bird marker. All of the new technologies involving tracking devices and intrinsic markers require birds to be captured and marked safely and the determination of age, sex and moult characteristics from plumage and other features, all of which need the considerable skills of volunteer ringers. Some studies may require fewer individuals to be marked than in the past, but the information obtained from each individual will be much greater. The existing trend towards a much greater focus on integrated population studies using CES, RAS, nest recording and similar approaches will continue. Development of regional and local ringing projects will be strengthened through the deployment of new technologies and increased collaboration between volunteer ringers and professional researchers.

The achievements of the past 100 years of bird ringing have only been possible as a result of the efforts of many thousands of highly qualified bird ringers. As is clear from this and other papers in this volume, it is essential that these skills and enthusiasms are fostered and strengthened to support the developments that we anticipate over the next 20 years. This will be a time of unprecedented change in field methods and study design, linked to continuing rapid development of information technology. All of these issues can be addressed successfully but they will require bird-marking centres to identify this as a significant challenge, to enhance feedback and training, and wherever possible to involve volunteers in the decision-making process. In 50 years from now we may well be talking about marking schemes rather than ringing schemes for birds. However, in a rapidly changing world with huge environmental and conservation problems, studies of movements and population dynamics based on marked

birds, undertaken through a close collaboration between volunteer and professional researchers, will continue to make a vital contribution to ecology and conservation science.

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