BTO RESEARCH REPORT 710

A world informed by science: the impact of BTO in 2012–18

Pearce-Higgins, J.W. & Robinson, R.A. (Eds)

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BTO
Looking out for birds

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SUMMARY

1) OVERVIEW

BTO's core mission is to combine professional and citizen science to provide evidence of change in wildlife populations, particularly birds, and to make this information available to the public, opinion-formers and environmental policy-makers.

Our surveys engage around 50,000 volunteers with their local environment and facilitate their understanding of changes in it. They collect large-scale and long-term data on the distribution, abundance and population trends of species that occur regularly in the UK.

The combination of citizen science data to examine large-scale patterns and processes, complemented by more detailed measurements and studies, at individual sites or a range of study areas, is a powerful one.

An important characteristic of BTO is that we design, implement and coordinate surveys quantifying numbers, distribution and demographic rates, but also analyse and interpret their outputs. We take an integrated approach to data collection, combining data from different parts of an animal's life-cycle to understand not just the pattern, but also the process, of change.

Our organisation plays an important role in delivering significant infrastructure and capability for use by the wider academic, conservation and policy communities to achieve greater impact, where our reputation for providing impartial evidence and an ability to work with a range of stakeholders as an 'honest broker' is crucial.

A substantial amount of our research is commissioned directly by policy-making bodies ensuring impact at a policy level, and much of the rest is informed by, or relevant to, wider policy needs.

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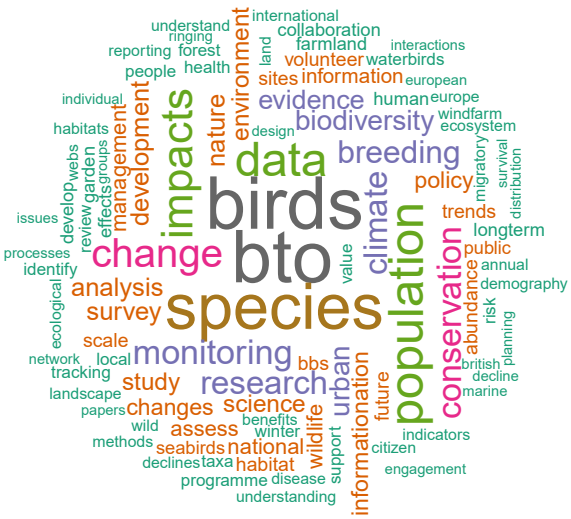


2) KNOWLEDGE GAINED AND INFORMATION MADE AVAILABLE

We are committed to making our data accessible and we fulfil about 500 requests for data each year. We have, for example, provided, over 170 million records to the *NBN Living Atlas.*

We publish regularly in the scientific literature, with over 300 publications listed on *Web of Science* for the period 2012–18; these have an average of 14 citations per item so far and an h-index score of 32.

ASSESSING STATUS

Our long-term monitoring programme produces robust population trends on over 100 breeding and ~50 wintering species, which are reported on annually at bto.org/birdtrends (breeding species), WeBS Report online (wintering) and through the *State of UK's Birds* (SUKB) and *State of Nature* publications. Our long-term data sets (including the longest-running single species bird survey in the world) show how dynamic populations can be. From these data we provide evidence and interpretation of both temporal and spatial changes.

We provide the information that underpins the conservation status assessment for most UK bird species and our research also contributes significantly to the conservation science evidence-base.

Our monitoring data are essential for formal assessments by statutory bodies in support of national and international reporting requirements, such as under Article 12 of the *Birds Directive*. In particular, the UK supports internationally important populations of non-breeding waterbirds and our data are used to identify important areas for conservation designation (notably the *Natura 2000* network) based on internationally recognised thresholds.

Natural capital, and the ecosystem services that flow from it, is an increasingly important concept that BTO needs to engage with more. Although birds may provide relatively few ecosystem services (and those mostly cultural and aesthetic), counts or densities derived from data sets, such as the BTO/JNCC/RSPB Breeding Bird Survey (BBS), have the potential to provide direct measures of natural capital.

QUANTIFYING THE IMPACT OF ENVIRONMENTAL CHANGE

Identification of one of the highest profile conservation issues of our time, the collapse of farmland biodiversity in the UK, in a large part stems from analysis of BTO's long-term monitoring data; these made real the concerns documented by Rachel Carson in *Silent Spring*.

More recently our research, supported by Natural England (NE), revealed the first evidence for positive, landscape-scale impacts of agri-environment schemes (AES) management with the potential to reduce rates of population decline in seed-eating bird species.

The first evidence, globally, that the phenology of animal populations was being affected by climate change came from analysis of our Nest Record data, and led to us undertaking a review of climate change impacts on (all) migratory species, funded by Defra, for CoP 8 of the Bonn Convention (CMS).

Subsequently, our data and research have contributed significantly to the evidence-base on the impacts of climate change on UK biodiversity. This has been summarised for policy-makers, conservationists and the general public through a number of key publications, such as the Marine Climate Change Impacts Partnership (MCCIP), SUKB and Living with Environmental Change (LWEC) biodiversity report cards.

The BTO is a partner in the GB Non-native Species Information Portal, which provides comprehensive information on all non-native species in Great Britain and an alert system for a suite of non-native species known to have serious negative effects on native species or ecosystems.

IDENTIFYING CONSERVATION ISSUES AND THREATS TO BIODIVERSITY

Our monitoring data have recently revealed strong regional patterns to the declines in long-distance migrants. A combination of our tracking studies and analyses of long-term monitoring data suggest that deterioration of breeding conditions in the UK, reducing the number of young birds recruiting into populations, may play an important role in the declines of these species.

A BTO-led analysis of BBS data demonstrated that population trends in urban habitats were more negative (or less positive) than in other habitats. This is leading us to address pressing questions about the relationships between birds and people across Britain's entire urban gradient, from expanding cities to compact villages.

BTO research has played a significant role in raising the profile of Curlew *Numenius arquata* population declines in the UK, achieving significant press coverage and public attention. It has also assessed global risks to curlews and godwits more widely, with this work being presented to the CMS.

3) IMPACT ON POLICIES, DECISIONS AND MANAGEMENT

BTO, and our data, are at the centre of advice provision to Defra and the European Commission concerning the likelihood of incursion of economically significant diseases, notably highly pathogenic strains of the avian influenza virus.

IDENTIFYING IMPORTANT SITES AND VULNERABLE POPULATIONS

We are able to produce estimates of population size and trend for many key sites, such as Special Protection Areas (SPAs) and Sites of Special Scientific Interest (SSSIs), providing an invaluable resource for staff in Country Agencies and conservation NGOs to inform decision-making, casework and management. For example, BTO data and expertise have informed Habitats Regulation Assessments for both the Firth of Forth and Northern Ireland Sea Loughs.

A review and an expert workshop on the pressures associated with housing development on estuarine waterbirds has helped develop methods for assessing the impacts of disturbance to waterbirds on SPAs and provided advice on mitigation methods. These have fed into NE's advice on recreational disturbance to waterbirds and are having a wide impact on local authority decision-making.

A BTO-led review of global data on bird and bat collisions with wind turbines identified the species most likely to be vulnerable to collision and was presented to the 2nd Meeting of the CMS Energy Task Force. This includes data tables that can be used to assess the vulnerability of bird and bat species around the world, particularly where formal studies have yet to be undertaken.

BTO evidence for population declines in long-distance migrants were amongst those instrumental in CMS adopting the *African Eurasian Migratory Land Birds Action Plan*.

Using novel citizen science data, we developed a geographical tool to identify bat populations vulnerable to development. This is being used by Norfolk County Council to inform urban planning. We are now piloting work with NE, Norfolk County Council and Norfolk Wildlife Trust to assess whether the current approach to bat conservation, which requires expensive site-level surveys for each development, could shift to a more strategic, risk-based approach.

SUSTAINABLE LAND MANAGEMENT

We have been at the forefront of the development of UK biodiversity indices at a range of geographic scales, mainly for birds, but also across taxa, as a method for assessing, monitoring and reporting on biodiversity. Adoption of the Farmland Bird Indicator as a National Statistic led to the UK Government commissioning an extended programme of research into the population declines and their recovery.

BTO research evidence has played a central role in designing agri-environment schemes (AES), the principal policy response to the general issue of conservation of the farmland environment, notably new AES options for direct supplementary feeding in farmland, extended stubbles and two-year sacrificial crops with long-term retention of seed. By monitoring their efficacy in England and Wales, we provided the first evidence for positive, landscape-scale impacts of AES management.

A review of the effectiveness of conservation interventions for grassland breeding waders across Europe, undertaken with EU funding in collaboration with Sovon, provides important evidence in support of the effectiveness of AES, which has fed into a BirdLife International-led multi-species action plan for breeding waders. It is also providing important evidence to inform the development of species action plans for Curlew in Northern Ireland and Scotland.

We participated in the FarmLand international collaboration (funded by BiodiVRsA and Defra) that examined the role of cropping heterogeneity and the services it provided, allowing development of recommendations for land-use policies

that exploit these relationships in lieu of taking land out of production.

We work closely with the Forestry Commission (and Forestry Commission Scotland), producing guidance notes that have played a key role in developing forestry practices in the UK, such as around the distribution of young growth stages within forestry systems.

ADDRESSING PRESSURES IN THE MARINE ENVIRONMENT

Our work in the marine sector feeds extensively into the *Marine Strategy Framework Directive*, including developing indicators of Good Environmental Success (based on Kittiwake breeding success), and improving the effectiveness of European-level reporting by identifying species-specific 'ecologically coherent regions' within the data set.

Generation of renewable energy has a key role in addressing climate change, but potential impacts on the environment and biodiversity may be large. BTO evidence has reduced uncertainty in the impact assessment process, improved understanding of the potential impacts of offshore wind farms upon vulnerable bird populations, and highlighted the importance of cumulative impacts of multiple wind farms, which are just beginning to be recognised.

Novel analytical work bringing together disparate data sets measuring the height at which birds fly over the sea has led to change in the design of turbines proposed by Forewind for their Dogger Bank offshore wind farm projects, reducing the predicted rates of bird collisions with turbines.

ADAPTING TO A CHANGING CLIMATE

A BTO-led consortium, funded by NE, assessed the risk and opportunities that climate change poses to over 3,000 species across 17 taxonomic groups that occur in England. Species-level assessments and associated guidance were made available to NE staff and are currently being incorporated into their climate change adaptation manual.

The Defra-funded CHAINSPAN Project showed that by protecting an extensive network of large, semi-natural sites important for a wide-range of species, the SPA network could remain resilient to future climate change. This was quoted in the EU fitness check of *Birds and Habitats Directive* as evidence to support the continued value of *Natura 2000* sites in a changing climate.

Furthermore, results from the CHAINSPAN project have been used by NE to identify the SPAs where bird populations are performing better or worse than expected on the basis of climate change, and by other agency staff and RSPB to inform decision-making at the site-level.

BTO research on climate change adaptation has contributed to the evidence base in support of using AES to increase the extent of semi-natural habitats, and reduce fragmentation.

More recently, BTO has contributed to the development of the International Union for Conservation of Nature (IUCN) guidelines on climate change vulnerability assessment.

4) IMPACT ON SPECIES AND HABITATS

BTO analysis of BBS data has shown that some of the AES interventions have resulted in positive impacts on local breeding populations of farmland birds. In particular, the provision of over-winter stubbles is one of the most important components of the Entry-level Scheme for birds.

Data from a national survey of Nightingales have helped to identify key sites for this species, additionally providing important evidence to inform the debate and potential public enquiry about proposed residential development on a SSSI holding the largest remaining Nightingale population in the UK (>1% of the national population).

We have undertaken research to assess the impact of afforestation and of alternative silvicultural systems, resulting in the inclusion of shrubby interfaces at the margins of some new plantations to increase to their biodiversity contributions.

BTO studies of Nightjars in Thetford Forest have led the Forestry Commission to create more nesting habitat, although this has not yet reversed the local decline in Nightjars, which ongoing work suggests may be linked to food availability.

Collaborative research on peatland hydrology and climate change has informed the management decisions of conservation organisations, such as RSPB, National Trust and others, underlining that the blocking of drainage ditches can deliver key biodiversity benefits. This has, for example, contributed to the 30 km^2 of land within the Peak District now subject to habitat restoration.

A review of the impact of introduced Hedgehogs on the machair-breeding waders of the Outer Hebrides led to the Board of Scottish Natural Heritage (SNH) supporting the aim of eradicating these non-native predators from the Uists.

An online system developed to capture records of wildlife mortality, Garden Wildlife Health (GWH), has additionally been used by RSPB staff for managing post-mortem analysis of suspected victims of illegal persecution.

Through collaboration with partners, our research during the period covered by this report has covered eight non-UK species. This has included contributing to international efforts to save the globally Critically Endangered Spoon-billed Sandpiper from extinction and development of an Adaptive Management Plan to manage resources for the Endangered *rufa* population of Red Knot, which migrates through Delaware Bay in North America.

We have contributed evidence in several areas where human needs conflict with wildlife management. These include work examining the impact of fish-eating birds and managing geese in agricultural landscapes, leading to changes in policies. For example, BTO was a key partner in the '*Understanding Predation*' project that aimed to develop a basis for common understanding between scientists, conservationists and land managers. The report was launched by the Minister for Environment, Climate Change and Land Reform in Scotland,

Dr Aileen McLeod, MSP, and recommends developing an adaptive, collaborative approach to guide the development of management practices.

5) IMPACT ON PEOPLE AND WIDER SOCIETY

Taking part in the wide range of opportunities that BTO projects offer provides positive benefits to a volunteer's health and mental well-being; more time-demanding surveys, such as WeBS and the ringing programme, can also provide substantial exercise benefits. This is formally recognised in Wales through the Welsh Government's recent *Well-being of Future Generations Act* and BTO Cymru is working, with partners, on proposals in response.

Our volunteers commit a considerable amount of time to participate in our surveys, estimated at around 950 FTE staff and equating to a value of approximately £15 million. The Department of Work and Pensions estimated, in 2011, that volunteering at least once a month generated a societal value of ~£13,500 per year. On this basis, the societal value generated by BTO volunteers is in the order of £90 million per year. Volunteer participation in BTO science also democratises the scientific process within wider society and engages people with the changes happening in their local environment, meaning they are more likely to take action in response.

The growing disconnect of people from nature is not only potentially detrimental to human well-being, but is also perceived to be a significant barrier to successful engagement with biodiversity issues. Bringing people closer to nature is therefore of key importance to BTO's work within the urban environment, as seen, for example, in the Birds in Glasgow (BiG) project, which trained new surveyors and engaged local people with green spaces they may have previously overlooked.

A novel citizen science project engaged at least 12,000 school children from over 450 schools to collect data on the abundance of soil invertebrates from school playing fields, leading to a peer-reviewed publication using their data in an international soil journal.

The UK's garden bird feeding industry is worth over £200 million annually; our research, and the large network of people engaged with it, means we have also been able to disseminate practical best practice advice on bird feeding and the associated disease risks, with the research outputs being translated into a library of fact sheets.

Our project tracking the migration of Cuckoos *Cuculus canorus* has stimulated considerable public interest and engagement through articles in the news media on the issues facing migratory birds. The webpages reporting on their daily progress receive in excess of 70,000 users annually, and over 3,000 people have invested financially in supporting the purchase of the tags used on these birds. Ongoing support from BBC Springwatch has been particularly helpful in this regard, underlining how our data are valued by such organisations.

Our research is presented in a wide range of outlets from major national shows (such as *Gardeners' World Live*, with more than 100,000 visitors) to the more static displays, such as that in the Zoology Museum, University of Cambridge, engaging a wide range of audiences in the environmental challenges our birds face. In Thetford Forest our research activities are frequently used as demonstration events, engaging a wide range of people, and the work contributes information to forest discovery trails and other engagement programmes operated there.

We are increasingly working with partners in the arts and culture arena, exposing new audiences to science and seeking to inspire society about birds. This approach has seen us deliver messages to these audiences in ways that they find more relevant and accessible. BTO is seen as leading in this area by other organisations operating in our sector.

6) COLLABORATION AND CAPACITY BUILDING

A major strength of the BTO is the ability of our data archives to provide historical baselines from which to assess future risk of many environmental changes, such as in climate or disease incursion.

PROVIDING A SAMPLING NETWORK

The Breeding Bird Survey, in particular, provides a nationwide network of sampling sites, randomly sampled with respect to habitat and other geographical features, and Constant Effort Site (CES) ringing sites provide a network of sites where more detailed studies of individuals can, and have, been added.

Similarly, the Garden BirdWatch network provided a ready-made platform for establishing a disease monitoring network for wild birds, which has evolved into the Garden Wildlife Health scheme, now also encompassing mammals and amphibians.

By organising the ringing scheme and providing licensing for activities involving handling wild birds, we ensure high welfare standards are maintained. Through this we support a wide range of survey, ringing, tracking and other studies in Great Britain and Ireland. This expertise is influential globally, and we continue to improve methods for catching and marking birds, as evidenced by recent peer-reviewed outputs.

PROMOTING GOOD SAMPLING DESIGN AND DEVELOPING ANALYTICAL METHODS

BTO field survey methods are well-established, and often underpin guidance for professional surveyors and consultants. Our expertise in designing citizen science schemes, and in the development of appropriate analytical methods to make the most of the resulting data, is an important element of these schemes. The need for robust analysis of such large-scale data, which can be challenging, continues to spur the development of novel statistical methodology and BTO authors have co-authored 11 papers in *Methods in Ecology and Evolution* in this period.

In particular, we have developed novel approaches to model the impacts of climate change on the abundance of species, rather than just occurrence. We have also led the way in developing integrated population models that efficiently combine data of different types and increase the robustness of our inference.

We support seabird monitoring (largely organised by the Joint Nature Conservation Committee (JNCC) as members of the Seabird Monitoring Partnership (SMP), through development of a new online database for the scheme, and by participating in a current strategic review of the programme's role and operation.

SUPPORTING MONITORING OF OTHER TAXA

We are increasingly working with organisations studying non-avian taxa, sharing our experience to increase the quantity and quality of data collected and to ensure biodiversity trends are better monitored and understood. In particular, we have worked extensively with others during the last few years to improve the monitoring and reporting of wider biodiversity trends.

Pioneering work by one staff member, using passive acoustic recorders, has resulted in a methodology that is now being used to inform the design of a new national bat monitoring programme.

PROVIDING LEADERSHIP AND BRINGING PEOPLE TOGETHER

Members of staff serve on the boards of 15 organisations, nine journals and a wide range of committees in the biodiversity sector.

During the six year period of this review, BTO has collaborated with in excess of 25 UK universities, 30 statutory bodies, national government departments or local councils, 35 non-governmental organisations, 20 corporate bodies and 25 organisations based in Europe.

We provided the secretariat for the Strategic Ornithological Support Services (SOSS) group, which brought together expert stakeholders to identify key ornithological issues relating to the expansion of the UK offshore wind industry.

We were a key partner within the '*Understanding Predation*' project that aimed to develop a basis for common understanding between scientists, conservationists and land managers on the role of, and evidence for predation as drivers of change for ground nesting birds in Britain; conversations we are continuing to encourage in relevant locations.

By promoting the principles of monitoring through robust and rigorous sampling, in combination with surveys designed to have broader appeal yet still yield scientifically credible results, we provide a model for organisations in other countries.

1. OVERVIEW

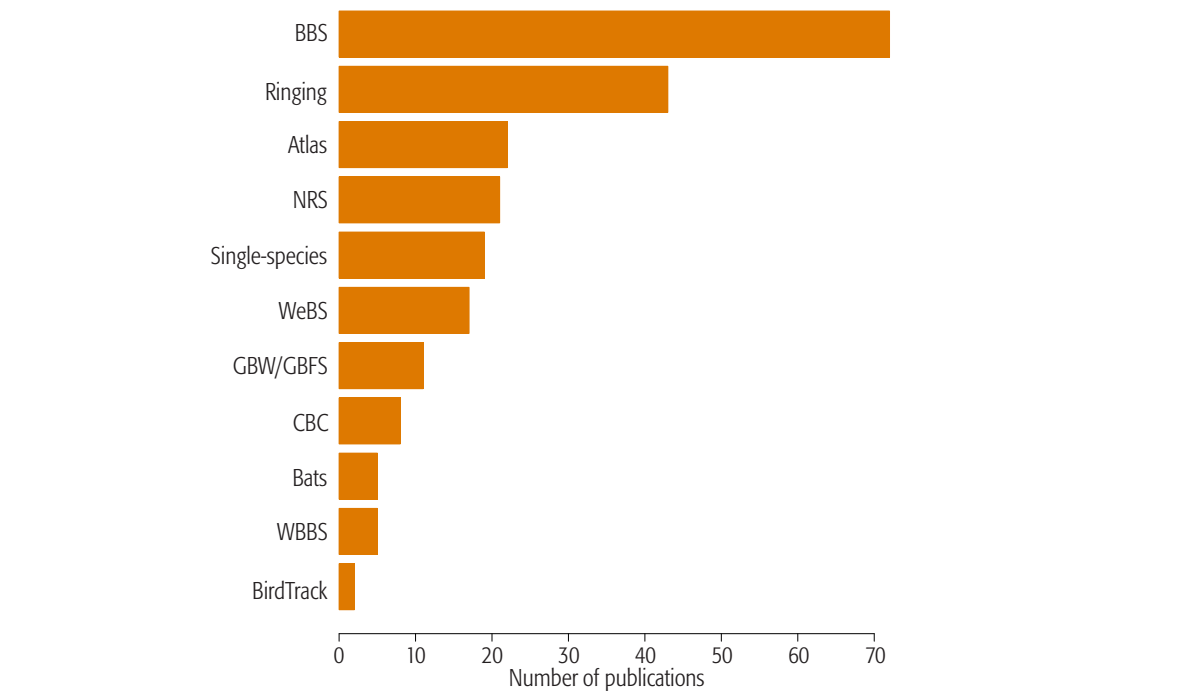
BTO has been in existence for 85 years. We were established "*to realise the potential for the public to inform conservation policy*". Our core mission uses professional and citizen science to provide evidence of change in wildlife populations, particularly birds, to inform the public, opinion-formers and environmental policy- and decision-makers. We are a charity with a membership of c.19,000 in 2018, a wider network of around 50,000 surveyors and supporters, and an annual turnover of about £6 million. Although we operate across the UK, in order to facilitate an effective response to increasingly devolved environmental agendas, our headquarters in Thetford, England is supported by offices in each of the devolved administrations (Stirling, Scotland; Bangor, Wales and Belfast, Northern Ireland). We also apply our scientific expertise to other, non-avian, taxa and on the European and global stages, by engaging with relevant partners and collaborators. We employ a total of 121 staff, of whom 50 are within the science department and 37 are actively publishing scientists.

Our science covers two important aspects: monitoring and research, the integration of which is a significant strength of the organisation. Much of BTO's monitoring relies on thousands of volunteers to help collect large-scale and long-term data on the distribution, abundance and population trends of a range of bird species, and on their survival and breeding success, as well as on the abundance and distribution of other taxa. These schemes provide unique data sets that are widely used for tracking biodiversity trends, for reporting against statutory targets, and for underpining a wide range of research that is both academic and applied in nature.

Our long-term monitoring programme produces robust national population trends, that are reported on annually through our website and other media, for 117 breeding species (and covering ~95% of the UK's estimated 85 million breeding bird pairs) and 48 populations of non-breeding waterbirds, weekly trends in reporting rates in gardens for 44 species, annual trends in survival rates for 59 species and of breeding success for 92 species. These data also contribute to nine of the UK biodiversity indicators (pressure from invasive species, status of UK priority species, farmland birds, woodland birds, water and wetland birds, seabirds, wintering waterbirds and butterfly populations), nine English biodiversity indicators, five Welsh biodiversity indicators (SoNaRR) and the Scottish terrestrial breeding bird and the wintering waterbird indicators.

BTO is committed to making its data accessible and has provided, for example, over 170 million bird records to the NBN Living Atlas and we fulfil about 500 requests for data a year. We also provide bespoke data products, such as the distribution and abundance data used by RSPB and other partners to target conservation initiatives. Beyond birds, the Breeding Bird Survey (BBS), which is delivered in partnership with JNCC and RSPB, provides annual monitoring data for nine mammal species and contributes to the Wider Countryside Butterfly Survey. In gardens, BTO's Garden BirdWatch (GBW) tracks 51 non-avian species across six taxa (butterflies and moths, dragonflies and damselflies, bees and wasps, reptiles, amphibians and mammals) and, through the Garden Wildlife Health (GWH) scheme, incidences of disease in birds and other animals.

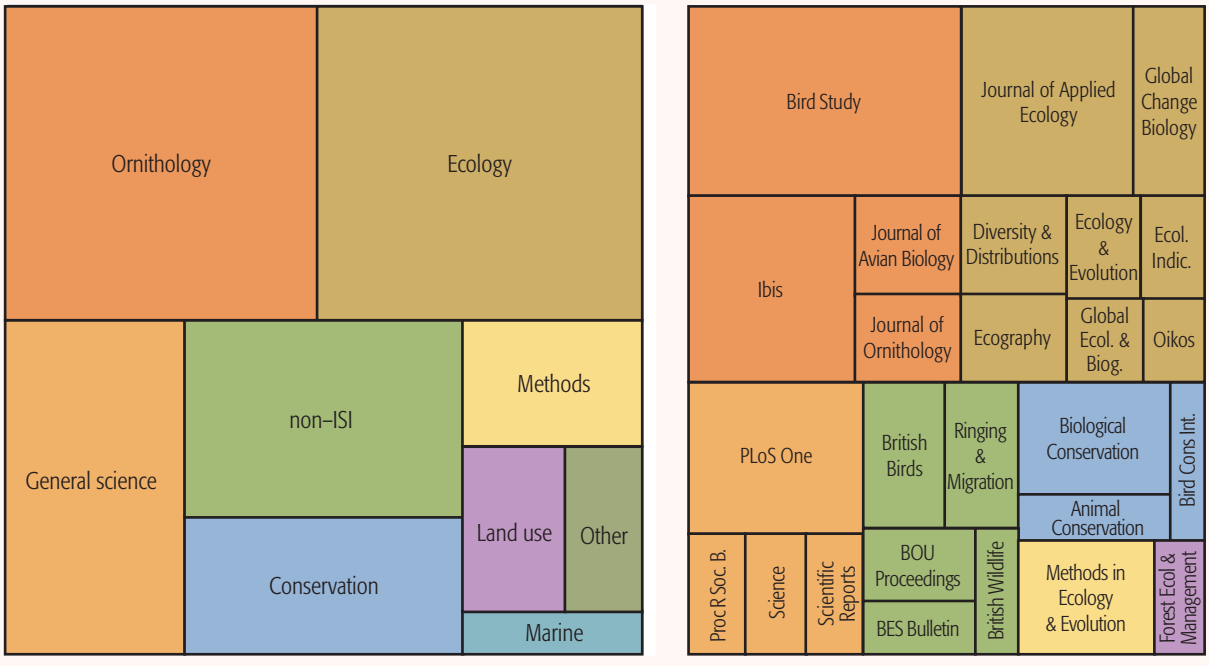
Figure 1. The number of papers with a BTO author that use data from different BTO schemes from 2012–2018. BBS – Breeding Bird Survey, CBC – Common Bird Census, GBW / GBFS – Garden Birdwatch / Garden Bird Feeding Survey, NRS – Nest Record Scheme, WBBS – Waterways Breeding Bird Survey, WeBS – Wetland Bird Survey.



During the period of interest (2012–18), a total of 168 publications with a BTO author originated from BTO monitoring schemes, with the majority from BBS (Figure 1). Many of these have addressed policy-relevant research, but have also considered more academic research questions. A search on *Web of Science* (31 October 2018) lists a total of 957 BTO publications (those with a BTO author) since 1980, which have been cited a total of 35,967 times – an average of 37.6 citations per item, and providing an h-index score of 86 (86 papers that have been cited at least 86 times). During the current period, 300 publications are listed on *Web of Science* with an average of 14 citations per item and h-index score of 32, and a total of 388 papers were authored by BTO. Of these 300 publications, 63 have been collaborations with the RSPB, 62 with CEH, 39 the University of Cambridge, 31 the University of East Anglia, 21 with the University of Exeter, 21 with Butterfly Conservation and 30 with JNCC or the individual statutory nature conservation bodies (SNCBs, NE, Natural Resources Wales (NRW) and Scottish Natural Heritage (SNH)). This reflects the outworking of the 2015–20 BTO Strategy to increase the ecological, rather than ornithological output of the organisation and to work increasingly with partners in the academic, statutory and NGO sectors to help us achieve that.

Most publications appeared in general ecology (n=94) or ornithology (n=91) journals (Figure 2). BTO seeks to promote its science widely, taking it beyond the traditional academic audiences and recognising that the work is often of wider interest. The success of BTO in doing this can be seen from the altmetric scores achieved by papers published during the period - e.g. Lawson *et al.* (2018) 357; Franks *et al.* (2017) 209 ; Plummer *et al.* (2015) 131, and by the numbers of press clippings (around 2,000 p.a.) and appearances on radio and television. During this period the BTO published the landmark *Bird Atlas 2007-11* and 12 other books. Staff also authored three other academic books on topics of birds and habitats, birds and climate change and ecology and conservation of forest birds.

Figure 2. BTO publications 2012–18. Left, all papers by journal type; right, by journal title, for all journals in which four or more papers were published. Size of square is proportional to number in each category.



2. OUR APPROACH

'BTO lets us see absences' (Mike McCarthy).

Science is fundamentally at the heart of BTO. It is written into the Trust's vision '*A world inspired by birds and informed by science*', whilst our mission to '*harness the skills and passion of birdwatchers to advance our understanding of ornithology and produce impartial science, communicated so that it can be of benefit to everyone*' is all about science impact. That science includes both the development and running of long-term monitoring schemes, which provide so much valuable information about the status and change of bird populations, and research that seeks to understand the causes of population change, to answer policy-relevant questions about environmental issues, and to inform and test conservation solutions.

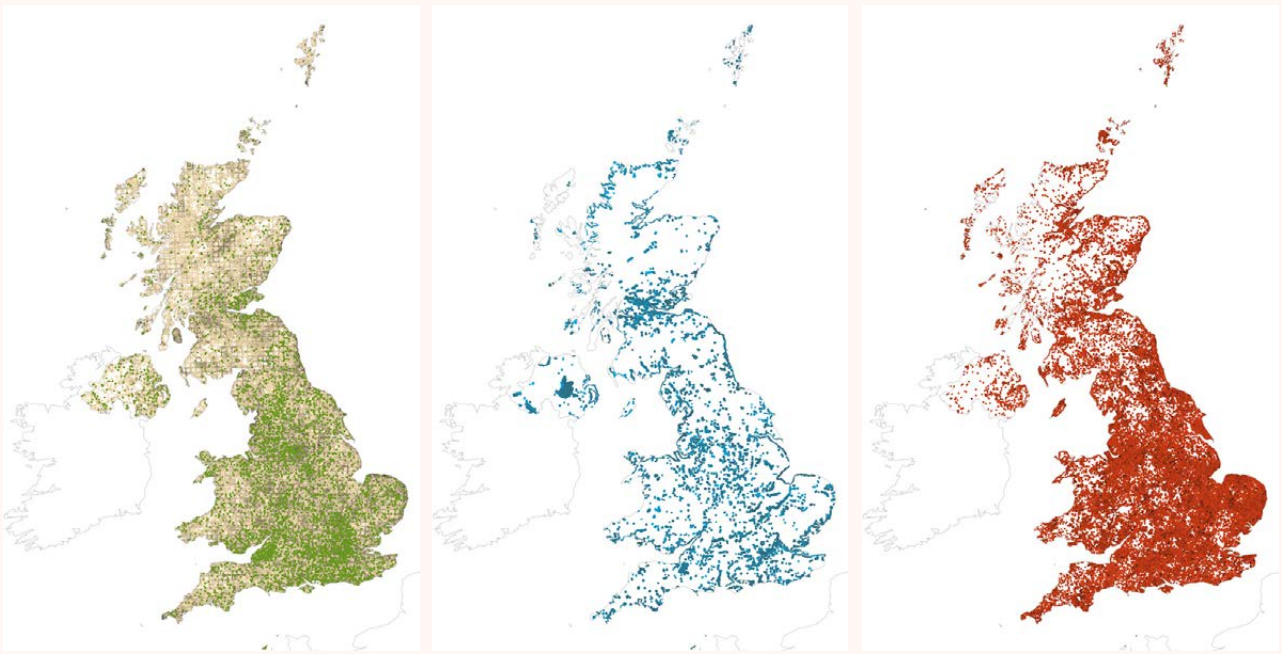
Many people equate BTO science with the surveys that we organise. Although only a part of our work, these surveys are a key strength of the organisation, providing some of the most extensive and long-term distribution, abundance and demographic monitoring of birds in the world. All operate via the crucial partnership of volunteer data collectors and professional scientists that characterises BTO. Structured surveys, such as BBS, atlases and WeBS (Figure 3), provide long-term monitoring of the highest quality, allowing population trends to be described (Frost *et al.* 2018, Harris *et al.* 2018), abundances estimated (Musgrove *et al.* 2013), distributions mapped (Massimino *et al.* 2015, 2017, Balmer *et al.* 2013), and changes in communities tracked (Magurran et al. 2010; Davey *et al.* 2012; Sullivan *et al.* 2016). Surveys also underpin the evidence base for remediation or management action (Baker *et al.* 2012).

Bespoke surveys are also conducted on certain species, such as Woodcock *Scolopax rusticola* and Nightingale *Luscinia megarhynchos*, or species-groups, such as non-estuarine waterbirds, to answer questions of particular interest, as well as providing continued opportunities for volunteer engagement and development. More broadly, through BirdTrack we provide a growing repository for birdwatchers' records that currently receives about six million records per year, data which can then be used to answer scientific questions (e.g. Newson *et al.* 2016). Population change occurs (mostly) as a result of changes in breeding success and survival, and our demographic monitoring (through the ringing and nest record schemes) can be used to understand the mechanisms underpinning the observed changes (e.g. Morrison *et al.* 2016a). When combined with the abundance data produced from surveys, the demographic projects offer an extremely powerful data set with which to understand long-term population change (e.g. Robinson *et al.* 2014).

Importantly, these schemes are only one component of the science that we do. One of the critical characteristics of the BTO is that we not only design, run and coordinate this range of schemes, but also analyse and interpret their outputs, not just for routine reporting of trends, but for the delivery of a wide-range of research outputs. This means that BTO ecologists using the monitoring data can be closely involved in the design and development of the schemes and have experience and familiarity with their methodology, whilst scheme organisers can advise and assist with the interpretation and communication of the science (Pearce-Higgins *et al.* 2018). This close integration of expertise is one of the key differences between BTO and other research institutes who may use these same data.

Equally, it should be recognised that many ecological and policy research questions cannot be answered using long-

Figure 3. Maps showing distribution of unstructured (BirdTrack, brown), structured (BBS, green) and waterbird (blue) counts, and demographic records (red) in the UK; darker colours indicate a higher density of records. Coverage is country-wide but concentrated in the south-east and areas of high population density.



term citizen science data alone, and therefore BTO scientists frequently undertake their own field-data collection as necessary. There is much potential for using BTO data to examine large-scale patterns and processes, complemented by more detailed measurements and studies at individual sites or a range of study areas (e.g. Gullett *et al.* 2013; Hewson *et al.* 2017), an approach that should be adopted more broadly.

KEY QUESTIONS

Our science is defined by three overarching questions, encompassing relationships between birds, other wildlife and the environment.

- What is the status of populations and what are the causes of changes?
- What processes explain observed ecological patterns amongst birds and other biodiversity?
- What is required to manage species and habitats sustainably?

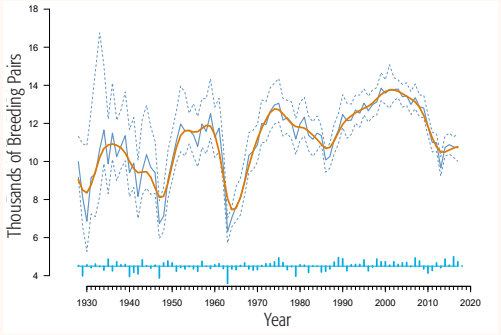
Thus most of our science is set within a policy context; we aim to understand how human activities, natural processes, and their interaction, affect birds and other wildlife to inform potential solutions to conservation and other environmental problems.

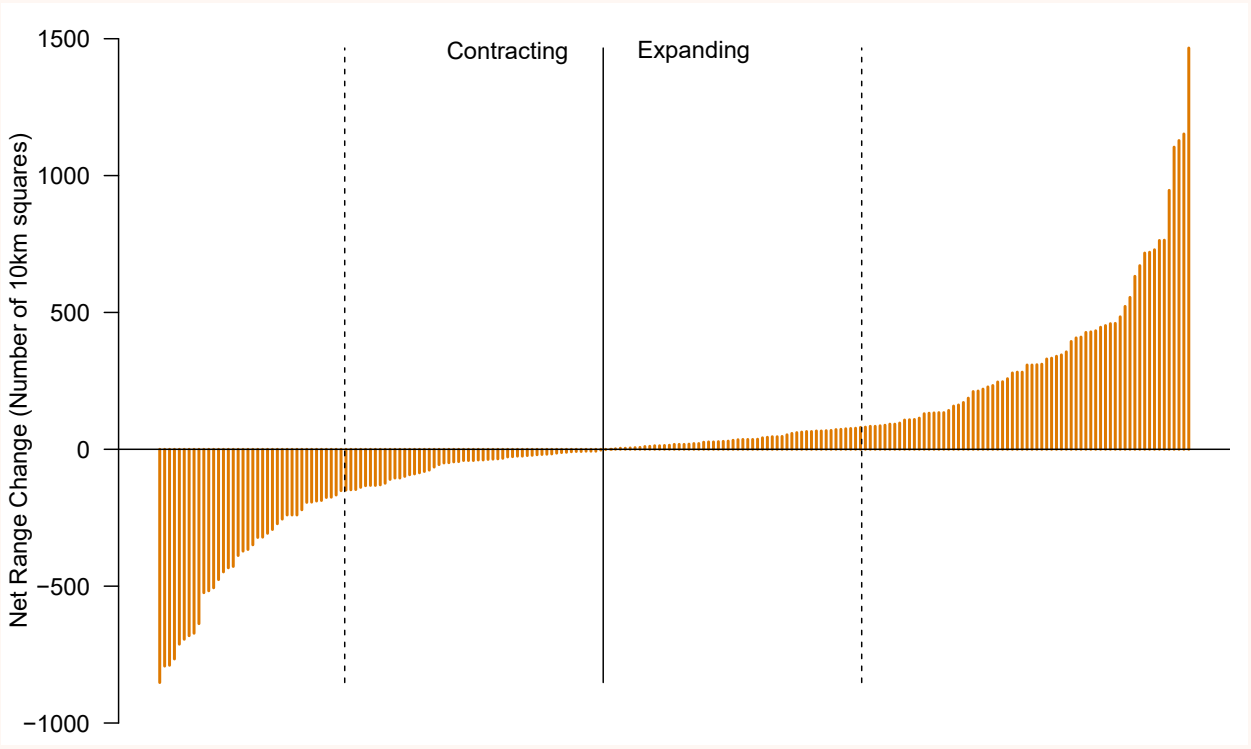
We utilise these questions to give a broad structure to the rest of this document. First, we consider the impact of the monitoring that we do to document population status and trends. Secondly, we describe the impact of areas of ecological research that have particularly addressed a range of key environmental challenges or issues, before, thirdly, summarising the contribution BTO makes to more species-focused conservation science. Whilst much of this work has a national (England, Scotland, Wales, Northern Ireland) or UK focus, we also work at a European scale (for example through EURING, EBCC and EuroBirdPortal collaborations), and globally, particularly through the Cambridge Conservation Initiative. Finally, we then consider the more diffuse impact that BTO has in providing capability and support for the wider environmental sector.

CHANGES IN BIRD POPULATIONS OVER 90 YEARS

Bird populations are continually changing, both in time and space. Grey Heron nests have been counted since 1928 (right). The numbers vary substantially between years (solid blue line). Dashed blue lines indicate 85% confidence limits; years in which these don't overlap have significantly different population sizes. Much of this variation is due to winter weather conditions; population size is reduced in years where mean winter temperature is lower than the long-term average (blue bars). Overlain on these annual fluctuations are longer-term decadal trends (orange line).

Comparing the first (1968–72) and most recent (2007–11) BTO atlases provides a measure of change in the distribution of breeding species with 118 species occupying more and 93 occupying fewer 10 km squares (below). The dashed lines delineate the middle 50% of species (ranging from a net loss of 150 squares to a net gain of 80, from a total of ~3,200), the remainder show greater net changes in range.





3.THE SCIENCE OF MONITORING: THE STATE OF BIODIVERSITY AND HOW TO MEASURE THIS

'Nowhere else on earth is as well known in terms of bird distribution and populations thanks to the astonishing effort of accomplished volunteers and BTO' (Chris Packham).

Much of ecology is the study of change – understanding change in populations over time, change in occurrence and abundance in space, and how interactions between species alter these. Over the course of the last four decades BTO atlas projects highlight that most species have shown substantial changes in their distribution – either expanding (e.g. Cetti's Warbler *Cettia cettia*, Red Kite *Milvus milvus*) or contracting (e.g. Red-backed Shrike *Lanius collurio*, Hawfinch *Coccothraustes coccothraustes*) their range; few species exhibited no (or little) net change over this period. The Heronries Census, the longest-running single species bird survey in the world, typifies how dynamic populations can be. Since 1928, the British population of Grey Heron *Ardea cinerea* has fluctuated strongly over annual – particularly in response to winter weather (Pearce-Higgins 2017) – and decadal time-scales, but also shows a gradual increase in the number of breeding pairs over the 90 years.

METHODS DEVELOPMENT

Clearly, contributed data comes in many forms, from unstructured biological recording of the presence or behaviour of a particular species at a particular location, through to formal monitoring schemes following standard protocols. In many cases this is by design, but at all levels, record verification and validation is important, and appropriate statistical methods need to be applied in their analysis (e.g. Siriwardena *et al.* 2013). Indeed, the need for robust analysis of such large-scale data, which can be challenging, continues to spur the development of novel statistical methodology, with BTO authors involved in 11 papers in *Methods in Ecology and Evolution* in this period.

Field survey techniques developed by BTO, particularly those based on mapping territories (Common Birds Census) and distance-based line transects (Breeding Bird Survey) have long been used by surveyors more widely (Dobinson 1976; Gilbert *et al.* 1998), and are incorporated into standard texts on biodiversity survey methods (e.g. Bibby *et al*. 2000; Sutherland *et al.* 2006) and BTO research often underpins guidance for professional surveyors. For example, research on the efficacy of monitoring protocols in moorland habitats (Calladine *et al.* 2009) was influential in determining SNH's Environmental Impact Assessment (EIA) methodology guidelines for that habitat. Similarly, guidance around surveying for Short-eared Owls *Asio flammeus* is based, in part, on recent BTO research into their behaviour (Calladine & Morrison 2013). In lowland habitats, recent work on how to survey Nightingale populations (Hewson *et al*. 2018) is likely to influence future survey methodology and impact assessments for this species of conservation concern. BTO authors have contributed to a total of 85 papers describing developments of either field methods or analytical approaches over the period of the review, of which 54 were BTO-led.

MONITORING SCHEMES

The bird populations of the UK are often referred to as the best-studied of this taxonomic group anywhere in the world. The foundations for that situation can arguably be traced back to monitoring schemes such as the Birds of Estuaries Enquiry (BoEE) and the Common Birds Census (CBC) established by the BTO in the 1960s, both born out of practical conservation need: a response to potential large-scale barrage developments and use of pesticides respectively (Hickling 1983). The first national BTO atlas (Sharrock 1976) cemented this, and developments since, such as rolling programmes of single-species surveys, the launch of the BBS and other initiatives such as BirdTrack, have served to improve our knowledge. Although led by professionals, each of these schemes depends on a massive contribution of time, effort and expertise from volunteer observers across the UK, who we wish to recognise here and whose efforts are fundamental to what we do.

The BTO is perhaps best known for leading on large-scale bird atlases, which aim for coverage of all 10-km squares in the British Isles to produce comprehensive distribution maps, and for a sample of tetrads (2 x 2 km squares) in every 10-km square to be covered with Timed Tetrad Visits to record and count the species present in a standardised manner. The latest *Bird Atlas 2007–11* (Balmer *et al.* 2013) presented, for the first time, information about both breeding and wintering distributions and relative abundances for 296 species, based on the records of some 40,000 people, and charts changes over a 40 year period. About 10,000 copies of the atlas have been sold, demonstrating the significant public-outreach and engagement potential of the work, and the maps are freely viewable in an online mapstore. These data have been used for conservation targeting by a range of organisations, from the RSPB to the SNCBs. For example, they have been used to identify wader hotspots as part of the *Working for Waders* project to inform planning and the targeting of conservation advice to land owners on the ground.

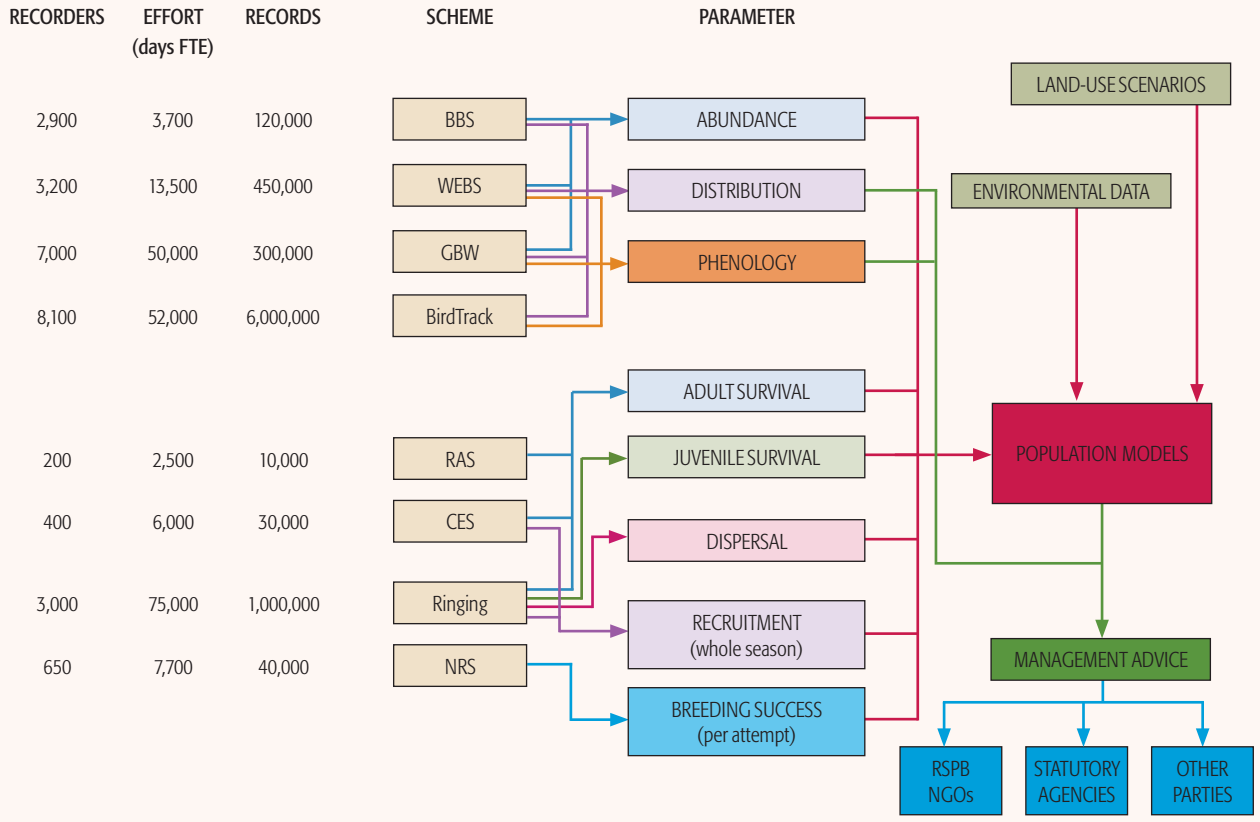
We continue to facilitate the collection of list-type data through BirdTrack, which captures about six million bird records from the UK annually; over 80% are submitted as complete lists, providing valuable information about null records and hence detectability. BirdTrack is also available globally, enabling birdwatchers to log sightings of any bird, anytime, anywhere, and we continue to work with those developing similar tools elsewhere to maximise interoperability of data systems. The database is set up to capture a range of information about birds seen, whether via behavioural codes that are directly analogous to information captured during atlas studies, or more bespoke information about, for example, the age or sex-ratios of species. Over

650,000 records from BirdTrack were used to feed into the current *European Breeding Bird Atlas* (EBBA2) project (along with 600,000 records from BBS and nearly 200,000 from other BTO schemes). BirdTrack data have also been central to the latest reassessment of bird migration periods for the UK and Ireland component of a Europe-wide review of *Birds Directive Annex 2* huntable species that will inform the timing of hunting seasons (Baillie & Gargallo 2018).

BBS, which was established in 1994, provides a nationwide network of sampling sites, randomly sampled with respect to habitat and other geographical features (but stratified with respect to observer density) to maximise the representativeness of the underlying data. Not only does this provide robust estimates of annual population trend for 117 breeding bird species, but it also provides the capability for other biodiversity and ecological features to be surveyed; for example, BBS squares were used to gather data on winter bird occurrence to assess the potential impacts of agri-environment schemes (Gillings *et al.* 2005). BBS surveyors also collect habitat data, demonstrating the potential value of citizen science to help track land-use change (Martay *et al.* 2018). While they are counting birds, BBS surveyors also record the presence of mammals and this dataset now forms the best evidence for long-term population changes in nine species (Massimino *et al.* 2018). Coordinated collection of data on different taxa also allows for direct comparison of, for example, community structure; Eglington *et al.* (2015) showed that bird and butterfly communities on BBS squares had similar patterns of diversity and richness, but not evenness. Understanding such patterns is helpful in determining whether species groups can be used as surrogates or proxies for each other. Collection of data on such secondary taxa is most effective where they can be detected reliably by methods devised for the core survey. In such cases the data are inexpensive and inherit some of the benefits of the underlying structure and power of the core survey; they also provide opportunities to engage and enthuse people about conservation issues of other species groups.

Other schemes, such as WeBS, led by BTO, in partnership with RSPB and JNCC and in association with WWT, aim to provide more complete geographic coverage, in this instance focused on counting key wetland sites to provide close to full population estimates for many internationally important wintering waterbird populations (Musgrove *et al.* 2011). This resolution of information means that high quality site-based information about population size and trend can be produced for key sites, such as SPAs and SSSIs, providing an invaluable resource for staff in the SNCBs and conservation NGOs to inform decision-making, casework and management, for example, in quantifying the status of qualifying interest species for the Firth of Forth SPA under Habitats Regulation Assessment process (HRA) (Woodward *et al.* 2015). This document, and another similar document commissioned by NIEA for Northern Ireland Sea Loughs, provides those involved with HRA (including developers, planners and

Figure 4. Data collected by BTO volunteers quantify different aspects of population processes, these can be combined with environmental and other data to inform conservation policy and other management issues.



others assessing applications for developments and otherwise advising on developments) with basic information on the ecology of qualifying bird species and factors that can affect birds within the estuary. The sampling of less-aggregated species is more difficult, but counts can be analysed to produce robust trends that attempt to account for these underlying biases (Chamberlain *et al.* 2013; Méndez *et al.* 2015), improvements to which are continuing.

Changes in bird, and other, populations are driven by variation in demographic rates (productivity, dispersal, recruitment and survival), which BTO's demographic schemes provide estimates of. The Constant Effort Site (CES) scheme ensures ringers follow a standardised protocol to provide trends in abundance, productivity and survival for common passerines (Robinson *et al.* 2009), while the Retrapping Adults for Survival (RAS) ringing protocol targets effort towards particular species, with around 200 projects per year. The Nest Record Scheme (NRS) involves the study of individual nests to provide standardised information on breeding performance and nest location, producing annual trends for 70–80 species per year. In addition, a range of other ringing activities are supported, delivering information about phenology of the life cycle (Morrison *et al.* 2015), dispersal (Robinson *et al.* 2007) and the spread of disease (Bessell *et al.* 2017; Lawson *et al*. 2011)

The combination of demographic and bird survey data to estimate annual variation in abundance, is a powerful one, enabling the drivers of population change to be identified (Figure 4). The benefits of combining data sets in this way allow uncertainty to be properly accounted for, and enable parameters that may not be measured directly to be inferred. BTO has been at the forefront of developing Integrated Population Models (IPM) that combine data on population abundance with that on demographic processes (Besbeas *et al.* 2005; King *et al.* 2008; Cave *et al.* 2010). In the largest IPM study of its kind to date, Robinson *et al.* (2014) identify the role that recruitment to breeding populations may play in driving populations of 17 species, with the proximate processes driving population declines across species, while variation in adult survival was more important in species whose numbers were increasing. Such information is important to help identify proximate causes of decline, for example, the long-term decline in breeding Lapwing *Vanellus vanellus* populations in the UK was largely driven by a series of severe winters causing short-term reductions in adult survival, but this was superimposed upon a long-term declining trend in reproductive success, which rendered the population incapable of reversing these losses. Such results highlight the decreasing resilience of our landscapes and the populations that reside in them to external pressures. Similarly, a reduction in reproductive success, coupled with a failure for years of high survival to coincide with years of high productivity, appear responsible for differing regional trends in Willow Warbler *Phylloscopus trochilus* populations (Morrison *et al.* 2016a).

MONITORING OUTPUTS

Information about annual variation in population trends, and the underlying demographic parameters, are made available through BirdTrends, a searchable series of species-focused web-pages that are widely used by volunteers, the general public and conservation professionals. Species accounts also summarise the evidence for likely causes of population change. This resource is used on an almost daily basis by ornithologists from the SNCBs.

In 2002, JNCC noted the value of a single, quality-assured source of population estimates for statutory conservation purposes (Stroud *et al.* 2002). This value increased with the requirement under Article 12 of the EU's *Birds Directive* (2009/174/EC) for the member states to report regularly on the impact of implementation of the directive. The 2013 UK Article 12 report was used for over 25 policy purposes at UK and regional levels by Defra and JNCC. This included assessment of the status of wetland species for UK reporting to MoP 12 of the Ramsar convention, UK waterbird status reporting to the AEWA (*Agreement on the Conservation of African-Eurasian Migratory Waterbirds*) MoP 6 and the first *European Red List of Birds* (Dsouza 2018). Our data have been at the heart of each of the three assessments that have been undertaken to date, particularly the most recent (Musgrove *et al.* 2013), through the work of the Avian Population Estimates Panel.

BTO has been at the forefront of the development UK biodiversity indices at a range of geographic scales, mainly for birds, but also across taxa, as a method for assessing, monitoring and reporting on general trends in biodiversity. Indicators have good political traction. The Farmland Bird Indicator for England was for many years used as a formal measure of progress in sustainable agriculture as part of a Public Service Agreement and still continues to be politically relevant – it is mentioned in the 25 Year Environment Plan. It ensured the issue of the impacts of agricultural intensification on birds, and wildlife more generally, were on the political agenda, and stimulated much work on the topic. Now that biodiversity and environmental matters are largely devolved to the respective parliaments and assemblies, our data continue to contribute to biodiversity indices in each country.

BTO has critically examined approaches to indicator development, either by ourselves, or in collaboration with others. Analytically, this has included assessing confidence, dealing with incomplete data sets or time series, and developing new approaches for summarising changes in communities. Indicator trends can be subject to bias, particularly as declining species become too rare to be covered by monitoring schemes, resulting in an artificially positive indicator trend. In response to this issue, we have considered the impact of changing the constituent species of indicators (e.g. Butler *et al.* 2012; Renwick *et al.* 2012), and reporting on spatial as well as temporal change (Massimino *et al.* 2015). Importantly, this latter approach has enabled previously unidentified patterns in species' trends to be highlighted, with particular declines in farmland habitat specialists in south-eastern England, informing regional conservation priorities. Decreasing bird populations in the south-east have been identified by other analyses (Ockendon *et al.* 2012; Morrison *et al.* 2013), and may indicate a broad-scale deterioration of environmental quality in this part of the

Whilst a number of core BTO bird surveys encourage volunteers to capture data on non-avian taxa, recent field projects have also sampled other groups, often integrated with surveys of birds, to provide greater understanding of the environment. Research into the effects of changes in street lighting on moths for Defra used a combination of existing data, from citizen science and professional monitoring, and new experimental work to demonstrate the impact these changes may have (Plummer *et al.* 2016). Research on habitat heterogeneity effects on biodiversity and ecosystem services, also for Defra but as part of a major international collaboration (BiodivERsA), used professional, multi-taxa field sampling, observation and experiments, and has already demonstrated how landscape configuration affects pollinator abundance (Hass *et al.* 2018). By developing approaches for citizen scientists to borrow passive sound-recording devices, BTO has pioneered new approaches to bat monitoring that is transforming thinking about national-scale bat monitoring (Newson *et al.* 2015). At the same time, bush crickets are recorded incidentally by bat detectors, and BTO has developed tools for the automatic sound identification of these (Newson *et al.* 2017); this work has helped inform planned reintroductions of localised species. Ongoing monitoring of agri-environment schemes in both England and Wales now takes advantage of these developments capturing information not just on birds and butterflies, but also other pollinators and bats.

The willingness of BTO volunteers to collect information on taxa other than birds can be seen from the contributions made to core monitoring schemes, like the BTO/JNCC/RSPB Breeding Bird Survey, BTO Garden BirdWatch, the Waterways Breeding Bird Survey and BirdTrack, which collectively generate *c.* 4.6 million other taxa records per year.

Muntjac, by Paul Newton

BREEDING BIRD SURVEY, WATERWAYS BREEDING BIRD SURVEY (WBBS)

BBS was launched in 1994, and involves thousands of birdwatchers carrying out standardised annual bird counts on randomly-located 1-km sites. WBBS is an annual survey of breeding birds along rivers and canals. It uses transect methods akin to those of BBS but with minor adaptations to a linear habitat. Comparing these annual counts enables us to monitor the population changes of over 100 bird species. Mammal recording was introduced in 1995. Compared with birds, the population trends of mammals are relatively poorly known. Even though mammal recording has always been a voluntary addition to the scheme, 90% of BBS observers look for them during their visits. Roughly one in ten of our BBS observers also contributes to the Wider Countryside Butterfly Survey.

Common Toad, by Mike Toms

BTO GARDEN BIRDWATCH

BTO Garden BirdWatch monitors the changing fortunes of birds and other garden wildlife through its network of 12,000 citizen scientists, who submit records of the wildlife using their gardens each week throughout the year. Launched in 1995, the survey has provided a great deal of information on garden wildlife, supporting research and the peer-reviewed publication of scientific papers. After an initial trial, other wildlife recording was formerly introduced to the survey in 2007 and these data have since contributed to the national dragonfly atlas, to the Reptiles and Amphibians in Gardens Survey, to a PhD on bumblebees and to local record centres.

Broad-bodied Chaser, by Moss Taylor

BIRDTRACK

BirdTrack is an exciting project, through a partnership between the BTO, the RSPB, Birdwatch Ireland, the Scottish Ornithologists' Club and the Welsh Ornithological Society, that initially looked at migration movements and distributions of birds throughout Britain and Ireland, but is now available for data entry globally. BirdTrack provides facilities for observers to store and manage their own personal records as well as using these to support species conservation at local, regional, national and international scales. Dragonflies are a popular order of insects among birdwatchers. They occur at many birding sites, are relatively conspicuous, and can usually be identified fairly easily. BirdTrack allows life-stage recording for dragonflies.

Other taxa icons, Eva_Mask, Nev, Utopia88, Hein Nouwens, Dn BR/Shutterstock.com

country, but the mechanism underpinning this trend has not yet been identified. BTO has also explored alternative metrics such as indicators of the impact of climate change, the spread of non-native species, and the use of community profiles (Siriwardena *et al.* 2017).

Although our core monitoring work focuses on birds, we are increasingly working with groups studying non-avian taxa, sharing our experience to increase the quantity and quality of data collected and ensure biodiversity trends are better monitored and understood. We do this in two ways: by collaborating with other relevant organisations, and by promoting collection of data on other taxa by our volunteers, especially on sites already surveyed for birds, such as BBS and CES. Thus, for example, BTO plays a leading role in the UK Terrestrial Evidence Partnership of Partnerships, which was created to facilitate communication across the terrestrial biodiversity surveillance and monitoring schemes, and actively contributes to organisations such as the National Biodiversity Network and the National Forum for Biological Recording.

Beyond birds, BBS provides annual monitoring data for nine mammal species (Wright *et al.* 2014; Massimino *et al.* 2018), and in gardens, Garden BirdWatch tracks 51 non-avian species across six taxa (butterflies and moths, dragonflies and damselflies, bees and wasps, reptiles, amphibians and mammals). BirdTrack also has the capability for capturing Odonata (dragonfly and damselfly) records, which are passed to the British Dragonfly Society, and those of mammals. In addition, BTO has significant field capabilities for such studies, not just on birds, but on other taxa and habitat recording, and we aim to build on and extend this capability in the future, not just in the UK, but also internationally.

SOCIETAL BENEFITS OF MONITORING

Characterising ecological processes at such large spatial and temporal scales is only feasible with the support of a large number of dedicated observers who contribute time, effort and often individual financial resources to achieve these aims. By doing so they not only contribute data to formal monitoring programmes, but also likely derive significant benefits by engaging with nature, their local environment and changes therein (Cox *et al.* 2017). Volunteer participation democratizes the scientific process within wider society (Greenwood 2007), improving the public understanding of, and engagement with, science (Pearce-Higgins 2015). Often the distinction between top-down and bottom-up approaches becomes blurred, with volunteers organising themselves, for the purpose of gathering data in a more coherent way. Simultaneously, their personal experience of monitoring activities, and of the organisation they have created, leads to knowledge, learning and a desire to communicate it (Lawrence 2006).

Taking part in the wide range of opportunities that BTO projects offer also provides positive benefits to a volunteer's health and mental well-being. This was presciently demonstrated in 2009 by a storyline in the long-running BBC Radio drama *The Archers*, where one of characters (Pip) was encouraged to monitor, and later participate in ringing, a brood of owl chicks as a distraction during a troubled period. Recent research has shown that being surrounded by green spaces lowers stress levels and raises positive mental thought processes (Cox *et al.* 2017; Wood *et al.* 2017) and that the simple act of providing food for garden birds can be rewarding in itself (Cox & Gaston 2016). Promotion of such interactions with the outdoors can start from the simplest of

ECONOMIC VALUATION OF VOLUNTEERING BENEFITS

Based on estimated levels of volunteer time contributing to schemes, and the numbers of volunteers involved, it is possible to estimate, in very broad terms, the economic value of BTO volunteers to the organisation and the sector in terms of what it would cost to undertake the required research professionally, and to society, in terms of the health and well-being value of volunteering.

Estimates of the value to the BTO based upon this volunteer effort are derived from product of estimates of the average number of hours that each volunteer spends undertaking each activity in a year, and the total numbers of volunteers engaging in that activity (Figure 4). This figure is then converted to give an estimate of what it would cost to replace this effort professionally, based on a salary of £150 per day. Estimates exclude contributions by Garden BirdWatch (who pay to support the scheme) and BirdTrack (which is not a formal survey but a data repository for birdwatchers, albeit one that provides scientifically useful data).

Estimates of the economic value of the health and well-being benefit to volunteers are based on the Department of Work and Pensions Working Paper 12 (Fujiwara *et al.* 2013) which provide estimates of the value of volunteering. Using a modelling approach from qualitative well-being data, they estimate the well-being value for frequent volunteers (those that volunteer at least once per month) to be £13,500 (at 2011 prices). We assume that WeBS surveyors, who undertake monthly surveys, ringers and nest-recorders (who contribute an estimated 85–200 hours volunteering per year), and our regional representatives, that oversee the network, achieve this threshold. Annual estimates of this value, based on these assumptions, are plotted below for the period of interest.

Estimated value to BTO of volunteer effort (red) and estimated value to society of the health and well-being benefit to frequent volunteers (green).

projects and surveys such as BirdTrack (8,100 participants), Garden BirdWatch (15,000) and, most recently, the Tawny Owl Calling Survey (10,000). All three are easy to get involved with and can be carried out from a volunteer's garden encouraging them to go outdoors and engage in wildlife on their doorsteps; even the ability to identify birds visiting feeders is anticipated to have knock-on benefits to health and well-being (Cox & Gaston 2015). The added benefit of being able to see how their observations feed into high quality research is another area of motivation BTO can provide, and that has been previously highlighted as an important reason for participation (Martin *et al.* 2016).

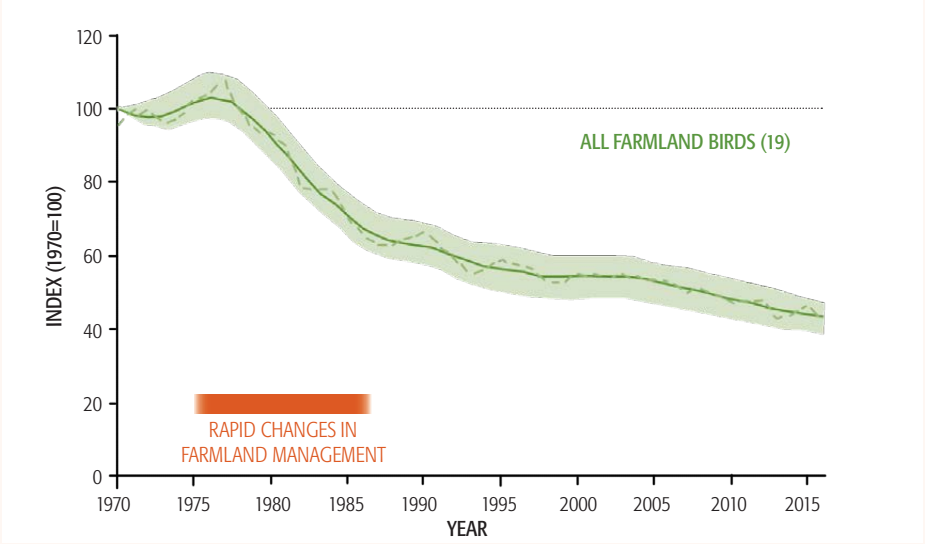
More time-demanding surveys, such as WeBS and the ringing programme, engage a different level of volunteer and provide exercise benefits as well as mental well-being. Walking has long been praised for its benefits, even at a gentle level, and both of these surveys draw people out and away from urbanised areas and engage multiple senses. Given recent news that GPs in Shetland are now issuing 'nature prescriptions' to their patients to help with a variety of conditions, the credibility of such activity as a treatment is now being seen. The sound of bird song has also been shown to have a positive effect on mental health (Alvarsson *et al.* 2001; Zhao *et al.* 2018), with most BBS recorders now specifically noting whether they identify individual birds by sight or sound.

In Wales, BTO Cymru is working on new proposals that fit in with the Welsh Government's recent *Well-being of Future Generations Act* (2015). Here the goal of "a healthier Wales" includes maximising mental well-being as well as the population's physical health alongside other goals,

INDICATORS AND TARGETS

The Farmland Bird Indicator (FBI) has been very successful as a promotional tool, providing a simple, visual summary of population change among a fairly coherent group of species and achieving wide reach amongst government and stakeholders. This has helped maintain the issue of a farmland biodiversity crisis on the political agenda, supporting the associated programme of research, policy-development and interventions through agri-environment schemes.

The farmland bird indicator for the UK, 1970 to 2016, as presented as part of the Defra Wild Bird Indicators. The graph shows an unsmoothed trend (dashed line), and smoothed trend (solid line) with 95% confidence intervals (shading). In brackets are the number of species.



However, attempts to use the indicator as a truly quantitative metric in science and policy have been less successful. First, a conceptual target of 'reversing decline' was difficult to express as a specific, quantitative target. Second, incremental and inter-annual changes are difficult to interpret because of the diverse nature of the species included, lack of habitat specificity and the wide range of potential influences on changes in species' abundances. Together with a change in the approach of the UK Government towards targets and metrics, these issues led to the dropping of the farmland bird PSA target in 2010, although the FBI remains an official UK national statistic and its analogues are still in use at a European-scale.

BTO has continued to work on indicator development, demonstrating the resilience of farmland and woodland bird indicators to variation in species selection and habitat specificity (Renwick *et al.* 2012) and producing maps of indicator trends to highlight more extreme regional patterns (Massimino *et al.* 2015). Ongoing development of other statistical approaches to indicators (e.g. Studeny *et al.* 2013; Harrison *et al.* 2014, 2016) provide new insights, but support the same general patterns of change, and have resulted new opportunities to disseminate these patterns to policy-makers, such as through the SNH *Trend Notes*.

such as bringing communities together and providing a globally responsible country. BTO volunteers themselves might provide opportunities for research into the benefits of engagement in the natural world. From a more familiar perspective, a new partnership is being developed between BTO Cymru, Forest Research and a number of Welsh charities and NGOs; this will consider the ecosystem services provided by small woodlands across the urban-rural gradient. Within the proposed bid, quantifying the well-being benefits that local people and their communities gain from such woodlands will be a key output.

4. SCIENCE FOR ECOLOGICAL CHALLENGES: WHAT PROCESSES DRIVE BIODIVERSITY CHANGE?

'For the vast majority of bird features on coastal and wetland SPAs, WeBS data inform changes in abundances'
Alex Banks (Natural England)

This section outlines how BTO science has addressed a series of ecological challenges and delivered research that is relevant to both policy and management. First we consider how this work has informed decision-making in relation to key issues of terrestrial land-use associated with farming, forestry and the urban landscape, and increasing pressures on the marine environment. Next, we outline BTO research to address policy needs associated with the more dispersed threats of climate change and problem species interactions. Finally, we consider the role that BTO science has played in addressing more societal challenges of ecosystem services and natural capital, and in inspiring people with ornithology, through arts and culture.

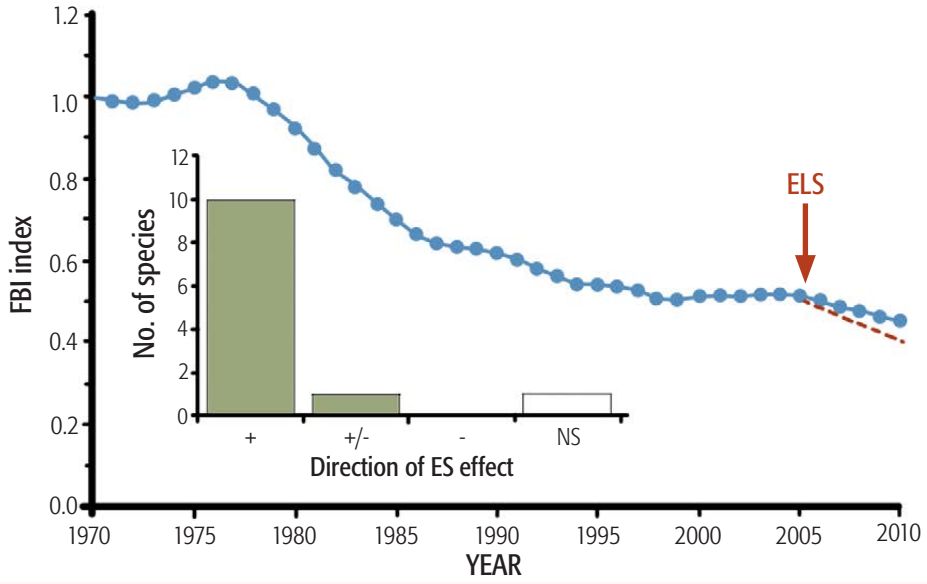
FARMING

BTO science has probably had greater policy and public impact in the area of farmland conservation than in any other. Arguably, the entire notion of a farmland biodiversity crisis, one of the highest profile conservation issues of our time, stems from a combination of long-term BTO monitoring and Rachel Carson's *Silent Spring*. By the late 1980s, the time series of farmland survey data collected by the CBC was sufficiently long that it could measure population trends over decades, and signs of sustained population declines of farmland birds were revealed by the analyses presented in the original Trends Guide (Marchant *et al.* 1990). The patterns were then highlighted in the scientific literature for the first time by Fuller *et al.* (1995), followed by quantification using more robust statistical methods in the late 1990s (Siriwardena *et al.* 1998a). This led to widespread acceptance that farmland bird decline was a real phenomenon (e.g. Krebs *et al.* 1999), and RSPB and BTO produced a summary indicator from CBC indices, the Farmland Bird Index, that was adopted as a 'Public Service Agreement' policy metric by the UK government. In the context of monitoring, the profile of the FBI encouraged the development of analogous metrics for other habitats, and regional and continental versions for use by other administrations.

DIAGNOSING CAUSES OF DECLINE

The conservation pressure that followed the adoption of the FBI as a national statistic led to the UK government commissioning an extended programme of research, with work to identify the causes of population decline and the trialling of management solutions to stem, or reverse, those

Figure 5. The trend in the farmland bird index (FBI index) plotted through time, with the hypothesised trend in the absence of the introduction of the Entry-level scheme (ELS) in red. The frequency distribution of positive and negative responses to over-winter stubble provision under ELS from Baker *et al.* (2012) is also shown.



declines being conducted more-or-less in parallel. Initial work exploited our long-term data archives to investigate both the demographic and ecological processes, and the environmental patterns, behind farmland bird declines. Patterns in the timing of population changes from the CBC relative to those in agriculture and the occurrence of key shifts in practices suggested that a period of rapid intensification beginning in the 1970s, including a widespread shift from spring- to-autumn sowing, a loss of mixed farming, and increases in agro-chemical use and efficacy, was broadly responsible (Chamberlain *et al.* 2000; Robinson & Sutherland 2002; Siriwardena *et al.* 1998a). Analyses of BTO ring-recovery data, supported by early CES ringing results, showed that most species' population changes were best explained by changes in over-winter survival (Siriwardena *et al.* 1998b; 1999; Peach *et al.* 1999), and analyses of BTO Nest Record Scheme data showed that breeding success had mostly increased over time (Siriwardena *et al.* 2000a). In general, therefore, national population change in farmland birds was shown to be driven by factors such as winter food or predation of adults, affecting survival, rather than the availability of insects or nest predation, affecting breeding (Siriwardena *et al.* 2000b).

TESTING SOLUTIONS

Research into potential conservation solutions has encompassed both breeding season and winter management. Seed-bearing sacrificial crops, sown primarily for gamebirds, were found to attract significant numbers of conservation-priority seed-eaters (Henderson *et al.* 2004), while over-wintered stubble crops both attracted seed-eaters in winter and were associated with more positive breeding population trends (Gillings *et al.* 2005), and set-aside fields (rotational fallows) attracted many species in both summer and winter (Henderson *et al.* 2000a, b). Landscape-scale experiments showed that winter food provision could indeed have positive effects in breeding populations and revealed that food resource patches should be separated by 0.5–1km to maximize efficiency (Siriwardena *et al.* 2006, 2007). Further experiments showed that the proportion of uncropped (but still cultivable) land was positively associated with the abundances of a range of farmland species (Henderson *et al.* 2012). In grassland, diverse swards were shown to be important for invertebrate food supplies, but they also need to have an open or heterogeneous structure to give birds access to that food (Atkinson *et al.* 2005). Meanwhile, analyses investigating whether increases in Sparrowhawk *Accipiter nisus* and Magpie *Pica pica* may also have contributed to farmland bird declines by increasing predation pressure on adults or nests, respectively, found no evidence for broad effects (Newson *et al.* 2010).

Evidence such as this then played a central role in designing the principal policy response to the general issue of conservation of the farmland environment, agri-environment schemes (AES). After initial trials and local schemes, AES were integrated into Pillar II of the EU Common Agricultural Policy (CAP) across Europe, modulating agricultural subsidies such that they paid for the income foregone by farmers in undertaking environmental management within, or on the fringes of, productive farmland. Several specific AES 'options' available to farmers (as described in the AES handbooks series) derive directly from evidence from BTO research, such as retained, unsprayed stubbles (Gillings *et al.* 2005) and wild bird seed mixture crops (Stoate *et al.* 2004). As investment in AES grew over time – for example, in England the Single Payment Scheme provides around £2 billion per annum to over 97% of farm businesses – there was increasing interest from government, industry and the public in their efficacy. In this context the BBS represented an invaluable resource as a national-scale survey with sufficient sample intensity across the farmed landscape for use in the evaluation of national-scale schemes. Initial evaluations after three years of the first ubiquitously available scheme in England, Environmental Stewardship (ES), showed little evidence of effects on bird populations, but highlighted a clear balance of management options chosen by farmers away from critical, in-field areas (Davey *et al.* 2010). This contributed to a shift in scheme emphasis to encourage farmers to undertake in-field management (ES Handbooks 2010).

Meanwhile, weaknesses in the design of specific options were identified by a BTO volunteer survey of fallow plots for Lapwings – plots were often situated in landscape contexts that would deter the target species (Chamberlain *et al.* 2009) – and analyses of landscape-scale feeding experiment data. The latter revealed that peak demand for food by birds falls after seed ceases to be available from the key options each winter, potentially nullifying option efficacy or causing an ecological trap (Siriwardena *et al.* 2008). PhD research showed that modifying field margin management such that half of buffer strips are mown occasionally provides a combination of high abundance and high availability of invertebrate food to birds (Douglas *et al.* 2009). All of this work fed directly into AES policy revisions (ES Handbooks 2013).

A second iteration of BBS analyses evaluating ES effects on birds made use of further years of data, improving on the previous analysis by exploiting the repeated counts available from individual BBS squares (Baker *et al.* 2012). This revealed the first evidence for positive, landscape-scale impacts of AES management, specifically winter seed provision in stubble management and wild bird seed mix, to reduce rates of population decline in seed-eating species. This underlined the previous results from demographic analyses and landscape-scale experiments pointing to the critical importance of food supplies over winter and supported the central role of winter food options in AESs. Although many farmland bird species are still declining, this suggests that the rate of decline may be less than it otherwise would have been (Figure 5).

The programme of work focused on birds and schemes in England, initially because the bulk of CBC and demographic data came from there, then because England provided most of the funding. After environmental policy diverged within the UK, we were less involved in the monitoring and evaluation of AES schemes in the other countries, but this has improved. Since 2013, the BTO has become an integral part of AES and wider farmland monitoring in Wales since 2013, which, through the *Glastir Monitoring and Evaluation Programme* (GMEP), has delivered a comprehensive programme of

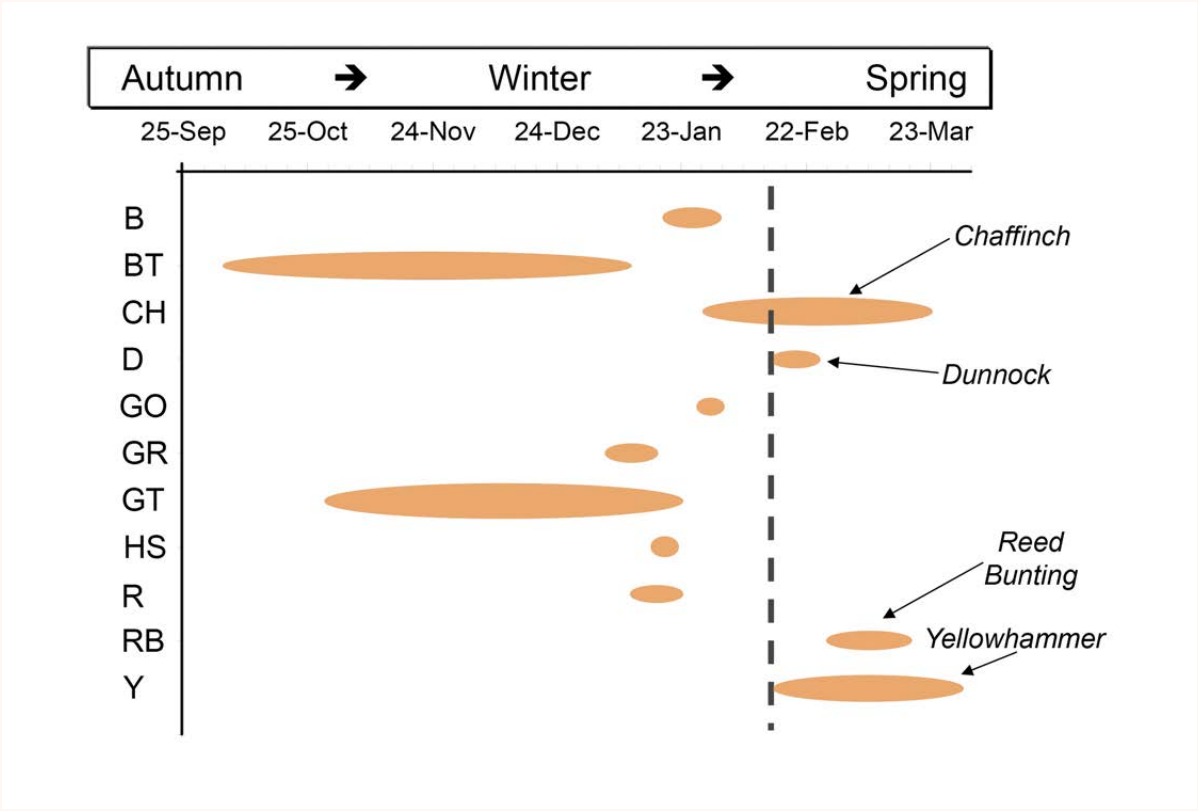
monitoring to establish a baseline against which future assessments can be made. Further, in collaboration with the Defra, the BTO will analyse historical bird data for Northern Ireland to provide an initial assessment of AES effectiveness.

Ongoing farmland bird research at the BTO is increasingly focussed on AES evaluation. This includes repeat analyses of BBS data quantifying the long-term development of population responses to AES management, including intriguing suggestions that negative effects could be developing over time. Further work has investigated responses of breeding waders to management of in-bye farmland (Siriwardena *et al.* 2018) and also provides direct policy impact. A recent review of the literature considered the responses of breeding wader populations to management across Europe is also relevant here (Franks *et al.* 2018), providing an important evidence-base to inform future decision-making.

THE HUNGRY GAP

Basic ecology, demographic analyses, habitat selection studies and large-scale experiments all suggested that granivorous farmland bird populations are likely to be limited by overwinter food availability, and that the long-term declines during agricultural intensification are likely to be due to reductions in that resource. The retention of unsprayed (i.e. weedy) crop stubbles over winter and the planting of sacrificial, seed-bearing crops formed the principal AES response to address this problem. In the course of Defra-funded, landscape-scale feeding experiments, it appeared that the use of supplementary food by target species like Yellowhammer *Emberiza citrinella* peaked in late winter. This was confirmed analytically, outside of specific contract requirements, showing that demand for food was highest in February and March, despite any effects of cold weather in mid-winter and falling overall abundance due to natural mortality.

Peaks of demand for birds using supplementary food, shown by the orange ovals. These peaks fall after the point where standard AES seed-providing options were allowed to be destroyed (dashed line) for four species.



Seed availability is bound to decline through the winter due to consumption by seed predators, germination and burying due to ploughing or natural processes, while birds will not switch to feeding on invertebrates until they begin to breed, as late as May or June for buntings. Late winter is therefore likely to be a natural bottleneck for survival, but AES stubbles are typically allowed to be ploughed after 14 February and seed crops after the end of January. The options therefore fail to fill the late winter 'hungry gap' and attraction to them could exacerbate it.

Communication of these results led to policy revision, notably new AES options for direct supplementary feeding in farmland, extended stubbles and two-year sacrificial crops with long-term retention of seed, after direct intervention from the then agriculture minister.

CONCLUSIONS

Overall, impact at a policy level has generally been integral to farmland research because, since the original identification of the problem, the work has been commissioned directly by policy-making bodies. Scientifically, the farmland biodiversity crisis continues to drive well-cited research effort. Two key BTO papers (Chamberlain *et al.* 2000; Siriwardena *et al.* 1998a) were included in the *Journal of Applied Ecology* 'Fifty years of scientific impact' Virtual Issue among the ten most influential papers for the decade 1991–2000, while a third was made 'Editor's Choice' in that journal on publication in 2012 (Baker *et al.* 2012). Although the long-term declines in most farmland bird species have not been reversed, despite relatively wide uptake of AES by farmers, is this a failure of science impact? Instead, it probably results from AES measures being applied over too small an area and the selective implementation of the least inconvenient rather than most effective measures (Newton 2017, Dsouza 2018).

Integration with parallel research programmes from around Europe has been strong, with UK and BTO work often a leading example (Farmers for Nature, BiodivERsA). Attempted integration with other regions globally, such as with issues of grassland bird conservation in North America or Indian agroecology, have been less successful, probably because geographical and socio-economic contexts are different, so common problems and solutions are rarely apparent. High-profile, well-attended conferences, such as a series operated by the British Ornithologists' Union (Aebischer *et al.* 2000; Vickery *et al*. 2004; Dadam *et al*. 2009) with representation from government ministers and the press, have helped to communicate research to the wider public, as has mass media coverage for BTO work via outlets such as national newspapers (*The Guardian*), radio (*Farming Today,* local radio) and television (*Countryfile*).

Looking to the future, farmland remains the dominant land-use in the UK and conservation of its biodiversity is likely to retain broad interest across society, which has helped stories around the sustainability of farming to remain newsworthy, particularly given potential areas of conflict with other sectors and land-users across the British countryside. Given the impending departure of the UK from the EU, with uncertain implications for farming and particularly AES, coupled with the ambition for an increased focus around funding to be for public goods, this high profile is likely to remain. As much of the funding for farmland specific monitoring and research is tied to CAP, what remains uncertain is the extent to which that resource, which has been essential for the monitoring, evaluation and development of AES, will continue after the UK leaves the EU. However, given adequate resource, the BTO's approach monitoring and research is likely to remain important to the ongoing monitoring and evaluation of AES and any switch to payment of public money for public goods.

URBAN LANDSCAPES

Although urban areas have traditionally been overlooked from a wildlife conservation perspective, the value of 'green infrastructure' for biodiversity is now widely acknowledged and there is an emerging realisation, globally, that urban landscapes can, and must, contribute to wildlife conservation. While many would, justifiably, argue that urban biodiversity warrants conservation for its intrinsic value, recent evidence of the importance of biodiversity for human health and well-being has been instrumental in pushing urban wildlife conservation into the public consciousness and up the policy agenda.

Parallel to this, there has been increased awareness of the threats that biodiversity within urban areas are facing. A BTO-led analysis of BBS data documented large-scale declines in urban bird populations, and demonstrated that across species, population trends in urban habitats were more negative, or less positive, than in other habitats (Sullivan *et al.* 2015). These trends have been driven by losses of rare species from urban areas, and large declines in the commonest urban birds, particularly House Sparrow *Passer domesticus* and Starling *Sturnus vulgaris* (Harrison *et al.* 2015). This has opened up opportunities for BTO scientists and survey organisers to address pressing questions about the relationships between birds and people across UK's entire urban gradient, from expanding cities to compact villages.

BTO is currently developing a growing portfolio of urban-focused research to inform landscape planning and management for the benefit of both wildlife and people, the potential to use BTO data and expertise provides a solid basis for achieving this ambitious goal. This work is focused on three interrelated lines of enquiry: understanding how wildlife responds to urban processes, interpreting the value of urban wildlife for human well-being, and using applied research to inform wildlife-friendly urban landscape planning. While this work has largely focused on birds, we have also considered issues relating to other taxa, including bats, moths and butterflies.

URBAN WILDLIFE: PATTERNS, PROCESSES AND CONSEQUENCES

An increased understanding of the processes influencing the spatial and temporal patterns of urban wildlife, its behaviour and demography is essential in order to optimise urban wildlife conservation targeting and approaches.

With the majority of the UK's human population living in urban areas, there is great potential for citizen science data collection close to where people live and work, exemplified by the regular participation of approximately 6,000 people in BTO's Garden BirdWatch survey. Gardens are a key component of overall urban green space and a critical resource for urban wildlife, which BTO research has been instrumental in demonstrating for British birds in particular (Gregory & Baillie 1998; Cannon 1999; Bland *et al.* 2004; Chamberlain *et al.* 2005).

The success of GBW in attracting thousands of participants to monitor the birds, and other wildlife, in their gardens on a weekly basis has provided an unparalleled resource for understanding how, and why, gardens support urban wildlife. Examining temporal patterns of garden use has revealed the periods of the annual cycle when different bird species rely on gardens to the greatest extent (Cannon *et al.* 2005; Mckenzie *et al.* 2007). However, it is frequently the local

habitat characteristics surrounding gardens and natural food availability, rather than the specific features of the gardens themselves, that are most likely to influence spatial patterns of garden use by particular bird species (Chamberlain *et al.* 2004, Mckenzie *et al.* 2007). Though this early work provided valuable insights, GBW data have largely been under-exploited as a science resource to date (though see Morrison *et al.* 2014 and Plummer *et al.* 2015 described below). With regular monitoring of numerous other taxa besides birds, GBW is unique in capturing, and aiding the understanding of, long-term trends of British wildlife populations within human-dominated habitats (Toms & Newson 2006), which are frequently poorly represented by other national monitoring schemes. Indeed, work is currently underway to determine the importance of gardens for British butterflies. With more than 20 years of data accrued, spanning the whole annual cycle, the scheme provides considerable scope to investigate patterns and processes of ecological, policy and conservation relevance.

Urban landscapes are characterised by a large amount of anthropogenic food resources, most notably the supplementary foods deliberately provided for birds in residential gardens. Therefore, a particular focus of BTO's urban research has been to investigate how wild bird populations are affected by garden bird feeding. This research has benefited greatly from both the GBW data set and the earlier established Garden Bird Feeding Survey (GBFS), which has specifically monitored the supply and use of garden bird feeders in a subset of approximately 200 gardens every winter since the 1970s. BTO was the first to establish the importance of bird feeders in influencing large-scale patterns of garden use by birds throughout Britain (Chamberlain *et al.* 2004), and in documenting widespread increases in the use of garden feeders over time (Chamberlain *et al.* 2005). This work has also suggested that food provided in gardens plays a significant part in the population dynamics of certain species (Chamberlain *et al.* 2007). Experimental research, conducted for a PhD studentship at the University of Exeter and supported by BTO, has shown that winter feeding can have measurable downstream consequences on the health and productivity of breeding Blue Tits *Cyanistes caeruleus* (Plummer *et al.* 2013a, 2013b, 2018). More recently, BTO scientists further discovered that extensive winter garden bird feeding practices across Britain have even helped to shape the evolutionary trajectory of migratory Blackcaps *Sylvia atricapilla* (Plummer *et al.* 2015).

Other collaborative research with the University of Exeter has recently revealed a clear 'pecking order' among different bird species at feeders, with larger species out-competing smaller birds for access to feeders and highly value food stuffs (Francis *et al.* 2018). While new BTO research is the first to explore the large-scale, long-term impacts of garden bird feeding on avian community ecology (Plummer *et al.* submitted), given the immense popularity of garden bird feeding (not only in Britain, but also across much of Europe, North America and beyond), this line of research has evoked high levels of interest among BTO members, the academic community, national and international media and the wider public. This research has informed garden bird feeding best practice and engaged new audiences with the work of the BTO. Perhaps most notable, however, are the outcomes from BTO's involvement in the Garden Wildlife Health scheme, which have been especially important in demonstrating and promoting the importance of good bird feeder hygiene (e.g. Lawson *et al.* 2014, 2018).

With urban expansion widely observed to have had negative implications for many species and with urbanisation now considered one of the leading threats to biodiversity globally, another important aspect of BTO's urban work has been to identify and better understand the issues facing particular vulnerable species. This has included highlighting the long-term declines in two archetypal urban birds, House Sparrow *Passer domesticus* and Starling *Sturnus vulgaris*, which rely heavily on the urban environment (Robinson *et al.* 2005a, 2005b, Freeman *et al.* 2007), with a Defra funding an 'evidence assessment' prior to a consultation on the species' continued inclusion under the General Licence for control purposes (Crick *et al.* 2002). This resulted in amendments to the licence and both species were placed on the UK Birds of Conservation Concern 'Red List' as birds of highest conservation concern. Subsequently, a substantial research programme on both species was initiated by the RSPB and others to understand the nature of these declines better. Defining the clear underlying drivers of these dramatic changes, though, has proven more challenging. A novel way of using GBW counts to estimate House Sparrow

URBAN BIRDS AND HUMAN WELL-BEING

In order to design and manage urban landscapes to be mutually beneficial to both birds and people, there is a need to better understand the value of birds in urban areas from a cultural ecosystem services perspective. Broadly, ecosystem services can be defined as human benefits derived from the natural environment. Cultural values (which encompass aesthetic, educational, recreational and other non-material benefits one might gain from experiencing the natural world) provide a pathway via which biodiversity can enhance human health and well-being, and these are of particular importance in urban environments since this is where the majority of our interactions with nature now take place. Work in collaboration with colleagues at the Universities of Exeter, Cranfield and Sheffield, funded by the NERC Biodiversity and Ecosystem Service Sustainability (BESS) framework, has investigated how the biodiversity of towns and cities contributes to human well-being and shown that people living in neighbourhoods with a high abundance of birds have lower self-reported rates of depression, anxiety and stress (Cox *et al.* 2017). However, further research has suggested that the chances of having positive interactions with birds are reduced in areas of high-density housing, due to the higher abundance of potentially 'nuisance' species (Cox *et al.* 2018). This, and related high impact papers from the University of Exeter, has prompted intense media coverage, and has substantial potential through time to significantly affect policies around urban development, health and well-being, although it has not been widely associated with BTO as yet.

productivity (a combination of breeding success and post-fledging survival, Morrison *et al.* 2014) showed that it mirrored regional population trend. Predation pressure from Sparrowhawks has also been implicated in the House Sparrow's reduction in the use of garden feeders during winter, although impacts on overall breeding populations are probably small (Chamberlain *et al.* 2009; Swallow *et al.* 2015).

The potential for citizen science in urban areas has been demonstrated to great effect in the recruitment of volunteers to conduct new survey work aimed at investigating the rapid declines of another urban-dwelling species, the House Martin *Delichon urbicum*. A randomised survey which involved these volunteers visiting 2,934 1-km squares nationwide was carried out in 2015, successfully producing a robust population estimate against which future changes can be compared. This also identified patterns of habitat use by the species, indicating that House Martins nest in 'looser' colonies in suburban areas compared to rural areas, with fewer nests per building but more buildings occupied. A further volunteer study of House Martin nests conducted in 2016 and 2017 found that nest success was higher in areas with greater amounts of urban land cover. The findings from this research are expected to be published shortly.

The BTO's expertise in public engagement across the urban environment have also proven of value in studying wildlife responses to street lighting, which has widely been associated with discernible impacts on animal behaviour, species interactions and fitness parameters. The 2014 Early Bird Survey recruited 3,460 volunteers across the UK to study the broad-scale effects of street lighting on avian foraging behaviour, suggesting that, contrary to previous assumptions, artificial light has little influence on the timing of garden bird foraging patterns in winter (Clewley *et al.* 2015). BTO has also engaged in research in collaboration with the University of Birmingham to investigate the effects of street lighting on moths, which may be particularly vulnerable to negative impacts associated with the increasing prevalence of artificial light at night. This work examined the consequences of changing street lighting regimes on the composition of moth communities in suburban Birmingham, revealing greater attraction of moths into gardens where street lamps were more spectrally diverse, in closer proximity and at higher densities (Plummer *et al.* 2016). These findings suggest that suburban areas could represent ecological traps for moths, unless they are able to provide sufficient resources to support moth communities. Further research experimentally testing behavioural responses to differential light types, and demonstrating the relationships between variation in artificial night lighting and moth diversity across broad spatial scales, is awaiting publication.

BTO-led research based on professional surveys in Luton, Bedford and Milton Keynes has looked at how bird ecology, habitat use, behaviour and aesthetic characteristics influence their likelihood of being encountered by people and, therefore, delivering a human well-being benefit. This has identified obvious differences in the activity patterns of birds and people; birds are most active early in the day, when people are less likely to be out and about. Consequently, people are only experiencing a subset of the total bird community present, which is further compounded by the density of human habitation and individual species' size and song characteristics (Plummer & Siriwardena in prep.). Moreover, bird abundances in the afternoon are associated with positive mental health, but those detectable in the morning are not (Cox *et al.* 2017). This means that much of the potentially positive effect of biodiversity upon human well-being is therefore not being fully realised. As such, society could benefit considerably from bringing people in urban areas closer to nature, or bringing nature closer to people. BTO-led outputs from this work are ongoing and will provide clear possibilities for further impact.

The growing disconnect of people from nature is not only potentially detrimental to human well-being, but is also perceived to be a significant barrier to successful biodiversity conservation (see Miller 2005). Bringing people closer to nature is therefore of key importance to BTO's work within the urban environment. The 2005 London Bird Project (LBP) and 2010 Birds in Glasgow (BiG) projects focused on characterising the bird communities and their key habitat requirements in urban parks and other green spaces in these major cities (Chamberlain *et al.* 2007; Humphreys *et al.* 2011). These projects were delivered in collaboration with local councils, who had an interest in collecting key biological data for the Local Biodiversity Action Plan process and in promoting the use of green spaces. A key impact from the BiG project was the delivery of training of new surveyors and of engagement of local people with green spaces that they may have previously overlooked. Repeat surveys in these cities could engage more people who are not regular surveyors, as well as delivering evidence as to management options that maximize positive changes in urban biodiversity; plans to do this have been developed but suitable funders have yet to be identified.

INFORMING URBAN DEVELOPMENT AND MANAGEMENT

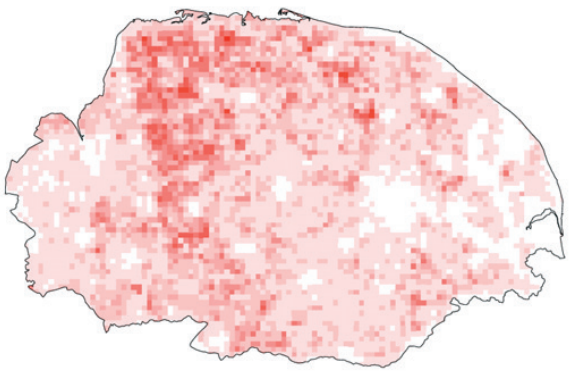
Globally, urban expansion and increasing housing densities are occurring at pace to keep up with demands of growing human populations; in the UK, the government has supported the creation of more than 20 new garden towns and villages. Though this could pose a considerable threat to biodiversity, it equally presents an opportunity to incorporate wildlife requirements into the planning process. BTO research has been targeting our understanding of avian (and other taxa) responses to urban landscape forms, with the aim of providing guidance, advice and tools that can inform future urban development in the UK.

The research conducted in London (LBP) and Glasgow (BiG) has made significant contributions to the formation of Local Biodiversity Action Plans, highlighting the value of features such as green space size, open water, rough grassland and wetland/marsh areas within urban parks to enhance species richness (Chamberlain *et al.* 2007; Humphreys *et al.* 2011). Work completed under the BESS project has illustrated the importance of woodland patches and corridors in facilitating bird movements through urban landscapes, with implications for urban green space design (Grafius *et al.* 2017). Further

work has demonstrated the value in using a spatially explicit approach to modelling biodiversity patterns (including plants, invertebrates and birds) across urban landscapes at spatial scales are of relevance to urban planners and managers (Grafius *et al.* in press). Of course, urban centres are linked, and BTO and our data often play a key part in the evidence used in the planning process, either indirectly, through supporting consultants conducting Environmental Impact Assessments, or, in the case of larger developments, by undertaking bespoke analysis, for example, in determining where habitat mitigation for Barn Owls *Tyto alba* might best be placed along the route of the new HS2 rail line (Pringle *et al.* 2018).

One of the best examples of BTO-led research leading to applied outcomes in the urban environment is the modelling the potential impacts of urbanisation on bat populations in Norfolk, using data collected between 2013 and 2015 by the Norfolk Bat Survey citizen science project (Newson *et al.* 2015). Working with Norfolk County Council, we were able to estimate the impacts of proposed housing developments on the activity and occurrence of 12 bat species, identifying spatial variation in the potential conflict between new urban development and bat conservation across the country, and demonstrating that it is possible to mitigate against negative impacts to some extent by the strategic placement of housing at different spatial scales (Border *et al.* 2017). As a consequence of this work, BTO is piloting work with Natural England, Norfolk County Council and Norfolk Wildlife Trust to assess whether the current approach to bat conservation, which requires expensive site-level surveys for each development, could shift to a more strategic and risk-based approach. County-level risk maps could be used to aid decision making in the planning and licensing systems that would identify the most important features of the landscape to avoid, complemented by opportunity maps to target habitat improvement through a wide range of mechanisms. This project has shown how coordinated surveys at a landscape-scale, for example through citizen science, might be the best approach to develop a robust evidence base to improve decision making, whilst also delivering multiple additional benefits.

The predicted distribution of Barbastelle *Barbastella barbastellus* in Norfolk, using data derived from the Norfolk Bat Survey. Darker colours indicate higher levels of predicted activity (Newson *et al.* 2015).



Data derived from *Bird Atlas 2007–11* and BBS are now being used to develop ecological modelling approaches capable of predicting bird community responses to urban landscape configuration (Gillings *et al.* 2019; Plummer *et al.* 2019). Outputs from this research could offer a viable means of improving the integration of biodiversity goals into future urban development across the UK. However, effecting change to planning policy, practice and decision-making processes is likely to be difficult, as urban development involves a large number of stakeholders negotiating under a complex planning system, while responsibility for matters such as landscape planning and park management are largely devolved. Effective communication with a wide range of diverse audiences is likely to be extremely challenging, but it will be critical for BTO urban research to have broad policy relevance in the future.

CONCLUSIONS

To effect population-level change for urban birds, impact has to be large in scale, and therefore requires active communication with important decision-makers in local government or industry, and/or changing the behaviour of a large proportion of the general public. The GBW constituency, while large, is still only a small fraction of garden-owners across Britain. Consequently, to promote change, the key messages evolving from BTO urban research need to be disseminated beyond current and future GBW members, though the pathways to do so are not clear. The planning process may offer opportunities from the other direction, where BTO's growing evidence of urban influences on wildlife abundance and distribution is of particular relevance. However, as highlighted, influencing planning decisions will likely be an ongoing challenge.

Through BTO's urban research, we hope to change the narrative around urban biodiversity, going beyond simply considering urbanisation as a threat and towards the optimisation of what could be supported by well-designed, wildlife-friendly urban landscapes, either from a conservation or an ecosystem services perspective. Within this, communication with planning authorities, the Town and Country Planning Association and/or building companies would be critical. To date, this is a work in progress, for example establishing connections with local authority biodiversity officers and sharing ideas at regional and national planning conferences. With the completion of ongoing modelling projects, we should soon have a clearer product available to present to the different stakeholder groups, both as a seed for further research funding and as a tool to develop engagement.

AFFORESTATION AND SILVICULTURE

Forest and woodland cover in the UK is low by historic standards, and in comparison to other European countries, thus each of the four UK nations has ambitious targets for forest expansion, including commercially managed plantations, the establishment of new native-type woodlands, through both planting and natural regeneration, and other policy and farm woodlands. Woodland supports a wide range of biodiversity, so, if implemented, such strategies would see major changes in the natural capital make-up of the UK, both

in terms of species gained, but also those lost from afforested areas, which may include many open-country specialists. The Scottish Forest Strategy has been the most successful in terms of extent of forest expansion and where current cover is estimated at 18% of the land surface (from a minimum of 5% around 1900) and with recently revised targets of 15,000 ha of new forest per year to reach 25% forest cover by 2050. This arguably represents the biggest single change in land use (and of landscape) currently underway and planned for the foreseeable future. Timescales for forest management and (re-)establishment encompass decades, even centuries, however, a range of BTO studies have tried to assess the impact of afforestation and of alternative silvicultural systems. A broad review on the opportunities and limitations for forest birds within plantations in Europe was published by Calladine *et al.* (2018).

WORKING NATIONALLY TO INFORM SILVICULTURAL GUIDANCE

Ongoing monitoring of new forests looking at natural forest regeneration on moorland in the Scottish Highlands started in 1998 (Fuller *et al.* 1999), and has been repeated at five-yearly intervals, with the latest in 2018. Complementary work has monitored changes in both naturally regenerating as well as newly planted woodlands since 2007. Research such as this has played a key role in developing forestry practices through the provision of Guidance Notes. For example, we have shown that the distribution of young growth stages within Sitka Spruce *Picea sitchensis* forests (the most extensively grown tree crop species in Britain) influences the birds that can be supported. Although continuous cover forestry (CCF) systems support more forest birds (e.g. Goshawk *Accipiter gentilis* and Redstart *Phoenicurus phoenicurus*), more typical clear-felling rotational (CFR) systems support more shrubland species (e.g. Cuckoo *Cuculus canorus* and Willow Warbler) within the extensive blocks of young new plantings or restocks. An optimal bird conservation strategy for conifer plantations in the British uplands could, therefore, be to include CFR, with associated young growth areas, alongside CCF, as this would provide conditions for both shrub and mature tree dependent species (Calladine *et al.* 2015). These findings have been made available to forest industry through a Forestry Commission (FC) Guidance Note (Calladine *et al.* 2016). Whinchat *Saxicola rubetra*, is a declining species of particular conservation concern, with documented impacts of forestry on breeding numbers (Calladine & Bray 2012; Murray *et al.* 2016); a further three manuscripts on habitat and micro-climate associations in developing upland woodland are in preparation at the time of writing. This research will be summarised in a BTO Guidance Note to inform land managers and policy makers about the opportunities for management interventions to benefit grassland, moorland and shrubland birds within long-term forest planning.

The Sitka Spruce silvicultural study was limited by the restricted extent of CCF managed stands; the oldest had been managed as such for three or four decades only. As current policy encourages conversion to CCF (usually from CFR) with the intention of indefinite management as such, a related study in managed and natural stands of Scots Pine *Pinus sylvestris* looked at the likely longer term impacts on breeding birds (Calladine *et al.* 2017). This supported the previous finding of the importance of young growth stage stands for birds of shrublands and more open habitats, but also found a much enhanced forest bird assemblage supported by the retention of even quite limited numbers of 'commercially over-mature' trees and of snags.

Bespoke studies in commercially managed plantations have also identified the importance of shrubs (or young growth stage trees) for birds within plantations. This has identified the positive effects of creating shrubby borders at plantation boundaries; these not only provide new niches for species to colonise but also appears to have benefits for some birds within the plantations close to those borders, presumably through the provision of additional resources available to them (Calladine *et al.* 2013). Due, in part, to this work, private and commercial forestry sectors now include shrubby margins at the interfaces of some plantations with open habitats to add to their biodiversity contributions.

WORKING LOCALLY TO INFORM MANAGEMENT IN THETFORD FOREST

Effective species conservation management requires accurate information on habitat dependency; the capacity of species to access new habitats will affect their adaptability to change. The BTO Breckland studies use bird species of local and national conservation interest to investigate bird-habitat interactions at local, national and international scales and scale of movement. Alongside ecological studies, we use remote tracking to fill behavioural knowledge gaps for wide-ranging, elusive, cryptic or nocturnal species. This autecological work is balanced by pan-species monitoring used to quantify the forest's support for bird communities (e.g. Henderson *et al.* 2018). Within the Breckland SPA, the Breckland Forest SSSI (including Thetford Forest) is managed for multi-functional benefits: sustainable timber production is planned around statutory obligations towards biodiversity, recreation and public engagement. The FC adopted a series of Thetford Forest Design Plans (FDPs) that set out the future aims for management, to maintain or enhance nature conservation and landscape benefits, create a sustainable mixture of forest and open habitats, and grow quality timber for future generations. Forest management must adapt to change by embedding resilience into its production schedule with potential impacts on biodiversity. BTO engages with the FC (and FC Scotland) to provide information to help management decisions accommodate these complex demands through assemblage monitoring (funded by the FC *Resilience Programme*). This provides a benchmark of forest support for the wider bird community (Sharps *et al.* 2015), in advance of future changes to forest practice and is supplemented by remote tracking of individual, to quantify previously unknown scales of movement and habitat interaction. Research to date has focused on Nightjar *Caprimulgus europaeus*, a species of high conservation concern and one of three species for which the Breckland SPA is designated.

BTO has been involved in Nightjar studies at all levels, from national and regional surveys of population status in 2004 (Conway *et al.* 2007), to ecological and tracking studies.

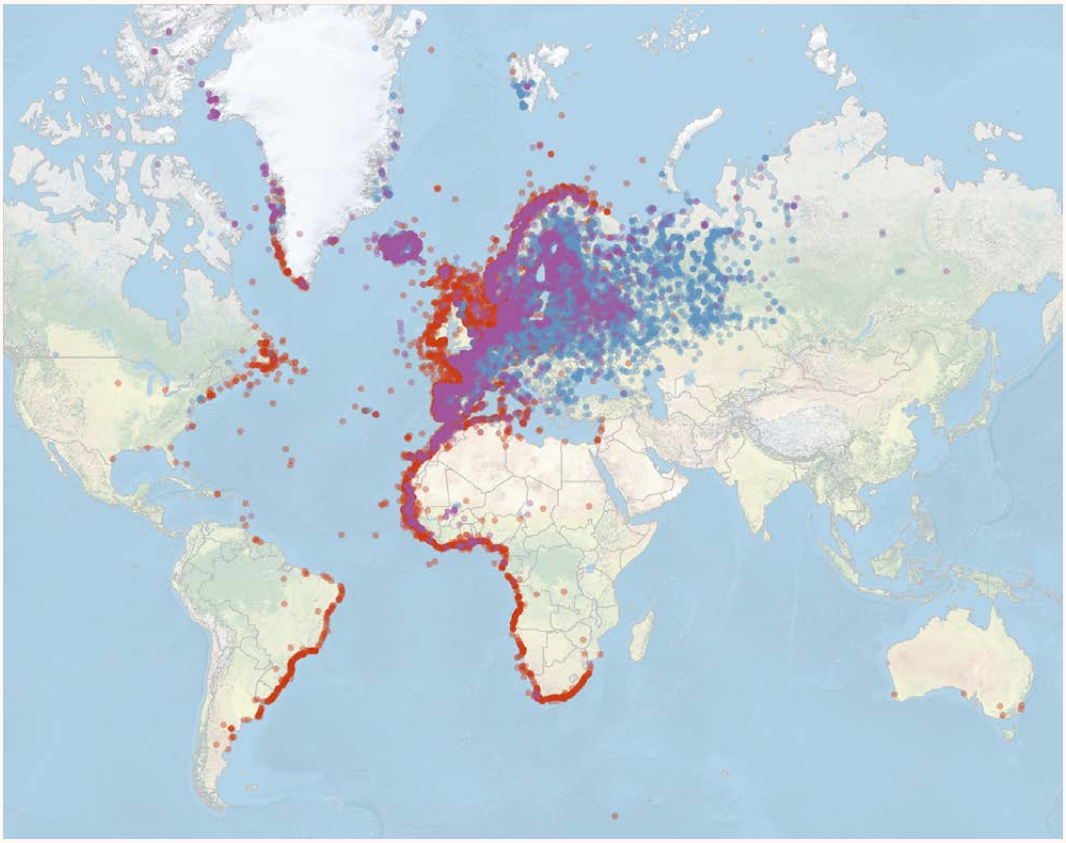
The Breckland Nightjar population has declined by 43% since 1998, and since 2007 collaborative nest camera, radio tracking and GPS tracking studies, initially led by UEA though all with BTO input, have investigated the reasons why. In response, the FC has created more nesting habitat, but there is unoccupied nesting habitat in Thetford Forest suggesting that nesting abundance must be determined other processes, such as the availability of food or foraging habitat. Since 2014, BTO with NE staff, embarked on a ground-breaking study using novel GPS tags, to provide highly detailed information on foraging movements and habitat use (Evens *et al.* 2017). Further, in 2016, moth abundance and species composition was examined at Thetford Forest nest and foraging sites identified by the GPS tracking work (Henderson *et al.* 2018). This information has demonstrated the importance of having specific foraging habitats in close proximity to nest sites and has provided biological meaning to the concepts of landscape and connectivity for this species, within the plantation forests and heathlands mosaic. Other BTO tracking studies include Goshawk, Tree Pipit *Anthus trivialis* and Willow Warbler which run parallel to detailed ecological studies of the latter two declining migrants.

The Thetford Forest project is very much a collaborative one, providing opportunities for MSc students to learn fieldwork skills by investigating habitat use and/or demographic aspects in populations of seven species to date. It also provides opportunities for volunteer engagement; no other BTO research programmes, outside of national monitoring, attain the same constant level of volunteer/amateur engagement. Our work on Nightjars attracts skilled and non-skilled enthusiasts who, in return, help underpin parts of the research programme by assisting with nest finding, ringing and survey work. The Nightjar programme alone has attracted at least 50 volunteers per summer, for the last 10 years, involving at least 250 different volunteers. The research programme is frequently used as a demonstration event, hosting groups including FC district managers and ecologists, academics from the Cambridge Conservation Initiative, national journalists and even BTO Board members. Additionally the work provides material for public engagement, by contributing information to forest discovery trails and engagement programmes (e.g. 'Wings-Over-The-Brecks' and 'Breaking New Ground').

CONCLUSIONS

Through continued working with the FC and FCS who have control over the management of large areas of forested landscape, BTO science will continue to influence the management and design of forested landscapes, across a range of scales. Through the ongoing intensive citizen science monitoring and autoecological work in Thetford Forest, close to the BTO national headquarters, BTO will continue to inform management decisions across the SPA. More broadly, particularly in Scotland, BTO data has the potential to inform future planting decisions through risk and opportunity mapping, whilst more bespoke work will continue to develop the evidence base around silviculture practices.

Figure 6. Recovery locations of ringed seabirds (red), waterfowl (blue) and shorebirds (purple) encountered in Britain and Ireland.



CHANGING SEAS

The UK supports internationally important populations of both breeding seabirds and non-breeding waterbirds (Mitchell *et al.* 2004; Musgrove *et al.* 2011, 2013), most of which are strongly migratory. The non-breeding ranges of our breeding seabirds stretch throughout the Atlantic from Arctic to Antarctic waters (Figure 6). The UK also provides key passage and wintering sites for waterbirds on the East Atlantic Flyway, many of which breed in the Arctic and sub-Arctic regions, and some of which fly on to winter in western, and even southern, Africa. The UK has obligations to conserve these populations, notably through the *Convention on the Conservation of European Wildlife and Natural Habitats* (EC/79/104), *Ramsar Convention on Wetlands of International Importance*, the *Agreement on the Conservation of African-Eurasian Migratory Waterbirds* (AEWA) as part of the *Convention on Conservation of Migratory Species Migratory Species*, the Oslo-Paris *Convention for the Protection of the Marine Environment of the North-East Atlantic* (OSPAR Convention) and the *Marine Strategy Framework Directive* (MSFD).

BREEDING SEABIRDS: MONITORING CHALLENGES AND INTERNATIONAL RESPONSIBILITY

Among the UK's breeding bird populations, those of seabirds are perhaps the most globally significant: 85% of the world's Manx Shearwaters *Puffinus puffinus*, 68% of Northern Gannets M*orus bassanus* and 60% of Great Skuas *Stercorarius skua* breed in Britain or Ireland (Mitchell *et al.* 2004). A recent review, undertaken by BTO with input from European partners, has highlighted the value of citizen science in monitoring marine bird populations across the countries covered by the OSPAR, ICES and HELCOM conventions and how these citizen projects fed into reporting requirements (ICES 2017). Nevertheless, monitoring seabirds raises a number of challenges, both due to the size of colonies and the logistical and financial constraints associated with the remoteness of many sites from human centres of population.

While the status and trend of seabirds breeding in terrestrial habitats – the gulls, inland-breeding terns and Cormorant *Phalacrocorax carbo* – is less-well understood than many other groups, the ecology and distribution of seabird species away from the breeding grounds is even more poorly understood. Such information is particularly important because sebairds are facing increasing pressures, from climate change and increasing exploitation of the marine environment, and are among the world's most threatened groups of birds (BirdLife International 2018). It is vital that there is a firm monitoring and research evidence base to inform the evaluation of these pressures, whether at a local level, for instance in response to offshore energy infrastructure developments (as required under UK legislation and the current EC Directive on Environmental Impact Assessment, 1997/11/EC) or at wider strategic levels, for example, with respect to the potential future changes to fisheries policy associated with EU departure.

Within the UK, volunteers make an important contribution to seabird monitoring, with the outputs from the national monitoring schemes complementing those provided by more focussed, often professional, studies at key sites. BTO plays a leading role in seabird monitoring by being both a partner in the Seabird Monitoring Programme (SMP) and as a member of the steering group of the current 2015–2019 seabird census for Great Britain and Ireland, *Seabirds Count*. Through funding from the Northern Ireland Environment Agency (NIEA), BTO provides regional coordination of seabird monitoring in Northern Ireland (Booth Jones & Wolsey 2017). BTO is also providing direct support to the SMP through development of a new online database for the scheme and contributing to a current strategic review of the programme's role and operation. To better inform the programme's development, BTO has carried out reviews of the representiveness of SMP data (Cook & Robinson 2010), and the value of and requirements for demographic monitoring of seabirds (Robinson & Baillie 2012; Horswill et al. 2017, 2018). In particular, these analyses have identified the importance demographic information, for example to inform assessment of wind farm impacts on seabirds (see below).

The annual SMP scheme is complemented by periodic censuses which provide national population estimates (these support reporting under Article 12 of the *Birds Directive*). Such censuses also deliver the site-level population estimates underpinning protected site *Common Standards Monitoring* and inform case-work, for example, the Scottish Executive on conflicts around urban gulls (Calladine *et al.* 2006). These more or less comprehensive periodic snapshots of seabird populations, that additionally provide verification and qualification for annual SMP trend data, are the primary means of monitoring species for which annual surveys are not feasible. The current initiative is the fourth such national census and, as for past censuses, BTO has made its network of regional representatives available to JNCC to help coordinate local coverage. On behalf of NE, BTO assessed potential methodologies for surveying urban breeding gulls and designs for producing national population estimates (Ross *et al.* 2016; Thaxter *et al.* 2017). Building on this work, and funded by Defra, BTO is currently undertaking pilot work to assess the value of ground-based volunteer surveys for determining population size, quantifying the expected underestimation using aerial and vantage-point surveys.

To meet the requirements of the MSFD, which aims to protect the marine environment across Europe, data from the annual SMP scheme are used to assess environmental status at (administrative) regional and sub-regional levels. Cook *et al.* (2011) assessed the effectiveness of European-level reporting by identifying species-specific 'ecologically coherent regions' within the data set. Trends in abundance and breeding success for these ecologically-based regions more closely matched those observed between the periodic national censuses, and were more consistent between colonies within the region, than the regions identified for more policy-driven monitoring. By accounting for ecology in the design of monitoring regions, population variation in mobile species can be more accurately represented, leading to the design of more useful monitoring regions.

Development and comparison of indicators of seabird abundance, breeding failure and breeding success (of Black-legged Kittiwake *Rissa tridactyla*) for the MSFD has

highlighted the importance of demographic monitoring in understanding the mechanisms of species' responses to environmental change, such as fisheries pressure, and in providing policy-makers with an early-warning system (Cook *et al.* 2014). The large numbers of birds that can be readily caught and marked at colonies mean that seabirds are particularly suited to lower intensity mark-recapture studies, such as those undertaken by volunteers, an approach that is now being adopted to monitor environmental change in other areas, such as the Wadden Sea (Koffijberg *et al.* 2016). Assessment of RAS data has highlighted the value of volunteers in enabling more representative monitoring of seabird survival rates and provided recommendations that aimed to maximise the value of smaller studies and thereby improve spatial representation (Horswill *et al.* 2018).

NON-BREEDING WATERBIRDS: MONITORING IN AN INTERNATIONAL FLYWAY

Data from the Wetland Bird Survey (WeBS) are used to assess the size of non-breeding waterbird populations, which the UK supports in internationally important numbers (Musgrove *et al.* 2011). This allows the determination of trends in their numbers and distribution (Frost *et al.* 2018), and provides an ability to assess the importance of protected sites for waterbirds in line with the requirements of international conservation conventions and directives (Cook *et al.* 2013). Assessment of WeBS data has also shown that fluctuations in waterbird population size are more likely to result in changes in local abundance than distribution. This may have consequences for site protection given the use of thresholds of relative abundance in site designation (Méndez *et al.* 2018). WeBS data also contribute to the International Waterbird Census, enabling the status of waterbirds to be assessed at an international scale across the African-Eurasian Flyway area. This international initiative delivers vital data to support the *Agreement on the Conservation of African-Eurasian Migratory Waterbirds* (AEWA) and shape global conservation policy (Amano *et al.* 2018).

Arctic-breeding waterbirds, especially waders (Charadriidae and Scolopacidae), are amongst the most vulnerable to climate change (Robinson *et al.* 2009) and future changes are likely to have significant impacts on their numbers and breeding and non-breeding distributions (e.g. Austin & Rehfisch 2005; Lehikoinen *et al.* 2013; Pavón-Jordán *et al.* 2015). There is little direct monitoring of birds in the Arctic due to logistic and other challenges. However, there is significant potential to monitor not only abundance, but also productivity and survival on temperate non-breeding grounds through volunteer-based schemes (Robinson *et al.* 2005). A BTO review of the information available has informed both national (*UK Marine Climate Change Impacts Partnership* report cards, Pearce-Higgins & Holt 2013) and international (*Convention on Migratory Species*, UNEP/CMS/Conf. 8.22) policy-making. Subsequently, BTO developed a set of 17 representative indicators whose attributes could quantify impacts of climate change on the global status of migratory species (Newson *et al.* 2009), and reviewed the effects of climate change on migratory waterbirds within the Africa-Eurasian flyway for the AEWA secretariat, one of the first attempts at assessing the future vulnerability of species to climate change (see below). Both documents were recognised as important in a 2017 CMS workshop on migratory species and climate change. The BTO review remains the keystone document of climate change for migratory species used by CMS, while the AEWA Secretariat reported that '*the BTO study of populations of AEWA-listed species had identified the most vulnerable sub-regions, and had therefore enabled actions to be prioritised*.'

THE CHALLENGE OF MARINE RENEWABLE DEVELOPMENTS

The development of renewable energy infrastructure provides a key component of governments' policies to mitigate the impacts of climate changes; however, there is much concern regarding the potential environmental and biodiversity impacts associated with the development of these technologies. BTO has been providing advice about the potential ornithological impacts of renewable energy schemes since the 1980s, initially with a focus on tidal energy, e.g. overseeing the waterbirds and biodiversity topic papers for the Severn Tidal Power Strategic Environmental Assessment (Burton *et al.* 2010a) and, latterly, wind farms, especially in offshore environments (BTO 2017), including the world's two largest operational marine wind farms (the London Array in the Thames Estuary and Walney off north-west England). This has involved working closely with government departments (notably DECC, now BEIS), the SNCBs, industry (e.g. Ørsted, Forewind, Tidal Lagoon Power) and other stakeholders, especially in the conservation and consultancy arenas, in order to build a robust evidence base and consensus on appropriate and robust methodologies for the impact assessment process.

In particular, BTO provided the secretariat for the Strategic Ornithological Support Services (SOSS) group, which brought together expert stakeholders to identify key ornithological issues relating to the expansion of the UK offshore wind industry. Five projects were commissioned through the group, considering the evidence for displacement from wind turbines, estimating collision risk, considering impacts on population viability, developing methods to monitor collisions and assessing the cumulative risk of offshore wind farm development to migratory bird species. Three of these projects were undertaken by BTO. By developing the evidence base and better methods for assessment through the SOSS and the preceding COWRIE (Collaborative Offshore Wind Research into the Environment) work programmes, BTO has had a significant impact in reducing uncertainty in the impact assessment process and provided an understanding of the potential impacts of offshore wind farms.

Offshore wind farms may potentially affect birds in a number of ways, most notably by posing a barrier to regular movements to and from breeding colonies or migration, displacement (equating to a loss of foraging habitat), and through collisions with turbines. BTO has undertaken an extensive research program to better understand the risks posed by offshore wind farms and improve the impact assessment process. Evaluations of the statistical power of detecting changes in the abundance of seabirds at sea (Maclean *et al.* 2013) and of post-consent monitoring for birds, undertaken on behalf of the Marine Management

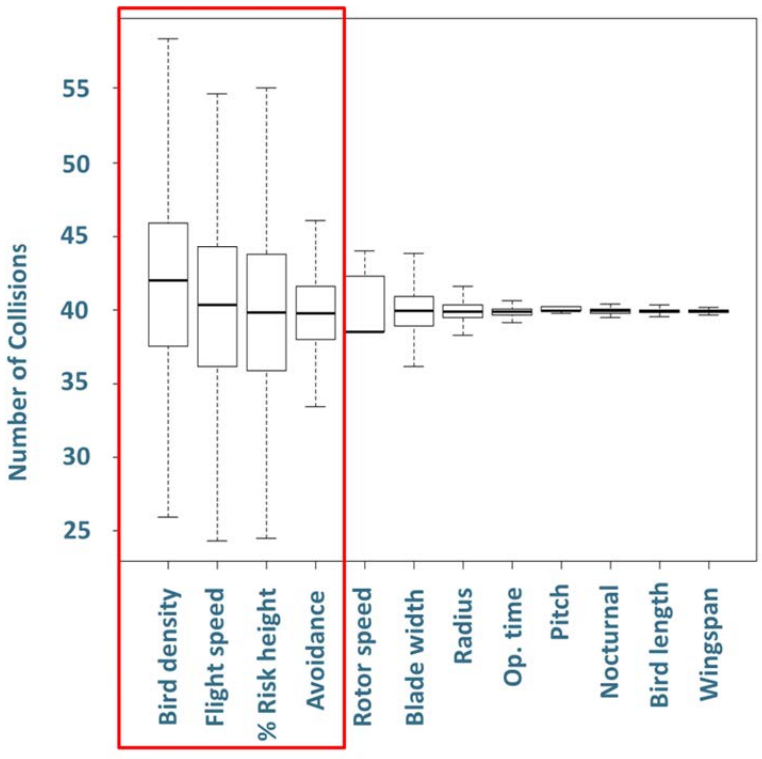
Organisation (MMO 2014), have both highlighted the need for improved survey protocols to be able to assess displacement effects. In the absence of more detailed information about collision rates, Collision Risk Models (CRMs) are routinely used to predict the risk posed by offshore wind farms to seabird populations as part of pre-construction Environmental Impact Assessments (Masden & Cook 2016). However, outputs from CRMs are known to be sensitive to assumptions made about the avoidance behaviour of the species concerned, flight height and flight speed, which are often based on extremely limited data (Chamberlain *et al.* 2006) and which has been a key area of debate between industry, developers and other stakeholders. BTO recently reviewed the quality of current evidence available to quantify avoidance behaviour for five key species considered particularly sensitive to collision risk, providing overall avoidance rates suitable for use in CRMs and highlighting data needs (Cook *et al.* 2018), thereby informing SNCB recommendations on the avoidance rates in predicting impact to the offshore wind farm industry.

A key challenge facing the industry as a whole, is the harmonisation of data collection and reporting. Data from individual developments are often collected in different ways, hampering our ability to undertake synthetic analyses across them. One area in which this is particularly true is in estimating the height at which birds fly (and hence their likelihood of intersecting a wind turbine), which presents both methodological and logistical difficulties at sea. We developed a novel method to combine different types of data to generate species-specific flight height distributions, and hence the proportion of in-flight populations at risk of collision (Johnston *et al.* 2014). These modelled data, collected from boat-based surveys at multiple developments, have enabled more realistic estimates of seabird flight heights across 25 seabird species and, importantly, led to change in the design of turbines proposed by Forewind for their Dogger Bank offshore wind farm projects, in order to reduce rates of collision.

A subsequent BTO-led review of global data on bird and bat collisions with wind turbines provided further evidence that turbine size can have a significant impact on the rates of collision per unit energy generation, as well as identifying the species most likely to be vulnerable to collision (Thaxter *et al.* 2017). This work was presented to the Second Meeting of the CMS Energy Task Force, providing important information to government and industry, and including data tables that can be used to assess the vulnerability of bird and bat species to wind farm collision around the world, particularly where formal studies have yet to be undertaken.

The need to understand the extent of seabird movements and key foraging areas, both to inform identification of

Figure 7. Areas of uncertainty that have a large impact on estimated collision risk (red box) have been addressed by BTO research (from Masden & Cook 2016). BTO has developed modelling approaches to estimate abundance across proposed wind farms from multiple data sources, accounting for uncertain bird identification (Johnston *et al.* 2015), improved estimates of flight height (Johnston *et al.* 2014, Ross-Smith *et al.* 2016, Thaxter *et al.* 2018) and avoidance rates (Thaxter *et al.* 2018, Cook *et al.* 2018) for multiple species, and is currently working on improving estimates of flight speed.



Marine Protected Areas (MPAs) (Thaxter *et al.* 2012) and understand the interactions between bird populations in protected sites and offshore developments has benefited enormously in recent years from the development of remote-tracking technologies, with BTO at the forefront of applications in this area. For example, tracking of over 240 individual Lesser Black-backed *Larus fuscus* and Herring *Larus argentatus* Gulls from protected sites has quantified the extent of interaction with proposed and operational offshore wind farm developments, and other renewables, across a range of spatial and temporal scales (Thaxter *et al.* 2015; Wade *et al.* 2014).

At a fine scale, tracking has provided additional information on spatial variation in flight heights and space use within offshore wind farms, informing key metrics required in CRMs (Ross-Smith *et al.* 2016; Thaxter *et al.* 2018). At broader scales, data have highlighted the variation in seabird-wind farm interactions within and between-breeding seasons (Thaxter *et al.* 2015) and the relative vulnerability of populations across their annual life cycles and migrations. By detecting novel migratory pathways for these species, this work has highlighted previously unknown potential interactions for populations breeding at SPAs in the UK with wind farms in Iberia. In combination, BTO research has significantly improved the evidence base to inform impact assessment for offshore wind farms, significantly reducing uncertainty over estimated impacts (Figure 7).

Whilst it is important to understand effects associated with particular renewable developments, ultimately we need to understand the consequences of any resulting impacts at a population level. BTO has been working closely with governmental advisors in order to develop robust approaches for population modelling in the impact assessment process, leading to changes to the way in which the population level consequences of wind farms are assessed in the UK (Cook & Robinson 2017; O'Brien *et al.* 2017), both at the level of the individual wind farm but also, increasingly, cumulatively for multiple wind farms. This is a challenging issue, but BTO has led the development of clear guidance for the wind farm industry on how best to deal with cumulative impact assessment (Humphreys *et al.* 2016). A key outcome from recent BTO work has been highlighting the importance of how density dependence is considered in population models (Horswill *et al.* 2017). For some species, there is evidence that as population size declines, population growth rates also decrease; if wind farms have a significant effect at a population level, this may cause some populations to decline faster than previously expected.

DEVELOPMENT AND DISTURBANCE ISSUES FOR NON-BREEDING WATERBIRDS

Much of the BTO's advice on non-breeding waterbirds to the SNCBs focuses on the features for which protected sites are designated. Coastal landscapes are some of the most vulnerable to human development, facing pressures from both the landward and seaward sides, and BTO data are often used to inform the debate surrounding the environmental impact of such development, for example when an airport in the Thames estuary was proposed (Wright *et al.* 2014). A review and an expert workshop on the pressures associated with housing development on estuarine waterbirds has helped develop methods for assessing the impacts of disturbance to waterbirds on SPAs and provided advice on mitigation methods. These have fed into NE's *Recreational Avoidance and Mitigation Strategy*. Related work has informed the Solent Recreation Mitigation and Essex Coastal Recreational Avoidance and Mitigation Strategies. Waterbirds may also suffer from increased marine activity associated with exploitation of coastal wind, wave and tidal resources, and other activities such as aquaculture. These pressures are particularly acute in Scotland, where work undertaken by BTO is being used by SNH to inform consenting/licensing of marine activities in SPAs in the Northern and Western Isles (Jarrett *et al.* 2018). This study filled knowledge gaps on sensitivity to disturbance for species about which little was previously known, such as Great Northern Diver *Gavia immer*, Black-throated Diver *Gavia arctica* and Slavonian Grebe *Podiceps auritus*. More generally, WeBS data are used to assess the status of features of SPAs and SSSIs through the online WeBS 'Alerts' report (e.g. Cook *et al.* 2013) and analyses of WeBS 'within-site' data have also helped inform management of protected sites by the SNCBs (Austin & Ross-Smith 2014). Through WeBS, BTO is developing work to map waterbird roost sites to support ongoing SNCB work on coastal access.

During winter, the UK hosts a large population of gulls, with up 2.5 million individuals present. Numbers have been quantified by the Winter Gull-roost Survey (WinGS) to identify new thresholds of international importance for these species, and highlighting sites that reach thresholds of significance (Burton *et al.* 2013). These results have been used, for example, to inform SNH's and NE's advice on the proposed extension to the existing Upper Solway Flats and Marshes Special Protection Area (SPA), in the marine waters of the "Solway Firth", and the wider recommendations provided in the third SPA Review (Stroud *et al.* 2016), for which BTO also provided significant expert input. WinGS and WeBS data have also been widely used to inform Defra in how to respond to recent avian influenza (AI) outbreaks, with gulls a potential vector in some instances, and potentially transmitting it to poultry. Given the importance of these data for conservation, management and even economic reasons, there is an urgent need to repeat the wintering gull survey to update these estimates, as populations are likely to have changed markedly in the 15 years since the survey was last undertaken.

MANAGING WATERBIRD-HUMAN CONFLICTS

Both gulls and Cormorants present particular management dilemmas, with the SNCBs issuing licenses for lethal control at certain locations, while also needing to ensure that important site populations are protected. Monitoring and research on populations at site and national levels vital is thus vital in informing balanced conservation and management decisions (Ross-Smith *et al.* 2014) and a current CASE PhD studentship (supported by NE) is assessing some of these conflicts with respect to Lesser Black-backed Gulls. BTO continues to provide advice on the impacts of fish-eating birds, to SNH on their importance to salmonids and game fisheries in Scotland (Humphreys *et al.* 2016), to NRW by participating in their

Fish-eating Birds Advisory Group, and to Defra's 2013 *Fish-Eating Birds Review*, through improved population estimates of breeding and wintering Cormorants (Chamberlain *et al.* 2013a; Newson *et al.* 2013) and detailed analyses of WeBS data (Chamberlain *et al.* 2013b). These analyses provided no evidence that control of Cormorants had a significant impact on local populations in subsequent years, and suggested that greater priority needed to be given to determining whether control has the desired impact on predation rates of fish, and the extent to which the cost of control measures compares against other (non-lethal) measures to reduce Cormorant predation.

In the 1940s wild geese were rare in Scotland, but following the protection afforded by the Wildlife and Countryside 1981, numbers began to rise, as did farming concerns, with an increasing number of complaints were received by the Scottish Government about agricultural damage and loss of yield due to goose grazing. BTO contributed to the 2010 Review of Goose Management Policy in Scotland by presenting possible future options for goose management and mechanisms for policy delivery, including consideration of the costs and benefits of treating them as quarry species. This led to revisions of the management policy, for example permitting the sale of carcasses, and a greater awareness of the potential role that adaptive management processes could play, which were piloted as "sustainable management strategies". This work identified the importance of the social and economic concerns of some parties in the development of goose management approaches. Such concerns need to be considered alongside scientific advice based on population numbers and trends; future management policies are likely to be a difficult compromise between sometimes opposing positions and views.

CONCLUSIONS

BTOs work on seabirds has been one of the key growth areas over the period, significantly increasing our knowledge of the vulnerability of species to marine renewables. Given ongoing needs for climate change mitigation, which offshore wind seems well-placed to deliver, this work will continue to have important impact, informing decision-making and reducing the risk of conflict between renewable energy generation and bird conservation. Through collaboration, this work is now being used to provide advice and information internationally, and there are likely to be significant opportunities to extend these approaches to other parts of the world where marine renewables, particularly offshore wind, is expanding. Ongoing challenges with the monitoring of seabirds and wintering waterbirds should be addressed as a matter of urgency to provide essential data to track the continued impact of ongoing environmental change and potentially significant policy-changes associated with EU departure, that will impact on future fisheries policy.

CLIMATE CHANGE

Climate change is regarded as one of the greatest current challenges for conservation, as well as for human society. So far, global climate has warmed by about 1°C since pre-industrial levels, with changes in the frequency and intensity of extreme events, precipitation patterns and rising sea-levels (IPCC 2013). This has had detectable impacts on a range of biological processes, from genetic to ecosystem, with significant impacts on ecosystem function and human well-being (Scheffers *et al.* 2016; Pecl *et al.* 2017). Indeed, climate change is likely to also have far-reaching consequences for human society, affecting all sectors, from transport and industry to agriculture and health, and projected future impacts of climate change are likely to be much more severe than those already experienced. Understanding the likely scale of those future impacts on biological systems is important to inform decision making, and to guide conservation planning, along with evidence about the likely effectiveness of different responses to climate change (adaptation).

The scale of this challenge is global and all pervasive, affecting all natural systems. Given its history of long-term biological monitoring, data from the UK have played a key part in building evidence for the ecological impacts of climate change. BTO has been in the forefront of the collection of these monitoring data, and in the underpinning research to demonstrate the impacts of climate change on UK biodiversity. The first evidence that the phenology of animal populations was being affected by climate change came from BTO analysis of nearly 75,000 BTO nest records of 65 bird species provided by a network of 1,000 volunteers from 1971 to 1995. This analysis demonstrated an overall preponderance towards earlier laying (Crick *et al.* 1997), trends that were subsequently linked to changes in temperature (Crick & Sparks 1999). Similarly, the first clear demonstration that animal distributions were shifting northwards in response to climate change came from analysis of changes in the range margins of 101 breeding species in Great Britain, compiled from the first and second national breeding atlases (Thomas & Lennon 1999). These three seminal papers, based upon the unique long-term and large-scale citizen science of the BTO, have been cited over 2,000 times, and played a major part in the gathering evidence during the late 1990s that climate change was affecting the world's natural systems.

CLIMATE CHANGE EVIDENCE NEEDS

The *Climate Change Act* of 2008 contained a commitment to a six-yearly appraisal of the risk that climate change poses to the UK (the Climate Change Risk Assessment; CCRA), the first iteration of which was published in 2012 (Defra 2012). This highlighted that sensitive species are likely to come under increasing pressure from climate change, but the ability of the CCRA to provide a comprehensive assessment of biodiversity risks and impacts was limited by the availability of suitable data and completed studies which clearly identified impacts of climate change on biodiversity. The need for detailed analyses to identify and attribute climate change impacts was recognised in the English Biodiversity Strategy and UK Biodiversity Partnership, and specified in *Biodiversity 2020: a strategy for England's wildlife and ecosystem services.* These same needs are highlighted by the SNH Strategy and Priorities 2012 to 2015, and the Wales Environment Strategy adopted in 2006.

By 2010, climate change was an organisational priority for BTO, with the work split into three components: 1) to document the impacts of climate change, 2) to undertake projections of future impacts of climate change and 3) to inform adaptation. Through a combination of significant, multi-year Defra funding for projects such as BICCO-Net, from NE, NERC, the JNCC Partnership, and supported by BTO itself, a significant programme of work, some led by the BTO and some by others, has documented climate change impacts on UK birds and other biodiversity, a key knowledge gap required to address an important policy need. This work has successfully filled many of these key knowledge gaps over the subsequent years, providing important evidence for policy-makers and as summarised by a number of key external documents.

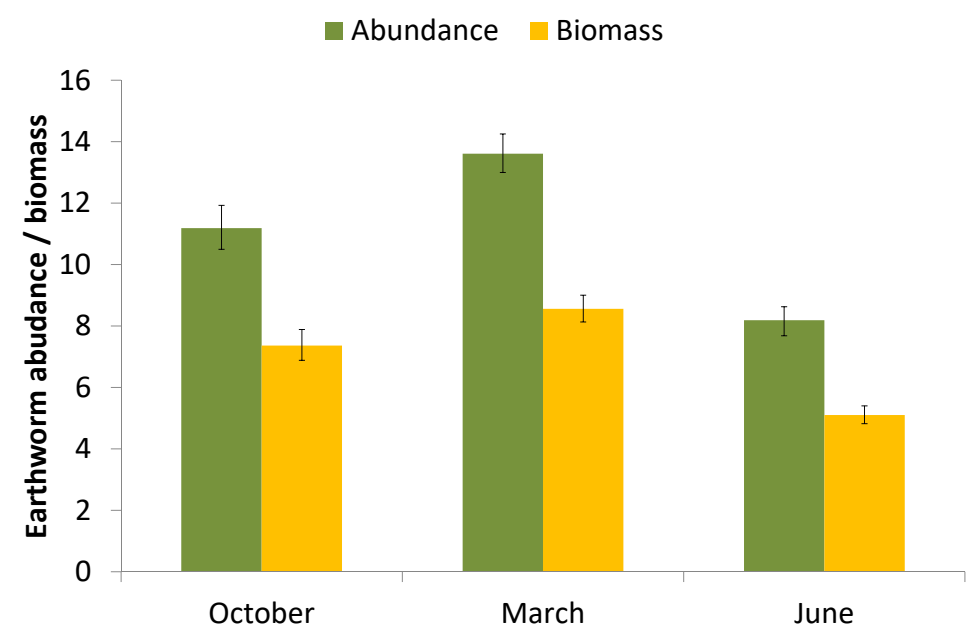
OBSERVED IMPACTS OF CLIMATE CHANGE

More specifically, BTO research has provided evidence that populations of many resident bird species are likely to have increased in response to warmer temperatures, whilst populations of long-distance migrants do not show this same benefit, and may be more susceptible to negative effects of hot, dry summer weather (Pearce-Higgins *et al.* 2015). The combined effect of these responses has been to change the composition of bird assemblages in the UK (Davey *et al.* 2012), and across Europe, as shown by high profile continent-wide research led by external collaborators to which BBS data have contributed (Devictor *et al.* 2012; Le Viol *et al.* 2013; Stephens *et al.* 2016). The net result of these individual populations changes is to alter the distribution of species. Analysis undertaken by the BTO in *Bird Atlas 2007–11* (Balmer *et al.* 2013; Gillings *et al.* 2015) confirmed the continuation of the previously described poleward range shifts, but demonstrated that the actual patterns of change are multidirectional. Complementary BTO analyses of BBS data found that from 1994 to 2009, the rate of poleward shift at the northern-range margin of a species' distribution was greater than at the southern range-margin. Species' ranges have therefore expanded in response to climate change over this period (Massimino *et al.* 2015).

Beyond documenting impacts, there is considerable value in attempting to identify the mechanisms underpinning those changes. The mechanism which has received the greatest attention has been that of phenological change. BTO has contributed Nest Record Scheme data to CEH-led analyses highlighting the potential risk that climate change poses to existing ecological interactions between species (Thackeray *et al.* 2010) that, as a subsequent high impact paper published in *Nature* documented, is caused by variation in the sensitivity of different species to warming (Thackeray *et al.* 2016). However, subsequent BTO analyses suggest that changes in phenology may have a more limited impact on bird populations than initially thought; analyses of BTO Ringing and Nest Record Scheme data have failed to provide strong evidence of a mechanistic link between mismatch and breeding success, at least at a national-scale (Finch *et al.* 2014; Franks *et al.* 2018).

Another key mechanism which BTO, in collaboration with others, has been key in highlighting, is that of climate-driven reductions in prey populations. First identified as an issue for seabirds (Frederiksen *et al.* 2004), and later by RSPB-led work on upland birds (Pearce-Higgins *et al.* 2010; Pearce-Higgins 2011); a PhD collaboration with the University of York and RSPB has extended this work and highlighted the role of changes in peatland hydrology as a mechanism for reducing invertebrate abundance and affecting population trends of some peatland species (Carroll *et al.* 2011; 2015). This body of evidence demonstrates the biodiversity and climate change adaptation benefits of peatland restoration being undertaken to improve habitat condition, improve water quality and manage flood risk. It has helped conservation organisations

Figure 8. Variation in the abundance (no ./ 30 cm x 30 cm turf) and biomass (g / 30cm x 30cm turf) of earthworms through the season as measured by the BTO-led What's Under Your Feet? project.



like RSPB, the National Trust and others prioritise the blocking of drainage ditches on peatland areas on their land, contributing to, for example, the 30 km² of land in the Peak District subject to habitat restoration.

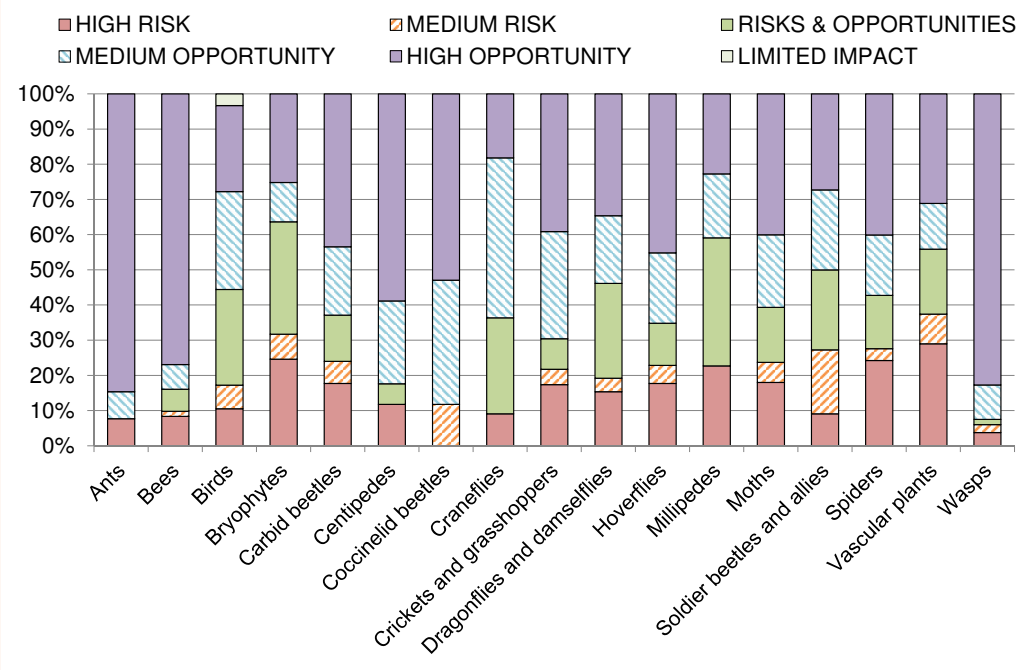
BTO analyses of data on other taxa, derived from a range of biodiversity surveillance schemes, have demonstrated the contribution that climate change, particularly warmer, wetter winters, appears to have made in driving large-scale moth declines, whilst warmer temperatures may have increased the abundance of flying aphids (Martay *et al.* 2017). With variable impacts across trophic levels, these trends have potential implications for ecosystem function and may affect populations of insectivores which feed on those groups, as illustrated for Cuckoo through an RSPB-funded PhD project that analysed BBS data (Denerley *et al.* 2018). The potential vulnerability of species that feed on earthworms to summer drought (Figure 8) has been highlighted by a novel citizen science project engaging at least 12,000 school children from over 450 schools to collect data on the abundance of soil invertebrates from school playing fields (Martay & Pearce-Higgins 2018). This work has been supported through EDF Energy's award winning POD to inspire the next generation of ecologists.

Given ongoing uncertainty over the impacts of climate change on global biodiversity, BTO-led a collaborative review of the mechanisms linking natural population responses to climate change around the world. This identified that climate-driven changes in species interactions, such as reductions in prey populations, were the most important mechanisms driving responses to climate change (Ockendon *et al.* 2014), and showed that the effect of temperature or precipitation upon species' populations varied predictably with latitude, and between species groups (Pearce-Higgins *et al.* 2015). Importantly, both papers identified that these relationships are altering in response to climate change, whilst also emphasising that the evidence base on climate change impacts in the tropics, where the majority of biodiversity occurs, is poor, compared to well-studied parts of Europe and North America. This work forms the basis for a display in the Zoology Museum, Cambridge that also draws upon the work of BTO looking at carry-over effects of weather conditions in Africa upon the breeding of migrants (Ockendon *et al.* 2013).

BTO data and research have contributed significantly to the evidence base on the impacts of climate change on UK biodiversity, something that has been summarised for policy-makers, conservationists and the general public through a number of key publications. These include the two LWEC terrestrial biodiversity report cards (Morecroft & Speakman 2013; 2015), where three of the underpinning 17 papers were authored or co-authored by BTO staff, and 30% of the summary impact statements in the 2015 report, which were wholly or partly based on inference from BTO studies. For the marine environment, the MCCIP report card provides the same level of summary and BTO authored a contributing paper on waterbirds for the 2013 assessment (Pearce-Higgins & Holt 2013) that is being updated in November 2018.

BTO studies have also contributed to the evidence-base for the *UK Climate Change Risk Assessment* chapter on the natural environment (Brown *et al.* 2017), which particularly utilised the results of the BICCO-Net project to summarise the impacts of climate change on terrestrial species' populations. The evidence for impacts of climate change on birds was summarised in the 2017 edition of the *SUKB*, where one third of the references cited were BTO-led, and a further quarter had a contributing BTO author. Unfortunately, plans to develop a searchable online resource through two BTO-led Defra-funded projects (BICCO-Net and BICCO-NET II), modelling the impacts of climate change on species across

Figure 9. Proportion of species categorised as likely to be at risk or to have an opportunity for expansion from climate change in the UK, under a low-emissions scenario for 2070–99 (from Pearce-Higgins *et al.* 2017).



a range of taxa, had to be abandoned due to changes in government policy around the development of project-specific websites. Despite this, BTO research has played a major role in reducing the uncertainty associated with the impacts of climate change on UK biodiversity, as required to address UK and country policy needs.

FUTURE PROJECTED IMPACTS OF CLIMATE CHANGE

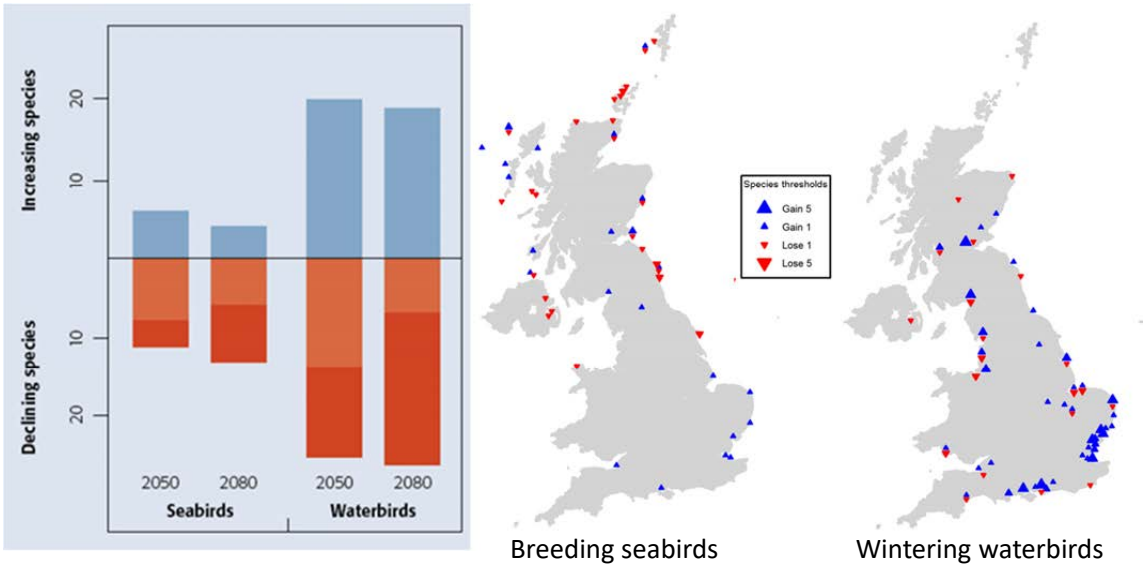
Recognising that the impact of future climate change is likely to be greater than that already experienced, BTO has undertaken a programme of work to improve the evidence-base around the projection of future climate change impacts. Most projections of climate change impact focus on distributions and range-change, underpinned by widely available records of presence. However, abundance and population size are much more sensitive measures of conservation status (and underpin criteria about international importance), while conservation prioritisation is more often based upon trends in abundance than occupancy. BTO has developed novel approaches to model the impacts of climate change on the abundance of species, rather than simply occurrence. A proof of concept paper used BBS data to estimate breeding density and relate that to climate across the UK for four species (Renwick *et al.* 2012). The benefits of this approach were further developed by a PhD CASE studentship at the University of Durham (Howard *et al.* 2014).

Projected future impacts of climate change on internationally important populations of wintering waterbirds and breeding seabirds, undertaken through the Defra-funded CHAINSPAN project, identified the particular vulnerability of seabirds to future climate change, and also provided important evidence (see below) in support of the resilience of the SPA network to climate change (Johnston *et al.* 2013). The underpinning models relating bird populations to climate have been used by NE to identify the SPAs where bird populations are performing better or worse than expected on the basis of climate change; this has been used as a tool to inform decision making, for example to inform management at sites around the Severn Estuary. More recently, a fuller assessment of the projected future impacts of climate change on UK avifauna, provided important evidence about species' vulnerability and identified where changes are most likely to occur (Massimino *et al.* 2017), highlighting that species of current conservation concern are likely to be more susceptible to negative future climate change impacts than other species.

The BTO has also worked with bioclimate modelling approaches that rely on distribution, rather than abundance data, since these tend to be much more available for other taxa. BTO led a NE funded consortium to assess the risk and opportunities that climate change poses to over 3,000 species across 17 taxonomic groups that occur in England (Pearce-Higgins *et al.* 2015). Bryophytes, vascular plants, and upland habitats, contained the greatest proportion of species at high risk from climate change (Figure 9), although for many taxa there was a high degree of uncertainty in these assessments (Pearce-Higgins *et al.* 2017). Species-level assessments and associated guidance are being incorporated into updates to the NE adaptation manual.

Based on our development of approaches to climate change projections, and understanding of the uncertainties and constraints involved, BTO has contributed to the development of the IUCN guidelines on climate change vulnerability assessment (Foden *et al.* 2016; 2018). Continued work on the development of appropriate approaches to climate change vulnerability assessment is being undertaken

Figure 10. Despite projected changes in the number of waterbirds and particularly seabirds likely to be Amber (orange) or Red-listed (red) as a result of climate change (left), and significant turnover in the number of qualifying species at SPAs with many sites showing both increases (blue) and declines (red), the SPA network will remain resilient to future climate change (Johnston *et al.* 2013; Pearce-Higgins *et al.* 2012).



through a PhD at the University of York, in collaboration with RSPB, leading to an important assessment of the efficacy of existing approaches (Wheatley *et al.* 2017), and ongoing development of assessment for European biodiversity.

TESTING ADAPTATION

Climate change vulnerability assessment provides important evidence, enabling conservation organisations to prioritise the resources that they spend. However, a critical additional component of BTO's climate change work has been to provide the evidence to inform adaptation. This has primarily focussed on two areas. Firstly, building evidence about observed shifts in species' distributions in response to climate change (see above), which has led some to question the conservation paradigm associated with the maintenance of static protected areas. A multi-taxa collaborative study led by the University of York demonstrated that colonisation events of range-expanding species were three-times more likely to have been located on protected areas than expected by chance, whilst local extinctions were less likely to have occurred on protected areas, particularly close to the southern range-margin of species (Gillingham *et al.* 2015; Thomas *et al.* 2012). Given that the magnitude of future climate change is likely to be much greater than that already experienced, Defra funded BTO to lead a large project (CHAINSPAN) to assess the impacts of climate change on the UK SPA network. This showed that by protecting an extensive network of large, semi-natural sites important for a wide-range of species, the SPA network could remain resilient to future climate change (Figure 10), even if the species assemblage and composition of the species present at each site, may change (Johnston *et al.* 2013; Pearce-Higgins *et al.* 2012). This work was highlighted by a *Nature Climate Change* commentary piece (Dunlop *et al.* 2013), and was quoted directly in the fitness check of *Birds and Habitat Directives* as evidence to support the continued value of *Natura 2000* sites in a changing climate.

Secondly, a much discussed principle of climate change adaptation is that of having increasingly connected landscapes, with networks of semi-natural habitats, to facilitate species movements and range expansion. BTO-led analyses of woodland CBC data demonstrated that populations in sites with a greater amount of woodland in the wider landscape are more likely to recover quickly from cold-winter events, from which we can infer that the greater connectivity in such landscapes facilitates more rapid immigration and colonisation of such sites (Newson *et al.* 2014). Further, changes in the structure of butterfly and bird communities in response to warming, revealed using a combination of the UK Butterfly Monitoring Scheme (BMS) and CBC data, are related to the extent of semi-natural habitat in the wider landscape (Oliver *et al.* 2017). This work has direct policy-relevance, for example contributing to the evidence base in support of using AES to increase the extent of semi-natural habitats, and reduce fragmentation (e.g. Munday *et al.* 2018).

CONCLUSIONS

Citizen science monitoring provides the most cost-effective and sustainable solution for large-scale and long-term data collection required to examine the impacts of climate change. Long-term BTO data, and wider analyses have provided crucial evidence to examine the impacts of climate change on UK biodiversity, addressing a clear evidence gap for policy, and have made a contribution to documenting the impacts of climate change globally. BTO has led a number of analyses projecting future impacts of climate change across taxa for the UK, providing a good basis on which to identify the most vulnerable species, and has contributed to the evidence base about climate change adaptation – particularly the role of protected areas. Whilst ongoing monitoring data will continue to provide a resource to track impacts of climate change, more work is required to understand the ecological mechanisms underpinning such impacts. Addressing the more limited evidence-base around climate change adaptation, and considering how adaptation projects should be monitored through time, is a current organisational priority for BTO.

SPECIES INTERACTIONS

There is increasing evidence that changes in the abundance of species can have disproportionate impacts on other species that they interact with. Almost 40% of globally threatened species are impacted by invasive species (BirdLife International 2018), whilst increasing populations of native species can cause conservation challenges for ground nesting bird species in the UK (Roos *et al.* 2018). With a rising awareness of the impact that climate change can also play on affecting these interactions (Ockendon *et al.* 2014), understanding the potential impact that non-native species, predators and disease can play upon bird and other wildlife populations has been a key component of BTO science, combining bespoke research, analyses of large-scale and long-term citizen science data, and extensive collaboration. Crucially, in many areas, these topics are controversial in nature, which plays to BTO's strengths for impartial evidence and an ability to work with a range of stakeholders as an honest broker.

PREDATION AND ITS MANAGEMENT

Predation is an interesting and natural process worthy of study in its own right. The impact of non-native predators, and of the control of predators for managing other (prey) species can divide opinions, however. Impartial and objective approaches have proven to be important in the BTO's involvement in some of these important but potentially divisive issues. Through a combination of analyses of long-term monitoring data, such as CBC and BBS, which enable statistical interactions between species abundance changes to be modelled (Freeman & Newson 2007), it is possible to identify the extent to which spatio-temporal changes in bird populations are consistent with potentially negative impacts of high or increasing predator populations causing reductions in prey species. For example, in the largest such study published, Newson *et al.* (2010) identified that whilst there many be a small number of negative effects between predator and prey species, for the majority of species, there is no evidence that increases in common avian predators or Grey Squirrels *Sciurus carolinensis* are associated with large-scale population declines. More recent studies, in collaboration with University of St Andrews developing novel

statistical approaches to analyse such interactions, have focussed on potential impact of Sparrowhawk predation on House Sparrows at garden bird feeders (Jones-Todd *et al.* 2018; Swallow *et al.* 2015), detecting a negative association that could either result from localised population declines, or behavioural avoidance by the sparrows.

The breeding wader assemblages supported by machair and associated habitats in the Western Isles of Scotland are recognised as being of international importance (e.g. Fuller *et al.* 1986) but the assemblage has changed, with key species, notably Dunlin *Calidris alpina* and Ringed Plover *Charadrius hiaticula,* declining markedly over the past three decades (Calladine *et al.* 2015). Although some changes were associated with habitat and, in particular, changes in agricultural management of the machair (Calladine *et al.* 2014), a key driver has been predation of eggs by Hedgehogs *Erinaceus europaeus* that were introduced to the archipelago in 1974 (e.g. Jackson *et al.* 2004). A programme to control Hedgehogs had largely removed them from North Uist by the mid-2000s, but was subject to public criticism and pretty much halted before progressing further. In response, SNH commissioned a consortium led by BTO, with the James Hutton Institute and Macarthur-Green, to further assess the role of Hedgehog predation in wader population declines. Clutch survival rates were lower where Hedgehogs were relatively abundant and Hedgehogs were the most frequent predator of nests (Calladine *et al.* 2017). With that supporting evidence, the board of SNH agreed to support the aim to eradicate hedgehogs from the Uists when a means of funding became established.

The role of controlling predation in maintaining assemblages of ground nesting birds is now widely acknowledged (e.g. Franks *et al.* 2017; Roos *et al.* 2018), but remains controversial. This is especially so where control of predators is used to support extensive populations of breeding waders in mainland Britain that are often associated with sport shooting, especially driven grouse shooting. Perceptions and evidence that predators can be controlled beyond what is legally permitted, and habitats managed in ways that can reduce diversity or even be damaging (e.g. Thompson *et al.* 2016), has contributed to distrust between and within some conservation and land management stakeholders. BTO was a key partner within the *Understanding Predation* project (Ainsworth *et al.* 2016), which aimed to develop a basis for common understanding between scientists, conservationists and land managers on the role of, and evidence for, predation (amongst other factors), as a driver of change for ground nesting birds in Britain. Although there was broad common agreement about rates of decline among the selected species (Black Grouse *Lyrurus tetrix*, Grey Partridge *Perdix perdix*, Curlew *Numenius arquata*, Golden Plover *Pluvialis apricaria,* Lapwing and Oystercatcher *Haematopus ostralegus*) in Scotland, there were some disagreements about the importance attributed to sources of knowledge on drivers of change, with personal experience often set against data published in peer-reviewed journals.

Importantly, the collaborative process adopted by the *Understanding Predation* project was greatly valued by all participants and the approach is being taken forwards with further studies, mostly centred on breeding waders. The report was launched by the Minister for Environment, Climate Change & Land Reform in Scotland, Dr Aileen McLeod, MSP, and recommends developing an adaptive, collaborative approach, linking scientific evidence gathering and stakeholders' knowledge, to guide the development of management practices.

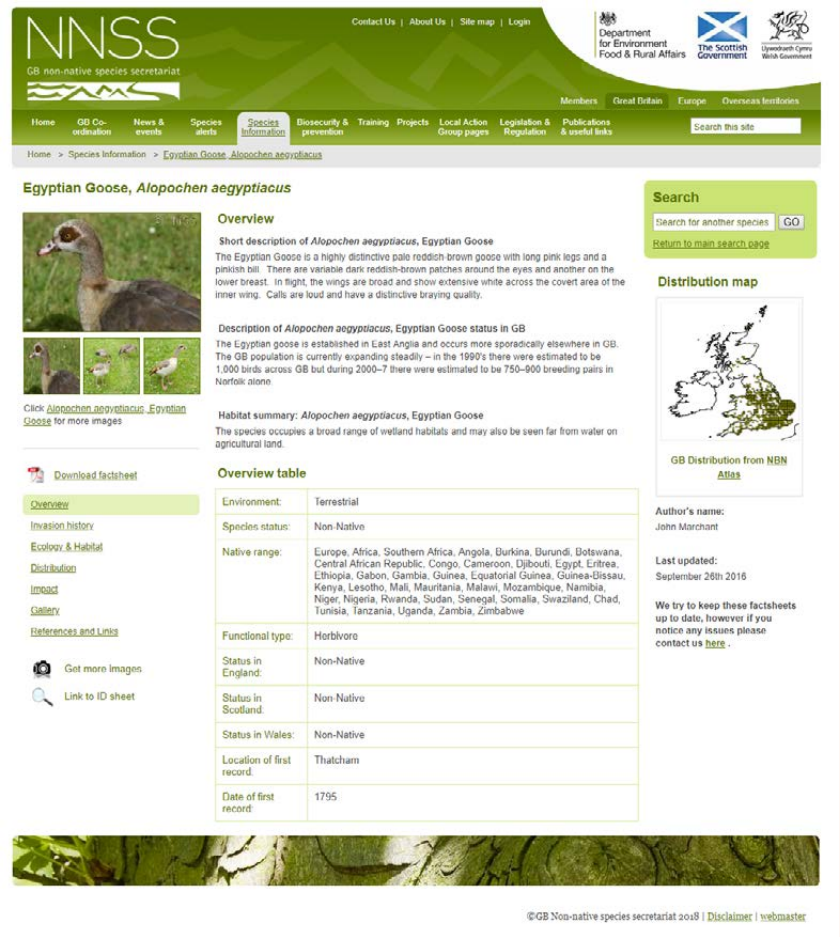
Engaging with all stakeholders (including estate managers and conservationists) at all stages, from study design, through execution and reporting, has been key to two trial programmes to monitor breeding waders and identify nest predators in the Yorkshire Dales (Jarrett *et al.* 2017) and in the east Cairngorms (work in progress). More broadly, the *Working for Waders* project is developing adaptive and collaborative approaches to link scientific evidence gathering with stakeholders' knowledge, to guide the development of management practices in Scotland. The ultimate objective is to develop common understanding and agreed practices that maximise our ability to sustain assemblages of breeding waders in the future. The potential role of predation in affecting North American and European breeding populations of Numeniini (curlews and their relatives), one of the most threatened groups of birds worldwide, was highlighted by Pearce-Higgins *et al.* (2017), work that was presented to the CMS CoP11.

NON-NATIVE SPECIES

Non-native species (NNS) are regarded as one of the largest threats to biodiversity worldwide and with more than 3,000 species in the UK, many of which are well established, ecosystems here have experienced significant impacts. To assess the threat of non-native species in the UK, we need: (i) reliable and up to date information on their presence and numbers; (ii) knowledge of the most imminent and serious threats of colonisation from outside the UK and the likely pathways involved; and (iii) good understanding of the impacts of each species, which range from largely benign to those which are serious threats to entire ecosystems and require most urgent action.

The BTO makes a major contribution to tracking the colonisation of non-natives in two ways. Firstly, through its extensive programme of surveys and atlases of birds and other wildlife, most of which explicitly include non-native species recording, and, secondly, through its partnership role in the GB Non-Native Species Information Portal (NNSIP) since its inception more than a decade ago (Roy *et al.* 2014a). Hosted by the NSS Secretariat, the portal provides a one-stop shop for information on all non-native species in Great Britain, including detailed factsheets for many of the established species, and an alert system for a suite of non-native species known to have serious negative effects on native species or ecosystems (Figure 11). New reports of any species on this list are forwarded to partners, the BTO for birds and mammals (e.g. Sacred Ibis *Threskiornis aethiopicus*, Ruddy Duck *Oxyura jamaicensis*, Siberian Chipmunk *Eutamias sibiricus*, Raccoon *Procyon lotor*) for rapid validation as well as directly to the responsible authorities for appropriate conservation action.

Figure 11. Example species information page produced by BTO.



Undertaking conservation action requires setting priorities and as part of NNSIP, BTO has contributed to studies to identify the most imminent threats of colonisation and establishment by non-native species through horizon scanning (Roy *et al.* 2014b), to better understand the potential for colonisation based on climatic conditions (Border *et al.* 2018) as well as developing methods for rapidly assessing their potential impact.

For dealing with established non-native species such as Grey Squirrel and Reeves' Muntjac *Muntiacus reevesi*, mitigating action needs to be targeted on those species known to have the most serious impact and a considerable body of BTO and partnership research has focused on identifying these species. The best evidence on those affecting bird populations comes from BTO studies on the impact of deer on woodland birds (Newson *et al.* 2012), of non-native geese (Rehfisch *et al.* 2010) and of Grey Squirrels (Newson *et al.* 2010). In other cases, although impacts have been suspected, none have yet been found (study on Ring-necked Parakeets *Psittacula krameri*, Newson *et al.* 2011) and work continues to identify the impact on riverine wildlife by American mink *Neovison vison* and the effects of annual releases of gamebirds such as Pheasant *Phasianus colchicus* and Red-legged Partridge *Alectoris rufa*, among others.

IMPACTS OF DISEASE IN WILD BIRDS

Individual birds suffer from the effects of a wide range of parasites (both internal and external) and diseases, but the impacts of these at a population level have mostly been unclear. Citizen science offers a cost-effective means to undertake large-scale wildlife disease surveillance in conjunction with the monitoring of wildlife populations and their distributions and abundances. Such monitoring has been achieved over a 25-year period in the UK through public reporting of observed morbidity and mortality of garden birds. Reports of diseased individuals, and carcasses for post-mortem examination, have been collected on an opportunistic basis since the early 1990's (Lawson *et al.* 2012a). This allowed the presence of various disease organisms to be noted, but did not enable robust analysis of distribution or epidemiological trends, and hence impact has been hard to quantify.

Since 2005, BTO has promoted systematic data collection through using its established GBW network. By encouraging a subset of GBW participants to reliably record the presence (or not) of sick or dead birds in their garden throughout the year, it becomes possible to assess the relative occurrence of disease in both temporal and spatial contexts, and, in combination with other survey data collected by BTO, to assess population impact. Through this network of

participants, we have also been able to disseminate practical advice on bird feeding best practice.

A good example of this concerns the impact of the protozoan parasite *Trichomonas gallinae* on Greenfinch *Chloris chloris* populations. While trichomonosis has been recorded in pigeons, doves and birds of prey for many years, this disease was only detected in wild British finches in 2005. Epidemic mortality occurred the subsequent year, with greatest intensity in the West Midlands of England and declining prevalence further east. Work to diagnose the epidemiology of the outbreak combined genetic and histopathological identification of the disease organism and its effects, with citizen science reporting of changes in bird numbers (Robinson *et al.* 2010). The impact on Greenfinch breeding populations, as measured by the BBS, was large, with a 35% decrease in numbers in the region of the initial outbreak within a single year. The effects of the outbreak have continued subsequently, with an average annual decrease in the national population of 10% (Woodward *et al.* 2018). This decline, identified by BTO surveillance, is of sufficient magnitude to warrant Greenfinch being listed as endangered in the UK using IUCN criteria (Stanbury *et al.* 2017).

Finch trichomonosis represents the largest scale wild bird infectious disease outbreak on record in Europe, with an estimated mortality of c.3 million Greenfinches to date in the UK. It illustrates the potential for disease to cause significant and unpredictable wild bird population declines and emphasises the need for collaboration between ornithologists, veterinarians and other disease ecologists to understand this potential conservation threat. Epidemiological analysis, using our ring-recovery data sets, indicated that Chaffinches *Fringilla coelebs* were likely responsible for the spread of the finch trichomonosis into Europe (Lawson *et al.* 2011). BTO continues to work with European colleagues to track the spread and impact of this emerging infectious disease and this integrated approach to data collection, allowing us to combine research from different parts of the life-cycle, is a key element of our ability to generate impact, and one which makes the BTO almost unique in a global context.

BTO has a strong track record of partnership working to capitalise on organisational synergies and maximise multi-disciplinary outputs. An example of this is collaboration with the veterinarians at the Zoological Society of London (ZSL), University of Liverpool, Scottish Agricultural College and others, along with science staff at the RSPB and the Universities Federation for Animal Welfare (UFAW), who together established the Garden Bird Health *Initiative* in 2005 to collect data on wild bird health, primarily in gardens (Lawson *et al.* 2018a). In 2013, BTO, ZSL and RSPB, along with Froglife expanded this network into the Garden Wildlife Health project to collate information on a wider range of diseases. The information collected is reported to Defra as part of its wider disease monitoring activities. In particular, BTO has been able to use its extensive online database development experience to provide an intuitive data submission and interactive reporting system that, at the time of writing, has resulted in 8,652 incidence reports from 6,127 sites being submitted and facilitated the collection of 1,904 sample for post-mortem examination. The online system was designed to be sufficiently flexible to provide opportunities for routine collection of wildlife mortality information in other contexts; for example, the system has been used by RSPB Investigations Team for managing post-mortem analysis of suspected victims of illegal persecution.

These collaborations have made a significant contribution to national disease surveillance networks; reporting through the SNCBs has facilitated the study of the occurrence and impact of a range of wildlife diseases (Beckmann *et al.* 2014; Lawson *et al.* 2012b, 2018a, 2018b).The ZSL vets report collaborative findings from the Garden Wildlife Health project to Defra and the Animal Plant Health Agency as part of the government's GB Wildlife Disease Partnership. Open access quarterly reports are also published, and emerging threat reports describing new findings are submitted to government for consideration.

Research outputs are translated into a library of disease fact sheets available on the Garden Wildlife Health website, currently covering over 25 conditions to which the BTO contribute and help disseminate. These provide science-based guidance on the actions that members of the public can take to help prevent or control disease outbreaks in local wildlife, and the steps that they can take to protect human, livestock and companion animal health where relevant. This best practice guidance is communicated through multiple formats including e-newsletters, BTO magazine articles and collaborative press releases which have generated considerable media and public attention in recent years. Whilst feeding garden birds has multiple benefits, and is promoted by BTO, there is a concomitant risk of increased opportunities for disease transmission, particularly when large numbers of birds congregate, hygiene levels are poor and bird species that would not normally mix feed in close proximity. BTO and ZSL published a recent review of health hazards to wild birds in Great Britain and risk factors associated with supplementary feeding (Lawson *et al.* 2018). Dissemination of the guidance from this research enables BTO to positively impact wild bird welfare, by helping to promote practices to minimise disease transmission.

While this research has clearly demonstrated that pathogens can influence wild bird populations, they can also have wider economic significance, through impacts on livestock or human health. For instance, collaboration with ZSL and Public Health England amongst others, demonstrated the importance of garden birds as a reservoir for specific strains of *Salmonella* which can infect vulnerable portions of the human population (Lawson *et al.* 2014). Importantly, this study also enabled quantification of the level of risk, with only 0.2% of *Salmonella* isolates from humans in England and Wales over a decade being of garden-bird associated biotypes of this bacterium. Having a solid evidence base enables us to provide proportionate advice on the risks involved with particular activities, through, for example websites or more traditional print media (UFAW 2005). Routine hygiene precautions recommendations are communicated to the general public to help safeguard public health. It also provides

a national tissue archive (now consisting of tens of thousands of samples) through which emerging diseases and other mortality agents can be identified in the future.

A major strength of BTO is the ability of our data archives to provide historical baselines from which to assess future risk, for instance the risk of incursion of zoonotic diseases (those that are transmitted from animals to people) to the UK. Ringing data were used in this way to model the potential spread of West Nile Virus, as the northward expansion of its mosquito vector's distribution in response to a changing climate is bringing it increasingly into contact with birds that are migrating to Britain, providing a potential incursion route (Bessell *et al.* 2017). The activities of British ringers continue to contribute to collecting new data on occurrence of pathogens (e.g. Hughes *et al.* 2009; Graham *et al.* 2010; Foley-Fisher *et al.* 2012), and our expertise contributes to developing sampling guidelines, e.g. for the Food & Agriculture Organization of the United Nations (FAO, Whitworth *et al*. 2007).

Probably the most significant economic risk in recent years has come from highly pathogenic strains of avian influenza, which have the potential to have a devastating impact on the domestic poultry industry, which is worth in excess of £3 bn annually to the national economy (Clarke 2015). The highly pathogenic Asian-origin H5N1 strain, which emerged in 2005-6 and affected wild birds as well as poultry, was zoonotic and therefore raised considerable public health concerns. BTO, and its data, was at the centre of advice provision to the European Commission concerning the response to the H5N1 outbreak in 2006, at both a national and European level (Delany *et al.* 2006). This included both an assessment of the areas in which the density of wild birds and poultry farms were highest, thus helping target national surveillance activities (Snow *et al.* 2007), and development of an online tool, initially for the UK (Crick *et al.* 2006), later for the European Union (Delany *et al.* 2006; Veen *et al.* 2007), enabling information on wild bird movements to be easily visualised and the risk of incursion to be assessed. Ongoing use of this migratory mapping tool and information about the abundance and distribution of potential wild bird vectors, particularly from WeBS and BirdTrack data, is used to guide Defra responses to highly pathogenic avian influenza virus outbreaks, e.g. 2017 and 2018.

CONCLUSIONS

An increasingly connected world, coupled with climate-driven range shifts, will continue to bring new species into contact with each other, and alter species' interactions. Issues associated with expanding non-native species and novel diseases are likely to grow, requiring ongoing surveillance coupled with research to understand their impact upon biodiversity and the wider environment. The potential for these new interactions to have a significant conservation impact, or to impact economic or other societal interests, underlines the need to ensure sufficient long-term resourcing for the required terrestrial surveillance schemes. In particular the potential value of the network of licensed and trained ringers who can catch and sample wild birds should not be neglected.

More generally, understanding these changes and informing potential policy and management responses to issues of predation, non-natives and disease, is likely to continue to be an important area for BTO science, often carried out in collaboration with others. Where that management may be controversial, particularly around issues of human-wildlife conflict, there will be a need for impartial evidence provision and clear communication, and therefore an ongoing role for BTO's unbiased provision of data and information.

VALUING NATURE AND ECOSYSTEM SERVICES

Ecosystem services (ES) is a catch-all term developed to describe the ways in which nature provides benefits to humanity. It attracts controversy from some in the conservation sector because of the risk that nature is reduced from having intrinsic value to being entirely utilitarian. Conversely, however, ES can be used to quantify benefits to society in addition to intrinsic conservation value, the better to communicate with government and industry audiences who might not be aware of the benefits they receive from the natural environment and whose thinking is driven by economics. Thus, there is no reason why the concept cannot be entirely complementary to that of intrinsic conservation value. Either way, the concept of ES, together with that of "natural capital", which can be viewed as the "stocks" of critical features of nature from which services "flow" (Jones *et al.* 2016), is increasingly important at policy level and BTO research needs to engage with this agenda.

Ecosystem services provided directly by birds are limited and, in the UK, probably mostly involve cultural or aesthetic value. Potential exceptions include scavenging by generalist predators and provisioning services by a few quarry species. However, BTO science is increasingly concerned with multi-taxa, whole-ecosystem effects, so has broadened from simply considering birds, and a wider consideration of the ecosystem services provided by other groups is well within our scope (e.g. Eigenbrod *et al.* 2010). Moreover, bird responses may be valuable as indicators of the wider environment and to the services provided by other taxa. To date, BTO research into ES and related issues has been piecemeal, rather than following a coherent programme. At a conceptual level, we were involved in a broad *Valuing Nature Network* collaboration considering the characterization of services in terms of stocks and flows (Jones *et al.* 2016), although it is unclear how widely this framework has been applied. Data from the *Bird Atlas 2007–11* (Balmer *et al.* 2013) contributed information to a study of correlates between environmental indicators and public health, finding a positive association between good health prevalence among the British public and bird species richness (Wheeler *et al.* 2015).

FarmLand was a BiodivERsA- and Defra-funded, international collaboration investigating the role of cropping heterogeneity in driving variation in biodiversity and the services it provides (pollination and predation of crop pests), with a view to developing recommendations for land-use policies that exploit these relationships in lieu of taking land out of production. The collaboration was large and complex, across five countries and eight regions, and outputs are still being produced, so impact is still in progress. However, a paper

demonstrating value for pollination has already appeared (Hass *et al.* 2018). UK-specific patterns were reported to Defra but have not been widely publicized as they were primarily contributors to the international patterns. An analysis of bird patterns as potential indicators of those in other taxa did not produce clear-cut results and awaits submission to a journal. Separate BTO analyses using BBS data to compare spatial variation in bird and butterfly communities also showed mixed results, with covariation in species richness and diversity but not evenness and community specialisation (Eglington *et al.* 2015).

The NERC Biodiversity and Ecosystem Service Sustainability (BESS) programme supported four major consortium projects investigating links between wild species and services, three of which featured BTO research. In the DURESS project, which focused on riverine systems in Wales, the links between the cultural and provisioning ecosystem services provided by Brown Trout *Salmo trutta* and riparian birds such as Dipper *Cinclus cinclus* and Grey Wagtail *Motacilla cinerea*, the abundance and availability of their invertebrate prey, and parameters of water quality was explicitly quantified and used to predict the outcome of land-use scenarios. Socio-economic studies were used to further explore the value of these ecosystem services to a range of local and national stakeholders. In CBESS, which considered coastal and estuarine systems, BTO, in collaboration with socio-economists from the University of St Andrews and Queen's University, Belfast, explored the relationships between the cultural services and biodiversity of estuaries. The work highlighted the importance of multi-dimensional concepts of biodiversity in assessing cultural service provision and that positive biodiversity outcomes do not necessarily influence willingness to pay (Boeri *et al.* submitted).

The largest BTO involvement in a BESS project was in F3UES (Fragments, Functions and Flows in Urban Ecosystem Services), a collaboration with Cranfield, Sheffield and Exeter Universities working in the three contrasting towns of Luton, Bedford and Milton Keynes, quantifying the influence of urban habitat structure on biodiversity and a range of ecosystem services. BTO used professional surveyors to measure actual and human-perceivable bird populations, while social scientists at the University of Exeter measured human health and well-being. This showed that people in socio-economically deprived areas are exposed to more negatively influential species (providing ecosystem disservices) and fewer positive ones (Cox *et al.* 2018). Bird surveys contrasting early mornings with times of day when people are most active, and novel assessments of the influence of habitat structure on the means by which people will detect birds, revealed that denser human habitation and typical patterns of activity are associated with disproportionately low bird detectability given the birds present (Plummer & Siriwardena in prep.). Moreover, bird abundances in the afternoon are associated with positive mental health, but those detectable in the morning are not (Cox *et al.* 2017). This means that much of the potential premium of human well-being from biodiversity is not being realised, so society could benefit considerably from bringing people in urban areas closer to nature, or bringing nature closer to people. Formal BTO outputs from this work are still in development, but will bring clear possibilities for significant human impact.

The concept of natural capital is a further development of the ecosystem services concept. Clearly, some birds form a natural capital resource in their own right: quarry species represent a provisioning service because they are a human food resource. Counts or densities in data sets such as BBS can therefore be regarded as direct measures of this natural capital. Similarly, densities of scavenging species (corvids and certain raptors) describe another form of natural capital. It is possible that other species, combinations of species or indices derived from species data, could form effective indicators of natural capital by describing the variation in the quality or quantity of other features of the environment. For example, upland wader densities may reflect peat quality and hence the delivery of carbon sequestration or flood prevention services by this habitat, as both are driven by hydrology (Carroll *et al.* 2015). Conceivably, numbers of invertebrate feeders could also be related to densities of pollinating insects. However, there are conceptual reasons why relationships such as these may not hold. Hence, it is critical to demonstrate the fundamental relationships before it can be supportable to derive putative indicators. Nevertheless, some initial work constructing possible indicators has been conducted, but assessments of the practical value and potential impact (wider adoption of indicators) are limited by a lack of data on the variation in the natural capital that would then support the necessary analyses.

CONCLUSIONS

Concepts of natural capital and the ecosystem services that the natural world can provide have grown in traction and importance to society and decision-makers. BTO engagement in this area has so far been limited, as birds only play a limited direct role in delivering ecosystem services. However, given that birds are amongst the best-monitored taxa, in terms of robust measures of abundance and community structure, based upon well-designed schemes, and that they occupy a high trophic position, there is a good likelihood that they may be able to help monitor changes in the state of the environment relevant to the monitoring of natural capital and the services that other species provide.

Properly understanding and quantifying this potential could become an increasing priority for BTO science, potentially through new collaborations and by working across sectors. At the same time, BTOs role in encouraging and supporting the monitoring of other taxa, for example by taking advantage of our network of volunteers and expertise in developing novel opportunities for citizen science, should also lead to new opportunities to increase understanding in this area. Achieving this is likely to be important if BTO data are to have maximal impact in the current policy climate.

ART AND CULTURE

It is increasingly recognised that engagement with science can be greatly enhanced where that engagement takes place through the creative arts. Audiences exposed to scientific ideas through such pathways have been shown

to demonstrate meaningful change in their understanding and – where the topic has an environmental basis – their behaviour. It is for this reason that BTO has been working with partners operating within the arts and culture workspace, including New Networks for Nature and the Norfolk Festival of Nature, exposing new audiences to science and seeking to inspire society about birds. A good example of how this approach can deliver impactful outputs can be seen through our work with the Society of Wildlife Artists (SWLA) on the BTO/SWLA Flight Lines project. This project has seen SWLA member artists, storytellers and photographers accompany BTO researchers and volunteers working on migrant birds, both here in the UK and elsewhere in Europe and West Africa. A book produced through the project (Toms 2017) showcased both artwork of internationally prominent wildlife artists working in a range of media and the latest research into migratory birds that breed in the UK and winter in Africa. The book has been supported by a range of other activities including regional art exhibitions, and work with photojournalists to give increased immediacy to some of the results revealed, especially by our tracking work. BTO has shown significant leadership in this approach, demonstrating to partners how an arts and culture approach can make scientific and conservation messages more relevant and more accessible. In a similar vein, two BTO scientists, James Pearce-Higgins and Blaise Martay have recently participated in a collaboration with poets writing about biodiversity and climate change for a special issue of the poetry magazine *Magma Poetry* that brings our work on climate change to a new audience.

BTO's science programme continues to be presented in an engaging way to a broad range of audiences, including, for example, the annual Birdfair (20,000+ visitors) and at the regional Norwich Science Festival (7,500 visitors), and around specific topics, such as our tracking studies at New Scientist Live (30,000+ visitors) and disease monitoring work at Gardeners' World Live (100,000+ visitors).

5. CONSERVATION SCIENCE

'Although not a campaigning organisation per se, BTO is one of the most influential conservation organisations in Britain today. It has had a disproportional input to the UK Biodiversity Action Plan simply through the strength of its distribution and monitoring data.' (Lawrence 2006)

As already outlined, BTO science is fundamental to conservation action in the UK, and contributes significantly to Europe-wide assessment. Most obviously, the long-term monitoring schemes undertaken by BTO provide the information that informs conservation status assessment for most UK bird species. The latest UK Red List for Birds (*Birds of Conservation Concern 4*, Eaton *et al.* 2015) relied upon BBS and WeBS trend information, as well as data from the *Bird Atlas 2007–11* (Balmer *et al.* 2013) to inform the assessment. These same data contributed to an application of the IUCN criteria to 'Red List' species (Stanbury *et al.* 2017), and to equivalent European and global assessments. As well as providing trend information, these same schemes can be used to provide estimates of population abundance. This is required for reporting to Europe against Article 12 of the *Birds Directive* and to identify nationally and internationally important thresholds for site designation. This process was led by BTO (Musgrove *et al.* 2013), and is currently being updated for the current reporting cycle. WeBS is providing winter population estimates for 48 populations of 46 waterbird species, whilst a combination of WBS/WBBS and BBS data contribute to estimates for 97 species. The role that BTO monitoring plays, through its engagement with thousands of citizen scientists, in delivering this foundational information cannot be overstated. The monitoring undertaken, especially by ringers, can also have an important conservation impact at a local level on land management (e.g. on the Ministry of Defense land at Pippingford and Foxglove Covert, celebrated in the most recent issue of MoD's *Sanctuary* magazine) and on the conservation of locally scarce species, for instance in promoting the conservation of Tree Sparrows *Passer montanus* in Wiltshire.

BTO research has contributed significantly to the conservation science evidence-base. Since 2012, papers have presented results for a minimum of 76 species, as well as 92 papers focussed on particular species groups (Figure 12). Whinchat, a rapidly declining long-distance migrant, benefits from the greatest number of publications, as a result of a successful PhD (Border 2015) and being the focus of fieldwork in Scotland and by staff in Thetford. A large number of papers on the Lesser Black-backed Gull result from a focused programme of tracking work, particularly to assess vulnerability to wind farms, but that also provide novel information about the ecology of the species, while studies of Blue and Great Tits *Parus major* have looked at the role of garden feeding in the urban environment (e.g. Harrison *et al.* 2013; Plummer *et al.* 2018), as well as impacts of climate change on breeding phenology (Phillimore *et al.* 2016; Burgess *et al.* 2018). Of the top 10 species, BTO publications have been informed by PhDs for five, each undertaken at a different university (Whinchat [Lancaster], Great Tit [Birmingham], Blue Tit [Exeter], Gannet [Liverpool], Willow Warbler [East Anglia]) and the provision of BTO analysis and advice supporting PhDs for a further two (Pied Flycatcher and Cuckoo [Aberdeen]), demonstrating the value of collaborative PhDs as a mechanism for delivering species-level information. Through collaboration, BTO research has also covered eight non-UK species, including contributing to international efforts to save the globally Critically Endangered Spoon-billed Sandpiper *Calidris pygmaea* from extinction (Zöckler *et al.* 2010; Clark *et al.* 2016; Aung *et al.* 2018). Additional to these species-focussed papers, many other conservation-relevant papers consider multiple species groups, with particular representation of seabirds, long-distance migrants, farmland, woodland and upland birds (Figure 13).

Thus, even excluding papers which have considered patterns across all species (e.g. Davey *et al.* 2012; Sullivan

et al. 2015), BTO research has provided useful information and evidence relevant to most UK bird species, as we have seen, addressing conservation issues as diverse as the impact of increasing deer species upon declining woodland breeding birds, identifying seabird foraging ranges to identify candidate marine protected areas and the impact of agri-environment schemes upon farmland birds. In addition to our own monitoring and research, we play an important role in providing advice and tools for other conservation organisations. This includes: provision of *Bird Atlas 2007–11* data to the SNCBs and RSPB to inform casework, planning and decision making; using modelled bird densities across the UK from Massimino *et al.* (2015) to support their spatial targeting of intervention; and the development of web-based tools to increase accessibility to data and information products, such as WeBS Report Online, BirdTrends and BirdTrack.

At a European level, we are contributing to debate around the extent of spring hunting allowable under the *Birds Directive* through the use of both BirdTrack (Gargallo & Baillie 2018; Massimino & Gillings 2018) and ringing/tracking data, where we are playing a leading role in the development of a *European Migration Atlas*, funded through the CMS (Baillie *et al.* 2018). BTO staff have also made significant contributions to the thinking and approaches of wider conservation policy and practice, for example through a range of policy and perspective-type journal articles covering issues as wide-ranging as woodland management (Fuller 2013), monitoring conservation interventions (Fuller *et al.* 2016), historical perspectives on conservation (Fuller *et al.* 2016) and open data (Pearce-Higgins *et al.* 2018). This has also extended to contributing to the development of the PRISM toolkit to help conservation organisations monitor the effectiveness of their actions. PRISM was led by BirdLife and funded through the CCI Conservation Initiative, with BTO contributing by authoring the guidance for species and habitats. This project has already been trialed to assess the impact of a range of CCI partner projects around the world, and has been well-received by the donor community.

In line with the three overarching questions outlined at the start of this review, our contributions to conservation science in the last few years have really been in three broad areas: methodological development to inform studies of particular species or species groups, analyses to understand causes of change, and the testing of conservation solutions.

METHODOLOGICAL DEVELOPMENT

With our wide expertise in field ornithology, we continue to improve methods for surveying and counting bird species. BTO has led trials of methods to survey a range of species from owls (Clewley *et al.* 2016; Worthington-Hill & Conway 2017) to Nightingales (Hewson *et al.* 2018), where particularly difficult issues of nocturnal behaviour, or uncertain detectability, exist. This latter study presented novel methodological recommendations for estimating national population sizes and identifying key sites for dispersed species,and provided important evidence to inform the debate and potential public enquiry about proposed residential development at Chattenden Woods and Lodge Hill SSSI, Kent, which this work has shown supports the largest remaining Nightingale population in the UK and more than 1% of the national population.

Even the methods associated with the surveying or analyses of established schemes are under continual review and development. For example, in relation to BBS, BTO has undertaken analyses of the importance of detectability in determining population trends and estimates of abundance (e.g. Johnston *et al.* 2014; Newson *et al.* 2013), as well as trialling, and then implementing, changes to the BBS methodology in 2014 to allow more information about species detection to be captured. In relation to WeBS, analytical developments have been undertaken to deliver improved representation of population trends and estimates (Chamberlain *et al.* 2013; Méndez *et al.* 2015). Development of new analytical methods to better describe underlying processes (e.g. Miller *et al.* 2017) will be key to making full use of demographic data; we are increasingly integrating the results from our demographic schemes by developing integrated population models, which deliver important understanding of the demographic processes underpinning species population trends, and require the development of new analytical approaches (Robinson *et al.* 2012; 2014).

BTO design of citizen science schemes, and development of the appropriate analytical methods to make the most of the resulting data, is an important element of these schemes being run by a science-focussed organisation that also leads on research being undertaken from those schemes. This means that the scientists involved in analysing the results of these data for research purposes also play a part in the design and development of those schemes (Pearce-Higgins *et al.* 2018), meaning they are more likely to be optimally developed for both monitoring and research purposes, as well as for engagement. Although much of this development occurs in house, BTO has also worked through collaboration with others, particularly statisticians from other organisations with expertise in sampling design (e.g. Buckland *et al.* 2012), analytical methods (e.g. Swallow *et al.* 2016a, 2016b; Elston *et al.* 2017; Mcmahon *et al.* 2017; Jones-Todd et al. 2018) and reporting (e.g. Studeny *et al.* 2013; Harrison *et al.* 2014, 2016, Yuan *et al.* 2016) to develop improved design, analysis and reporting of citizen science schemes.

Building on this expertise of citizen science approaches to bird monitoring, and recognising the need for wider collaboration across the sector, the BTO has worked extensively with others during the last few years to improve the monitoring and reporting of wider biodiversity trends. For example, the BBS scheme provides the best annual monitoring data for nine British mammal species (Wright *et al.* 2015), with sufficient coverage to describe spatial variation in those trends (Massimino *et al.* 2018). This information has already contributed to the identification of previously undetected large-scale declines in Mountain Hare *Lepus timidus* populations in the Highlands of Scotland, supporting the results of other analyses (Watson & Wilson 2018), and contributing to discussions about the conservation status of the species, and the extent to which upland land management is detrimental to their conservation status (https: //www.britishecologicalsociety.org/policy/policy-networks/scottish-policy/).

Figure 12. The number of BTO papers focussed (covering <5 species) on particular species, published from 2012-2018. Colours indicate the Birds of Conservation Concern status.

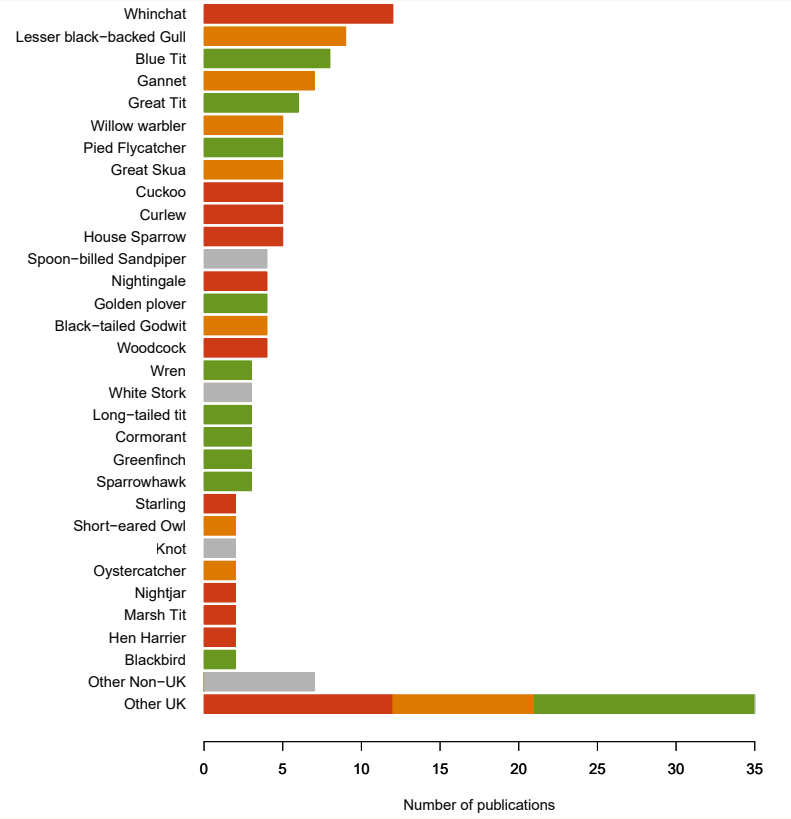
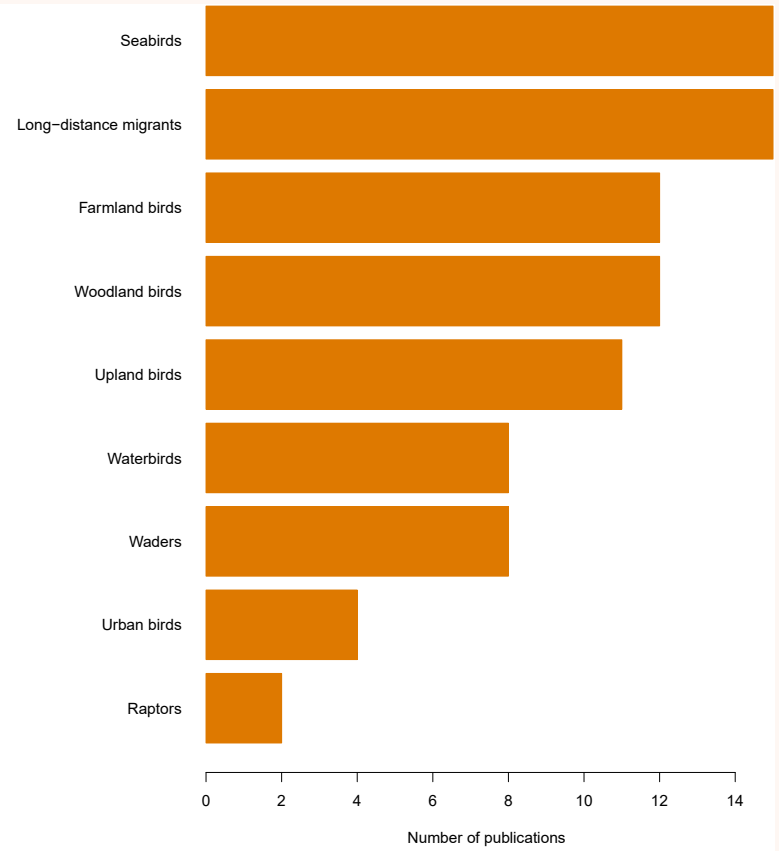


Figure 13. The number of multi-species (5+ species) BTO papers published from 2012–2018



There is potential for our network of volunteers to assist with the monitoring of habitat change, or ground-truthing of Earth observation data, as analyses of the habitat data recorded annually by BBS surveyors have identified spatial patterns and trends in habitat measures across the British countryside that are in many cases consistent with other independent data (Martay *et al.* 2018). This question was investigated in more detail in a Defra-funded project to assess how volunteers could help to ground-truth *Living Maps* (Newson *et al.* 2016). Using the pilot Living Map of Norfolk as a case study, we worked with the local data centre, Norfolk Biodiversity Information Systems (NBIS), to interview and understand volunteer motivations and capacities for validating the map. We tested what strategies might be employed to decide which sample squares to visit to ensure enough different parcels of land were checked and we reviewed existing web and smartphone applications to identify what technology could make the task easier. Following this work, we are in a better position to ensure that local knowledge and expertise of volunteers is used to best effect in the monitoring of the nation's habitats.

The BTO has also led the development of novel approaches to the monitoring of other taxa. The Norfolk Bat Survey, established in 2013 in collaboration with NBIS, pioneered a novel citizen science approach to bat monitoring by enabling volunteers to borrow expensive passive bat detectors, which they would deploy, and then submit the memory cards for analysis by BTO. The volunteers receive feedback on the bats recorded, while the data are captured by BTO for modelling and reporting (Newson *et al.* 2015). We are also exploring, with others, the use of machine learning techniques to better process and analyse recordings (Guyot *et al.* 2016; Mac Aodha *et al.* 2018). Further analyses of the sound recordings has identified that bush crickets can be monitored at the same time (Newson *et al.* 2017), with ongoing analysis to consider the contribution that such passive recording could make to bird monitoring.

This project has engaged over 1,200 volunteers in Norfolk and Suffolk over five years, delivering fine-grain information on the distribution of 12 bat species across both counties (Newson & Parry 2018). Analyses of these data have ranked bats according to their sensitivity to human habitation (Border *et al.* 2017), enabling a geographical tool to be developed to identify populations of bats vulnerable to development, and which is being used by Norfolk County Council to inform urban planning. This scheme approach was successfully extended to southern Scotland in 2016, providing enough data to develop maps of likely sensitivity to wind farm development (Newson *et al.* 2017), and to provide baseline data for the North Yorkshire Moors in 2018. Similar approaches have been started in Devon by Devon Wildlife Trust and Wales by the Bat Conservation Trust, with input from the BTO, and is now being used to inform the design of a new national bat monitoring programme (http: //www.bats.org.uk/pages/british_bat_survey.html), which has included the development of an online portal to return survey results to volunteers, piloted here on Norfolk data https: //app.bto.org/bat-vis/NorfolkBatSurvey/

CAUSES OF CHANGE AND TESTING SOLUTIONS

During the 2012 period onward, long-distance migratory passerines and breeding waders have been a particular focus of research to understand their causes of decline.

LONG-DISTANCE MIGRANTS

BTO work on long-distance migratory species over this period has covered two complementary approaches – the deployment of new tracking devices to understand the ecology, movements and non-breeding locations of individuals from breeding populations, many of which are declining, and analyses of long-term monitoring data to identify drivers of population change. A total of 12 species have been tracked by the BTO, of which nine have been led, or jointly led, by BTO (Nightjar, Swift *Apus apus*, Cuckoo, Whinchat, Tree Pipit, Nightingale, Spotted Flycatcher *Muscicapa striata*, Wood Warbler *Phylloscopus sibilatrix* and Willow Warbler). These studies have so far led to 8 publications, with more currently being developed. Importantly, the results have also stimulated considerable public interest and engagement through articles in the news media. For example, the BTO tracking of Cuckoos from 2011 onwards, has so far delivered an important and high profile publication (Hewson *et al.* 2016) demonstrating a link between differing survival rates on migratory routes linked to geographical location and long-term breeding population trend and providing the first evidence on the potential causes of decline of the species. This work has also had a very high public profile, with the routes of the cuckoos revealed in almost real-time through dedicated pages on our website that receive in excess of 70,000 page views per annum and further disseminated through an exclusive article in *The Independent* newspaper. The individual birds have been followed on the BBC's Springwatch programme, whilst the publication of the paper and other major milestones and events in the project have been accompanied by multiple national written and broadcast news reports (including BBC Radio 4's flagship *Today* programme) and many appearances in local and regional media. Over 3,000 individuals have invested financially to support the work through the sponsorship of individual Cuckoos. This work has been complemented by further collaborative analyses of correlates of change of Cuckoo breeding populations in the UK using BBS data (Denerley *et al.* 2018), and potential effects of mismatch on Cuckoos (Douglas *et al.* 2010).

Tracking of Nightjars, and Swifts has also been used, in collaboration with data from elsewhere in Europe to identify migratory routes and patterns of connectivity with the wintering grounds in Africa. This complements information from the tracking of habitat-use by breeding birds in Thetford Forest for NIghtjars using GPS tags achieved through a combination of BTO research, PhD studentships and volunteer staff time (Evens *et al.* 2017; Sharps *et al.* 2015), and has delivered important information for the Forestry Commission assisting them with the management of Thetford Forest and their wider estate (see above section on forestry). Similar work elsewhere in East Anglia has provided novel information on ranging behaviour and habitat use of breeding Swifts while BTO expertise gained from this project has enabled development of a collaborative project with

RSPB on foraging behaviour in Northern Ireland. Future plans will see this work both provide extensive information about the behaviour of breeding swifts that will have implications for urban and rural planning as well as engagement opportunities within urban areas occupied by Swifts.

The tracking work on long-distance migrants has been complemented by extensive analyses of the population trends of these species to further understand causes of change. There is a long-history of analyses of CBC and BBS population time-series demonstrating the role that conditions in Africa may play in driving population trends and fluctuations in these species. Analyses of these data revealed that species wintering in the humid tropics of West and Central Africa were those in decline more recently, with declines of species wintering in the arid zone just south of the Sahara being primarily restricted to the period between the late 1960s and mid 1980s (Hewson & Noble 2009, Thaxter *et al.* 2010). These findings, together with results from the Repeat Woodland Bird Survey (Hewson *et al.* 2007), were amongst those instrumental in CMS adopting the African Eurasian Migratory Land Birds Action Plan (AEMLAP).

More recently, these relationships have been extended by new analyses of BBS data (Ockendon *et al.* 2014a), and novel analyses of annual and spatial variation in warbler survival rates across Europe using CES data (Johnston *et al.* 2016). Importantly, this second paper suggested that declining species were those with the weakest link between population growth rates and survival, indicating that causes of decline may be driven by variation in breeding success rather than survival, as has been demonstrated for the Willow Warbler (Morrison *et al.* 2016a). A complementary analysis of the EuroCES data found significant relationships between productivity and breeding season temperature and latitude consistent with the idea of there being optimum climatic conditions for the productivity of these warbler species across Europe (Eglington *et al.* 2015), and evidence that productivity declines in years when temperature departs from the climatic average. Further analyses identified potential carry-over effects of African weather conditions and passage conditions in southern Europe upon the timing of breeding and clutch size in some UK breeding migratory bird species (Ockendon *et al.* 2014b; Finch *et al.* 2014), although the overall magnitude of these impacts were relatively small compared to effects of breeding season weather conditions. These results suggest that deterioration of breeding conditions in the UK is playing an important role in the population declines of long-distance migrants. Although further work on additional species is required to understand the causes of relationships between wintering location and population trend and the diversity of demographic drivers of declines, studies of species such as Cuckoo and Willow Warbler demonstrate that the combination of tracking studies and analyses of long-term demographic data will continue to provide important insights into the causes of the decline of these species, as a precursor to informing appropriate conservation responses.

BREEDING WADERS

BTO has a long track record of research on waders, but breeding populations, particularly Curlew, have been a significant focus since 2014, following a successful appeal that focussed on this species. This appeal, which made considerable use of BTO monitoring data to flag up the long-term decline in British breeding and wintering Curlew, and concerns over the conservation status of the species, helped raise public awareness of the issue. Working closely with RSPB, BTO staff led an expert-based review of global threats to the Numeniini, the tribe that includes curlews (genus *Numenius*) and godwits (genus *Limosa*). Of the 13 species covered, seven are of global conservation concern. This workshop was written up by RSPB for the Eleventh CMS CoP, and led to a peer-reviewed publication (Pearce-Higgins *et al.* 2017) which has the highest Altmetric score (124) from the journal (*Bird Conservation International*). It was reported on the Radio 4 *Today* programme, resulting in the story being summarised on the BBC website in comic-book style. The article was also summarised in other media outlets, including in a high profile blog.

Subsequently, an analysis of the drivers of national-scale declines in Curlew in the UK identified detrimental land management, predator population and climatic trends as contributing to a 50% decline in numbers of this species across the UK since the mid-1990s, which is now in danger of extinction in Ireland and Wales (Franks *et al.* 2017). With an Altmetric score of 209, also the highest for the journal (*Bird Study*) this work has received significant public attention, with significant news coverage and articles written for a number of more popular publications, ranging from *The Field* to *BTO News*. These findings have been widely presented at regional and national events held around Curlew conservation in the Republic of Ireland, Northern Ireland, Wales, Scotland and England, including at a summit hosted by HRH, the Prince of Wales. Complementary to this, a review of the effectiveness of conservation interventions for grassland breeding waders across Europe (Franks *et al.* 2018), undertaken with EU funding in collaboration with Sovon, provides important evidence in support of the effectiveness of agri-environment schemes, particularly higher-tier schemes for breeding waders. This work has fed into a BirdLife International-led multi-species action plan for breeding waders compiled by Leyrer *et al.* (2018), as well as providing important evidence to inform the development of species action plans in Northern Ireland and Scotland.

6. SCIENTIFIC SUPPORT IN THE WIDER SECTOR

The success of the partnership approach of BTO to biodiversity research and monitoring is underlined by the role that the organisation plays in delivering significant infrastructure and capability for use by the wider academic, conservation and policy-communities to achieve greater impact. Furthermore, the staff and volunteers of the BTO, in an individual capacity, fulfil a wide range of roles in the wider community that deliver significant impact beyond the direct work of the organisation. These contributions, which are

sometimes less closely tied to the direct scientific work of the organisation but can be a mechanism to achieve significant impact, are the focus of this section of the review.

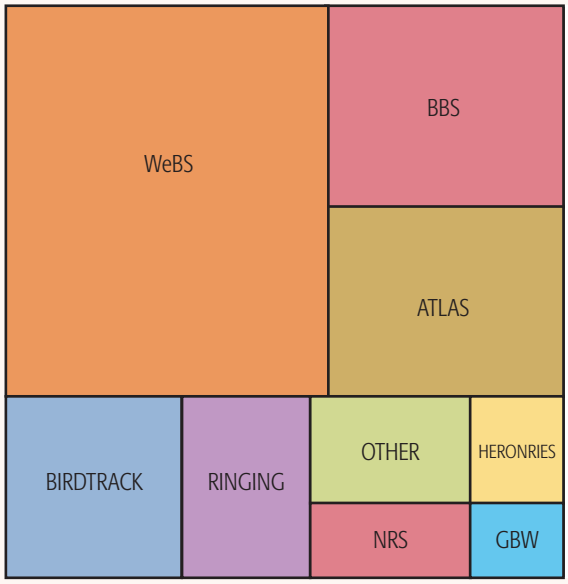
Members of staff serve on the Boards of a number of organisations, both in the UK (e.g. British Ornithologists' Union, National Forum for Biological Recording, Natural England, Scottish Ornithologists' Club and Welsh Ornithological Society) and overseas (e.g. Euring, European Bird Census Council, Ornithological Society of the Middle East, World Seabird Union). They also serve on a range of Committees (including for the UNEP African-Eurasian Waterbirds Agreement, British Ecological Society, International Wader Study Group, National Biodiversity Network, New Networks for Nature, Tracking Mammals Partnership and UK Seabird Monitoring Programme) and Expert and Working Groups, again both nationally (e.g. the Science Advisory Committees of NE and SNH, Defra's Ornithological Expert Panel, JNCC's Avian Population Estimates Panel, NRW's Fish-eating Birds Advisory Group) and internationally (e.g. CMS Energy Task Force, IUCN Climate Change Specialist Group, Joint Working Group on Birds for the ICES/HELCOM/OSPAR Conventions, Pan-European Common Bird Monitoring Steering Group). BTO produces two journals (*Bird Study* and *Ringing & Migration*) – which together publish c. 80 papers annually, provides senior editors for two (*Bird Conservation International* and *Wader Study*) and Associate/Subject Editors for six more (*Animal Conservation*, *Ibis*, *Journal of Applied Ecology*, *Oikos*, *Ornis Fennica*, *British Birds*).

BTO data are subject to about 500 requests per year, of which about 200 are for WeBS data, particularly from consultancies to inform impact assessment, and many of the others are for Atlas, BBS and BirdTrack data (Figure 14). Although BTO has marshalled sector-wide concerns about certain models of open data dependent upon mandatory archiving by third-parties (Pearce-Higgins *et al.* 2018), data are generally made available for wider use and collaboration by students, academics and conservation organisations through this request service, achieving considerable additional impact from the monitoring that we undertake.

In addition to BTO data, the wider infrastructure of BTO Regional Representatives, Scheme Ambassadors and mentors/trainers provide an invaluable resource that delivers significant reach for the organisation. Many of these volunteers play an important role in regional ornithology, organising local or single-species surveys. For example, associated with the *Bird Atlas 2007–11*, many counties also undertook their own detailed bird atlas projects, leading to 25 local atlases being published, delivering significant additional information for the public, for local conservationists and decision makers.

BTO is licensed by each of the SNCBs under the *Wildlife and Countryside Act 1981* (as amended) to "take wild birds for the purposes of ringing or examining any ring mark", which we achieve through training and authorising ringers. Similar legislation exists in the Republic of Ireland, and BTO welcomes Irish ringers as part of its scheme as a service to the Irish statutory agency (the National Parks and Wildlife

Figure 14. Source of external data requests to the BTO in 2017.



Service). Certain species are considered particularly sensitive, either because of their scarcity or susceptibility to disturbance; these are listed under Schedule 1 of the Act, and BTO administers a licensing process (again on behalf of the UK SNCBs) for working with these species during the breeding season. This infrastructure supports a wide range of survey, ringing, tracking and other activities in Great Britain and Ireland. Between 2012 and 2018, a total of 4,338 individuals (2,795 with full permits, and 1,543 as trainees) were licensed to undertake bird ringing, and 713 with Schedule 1 licenses to work with protected species were granted. BTO has recently reviewed the risks associated with ringing (Clewley *et al.* 2018), as a means for identifying the risks to the birds involved of this activity and actions that should be taken to mitigate them. At the 2017 partnership meeting between the UK Government Home Office Inspectorate and BTO, the Home Office 'recognised this is the area of wildlife that they have good security in, and appreciated the hard work of the BTO in enabling this.'

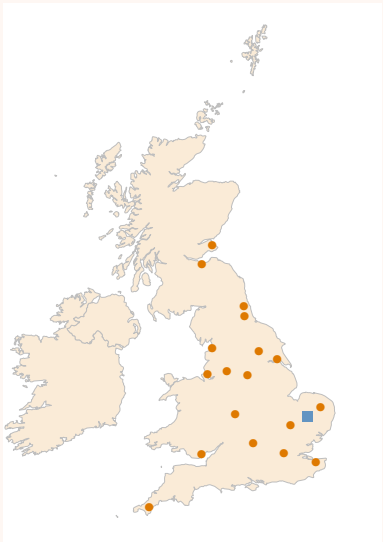
Increasingly, researchers are marking individual birds with electronic tags or devices that are revolutionising our knowledge of bird movements and behaviour. To ensure high welfare standards are maintained, these activities are overseen by a Special Methods Technical Panel (SMTP) of the BTO Ringing Committee, comprising experienced ringers and veterinarians serving in a voluntary capacity, who consider particularly complex or uncertain applications in detail. This function underpins a large volume of scientific research, for example, around 70 papers involved the tracking of birds from the UK in this period. In 2017, a total of 2,100 endorsements were issued for 645 projects (of which 108 were new and 69 required individual review); of these 283 actively marked birds involving 11,154 individual birds of 90 species. BTO has recently undertaken a review of the impact of such devices by reviewing in excess of 3,400 published studies since the 1960s and summarising those that showed

some level of effect (~1,500 studies), ranging from minor behavioural alterations to mortality of individuals (Geen *et al.* 2019). The database underlying this study has been made available to ringing scheme organisers across Europe, through the EURING network, in order to improve welfare decisions more widely.

More specifically, BTO has led the development and testing of harnesses for the tracking of a range of seabird species (Thaxter *et al.* 2014, 2016), as well as contributing to equivalent development on other species (e.g. Bell *et al.* 2017; Blackburn *et al.* 2016); and we continue to improve ways of deploying 'old' methods, such as colour flags (Clark *et al.* 2005; Tucker *et al.* in press). Through collaboration, BTO has also assisted with the development of methods for the analyses of bird movements, particularly from geolocator data (e.g. Lisovski *et al.* 2012, 2018) and ringing recoveries (e.g. Ambrosini *et al.* 2014; du Feu *et al.* 2016; Thorup *et al.* 2014), and has also been involved in testing new methods for habitat recording relevant to birds and other biodiversity (Eichorn *et al.* 2017; Rhodes *et al.* 2015; Sullivan *et al.* 2017).

BTO expertise in ringing, more generally, is widely recognised, with several overseas schemes adapting the rules and guidance of the British and Irish ringing scheme (Redfern & Clark 2002) to local conditions. BTO ringers are also active abroad, training and mentoring others. One particularly good example of this, involves monitoring of west Atlantic flyway population of Knot *Calidris canutus rufa,* which was established in 1998 as a collaborative effort with local state agency staff in Delaware and New Jersey and BTO ringers (and, initially at least, staff). Information gathered through sustained fieldwork since has led to recognition of the population's conservation needs, with listing under the Endangered Species Act (Niles *et al.* 2007) and a formal adaptive management plan to manage conflicts between human and bird use of their primary food resource on spring migration (Niles *et al.* 2009; McGowan *et al.* 2015).

Figure 15. Map showing location of universities with whom BTO (square) co-supervised students 2012–18.



BTO also supports the next generation of scientists by being actively involved in supervising post-graduate students at both Masters and Doctoral level. We are involved as a formal partner in four of NERC's Doctoral Training Partnerships, notably the ARIES Partnership, where we are a hosting organisation, along with the Universities of East Anglia, Essex, Kent and Plymouth. During the period of this review, the BTO has been involved in the direct supervision of 38 PhDs involving students from 18 universities (Figure 15) and seven Masters projects, which have resulted in 48 papers. Of those whose current position post-graduation is known, five have continued working in universities, five are working in non-university research roles (including two current BTO staff members) and two are working elsewhere in the biodiversity sector.

7. CONCLUSIONS

'The BTO provides that infrastructure for surveys and ringing which enable an amateur like me to do things.' (Holland 2018).

Using a combination of professional and citizen science, BTO aims to document the status of populations and the causes of changes, the processes behind observed ecological patterns, and to inform the sustainable management of species and habitats. Most of this work has a national UK focus, but also includes more local or regional studies, or larger-scale research across Europe and even globally. In this report, we have documented the impact of BTO science by considering the knowledge gained and made available, the effect of this information on policy and management decisions, and the impact on particular species and habitats. In addition, we also consider the effect of our work on people and society and BTOs capacity-building role across the conservation and academic sectors.

Although the focus of this review is on the last six years, from 2012–18, much of our work has longer-term impact, as a result, some of the science documented in this report was undertaken outside of this period, but has delivered impact more recently. We also recognise the difficulty in attributing impact to specific pieces of research, particularly when considering impact on wider policy and management decisions. Increasingly, science needs to be collaborative and cooperative to deliver the large-scale impact we seek on species and habitats. This report therefore includes a combination of work that BTO has done alone, that BTO has led in collaboration with others, work that has been led by others, but in collaboration with the BTO, or that has used BTO data. Looking to the future we will ensure our rigorous monitoring continues, and further develop our reporting to ensure that it is timely, accessible and delivers greatest impact.

During the last six years, BTO has made significant contributions to knowledge about our avifauna, and ecosystems more widely. Our surveys have particularly highlighted large declines in long-distance migrants,

particularly in south-eastern England; upland birds, particularly ground-nesting waders; and populations of birds in the urban environment. Programmes of research have significantly advanced our understanding about the potential impacts of marine renewables upon seabirds, the impacts of climate change on UK biodiversity, and the migration and population dynamics of Afro-Palaearctic migrants. Understanding the complex nature of the processes governing these iconic species will be a major priority in the coming years, bringing together detailed understanding of individual decisions, revealed through our tracking work, and population consequences, from our wider large-scale demographic datasets to identify conservation priorities.

The monitoring and abundance data generated by BTO schemes are foundational to assessing species' conservation status and the reporting of progress against national and international biodiversity targets and indicators. These data are invaluable to support casework, and to inform planning decisions, particularly around major infrastructure projects, renewable energy development and urban planning. Research on farmland birds has been instrumental to the design of agri-environment schemes (AES), and with the Forestry Commission improving forestry practice. There are ambitious targets for woodland expansion in each of the UK countries, but especially in Scotland. Our research will provide evidence on the benefits of this, or otherwise, to different bird species and assemblages to guide forest management (of both commercial and utility function), increasing their contribution to our net natural capital.

BTO evidence and guidance has improved approaches to environmental impact assessment, particularly for offshore wind farms. Projections to identify species' vulnerability to climate change have provided important information for Statutory Nature Conservation Bodies and conservation NGOs, and contributed to the EU fitness check of Birds and Habitats Directive. These impacts have generally occurred through research that has been commissioned and funded by government (notably DECC, Defra) and the SCNBs to address a particular policy or evidence need. This co-design of research is important, but has become increasingly difficult as public sector funding for research has diminished over the last decade, and due to losses in and turnover of civil servants working on relevant areas of work. An ethos of co-designing robust research will be critical in addressing one of the UK's most pressing conservation needs, that of declining breeding waders. We will aim to bring together stakeholders from different backgrounds, both to improve understanding of the causes of declines, and how they may be reversed, but also to engage non-traditional audiences with the science in a manner relevant to them, to create a legacy of better land management practices.

There is increased recognition of the impact of BTO science upon people and society, although robustly quantifying such impacts is challenging. By engaging thousands of volunteers, BTO monitoring schemes is estimated to support up to £100 million of health and well-being benefits; this figure depends upon the economic model used and assumptions made, something which BTO could address through its experience with its volunteer network. We also provide important information about garden feeding and inform best practice across what is a £200 million industry annually. More generally, we encourage and support engagement with nature, and improve the public understanding of science and the natural world, either locally to Thetford and Norfolk where we have the greatest presence, or more widely through the BTO website. One project alone has engaged more than 12,000 school children in collecting data that have contributed to peer-reviewed science. However, even with a volunteer force of 50,000, and a membership of 19,000 people, only a small fraction of the public actively engage with BTO, which will be important to expand in order to increase BTO impact in future. Expanding BTO's reach into, and influence on, urban areas will be one way to achieve this. We will combine traditional approaches, such as evaluating habitat effects on abundance, with new perspectives focused on advising planning and development, or on human perception of local biodiversity. The aim will be to open up a new dimension in planning and development, whereby quantitative predictions of biodiversity consequences are used to maximize the presence and exposure to people of wildlife as new developments are planned and constructed or as older areas are renovated.

The final component of BTO impact that we considered was in terms of collaboration and capacity building. BTO has been providing a wide-range of openly available data and information products and collaborated with well over 100 organisations, from academic staff at universities to NGOs and industry, extending our reach and impact, whilst also complementing and supporting others' expertise. Expanding collaboration has been an organisational priority that has delivered additional impact. The BTO volunteer network is used to gather additional information on other components of the environment, such as the surveillance of animal disease and to support other monitoring schemes, such as on butterflies and plants. BTO staff have a strong track-record in the development of field survey and analytical methods, not just relevant to birds, but a wide range of other taxa from moths to bats. We will continue to use our expertise to support and improve monitoring of taxa not covered by our schemes. An immediate priority, in this respect, will be contributing to a review of monitoring of our globally important seabird populations, to ensure they are appropriately valued, and decisions about them and their habitats are informed by the best evidence.

To conclude, it is clear that the sorts of data and information which BTO science provides will continue to be important. The combination of professional and citizen science delivers large-scale and long-term environmental monitoring in a manner that is relatively efficient for the public purse, whilst also delivering multiple additional benefits to society. This information will be valuable at a range of scales, from local decision making, to national-scale reporting against international targets. BTO will continue to focus on delivering policy-relevant science for impact. In the face of ongoing challenges with public-sector funding and capacity, this will require innovative approaches to maximise the ability of our science to affect policy and management, and ultimately to

make a difference to species and habitats. Increased working in partnership and collaboration will help address some of these issues, whilst at the same time we will need to engage new audiences with our science, and to expand our profile with the public to secure a firmer supporter base. This will widen the societal impact of our work. Although the future is uncertain, BTO's approach to science should provide the tools and information required to document and understand change, and to inform decision-making. Doing so will be our contribution towards a world inspired by birds, and informed by science.

ACKNOWLEDGEMENTS

This document represents the collective input of BTO staff from across the organisation. The following deserve particular recognition for leading on the writing of key sections: Gavin Siriwardena (farming, urban landscapes, valuing nature and ecosystem services), Kate Plummer (urban landscapes), John Calladine and Ian Henderson (afforestation and forestry) Niall Burton (changing seas), David Noble (non-native species), Mike Toms (art and culture) and Chris Hewson (long-distance migrants). This work was overseen by a steering group of James Pearce-Higgins, Rob Robinson, Rachel Taylor, Emma Douglas, Stuart Bearhop (University of Exeter), Andrew Watkinson (UEA), Jenny Gill (UEA) and Stephen Lee (CASS Business School), with additional input from Mike Toms, Ieuan Evans and Andy Clements. We are grateful to them all. Finally, BTO science would not exist without our network of volunteers, regional organisers, supporters, trainers and mentors; we hope they feel the impacts outlined here do justice to their unstinting efforts.

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COLLABORATORS

There follows a list of our major scientific collaborators during the period, grouped by broad sector type.

ACADEMIC

Bangor University
Cardiff University
Cambridge Conservation Initiative
Centre for Ecology and Hydrology
Cranfield University
Durham University
James Hutton Institute
Lancaster University
Newcastle University
Queen's University, Belfast
Rothamsted Research
Royal Holloway, University of London
University College, London
University of Aberdeen
University of Birmingham
University of Bristol
University of Cambridge
University of East Anglia
University of Edinburgh
University of Exeter
University of Glasgow
University of Highlands and Islands
University of Hull
University of Kent
University of Leeds
University of Reading
University of Sheffield
University of St Andrews
University of Stirling
University of Sussex
University of York
Zoological Society of London

CORPORATE

Anglian Water Group
APEM
Bureau Waardenburg BV
Cambridge Conservation Initiative
COWRIE (Collaborative Offshore Wind Research Into The Environment)
DONG Energy
EDF Energy
Environment Resources Management
Essex and Suffolk Water
HiDef Aerial Surveying
Marshall Agroecology
NIRAS Consulting Ltd.
Northumbrian Water Ltd.
National Rail
Syngenta
Tidal Lagoon Power
Unilever

GOVERNMENT AND STATUTORY AGENCIES

Animal and Plant Health Agency
Animal Health & Veterinary Laboratories Agency
BioSS
Breckland Council
Cairngorms National Park Authority
Centre for Environment, Fisheries and Aquaculture Science
Conwy County Borough Council
Country Land and Business Association
Crown Estate
Delaware Dept of Natural Resources & Environmental Control
Department for Business, Enterprise and Skills
Department of Energy and Climate Change
Department of the Environment, Food & Rural Affairs
Environment & Heritage Service in Northern Ireland
Environment Agency
Forest Research
Forestry Commission
Forestry Commission Scotland
Joint Nature Conservation Committee
Marine Scotland Science
Ministry of Defence
Natural England
Natural Resources Wales
Northern Ireland Environment Agency
New Jersey Division of Fish and Wildlife
Norfolk County Council
Scottish Government
Scottish Environment Protection Agency
Scottish Natural Heritage
Suffolk County Council
Welsh Government
Yorkshire Dales National Park Authority

NON-GOVERNMENTAL AND CONSERVATION ORGANISATIONS

ADAS
Amphibian and Reptile Conservation
Bat Conservation Trust
Biological Records Centre
BirdLife International
BirdWatch Ireland
British Association for Shooting and Conservation
British Dragonfly Society
Broads Authority
Butterfly Conservation
Cairngorm National Park
Dartmoor National Park Authority
Devon Birdwatching and Preservation Society
Devon Wildlife Trust
Durrell Institute of Conservation and Ecology
Fera UK Ltd
FrogLife
Game & Wildlife Conservation Trust
Mammal Society
Manx BirdLife
National Farmers Union
National Trust
National Trust for Scotland
Natural History Museum
Norfolk Biodiversity Information Services
Norfolk Ornithologists' Association
North Wales Wildlife Trust
Northern Ireland Raptor Study Group
Royal Society for the Protection of Birds
RSWT
Scottish Ornithologists' Club
Scottish Raptor Study Group
Welsh Ornithological Society
Wetlands International
Wildfowl & Wetlands Trust
Woodland Trust Scotland

OVERSEAS ORGANISATIONS

Carleton University, Ottawa, Canada,
CNRS-CEFE, Montpellier, France
CNRS-CEBC, Chizé, France
CNRS & University of Rennes, France
CTFC, Solsona, Spain
Czech Society for Ornithology, Czechia
DHI (Henrik Skov & co)
European Union of Ringing Schemes (Euring)
Euro Bird Portal
European Bird Census Council
Fondation Tour du Valat, Arles, France
Georg-August University Göttingen, Germany
Helmholz Centre for Environmental Research, Germany
Institute of Avian Research, Germany
Institute for European Environmental Policy
Institute of Catalan Ornithology, Spain
INRA-Toulouse, France
Joint Research Centre, European Commission
Michigan State University
Muséum National d'Histoire Naturelle, Paris
SOVON, The Netherlands
Swiss Ornithological Institute, Sempach, Switzerland
University of Lund, Sweden
University of Hasselt, Belgium
University of Turin, Italy

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Image: Nuthatch, by Edmund Fellowes.

A world informed by science: the impact of BTO in 2012–18

This report provides an assessment of the impact of BTO science over the period 2012–2018, measured in terms of knowledge and information, policies and management, species and habitats, people and society and collaboration and capacity building.

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