The Bernard Tucker Memorial Lecture

The RSPB Centre for Conservation Science: developing evidence-based solutions to address the biodiversity crisis

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Andrew Callender

3. Tristan Albatross *Diomedea dabbenena* with chick, Gough Island, September 2019.

Abstract We live in an era thought by many to represent the sixth mass extinction event, but the first driven by human activity alone: the 'anthropocene' (Johnson *et al.* 2017). There is growing recognition that the fate of nature and humankind are closely interlinked, and that nature underpins our economies, our health and social wellbeing. Against the backcloth of biodiversity in crisis, the RSPB Centre for Conservation Science was established in 2014. Its aim is to identify, provide and interpret the scientific evidence needed to help the RSPB and others to make informed decisions on biodiversity conservation and the environment. This paper, presented originally as the Bernard Tucker Memorial Lecture in 2018, highlights the work of the Centre and introduces its adopted model of conservation. The paper is illustrated with examples of conservation action and science from the UK and overseas.

Introduction

From its roots, the RSPB has focused on the protection of birds and their habitats. While that remains a key goal, and an area where, in collaboration with many partners, it has a record of success, the Society is increasingly working to save nature in a broader sense. That means working on a great variety of taxa and tackling a wide range of environmental pressures (such as land-use change, environmental pollution, invasive alien species and climate change) and their drivers.

The RSPB is the largest UK conservation charity, supported by over a million members, with a remit encompassing both national and international conservation issues. Its overseas work is carried out primarily with BirdLife International partners, focusing on the 14 UK Overseas Territories, home to an array of diverse but highly threatened wildlife, including albatrosses, penguins and parrots. The RSPB seeks to recover populations of highly threatened species and to protect, restore and manage habitats for wildlife, both within its UK nature reserves and elsewhere. It also acts to influence national and international environmental ambition and policies, and to encourage sustainable living across society and in different policy sectors. The Society prides itself on being an evidence-led organisation seeking, where possible, to find practical solutions to the most pressing environmental issues.

The RSPB established its Centre for Conservation Science in 2014, the aim of which is to develop evidence-based solutions to address the biodiversity crisis and to bridge the gap between science, policy and practice (www.rspb.org.uk/our-work/conservation/centre-for-conservation-science/). RSPB's current priorities are to intervene to save species and sites directly; to empower more people to act on behalf of nature; and to work with partners and other organisations to tackle the drivers that threaten our vision for a world richer in nature.

The investment in conservation science helps to keep the RSPB focused, successful and credible, and to ensure that policies and practice are based on sound evidence. Our scientists help to identify and prioritise conservation problems, diagnose their causes, discover solutions, and then test the efficacy of those solutions when implemented. The science team comprises more than 50 scientists, as well as technical and administrative support staff, based at more than a dozen locations in the UK, and working on issues across the world. We employ short-term staff to help us with the 50 or more projects that we run each year, and in addition have affiliations with over 20 PhD students, and a growing number of Masters students each year. Project funding comes from our members and supporters and from many partners and funders. Much of our science is undertaken in partnership with others, including NGOs, universities, institutes, statutory agencies and government departments. We publish our results in the peer-reviewed scientific literature, generating about 100 scientific papers each year. A recent assessment ranked the RSPB fourth highest for citations in the field of environment and ecology out of 61 UK institutions, including all universities (see also Butchart *et al.* 2019). We also publicise our work in the general media and, increasingly, on social media (@RSPBScience). While scientific publications represent one tangible product from our work, our ultimate aim is to have a positive impact on conservation, which is more difficult to measure.

The starting point for conservation

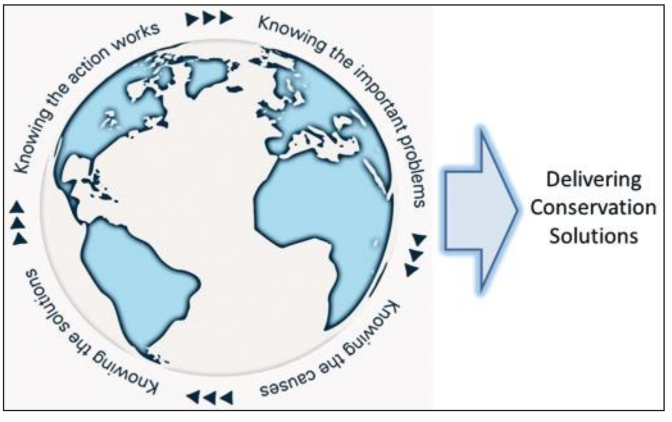

Fig. 1. The RSPB Centre for Conservation Science model for conservation science delivery.

science is to identify and prioritise the most important conservation issues (Gibbons *et al.* 2011; Gibbons 2016; fig. 1). We do this by conducting and supporting monitoring schemes and surveys, often in close collaboration with expert partners. Typically, the RSPB provides part funding for such programmes and is part of the process of survey design and operation. Monitoring allows us to identify the species that are most threatened, the sites that are most important to protect, and the environmental challenges that are the most pressing to tackle. These biological priorities frame much of our work. We also try to look ahead, to assess the likely impact of factors such as new technology, changing patterns of land use and climate, industrial and social developments, and government and international policies on nature (see Sutherland *et al.* 2018).

Once the key conservation problems are identified, we need to diagnose their causes. This generally involves painstaking and careful detective work, often focused on single species, or groups of species. Typically, it might involve comparative or experimental field-based studies of wildlife populations to understand their ecological requirements and what drives population change. For birds, this might involve locating nests, measuring breeding success and survival, and marking individual birds in different habitats or regions to follow their life history in detail.

If all goes well, that work leads to potential solutions that we can test in field conditions. Testing solutions on a small scale is often critical to gain the confidence of land managers and other stakeholders prior to wider implementation. It is important to understand the practicality and economic feasibility of any solutions. It is also the case that trial management, or solution testing, might prove to be the best way to understand causes. The RSPB is fortunate in having access to an estate of over 200 nature reserves and several working farms in the UK, as well as being involved with various conservation projects overseas, such as rainforest sites in West Africa and Indonesia. This estate is central to our diagnostic and solution-testing work, providing a research platform for scientific observation and experiments.

Ultimate success comes when our science is translated into effective conservation action, and environmental policies that can be sustained. Those actions are usually led by others – for example land managers and policy makers or advocates – but it is the role of our scientists to support them, monitor the effectiveness of conservation interventions, and to refine actions and advice where necessary. The virtuous circle continues as we

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4. Eurasian Bittern *Botaurus stellaris*, RSPB Minsmere, Suffolk, March 2014. Work on this species provides a notable example of the stages of conservation management, from diagnosis, through solution testing, to a plan for population recovery.

monitor the state of nature and scan the horizon for emerging and potentially threatening issues.

Inevitably, some conservation projects stumble as they move around this imaginary circle. Often our most promising candidates or hypotheses prove to be unfounded when tested, so we move back from testing solutions to diagnosis. There are many issues in conservation that remain unresolved. A prominent example is the decline of many long-distance African-Eurasian migrant birds, where the driver of change may be on the breeding or non-breeding grounds, or both, and it is unclear where conservation action will be most effective. Another example is the degree to which climate change might affect wildlife populations, both positively and negatively, and how best to respond. While change seems inevitable, the impacts on bird communities in the medium to long term are much more uncertain and disruptive, so we need to think about both mitigation and adaptation in terms of species and site management. Many issues in ecology and conservation prove to be complex and we recognise that science can only take you so far, and that other factors play an important role in decision making.

In the rest of this paper, I describe the way in which the RSPB goes about organising and delivering its conservation science, illustrating each step in the process with recent published examples, before discussing some of the scientific opportunities and challenges that face those involved in nature conservation.

Identifying the important problems

The starting point for our work is robust and representative monitoring and surveillance. In the UK we are fortunate to have a series of excellent monitoring programmes, led primarily by the BTO or RSPB, which assess population and demographic changes in a wide variety of species. BTO leads on the monitoring of more widespread breeding and wintering species (e.g. BTO/JNCC/RSPB Breeding Bird Survey and BTO/JNCC/RSPB/WWT Wetland Bird Survey: Woodward *et al.* 2018), while RSPB helps to organise a rolling programme of surveys or censuses of our rarer breeding birds (for example Hayhow *et al.* 2017, 2018a,b, Jeffs *et al.* 2018, Wilkinson *et al.* 2018a,b, Wotton *et al.* 2018). These surveys are organised under the banner of the 'Statutory Conservation Agency/RSPB Annual Breeding Bird Scheme', which is an ongoing programme of single-species surveys

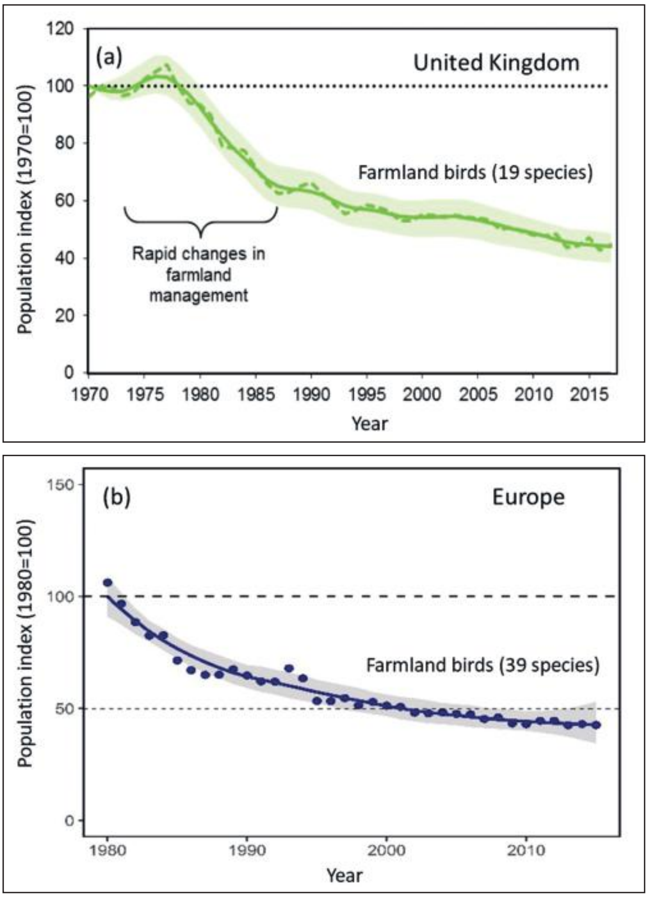


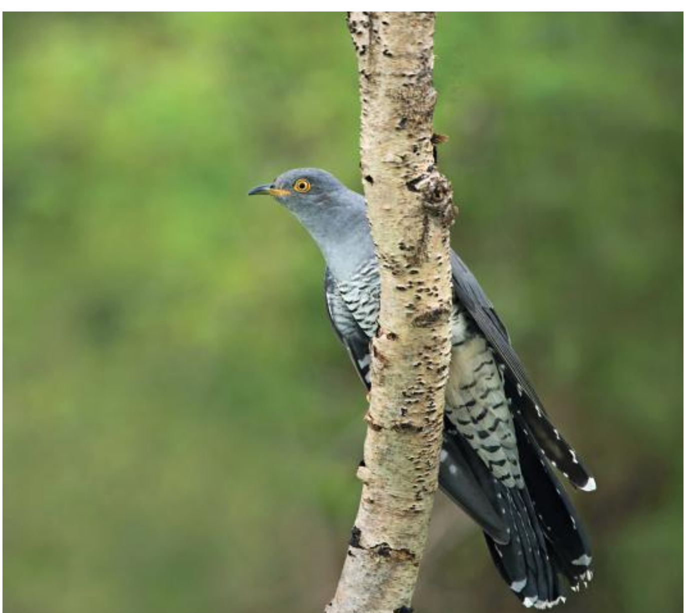
Fig. 2. Statistically smoothed population trends for widespread farmland birds in a) the UK and b) Europe. The UK trend runs from 1970 to 2017 (Defra/BTO/RSPB). The European trend runs from 1980 to 2015 (European Bird Census Council/BirdLife International/RSPB/Czech Society for Ornithology). Farmland Bird Indicators (FBIs) are fixed to a value of 100 in their first year.

for birds of high conservation concern. Note, however, that budget cuts to the statutory agencies along with changing priorities make the future of these vital surveys uncertain. There are also regular national atlas projects, led by the BTO, the Scottish Ornithologists' Club (SOC) and BirdWatch Ireland, charting the ranges and distributional change of all bird species across Britain and Ireland (Balmer *et al.* 2013). This basic information provides the foundation of much of our conservation work and helps to shed light on environmental pressures and potential solutions. These data also allow us to assess the conservation status and extinction risk of bird species and to review and refresh conservation priorities regularly (Eaton *et al.* 2015; Stanbury *et al.* 2017).

We can combine population trends across species to create multispecies indicators, and these metrics of biodiversity change are increasingly used at national and international scales to report on biodiversity and environmental commitments (Gregory & van Strien 2010; Gregory *et al.* 2019). For example, in the UK, the Farmland Bird Index has been instrumental in highlighting the plight of farmland wildlife in general, stimulating research to understand the drivers of change and guiding policy actions (Gregory *et al.* 2004). The same is true in a wider European context, where farmland bird populations have declined precipitously, the Farmland Bird Index falling by nearly 60% between 1980 and 2015 (fig. 2). This index is now widely used as an official measure of biodiversity change (Gregory & van Strien 2010; Gregory *et al.* 2019).

Birds are frequently used as an indicator of the state of nature, but recent initiatives describe the state of nature more broadly, pulling together the very best monitoring information available across freshwater, terrestrial and marine taxa in the UK (Burns *et al.* 2018; Hayhow *et al.* 2016, 2019). The 2019 State of Nature report (Hayhow *et al.* 2019), involving nearly 80 partner organisations, showed that 41% of species assessed had decreased in abundance, compared with only 26% that had increased since 1970. Of 8,431 species of wildlife that had been assessed using Red List criteria, 15% were classified as threatened with extinction in Britain and 2% were already extinct. Many freshwater and terrestrial species have declined, strongly influenced by agricultural management and climate change, among other factors (Burns *et al.* 2016). For marine species, seabird populations are falling, but other taxa are fluctuating or increasing, as sea surface temperatures rise, and ocean systems change (Hayhow *et al.* 2019).

As part of our work, we also undertake reviews to help guide our research and conservation agenda. For example, we have undertaken reviews of crop management and farmland birds (Wilson *et al.* 2005), the impacts of windfarms (Drewitt & Langston 2006) and the decline of Afro-Palearctic migrants (Vickery *et al.* 2014). Another issue, the impact of increasing vertebrate predator numbers on bird populations, is a hot topic among game managers, conservationists and the wider public. Roos *et al.* (2018) investigated whether predation limits the populations of European birds and



Ben Andrew/RSPB

5. Male Common Cuckoo *Cuculus canorus*, Surrey, April 2018.

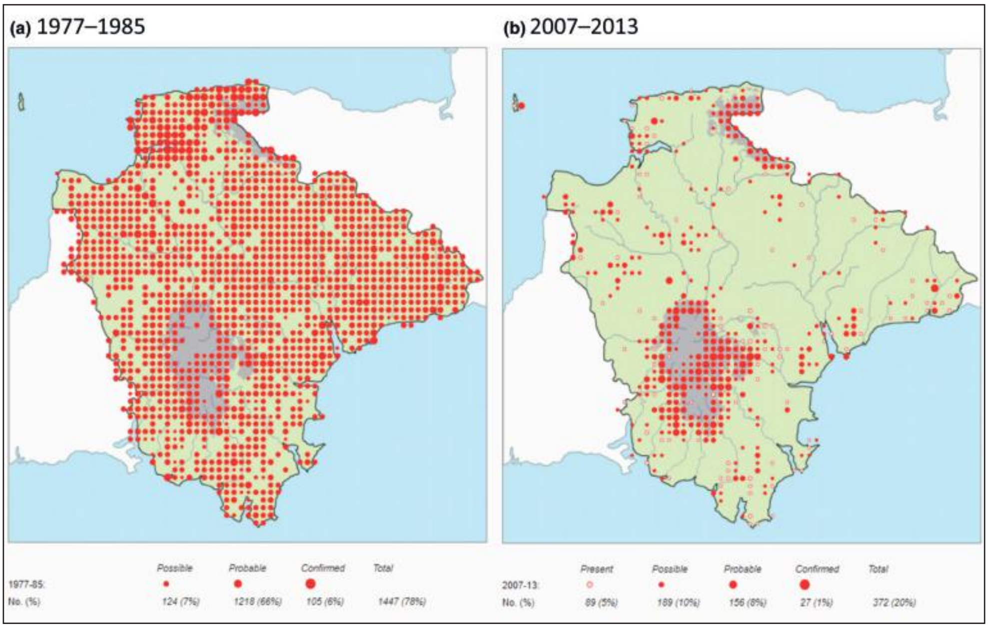


Fig. 3. Map showing the dramatic change in the distribution of Common Cuckoos *Cuculus canorus* in Devon from 1977–85 to 2007–13. Dots represent different categories of Cuckoo presence (see legend). The shaded area to the south represents the upland area of Dartmoor and the shaded area in the north represents Exmoor (Denerley *et al.* 2018).

showed that generalist predators (such as Red Foxes *Vulpes vulpes* and crows *Corvus corone/cornix*) occurred at higher densities in the UK compared with other European countries, and that populations of some avian and mammalian predators have increased in recent decades. Yet they found little evidence that predation limits populations in most birds, the exception being ground-nesting waders, seabirds and gamebirds. The study concluded that future research should identify land-use practices and landscape configurations that would reduce predator numbers and predation rates.

Establishing the causes

When there is evidence of population or range declines, we typically move into detective mode to understand what might drive them. This may involve comparisons across time or space and/or examining different demographic characteristics, such as population trends, survival rates, productivity and dispersal. For example, the Common Cuckoo *Cuculus canorus* population has collapsed in the UK and its distribution shifted northwards. Denerley *et al.* (2019) explored this change at two spatial scales (fig. 3) and showed that the abundance of those moths identified as the Cuckoo's main prey had declined much faster than non-prey moth species. Those moths had also declined sharply in grassland, arable and woodland habitats, but had increased in semi-natural habitats (heaths and rough grassland). Denerley *et al.* suggested that Cuckoos are likely to remain scarce in lowland agricultural landscapes without large-scale changes in agricultural practices to boost food supplies and habitat availability. Related tracking work led by the BTO also suggests that population decline might be linked to migration routes (Hewson *et al.* 2016), raising the possibility that several factors might be in play for this and other migrant birds across their annual cycle.

Many woodland specialists, both resident and long-distance migrant species, have also declined precipitously in the UK. Mallord *et al.* (2016) studied the Wood Warbler *Phylloscopus sibilatrix* and explored whether warmer springs had caused timing asynchrony between their breeding cycle and the emergence of caterpillars, the staple food of their chicks. The main period of caterpillar

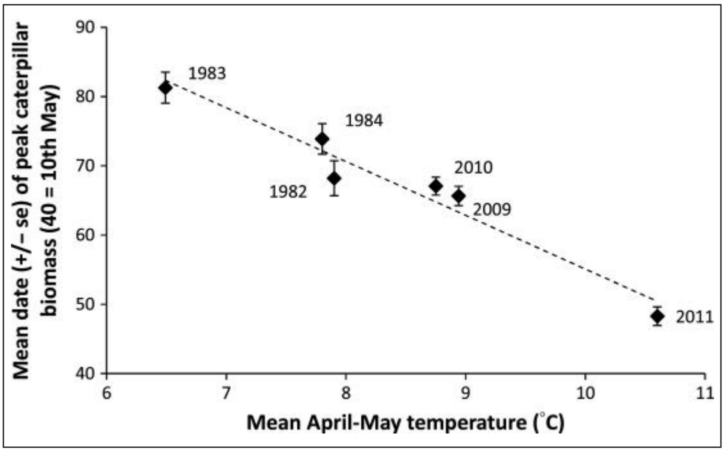


Fig. 4. The trend in the timing of peak caterpillar biomass in relation to mean April–May temperature (Mallord *et al.* 2016).

emergence has indeed become earlier as spring temperatures have warmed in the UK (fig. 4) but, to our surprise, while caterpillars declined rapidly in the diet through the breeding season, the warblers were able to compensate fully for this loss by switching to other invertebrate prey (fig. 5). In this case, phenological mismatch does not explain the decline of the Wood Warbler in the UK, so our research shifted to potential factors on the non-breeding grounds. One hypothesis for the Wood Warbler's decline in Europe is the loss of forests on the wintering grounds, in Africa. Yet Wood Warblers show a strong preference for moderately forested rather than dense forest habitat (Mallord *et al.* 2018) and there is evidence that the former is probably increasing across the bird's wintering range in West and Central Africa (Buchanan *et al.* 2018). In this case, we have come full circle to look afresh at what might drive the population decline of a long-distance migrant on its breeding grounds.

Another example of diagnosis comes from our work on the UK Overseas Territories, looking specifically at the impact of the introduced House Mouse *Mus musculus* on breeding success of nesting seabirds on Gough Island. Caravaggi *et al.* (2019) found that seabirds on Gough Island had low breeding success compared with similar species elsewhere, losing around two million

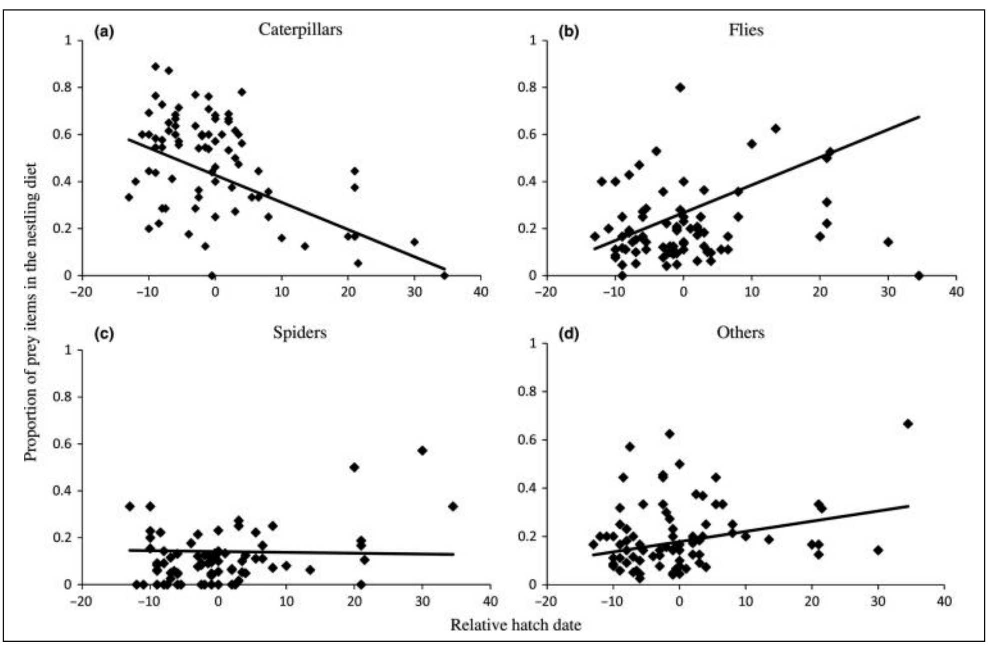


Fig. 5. Trends in the proportion of (a) caterpillars, (b) flies, (c) spiders and (d) other invertebrates in the diet of Wood Warblers *Phylloscopus sibilatrix* in relation to relative hatch date, calculated as actual laying date minus year-specific median laying date in days (Mallord *et al.* 2016).

eggs or chicks annually. Seven of the ten key species had particularly high chick mortality and may have been subject to intense mouse predation (fig. 6). The authors concluded that the endemic or near-endemic 'MacGillivray's Prion' *Pachyptila (salvini) macgillivrayi*, Atlantic Petrel *Pterodroma incerta* and Tristan Albatross *Diomedea dabbenena* could be driven to extinction on Gough this century if the mice were not removed. In this example, both the evidence and the diagnosis are crystal clear, as is the solution to remedy the problem, and plans to eradicate the non-native mice and to restore the native ecosystem are well advanced.

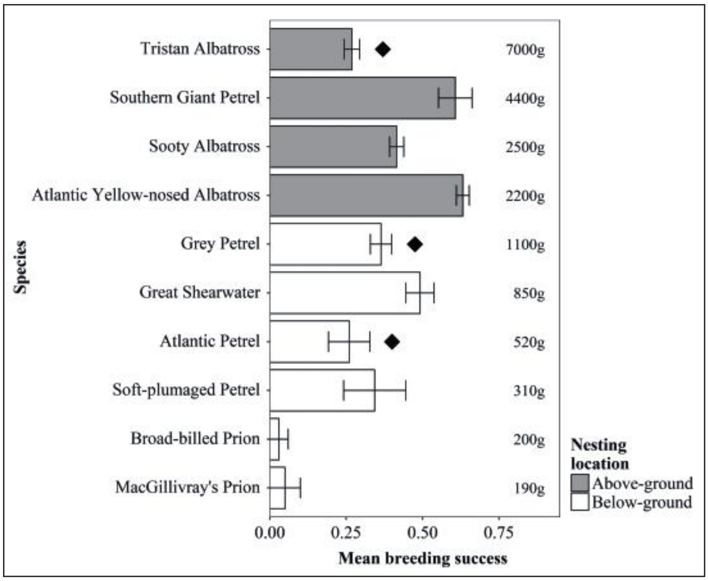
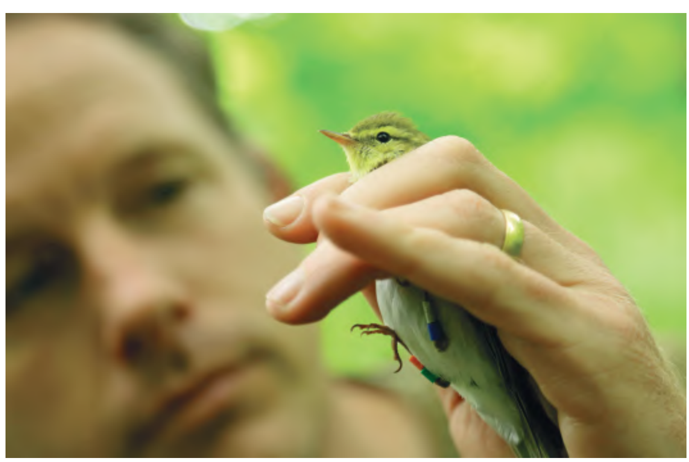


Fig. 6. Mean breeding success (chicks fledged per pair ± SE) of above-ground and below-ground breeding seabirds on Gough Island. Species are listed in order of adult body mass (given, right). ◆ Winter-breeding species – all others breed in the summer (Caravaggi *et al.* 2019).
[Scientific names of species not mentioned in the text are as follows: Southern Giant Petrel *Macronectes giganteus*, Sooty Albatross *Phoebetria fusca*, Atlantic Yellow-nosed Albatross *Thalassarche chlororhynchos*, Grey Petrel *Procellaria cinerea*, Great Shearwater *Ardenna gravis*, Soft-plumaged Petrel *Pterodroma mollis*, Broad-billed Prion *Pachyptila vittata*.]

Finding the solutions

The resolution of a conservation problem is not always as clear-cut as in the chick-predation example above. But with an understanding of what might drive population decline and range contraction of vulnerable species, we are able to devise and test potential solutions. This step is vital to convince ourselves and others that we have the correct diagnosis before a solution is promoted and implemented more widely.

As mentioned above, there is good evidence to show that predation can be an important factor limiting populations of ground-nesting birds, including waders (Roos *et al.* 2018). Breeding waders on lowland wet grassland have undergone dramatic declines across Europe in recent decades and mammalian predators are thought to be a major factor limiting nest survival and productivity (Malpas *et al.* 2013). Predator management through lethal control is often controversial and not necessarily effective, however, so alternatives such as using electric fences to exclude predators have been explored. Malpas *et al.* tested whether this method worked to protect



Andy Hay/RSPB

6. A long-term study of the Wood Warbler *Phylloscopus sibilatrix* has helped researchers to understand more about the causes of the species' decline in the UK; Dartmoor, Devon, June 2013.

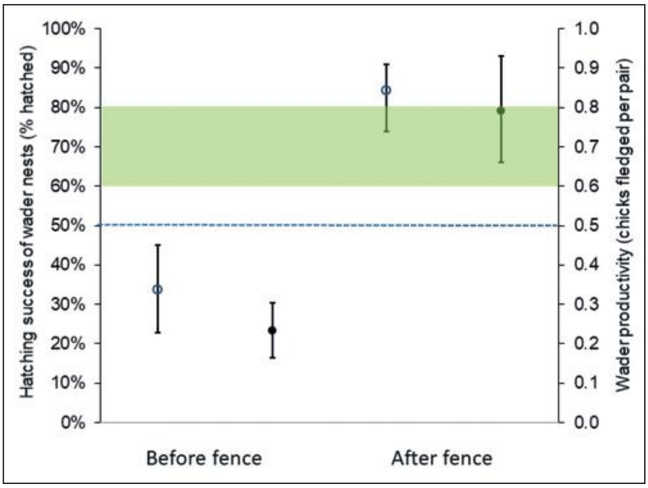


Fig. 7. Mean Northern Lapwing *Vanellus vanellus* hatching success (open circles ± 1SE) and productivity (filled circles ± 1SE) across all sites for years before and after predator fence construction. The dotted line and shaded area indicate the minimum hatching success and productivity range (0.6–0.8 fledged chicks per pair) necessary for population stability (Malpas *et al.* 2013).

Northern Lapwings *Vanellus vanellus*, comparing sites across the UK before and after the construction of predator-exclusion fences. The results were striking (fig. 7). Lapwing nest survival was significantly higher in the presence of a fence, with significantly fewer nests predated each day. Overall productivity also improved, with significantly higher numbers of chicks fledged per pair in years when fences were operational. Taken together, these responses helped to boost local populations. The authors conclude that predator-exclusion fencing is an effective management tool for protecting restricted and declining populations of breeding waders on lowland wet grassland, although it is demanding in terms of capital and management costs.

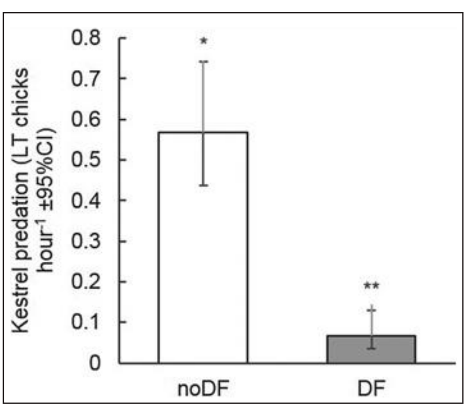


Fig. 8. The mean hourly rate of predation of Little Tern *Sternula albifrons* chicks by Common Kestrels *Falco tinnunculus* during timed watches (2006–09) in relation to years with no diversionary feeding (noDF, white bars) and diversionary feeding (DF, grey bars; Smart & Amar 2018).

Seabirds can also be severely affected by avian and mammalian predators. The decline of the Little Tern *Sternula albifrons* in the UK is thought to be due to poor productivity, influenced by (in order of apparent importance): predation, tidal flooding, weather, disturbance and food availability (Ratcliffe 2003). Breeding colonies are protected by a combination of 24-hour wardens and/or electric fences to deter mammals (largely Foxes, Hedgehogs *Erinaceus europaeus*, domestic cats *Felis catus* and humans). However, predation of Little Tern chicks by Common Kestrels *Falco tinnunculus*, which are protected and declining in the UK, can be a considerable problem at some sites. Smart & Amar (2018) tested whether diversionary feeding, where predators are provided with sufficient food to reduce their motivation to hunt, might provide a solution. Diversionary feeding was used at focal Kestrel nests in alternate years and the authors measured rates of predation and tern productivity. Predation rates were 47% lower and productivity of terns doubled in years when Kestrels were fed (fig. 8). The magnitude of these effects was sufficient to promote recovery of the Little Tern population at this colony (Smart & Amar 2018), although intervention of this kind is demanding of staff time and other resources.

Wakefield *et al.* (2017) combined GPS-tracking and statistical modelling of Shags *Phalacrocorax aristotelis*, Kittiwakes *Rissa tridactyla*, Common Guillemots *Uria aalge*, and Razorbills *Alca torda* from a sample of colonies around Britain & Ireland to estimate their distribution at sea for all colonies in the region (fig. 9). The results helped to inform

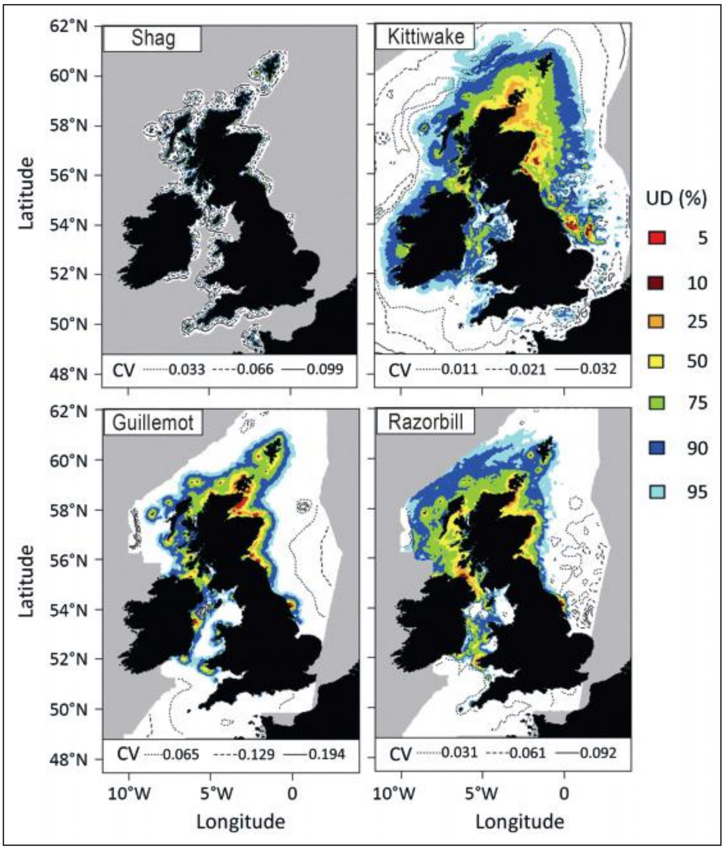


Fig. 9. Percentage at-sea utilisation distribution (UD) of Shag *Phalacrocorax aristotelis*, Kittiwake *Rissa tridactyla,* Common Guillemot *Uria aalge* and Razorbill *Alca torda* breeding within Britain & Ireland during late incubation/early chick-rearing estimated as functions of colony distance, coast geometry, intraspecific competition and habitat. Warmer colours indicate higher usage (Wakefield *et al.* 2017).

and direct appropriate conservation measures, information which is crucial in, for example, helping to locate marine protected areas, or in discussions of where to site marine renewable energy sources such as wind-farms.

Confirming that solutions work

The final stage of the circle focuses on knowing that actions are working as intended and delivering benefits at a scale to meet conservation and/or policy goals. Our work on the Eurasian Bittern *Botaurus stellaris* is a prime example of how we moved from diagnosis, through solution testing, to population recovery (Gilbert *et al.* 2005, 2007; Brown *et al.* 2012). The Bittern was lost from the UK

Lyn Ibbitson-Elks

7. Adult Little Tern *Sternula albifrons* feeding chick at the colony at Winterton, Norfolk, August 2017.

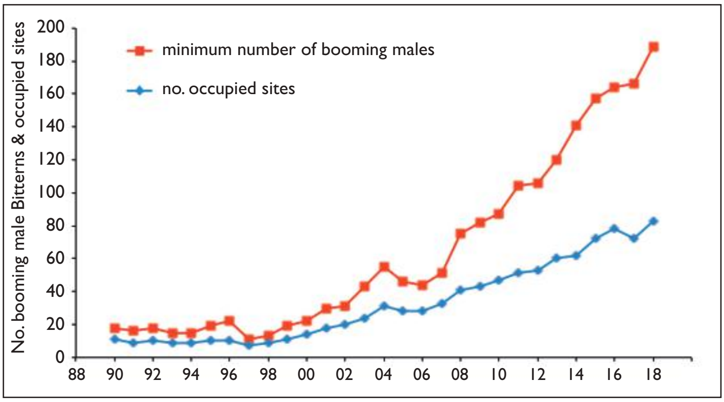


Fig. 10. The number of booming male Eurasian Bitterns *Botaurus stellaris* (red squares) and number of occupied sites (blue diamonds) in the UK (see Brown *et al.* 2012).

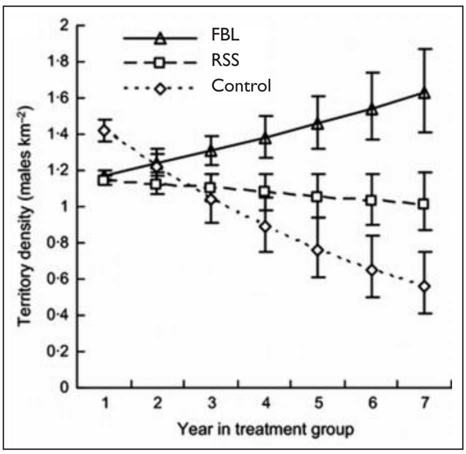


Fig. 11. Corn Bunting *Emberiza calandra* population trends on agri-environment scheme (AES) and control farms, plotting model estimates for mean density of territorial males per farm type (±1 SE) in each treatment year. The Farmland Bird Lifeline (FBL) was the targeted AES designed for Corn Buntings and the Rural Stewardship Scheme (RSS) was the general scheme (Perkins *et al.* 2011).

but then returned, only to reach another low point in 1997, when the population was only just into double figures. Research showed that the population was limited by the low number of suitable large wet reedbeds and by a lack of management of occupied sites to maintain suitable conditions for nesting and feeding. Extinction for a second time in Britain was a real possibility. However, concerted conservation efforts proved highly effective as an ambitious programme to create extensive new reedbeds was put in place (fig. 10). The combination of extensive reedbed creation and better reedbed management for Bitterns means that the future for this flagship species in the UK now looks more secure. Yet climate change, sea-level rise and soil drying present new challenges and threaten to undermine what has been achieved (Brown *et al.* 2012). This is a reminder that we cannot stand still; we must continue to monitor conservation actions and interventions. For Bitterns, the long-term strategy involves the creation of new inland sites and the active management of existing, and especially coastal sites threatened by sea-level rise.

As described above, monitoring data show the collapse in farmland bird populations (fig. 2) and research shows clearly how changing farming practices have driven the loss of farmland wildlife. Agri-environment schemes (AES), whereby farmers receive financial payments for implementing environmental management, are the main policy response to biodiversity loss under the EU's Common Agriculture Policy. The RSPB has worked with partners to test, develop and refine these options over time. Perkins *et al.* (2011) measured changes in breeding abundance of Corn Buntings *Emberiza calandra* in response to AES in Scotland over seven years on a large sample of farms. In this example, bird populations on 'control' farms using conventional methods were compared with those on two with different AES interventions. Encouragingly, Corn Buntings increased by 5.6% per annum on farms in the targeted scheme and showed no significant change on farms in the general scheme; in contrast, they declined by 14.5% per annum on farms outside the scheme (fig. 11). This classic study shows that well-designed and implemented AES can be highly beneficial for farmland birds.

A related example at a large scale comes from the work of Walker *et al.* (2018) on farmland birds in England. Specially designed AES measures have proved successful for range-restricted birds in the UK, including Cirl Buntings *Emberiza cirlus* (Peach *et al.* 2001), Corn Crake *Crex crex* (O'Brien *et al.* 2006; Wotton *et al.* 2015), and Corn Buntings (Perkins *et al.* 2011 above), but their broader success and efficacy in protecting wildlife has been a matter of considerable debate in Europe. Some of the difficulty arises when schemes are poorly designed, poorly implemented and/or poorly monitored. Walker *et al.* (2018) investigated the effects of a higher tier AES on the abundance of priority farmland birds across three English regions (fig. 12) and focused on a suite of farmland birds comprising the UK Government's Farmland Bird Indicator (FBI). The AES involved the deployment of a whole farm, higher-level package of wildlife-friendly land-management options covering an average of 7% of the farmed area. One of the great strengths of this study is that bird populations on 'treatment' farms (those in AES) were compared with those on 'non-treatment' farms in the same region using data collected by the Breeding Bird Survey (fig. 12). Counterfactual study designs of this kind are surprisingly rare in conservation, for a variety of practical reasons, but they provide a powerful means for understanding whether conservation interventions are genuinely successful. In this example, over 70% of priority bird species, and the FBI, showed more positive abundance changes on AES farms in at least one region (fig. 13). Eight species

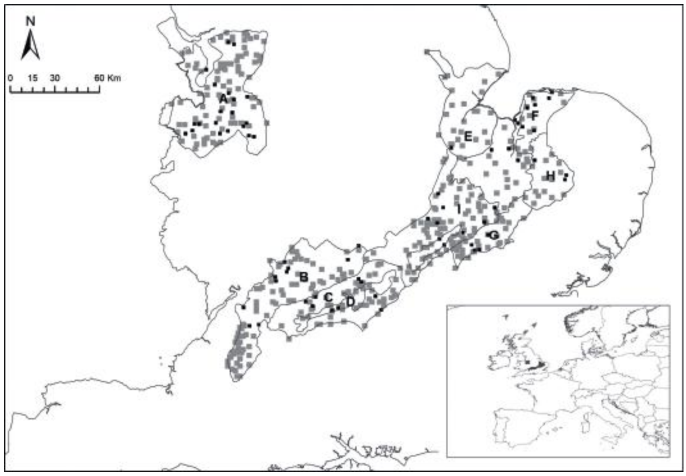


Fig. 12. Location of Higher Level agri-environment scheme (AES) Stewardship farms (black squares) and Breeding Bird Survey squares (grey squares) from Walker *et al.* (2018). West Midlands region comprises the Shropshire, Cheshire and Staffordshire Plain (A); Oxfordshire region comprises The Cotswolds (B), Oxfordshire Upper Thames Clay Vales (C) and Midvale Ridge (D); and the East Anglia region comprises The Fens (E), North West Norfolk (F), East Anglian Chalk (G), Breckland (H), and Bedfordshire and Cambridgeshire Claylands (I).

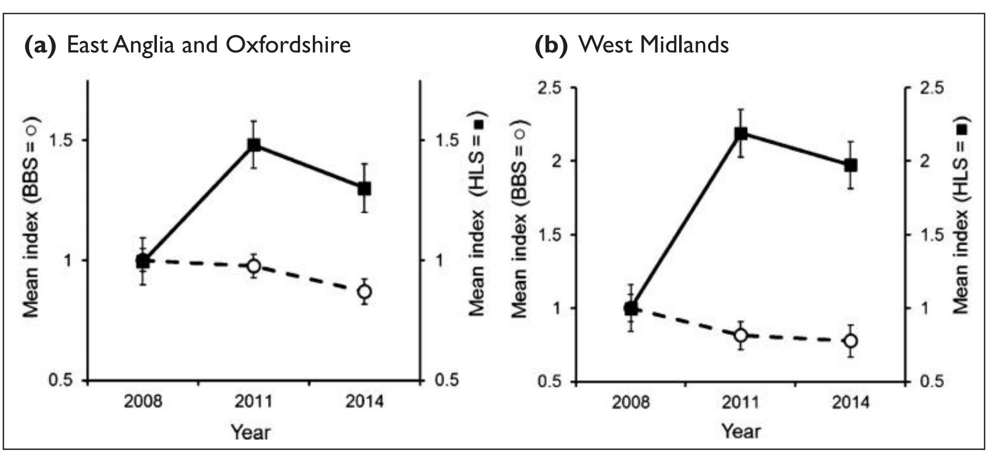


Fig. 13. Temporal changes in Farmland Bird Indicator (FBI) on Higher Level Stewardship (HLS) farms (solid lines, square symbols) and on Breeding Bird Survey (BBS) squares (dashed lines, open circles) in (a) East Anglia and Oxfordshire and (b) the West Midlands. Points represent mean indices of abundance for FBI species (± 1SE) relative to a value of 1 in 2008 (Walker *et al.* 2018).

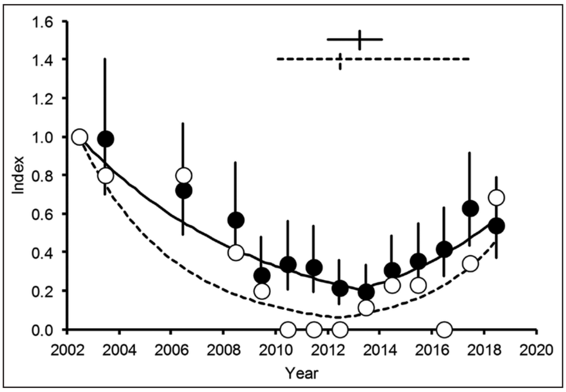


Fig. 14. Annual index values for populations of the Critically Endangered White-rumped Vulture *Gyps bengalensis* (filled circles & solid line) and Slender-billed Vulture *G. tenuirostris* (open circles & dashed line) in Nepal for 2002–2018, relative to one in 2002. Vertical lines are 95% confidence intervals. Crosses in the upper part of the diagram show the estimated breakpoints and their 95% confidence intervals (Galligan *et al.* 2019).

exhibited sustained responses to AES management in at least one region, and eight species exhibited a temporary enhancement in abundance in at least one region. Overall, this study demonstrates the potential for well-designed and implemented AES land management to rapidly enhance the abundance of a suite of farmland birds (fig. 13). It also provides a blueprint for good study design and demonstrates the power of a counterfactual analysis in conservation science.

The final example is from Asia and concerns the plight of vultures across the continent (and now the first signs of population recovery). The introduction of diclofenac as a veterinary product for livestock in the Indian subcontinent and its subsequent impact on the region's vulture populations is one of the most dramatic examples of the unexpected consequences of pharmaceuticals in the environment (Cuthbert *et al.* 2014). In the 1980s, vultures were some of the most numerous birds in that region but by the 1990s and 2000s their populations had crashed, and five species were listed as Endangered by the IUCN. Thankfully, concerted efforts by organisations working closely with governments led to India, Nepal, Pakistan and Bangladesh banning the manufacture and importation of diclofenac and promoting the drug meloxicam as a 'vulture-safe' substitute.

Diclofenac was banned in Nepal in 2006 and this was followed by the implementation of a Vulture Safe Zone programme to advocate vulture conservation, raise awareness about diclofenac, provide vultures with safe food and encourage the veterinary use of vulture-safe alternatives (Galligan *et al.* 2019). The latest survey data show a rapid decline of the White-rumped Vulture *Gyps bengalensis* from 2002 to 2013, but partial recovery between 2013 and 2018; more limited data for the Slender-billed Vulture *G. tenuirostris* indicates that a rapid decline has given way to partial recovery from about 2012 onwards (fig. 14). There are real signs of hope for Asia's vultures, but the hard work must continue to ensure their future (Galligan *et al.* 2019).

John Mallord

8. White-rumped Vultures *Gyps bengalensis*, India, November 2018.

Opportunities and challenges for conservation science

The RSPB has identified ten scientific challenges that encompass nature conservation across a range of environments, and will involve multi-disciplinary science (table 1). In terms of priorities, we remain committed to the conservation of our long-

Table 1. Ten scientific challenges identified by the RSPB Centre for Conservation Science.

1. Monitoring the state of nature and identifying conservation priorities
2. Understanding the causes of decline of priority species and finding solutions to improve their status
3. Understanding the impacts of pollutants, climate change, emerging diseases and invasive non-native species on wildlife
4. Evaluating the effectiveness of conservation solutions once implemented
5. Informing protected area designation and management on land and at sea
6. Providing the scientific underpinning for conservation at a landscape scale
7. Guiding the restoration of degraded habitats and ecosystems
8. Reconciling infrastructure development and the production of food, fibre and energy with wildlife conservation
9. Understanding the relationships between ecosystem services and biodiversity
10. Understanding how people connect to and benefit from nature and how to encourage pro-environmental behaviours

distance migrant birds, upland birds and seabirds, as well as farmland and woodland birds in trouble. We are keen to continue to tackle the threat posed by alien invasive species in the UK Overseas Territories and to expand our work to safeguard tropical forests and people's livelihoods. We are also keen to develop our interaction and engagement with skilled naturalists, 'citizen scientists', to pursue scientific goals. An increasing focus on nature as 'natural capital' and as an asset is encouraging because it recognises its value, but a utilitarian view that only takes a monetary value could be damaging for biodiversity and hasten its loss.

In terms of opportunities, technological advances, notably miniaturisation and increasing computer power, are already transforming conservation science, although many of the examples discussed here rely on more traditional methods too. Increasingly sophisticated tagging and tracking devices are shedding light on conservation problems, potential solutions and providing critical insights. Remote cameras, audio recorders, tags and satellite technologies passively collect huge amounts of information on key species and the environment, and increasingly we have the knowledge and computing capacity to analyse such data in real time. For example, tiny nest cameras, in combination with nest-temperature loggers, show that nocturnal/mammalian predators make the largest contribution to wader nest predation (MacDonald & Bolton 2008). By individually marking Red Kites *Milvus milvus*, we can estimate survival and begin to understand poor population growth in northern Scotland, which is linked to illegal killing (Smart *et al.* 2010). While many of us assumed that Shetland's Red-necked Phalaropes *Phalaropus lobatus* wintered in the Arabian Sea, several recovered geolocators show that they winter in the Pacific Ocean (e.g. Smith *et al.* 2018). More generally, conservation is changing and conservationists are looking more carefully at what motivates individuals, organisations and businesses to make (or not make) pro-environmental choices – encompassing farmers, consumers and businesses. Conservation has much to learn and gain from an understanding of social science and other interdisciplinary research.

The post-2020 strategic plan for the Convention on Biological Diversity is an opportunity to set ambitious targets for actions to restore global biodiversity. There is a growing consensus that we must 'bend the curve' of biodiversity loss by 2030 and set it on a path to recovery by 2050 (Mace *et al.* 2018). We and others will be encouraging that Convention to set progressive and measurable targets for the recovery of nature when they meet in Kunming, China, in 2020. Our experience tells us that 'SMART' biodiversity targets make greater demonstrable progress (Green *et al.* 2019).

In terms of challenge, we live at a time of unprecedented climate and biodiversity crisis. The two are overwhelming in scale and yet simple at the same time. We have solutions to both the climate and the biodiversity crisis. The great challenge for conservation is that we address the two in tandem and that biodiversity is not sidelined. Many of the actions we might take to address climate change will benefit biodiversity and be synergistic, but that is not always, or necessarily, the case. Without due care and attention, action on climate change could inadvertently damage and degrade biodiversity further.

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