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REVIEW

The movement shortfall in bird conservation: accounting for nomadic, dispersive and irruptive species

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Abstract

Efforts to prioritize conservation planning are undermined by several recognized knowledge shortfalls. Here we highlight a further shortfall, which we term the 'movement shortfall', in our knowledge of species movements, with particular reference to dispersive, irruptive and nomadic birds. Despite 100 years of ringing effort, the movement characteristics of these species are still poorly known, as the irregularity of their movements and low human population densities in parts of their range impede traditional methods. A lack of understanding of their movements, combined with an inappropriate conservation approach that relies on protected areas and international frameworks, means that the conservation status of these species continues to deteriorate. We call for the application of new tracking technology and outreach initiatives to help formulate innovative conservation approaches that are better suited to species with irregular movement behaviours.

Introduction

To address the fundamental questions of conservation biogeography, we require an accurate and extensive knowledge of the basic units of study (Riddle *et al*., 2011). Deficits in our biogeographical knowledge not only hamper our ability to understand patterns in biodiversity, but also constrain our ability to plan effective conservation strategies. A particularly important area where limited biogeographical knowledge overlaps with conservation shortcomings concerns bird movements (Bauer & Hoye, 2014). While migratory species are increasingly well studied, and are the focus of international conservation efforts (Faaborg *et al*., 2010; Birdlife International, 2013a), the irregular movements of those species that exhibit dispersive, irruptive and nomadic behaviours are poorly understood (Table 1). Furthermore, while migratory species are harder to conserve than sedentary species (Shuter *et al*., 2011), species with irregular movement patterns are harder still to conserve, not least because of the reliance on protected areas in most conservation strategies. For too long, our attempts to conserve mobile species have drifted, but with new technology and methods promising to overhaul the way we conduct research on species movements, it is time to galvanize ecologists and conservationists around this hitherto intractable conservation issue.

The movement shortfall

Improving our knowledge of birds that exhibit irregular movement behaviours should improve our ability to conserve them. We urgently need higher resolution and broader scale ecological data to equip conservation actors with the basic information needed to engage authoritatively with the range of stakeholders involved in conserving highly mobile species. To this end, we wish to highlight the lack of knowledge on bird movement behaviours to a wide audience (see Bauer & Hoye, 2014), in particular for dispersive, irruptive and nomadic species, by formally identifying it as the movement shortfall.

Other shortfalls include the Linnean, Wallacean, extinction deficit, Prestonian, Hutchinsonian, Eltonian and Darwinian shortfalls (Raven & Wilson, 1992; Cardoso *et al*., 2011; Mokany & Ferrier, 2011; Riddle *et al*., 2011; Diniz-Filho *et al*., 2013; Morales-Castilla *et al*., 2015; Table 2). Identifying and naming shortfalls in our knowledge

Table 1 A typology of bird movement behaviours

Name	Definition	Examples
Migratory	Species that perform regular, seasonal movements from breeding to non-breeding areas (Berthold, 2001; Newton, 2008).	Black-throated blue warbler (*Dendroica caerulescens*; Townsend *et al*., 2013); greater white-fronted goose (*Anser albifrons*; Ely *et al*., 2013)
Dispersive	Species that move with no fixed direction or distance from their breeding site (Newton, 2008).	Australasian gannet (*Morus serrator*; Pyk *et al*., 2013), Western gull (*Larus occidentalis*; Coulter, 1975)
Irruptive	Species that make seasonal movements where the number of individuals, timing, direction and distance travelled varies greatly between years (Lack, 1968; Newton, 2008).	Common crossbill (*Loxia curvirostra*; Newton, 2006a), snowy owl (*Bubo scandiacus*; Fuller *et al*., 2003)
Nomadic	Species that move with no fixed spatial or temporal pattern (Newton, 2008).	Gouldian finch (*Erythrura gouldiae*; Woinarski *et al*., 1992); Princess parrot (*Polytelis alexandrae*; Pizzey & Knight, 2007)
Vagrant	An individual bird that appears in an area far beyond the limits of its normal range and migration routes (Newton, 2008).	American robin in Europe (*Turdus migratorius*; Svensson *et al*., 2010); Amur falcon in the UK (*Falco amurensis*; Hudson & the Rarities Committee, 2010)

Table 2 Named knowledge shortfalls in conservation biogeography

Name	Definition	Reference
Linnean shortfall	The disparity between the number of formally described species and the total number of species in existence.	Lomolino *et al*., 2010:775
Wallacean shortfall	The inadequacy of our knowledge on the geographical distribution of species.	Riddle *et al*., 2011:54
Extinction deficit shortfall	The uncertainty surrounding our knowledge of extinction rates.	Riddle *et al*., 2011:58
Prestonian shortfall	The scarcity of comparative species abundance data in time and space.	Cardoso *et al*., 2011:2650
Hutchinsonian shortfall	The lack of knowledge of species ecology and sensitivities to habitat change (including natal dispersion).	Mokany and Ferrier, 2011:375
Eltonian shortfall	Uncertainty concerning the networks of interactions between organisms.	Peterson *et al*., 2011:201
Darwinian shortfall	The lack of relevant phylogenetic information.	Diniz-Filho *et al*., 2013:689
Movement shortfall	The limited knowledge of species movements.	

Definitions are adapted from the source references.

of biodiversity is an increasingly important conservation tool (Riddle *et al*., 2011). The practice helps to shape a problem, improve referral and build momentum towards addressing it. The formal identification of earlier knowledge shortfalls, such as the Linnean or Wallacean shortfall, have helped focus research efforts in conservation biology, and have been frequently cited (a Google Scholar search for the term 'Linnean Shortfall' returns 107 citations since 2005, with 139 for Wallacean over the same period). The movement shortfall is distinct in that it accounts for short-term, temporary movements, rather than long-term adaptive dispersal in response to environmental change encompassed by the Hutchinsonian (Mokany & Ferrier, 2011). This shortfall is currently undermining our ability to conserve highly mobile species, but by identifying the problem and embracing modern technology, exciting opportunities to address this shortfall are now within reach.

Current conservation status of different movement groups

Migratory species

The importance of identifying the movement shortfall is underlined by the proportion of birds of conservation concern within each movement group, along with the inadequacies of our current conservation strategies (Koleček, Albrecht & Reif, 2014). For migratory birds, which are the best studied, 11% of the world's migratory land and water birds were classified as threatened or near-threatened in 2008 (Kirby *et al*., 2008). Some groups are under particularly high pressure, such as raptors that migrate between Africa and Eurasia (Goriup & Tucker, 2007), while 27 of 39 soaring birds (69%) that migrate along the Rift Valley/Red Sea Flyway are reported to have an unfavourable conservation status (Tucker, 2005). Despite the volume of work carried out on migratory species, with 4539 publications under the topic 'Migratory Birds' found in the Web of Science (Somveille *et al*., 2013), there is still little accurate knowledge about the status of breeding and wintering populations of some of the best studied species, including Africa–Eurasia migratory raptors (Kirby *et al*., 2008).

Dispersive species

While the conservation status of a large proportion of migratory birds is worrying, the situation for the other movement groups is of even more concern. Dispersive species, which make movements from their breeding areas with no fixed direction or distance (Alerstam, 1990), present even greater monitoring and conservation challenges than species which conduct regular migratory movements. Examples of dispersive species include the critically endangered regent honeyeater (*Xanthomyza phrygia*; Higgins, Peter & Steele, 2001), and many pelagic seabirds, with regular population aggregations at colonial breeding sites for part of the year, followed by long periods of maritime foraging (Newton, 2008). Their vulnerability to nest predation during the breeding season, coupled with their wide-ranging non-breeding habits, is sufficient to place many dispersive species under a high level of threat (Wanless *et al*., 2009; Cherel *et al*., 2013). Of the 22 albatrosses, for example, 17 are listed as globally threatened, of which three are critically endangered (Birdlife International, 2013b). The situation for seabirds in general is not much better: 28% are globally threatened (Croxall *et al*., 2012), and this group has experienced a faster decline than any other bird group in Red List Index scores over the last two decades (Butchart *et al*., 2005; Birdlife International, 2013c). The conservation challenges and mitigation measures during the breeding season are well documented, such as controlling alien predators on islands, even if they are difficult to execute in practice (Nogales *et al*., 2004; Howald *et al*., 2007; Whittaker & Fernández-Palacios, 2007). Conserving dispersive species throughout the rest of their life history is more complicated, as they can have very large range areas, which in the marine realm are particularly difficult to monitor, making it hard to assess movement patterns and to carry out effective conservation work (Jouventin & Weimerskirch, 1990; Croxall *et al*., 2012; Cherel *et al*., 2013).

Irruptive species

Irruptive species, which make irregular seasonal movements where the number of individuals, timing, direction and distance travelled varies greatly between years, present another case of limited knowledge restricting conservation action (Newton, 2008). Boreal finches, especially those that depend on fluctuating tree-seed crops (Newton, 2006a), and birds of prey that depend on cyclically fluctuating rodent populations (Fuller, Holt & Schueck, 2003), typically exhibit large-scale irruptive movements with little breeding or non-breeding site fidelity (Newton, 2006b). Specific examples of long-distance irruptive bird movements include common crossbills *Loxia curvirostra*, where individual adults have been found in locations up to 3200 km apart in different breeding seasons (Newton, 2006a), and common redpoll *Carduelis flammea* where an individual that was ringed in Michigan, USA was later recovered near Okhotsk in Siberia, 10 200 km away (Troy, 1983). While the occurrence of irruptions is apparent through observation, much of our scientific understanding of irruptive behaviour is based on ringing recoveries, which have limited data collection to 'scraps of information collected over a long period' (Newton, 2006b, p. 434). While the rarity of ring recoveries in the same area the year after an irruptive migration suggests dramatic geographical changes in population demographics, they do not provide an indication of movement patterns, alternative destinations and population fluctuations.

Nomadic species

Nomadic species, which have no fixed spatial or temporal patterns in their movements, present a major challenge to conservationists, as a conventional protected area approach would require the creation of prohibitively large reserves (Andersson, 1980; Woinarski *et al*., 1992). Nomadic birds are believed to respond to resource fluctuations, ranging widely and breeding where food is locally abundant, leading to obligatory changes in distribution (Dean, 2004). Nomadic species include many dryland waterbirds, granivores, nectarivores and carnivores, such as the black honeyeater (*Sugomel niger*; Tischler, Dickman & Wardle, 2013), grey-backed sparrow-lark (*Eremopterix verticalis*; Dean, 1997) and Australian painted snipe (*Rostratula australis*; Marchant & Higgins, 1993). The erratic movements made by many of these species make it difficult to quantify their population sizes, or to design site based conservation strategies (Woinarski *et al*., 1992, 2005). The highly nomadic princess parrot *Polytelis alexandrae*, for example, which occurs in Australia's interior deserts, defies accurate population assessment because of its erratic occurrence at most sites, and a lack of information on its movements (Higgins, 1999; Forshaw & Cooper, 2002; Garnett, Szabo & Dutson, 2011). Indeed, overcoming limited movement information is a key challenge for bird conservation in Australia, where 93 out of 742 species of resident land birds are considered to be primarily nomadic (Marchant & Higgins, 1993; Higgins, 1999; Higgins *et al*., 2001; Pizzey & Knight, 2007). Seven of these species are considered threatened according to the Commonwealth Government listing, and 10 by Birdlife International, and in an analysis comparing movement behaviour and International Union for Conservation of Nature threat status, we found a significant association with Fisher's exact test ($P = 0.001$; see Table 3 and caption for methods; Keast, 1960; Garnett *et al*., 2011). Our current knowledge of nomadic bird movements is based on chance observations and inference, with few relevant ring recoveries, and a lack of detailed records (Newton, 2008). As a result, many fundamental questions about their behaviour remain unanswered: how do nomadic species know where to go to find isolated resources in a vast desert, how far away can they detect suitable conditions, are there any directional patterns in their movements and what is the primary reason for so many of them being threatened (Newton, 2010)?

Twenty-first century conservation

While many of the basic questions of migratory biogeography are only beginning to be solved (Wikelski *et al*., 2007), migratory birds have received a high level of scientific attention and have been the focus of several international conservation agreements (e.g. the Ramsar Convention in 1971, the EEC Directive for the Conservation of Wild Birds in 1979 and the Bonn Convention on the Conservation of Migratory Species of Wild Animal in 1983; Berthold, 2001). Dispersive, irruptive and nomadic species, on the other

Table 3 The number of Australian bird species grouped by threat status and by their primary movement behaviours

Category	CR	EN	VU	NT	LC	IUCN	EPBC	Total species	Percentage threatened
Dispersive	6	8	10	5	54	29	19	83	35%
Irruptive	0	1	0	1	27	2	1	29	7%
Nomadic	0	5	2	3	83	10	7	93	11%
Migratory	1	2	4	2	105	9	2	114	8%
Sedentary	2	10	8	12	391	32	16	423	8%

Data on movement behaviours were collected from the *Handbook of Australian, New Zealand, and Antarctic Birds* (Marchant & Higgins, 1990) and *The Field Guide to the Birds of Australia* (Pizzey & Knight, 2007). In cases where species displayed multiple movement behaviours, the primary movement behaviour was taken to be that undertaken by the majority of the adult population. Abbreviations are CR, critically endangered; EN, endangered; VU, vulnerable; NT, near-threatened; LC, least concern, and the values in these columns refer to the number of species that are listed in these categories according to the International Union for Conservation of Nature (IUCN) Red List criteria, taken from Garnett *et al.*, 2011. The values in the IUCN column refer to the total number of species in each movement group that are listed in categories other than LC. The values in the EPBC column refer to the total number of species listed under the Australian Government's Environment Protection and Biodiversity Conservation Act (1999) in each movement group. The percentage of threatened species in the final column refers to the IUCN listing. There was a significant association between the type of movement behaviour (because of issues of small sample size, we grouped migratory, dispersive, irruptive and nomadic species into a single movement category) and IUCN threat status according to Fisher's exact test ($P = 0.001$).

hand, are often overlooked in these and other frameworks, despite the distinctive challenges they face. Their irregular movements place many of them beyond the capacity of conventional conservation approaches that use the protected area as their primary tool, while efforts to estimate their population sizes have low reliability because of their rapidly shifting distributions, which often occur in remote locations (Woinarski *et al.*, 1992; De Frutos & Olea, 2008; Burnham & Newton, 2011; Garnett *et al.*, 2011).

Improving our capacity to conserve dispersive, irruptive and nomadic species first requires an improvement in our ability to gather better data on their movements. We need very precise data to see what resources they are tracking, uncover any movement patterns and identify any hidden site dependencies (Wikelski *et al.*, 2007; Limiñana *et al.*, 2012). While this presents a challenge, the movement shortfall is distinctive in that it has, until recently, largely been the result of limited technology rather than effort, funding or public interest.

Previous attempts to address this shortfall in migratory birds have focused on ringing schemes. However, this technology provides limited information even for birds that have high site fidelity and follow regular migration routes (Schmaljohann *et al.*, 2012). It is not well adapted to species that make irregular movements, spatially or temporally, as recapture rates are very low (Newton, 2006b) — a function of the nature of the movements and the low human population densities in the pelagic, boreal and arid environments inhabited by many of these species (Newton, 2010). Furthermore, the data gathered do not help address many of the important questions surrounding dispersive, irruptive and nomadic species (see Hays, 2013).

New tracking devices, using geolocators or satellite telemetry, can now provide high-quality data over long time scales, and in some cases also remove our dependency on retrapping tagged birds (Berthold, 2001; Robinson *et al.*, 2010). Stable isotope ratio analysis and the use of genetic markers can be used to identify both the breeding and non-breeding grounds of irruptive or dispersive birds (Coiffait *et al.*, 2009; Marquiss *et al.*, 2012; Cherel *et al.*, 2013), while the International Cooperation for Animal Research Using Space Initiative is working towards establishing a platform to remotely sense animal movements on a global scale (http://icarusinitiative.org). While there is a clear need to improve the miniaturization of tracking technologies, improve analytical techniques and standardize data collection and reporting protocols, the increased roll-out of these technologies should ensure such advances are swiftly made (Baillie *et al.*, 2009; Fiedler, 2009).

Applying the methods of successful migration studies may also help raise public awareness and improve engagement with the issues facing dispersive, irruptive and nomadic species. The use of Movebank (https://www.movebank.org) as a resource for data storage, sharing and visualization may be useful as a tool for wider public engagement (Baillie *et al.*, 2009). Expanding satellite-tracking studies of sociable lapwing *Vanellus gregarius* and Eurasian cuckoo *Cuculus canorus* to species with irregular movements (Birdlife International, 2013d; BTO, 2013a) may highlight the difficulties conservationists face in devising appropriate strategies for them. Finally, initiatives such as Blogging Birds, which uses satellite tracking technology and innovative software to provide automated updates of individual red kites' *Milvus milvus* activities online (Ponnamperuma *et al.*, 2013), may help realize the power of communicating real-time data to the public, stimulating interest and directing finance towards conservation efforts.

The integration of bird movement data collection, public engagement and new technology is perhaps best illustrated by the rise of eBirds in the USA. A freely available web platform, eBirds allows users to input their bird observations as electronic personal checklists, while also allowing them to share their records with the scientific community (Bonney *et al.*, 2014; Supp *et al.*, 2014). Since launching in 2002, eBirds has grown rapidly, and by 2012 was receiving over 3 million bird records in a month in North America (http://ebird.org/content/ebird/about/). Other new approaches to citizen science and communication are already helping to address the movement shortfall in the irruptive Bohemian waxwing *Bombycilla garrulus* in the UK. The @WaxwingsUK Twitter feed gathers live information on Waxwing sightings across the UK (https://twitter.com/WaxwingsUK), while the television programme BBC AutumnWatch has promoted widespread online reporting of Waxwing sightings to help identify irruption years and track their movements (http://www.bbc.co.uk/programmes/b0079t1p). Some communication strategies have also created new fundraising streams, such as sponsoring a tracked bird (BTO, 2013b), or betting on bird dispersal movements in the Big Bird Race of shy albatrosses (*Thalassarche cauta*; Kirby, 2004).

Like many conservation programmes, schemes targeted at dispersive species have required widespread public support and stakeholder engagement. In the Southern Ocean, long line fisheries had been identified as the major driver of decline in albatrosses and other seabirds (Croxall, 2008). By working with fishermen to identify strategies that could minimize pelagic seabird by-catch, and introducing new fishing technology, the Albatross Task Force has started to reduce by-catch mortality on long line vessels (Birdlife International, 2012). Hopefully, further technological innovation will help modernize our approach to conservation while also helping to address the movement shortfall.

The need to bring 21st century technologies and strategies to mobile species conservation is particularly pertinent considering the age of many of the conservation frameworks targeted at migratory birds (see above), which may be one reason why species with irregular movements lie beyond the scope of the traditional protected areas approach. New innovations, such as delimiting temporary protected areas or micro-sites that reflect the dynamism of the species they are aimed at conserving, may be one idea worth exploring.

The major international conservation organizations could also help address this shortfall by implementing suitable strategies to help conserve mobile species with irregular movements. While migratory birds and flyways is one of their nine conservation programmes, Birdlife International, for example, are uniquely placed to make real progress in this arena. They and other international conservation organizations could help by adopting a broader approach, recognizing the plight of species with irregular movements along with more conventional migrants. These organizations could bring technology manufacturers, software programmers and scientific researchers around the table to find ways to aggressively invest in driving tracking technology forward and cutting manufacturing costs.

It is also time for the conservation community to galvanize their response to the threats these species face. A major conservation organization could consider dedicating a year to focus on mobile species and overhaul our failing approach to negotiating with stakeholders with radically opposed views (see, for example, Jepson, 2012). There is also scope for an individual champion of the cause to emerge, to set the agenda and act as a figurehead to drive the movement forward, much like Thoreau did as a voice for wilderness in the 19th century (Nash, 2014). After the media attention generated by the arrest of British wildlife presenter Chris Packham in Malta in 2014 (http://www.theguardian.com/environment/2014/apr/28/chris-packham-malta-is-a-bird-hell), such a strategy may be especially effective in this age of celebrity.

Conclusion

In reality, migratory, dispersive, irruptive and nomadic behaviours are different configurations along the same movement axis (Newton, 2008). Different populations of the same species can exhibit migratory or irruptive behaviour (e.g. the red-billed quelea *Quelea quelea* or Eurasian bullfinch *Pyrrhula pyrrhula*; Dingle, 1996; Newton, 2010). However, this classification helps draw attention to the particular issues faced by species belonging to the more irregular movement classes, which are often overlooked within conservation agendas. Hopefully, outlining the extent and dangers of the movement shortfall with this classification system will highlight the particular knowledge deficit in these species, accelerating the application of new technology to help unravel the mysteries of their biogeography and drive the innovative conservation strategies they need.

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References

Alerstam, T. (1990). *Bird migration*. Cambridge: Cambridge University Press.

Andersson, M. (1980). Nomadism and site tenacity as alternative reproductive tactics in birds. *J. Anim. Ecol.* **49**, 175–184.

Baillie, S.R., Robinson, R.A., Clark, J.A. & Redfern, C.P.F. (2009). From individuals to flyways: the future of marking birds for conservation. *Ringing Migr.* **24**, 155–161.

Bauer, S. & Hoye, B.J. (2014). Migratory animals couple biodiversity and ecosystem functioning worldwide. *Science* **344**, 1242552.

Berthold, P. (2001). *Bird migration*. Oxford: Oxford University Press.

Birdlife International. (2012). Birdlife's Albatross Task Force is bridging the gap between conservationists and fishermen. Presented as part of the Birdlife State of the world's birds website. Available from: http://www.birdlife.org/datazone/sowb/casestudy/264 (accessed November 11, 2013).

Birdlife International. (2013a). Migratory birds and flyways. Available from: http://www.birdlife.org/worldwide/programmes/migratory-birds-and-flyways (accessed November 11, 2013).

Birdlife International. (2013b). Birds in some families, notably seabirds, have deteriorated in status faster than others. Presented as part of the Birdlife State of the world's birds website. Available from: http://www.birdlife.org/datazone/sowb/casestudy/122 (accessed November 11, 2013).

Birdlife International. (2013c). IUCN Red List for birds. Available from: http://www.birdlife.org (accessed November 11, 2013).

Birdlife International. (2013d). The amazing journey. Available from: http://www.birdlife.org/sociable-lapwing/ (accessed November 11, 2013).

Bonney, R., Shirk, J.L., Phillips, T.B., Wiggins, A., Ballard, H.L., Miller-Rushing, A.J. & Parrish, J.K. (2014). Next steps for citizen science. *Science* **343**, 1436–1437.

BTO. (2013a). Tracking cuckoos to Africa . . . and back again. Available from: http://www.bto.org/science/migration/tracking-studies/cuckoo-tracking (accessed November 11, 2013).

BTO. (2013b). Name a cuckoo. Available from: http://www.bto.org/science/migration/tracking-studies/cuckoo-tracking/name-cuckoo (accessed November 11, 2013).

Burnham, K.K. & Newton, I. (2011). Seasonal movements of Gyrfalcons *Falco rusticolus* include extensive periods at sea. *Ibis* **153**, 468–484.

Butchart, S.H.M., Stattersfield, A.J., Baillie, J., Bennun, L.A., Stuart, S.N., Akçakaya, H.R., Hilton-Taylor, C. & Mace, G.M. (2005). Using red list indices to measure progress towards the 2010 target and beyond. *Phil. Trans. R. Soc. B* **360**, 255–268.

Cardoso, P., Erwin, T.L., Borges, P.A.V. & New, T.R. (2011). The seven impediments in invertebrate conservation and how to overcome them. *Biol. Conserv.* **144**, 2647–2655.

Cherel, Y., Jaeger, A., Alderman, R., Jaquemet, S., Richard, P., Wanless, R.M., Phillips, R.A. & Thompson, D.R. (2013). A comprehensive isotopic investigation of habitat preferences in nonbreeding albatrosses from the Southern Ocean. *Ecography* **36**, 277–286.

Coiffait, L., Redfern, C.P.F., Bevan, R.M., Newton, J. & Wolff, K. (2009). The use of intrinsic markers to study bird migration. *Ringing Migr.* **24**, 169–174.

Coulter, M.C. (1975). Post-breeding movements and mortality in the Western Gull, Larus occidentalis. *Condor* **77**, 243–249.

Croxall, J.P. (2008). The role of science and advocacy in the conservation of Southern Ocean albatrosses at sea. *Bird Conserv. Int.* **18**, S13–S29.

Croxall, J.P., Butchart, S.H.M., Lascelles, B., Stattersfield, A.J., Sullivan, B., Symes, A. & Taylor, P. (2012). Seabird conservation status, threats and priority actions: a global assessment. *Bird Conserv. Int.* **22**, 1–34.

De Frutos, Á. & Olea, P.P. (2008). Importance of the premigratory areas for the conservation of lesser kestrel: space use and habitat selection during the post-fledging period. *Anim. Conserv.* **11**, 224–233.

Dean, W.R.J. (1997). The distribution and biology of nomadic birds in the Karoo, South Africa. *J. Biogeogr.* **24**, 769–779.

Dean, W.R.J. (2004). *Nomadic desert birds (adaptations of desert organisms)*. Berlin: Springer-Verlag.

Dingle, H. (1996). *Migration: the biology of life on the move*. Oxford: Oxford University Press.

Diniz-Filho, J.A.F., Loyola, R.D., Raia, P., Mooers, A.O. & Bini, L.M. (2013). Darwinian shortfalls in biodiversity conservation. *Trends Ecol. Evol.* **28**, 689–695.

Ely, C.R., Nieman, D.J., Alisauskas, R.T., Schmutz, J.A. & Hines, J.E. (2013). Geographic variation in migration chronology and winter distribution of midcontinent greater white-fronted geese. *J. Wildl. Mgmt.* **77**, 1182–1191.

Faaborg, J., Holmes, R.T., Anders, A.D., Bildstein, K.L., Dugger, K.M., Gauthreaux Jr, S.A., Heglund, P., Hobson, K.A., Jahn, A.E., Johnson, D.H., Latta, S.C., Levey, D.J., Marra, P.P., Merkord, C.L., Nol, E., Rothstein, S.I., Sherry, T.W., Sillett, T.S., Thompson III, F.R. & Warnock, N. (2010). Recent advances in understanding migration systems of New World land birds. *Ecol. Monogr.* **80**, 3–48.

Fiedler, W. (2009). New technologies for monitoring bird migration and behaviour. *Ringing Migr.* **24**, 175–179.

Forshaw, J.M. & Cooper, W.T. (2002). *Australian parrots*. 3rd edn. Robina: Alexander Editions.

Fuller, M., Holt, D. & Schueck, L. (2003). Snowy owl movements: variation on a migration theme. In *Avian migration*: 359–366. Berthold, P., Gwinner, E. & Sonnenschein, E. (Eds). Berlin: Springer Verlag.

Garnett, S.T., Szabo, J.K. & Dutson, G. (2011). *The action plan for Australian birds 2010*. Collingwood: CSIRO Publishing.

Goriup, P. & Tucker, G. (2007). *Assessment of the merits of a CMS instrument covering migratory raptors in Africa and Eurasia*. Bristol: DEFRA.

Hays, G.C. (2013). Tracking animals to their death. *J. Anim. Ecol.* **83**, 5–6.

Higgins, P.J. (Ed.) (1999). *Handbook of Australian, New Zealand and Antarctic birds. Volume 4: parrots to dollarbird*. Melbourne: Oxford University Press.

Higgins, P.J., Peter, J.M. & Steele, W.K. (Eds) (2001). *Handbook of Australian, New Zealand and Antarctic birds: tyrant-flycatchers to chats*. Oxford: Oxford University Press.

Howald, G., Donlan, C.J., Galván, J.P., Russell, J.C., Parkes, J., Samaniego, A., Wang, Y., Veitch, D., Genovesi, P., Pascal, M., Saunders, A. & Tershy, B. (2007). Invasive rodent eradication on islands. *Conserv. Biol.* **21**, 1258–1268.

Hudson, N. & the Rarities Committee. (2010). Report on rare birds in Great Britain in 2009. *British Birds* **103**, 562–638.

Jepson, P. (2012). *Opti-hunting policy and business concept. School of Geography and the Environment*. Oxford: University of Oxford.

Jouventin, P. & Weimerskirch, H. (1990). Satellite tracking of wandering albatrosses. *Nature* **343**, 746–748.

Keast, A. (1960). *Bird adaptations to aridity in on the Australian continent*. Proceedings of the XII International Ornithological Conference, 373–375.

Kirby, A. (2004). Place your bets on the big birds. BBC News Online. Available from: http://news.bbc.co.uk/1/hi/sci/tech/3417883.stm (accessed November 11, 2013).

Kirby, J.S., Stattersfield, A.J., Butchart, S.H.M., Evans, M.I., Grimmett, R.F.A., Jones, V.R., O'Sullivan, J., Tucker, G.M. & Newton, I. (2008). Key conservation issues for migratory land- and waterbird species on the world's major flyways. *Bird Conserv. Int.* **18**, 49–73.

Koleček, J., Albrecht, T. & Reif, J. (2014). Predictors of extinction risk of passerine birds in a Central European country. *Anim. Conserv.* **17**, 498–506.

Lack, D. (1968). Bird migration and natural selection. *Oikos* **19**, 1–9.

Limiñana, A., Romero, M., Mellone, U. & Urios, V. (2012). Mapping the migratory routes and wintering areas of lesser kestrels *Falco naumanni*: new insights from satellite telemetry. *Ibis* **154**, 389–399.

Lomolino, M.V., Riddle, B.R., Whittaker, R.J. & Brown, J.H. (2010). *Biogeography*. 4th edn. Sunderland: Sinauer Associates Inc.

Marchant, S. & Higgins, P.J. (Eds) (1990). *Handbook of Australian, New Zealand and Antarctic birds. Volume 1: ratites to ducks*. Melbourne: Oxford University Press.

Marchant, S. & Higgins, P.J. (Eds) (1993). *Handbook of Australian, New Zealand and Antarctic birds. Volume 2: raptors to lapwings*. Melbourne: Oxford University Press.

Marquiss, M., Newton, I., Hobson, K.A. & Kolbeinsson, Y. (2012). Origins of irruptive migrations by common crossbills *Loxia curvirostra* into northwestern Europe revealed by stable isotope analysis. *Ibis* **154**, 400–409.

Mokany, K. & Ferrier, S. (2011). Predicting impacts of climate change on biodiversity: a role for semi-mechanistic community-level modelling. *Divers. Distrib.* **17**, 374–380.

Morales-Castilla, I., Matias, M.G., Gravel, D. & Araújo, M.B. (2015). Inferring biotic interactions from proxies. *Trends Ecol. Evol.* **30**, 347–356

Nash, R.F. (2014). *Wilderness and the American mind*. 5th edn. New Haven: Yale University Press.

Newton, I. (2006a). Advances in the study of irruptive migration. *Ardea* **94**, 433–460.

Newton, I. (2006b). Movement patterns of common crossbills *Loxia curvirostra* in Europe. *Ibis* **148**, 782–788.

Newton, I. (2008). *The ecology of bird migration*. London: Academic Press.

Newton, I. (2010). *Bird migration*. London: Collins.

Nogales, M., Martín, A., Tershy, B., Donlan, C.J., Veitch, D., Puerta, N., Wood, B. & Alonso, J. (2004). A review of feral cat eradication on islands. *Conserv. Biol.* **18**, 310–319.

Peterson, A.T., Soberón, J., Pearson, R.G., Anderson, R.P., Martínez-Meyer, E., Nakamura, M. & Araújo, M.B. (2011). *Ecological niches and geographic distributions*. Princeton: Princeton University Press.

Pizzey, G. & Knight, F. (2007). *The field guide to the birds of Australia*. 8th edn. Sydney: HarperCollins.

Ponnamperuma, K., Siddhartan, A., Zeng, C., Mellish, C. & van der Wal, R. (2013). *Tag2Blog: narrative generation from satellite tag data*. Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics, 169–174.

Pyk, T.M., Weston, M.A., Bunce, A. & Norman, F.I. (2013). Establishment and development of a seabird colony: long-term trends in phenology, breeding success, recruitment, breeding density and demography. *J. Ornithol.* **154**, 299–310.

Raven, P.H. & Wilson, E.O. (1992). A fifty-year plan for biodiversity surveys. *Science* **258**, 1099–1100.

Riddle, B.R., Ladle, R.J., Lourie, S.A. & Whittaker, R.J. (2011). Basic biogeography: estimating biodiversity and mapping nature. In *Conservation biogeography*: 47–92. Ladle, R.J. & Whittaker, R.J. (Eds). Oxford: Blackwell Publishing.

Robinson, W.D., Bowlin, M.S., Bisson, I., Shamoun-Baranes, J., Thorup, K., Diehl, R.H., Kunz, T.H., Mabey, S. & Winkler, D.W. (2010). Integrating concepts and technologies to advance the study of bird migration. *Front. Ecol. Environ.* **8**, 354–361.

Schmaljohann, H., Buchmann, M., Fox, J.W. & Bairlein, F. (2012). Tracking migration routes and the annual cycle of a trans-Sahara songbird migrant. *Behav. Ecol. Sociobiol.* **66**, 915–922.

Shuter, J.L., Broderick, A.C., Agnew, D.J., Jonzén, N., Godley, B.J., Milner-Gulland, E.J. & Thirgood, S. (2011). Conservation and management of migratory species. In *Animal migration: a synthesis*: 172–206. Milner-Gullard, E.J., Fryxell, J.M. & Sinclair, A.R.E. (Eds). Oxford: Oxford University Press.

Somveille, M., Manica, A., Butchart, S.H.M. & Rodrigues, A.S.L. (2013). Mapping global diversity patterns for migratory birds. *PLoS ONE* **8**, e70907.

Supp, S.R., La Sorte, F.A., Cormier, T.A., Lim, M.C.W., Powers, D.R., Wethington, S.M., Goetz, S. & Graham, C.H. (2014). Citizen-science data provides new insight into annual and seasonal variation in migration patterns. *Ecosphere* **6**, 15.

Svensson, L., Mullarney, K., Zetterström, D. & Grant, P.J. (2010). *Collins bird guide*. 2nd edn. London: HarperCollins.

Tischler, M., Dickman, C.R. & Wardle, G.M. (2013). Avian functional group responses to rainfall across four vegetation types in the Simpson Desert, central Australia. *Austral. Ecol.* **38**, 809–819.

Townsend, A.K., Sillett, T.S., Lany, N.K., Kaiser, S.A., Rodenhouse, N.L., Webster, M.S. & Holmes, R.T. (2013). Warm springs, early lay days, and double brooding in a North American migratory songbird, the black-throated blue warbler. *PLoS ONE* **8**, e59467.

Troy, D.M. (1983). Recaptures of redpolls: movements of an irruptive species. *J. Field Ornithol.* **54**, 146–151.

Tucker, G. (2005). *Conservation of birds in the eastern sector of the African-Eurasia Flyway System. Migratory soaring birds: review of status, threats and priority conservation actions*. Ecological Solutions (report to Birdlife International), Huntingdon, UK.

Wanless, R.M., Ryan, P.G., Altwegg, R., Angel, A., Cooper, J., Cuthbert, R. & Hilton, G.M. (2009). From both sides: dire demographic consequences of carnivorous mice and longlining for the Critically Endangered Tristan albatrosses on Gough Island. *Biol. Conserv.* **142**, 1710–1718.

Whittaker, R.J. & Fernández-Palacios, J.M. (2007). *Island biogeography: ecology, evolution and conservation*. 2nd edn. Oxford: Oxford University Press.

Wikelski, M., Kays, R.W., Kasdin, N.J., Thorup, K., Smith, J.A. & Swenson, G.W. Jr. (2007). Going wild: what a global small-animal tracking system could do for experimental biologists. *J. Exp. Biol.* **210**, 181–186.

Woinarski, J.C.Z., Whitehead, P.J., Bowman, D.M.J.S. & Russell-Smith, J. (1992). Conservation of mobile species in a variable environment: the problem of reserve design in the Northern Territory, Australia. *Global Ecol. Biogeogr.* **2**, 1–10.

Woinarski, J.C.Z., Williams, R.J., Price, O. & Rankmore, B. (2005). Landscapes without boundaries: wildlife and their environments in northern Australia. *Wildlife Res.* **32**, 377–388.