Migration general

Table of Contents

Migration general

Migration general 2017

Gilroy JJ. Stay-at-home strategy brings fitness benefits to migrants. J Anim Ecol. 2017;86:983-986. Doi:10.1111/1365-2656.12717

(Abstract)

In this issue, two studies examine the extent to which variation in migratory behaviour influences individual fitness across a population. Lok, Veldhoen, Overdijk, Tinbergen, and Piersma (2017) examine reproductive success and post-fledging survival in a population of Eurasian spoonbills (*Platalea leucorodia*), comparing individuals that winter in south-west Europe against those migrating to sub-Saharan Africa, while Grist et al. (2017) measure reproductive success in a population of European shags (*Phalacrocorax aristotelis*) breeding in Scotland that either remain resident or migrate to surrounding waters. Both studies find that individuals migrating longer distances tend to show later initiation of breeding attempts. In turn, longer migration correlates with lower reproductive success in both populations. In spoonbills, this effect is most pronounced in older male birds, while young individuals show little difference in breeding success with respect to migration distance. In shags, fitness benefits of residence were most pronounced when both individuals of a pair were resident, although there was no evidence of assortative mating. Both studies provide fascinating new insights into the role migratory variability can play in shaping population dynamics.

Sol D, Garcia N, Iwaniuk A, Davis K, Meade A, *et al*. 2010. Evolutionary Divergence in Brain Size between Migratory and Resident Birds. PLoS ONE 5(3):e9617. doi:10.1371/journal.pone.0009617

(Abstract)

Despite important recent progress in our understanding of brain evolution, controversy remains regarding the evolutionary forces that have driven its enormous diversification in size. Here, we report that in passerine birds, migratory species tend to have brains that are substantially smaller (relative to body size) than those of resident species, confirming and generalizing previous studies. Phylogenetic reconstructions based on Bayesian Markov chain methods suggest an evolutionary scenario in which some large brained tropical passerines that invaded more seasonal regions evolved migratory behavior and migration itself selected for smaller brain size. Selection for smaller brains in migratory birds may arise from the energetic and developmental costs associated with a highly mobile life cycle, a possibility that is supported by a path analysis. Nevertheless, an important fraction (over 68%) of the correlation between brain mass and migratory distance comes from a direct effect of migration on brain size, perhaps reflecting costs associated with cognitive functions that have become less necessary in migratory species. Overall, our results highlight the importance of

retrospective analyses in identifying selective pressures that have shaped brain evolution, and indicate that when it comes to the brain, larger is not always better.

Migration general 2016

Duan, H., H. Zhang, Q. Huang, Y. Zhang, M. Hu, Y. Niu, and J. Zhu. 2016. Characterization and environmental impact analysis of sea land reclamation activities in China. *Ocean & Coastal Management* **130**:128-137.

(Abstract)

With rapid urbanization and soaring land prices, many coastal cities in China have turned their eyes to the ocean and built airports or factories on reclaimed land. However, sea land reclamation activities have brought about serious environmental impacts. This study therefore combines qualitative and quantitative information to focus on reclamation activities in China and to highlight the major impacts: ecosystem damage and geological disasters, and the deterioration of marine environmental quality resulting from polluted air, water, soil, and sediment. The realized and potential environmental damages are substantial. A resultant policy recommendation is for local Chinese governments to limit land reclamation and to strengthen environmental assessment systems, especially in fragile coastal regions containing important oceanic resources such as mangroves and protected wildlife. Our study can also serve as a reference for the better management of land reclamation in densely populated coastal regions of the world.

Shimeta, J., L. Saint, E. R. Verspaandonk, D. Nugegoda, and S. Howe. 2016. Long-term ecological consequences of herbicide treatment to control the invasive grass, *Spartina anglica*, in an Australian saltmarsh. *Estuarine, Coastal and Shelf Science* **176**:58-66.

(Abstract)

Invasive plants acting as habitat modifiers in coastal wetlands can have extensive ecological impacts. Control of invasive plants often relies on herbicides, although little is known about subsequent environmental impacts. Studying effects of herbicides on non-target species and long-term cascading consequences may yield insights into the ecology of invasive species by revealing interactions with native species. We conducted a long-term field experiment measuring effects of treating the invasive saltmarsh grass, *Spartina anglica*, with the herbicide Fusilade Forte®. No changes in sedimentary macrofaunal abundances or species richness, diversity, or assemblages were detected 1-2 months after spraying, despite known toxicity of

Fusilade Forte® to fauna. This lack of impact may have been due to low exposure, since the herbicide was taken up primarily by plant leaves, with the small amount that reached the sediment hydrolyzing rapidly. Six months after spraying, however, total macrofauna in treated plots was more than four times more abundant than in unsprayed control plots, due to a fifteen-fold increase in annelids. This population growth correlated with increased sedimentary organic matter in treated plots, likely due to decomposition of dead *S. anglica* leaves serving as food for annelids. After another year, no differences in macrofauna or organic matter remained between treatments. The indirect effect on annelid populations from herbicide treatment could benefit management efforts by providing greater food resources for wading birds, in addition to improving birds' access to sediments by reducing plant cover. This study shows that an invasive grass can have a significant impact on native fauna through food-web interactions, influenced by herbicide usage.

Stillman, R. A., K. A. Wood, and J. D. Goss-Custard. 2016. Deriving simple predictions from complex models to support environmental decision-making. *Ecological Modelling* **326**:134–141.

(Abstract)

Recent decades have seen great advances in ecological modelling and computing power, enabling ecologists to build increasingly detailed models to more accurately represent ecological systems. To better inform environmental decision-making, it is important that the predictions of these models are expressed in simple ways that are straightforward for stakeholders to comprehend and use. One way to achieve this is to predict threshold values for environmental perturbations (e.g. climate change, habitat modification, food loss, sea level rise) associated with negative impacts on individuals, populations, communities or ecosystems. These thresholds can be used by stakeholders to inform management and policy. In this paper we demonstrate how this approach can use individual-based models of birds, their prey and habitats, to provide the evidence-base for coastal bird conservation and shellfishery management. In particular, we show how such models can be used to identify threshold values for perturbations of food abundance that can impact negatively on bird populations. We highlight how environmental thresholds could be used more widely to inform management of species and habitats under environmental change.

Li, S., B. Cui, T. Xie, and K. Zhang. 2016. Diversity Pattern of Macrobenthos Associated with Different Stages of Wetland Restoration in the Yellow River Delta. *Wetlands* **36**:S57–S67.

(Abstract)

Because wetland restoration projects are becoming more common and are expensive, it is important to evaluate their success. Evaluation studies common use measurements of soils, vegetation, hydrology and wildlife to evaluate the success of wetland restoration. In contrast, the diversity of macrobenthos and their relationships with environmental factors are often neglected. To better understand the success of wetland restoration, we examined the abundance and diversity of macrobenthos in different stages of a freshwater wetland restoration project in the Yellow River Delta in China, with reference to environmental factors that might explain macrobenthic patterns. Macrobenthic species richness and density were greater in the oldest restoration area versus the younger and no-treatment areas. Macrobenthic biomass, however, was greatest in the no-treatment area. The oldest restoration area had deeper water levels, lower salinities, softer and wetter soils, and higher soil organic, nitrogen and carbon contents, and these variables largely distinguished the macrobenthic samples in a CCA analysis. A combination of landscape position and recovery time (time since the restoration was implemented) likely explains the abiotic differences among restoration areas. We recommend an adaptive management strategy, guided by long-term monitoring and experiments, to improve the success of this and other wetland restoration projects.

Sesser, K. A., M. E. Reiter, D. A. Skalos, K. M. Strum, and C. M. Hickey. 2016. Waterbird response to management practices in rice fields intended to reduce greenhouse gas emissions. *Biological Conservation* **197**:69–79.

(Abstract)

There are many benefits of agricultural landscapes for wildlife. In California's Central Valley, post-harvest flooding of rice fields increases the decomposition of rice stubble and provides habitat for over 50 species of waterbirds. These fields are also flooded during planting, providing habitat for spring migrants and locally breeding birds. Because California has lost over 90% of its historic wetlands, flooded rice is critical wildlife habitat, providing 80% of the total flooded habitat in the Sacramento Valley. Flooding rice fields, however, contributes to greenhouse gas (GHG) emissions. Several rice field management practices may reduce methane emissions including reduced flooding in winter, removal of rice straw after harvest (baling), and drill seeding during planting. During the winters of 2011–2012 and 2012–2013, we compared waterbird use in four combinations of post-harvest practices: baled/flooded, baled/non-flooded, non-baled/flooded, and non-baled/non-flooded. We found significantly higher dabbling duck and shorebird densities in the non-baled/flooded practice compared to the other three practices. During the spring of 2012 and 2013, we compared waterbird use of drill-seeded fields (reduced GHG) with flooded fly-on seeded fields (status quo GHG). We found no significant differences in mean density between the two seeding practices for waterbirds. Our study found evidence that some post-harvest practices (reduced winter flooding, baling) that reduce GHG emissions from rice also reduce use by waterbirds. While reducing GHG is globally necessary to minimizing the impacts of climate change, doing so in an area of hemispheric importance for waterbirds should be done with caution.

Żmihorski M, Pärt T, Gustafsson T, Berg A. 2016. Effects of water level and grassland management on alpha and beta diversity of birds in restored wetlands. *Journal of Applied Ecology* **53**:587–595.

(Abstract)

1. Nearly 60% of European wetlands have been lost to drainage or to the cessation of grassland management. Large amounts of resources are put into wetland restoration with the aim to recover biodiversity. However, few studies have simultaneously evaluated effects of management, wetness and flooding dynamics on biodiversity of restored wetlands such as seasonally flooded wet grasslands.

2. We inventoried bird communities over 4 years at 137 sites (each 3.1 ha) within five restored wet grassland areas in Sweden to investigate whether species richness and occurrence of 12 common wet grassland species were related to (i) local conditions such as management (grazing, mowing and unmanaged areas), basic wetness and spring flooding dynamics. Further, we investigated whether (ii) the composition of the adjacent landscape (20 ha) related to local bird diversity and (iii) species turnover (i.e. beta diversity) differed between sites characterized by their basic wetness, degree of flooding and predominant management regime.

3. Local species richness was positively linked to degree of flooding and basic wetness of grasslands but not to type of grassland management. Species richness tended also to be negatively linked to proportion of forest at the landscape scale. Although variable, the same results were also true concerning the probability of the occurrence of a single species at the local scale.

4. Species turnover between sites, and thus total species richness, was distinctly higher in (i) grazed as compared to mowed grasslands except in dry non-flooded grasslands and (ii) flooded as compared to non-flooded sites. Similar patterns held for the subset of 12 red-listed species. We suggest that the high beta diversity in grazed and flooded grasslands is driven by the heterogeneous vegetation structure, resulting in good conditions for foraging and nesting for several wet grassland bird species.

5. Synthesis and applications. The selection of wetlands for conserving wet grassland birds should prioritize temporary flooded grasslands of moderate wetness, preferably far from forest edges. Restoration and management of wet grasslands should include water level management, removal of shrubs and trees, and low-intensity grazing, whereas mowing could be used in non-flooded grasslands of low basic wetness.

Zhang C, Yuan Y, Zeng G, Liang J, Guo S, Huang L, Hua S, Wu H, Zhu Y, An H, Zhang L. 2016. Influence of hydrological regime and climatic factor on waterbird abundance in Dongting Lake Wetland, China: Implications for biological conservation. *Ecological Engineering* **90**:473–481.

(Abstract)

Understanding how migratory waterbirds respond to hydrology and climate is of great importance for providing valuable insight into conservation in wetland system. Dongting Lake Wetland is an important wintering habitat in the East Asian-Australasian Flyway. However, little is known about the effects of hydrology and climate on wintering waterbirds. Therefore, it is urgent to analyze the relationship between them. To better interpret the ecological significance, we divided the bird species into five functional groups on the basis of their typical feeding habits. Redundancy analysis (RDA) combined with forward selection procedure was applied to select the hydrological and climatic variables with significant influences. Then, response surface methodology (RSM) was carried out to identify the thresholds of the variables. The results showed that inflow and water level were probably the two critical variables accounting for 52.13% and 47.87% of the variation in the bird species, respectively. However, other variables did not reach a significant level in this study. As for the group-level, different functional bird groups had different reflections to inflow and water level. Minimal guaranteed values of the two variables were identified as 3518.82–3736.28 m^3/s and 22.61–23.49 m respectively based on the hydrological requirements and the weights of all groups. The results highlighted that the minimal requirements of inflow and water level should be satisfied to provide appropriate habitats for waterbirds. Besides, the regulatory authorities and environmental protection agencies should develop relevant law or regulation to protect waterbird habitats from human destruction especially the activities which could change the hydrological regime.

Liu C-Y, Jiang H-X, Zhang S-q, Li C-r, Pan X, Lu J, Hou Y-Q. 2016. Expansion and Management Implications of Invasive Alien *Spartina alterniflora* in Yancheng Salt Marshes, China. *Open Journal of Ecology* **6**:113-128.

(Abstract)

Improved understanding of the spatial dynamics of invasive plant species is critical for effective land management and control of future invasion. The Yancheng National Nature Reserve (YNNR), an internationally important wetland, has the largest distribution of alien *Spartina alterniflora* in China. This alien plant was intentionally introduced for erosion prevention and dike protection in China. However, it became an aggressive competitor with native salt marsh plants in the coastal regions in China. High resolution imagery, SPOT-5, was used to map plant communities including invasive species in the south core zone of YNNR with the natural ecosystem of salt marshes in 2003, 2005 and 2008. The fuzzy set assessment method significantly improved the classification accuracies over the conventional error matrix, i.e., from 73.8%, 73.5% and 81.4% to 91.5%, 91.6% and 93.4% in 2003, 2005 and 2008,

respectively. It shows a great potential for mapping invasive plant species. *Phragmites australis* and *S. alterniflora* were the most accurately mapped classes, and sparse and dense *Suaeda glauca* were the least accurately mapped. From 2003 to 2008, *S. alterniflora* increased 28.8% from 1664.1 to 2142.6 ha in area size, and more than 2.5 times from 742 to 2608 patches. The highest increase in patch number occurred within the interval between 2001 and 3000 m from the eastern baseline. This increase was dominated by small patches with area less than 200 m^2. During the study period, the mean spread width was 405 ± 80.7 m in the original large patch of area over 200 ha. The eastward/seaward spread was distinctively larger than the westward/landward. The results enhance the understanding of alien plant's invasion patterns and help improve conservation efforts.

Casazza ML, Overton CT, Bui T-VD, Hull JM, Albertson JD, Bloom VK, Bobzien S, McBroom J, Latta M, Olofson P, Rohmer TM, Schwarzbach S, Strong DR, Grijalva E, Wood JK, Skalos SM, Takekawa JY. 2016. Endangered species management and ecosystem restoration: finding the common ground. *Ecology and Society* **21** (1):19.

(Abstract)

Management actions to protect endangered species and conserve ecosystem function may not always be in precise alignment. Efforts to recover the California Ridgway's Rail (*Rallus obsoletus obsoletus*; hereafter, California rail), a federally and state-listed species, and restoration of tidal marsh ecosystems in the San Francisco Bay estuary provide a prime example of habitat restoration that has conflicted with species conservation. On the brink of extinction from habitat loss and degradation, and non-native predators in the 1990s, California rail populations responded positively to introduction of a non-native plant, Atlantic cordgrass (*Spartina alterniflora*). California rail populations were in substantial decline when the non-native *Spartina* was initially introduced as part of efforts to recover tidal marshes. Subsequent hybridization with the native Pacific cordgrass (*Spartina foliosa*) boosted California rail populations by providing greater cover and increased habitat area. The hybrid cordgrass (*S. alterniflora* × *S. foliosa*) readily invaded tidal mudflats and channels, and both crowded out native tidal marsh plants and increased sediment accretion in the marsh plain. This resulted in modification of tidal marsh geomorphology, hydrology, productivity, and species composition. Our results show that denser California rail populations occur in invasive *Spartina* than in native *Spartina* in San Francisco Bay. Herbicide treatment between 2005 and 2012 removed invasive *Spartina* from open intertidal mud and preserved foraging habitat for shorebirds. However, removal of invasive *Spartina*caused substantial decreases in California rail populations. Unknown facets of California rail ecology, undesirable interim stages of tidal marsh restoration, and competing management objectives among stakeholders resulted in management planning for endangered species or ecosystem restoration that favored one goal over the other. We have examined this perceived conflict and propose strategies for moderating harmful effects of restoration while meeting the needs of both endangered species and the imperiled native marsh ecosystem.

Lu Q, Kang L, Shao H, Zhao Z, Chen Q, Bi X, Shi P. 2016. Investigating marsh sediment dynamics and its driving factors in Yellow River delta for wetland restoration. *Ecological Engineering* **90**:307–313.

(Abstract)

The wetlands of the Yellow River delta play important roles for Asian and west Pacific birds during migration. Marshes are the main component of wetlands in the delta, and their coverage area has experienced a decreasing trend for the last few decades. Wetland changes in the Yellow River delta have been analyzed in previous studies; however, those studies only partially analyzed the causes of the decline. Using statistical and spatial analysis based on observational data and remote sensing imagery for the period of 1986–2005, we found that the annual mean temperature and annual precipitation tended to increase, and the evapotranspiration and the moisture index tended to decrease. Consequently, these climate factors led to a significant decrease in river runoff, which resulted in decreased water supply for the marshes in the delta. A Wetland Restoration Project was launched in 1992, and it successfully conserved marshes within a relatively small area. However, the inadequate water supply still resulted in an overall decrease in marsh area over the entire study area. These results provide more insights into managing wetlands eco-restoration.

Puente-Rodriguez, D., E. van Slobbe, I. A. C. Al, and D. E. Lindenbergh. 2016. Knowledge co-production in practice: Enabling environmental management systems for ports through participatory research in the Dutch Wadden Sea. *Environmental Science and Policy* **55**:456-466.

(Abstract)

Coastal zone management is inconceivable without the mobilization and integration of different types of knowledge – that is, without knowledge co-production practices. This article applies the concept of knowledge co-production to analyze the process of emergence, standardization, and enculturation of environmental management systems (EMSs) within port communities in the Dutch Wadden Sea. Moreover, it is a report from the field in which we reflect on the participatory practices conducted to facilitate the knowledge arrangements required to develop EMSs for a group of ports. The article concludes that this type of knowledge arrangement and co-production practices (involving different types of actors and knowledge) might become mandatory in the near future to stabilize the EMS phenomenon in the practices of ports.

Migration general 2015

Vincze O, Vagasi C, Pap PL, Osvath G, Møller AP. 2015. Brain regions associated with visual cues are important for bird migration. *Biological Letters* **11**:20150678.

(Abstract)

Long-distance migratory birds have relatively smaller brains than short-distance migrants or residents. Here, we test whether reduction in brain size with migration distance can be generalized across the different brain regions suggested to play key roles in orientation during migration. Based on 152 bird species, belonging to 61 avian families from six continents, we show that the sizes of both the telencephalon and the whole brain decrease, and the relative size of the optic lobe increases, while cerebellum size does not change with increasing migration distance. Body mass, whole brain size, optic lobe size and wing aspect ratio together account for a remarkable 46% of interspecific variation in average migration distance across bird species. These results indicate that visual acuity might be a primary neural adaptation to the ecological challenge of migration.

Betini, G. S., M. J. Fitzpatrick, and D. R. Norris. 2015. Experimental evidence for the effect of habitat loss on the dynamics of migratory networks. *Ecology Letters* **18**:526–534.

(Abstract)

Migratory animals present a unique challenge for understanding the consequences of habitat loss on population dynamics because individuals are typically distributed over a series of interconnected breeding and non-breeding sites (termed migratory network). Using replicated breeding and non-breeding populations of Drosophila melanogaster and a mathematical model, we investigated three hypotheses to explain how habitat loss influenced the dynamics of populations in networks with different degrees of connectivity between breeding and non-breeding seasons. We found that habitat loss increased the degree of connectivity in the network and influenced population size at sites that were not directly connected to the site where habitat loss occurred. However, connected networks only buffered global population declines at high levels of habitat loss. Our results demonstrate why knowledge of the patterns of connectivity across a species range is critical for predicting the effects of environmental change and provide empirical evidence for why connected migratory networks are commonly found in nature.

Kishkinev, D. 2015. Sensory mechanisms of long-distance navigation in birds: a recent advance in the context of previous studies. *Journal of Ornithology* **156**:S145–S161.

(Abstract)

Displacement studies have clearly shown that experienced avian migrants are able to perform true navigation, i.e., they can find the correct direction leading to a target destination from unfamiliar sites. The sensory mechanisms of true navigation remain poorly understood, though some remarkable progress has been made in the last 10–15 years. There are two primary hypotheses explaining the sensory nature of navigation: (1) a magnetic map hypothesis proposes that birds use parameters of the geomagnetic field that are predictably distributed on the globe. As for the sensory nature of this hypothesis, it has been assumed by some researchers that the magnetic receptor cells reside in the upper beak (the so-called ‘‘beak organ’’), and transmit information via the trigeminal nerve to the brain; (2) an olfactory map hypothesis assumes that birds can smell their position by taking advantage of odours distributed in the atmosphere. There are a growing number of studies supporting both of the hypotheses mentioned though in different avian model species. In this review, an attempt is made to provide an overview of the evidence for different navigational cues proposed thus far, with the main focus on the recent studies addressing the magnetic and olfactory navigation hypotheses. Also, a list of key open questions, together with possible experimental approaches, is proposed.

Somveille, M., A. S. L. Rodrigues, and A. Manica. 2015. Why do birds migrate? A macroecological perspective. *Global Ecology and Biogeography* **24**:664–674.

(Abstract)

Aim: Bird migration poses a challenge to macroecology, because with one in five species moving twice yearly between breeding and non-breeding grounds, macroecological patterns in birds are dynamic rather than static. But migration is also a natural experiment for testing hypotheses about the ecological mechanisms driving species distributions. Here, we use macroecological patterns of migratory bird diversity to test whether seasonality, winter harshness and the cost of migration drive the global distribution of migratory birds.

Location: Global

Methods: We used data on the distribution of the world’s bird species to derive global empirical patterns of: the number of breeding migrants, the number of non-breeding migrants and the difference in seasonal diversity. We built statistical models with ecologically meaningful predictors related to each of the hypotheses and investigated if they can significantly explain global empirical patterns of migratory bird diversity. We formally tested these models by training on one hemisphere (Western or Eastern) to predict the other hemisphere in turn.

Model predictions were assessed in terms of match to the empirical data and their ability to predict the spatial features of patterns.

Results: We found strong support for the hypotheses that birds move to breeding grounds to exploit a surplus in resources, preferring areas with harsh winters (presumably to avoid competition). In contrast, distribution during the nonbreeding season seems driven by avoidance of harsh winters and connectivity to breeding grounds. Models integrating these hypotheses explain well the observed variance in the empirical patterns and reproduce key spatial features, even when models trained in one hemisphere are used to predict another.

Main conclusions: The strong predictive power of the models suggests that we have captured the main mechanisms that drive global patterns in bird migration. The fact that the models perform well despite being applied to species with very different ecologies suggests general mechanisms driving migration across taxa.

Goodenough, A. E., S. M. Fairhurst, J. B. Morrison, M. Cade, P. J. Morgan, and M. J. Wood. 2015. Quantifying the robustness of first arrival dates as a measure of avian migratory phenology. *Ibis* **157**:384–390.

(Abstract)

As the climate changes, many long-term studies have shown that the timing of bird migration is shifting, increasing the need for reliable measures of migratory phenology. Ideally, daily counts of birds at a site are used to calculate the mean arrival date (MAD) but, as this approach is not always possible and is very labour-intensive, simpler metrics such as first arrival date (FAD) have commonly been used. Here, we examine the relationship between FAD and MAD in 28 summer migrant bird species over a 42-year period (1970–2011) at Portland Bird Observatory, UK. Although significant correlations between FAD and MAD were detected, relationships were weak, particularly in long-distance migrants. We suggest that FAD, although a simple and straightforward measure, is not particularly robust as a proxy for overall migratory phenology at a population level.

Fristoe, T. S. 2015. Energy use by migrants and residents in North American breeding bird communities. *Global Ecology and Biogeography* **24**:406–415.

(Abstract)

Aim: Of the order of 5 billion birds comprising more than 700,000 tonnes of biomass migrate across North America every year to exploit seasonal resource pulses at high latitudes during breeding. Despite this impressive scale, little is known about the metabolic role of these

migrants in their breeding grounds across temperate ecosystems. I estimate the energy use of short- and long-distance migrant passerines as well as residents in over 2000 breeding bird communities covering the geographic scope of North America. My aim was to characterize the geographic patterns of energy use by each migratory group and test the hypothesis that seasonal patterns of resource availability structure temperate breeding bird communities.

Location: North America from 25 to 69° N.

Methods: I estimated the energy use of migrant and resident passerines using abundance data from the North American Breeding Bird Survey and scaling relationships for field metabolic rate as a function of body size. Linear regression was used to test the relationship between energy use by each migratory group and latitude as well as indirect measures of environmental productivity during different seasons.

Results: Energy use by all groups showed a strong relationship with latitude except for long-distance migrants, which were surprisingly invariant across geography. Energy use by migrants was highest in environments with low winter productivity and high seasonality, while resident energy use was highest where annual productivity was the highest.

Main conclusions: Migrant passerines contribute significantly to temperate breeding bird communities, especially in high latitudes. They account for 78% of consumption in habitats north of 50° N compared with 1.7% in the subtropics south of 35° N. Short-distance migrants are especially important to community energy use in the habitats where migrants consume the most. Future shifts in breeding bird community composition are likely to occur as climate change alters seasonal cycles of resource availability.

Pekarsky, S., A. Angert, B. Haese, M. Werner, K. A. Hobson, and R. Nathan. 2015. Enriching the isotopic toolbox for migratory connectivity analysis: a new approach for migratory species breeding in remote or unexplored areas. *Diversity and Distributions* **21**:416–427.

(Abstract)

Aim: We examined three potential enhancements of the stable isotope technique for elucidating migratory connectivity in birds inhabiting poorly studied areas, illustrated for Eurasian cranes (*Grus grus*) that overwinter in and migrate through Israel. First, we examined the use of oxygen stable isotopes ($d^{18}O$), seldom applied for this purpose. Second, we examined the relationship between ambient water $d^{18}O$ and hydrogen stable isotope ($d^{2}H$) values derived from various models, to determine the geographical origins of migrants. Third, we introduced the use of probabilistic distribution modelling to refine the assignment to origin of migrants lacking detailed distribution maps.

Location: Feather samples were collected in the Hula Valley (northern Israel) and across the species breeding range in north Eurasia.

Methods: We analysed $d^{18}O$ and $d^{2}H$ in primary and secondary flight feathers using standard mass spectrometry. The maximum entropy (MAXENT) model was used to map the probability surface of potential breeding areas, as a Bayesian prior for assigning Hula Valley cranes to potential breeding grounds.

Results: We found that $d^{18}O$ was suitable and informative. The soil water isoscape performed better for d18O while precipitation isoscape was preferable for $d^{2}H$. The MAXENT-based probability surface largely refined assignments. Overall, most (>85%) cranes were assigned to the area west of the Ural Mountains, but for two individuals, most of the assigned area (>90%) was farther east, suggesting, for the first time, that Eurasian cranes may undertake the North Asia–Middle East (and perhaps Africa) migration flyway.

Main conclusions: Our results call for broader use of $d^{18}O$ in migratory connectivity studies and for application of probabilistic distribution modelling. We also encourage investigation of factors determining $d^{18}O$ and $d^{2}H$ integration into animal tissues. The proposed framework may help improve our understanding of migratory connectivity of species inhabiting previously unexplored areas and thus contribute to the development of efficient conservation plans.

Ledwon, M., and J. Betleja. 2015. Post-breeding migration of Night Herons *Nycticorax nycticorax*tracked by GPS/GSM transmitters. *Journal of Ornithology* **156**:313–316.

(Abstract)

The migratory strategy of herons is poorly understood: only that of Purple Heron has been well studied. The migratory movements of three Night Herons from the Upper Vistula Valley (Poland) were studied using a GPS/GSM-tracking system in 2012. The results document a previously unknown autumn migration strategy of Night Herons with long stopovers en route, unlike that of Purple Herons. The different migration strategies of Purple Herons and Night Herons could be due to differences in wing-loadings and foraging ecology.

Palm, E. C., S. H. Newman, D. J. Prosser, X. Xiao, L. Ze, N. Batbayar, S. Balachandran, and J. Y. Takekawa. 2015. Mapping migratory flyways in Asia using dynamic Brownian bridge movement models. Movement Ecology 3:1-10.

(Abstract)

Background: Identifying movement routes and stopover sites is necessary for developing effective management and conservation strategies for migratory animals. In the case of migratory birds, a collection of migration routes, known as a flyway, is often hundreds to thousands of kilometers long and can extend across political boundaries. Flyways encompass

the entire geographic range between the breeding and non-breeding areas of a population, species, or a group of species, and they provide spatial frameworks for management and conservation across international borders. Existing flyway maps are largely qualitative accounts based on band returns and survey data rather than observed movement routes. In this study, we use satellite and GPS telemetry data and dynamic Brownian bridge movement models to build upon existing maps and describe waterfowl space use probabilistically in the Central Asian and East Asian-Australasian Flyways.

Results: Our approach provided new information on migratory routes that was not easily attainable with existing methods to describe flyways. Utilization distributions from dynamic Brownian bridge movement models identified key staging and stopover sites, migration corridors and general flyway outlines in the Central Asian and East Asian-Australasian Flyways. A map of space use from ruddy shelducks depicted two separate movement corridors within the Central Asian Flyway, likely representing two distinct populations that show relatively strong connectivity between breeding and wintering areas. Bar-headed geese marked at seven locations in the Central Asian Flyway showed heaviest use at several stopover sites in the same general region of high-elevation lakes along the eastern Qinghai-Tibetan Plateau. Our analysis of data from multiple Anatidae species marked at sites throughout Asia highlighted major movement corridors across species and confirmed that the Central Asian and East Asian-Australasian Flyways were spatially distinct.

Conclusions: The dynamic Brownian bridge movement model improves our understanding of flyways by estimating relative use of regions in the flyway while providing detailed, quantitative information on migration timing and population connectivity including uncertainty between locations. This model effectively quantifies the relative importance of different migration corridors and stopover sites and may help prioritize specific areas in flyways for conservation of waterbird populations.

Bishop, C. M., R. J. Spivey, L. A. Hawkes, N. Batbayar, B. Chua, P. B. Frappell, W. K. Milsom, T. Natsagdorj, S. H. Newman, J. Y. Takekawa, M. C. Wikelski, and P. J. Butler. 2015. The roller coaster flight strategy of bar-headed geese conserves energy during Himalayan migrations. *Science* **347**:250-254.

(Abstract)

The physiological and biomechanical requirements of flight at high altitude have been the subject of much interest. Here, we uncover a steep relation between heart rate and wingbeat frequency (raised to the exponent 3.5) and estimated metabolic power and wingbeat frequency (exponent 7) of migratory bar-headed geese. Flight costs increase more rapidly than anticipated as air density declines, which overturns prevailing expectations that this species should maintain high-altitude flight when traversing the Himalayas. Instead, a “roller coaster” strategy, of tracking the underlying terrain and discarding large altitude gains only to recoup them later in the flight with occasional benefits from orographic lift, is shown to be energetically advantageous for flights over the Himalayas.

Winkler DW, Jørgensen C, Both C, Houston AI, McNamara JM, Levey DJ, Partecke J, Fudickar A, Kacelnik A, Roshier D, Piersma T. 2014. Cues, strategies, and outcomes: how migrating vertebrates track environmental change. *Movement Ecology* **2**:10.

(No abstract available)

Runge, C. A., T. G. Martin, H. P. Possingham, S. G. Willis, and R. A. Fuller. 2014. Conserving mobile species. *Frontiers in Ecology and the Environment* **12**:395–402.

(Abstract)

The distributions of many species are dynamic in space and time, and movements made by individuals range from regular and predictable migrations to erratic, resource-driven nomadism. Conserving such mobile species is challenging; the effectiveness of a conservation action taken at one site depends on the condition of other sites that may be geographically and politically distant (thousands of kilometers away or in another jurisdiction, for example). Recent work has shown that even simple and predictable linkages among sites caused by “to-and-fro” migration can make migratory species especially vulnerable to habitat loss, and substantially affect the results of conservation prioritizations. Species characterized by more erratic or nomadic movements are very difficult to protect through current conservation planning techniques, which typically view species distributions as static. However, collaborations between migration ecologists, conservation planners, and mathematical ecologists are paving the way for improvements in conservation planning for mobile species.

Eikenaar, C., T. Klinner, T. de Lille, F. Bairlein, and H. Schmaljohann. 2014. Fuel loss and flexible fuel deposition rates in a long-distance migrant. *Behavioral Ecology and Sociobiology* **68**:1465–1471.

(Abstract)

Most migrating birds alternate flight bouts with stopovers, during which they rest and replenish

the fuel used during flight (refueling). The rate of refueling (fuel deposition rate, FDR) affects stopover duration, and hence is an important determinant of the overall time required for migration. Although environmental and endogenous factors affect FDR, the urge to refuel depends on the anticipated distance to be travelled and possibly also on the amount of fuel used during the flight preceding stopover. Combining a field study with a fasting–refueling experiment on long-term captive songbirds, we tested whether the extent of fuel loss prior to refueling indeed affects FDR. In the field study, we took a comparative approach and determined FDR in two subspecies of northern wheatear (*Oenanthe oenanthe*) that differ greatly in the distance flown, and thus the extent of fuel used to reach our study (stopover) site. As both winter in western sub-Sahelian Africa, they face the same remaining migration distance. We found that FDR was higher in the subspecies that uses more fuel to get to our study site. Solidifying this result, in the experiment on captive northern wheatears, we found that the extent of fuel loss as a consequence of fasting explained most of the variation in subsequent FDR. The observation that experimental birds losing little fuel did not maximize their FDR suggests there are costs to rapid refueling. Our study shows that FDR is shaped not just by current environmental and endogenous conditions but also by fuel loss prior to refueling.

Shamoun-Baranes J, Alves JA, Bauer S, Dokter AM, Hüppop O, Koistinen J, Leijnse H, Liechti F, van Gasteren H, Chapman JW. 2014 in press. Continental-scale radar monitoring of the aerial movements of animals. *Movement Ecology* **2**.

(Abstract)

Billions of organisms travel through the air, influencing population dynamics, community interactions, ecosystem services and our lives in many different ways. Yet monitoring these movements are technically very challenging. During the last few decades, radars have increasingly been used to study the aerial movements of birds, bats and insects, yet research efforts have often been local and uncoordinated between research groups. However, a network of operational weather radars is continuously recording atmospheric conditions all over Europe and these hold enormous potential for coordinated, continental-scale studies of the aerial movements of animals. The European Network for the Radar surveillance of Animal Movement (ENRAM) is a new e-COST research network aiming exactly at exploring this potential. The main objective of ENRAM is to merge expertise to utilize weather radars to monitor the aerial movement of animals across Europe for a broad range of stakeholders at an unprecedented scale and enable researchers to study the causes and consequences of movement. In this paper we describe the aims of ENRAM in more detail and the challenges researchers will address, provide an overview of aero-ecological studies using radar, and present some of the opportunities that a large sensor network can provide for movement ecology research.

Cresswell, W. 2014. Migratory connectivity of Palaearctic–African migratory birds and their responses to environmental change: the serial residency hypothesis. *Ibis* **156**:493–510.

(Abstract)

In most long-distance migratory birds, juveniles migrate without their parents and so are likely to lack detailed knowledge of where to go. This suggests the potential for stochasticity to affect their choice of wintering area at a large scale (> 1000 km). Adults, in contrast, may re-use non-breeding sites that promote their survival, so removing uncertainty from their subsequent migrations. I review the evidence for large-scale stochastic juvenile site selection followed by adult site fidelity, and then develop a 'serial-residency' hypothesis based on these two traits as a framework to explain both the migratory connectivity and the population dynamics of migrant birds and how these are affected by environmental change. Juvenile stochasticity is apparent in the age-dependent effects of weather or experimental displacement on the outcome of migration and in the very wide variation in the destinations of individuals originating from the same area. Adults have been shown to be very faithful to their wintering grounds and even to staging sites. The serial residency hypothesis predicts that migrants that show these two traits will rely on an individually unique but fixed series of temporally and spatially linked sites to complete their annual cycle. As a consequence, migratory connectivity will be apparent at a very small scale for individuals, but only at a large scale for a population, and juveniles are predicted to occur more often at less suitable sites than adults, so that survival will be lower for juveniles. Migratory connectivity will arise only through spatial and temporal autocorrelation with local environmental constraints, particularly on passage, and the distribution and age structure of the population may reflect past environmental constraints. At least some juveniles will discover suitable habitat that they may re-use as adults, thus promoting overall population-level resilience to environmental change, and suggesting value in site-based conservation. However, because migratory connectivity only acts on a large scale, any population of migrants will contain individuals that encounter a change in suitability somewhere in their non-breeding range, so affecting average survival. Differences in population trends will therefore reflect variation in local breeding output added to average survival from wintering and staging areas. The latter is likely to be declining given increasing levels of environmental degradation throughout Africa. Large-scale migratory connectivity also has implications for the evolutionary ecology of migrants, generally because this is likely to lead to selection for generalist traits.

Sergio, F., A. Tanferna, R. De Stephanis, L. Lopez-Jimenez, J. Blas, G. Tavecchia, D. Preatoni, and F. Hiraldo. 2014. Individual improvements and selective mortality shape lifelong migratory performance. *Nature* **515**:410.

(Abstract)

Billions of organisms, from bacteria to humans, migrate each year and research on their

migration biology is expanding rapidly through ever more sophisticated remote sensing technologies. However, little is known about how migratory performance develops through life for any organism. To date, age variation has been almost systematically simplified into a dichotomous comparison between recently born juveniles at their first migration versus adults of unknown age. These comparisons have regularly highlighted better migratory performance by adults compared with juveniles, but it is unknown whether such variation is gradual or abrupt and whether it is driven by improvements within the individual, by selective mortality of poor performers, or both. Here we exploit the opportunity offered by long-term monitoring of individuals through Global Positioning System (GPS) satellite tracking to combine within-individual and cross-sectional data on 364 migration episodes from 92 individuals of a raptorial bird, aged 1–27 years old. We show that the development of migratory behaviour follows a consistent trajectory, more gradual and prolonged than previously appreciated, and that this is promoted by both individual improvements and selective mortality, mainly operating in early life and during the pre-breeding migration. Individuals of different age used different travelling tactics and varied in their ability to exploit tail winds or to cope with wind drift. All individuals seemed aligned along a race with their contemporary peers, whose outcome was largely determined by the ability to depart early, affecting their subsequent recruitment, reproduction and survival. Understanding how climate change and human action can affect the migration of younger animals maybe the key to managing and forecasting the declines of many threatened migrants.

Delmore, K. E., and D. E. Irwin. 2014. Hybrid songbirds employ intermediate routes in a migratory divide. *Ecology Letters* 17:1211–1218.

(Abstract)

Migratory divides are contact zones between populations that use different routes to navigate around unsuitable areas on seasonal migration. Hybrids in divides have been predicted to employ intermediate and potentially inferior routes. We provide the first direct test of this hypothesis, using light-level geolocators to track birds breeding in a hybrid zone between Swainson's thrushes in western Canada. Compared to parental forms, hybrids exhibited increased variability in their migratory routes, with some using intermediate routes that crossed arid and mountainous regions, and some using the same routes as one parental group on fall migration and the other on spring migration. Hybrids also tended to use geographically intermediate wintering sites. Analysis of genetic variation across the hybrid zone suggests moderately strong selection against hybrids. These results indicate that seasonal migratory behaviour might be a source of selection against hybrids, supporting a possible role for migration in speciation.

Desholm, M., R. Gill, T. Bøvith, and A. D. Fox. 2014. Combining spatial modelling and radar to identify and protect avian migratory hot-spots. *Current Zoology* **60**:680–691.

(Abstract)

Migrating landbirds are known to follow coast lines and concentrate on peninsulas prior to crossing water bodies, especially during daylight but also at night, creating enhanced potential collision hazards with man-made objects. Knowing where these avian migration “hot-spots” occur in time and space is vital to improve flight safety and inform the spatial planning process (e.g. environmental assessments for offshore windfarms). We developed a simple spatial model to identify avian migration hot-spots in coastal areas based on prevailing migration orientation and coastline features known, from visual and radar observations, to concentrate migrating landbirds around land masses. Regional scale model validation was achieved by combining nocturnal passerine movement data gathered from two tier radar coverage (long-range dual-polarization Doppler weather radar and short-range marine surveillance radar) and standardised bird ringing. Applied on a national scale, the model correctly identified the ten most important Danish coastal hot-spots for spring migrants and predicted the relative numbers of birds that concentrated at each site. These bird numbers corresponded well with historical observational data. Here, we provide a potential framework for the establishment of the first three-dimensional avian airspace sanctuaries, which could contribute to more effective conservation of long-distance migratory birds.

La Sorte FA, Fink D, Hochachka WM, Farnsworth A, Rodewald AD, Rosenberg KV, Sullivan BL, Winkler DW, Wood C, Kelling S. 2014. The role of atmospheric conditions in the seasonal dynamics of North American migration flyways. *Journal of Biogeography* **41**, 1685-1696.

(Abstract)

Aim: Avian migration strategies balance the costs and benefits of annual movements between breeding and wintering grounds. If similar constraints affect a large number of species, geographical concentrations of migration routes, or migration flyways, may result. Here we provide the first population-level empirical evaluation of the structure and seasonal dynamics of migration flyways for North American terrestrial birds and their association with atmospheric conditions.

Location: Contiguous USA.

Methods: We modelled weekly probability of occurrence for 93 migratory species using spatio-temporal exploratory models and eBird occurrence data for the combined period 2004 to 2011. We used hierarchical cluster analysis to identify species with shared migration routes based on normalized spatio-temporal representations of autumn migration. We summarized atmospheric conditions within flyways using nocturnal wind velocity and bearing estimated at three isobaric levels (725, 825 and 925 mbar) for the combined period 2008 to 2011.

Results: We identified three migration flyways: an eastern and western flyway whose paths shifted westwards in the spring, and a central flyway whose core boundaries overlapped with the eastern flyway and whose width was more constricted in the autumn. The seasonal shift of the eastern flyway created potentially longer migration journeys in the spring, but this longer route coincides with a low-level jet stream that may enhance migration speeds. Atmospheric conditions appeared to have a more limited role in the seasonal dynamics of the western flyway.

Main conclusions: Migration routes for terrestrial species in North America can be organized into three broadly defined migration flyways: a geographically distinct flyway located west of the 103rd meridian and two interrelated flyways located east of the 103rd meridian. Seasonal shifts in flyway locations reflect the influence of looped migration strategies that for the eastern flyway can be explained by the trade-off between minimizing total migration distance while maintaining an association with favourable atmospheric conditions.

Rushing CS, Ryder TB, Saracco JF, Marra PP. 2014. Assessing migratory connectivity for a long-distance migratory bird using multiple intrinsic markers. *Ecological Applications* **24**, 445-456.

(Abstract)

Patterns of migratory connectivity are a vital yet poorly understood component of the ecology and evolution of migratory birds. Our ability to accurately characterize patterns of migratory connectivity is often limited by the spatial resolution of the data but recent advances in probabilistic assignment approaches have begun pairing stable isotopes with other sources of data (e.g., genetic and mark-recapture) to improve the accuracy and precision of inferences based on a single marker. Here, we combine stable isotopes and geographic variation in morphology (wing length) to probabilistically assign Wood thrush (*Hylocichla mustilena*) captured on the wintering grounds to breeding locations. In addition, we use known origin samples to validate our model and assess potentially important impacts of covariates of isotopic and morphological data (age, sex and breeding location). Our results show that despite relatively high levels of mixing across their breeding and non-breeding ranges, moderate levels of migratory connectivity along an east-west gradient exist. In addition, combining stable isotopes with geographic variation in wing improved the precision of breeding assignments by 10% and 37% compared to assignments based on isotopes alone or wing length alone, respectively. These results demonstrate that geographical variation in morphological traits can greatly improve estimates of migratory connectivity when combined with other intrinsic markers (e.g., stable isotopes or genetic data). The wealth of morphological data available from museum specimens across the world represents a tremendously valuable, but largely untapped, resource that is widely applicable for quantifying patterns of migratory connectivity.

Vickery JA, Ewing SR, Smith KW, Pain DJ, Bairlein F, Skorpilov J, Gregory RD. 2014. The decline of Afro-Palaearctic migrants and an assessment of potential causes. *Ibis* **156**, 1–22.

(Abstract)

There is compelling evidence that Afro-Palaearctic (A-P) migrant bird populations have declined in Europe in recent decades, often to a greater degree than resident or short-distance migrants. There appear to have been two phases of decline. The first in the 1960s–1970s, and in some cases into the early 1980s, largely affected species wintering predominantly in the arid Sahelian zone, and the second since the 1980s has mostly affected species wintering in the humid tropics and Guinea forest zone. Potential drivers of these declines are diverse and are spread across and interact within the migratory cycle. Our knowledge of declining species is generally better for the breeding than the non-breeding parts of their life cycles, but there are significant gaps in both for many species. On the breeding grounds, degradation of breeding habitats is the factor affecting the demography of the largest number of species, particularly within agricultural systems and woodland and forests. In the non-breeding areas, the interacting factors of anthropogenic habitat degradation and climatic conditions, particularly drought in the Sahel zone, appear to be the most important factors. Based on our synthesis of existing information, we suggest four priorities for further research: (1) use of new and emerging tracking technologies to identify migratory pathway and strategies, understand migratory connectivity and enable field research to be targeted more effectively; (2) undertake detailed field studies in sub-Saharan Africa and at staging sites, where we understand little about distribution patterns, habitat use and foraging ecology; (3) make better use of the wealth of data from the European breeding grounds to explore spatial and temporal patterns in demographic parameters and relate these to migratory pathways and large-scale patterns of habitat change and climatic factors; and (4) make better use of remote sensing to improve our understanding of how and where land cover is changing across these extensive areas and how this impacts A-P migrants. This research needs to inform and underpin a flyway approach to conservation, evaluating a suite of drivers across the migratory cycle and combining this with an understanding of land management practices that integrate the needs of birds and people in these areas.

Elmberg J, Hessel R, Fox AD, Dalby L. 2014. Interpreting seasonal range shifts in migratory birds: a critical assessment of 'short-stopping' and a suggested terminology. *Journal of Ornithology*.

(Abstract)

The term 'short-stopping' is increasingly used in ecology to describe spatio-temporal changes in occurrence of migratory species. Spurred by the insight that it has been used in a variety of contexts, we reviewed its use in avian ecology. A literature search yielded 59 papers explicitly

treating short-stopping in birds, most of them in peer-reviewed journals. The term was first used in 1967 to describe a northward shift in wintering Canada Geese in North America and has been used with increasing frequency to the present day. Geese dominate the short-stopping literature, which is confined to the northern hemisphere. Short-stopping has been used to describe (1) a shortened autumn migration that results in a wintering distribution closer to breeding areas, (2) a shortened spring migration that results in a breeding distribution closer to wintering areas, and (3) a delay in autumn migration that leads to a perceived reduced abundance in some part of the winter range. We advocate that short-stopping should be used only to describe (1) range shifts that involve shortening of the migratory corridor, and that they are qualified explicitly by season (i.e. breeding/winter) and degree (i.e. full or partial range shift). In other cases of breeding, wintering or entire range shifts where the migratory corridor is elongated or remains the same, we recommend using the term 'range shift', qualified by season, geography and orientation (i.e. the direction of the range shift). We also discuss the need for spatially explicit avian count monitoring mechanisms (rather than capture–recapture or hunting bag data) designed specifically to track such changes in distribution in the future.

Trierweiler C, Klaassen RHG, Drent RH, Exo K-M, Komdeur J, Bairlein F, Koks BJ. 2014. Migratory connectivity and population-specific migration routes in a long-distance migratory bird. *Proceedings of the Royal Society of London, B* **281**, 20132897.

(Abstract)

Knowledge about migratory connectivity, the degree to which individuals from the same breeding site migrate to the same wintering site, is essential to understand processes affecting populations of migrants throughout the annual cycle. Here, we study the migration system of a long-distance migratory bird, the Montagu's harrier *Circus pygargus*, by tracking individuals from different breeding populations throughout northern Europe. We identified three main migration routes towards wintering areas in sub-Saharan Africa. Wintering areas and migration routes of different breeding populations overlapped, a pattern best described by 'weak (diffuse) connectivity'. Migratory performance, i.e. timing, duration, distance and speed of migration, was surprisingly similar for the three routes despite differences in habitat characteristics. This study provides, to our knowledge, a first comprehensive overview of the migration system of a Palaearctic-African long-distance migrant. We emphasize the importance of spatial scale (e.g. distances between breeding populations) in defining patterns of connectivity and suggest that knowledge about fundamental aspects determining distribution patterns, such as the among-individual variation in mean migration directions, is required to ultimately understand migratory connectivity. Furthermore, we stress that for conservation purposes it is pivotal to consider wintering areas as well as migration routes and in particular stopover sites.

Jenni-Eiermann S, Jenni L, Smith S, Costantini D. 2014. Oxidative Stress in Endurance Flight: An Unconsidered Factor in Bird Migration. *PLoS ONE* **9**, e97650.

(Abstract)

Migrating birds perform extraordinary endurance flights, up to 200 h non-stop, at a very high metabolic rate and while fasting. Such an intense and prolonged physical activity is normally associated with an increased production of reactive oxygen and nitrogen species (RONS) and thus increased risk of oxidative stress. However, up to now it was unknown whether endurance flight evokes oxidative stress. We measured a marker of oxidative damage (protein carbonyls, PCs) and a marker of enzymatic antioxidant capacity (glutathione peroxidase, GPx) in the European robin (*Erithacus rubecula*), a nocturnal migrant, on its way to the non-breeding grounds. Both markers were significantly higher in European robins caught out of their nocturnal flight than in conspecifics caught during the day while resting. Independently of time of day, both markers showed higher concentrations in individuals with reduced flight muscles. Adults had higher GPx concentrations than first-year birds on their first migration. These results show for the first time that free-flying migrants experience oxidative stress during endurance flight and up-regulate one component of antioxidant capacity. We discuss that avoiding oxidative stress may be an overlooked factor shaping bird migration strategies, e.g. by disfavouring long nonstop flights and an extensive catabolism of the flight muscles.

Bauer S, Hoye BJ. 2014. Migratory Animals Couple Biodiversity and Ecosystem Functioning Worldwide. *Science* **344**, 54.

(Abstract)

Animal migrations span the globe, involving immense numbers of individuals from a wide range of taxa. Migrants transport nutrients, energy, and other organisms as they forage and are preyed upon throughout their journeys. These highly predictable, pulsed movements across large spatial scales render migration a potentially powerful yet underappreciated dimension of biodiversity that is intimately embedded within resident communities. We review examples from across the animal kingdom to distill fundamental processes by which migratory animals influence communities and ecosystems, demonstrating that they can uniquely alter energy flow, food-web topology and stability, trophic cascades, and the structure of metacommunities. Given the potential for migration to alter ecological networks worldwide, we suggest an integrative framework through which community dynamics and ecosystem functioning may explicitly consider animal migrations.

Gill Jr RE, Douglas DC, Handel CM, Tibbitts TLH, Gary, Piersma T (2014) Hemispheric-scale

wind selection facilitates bar-tailed godwit circum-migration of the Pacific. *Animal Behaviour* **90**, 117-130.

(Abstract)

The annual 29 000 km long migration of the bar-tailed godwit, *Limosa lapponica baueri*, around the Pacific Ocean traverses what is arguably the most complex and seasonally structured atmospheric setting on Earth. Faced with marked variation in wind regimes and storm conditions across oceanic migration corridors, individuals must make critical decisions about when and where to fly during nonstop flights of a week's duration or longer. At a minimum, their decisions will affect wind profitability and thus reduce energetic costs of migration; in the extreme, poor decisions or unpredictable weather events will risk survival. We used satellite telemetry to track the annual migration of 24 bar-tailed godwits and analysed their flight performance relative to wind conditions during three major migration legs between nonbreeding grounds in New Zealand and breeding grounds in Alaska. Because flight altitudes of birds en route were unknown, we modelled flight efficiency at six geopotential heights across each migratory segment. Birds selected departure dates when atmospheric conditions conferred the greatest wind assistance both at departure and throughout their flights. This behaviour suggests that there exists a cognitive mechanism, heretofore unknown among migratory birds, that allows godwits to assess changes in weather conditions that are linked (i.e. teleconnected) across widely separated atmospheric regions. Godwits also showed adaptive flexibility in their response not only to cues related to seasonal changes in macrometeorology, such as spatial shifting of storm tracks and temporal periods of cyclogenesis, but also to cues associated with stochastic events, especially at departure sites. Godwits showed limits to their response behaviours, however, especially relative to rapidly developing stochastic events while en route. We found that flight efficiency depended significantly upon altitude and hypothesize that godwits exhibit further adaptive flexibility by varying flight altitude en route to optimize flight efficiency.

Migration general 2013

Costantini D, Møller AP. 2013. A meta-analysis of the effects of geolocator application on birds. *Current Zoology* **59**, 697–706.

(Abstract)

An increasing trend in use of tracking devices such as geolocators is based on the assumption that the information gathered from such devices provides reliable information about the migratory behavior of free-living birds. This underlying assumption is rarely tested, as evidenced by the absence in many studies of controls, in particular treated controls, and so far never with a reasonable statistical power. Published studies have shown reduced survival prospects or delayed breeding in some species, suggesting that there may be reason to doubt

that tracking devices provide unbiased information. Therefore, we conducted a meta-analysis of studies applying geolocators to wild birds to determine whether geolocators affected fitness components. Geolocators had an overall negative effect on fitness components, in particular survival, and ecological variables. Effect size was larger for aerial foragers than for other species. Moreover, the leg band attachment method was more detrimental for birds than the leg-loop backpack harness. A meta-regression model of effect size showed independent negative effects of geolocators on aerial foragers, smaller species, species with smaller migration distances and in studies where geolocators were attached with a ring. These results suggest that geolocator studies should be interpreted with caution, but also raise questions whether it is ethically defensible to use geolocators on aerial foragers or small species without carrying out robust pilot studies.

Shephard JM, Ogden R, Tryjanowski P, Olsson O, Galbusera P. 2013. Is population structure in the European white stork determined by flyway permeability rather than translocation history? *Ecology and Evolution* **3**, 4881–4895.

(Abstract)

European white storks are long considered to diverge to eastern and western migration pools as a result of independent overwintering flyways. In relatively recent times, the western and northern distribution has been subject to dramatic population declines and country-specific extirpations. A number of independent reintroduction programs were started in the mid 1950s to bring storks back to historical ranges. Founder individuals were sourced opportunistically from the Eastern and Western European distributions and Algeria, leading to significant artificial mixing between eastern and western flyways. Here we use mitochondrial and microsatellite DNA to test the contention that prior to translocation, eastern and western flyways were genetically distinct. The data show a surprising lack of structure at any spatial or temporal scale suggesting that even though birds were moved between flyways, there is evidence of natural mixing prior to the onset of translocation activities. Overall a high retention of genetic diversity, high Nef, and an apparent absence of recent genetic bottleneck associated with early 20th century declines suggest that the species is well equipped to respond to future environmental pressures.

Marques PAM, Jorge PE. 2013. Winter Latitudinal Population Age-Structure of a Migratory Seagull (*Larus fuscus*) Differs between Its Two Major Migratory Flyways. *International Journal of Ecology* **2013**, 7.

(Abstract)

The migration is energy-demanding and is expected to greatly affect the distribution of individuals over the species range and condition the choice of migratory routes. We investigated the wintering distributions and migratory flyways use of geographically contiguous populations of Lesser Black-backed Gulls (*Larus fuscus*) and difference in population winter age structure between migratory flyways. Recoveries of metal ringed pulli from Denmark, Sweden, and Finland were used. The results showed that contiguous populations can have distinct wintering distribution patterns and migratory flyways. More importantly, we found that depending on the place of origin, the population winter distribution may or may not show a latitudinal cline in the age structure. The population migrating via the eastern Atlantic flyway (western flyway) showed a winter age-related latitudinal cline, with adults staying at more northern latitudes than immatures. In contrast, no such pattern was found in the population migrating along the Mediterranean/Black sea flyway (eastern flyway). Interestingly, immatures within the eastern population showed a more dispersed pattern of migratory bearings. Overall, our results enhance the importance of the migration flyway in shaping the age structure of populations in the winter quarters and how it may influence the effect of other factors like sexual maturation.

Arlt D, Low M, Pärt T. 2013. Effect of Geolocators on Migration and Subsequent Breeding Performance of a Long-Distance Passerine Migrant. *PLoS ONE* **8**, e82316.

(Abstract)

Geolocators are small light-weight data loggers used to track individual migratory routes, and their use has increased exponentially in birds. However, the effects of geolocators on individual performance are still poorly known. We studied geolocator effects on a long-distance migrating passerine bird, the northern wheatear (*Oenanthe oenanthe* L.). We asked the general question of whether geolocators affect migratory behaviour and subsequent reproductive performance of small passerines by comparing arrival time, breeding time, breeding success and survival of geolocator versus control birds of known identity and breeding history. During two years geolocator birds (n=37) displayed a lower apparent survival (30%) as compared to controls (45%, n=164). Furthermore, returning geolocator birds (n=12) arrived on average 3.5 days later, started laying eggs 6.3 days later, and had lower nest success (25%) than control birds (78%). Our results suggest that geolocators affect migratory performance with carry-over effects to the timing of breeding and reproductive success in the subsequent breeding season. We discuss the implications of such geolocator effects for the study of migratory strategies of small passerines in general and suggest how to identify and investigate such effects in the future.

Bridge ES, Kelly JF, Contina A, Gabrielson RM, MacCurdy RB, Winkler DW. 2013. Advances

in tracking small migratory birds: a technical review of light-level geolocation. *Journal of Field Ornithology* **84**, 121–137.

(Abstract)

Light-level geolocation data loggers, or geologgers, have recently been miniaturized to the extent that they can be deployed on small songbirds, allowing us to determine many previously unknown migration routes, breeding locations, and wintering sites. Use of geologgers on small birds has great potential to help address major research and conservation questions, but the method is not without its shortcomings. Among these shortcomings are the need to recapture birds after they have carried a device throughout a migration cycle and the potential for the devices to affect survival and behavior. We examined return rates of birds with geologgers in published and unpublished studies and found no evidence of a general negative effect of geologgers on survival, although there were a few individual studies where such an effect was evident. From these same studies, we found that most currently used harness materials are equivalent in terms of failure rates, and the most reliable geologgers are those made by the British Antarctic Survey (although these were also the largest geologgers used in the studies we examined). With regard to analysis methods, we believe there is much room for improvement. Use of online archiving of both data and analysis parameters would greatly improve the repeatability and transparency of geologger research.

Lok T, Overdijk O, Piersma T. 2013. Migration Tendency Delays Distributional Response to Differential Survival Prospects along a Flyway. *The American Naturalist* **181,** 12.

(Abstract)

When populations grow or decline, habitat selection may change due to local density-dependent processes, such as site dependence and interference. In seasonally migrating animals, nonbreeding distributions may be determined through these mechanisms of density dependence, which we examine here at a hemispheric scale for a long-distance migrating bird. Using summer and winter resightings of 2,095 Eurasian spoonbills *Platalea leucorodia leucorodia* that were ringed in the Netherlands during 16 years of fast population growth, we show that neither site dependence nor interference fully explains their patterns of survival and winter distribution. Within their three main wintering areas, annual survival decreased with an increase in population size. While survival was consistently higher in the two European wintering areas (France, Iberia), most spoonbills migrated onward to winter in west Africa. The number of birds wintering in Europe increased, but not enough to maximize annual survival. We conclude that a constraint of tradition (their “migration tendency”) inhibits birds from changing their migratory habits. We pose that this phenomenon may similarly constrain other migratory populations from rapidly responding to large-scale climate- and/or human-driven habitat changes at their wintering grounds.

McLaren JD, Shamoun-Baranes J, Bouten W. 2013. Stop early to travel fast: modelling risk-averse scheduling among nocturnally migrating birds.*Journal of Theoretical Biology* varies with foraging habitat. *Ibis* **316,** 90–98.

(Abstract)

Many migrating birds divide their journeys into nocturnal flights interspersed by stopovers where they build up energy reserves (fuel) for subsequent flights. Given the difficulty in monitoring fuel loads of individual migrants over long distances, theoretical models are often used to interpret observed relations between departure fuel loads (DFLs) and fuel deposition rates (FDRs) in the context of time-minimised migration. Models applicable to nocturnal migration have hitherto considered only the departure decision, i.e. ignored interim stopover possibilities before fuel loads are depleted. This results in 'risk-prone' migratory schedules in terms of choice of stopover. In this study we assess 'risk-averse' behaviour, whereby nocturnal migrants minimise migration time by adjusting not only DFLs to experienced and expected FDRs, but also stopping fuel loads (SFLs), below which they stop to refuel at high-quality sites. We developed analytical formulae to solve for maximal risk-prone and risk-averse migration speeds in modelled environments comprised of two stopover qualities (high-and low-quality), and a constant probability of encountering a high-quality site (encounter probability). Risk-aversion was beneficial to migration speeds in over 99% of the modelled environments, with median ratios of risk-averse to risk-prone migration speeds ranging from 1.5 to 2.8. Among modelled environments, this benefit increased with increasing FDRs at high-quality sites, and was highest with low probabilities of encountering high-quality sites. Time-minimising risk-averse DFLs at low-quality sites were minimal in nearly all modelled environments, and whenever encounter probabilities were low, risk-averse SFLs typically indicated that migrants should stop immediately on encountering high-quality sites. Modelled fuel loads in environments with high and low encounter probabilities resembled observed fuel loads of migratory populations with ubiquitous and scarce food availability, respectively. This study demonstrates the benefits of risk-averse exploitation of variable resources, presents a new approach to model time-minimised migration in heterogeneous environments and emphasises the importance of premium stopover sites to nocturnally migrating birds.

Garcia-Perez B, Hobson KA, Powell R, Still C, Huber GH. 2013. Switching Hemispheres: A New Migration Strategy for the Disjunct Argentinean Breeding Population of Barn Swallow *(Hirundo rustica). PLoS ONE* **8,** e55654.

(Abstract)

Background: Barn Swallows (*Hirundo rustica*) breed almost exclusively in the Northern Hemisphere. However, since the early 1980's, a small disjunct breeding population has become established in eastern Argentina, presumably by birds previously derived from those breeding in North America. Currently, it is unknown where these individuals go following

breeding and how they have adjusted to a reversal in phenology. Their austral wintering period corresponds to the breeding period of the northern ancestral population and so they can potentially return to these more traditional breeding sites or they may occupy other South American wintering regions left vacant by conspecifics returning to the Northern Hemisphere. Principal Findings: We used a three-isotope (d13C, d15N, d2H) approach to investigate potential wintering areas in Central and South America of individuals breeding in Argentina. Feather isotope values differed from those expected and measured at local breeding sites in Argentina indicating molt after the austral breeding period and away from the breeding grounds. Potential molting origins were identified applying likelihood-based assignment methods to a d2H isoscape for South America and dichotomous prior information on the distribution of C3 and C4 vegetation types based on modeled vegetation-d13C values. Barn Swallows now breeding in Argentina have changed their migratory behavior but presumably use the same cues as those used by the ancestral population, molting their feathers during the austral winter, likely in northeastern South America.

Dietz MW, Rogers KG, Piersma T. 2013. When the Seasons Don't Fit: Speedy Molt as a Routine Carry-Over Cost of Reproduction. *PLoS ONE* **8,** e53890.

(Abstract)

The failure of animals to fit all life-cycle stages into an annual cycle could reduce the chances of successful breeding. In some cases, non-optimal strategies will be adopted in order to maintain the life-cycle within the scope of one year. We studied trade-offs made by a High Arctic migrant shorebird, the red knot *Calidris canutus islandica,* between reproduction and wing feather molt carried out in the non-breeding period in the Dutch Wadden Sea. We compared primary molt duration between birds undertaking the full migratory and breeding schedule with birds that forego breeding because they are young or are maintained in captivity. Molt duration was ca. 71 days in breeding adults, which was achieved by an accelerated feather replacement strategy. Second-year birds and captive adults took ca. 22% and 27% longer, respectively. Second-year birds start molt in late June, more than four weeks before captive adults, and almost seven weeks before adults that return from breeding in late July–August. Adults finish molt in October when steeply increasing thermostatic costs and reductions in food availability occur. Primary molt duration was longer in female than in male knots (all ages), which was accordance with the somewhat larger body size of females. Since fast growth leads to lower quality feathers, the speedy wing molt shown by Arctic-breeding birds may represent a time constraint that is an unavoidable and routine cost of reproduction. So far it was hypothesized that only birds over 1 kg would have difficulty fitting molt within a year. Here we show that in birds an order of magnitude smaller, temporal imperatives may impose the adoption of non-optimal life-cycle routines in the entire actively breeding population.

Nilsson C, Klaassen RHG, Alerstam T. 2013. Differences in Speed and Duration of Bird Migration between Spring and Autumn. *The American Naturalist* **181,** 837-845.

(Abstract)

It has been suggested that birds migrate faster in spring than in autumn because of competition for arrival order at breeding grounds and environmental factors such as increased daylight. Investigating spring and autumn migration performances is important for understanding ecological and evolutionary constraints in the timing and speed of migration. We compiled measurements from tracking studies and found a consistent predominance of cases showing higher speeds and shorter durations during spring compared to autumn, in terms of flight speeds (airspeed, ground speed, daily travel speed), stopover duration, and total speed and duration of migration. Seasonal differences in flight speeds were generally smaller than those in stopover durations and total speed/duration of migration, indicating that rates of foraging and fuel deposition were more important than flight speed in accounting for differences in overall migration performance. Still, the seasonal differences in flight speeds provide important support for time selection in spring migration.

Bauer S, Klaassen M. 2013. Mechanistic models of animal migration behaviour – their diversity, structure and use. *Journal of Animal Ecology.* **82,** 498–508.

(Abstract)

1. Migration is a widespread phenomenon in the animal kingdom, including many taxonomic groups and modes of locomotion. Developing an understanding of the proximate and ultimate causes for this behaviour not only addresses fundamental ecological questions but has relevance to many other fields, for example in relation to the spread of emerging zoonotic diseases, the proliferation of invasive species, aeronautical safety as well as the conservation of migrants.

2. Theoretical methods can make important contributions to our understanding of migration, by allowing us to integrate findings on this complex behaviour, identify caveats in our understanding and to guide future empirical research efforts. Various mechanistic models exist to date, but their applications seem to be scattered and far from evenly distributed across taxonomic units.

3. Therefore, we provide an overview of the major mechanistic modelling approaches used in the study of migration behaviour and characterize their fundamental features, assumptions and limitations and discuss their typical data requirements both for model parameterization and for scrutinizing model predictions.

4. Furthermore, we review 155 studies that have used mechanistic models to study animal migration and analyse them with regard to the approaches used and the focal species, and

also explore their contribution to advancing current knowledge within six broad migration ecology research themes.

5. This identifies important gaps in our present knowledge, which should be tackled in future research using existing and to-be developed theoretical approaches.

Kuo Y, Lin D-L, Chuang F-M, Lee P-F, Ding T-S. 2013. Bird species migration ratio in East Asia, Australia, and surrounding islands. *Naturwissenschaften* **100,** 729–738.

(Abstract)

Bird migration and its relationship with the contemporary environment have attracted long-term discussion. We calculated the avian migration ratio (the proportion of breeding species that migrate) in the areas from 70°E to 180°E and examined its relationship with the annual ranges of ambient temperature, primary productivity (estimated by the Enhanced Vegetation Index), and precipitation, along with island isolation and elevational range. The avian migration ratio increased with increasing latitude in general but varied greatly between the two hemispheres. Additionally, it showed minimal differences between continents and islands. Our analyses revealed that the seasonality of ambient temperature, which represents the energy expenditure of birds, is the dominant factor in determining bird species migration. Seasonality in primary productivity and other environmental factors play an indirect or limited role in bird species migration. The lower avian migration ratio in the Southern Hemisphere can be attributed to its paleogeographical isolation, stable paleoclimate, and warm contemporary environment. Under current trends of global warming, our findings should lead to further studies of the impact of warming on bird migration.

Migration general 2012 and earlier

2012

Klaassen, M., B. J. Hoye, B. A. Nolet, and W. A. Buttemer. 2012. Ecophysiology of avian migration in the face of current global hazards. Philosophical Transactions of the Royal Society of London. Series B, *Biological Sciences* **367**:1719–1732.

(Abstract)

Long-distance migratory birds are often considered extreme athletes, possessing a range of traits that approach the physiological limits of vertebrate design. In addition, their movements must be carefully timed to ensure that they obtain resources of sufficient quantity and quality

to satisfy their high-energy needs. Migratory birds may therefore be particularly vulnerable to global change processes that are projected to alter the quality and quantity of resource availability. Because long-distance flight requires high and sustained aerobic capacity, even minor decreases in vitality can have large negative consequences for migrants. In the light of this, we assess how current global change processes may affect the ability of birds to meet the physiological demands of migration, and suggest areas where avian physiologists may help to identify potential hazards. Predicting the consequences of global change scenarios on migrant species requires (i) reconciliation of empirical and theoretical studies of avian flight physiology; (ii) an understanding of the effects of food quality, toxicants and disease on migrant performance; and (iii) mechanistic models that integrate abiotic and biotic factors to predict migratory behaviour. Critically, a multi-dimensional concept of vitality would greatly facilitate evaluation of the impact of various global change processes on the population dynamics of migratory birds.

Grönroos J, Alerstam T. 2012. To fly or not to fly depending on winds: shorebird migration in different seasonal wind regimes. *Animal Behaviour* **83,** 1449-1457.

(Abstract)

Migratory birds are predicted to adapt their departure to wind, changing their threshold of departure and selectivity of the most favourable winds in relation to the mean, scatter and skewness of the wind regime. The optimal departure behaviour depends also on the importance of time and energy minimization during migration and on the ratio of cost of flight to cost of resting and waiting for more favourable winds. We compared departure and flight activity of shorebirds migrating in contrasting wind regimes during autumn (high probability of wind resistance) and spring (high probability of wind assistance) in southern Scandinavia, using data obtained by radiotelemetry, radar tracking and visual observations. The shorebirds changed their threshold for departure in relation to wind between the two seasons, flying almost exclusively with wind assistance in spring but regularly with wind resistance during autumn. The degree of wind selectivity in relation to the distributions of available wind effects was similar during autumn and spring indicating that reducing time and energy costs for migration was important during both seasons. These results demonstrate that migratory birds change departure behaviour in relation to the prevailing wind regime. It remains unknown whether they change behaviour not only seasonally but also in different zones along the migration route and whether they respond to differences not only in mean wind conditions but also in scatter and skewness between wind regimes. Our study indicates the possible existence of an adaptive flexibility in responses to wind regimes among migratory birds.

Bairlein F, Norris R, Nagel R, Bulte M, Voigt C, Fox JW, Hussell DJT, Schmaljohann H. 2012.

Cross-hemisphere migration of a 25 g songbird. *Biology Letters* **8,** 505–507.

(Abstract)

The northern wheatear (*Oenanthe oenanthe*) is a small (approx. 25 g), insectivorous migrant with one of the largest ranges of any songbird in the world, breeding from the eastern Canadian Arctic across Greenland, Eurasia and into Alaska (AK). However, there is no evidence that breeding populations in the New World have established overwintering sites in the Western Hemisphere. Using light-level geolocators, we demonstrate that individuals from these New World regions overwinter in northern sub-Sahara Africa, with Alaskan birds travelling approximately 14 500 km each way and an eastern Canadian Arctic bird crossing a wide stretch of the North Atlantic (approx. 3500 km). These remarkable journeys, particularly for a bird of this size, last between one to three months depending on breeding location and season (autumn/spring) and result in mean overall migration speeds of up to 290 km/d. Stable hydrogen isotope analysis of winter-grown feathers sampled from breeding birds generally support the notion that Alaskan birds overwinter primarily in eastern Africa and eastern Canadian Arctic birds overwinter mainly in western Africa. Our results provide the first evidence of a migratory songbird capable of linking African ecosystems of the Old World with Arctic regions of the New World.

Versteegh MA, Helm B, Gwinner E, Tieleman BI. 2012. Annual cycles of metabolic rate are genetically determined but can be shifted by phenotypic flexibility. *The Journal of Experimental Biology* **215,** 3459-3466.

(Abstract)

Birds have adjusted their life history and physiological traits to the characteristics of the seasonally changing environments they inhabit. Annual cycles in physiology can result from phenotypic flexibility or from variation in its genetic basis. A key physiological trait that shows seasonal variation is basal metabolic rate (BMR). We studied genetic and phenotypic variation in the annual cycles of body mass, BMR and mass-specific BMR in three stonechat subspecies (*Saxicola torquata*) originating from environments that differ in seasonality, and in two hybrid lines. Birds were kept in a common garden set-up, under annually variable day length and at constant temperature. We also studied whether stonechats use the proximate environmental factor temperature as a cue for changes in metabolic rate, by keeping birds at two different temperature regimes. We found that the different subspecies kept in a common environment had different annual cycles of body mass, BMR (variance: Kazakh 4.12, European 1.31, Kenyans 1.25) and mass-specific BMR (variance: Kazakh 0.042, European 0.003, Kenyans 0.013). Annual variation in metabolic measures of hybrids was intermediate or similar to that of parental species. Temperature treatment did not affect the shape of the annual cycles of metabolic rate, but metabolic rate was higher in birds kept under the variable temperature regime. The distinct annual cycles in body mass and metabolic rate in stonechat subspecies kept in a common environment indicate different genetic backgrounds rather than merely a phenotypically flexible response to proximate environmental cues. Phenotypic effects

of temperature are superimposed on this genetically orchestrated annual cycle.

Sanz-Aguilar A, Bechet A, Germain C, Johnson AR, Pradel R. 2012. To leave or not to leave: survival trade-offs between different migratory strategies in the greater flamingo. *Journal of Animal Ecology* **81,** 1171-1182.

(Abstract)

1. The balance between costs and benefits of migration under different environmental, density-dependent and individual conditions may promote a broad range of migratory behaviours. We studied the factors influencing first-year migration and subsequent fidelity or dispersal among wintering areas, and the survival costs of different wintering behaviours in the greater flamingo (*Phoenicopterus roseus*).

2. We analysed by multievent capture–recapture modelling among-site dispersal/fidelity and sitedependent survival probabilities from 22 671 flamingos ringed in the Camargue (France) between 1977 and 2010 and resighted subsequently in their wintering grounds classified as France, Iberian Peninsula, Italy and North Africa.

3. We found that first- and second-year birds either resident or wintering at medium distances from their birth place, survived better than those wintering further afield. However, under severe winter conditions (extremely cold winter 1984–1985), individuals with the sedentary strategy suffered the highest levels of mortality. From the third winter onwards, the pattern of survival reversed: the long-distance wintering individuals (i.e. North Africa) survived better.

4. The proportion of first-year birds migrating for wintering was highly variable among cohorts and increased with favourable environmental conditions (wet years). After the first winter, birds showed high fidelity (>90%) to their previous wintering area and wintered preferably near their natal colony when they became adults (>2 years).

5. Survival estimates suggest that long-distance migration was costly for young and inexperienced individuals. Nonetheless, for adults, the most southern wintering areas seem to offer the most favourable local conditions for overwinter survival.The higher availability of intermediate stopover sites during wet years may facilitate first-year migration. Then, once they have some wintering experience, flamingos appear to favour the known wintering grounds. As they grow older, dispersing towards the vicinity of the natal colony may provide higher breeding prospects for individuals wintering closer to this high-quality and saturated breeding ground, as predicted by the arrival-time hypothesis.

Fraser KC, Stutchbury BJM, Silverio C, Kramer PM, Barrow J, Newstead D, Mickle N, Cousens BF, Lee JC, Morrison DM, Shaheen T, Mammenga P, Applegate K, Tautin J. 2012. Continent-wide tracking to determine migratory connectivity and tropical habitat associations of a declining aerial insectivore. *Proceedings of the Royal Society of London,* **B 279,** 4901-4906.

(Abstract)

North American birds that feed on flying insects are experiencing steep population declines, particularly long-distance migratory populations in the northern breeding range. We determine, for the first time, the level of migratory connectivity across the range of a songbird using direct tracking of individuals, and test whether declining northern populations have higher exposure to agricultural landscapes at their non-breeding grounds in South America. We used light-level geolocators to track purple martins, *Progne subis,* originating from North American breeding populations, coast-to-coast (n = 95 individuals). We show that breeding populations of the eastern subspecies, P. s. *subis*, that are separated by ca. 2000 km, nevertheless have almost completely overlapping non-breeding ranges in Brazil. Most (76%) P. s. *subis* overwintered in northern Brazil near the Amazon River, not in the agricultural landscape of southern Brazil. Individual non-breeding sites had an average of 91 per cent forest and only 4 per cent agricultural ground cover within a 50 km radius, and birds originating from declining northern breeding populations were not more exposed to agricultural landscapes than stable southern breeding populations. Our results show that differences in wintering location and habitat do not explain recent trends in breeding population declines in this species, and instead northern populations may be constrained in their ability to respond to climate change.

Delmore KE, Fox JW, Irwin DE. 2012. Dramatic intraspecific differences in migratory routes, stopover sites and wintering areas, revealed using light-level geolocators. *Proceedings of the Royal Society of London,* **B 279,** 4582-4589.

(Abstract)

Migratory divides are contact zones between breeding populations that use divergent migratory routes and have been described in a variety of species. These divides are of major importance to evolution, ecology and conservation but have been identified using limited band recovery data and/or indirect methods. Data from band recoveries and mitochondrial haplotypes suggested that inland and coastal Swainson's thrushes (*Catharus ustulatus*) form a migratory divide in western North America. We attached light-level geolocators to birds at the edges of this contact zone to provide, to our knowledge, the first direct test of a putative divide using data from individual birds over the entire annual cycle. Coastal thrushes migrated along the west coast to Mexico, Guatemala and Honduras. Some of these birds used multiple wintering sites. Inland thrushes migrated across the Rocky Mountains, through central North America to Columbia and Venezuela. These birds migrated longer distances than coastal birds and performed a loop migration, navigating over the Gulf of Mexico in autumn and around this barrier in spring. These findings support the suggestion that divergent migratory behaviour

could contribute to reproductive isolation between migrants, advance our understanding of their non-breeding ecology, and are integral to development of detailed conservation strategies for this group.

2011

Alerstam T. 2011. Optimal bird migration revisited. *Journal of Ornithology* **152,** S5–S23.

(Abstract)

Using optimality perspectives is now regarded as an essential way of analysing and understanding adaptations and behavioural strategies in bird migration. Optimization analyses in bird migration research have diversified greatly during the two recent decades with respect to methods used as well as to topics addressed. Methods range from simple analytical and geometric models to more complex modeling by stochastic dynamic programming, annual routine models and multiobjective optimization. Also, game theory and simulation by selection algorithms have been used. A wide range of aspects of bird migration have been analyzed including flight, fuel deposition, predation risk, stopover site use, transition to breeding, routes and detours, daily timing, fly-and-forage migration, wind selectivity and wind drift, phenotypic flexibility, arrival time and annual molt and migration schedules. Optimization analyses have proven to be particularly important for defining problems and specifying questions and predictions about the consequences of minimization of energy, time and predation risk in bird migration. Optimization analyses will probably also be important in the future, when predictions about bird migration strategies can be tested by much new data obtained by modern tracking techniques and when the importance of new trade-offs, associated with, e.g., digestive physiology, metabolism, immunocompetence and disease, need to be assessed in bird migration research.

2009

Robinson, R. A., H. Q. P. Crick, J. A. Learmonth, I. M. D. Maclean, C. D. Thomas, F. Bairlein, M. C. Forchhammer, C. M. Francis, J. A. Gill, B. J. Godley, J. Harwood, G. C. Hays, B. Huntley, A. M. Hutson, G. J. Pierce, M. M. Rehfisch, D. W. Sims, M. B. Santos, T. H. Sparks, D. A. Stroud, and M. E. Visser. 2009. Travelling through a warming world: climate change and migratory species. *Endangered Species Research* **7**:87-99.

(Abstract)

Long-distance migrations are among the wonders of the natural world, but this multitaxon review shows that the characteristics of species that undertake such movements appear to

make them particularly vulnerable to detrimental impacts of climate change. Migrants are key components of biological systems in high latitude regions, where the speed and magnitude of climate change impacts are greatest. They also rely on highly productive seasonal habitats, including wetlands and ocean upwellings that, with climate change, may become less food-rich and predictable in space and time. While migrants are adapted to adjust their behaviour with annual changes in the weather, the decoupling of climatic variables between geographically separate breeding and non-breeding grounds is beginning to result in mistimed migration. Furthermore, human land-use and activity patterns will constrain the ability of many species to modify their migratory routes and may increase the stress induced by climate change. Adapting conservation strategies for migrants in the light of climate change will require substantial shifts in site designation policies, flexibility of management strategies and the integration of forward planning for both people and wildlife. While adaptation to changes may be feasible for some terrestrial systems, wildlife in the marine ecosystem may be more dependent on the degree of climate change mitigation that is achievable.