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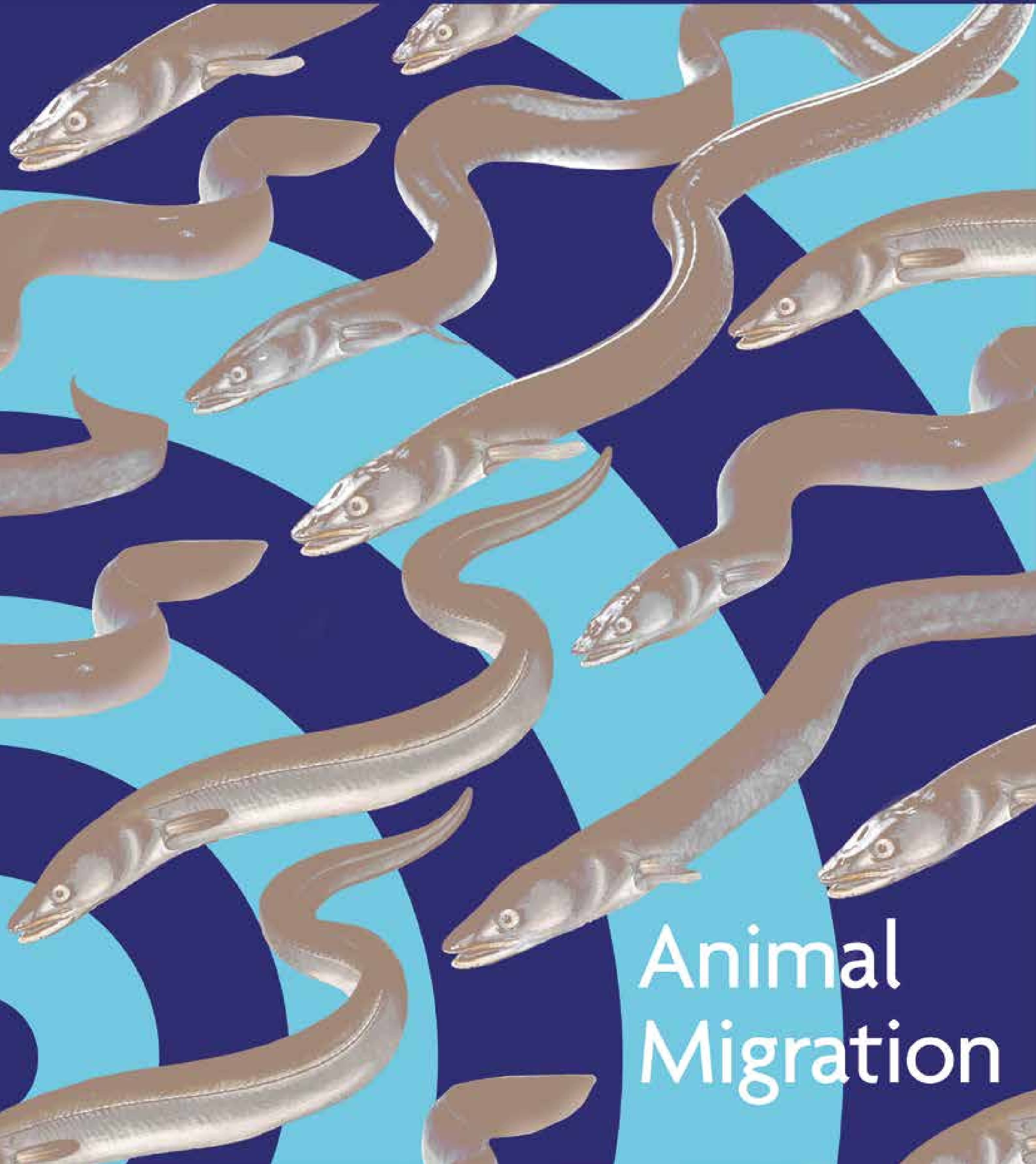

Animal Migration

EDITORIAL

Protecting nature's magnificent migrations

An estimated 8,000 to 10,000 species of wild animals in the world are migratory. The phenomenon of animal migration has evolved independently and over millennia in most vertebrate and invertebrate classes. While it has attracted scientific interest for centuries, many aspects remain unknown.

Some bird and mammal species are well studied and known for their very large and charismatic migrations. As an example, the Arctic tern completes an annual round-trip covering an average of 70,900 km,[1] connecting the planet's poles. Other taxa's migrations, including those of many freshwater fish species and insects, are less understood. One aspect of migration that is well known is that migratory species need suitable habitat for breeding, feeding and resting, and they need to be able to move freely to access such habitats. Ecological connectivity is therefore essential for the survival of migratory species.

The range of migratory animals can span across numerous countries and continents. As a result, they are often exposed to different landscapes, including heavily industrialised as well as relatively undisturbed natural areas. They also confront a range of barriers and threats to their migration: loss of natural areas largely due to agriculture, fragmentation of habitat by roads, railway lines and fences, and increased mortality resulting from the presence of energy infrastructure and power lines. Another of the key threats to migratory species is their overexploitation due to illegal or unsustainable hunting practices.

There are also a variety of laws and management regimes in place across their migratory paths. This can result in a wide variation in the level of protection for such species. A unique and global platform for the conservation and sustainable use of migratory animals and their habitats across their range is provided by the Convention on the Conservation of Migratory Species of Wild Animals (CMS). This United Nations treaty brings governments and wildlife experts together to address the conservation needs of terrestrial, aquatic and avian species around the world. CMS, and the international collaboration it facilitates, is critical in the face of climate change and global biodiversity loss.

The articles featured in this issue of the environmental SCIENTIST provide important contributions to better understand animal migrations and how vital it is to implement effective conservation measures to ensure the survival of animals across their entire ranges. Only through continued research and collective action will we be able to ensure the survival of these remarkable and unique species.

REFERENCES

1. Egevang, C., Stenhouse, I.J., Phillips, R.A., Petersen, A., Fox, J.W. and Silk, J.R.D. (2010) Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (5), pp. 2078–2081. https://doi.org/10.1073/pnas.0909493107 (Accessed: 23 September 2021).

Amy Fraenkel is the Executive Secretary of the Convention on the Conservation of Migratory Species of Wild Animals. A graduate of Harvard Law School, she has 30 years of experience in international environmental law and policy and has held senior positions in the UN and the U.S. Government.

Cover design: Joe Magee is an independent artist, designer, illustrator and filmmaker living and working in Stroud, England. He has designed for *The Guardian*, *Time Magazine*, *The New York Times* and *The Washington Post*. For more of his work, visit http://www.periphery.co.uk.

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INTRODUCTION

Animal migrations: spectacular and spectacularly threatened

Silke Bauer and **Andrew Farnsworth** consider the wonders of animal migration and the challenges migrant animals face.

Each year, trillions of animals – from nearly weightless aphids and butterflies to 40-tonne whales – fly, walk, swim or drift their way across the planet in pursuit of better foraging conditions, safety and reproductive opportunities, linking communities and ecosystems worldwide.[1] These migrations are largely directional movements from one destination to another and over distances that are often astounding.

However, perhaps the most extraordinary aspects of migration are how widespread the phenomenon is in the animal kingdom and how many individuals are involved. For instance, approximately 20 per cent of the world's bird species are presently defined as migratory. In some regions like the Palearctic (the geographic region that includes Europe, parts of North Africa and much of Asia), this number rises to 30 per cent. These measures may be conservative, with new studies informing our understanding every year and highlighting the dynamism of species' movements. The numbers of individuals involved in these migrations are even more stunning than their diversity. For example, 2 billion passerine birds migrate to sub-Saharan Africa; 3.5–5 billion birds migrate through the United States; more than 3 billion insects migrate over any 1 km stretch of countryside in southern England; and 1.5 million wildebeest, half a million gazelles and 200,000 zebras roam the Serengeti each year.

As migratory animals rely on multiple sites throughout their annual cycles and the conditions in and en route to them shape their fates, migrants are particularly at risk during the current planetary epoch's global changes. Indeed, climate change, habitat alteration and deterioration, the introduction of invasive species, the construction of barriers – buildings and other human-made structures – as well as sensory pollution change the connectivity among habitats at various spatial scales, increase mortality overall or at specific times of the year and deprive wildlife of fundamental resources.

Consequently, in the current biodiversity crisis, which might become the sixth mass extinction,[2] migratory animals may be the hardest hit with population abundances steeply declining, increasing numbers of species being lost and ecosystems being altered in their composition and in the entirety of the functional links between their members. A remarkable study spanning almost five decades yielded evidence of the stark decline of North American avifauna, revealing that almost 3 billion birds were lost during this period.[3]

Here we consider some of the most important threats that migrants currently face and outline the elements of efficient conservation.

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INTRODUCTION

CONSEQUENCES OF CLIMATE CHANGE

Climate change is probably the most important challenge of this century as it threatens human agriculture, economies and health worldwide, altering global oceanic and atmospheric circulations and every aspect of the biosphere's processes and patterns – including connectivity, resistance and resilience.[4] But the global climatic changes currently underway are not evenly distributed in space and time, nor are they producing uniform impacts. In some regions these impacts may manifest as changes in temperature and precipitation regimes, whereas in others they may result in a higher probability of occurrence and intensity of extreme events. So, too, across larger geographic areas, effects on seasonal events such as the onset and end of monsoon precipitation may change.

Over their collective histories migratory animals have evolved moving strategies and tactics, including timing and routing, such that their migratory bouts coincide with periods of resource availability where and when they travel. They evolved these behaviours as a function of seasonally changing climatic regimes, creating resource peaks and troughs. Yet, the rapid climate change induced by human activities in the last centuries is occurring at a pace unlike most other changes within these animals' evolutionary histories. Furthermore, these changes are occurring in parallel to others, such as habitat conversion and increases in human population and infrastructure, creating compounding, dramatic impacts in all places migrants touch. Additionally, in places where these changes no longer synchronise with migratory strategies, whether in time or space, the arrival of migratory animals will increasingly miss periods of previously more predictable resource availability and animals will consequently experience a mismatch between demand and resource availability.

Many studies have reported changes in migration timing coinciding with the changing climate for individual species and for entire continental migration systems. Atmospheric-sensing data over nearly a quarter of a century by US weather surveillance radars show that, in general, the average peak migration of nocturnal birds has advanced during spring and autumn. However, these changes were more rapid at higher latitudes, with those in the western flyway changing at the fastest pace – the part of the continental migration system with the highest number of species migrating the shortest distances and, perhaps, the most apt to exhibit systemic responses to changing resource availability.[5]

HABITAT DESTRUCTION AND LOSS OF CONNECTIVITY

Human activities have profoundly changed the appearance and functioning of the planet. Agricultural intensification, urbanisation and overutilisation have fragmented and changed the access, availability and quality of habitats that sustain wildlife. These apparent and functional changes impact all organisms, sessile and motile alike. But because migratory animals rely, serially or sequentially, on chains of habitats and ecosystems over their annual cycles, the loss or deterioration of even single links in these chains of sites may break connectivity and fundamentally alter individuals' behaviours and population dynamics, which can and does lead to dramatic population declines.

One prominent example of the consequences of habitat alteration and destruction is the East Asian–Australasian flyway of migratory birds. Many shorebird species migrate along this flyway from wintering grounds in Australia and New Zealand (southern hemisphere summers and northern hemisphere winters) to Russian, Canadian or Alaskan Arctic breeding grounds (northern hemisphere summers), via a string of stopover sites in eastern Asia. The numbers of shorebirds here have rapidly declined since the late 20th century and habitat loss, mostly in China and South Korea, is a primary reason behind these declines.[6] For instance, up to 60 per cent of China's 18,000 km coastline has been modified in the course of accelerating urbanisation and economic development. Consequently, almost half of all coastal wetlands in China have been lost, most notably in the Yellow Sea where almost a third of all tidal flats that existed in the 1980s had disappeared by the late 2000s. The loss of these areas has a direct relationship to the availability of stopover locations with valuable food resources where migrating shorebirds can stage and rapidly fuel for longer flights on their journeys.

ARTIFICIAL LIGHT, SENSORY POLLUTION AND COLLISIONS

In addition to habitat loss and broken connectivity among landscapes and systems, human activities alter landscapes in other ways that affect animals' sensory capabilities. Interference from anthropogenic noise and light in particular have powerful impacts. For migratory species, especially those that migrate nocturnally, light pollution represents a serious and growing threat that can fundamentally alter behavioural ecologies that evolved in the absence of light. Artificial light at night (ALAN) has sprawled dramatically over the past decades, and aerial migrants pass through increasingly photo-polluted skies.[7] In evolutionary terms it is a novel stimulus that can significantly alter behaviour, from migration to foraging to vocal communication. Nocturnal migrants are particularly affected, as this light interferes with their sensory systems and can draw them to illuminated areas, lead to disorientation, disrupt life histories or increase mortality through collisions with structures.

Although the cumulative effects of ALAN on migratory populations are still unknown, more local effects in space and time are clear. For example, a study at an iconic urban light installation – the national 9/11 Memorial & Museum's Tribute in Light in New York – showed that up to 1.1 million birds were affected over seven individual nights sampled across the seven years of the study, at altitudes of up to 4 km. Birds aggregated in high densities – 20 times greater than in surrounding baseline numbers – had decreased flight speeds, flew in circular paths and vocalised frequently. All these behaviours disappeared when the lights were extinguished.[8]

With increasing recognition of the deleterious effects of ALAN, global and local initiatives have attempted to reduce light levels overall, or at least during migration periods. Globally, the International Dark-Sky Association (see **Further Reading**) provides leadership, tools and resources to individuals, policymakers and industry to reduce light pollution for a beautiful, healthy and functional environment for humans and wildlife.

More locally, on a US city and state spatial scale, 'lights out' initiatives aim to engage business owners, local officials, and municipal and community stakeholders to make them aware of the threats ALAN poses and urge them to turn off lights at night or use lighting practices during spring and autumn migration periods that are more conducive to darker skies. One such initiative in Texas (see **Further Reading** on Lights Out Texas) employs ecological forecasting[9] to alert stakeholders both to critically important action periods when peak migration is occurring, as well give them 1–3 days' notice of impending high-intensity migration in order to protect the billions of migratory birds that fly over the state.

▲ **Birds killed in collisions with World Trade Center buildings on the night and early morning of 13-14 September 2021. Among those species killed were many small, nocturnally migrating songbirds including black-and-white warblers, American redstart, ovenbirds, and northern parula. Birds are collected by a volunteer community scientist monitoring buildings for injured and dead birds. Photo courtesy of Melissa Breyer.**

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ALAN may also often lead to collisions with power lines, communication towers, lighthouses, energy infrastructure, masts and buildings that increasingly encroach into the sky. These collisions can cause significant numbers of fatalities: in the US alone, an estimated 1.5 billion birds die each year in such collisions, with nocturnally migrating birds composing the majority of these casualties. Collisions may occur when birds are attracted to or disoriented by ALAN, when they are ascending to or descending from migration-cruising altitudes during dusk and dawn, respectively, or when flying at lower altitudes due to weather conditions.

CHALLENGES AND OPPORTUNITIES

Migratory animals know no boundaries, and effective and efficient conservation strategies and action plans to protect their populations require a multifaceted, dynamic, and international approach. Fundamental knowledge of their movement patterns across the broadest range of the scales in which they exist is critical, and it is especially important for capturing the complexities and generalities of the routes and timing of migration and the numbers of individuals involved. This knowledge will identify specific habitats used by migrants, map key regions sustaining their populations and, thus, assist in prioritising conservation areas.

However, it may be insufficient to set aside scattered and disconnected areas; perhaps more important is to ensure connectivity among such sites. This may include removing barriers, dams or fences in intermediate stretches, but also preserving portions of the airspaces and marine areas through which they move, which are equally valuable habitats for assuring safe passage. Similarly important, a more comprehensive understanding is essential in defining how migratory movements are influenced by various environmental and anthropogenic factors and processes, particularly those that change quickly and frequently.

Automated, remote-sensing monitoring systems are invaluable for providing such essential information. Among these, global networks of weather radars could be particularly useful for aerial migrants. Weather radars are installed around the world, and although designed primarily for meteorological purposes (e.g. to detect precipitation), they also detect biological targets such as flying birds, bats and insects. Since they are often organised in national or continental networks and survey the airspace over large regions and entire continents, they are, or could be, used to quantify and monitor large-scale movements of animals in a standardised and long-term scheme. In the US, an archive of data collected by the NEXRAD network (the WSR-88D radar) contains information dating to the early 1990s and has become a treasure trove of biodiversity data for researching the movements of migrating birds and the phenology and demographics of their populations,[3,5,10] as well as for the mitigation of human–wildlife conflicts.

Similar initiatives, such as the US BirdCast and Europe's GloBAM (see **Further Reading**), exist that work towards establishing standard radar-based monitoring of aerial migrants. Radar-based approaches are also increasingly employed in the mitigation of potentially negative impacts of human-made structures. In the wind energy sector, for instance, radar mapping of aerial migrations in the planning phase of windfarm construction can identify areas prone to human–wildlife conflicts and set spatial priorities for conservation and energy production, respectively. Furthermore, mobile radars can monitor migrations in real time and trigger shutdowns of windfarms during peak migration periods. Similarly, radar data are already used in lighting reduction policies (e.g. the Lights Out programmes in Texas, New York and other large urban centres in the US) in which alerts based on a prediction for high migration intensity inform stakeholders when to turn off lights. These alerts could even be refined using specific radar variables that could, for example, enhance the alert urgency for specific periods of the night when migration intensity is particularly high or during inclement weather conditions such as storms or fog.

In addition to weather surveillance radar, the 21st century holds many technological advances that can bridge our knowledge gaps and provide further detail on the biology of life on the move, especially in conjunction with ingenious scientific research and through engagement of the observational skills of communities globally.

CONCLUSION

Animal migrations are spectacular phenomena that have fascinated humanity for millennia. The links that migratory animals establish between distinct ecosystems across the globe make them an integral component of biodiversity as well as powerful indicators of global ecosystem health. Migrants perform important roles in all these systems, and their services may represent fundamental building blocks on which these systems are structured. However, migratory populations are in an alarming decline due to the manifold threats they face in our rapidly changing world – developments that we need to counteract if we are to keep these true wonders of nature and all the diversity they embody for future generations.

This issue of the environmental SCIENTIST explores the phenomenon of animal migration and the actions needed to reverse declines in the numbers of terrestrial, marine and avian travellers making these impressive journeys. There are articles on the system considerations of migration; a case study of saiga antelope conservation; the complexities of bird migration; the fascinating multigenerational monarch butterfly migration; an exploration of the initiatives to improve the future of the European eel; and on the importance of river, lake and wetland connectivity for freshwater fish migration. ES

Dr Silke Bauer is a Senior Researcher and bird migration specialist at the Swiss Ornithological Institute. Her main research interest is the ecology of animal migrations and their effects on shaping the dynamics of communities and ecosystems as well as their more applied facets such as mitigating human–wildlife conflicts and the cost-effective management of migratory populations.

Dr Andrew Farnsworth is a Senior Research Associate in the Center for Avian Population Studies at the Cornell Lab of Ornithology in Ithaca, New York. He studies bird migration at local to continental scales mainly by taking advantage of incredible and rapid 20th-century technological advances in radar and acoustic remote sensing. He works closely with the Lab's eBird team and an armada of citizen scientists to apply cutting-edge machine-learning tools to identify and understand patterns in the enormous quantities of radar and acoustic data.

Both Silke and Andrew are currently leading GloBAM, an international BiodivERsA and Belmont-Forum project on monitoring, understanding and forecasting global biomass flows of aerial migrants.

FURTHER READING

For more information on some of the programmes mentioned here, please visit:

1. International Dark-Sky Association: https://www.darksky.org.
2. Lights Out Texas: https://birdcast.info/science-to-action/lights-out/lights-out-texas.
3. BirdCast: https://birdcast.info.
4. GloBAM – Towards monitoring, understanding and forecasting GLObal Biomass flows of Aerial Migrants: https://globam.science.

REFERENCES

1. Bauer, S. and Hoye, B.J. (2014) Migratory animals couple biodiversity and ecosystem functioning worldwide. *Science*, 344 (6179). DOI: 10.1126/science.1242552.
2. Brondizio, E., Díaz, S., Settele, J., and Ngo, H.T. (editors). (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services. *Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services.* https://doi.org/10.5281/zenodo.3831673 (Accessed: 21 October 2021).
3. Rosenberg, K.V., Dokter, A.M., Blancher, P.J., Sauer, J.R., Smith, A.C., Smith, P.A., Stanton, J.C., Panjabi, A., Helft, L., Parr, M., Marra, P.P. (2019) Decline of the North American avifauna. *Science*, 366 (6461), pp. 120–124.
4. Intergovernmental Panel on Climate Change (2021) *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* https://www.ipcc.ch/report/ar6/wg1 (Accessed: 21 October 2021).
5. Horton, K.G., La Sorte, F.A., Sheldon, D., Lin, T-Y., Winner, K., Bernstein, G., Maji, S., Hochachka, W.M., Farnsworth, A. (2020) Phenology of nocturnal avian migration has shifted at the continental scale. *Nature Climate Change*, 10, pp. 63–68.
6. Studds, C.E., Kendall, B.E., Murray, N.J., Wilson, H.B., Rogers, D.I., Clemens, R.S., Gosbell, K., Hassell, C.J., Jessop, R., Melville, D.S., Milton, D.A., Minton, C.D.T., Possingham, H.P., Riegen, A.C., Straw, P., Woehler, E.J., Fuller, R.A. (2017) Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nature Communications*, 8 (14895). DOI: 10.1038/ncomms14895.
7. Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C.C.M., Elvidge, C., Baugh, K., Portnov, B.A., Rybnikova, N.A., Furgoni, R. (2016) The new world atlas of artificial night sky brightness. *Science Advances*, 2 (6). DOI: 10.1126/sciadv.1600377.
8. Van Doren, B.M., Horton, K.G., Dokter, A.M., Klinck, H., Elbin, S.B., Farnsworth, A. (2017) High-intensity urban light installation dramatically alters nocturnal bird migration. *Proceedings of the National Academy of Sciences*, 114 (42), pp. 11175–11180. https://doi.org/10.1073/pnas.1708574114 (Accessed: 21 October 2021).
9. Van Doren, B.M. and Horton, K.G.A. (2018) A continental system for forecasting bird migration. *Science*, 361 (6407), pp. 1115–1118.
10. Dokter, A.M., Farnsworth, A., Fink, D., Ruiz-Gutierrez, V. Hochachka, W.M., La Sorte, F. A., Robinson, O.J., Rosenberg, K.V., Kelling, S. (2018) Seasonal abundance and survival of North America's migratory avifauna determined by weather radar. *Nature Ecology & Evolution*, 2, pp. 1603–1609.

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FEATURE

Migration: a systemic consideration

Mark Everard looks at the importance of migration for the wider ecosystem services that animals and humans rely on for survival.

That organisms move on a regular, semi-predictable basis may not appear revelatory from our contemporary world view. However, in reality, this insight is profound, built from successive discoveries through the environmental sciences. It also remains an insight we are very far from embedding into how we manage the world.

OF BIRDS AND FISH

Before the phenomenon of migration began to be understood, the disappearance, reappearance and breeding of many organisms was a thing of mystery from which many ingenious theories emerged.

One example is the life cycle of the swallow *(Hirundo rustica*), a charismatic and graceful summer visitor to northern latitudes. Prior to vanishing in the autumn, swallows mass over ponds, streams and damp meadows to hawk for insects, feeding up before they disappear. Just as suddenly, they reappear in large numbers as a harbinger of spring, swooping and feeding voraciously on emerging insects from those same waterbodies. It was not such a massive intuitive leap for our forebears to surmise that swallows lay dormant during the winter in the beds of the waterbodies over which they massed in autumn and from which they reappeared in spring. This view prevailed right up to the 18th century. So, too, did a common belief that barnacle geese (*Branta leucopsis*), arriving suddenly in flocks, were born of the sun's heat on long-necked and admittedly goose-like goose barnacles (*Lepas* spp.) washing ashore on drifting wood.

The sudden appearance of wriggling masses of tiny translucent eels in the margins of the lower reaches of rivers in spring attracted similar myths. Aristotle (384–322 BCE) considered that this was because eels were born '...of nothing' and that 'They are produced from what are called the entrails of the earth, which exist spontaneously in mud and wet earth'.[1] The sudden appearance of small, hair-like elvers often found in depressions made by horse hooves in river margins after rain led Pliny the Elder (AD 23–79) to speculate that elvers grew from horsehair dropped into the water, or that 'They rub themselves against rocks, and their scraping comes to life'.[2]

In *The Compleat Angler* Izaak Walton and Charles Cotton's Piscator notes:

'… some say they breed by generation, as other fish do; and others, that they breed, as some worms do, of mud; as rats and mice, and many other living creatures, are bred in Egypt, by the sun's heat when it shines upon the overflowing of the river Nilus; or out of the putrefaction of the earth, and divers other ways.'

Walton and Cotton continue:

'And others say, that as pearls are made of glutinous dewdrops, which are condensed by the sun's heat in those countries, so Eels are bred of a particular dew, falling in the months of May or June on the banks of some particular ponds or rivers, apted by nature for that end; which in a few days are, by the sun's heat, turned into Eels...'[3]

In fact, no eel with testes has ever been found. A lesser-known fact is that Sigmund Freud, the Austrian founder of the psychoanalytic school of psychiatry, researched the mysteries of eel reproduction at the outset of his long career. After dissecting many eels, Freud concluded that '...all the eels which I cut open are of the fairer sex', before abandoning biology in favour of working on the human mind.[4] This observation only served to deepen the mystery of eel reproduction. Even when eel larvae were found in marine plankton, they were for many years misidentified as a new species, *Leptocephalus*, a name that persists for the migratory eel larvae borne on oceanic currents before they metamorphose on making landfall. There remain missing links and unfounded, albeit oft-repeated, assumptions related to migration in the life cycle of the European eel (*Anguilla anguilla*).

SURVIVAL STRATEGIES AND ECOSYSTEM IMPACTS

As we learnt more from observations of marked birds and other organisms, our awareness grew leading to our current – and still partial – understanding of migration. With it came the realisation that species exploit different habitats at different life stages to further their survival and fitness to reproduce.

The longest known regular migration is undertaken by the Arctic tern (*Sterna paradisaea*), a bird that migrates between breeding areas in the Arctic and sub-Arctic regions and wintering areas in the Antarctic. Tracking studies have found that these birds make annual journeys averaging 70,900 km.[5]

Many birds and flying insects also require mosaics of different roosting, feeding and loafing habitats that they exploit on daily, seasonal and other cycles of movement. Break the links between habitat units at

even fine scales and life cycles are compromised. Just one local-scale example is the importance of adjacent dry, short grassland for nesting and wet pasture for the feeding needs of hatching chicks of many wading birds such as the northern lapwing (*Vanellus vanellus*).

On a greater scale, the movement of whales from the Antarctic's krill-rich circumpolar regions carries nutrients northwards on their seasonal migrations. Furthermore, as whales feed in deep oceanic waters, they bring nutrients to the surface waters as they return to breathe. These nutrient pumps add substantially to planktonic photosynthesis, making tangible contributions to ocean productivity and climate regulation.

Various species of salmon migrate to sea to feed on small fish and large invertebrates, returning to spawn in nutrient-poor upland river reaches with a productivity too low to otherwise sustain them. Many species of Pacific salmon die upon spawning, their corpses liberating embodied nutrients obtained from rich sea-feeding into natal streams, boosting productivity and supporting hatching fry. In fact, these salmon function as substantial nutrient pumps bringing large amounts of marine nutrients from the ocean to the headwaters of otherwise low-productivity rivers.

These nutrients become incorporated into food webs in rivers and surrounding landscapes by the activities of a wide variety of mammals, birds and other species of fish. In south-eastern Alaska, spawning salmon contribute up to 25 per cent of the nitrogen found in tree foliage, resulting in tree growth rates nearly three times higher than in areas without spawning salmon. As the trees grow and age, they fall to create log jams in the streams, providing shelter for juvenile salmon and helping scour gravels in which adult salmon spawn. Whole catchments and their ecosystems depend upon the migratory habits of these salmonid fish.

Many large animals, mostly terrestrial but also some aquatic, migrate over daily cycles differentiating latrine from feeding areas. This serves both to enhance overall landscape productivity and diversity, but also, importantly, to break parasite life cycles.

ECOSYSTEM PROCESSES AND SERVICES

The many types of migration highlighted here and throughout this edition of the environmental SCIENTIST are fascinating in their own right. However, they also play vital roles in ecosystem processes, transferring nutrients, carbon, energy and genes, and supporting cultural resources and traditions.

They do so from scales as local as the seasonal movements of fish and invertebrates as they travel from river channels into adjacent floodplains; as regular as the journeys of whales into surface waters as they move from deep oceans to excrete after feeding at depth; and as long-term as their final journeys, sequestering embodied carbon as they decompose. Migratory species perform these fluxes by lateral and longitudinal movement across linked aquatic and terrestrial systems and major global flyways. Herds of large herbivores migrate across broad savannah landscapes, contributing to the heterogeneity and vitality of whole ecosystems and their processes. Migration is as functionally important at the staging posts between the pole-to-pole migration of the little Arctic tern and the oceanic travels of the great whales as it is in the daily vertical movements of plankton.

The timing of migration and interactions with the ecosystems through which species migrate also matter a great deal. The study of the timing of plant and animal life cycle events is known as phenology. Well-known, long-term phenological records – for example, the first springtime emergence of leaves, flowers and butterflies, the call of the cuckoo, and the reappearance of swallows and martins – highlight natural rhythms and synchrony linked to the seasons, but also indicate longer-term shifts in a time of profound climate change.

These longer-term shifts are concerning, as the myriad interconnections within nature are elaborately co-evolved. The seeds and berries of plants feed birds and mammals in preparation for overwintering or migration, while emerging aquatic insects in springtime feed juvenile fish, post-hibernation bats and arriving summer migrant birds. Flooding cycles enable fish migrating over both short and long distances to run over obstructions in river channels and to access marginal wetlands. Break the timings and, for all of nature's evolved adaptive capacities, natural processes are inevitably compromised, including the capacity of migratory species to access different habitats to complete their life cycles and play their important roles in ecosystem functions.

PEOPLE AND NATURE

All these movements and the processes they perform have tangible and significant importance for humanity.

At a basic biophysical level, the return of migratory birds and animals can form an important basis for local cultures and spiritual beliefs as well as serving as sources of food. As just one illustration of significance, the Grand Coulee Dam on the Columbia River in the United States, developed between 1933 and 1955, took no account of impacts on migratory fish, particularly salmon, or of the subsequent ramifications of declining fish populations for the livelihoods of upstream Native Americans and Canadian First Nations. Production of salmon and other fish had been a centrepiece of the area's indigenous economy and culture. In 1951, the Colville Confederated Tribes filed a lawsuit against the United States Government, which was finally settled 27 years later, in 1978, entitling the tribes to full compensation for all income losses associated with the dam. A total of US$66 million was paid as historic compensation, including annual payments of US$15 million to offset ongoing reduced income opportunities.[6]

Without the fluxes of nutrients and productivity enabled by migration, many marine and freshwater fisheries would collapse. Enclosure of land preventing free movement of herbivores on savannah and other formerly open grassland landscapes has been significant in changing the ecology of these systems. Furthermore, restriction of wider-ranging migratory behaviours of fenced grazing domestic animal herds results in the dual problems of persistent parasite issues – as latrine and feeding areas cannot be segregated – but also sward depletion as animals are no longer free to move with the availability of fresh grass. As a result, grazed areas are unable to regenerate and replenish longer roots to aid gas and water permeation, carbon storage and nutrient cycling in depleting soils.

Instead, inputs of energy, nutrient, biocidal and other agrochemicals to enclosed farmed land or aquaculture systems are intensified to compensate for the loss of nutrient regeneration, parasite regulation and other processes naturally replenished by migratory behaviours, at the same time resulting in alarming rates of global soil degradation and aquatic eutrophication.

PROTECTION OF NATURE AND PEOPLE

The protection of intercontinental flyways for migratory birds was one of the foundational purposes of the 1971 Ramsar Convention (on wetlands of international importance), now with 169 Contracting Parties globally. The Ramsar Convention has since evolved to address the wider functional roles of wetland systems, including the contributions from, as well as support for, migratory birds, fish and other organisms. The Convention on the Conservation of Migratory Species of Wild Animals, also known as the Convention on Migratory Species, was signed in 1979, entering into force in 1983 and now with 131 signatory Member States.

But the fact that many species migrate over varying scales is still far from adequately acknowledged. There remain naive assumptions that there are migratory and non-migratory species, simplistically overlooking the varying habits and needs of many organisms, their life stages and the different spatial and temporal scales over which they move together with their functional importance. Migratory needs are certainly not reflected in management relating to the permeability of landscapes that are heavily fragmented by economic uses. This, in turn, affects ecosystem processes and, with them, delivery of ecosystem services that are vital for the sustainability of ecosystems and the diverse human needs and socioeconomic benefits they support.

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As we progress within the UN Decade on Ecosystem Restoration (2021–2030), also recognising the importance of retaining or restoring ecosystem functionality for meeting the UN Sustainable Development Goals, there is a pressing need to remove these blinkered views about the migratory needs of species and acknowledge their importance. Only this way can we take appropriate management actions to protect species, ecosystems, natural processes and the many human needs that depend on them. ES

Dr Mark Everard is an ecosystems consultant and an Associate Professor of Ecosystem Services at the University of the West of England (UWE Bristol). He has a background in freshwater ecosystems and has been a champion of the development of ecosystems thinking and its application for over 40 years across academic, policy-development, NGO and business environments in both the developed and the developing world. Mark is also a Vice-President of the IES and a prolific author and broadcaster.

mark.everard@uwe.ac.uk; mark@pundamilia.co.uk

REFERENCES

1. Aristotle. (350 BCE). *The History of Animals.*
2. Pliny the Elder. (AD23-AD79). *The Complete Works of Pliny the Elder.* Republished in 2015. Hastings: Delphi Classics.
3. Walton, I. and Cotton, C. (1653) *The Compleat Angler*. 2010 edition. London: Arcturus.
4. Freud, S. (1876) Observations on the form and the finer structure of the lobular organs of the eel, organs considered to be testes, In Weiser, M. (2013) From the EEL to the EGO: psychoanalysis and the remnants of Freud's early scientific practice. *The History of the Behavioural Sciences*, 49 (3), pp. 259–280. https://doi.org/10.1002/jhbs.21606 (Accessed: 23 September 2021).
5. Egevang, C., Stenhouse, I.J., Phillips, R.A., Petersen, A., Fox, J.W. and Silk, J.R.D. (2010) Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (5), pp. 2078–2081. https://doi.org/10.1073/pnas.0909493107 (Accessed: 23 September 2021).
6. United States Congress (1994) *Colville Tribes, Grand Coulee Settlement: hearing before the Subcommittee on Oversight and Investigations of the Committee on Natural Resources, House of Representatives, One Hundred Third Congress, Second Session on H.R. 4757 to provide for the settlement of the claims of the Confederated Tribes of the Colville Reservation concerning their contribution to the production of hydropower by the Grand Coulee Dam, and for other purposes.* Hearing held in Washington, DC, August 2, 1994, Volume 4. Washington: U.S. Government Printing Office.

The saiga story: how international cooperation has been a key factor for conservation success

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CASE STUDY

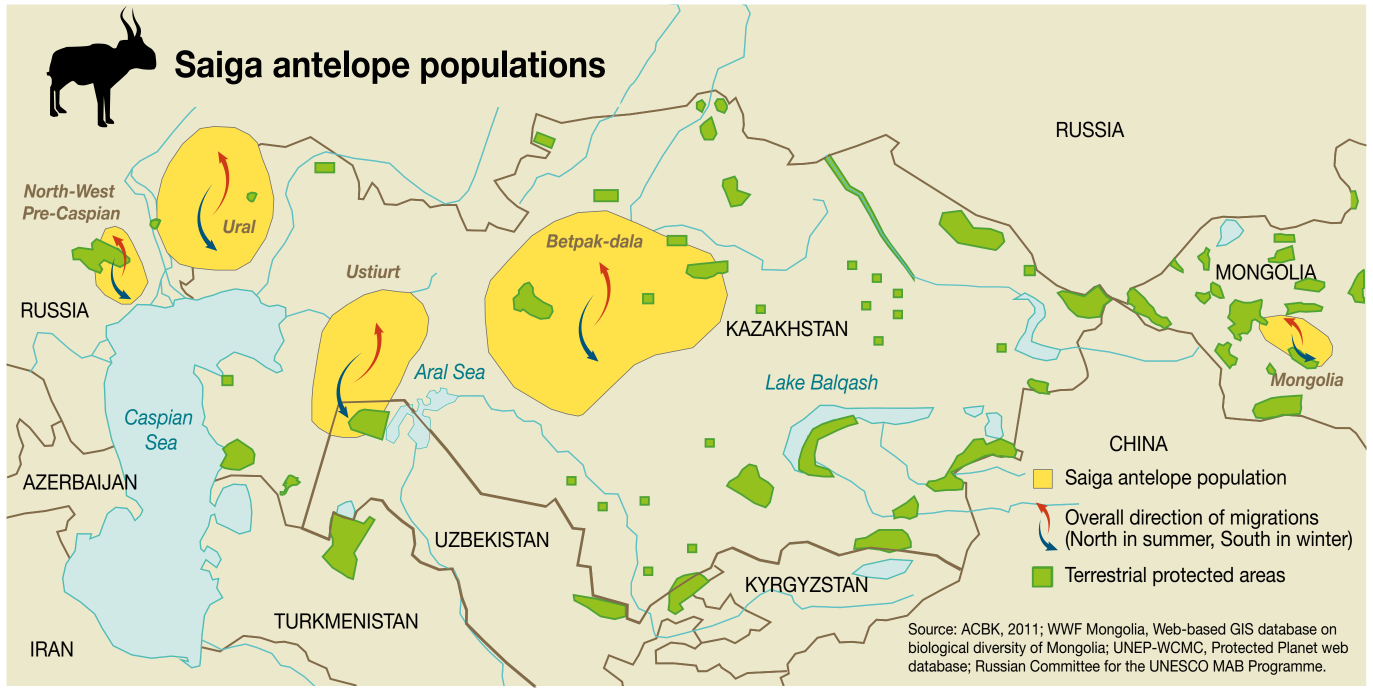
Aline Kühl-Stenzel recalls how the recovery of the saiga has been achieved and examines how much remains to be done.

AN ICE AGE SURVIVOR IN A MODERN WORLD

How many ice age species still successfully roam our planet today? The saiga antelope (*Saiga tatarica*) is one of the few survivors and has bounced back from the brink of extinction several times since then. A recent meeting under the UN Convention on Migratory Species (CMS) has agreed a new work programme until 2025 focusing on saiga conservation action.

During the last ice age, the saiga was found across most of the northern Eurasian hemisphere and even crossed the Bering Strait into North America.[1] Its ability to migrate and high reproductive rate have been essential factors in the species' ability to adapt and persevere (see **Box 1**). The trajectory towards the current 860,000 saigas[2] across Central Asia and Russia has been far from linear, though, and there have been numerous close shaves with extinction for individual subspecies and populations. **Figure 1** illustrates the breadth of the saiga's range across Central Asia and Russia.

During the past century the saiga's range has shrunk, and saigas went extinct in two former range states – China and Turkmenistan. Right now the overall global trend is excitingly positive (see **Table 1**) – a reflection of the conservation measures put in place, such as those in Kazakhstan. Range states and experts have recently discussed regulatory measures for any potential sustainable use of saiga antelopes given that individual populations have recovered well and there is a strong need to create incentives for saiga conservation in rural communities. However, there is much devil in the detail; individual populations perform very differently, and national interests by range and consumer states vary widely. The horn of the saiga is of considerable value in Chinese traditional medicine and there is local demand for saiga meat in several range states. Thus, the national and international management of the saiga is far from straightforward.



▲ **Figure 1. Saiga antelope populations and key terrestrial protected areas within their range. Note: The overall number of protected areas has increased since the original publication of this map, notably in the area of the Betpak-dala saiga population. (Figure taken with permission from *Living Planet: Connected Planet.*[2])**

BOX 1. MIGRATION AND CONSERVATION BIOLOGY OF THE SAIGA

The saiga antelope (*Saiga tatarica*) migrates up to 1,000 km between winter and summer ranges across the steppes and deserts of Central Asia and Russia. It can cover more than 100 km in a day and is highly adapted to this extreme continental climate. Only saiga males bear the precious horn, which is used in Chinese traditional medicine. Poaching for both meat and horn remain the core threats, with disease and climate change-related mass die-offs becoming increasingly important. The biological potential for recovery is high; while the majority of females are able to give birth to twins from the age of two, many are commonly pregnant before they even turn one. This explains how, despite the extreme crash from 1 million to fewer than 50,000 individuals in the early 2000s, individual populations have been able to increase ten-fold within six years (such as the Ural population). Three populations continue to be very small and in a precarious state: the North-west Pre-Caspian, Ustyurt and Mongolia populations.

THE SAIGA POLICY SETUP

In 2006, an international agreement specifically for the saiga antelope came into force under the auspices of CMS for all the relevant countries and stakeholders to address these management challenges: the Memorandum of Understanding concerning the Conservation, Restoration and Sustainable Use of the Saiga Antelope (Saiga MOU).[4] This agreement was negotiated at a time when the saiga population numbers had crashed by more than 95 per cent within a decade – down from 1 million to fewer than 50,000 animals – following the collapse of the Soviet Union in the early 1990s and due to unprecedented poaching levels.[5]

National commitment, together with a handful of highly committed scientists, non-governmental organisations (NGO), including the Saiga Conservation Alliance, intergovernmental organisations (IGO), and close cooperation between the CMS and the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES) made this policy coup possible. At the time, the CMS was still in a strong growth phase with regard to new agreements from which the saiga benefited. Such a single-species agreement requiring significant capacity and funding would be tough to negotiate in today's policy climate.

This remarkable setup facilitated close and regular dialogue in a neutral setting between range and consumer countries, scientists, NGOs, IGOs and other stakeholders. Over the years trust has grown, many long-term management measures and projects have been put into place and ultimately the conservation status of the species is improving, as is indicated by the latest approved population figures from September 2021.[3] Where national governments have invested heavily, both financially and in terms of capacity, we are seeing particularly positive trends today.

CASE STUDY

▼ **Table 1. Populations of saiga based on information collected from national governments for the 2021 CMS Saiga MOU meeting compared with the same information for the previous three MOU meetings[3]**

Population *	2006	2010	2015	2021	Trend in 2020
NW Pre-Caspian [RU]	15,000–20,000	10,000–20,000	4,500–5,000	10,000	Increasing
Ural [KZ, RU]	12,900	27,140	51,700	545,000	Increasing
Ustyurt [KZ, TM, UZ]	17,800	4,900	1,270	12,000	Increasing **
Betpak-dala [KZ]	18,300	53,440	31,300	285,000	Increasing
Mongolia [MN]	3,169	8,016 ±1,656	14,869	8,451	Increasing ***
Total	67,169–72,169	103,496–113,496	103,639–104,139	860,451	Increasing

Note: The figures are not directly comparable between years and populations because of variations in survey effort and methodology

* RU = Russia; KZ = Kazakhstan; TM = Turkmenistan; UZ = Uzbekistan; MN = Mongolia

** Decreasing in Uzbekistan

*** Following a major reduction in 2016–2017 to a low of around 3,000 individuals

The CMS Secretariat refers to the saiga agreement as one of most successful instruments amongst the 'CMS Family' of 26 agreements. Indeed, the fruitful cooperation that resulted from the Saiga MOU inspired range states to put into place a much wider umbrella policy under CMS – the 'Central Asian Mammals Initiative' – which was established in 2014.[6] This Special Species Initiative covers large mammals with transboundary populations in the wider Central Asian region, including the wild camel and the Mongolian gazelle. In this way, many more species and habitats can now benefit from CMS policies, such as the Guidelines for Addressing the Impact of Linear Infrastructure on Large Migratory Mammals in Central Asia.[7]

Of course, it is hard to tease apart how much the saiga agreement itself has contributed to this momentum, but it is clear that the strong international cooperation continues to be essential to making progress. National investment has certainly been the primary factor for success, as illustrated by Kazakhstan. Here, key measures have included strong expansion of the national network of protected areas and conservation corridors as well as strengthened law enforcement to improve the likelihood of capturing and prosecuting poachers and blocking trafficking networks. The saiga assessment from the International Union for the Conservation of Nature's Green Status of Species initiative illustrates just how much of a difference conservation action has made in terms of buffering the decline between 1950 and 2018, but also how much further conservation action will be needed for the species to recover.[8]

UN MEETING JUST ADOPTED NEW WORK PROGRAMME FOR THE SAIGA

The saiga range states with extant saiga populations – Kazakhstan, Mongolia, Russia and Uzbekistan – have just agreed on a new work programme for conservation action for 2021–2025 at the Fourth Meeting of Signatories to the Saiga MOU which was held online at the end of September 2021.[9]

New threats have emerged in recent years: new roads and railroads, including the Belt and Road Initiative, have dissected the saiga's migration in several parts, and climate change poses a major threat, not least since it appears to be connected to mass saiga die-off events.[10] In 2015, saigas made global headlines with a 62 per cent crash in overall numbers over a three-week period.[11] In addition, the only remaining population of the Mongolian subspecies, *Saiga tatarica mongolica*, was more than halved as a result of the *Peste des Petits Ruminants* in 2016–2017, a pathogen which is spreading in parallel with global warming in a north-westerly direction across Central Asia and has led to mass deaths of saigas as well as other wild and domestic ungulates.

The new work programme therefore continues to make wildlife health a priority, which is no doubt sensible in times of a global pandemic of potential animal origin.

CASE STUDY

The removal or at least mitigation of barriers to migration such as roads, railway lines and border fences is another priority. The transboundary Ustyurt saiga population suffers significantly from dissection due to border fences, motorways and railways.

Engaging rural communities more strongly in saiga conservation is possibly more important than it has ever been. Now that saiga populations are expanding their range again there is an increased need to enable the cohabitation of people, saiga and livestock, and to promote sustainable land use. The saiga's range is so vast that effective conservation is critically dependent on local people's actions and their willingness to contribute to steppe and desert biodiversity conservation. Rangers, law enforcement personnel and others engaged in saiga conservation can only ever cover a tiny fraction of the vast migratory range of the saiga.

PRECAUTIONARY DEBATE ON SUSTAINABLE USE OF SAIGAS

The CMS saiga meeting also discussed how any potential sustainable use of saigas could best be managed in the future and how stakeholders felt about this sensitive subject. One of the factors triggering this debate is human–wildlife conflict in some parts of the saiga range where saiga numbers have strongly increased in the past 15 years (see **Table 1**). The long-term vision of the Saiga MOU's work programme is 'To restore saiga populations to the point that sustainable use can again be envisioned', something which has been agreed by saiga range states since 2006 and remains unchanged. It is currently illegal to hunt saiga across the entire range, and export from range states is also prohibited.

However, there have been calls for years to discuss the intricacies and regulatory measures required for sustainable saiga hunting and for an adequate management framework to be put into place to avoid a situation where the complications of migration, international trade and the differences between populations are not properly addressed.

Generally speaking, hunting is a firmly engrained tradition in the region, and there is a need for additional measures to create incentives for conservation in rural communities. However, how local people and conservation would benefit from such trade and whether local people would be supportive of any future saiga hunt would first have to be thoroughly assessed. When looking at the latest population numbers, it must be recognised that the Betpak-dala population in Kazakhstan and the transboundary Ural population shared by Kazakhstan and Russia are areas where a certain level of hunting could be sustainable, provided that appropriate regulatory structures and mechanisms are developed and put into place.

There are many open questions and much work still to be done to avoid any illegal poaching in other populations if a limited amount of trade became legal and to ensure benefits to local communities. Therefore, it makes sense that the CMS meeting discussed the pre-conditions for any potential sustainable use, adopted a technical document on the matter and thereby built a foundation for any future decision-making by range states in this direction.

CONCLUSION

Right now, the emphasis should be placed on putting the new work programme into action to further build on the saiga's conservation success. National commitment is vital, coupled with support from a strong network of scientists and NGOs and with a good sprinkling of international cooperation. The latest population figures should inspire and motivate in the knowledge that we are on the right path. **ES**

Aline Kühl-Stenzel completed her PhD on the saiga and is a steering committee member of the Saiga Conservation Alliance. She spent ten years with the UN Environment Programme, including working for the CMS Secretariat and the Barcelona Convention. Today, she is the Policy Officer for Marine Conservation at NABU (Nature and Biodiversity Conservation Union) and holds an honorary professorship in international environmental policy at the Eberswalde University for Sustainable Development.

FURTHER READING

To find out more about saiga conservation in the range states and internationally, please visit:

Saiga Conservation Alliance (2021) *Newsroom*. http://saiga-conservation.org/news/saiga-news (Accessed: 23 September 2021).

REFERENCES

1. Harington, C.R. and Cinq-Mars, J. (1995) Radiocarbon dates on saiga antelope (Saiga tatarica) fossils from Yukon and the Northwest Territories. *Arctic*, 48 (1), pp. 1–7.
2. Kurvits, T., Nellemann, C., Alfthan, B., Kühl, A., Prokosch, P., Virtue, M. and Skaalvik, J.F. (2011) *Living Planet: Connected Planet – Preventing the End of the World's Wildlife Migrations through Ecological Networks. A Rapid Response Assessment*. United Nations Environment Programme, GRID-Arendal. https://www.grida.no/publications/199 (Accessed: 28 September 2021).
3. Convention on the Conservation of Migratory Species of Wild Animals (2021) *Overview Report on Conservation Status and MOU Implementation*, Fourth meeting of the signatories to the Saiga MOU (MOS4), online, 28–29 September 2021, UNEP/CMS/Saiga/MOS4/Doc.5[Rev.2]. https://www.cms.int/en/meeting/fourth-meeting-signatories-saiga-mou-mos4 (Accessed: 01 October 2021).
4. Convention on the Conservation of Migratory Species of Wild Animals (2021) *Memorandum of Understanding concerning Conservation, Restoration and Sustainable Use of the Saiga Antelope*. https://www.cms.int/saiga/en/documents/agreement-text (Accessed: 28 September 2021).
5. Sharp, R. (2002) Saiga antelope facing catastrophe. *Oryx*, 35, p. 323.
6. Convention on Migratory Species (2021) *Central Asian Mammals Initiative*. https://www.cms.int/cami/en/about-cami (Accessed: 6 October 2021).
7. Wingard, J., Zahler, P., Victuring, R., Bayasgalan, O. and Bayarbaatar, B. (2014) *Guidelines for Addressing the Impact of Linear Infrastructure on Large Migratory Mammals in Central Asia*. Wildlife Conservation Society; UNEP/CMS Secretariat (adopted as UNEP/CMS/COP11/Doc.23.3.2). https://www.cms.int/en/publication/guidelines-addressing-impact-linear-infrastructure-large-migratory-mammals-central-asia (Accessed: 28 September 2021).
8. Akcakaya, H.R., Bennett, E.L., Brooks, T.M., Grace, M.K., Heath, A., Hedges, S., Hilton-Taylor, C., Hoffmann, M., Keith, D.A., Long, B., Mallon, D.P., Meijaard, E., Milner-Gulland, E.J., Rodrigues, A.S.L., Rodriguez, J.P., Stephenson, P.J., Stuart, S.N. and Young, R.P. (2018) Quantifying species recovery and conservation success to develop an IUCN Green List of Species. *Conservation Biology*, 32 (5), pp. 1128–1138.
9. Convention on the Conservation of Migratory Species of Wild Animals (2021) *Medium-Term International Work Programme for the Saiga Antelope* (2021–2025), Fourth meeting of the signatories to the Saiga MOU (MOS4), online, 28–29 September 2021, UNEP/CMS/Saiga/MOS4/Doc.6. https://www.cms.int/en/meeting/fourth-meeting-signatories-saiga-mou-mos4 (Accessed: 1 October 2021).
10. Kock, R.A., Orynbayev, M., Robinson, S., Zuther, S., Singh, N., Beauvais, W., Morgan, E.R., Kerimbayev, A., Khomenko, S., Martineau, H.M., Rystaeva, R. Omarova, Z., Wolfs, S., Hawotte, F., Radoux, J. and Milner-Gulland, E.J. (2018) Saigas on the brink: Multidisciplinary analysis of the factors influencing mass mortality events. *Science Advances*, 4 (1) https://doi.org/10.1126/sciadv.aao2314 (Accessed: 01 October 2021).
11. Nicholls, H. (2015) Mysterious die-off sparks race to save saiga antelope. *Nature*. https://doi.org/10.1038/nature.2015.17675 (Accessed: 01 October 2021).

FEATURE

Bird migration: mysteries, movements, marathons and modifications

Anne Goodenough explores the complexities of bird migration.

Avian migration occurs when a bird alternates between a winter and a summer location such that, over time, that individual undertakes regular, seasonal journeys between two distinct geographical areas. This differs from a resident bird which remains in the same general area throughout the entire year.

Amongst birds, migration is a common and regular occurrence, involving huge numbers of species and individuals. Worldwide, about 20 per cent of bird species migrate,[1] with an estimated 5 million birds from almost 200 species moving between Africa and Europe each year and similar numbers moving between North America and Central/South America.

MYSTERIES

Humans have long been fascinated by avian migration. Before we understood biogeographical movements, the seasonal appearance and disappearance of birds in a given location was often rather puzzling. Several interesting theories arose to explain this phenomenon.

FEATURE

Perhaps the most intriguing involves the barnacle goose and the goose barnacle. The former is a medium-sized goose with a mottled grey colouring; the latter is a marine filter-feeding crustacean with grey mottling that looks superficially similar to the goose. Water-associated barnacle geese are found in the UK and Ireland during winter only, while goose barnacles sometimes attach to timber that comes into shore as driftwood. As a result, Giraldus Cambrensis and John Mandeville, writing in the 12th and 14th centuries respectively, assumed that barnacle geese and goose barnacles were actually different forms of the same species.[2] Similarly, Aristotle assumed that swallows hibernated during the winter as he could think of no other explanation for why they were only found in Ancient Greece during the summer.[3]

MOVEMENTS

We now know that there are many different types of avian migratory movements. The most common is latitudinal migration which occurs when the winter and summer ranges occur at different latitudes. Some latitudinal migrants are summer or reproductive migrants: these species move from lower to higher latitudes (i.e. northwards in the northern hemisphere and southwards in the southern hemisphere) in order to breed. Classic examples are the swifts and swallows that move from sub-Saharan Africa to Europe each spring, and the snow buntings that breed in the high Arctic areas of Alaska, Canada and Scandinavia but winter in the midlatitudes of the USA and Europe. Such movements are usually driven by food – either an increased supply of food or because it is easier to find. For example, swallows are aerial insectivores, which means that they hunt on the wing for small insects such as midges, mosquitoes and flying ants. There are large numbers of small insects on the wing year-round in Africa; however, by coming to the UK, swallows become one of only four bird species that hunt in this way, and they thus have a monopoly on this bounty instead of having to compete with numerous other species.

Other latitudinal migrants undertake their north–south journeys in reverse, spending the summer at high latitudes and heading south (in the northern hemisphere) as temperatures decrease in order to spend their winter in warmer climes. Good examples are Bewick's swans and white-fronted geese – and indeed many other waterbirds – that migrate from Scandinavia to the UK each autumn. For these species, latitudinal movements are necessitated by low temperatures freezing waterbodies – making it impossible to feed on the surface of the water or dive to feed on submerged vegetation – or by snow covering the grass on which they graze.

There are other types of migratory patterns too. In tropical and subtropical areas, avian species can be nectarivorous (nectar-feeding) or frugivorous (fruit-eating). Flowering and fruiting times differ with elevation, so birds often undertake altitudinal – rather than latitudinal – migration. Good examples are the frugivorous white-ruffed manakin in Honduras and the nectarivorous blue-tailed hummingbird in Nicaragua.

Other birds are partial migrants. This means that some populations migrate while others do not, such that the overall winter and summer distributions of the species overlap with one another. A classic case is the familiar robin: in the UK there are resident individuals that occur year-round but every winter numbers swell with the arrival of birds from more northerly areas. Partial migration is especially common where range sizes are large, particularly where land is contiguous. For instance, in Australia 44 per cent of non-passerine birds and 32 per cent of passerine species are partially migratory.[4]

A final type of migration is the rather alarmingly named 'irruptive' migration. Irruptive migration is where populations are resident in some years but migrate in others. The trigger for whether to stay or go is food supply. For example, snowy owls irrupt in winters when rodent populations crash (or owl numbers boom) but stay in the same location year-round when food supplies are good relative to the owl population.

MARATHONS

There are many birds that undertake migratory marathons, but none more so than the bar-tailed godwit and the Arctic tern. The bar-tailed godwit undertakes the longest non-stop flight of any migrant, flying 11,000 km from Alaska to New Zealand.[5] Meanwhile, the Arctic tern undertakes the longest migration of any bird species, clocking up an average 70,900 km per year (range 59,500–81,600 km), moving between the Arctic and the Antarctic.[6] This bird also sees the most sunlight of any animal; its time near the North Pole occurs in 24-hour daylight, as does its time near the South Pole.

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MODIFICATIONS

Migration is not a static phenomenon. Human-accelerated climate change is altering not just regional temperatures but also seasonal food availability and, in turn, spatial and temporal migration patterns. Some species that were historically migratory are starting to become resident, at least in some areas. For example, the blackcap is a small songbird that has historically bred in northern Europe including the UK, but which wintered in Mediterranean areas including northern Africa. This is now changing, with some individuals staying in their summer range year-round.

"Migration is not a static phenomenon. Human-accelerated climate change is altering not just regional temperatures but also seasonal food availability and, in turn, spatial and temporal migration patterns."

Climate change is also affecting migratory phenology. Phenology refers to the time at which species undertake annual events, including migration, and is largely controlled by the circannual rhythm. This is mainly kept in check by the endocrine (hormone) system, but hormones are themselves influenced by environmental stimuli. The main environmental stimulus – other than directly on the equator – is change in day length, as this is an effective proxy for seasonal change. However, problems arise in situations when individuals of a species are constrained in their ability to change (phenological inertia), or when changes in the timing of seasonal events differ between species within the same community leading to the breakdown of ecological links (phenological mismatch).

Phenological inertia can occur when, for example, a species migrates to its breeding grounds. Breeding clearly cannot start before arrival at breeding grounds and so any constraint in migration timing will also constrain the ability to adapt breeding timing.[7] Phenological mismatches occur when an organism is out of step with its environment. Birds should synchronise breeding so that peak demand for food from young coincides with peak supply. For many species this peak supply is caterpillars, which have been hatching earlier in more recent years. Therefore, if caterpillars emerge in an area, say, two weeks earlier now relative to 25 years ago but the birds are only breeding one week earlier, they are no longer fully synchronised. Such mismatches can have profound effects on breeding success and, ultimately, population size. For example, some Dutch populations of the migratory pied flycatcher have declined by up to 90 per cent, primarily because of mismatches with food. In turn, this impacts on breeding, leading to subsequent population-level effects.[8] The potential for mismatches is much higher in migratory birds because they are less able to respond to local phenological shifts in food supply.[9]

Migratory modifications are also occurring as a result of human activity. For many small birds it is not possible to make long-distance journeys in full without a break. This means that species such as the pied flycatcher, an Afro-European migrant species, need to use stop-over sites. Stop-over sites are akin to motorway service stations: areas where birds can rest and refuel on long journeys. For many woodland birds that migrate through the Mediterranean region, cork oak plantations make perfect stop-over sites. Cork oaks are harvested on an eight-year cycle with the outer layer of bark being removed to produce the traditional stoppers for wine bottles. These plantations also support woodland invertebrates upon which species such as the pied flycatcher feed. However, due to the rise in screw-top bottles for alcoholic beverages, the number of cork oak plantations is rapidly declining, and birds are being forced to use sub-optimal habitat. Perhaps supporting cork oak plantations, and their temporary avian inhabitants, is the perfect excuse for adding a bottle of wine (with a cork!) to your shopping list? ES

Anne Goodenough is Professor of Applied Ecology at the University of Gloucestershire, where she leads the IES-accredited MSc Applied Ecology programme. She has many research interests but is especially fascinated by birds.
@dockling83

REFERENCES

1. Rolland, J., Jiguet, F., Jønsson, K.A., Condamine, F.L. and Morlon, H. (2014) Settling down of seasonal migrants promotes bird diversification. *Proceedings of the Royal Society B*, 281 (1784), 20140473.
2. Goodhue, K. (2013) Science, superstition and the goose barnacle. *Shorelines*. Smithsonian Environmental Research Center. https://sercblog.si.edu/science-superstition-and-the-goose-barnacle (Accessed: 16 September 2021).
3. Marti, C. (2016) Aristotle and the migrating birds – what he wrote and what he did not. *Der Ornithologische Beobachter*, 113, pp. 309–320.
4. Chan, K. (2001) Partial migration in Australian landbirds: a review. *Emu*, 101 (4), pp. 281–292.
5. Gill, R.E, Piersma, T., Hufford, G., Servranckx, R. and Riegen, A. (2005) Crossing the ultimate ecological barrier: evidence for an 11,000 km-long nonstop flight from Alaska to New Zealand and eastern Australia by bar-tailed godwits. *The Condor*, 107 (1), pp. 1–20.
6. Egevang, C., Stenhouse, I.J., Phillips, R.A., Petersen, A., Fox, J.W. and Silk, J.R.D. (2010) Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences of the United States of America*, 107 (5), pp. 2078–2081. https://doi.org/10.1073/pnas.0909493107 (Accessed: 23 September 2021).
7. Goodenough, A.E., Hart, A.G. and Elliot, S.L. (2011) What prevents phenological adjustment to climate change in migrant bird species? Evidence against the "arrival constraint" hypothesis. *International Journal of Biometeorology*, 55 (1), pp. 97–102.
8. Both, C., Bouwhuis, S., Lessells, C.M. and Visser, M.E. (2006) Climate change and population declines in a long-distance migratory bird. *Nature*, 441, pp. 81–83.
9. Goodenough, A.E., Hart, A.G. and Stafford, R. (2010) Is adjustment of breeding phenology keeping pace with the need for change? Linking observed response in woodland birds to changes in temperature and selection pressure. *Climatic Change*, 102 (3), pp. 687–697.

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info@the-ies.org
+44 (0)20 3862 7484
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IES photography competition

This year's photography competition explored the theme of transformation. From stunning portraits to beautiful landscapes, we received a large number of submissions from across the world capturing transformation in action.

We are delighted to announce this year's winning image of a piece of sea glass on Compton Bay beach on the Isle of Wight, photographed by Laura Thomas. Laura, a student member of the IES, has been awarded one year of free professional membership upon graduation.

Laura's photo – titled 'junk to jewel' – highlights the power of the ocean to transform a discarded glass bottle into an attractive piece of sea glass, captured beautifully against the setting sun. It serves as a reminder that transformation can be complex, and it is full of ethical dilemmas and pitfalls. Pollution is not a desirable outcome but, in this case, it provides some beauty. We are reminded that nature has the capacity to adapt to changes in circumstances, albeit over a very long period, and ask: if we cannot mitigate a problem, to what degree are we able to adapt?

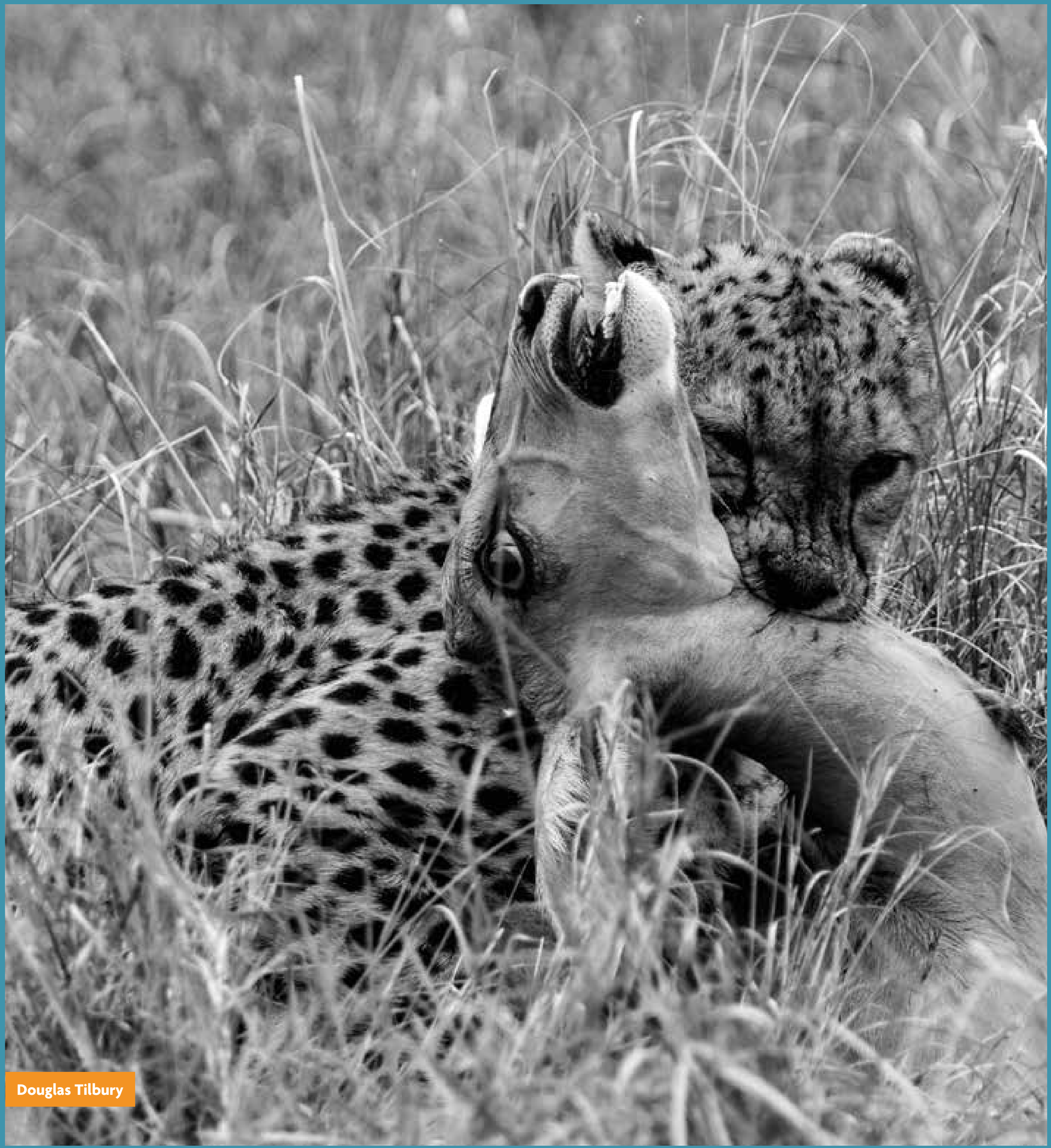
Winner

Laura Thomas

Highly commended

▲ **TRANSFORMATION OF A PERFECT FLYING V**
Jamie Wood captures the moment an absent-minded Whooper swan (*Cygnus cygnus*) disrupts the neat V formation of the swans' flight.

Jamie Wood



▲ **FROM LIFE TO DEATH**
This photograph by Douglas Tilbury shows Olpadan ('the Great Shooter' in Maa), leader of the Maasai Mara's famous Tano Bora (the Five Brothers) cheetah (*Acinonyx jubatus*) coalition, bringing down an eland (*Taurotragus oryx*) calf in a coordinated and ruthlessly efficient hunt. The brothers have developed international notoriety for their tight bond and military-like tactical hunting style. The image captures the moment the calf gives up the fight.

▶ **JUVENILE WHEATEAR (TOP RIGHT)**
Dan Clampin captures the change in a juvenile wheatear's (*Oenanthe oenanthe*) plumage from its mottled brown speck to the adult feathers along its belly.

▶ **NATURE TAKES OVER (BOTTOM RIGHT)**
This image by Aida Khalil shows nature recapturing a building at Ta Prohm, Angkor Wat, Cambodia.

FEATURE

The great Mexico-USA migration of the monarch butterfly

Joseph Martin looks at the threats to the monarch butterfly migration and what measures are being taken to preserve this impressive multigenerational journey.

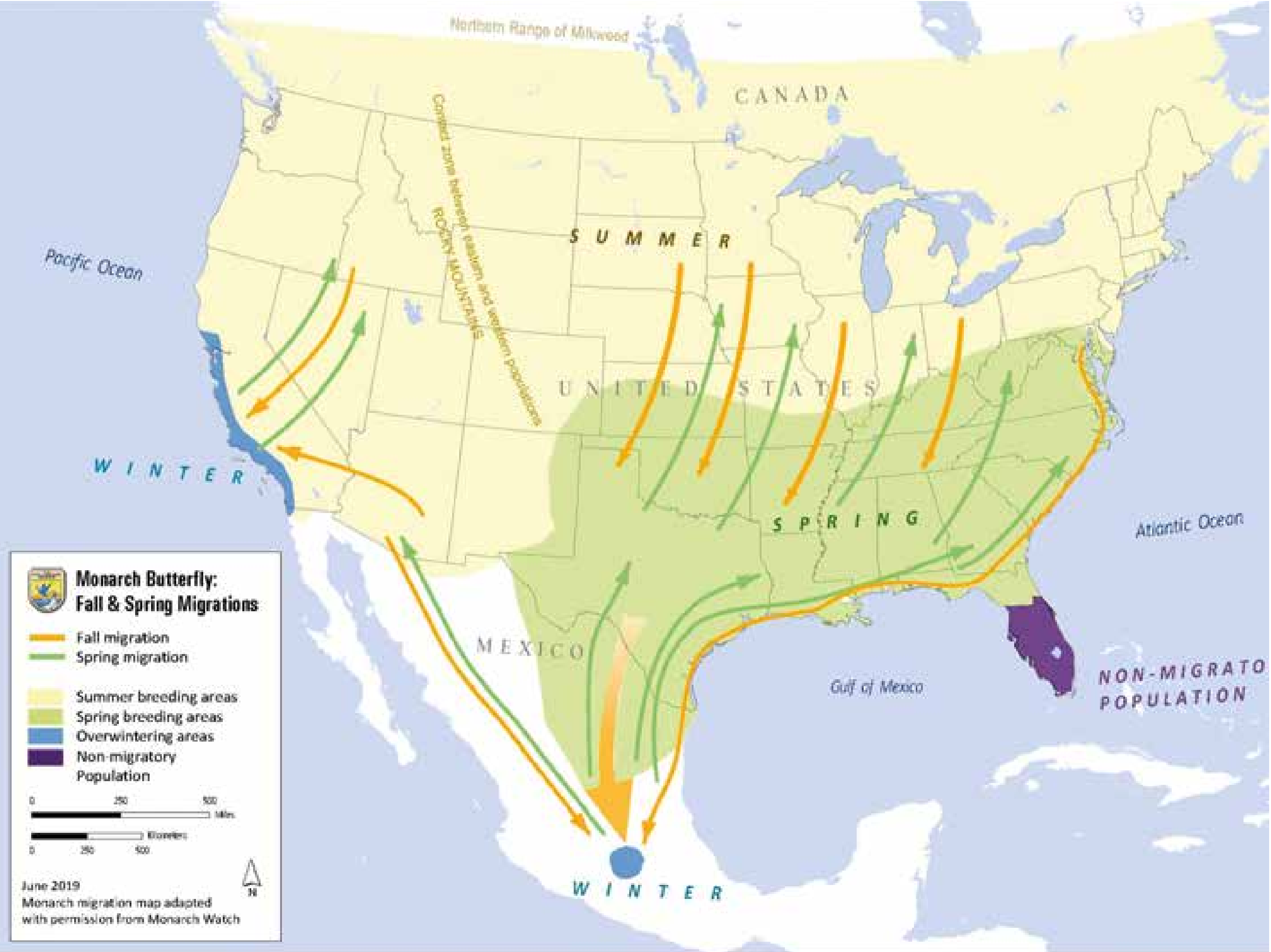
INTRODUCTION

Each autumn, North American monarch butterflies (*Danaus plexippus plexippus*) travel from their summer breeding grounds to overwintering locations. East of the Rocky Mountains, monarch butterflies travel almost 5,000 km south to central Mexico, where they ultimately make their home in the Trans-Mexican Volcanic Belt pine-oak forests, clustering on branches of pine and oyamel trees.[1]

From late October to early March, these insects bask and rest in the sunlight. As spring approaches, they come out of their hibernation and mate before embarking on a remarkable, multigenerational northward migration.

The first group of monarch butterflies leaving Mexico stops to lay eggs on the return journey, shortly after which they die; these eggs then develop into the next generation that continues north, repeating the same cycle. It is estimated that four generations of monarch butterflies are born and die over the spring return to North America.[1]

◀ **Monarch butterflies congregating in a central Mexican forest to overwinter. (© Alex Guillaume | Unsplash)**



▲ **Figure 1. Map showing the North American monarch butterfly range. The spring and summer breeding areas and overwintering locations for the eastern and western populations are highlighted, as are the spring and autumn migratory routes. (Source: USFWS)**

However, this cycle is under threat from climate change and shifting land use practices in both their summer breeding grounds and overwintering locations.[2]

THE MONARCH MIGRATION JOURNEY

There are three populations of monarch butterfly in North America: the eastern and western populations, and a non-migratory population that lives in Florida all year round. The eastern and western populations undertake simultaneous migrations between their breeding and overwintering areas (see **Figure 1**).

The eastern migration includes butterflies that reproduce to the east of the Rocky Mountains in southern Canada and the north-eastern United States. These butterflies travel to wintering hibernation sites in central Mexico, and in particular to the states of Michoacán and Estado de México. The same butterflies that arrived in Mexico begin the return journey to the United States in early spring. This migration comprises more than 90 per cent of the North American monarch butterfly population.[3]

The western migration includes those butterflies that reproduce to the west of the Rocky Mountains in southern Canada and parts of the western United States. These butterflies travel to various hibernation sites along the coast of California and Mexico. This migration comprises less than 10 per cent of the population of North American monarch butterflies.

There are estimated to be more than 390 wintering hibernation sites in California and northern Mexico distributed along the coast from San Francisco, California, in the north to Ensenada, Mexico, in the south and covering an area more than 900 km long. Historically, forests of Monterey pine (*Pinus radiata*) covered this region; however, these have been replaced by urban developments with only small pockets of what remains of the eucalyptus forests that were introduced around 1850.[3]

THE INSTINCTS THAT DRIVE THE MONARCH BUTTERFLY MIGRATION

How monarch butterflies navigate their way along their migratory routes is not fully understood. We know that they do not learn the route from their parents since only around every fifth generation migrates. As a result, it is likely that they rely on their instincts rather than learning how to find overwintering sites. Yet, even which instincts they use is a mystery although it is likely that celestial forces such as the sun and moon play an important role.[4]

The conservation partnership Monarch Joint Venture, a coalition of organisations across the United States, Canada and Mexico working to conserve the monarch butterfly, has identified three cues as the most likely drivers of the monarch butterfly migration:

'**Sun Compass:** Since monarchs migrate during the day, the sun is the celestial cue most likely to be useful in pointing the way to the overwintering sites. This proposed mechanism is called a sun compass. Monarchs may use the angle of the sun along the horizon in combination with an internal body clock (like a circadian rhythm) to maintain a south-westerly flight path.

'**Magnetic Compass:** Scientists have suggested that monarchs may use a magnetic compass to orient, possibly in addition to a sun compass or as a "back-up" orientation guide on cloudy days when they cannot see the sun. Studies of migratory birds have indicated that they register the angle made by the earth's magnetic field and the surface of the earth. These angles point south in the Northern Hemisphere and north in the Southern Hemisphere.

'**Genetics:** Upon dispersal, the Central and South American, Atlantic, and Pacific populations lost the ability to migrate. This prompted researchers to identify the gene regions in North American monarchs that appeared highly differentiated from non-migratory populations.[4]

THREATS TO THE MONARCH BUTTERFLY MIGRATION

In 2020, it was reported that the number of monarch butterflies reaching their winter resting grounds in central Mexico had decreased by 26 per cent, and that the butterfly population covered an area of 2.1 hectares compared to 2.8 hectares in 2019.[5]

Experts have highlighted a number of factors that are believed to have contributed to the observed population decline, including extreme climatic conditions, loss of milkweed habitat in the United States and Canada on which monarch butterflies depend, and deforestation in their wintering grounds in Mexico.[6]

Monarch Joint Venture states that 'Climate models predict that the overwintering grounds in Mexico may soon no longer be suitable for monarchs, indicating that the eastern North American monarch population may require different overwintering habitat'. This is particularly concerning for wintering monarch butterfly populations as they will have to adapt to wintering in colder climates in areas they are not familiar with in terms of survival needs.

The shifting climate patterns also affect migration routes and patterns in both the United States and Mexico. For example, severe winter storms in Texas, which the butterflies must cross while on their way back to their northern summer homes – feeding and laying their eggs en route – have disrupted the monarch butterfly migration. In 2016, at least 1.5 million monarch butterflies (approximately 3 per cent of the estimated 50 million roosting population) froze to death as an unusual storm of ice and wind moved through the mountains of Michoacán where the butterflies roost for the winter. Exactly how many butterflies perished in the freeze remains uncertain.[6]

The loss of habitats in Mexico is also being driven by illegal logging activities and land reclamation for farming which, while mostly localised, are still damaging population densities. In particular, the oyamel fir trees are an attractive haven for monarch butterflies. They serve as both a blanket and an umbrella during the winter, offering protection from extreme cold temperatures and precipitation. The encroachment of logging near overwintering sites and forest degradation from other causes can alter the microclimate which, in turn, may increase monarch mortality.

In terms of government policies, logging is banned in areas where monarch butterflies overwinter in Mexico. However, regulations, licensing and incentives to protect the butterfly populations have either not been strictly implemented or are not monitored. While many government policies promote sustainable forest management and ban most logging in Mexico's overwintering areas, these regulations and incentives have not been fully effective. Indeed, according to Monarch Joint Venture, illegal logging is still taking place within the Monarch Butterfly Biosphere Reserve, albeit on a smaller, more localised scale.[4]

As stated earlier, western North America's monarch butterflies also migrate to overwintering locations along the Pacific coast. Population numbers are also on the decline here, but the cause is less certain. There have been numerous monarch habitats lost to commercial and residential housing developments in recent years. This urbanisation growth has also led to increased pollution and to the fragmentation of natural water systems in areas where water sources are important on the migratory route.

In addition, while tourism has brought economic benefits to many areas – such as the Monarch Butterfly Biosphere Reserve – human activity has also led to overwintering clusters being severely disturbed.[4]

CONSERVING THE GREAT MONARCH MIGRATION

The primary monarch butterfly conservation principles are set out by the Monarch Joint Venture in the 2021 Monarch Conservation Implementation Plan.[7]

Some of the priorities outlined in the plan involve monarch habitat conservation on public and private land, including the enhancement and improved management of milkweed and nectar resources throughout the monarch range. There are also plans for improved education and outreach programmes to increase interest, awareness and engagement in monarch butterfly conservation. Research and partnership building are also crucial steps in improving awareness of the migration patterns of monarch butterflies.

Monarch Joint Venture has clearly stated its targets for both the eastern and western population areas.

Eastern population. For this population, the targets include:

- Reaching and maintaining an area of 6 hectares of forest in Mexico for overwintering monarch butterflies;
- Adding a minimum of 1.3 billion milkweed stems and abundant nectar resources throughout monarch breeding areas; and
- Restoration and enhancement of almost 3 million hectares of pollinator-friendly habitat nationally.

Western population. The Western Monarch Butterfly Conservation Plan, which informs the wider Monarch Conservation Implementation Plan, outlines the following short-term objectives to be reached by 2029:

- Achieve a five-year running average of 500,000 butterflies counted at 75 sites;
- Create an additional 50,000 acres of monarch-friendly habitat in California's Central Valley and adjacent foothills; and
- Establish protection and management for 50 per cent of all currently known and active monarch overwintering sites, including 90 per cent of the most important overwintering sites.[7]

CONCLUSION

The monarch butterfly migration is one of the most impressive sights in the natural world. Using instinct and celestial forces, monarch butterflies can navigate the most arduous of journeys across the North America. However, in 2021, the threat to this species is growing at both summer and overwintering locations. The looming threat of climate change combined with habitat

FEATURE

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FEATURE

loss from subsistence farming and illegal logging are piercing and fragmenting habitats which were once untouched by humans.

The solutions are not always clear, particularly in Mexico where overwintering takes place. Stricter implementation of government policies would help as would enforcement and protection of the Monarch Butterfly Biosphere Reserve to ensure population decline is limited and future migration patterns are retained indefinitely. To mitigate the impacts of climate change, it will be important to restore and increase the extent of appropriate habitat throughout the monarch butterfly range, as well as ensure that other pressures on the species are minimised.

As a migratory species, monarch butterflies frequently move between patches of suitable habitat. They also have a high dispersal ability across a large geographical range. This, combined with their short lifespan and high reproductive rate, suggests that monarch butterflies may have a high capacity to adapt to longer term changes in climate. ES

Joseph Martin is a Chartered Environmentalist at AECOM in Belfast. He works primarily on environmental impact assessments for major infrastructure schemes as well as on air quality monitoring. Joseph also has a background in renewable energy technologies and has been contributing to the environmental SCIENTIST since 2014.

joseph.martin@aecom.com

REFERENCES

1. McMenamin, S. (2021) *From Central Park to Central Mexico: The great monarch butterfly migration.* https://www.centralparknyc.org/articles/the-great-monarch-butterfly-migration (Accessed: 2 September 2021).
2. Watt, L. (2021) *The great monarch migration: A unique phenomenon under threat.* https://www.worldwildlife.org/stories/the-great-monarch-migration (Accessed: 15 September 2021).
3. Soy Monarca (2021) *The great journey*. https://www.soymonarca.mx/en/travesia.html (Accessed: 15 September 2021).
4. Monarch Joint Venture (2021) *Monarch migration*. https://monarchjointventure.org/monarch-biology/monarch-migration (Accessed: 15 September 2021).
5. World Wide Fund for Nature-Mexico (no date) *Less Monarch butterfly presence and increased degradation in its hibernation forests, press release.* https://monarchjointventure.org/images/uploads/documents/Monarch_Butterfly_Monitoring_2019-2020_PressRelease_Final.pdf (Accessed: 1 October 2021).
6. Maeckle, M. (2016) *At least 1.5 million monarch butterflies perish in deadly ice storm in Michoacán.* https://texasbutterflyranch.com/2016/03/13/at-least-1-5-million-monarch-butterflies-perish-in-deadly-ice-storm-in-michoacan (Accessed: 16 September 2021).
7. Monarch Joint Venture (2021) *2021 Monarch Conservation Implementation Plan.* https://monarchjointventure.org/our-work/monarch-conservation-implementation-plan (Accessed: 16 September 2021)

CASE STUDY

Eels in the River Thames

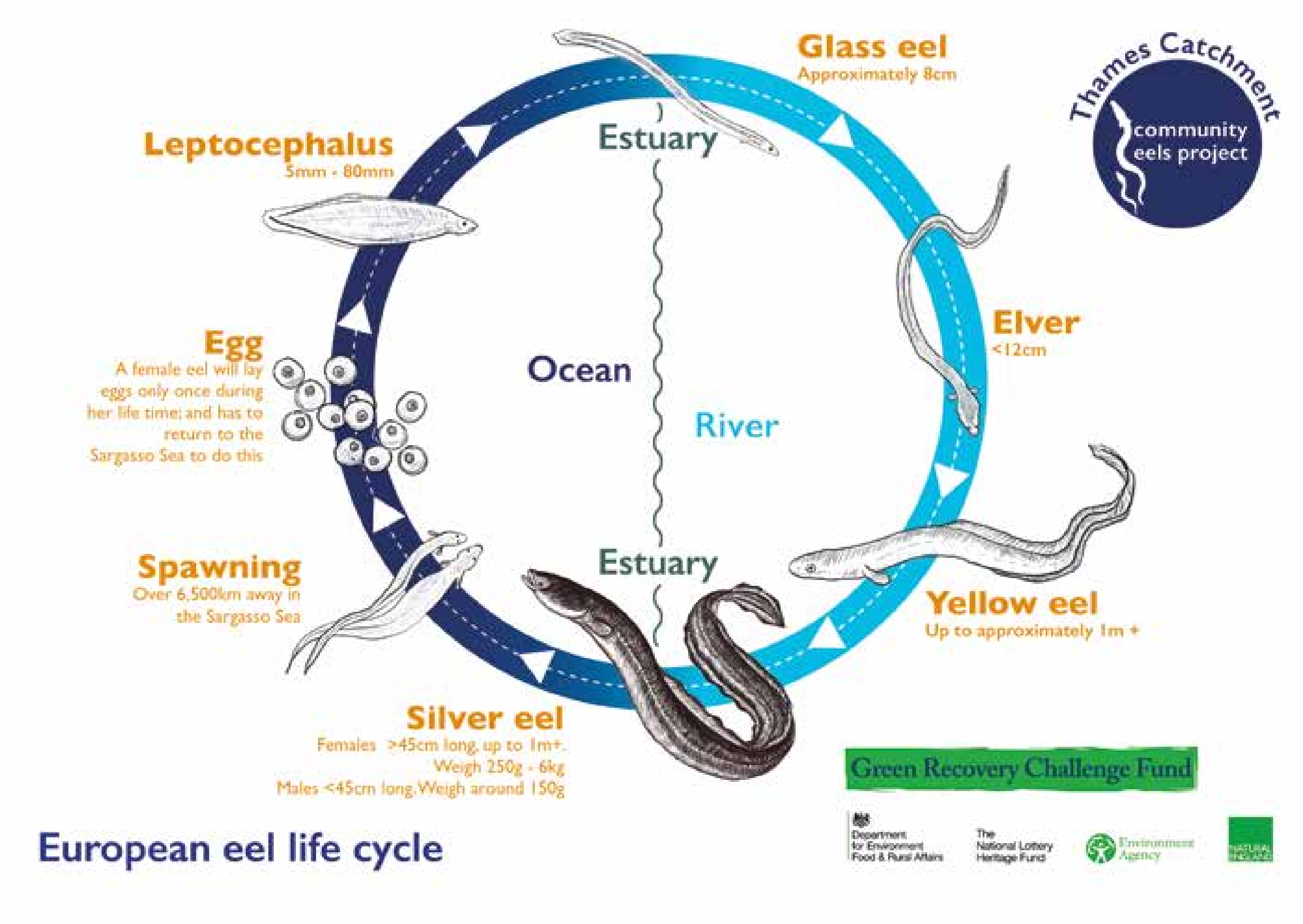
Anna Forbes, Oli Back, Mia Ridler, Jess Mead, Joe Pecorelli and **Wanda Bodnar** outline the latest initiatives to improve the future of the European eel across the Thames catchment.

The European eel (*Anguilla anguilla*) is a fish species synonymous with the River Thames and wider Thames catchment. Tides wash young eels, known as glass eels (see **Figure 1**), into the Thames estuary and, in the past, they have journeyed up through the catchment rivers in large numbers. A rich cultural heritage and social history exist based on the historic abundance of this keystone species; however, this once common fish has more recently faced a steep decline.

Eels are an unusual fish with an incredible life cycle that includes a migration of thousands of kilometres from the Sargasso Sea across the Atlantic Ocean and into our freshwater rivers – possibly the longest migration of any fish species in the world. Six organisations across the Thames catchment have partnered to work collaboratively and improve the eel's future. The Thames Catchment Community Eels Project was developed to strategically shape future practical improvements to eel habitats – the primary focus being to address barriers to eel migration – with eel monitoring and community involvement in place to support the initiative.

◀ **Figure 1. Glass eel. (© Jack Perks, Thames Catchment Community Eels Project)**

CASE STUDY



▲ **Figure 2. Illustration of the eel life cycle. (© Thames Catchment Community Eels Project)**

The project is led by the Thames Rivers Trust which oversees project delivery of work carried out by project officers from three river trusts: Thames21, South East Rivers Trust and Action for the River Kennet. Collaboration on strategy, methodology and data analysis is also performed by the Zoological Society of London (ZSL) and Thames Estuary Partnership. It is a geographically large and ambitious project, which aims to carve out a new form of partnership working as well as improve the prospects of a critically endangered species. This project is funded by the Government's Green Recovery Challenge Fund. The fund is being delivered by the National Lottery Heritage Fund in partnership with Natural England and the Environment Agency.

ABOUT EUROPEAN EELS

The European eel begins its life in the Sargasso Sea (see **Box 1**), over 6,000 km away from the Thames estuary. Millions of eggs laid here will hatch into eel larvae called leptocephali, often likened to a transparent leaf. These tiny leptocephali (5–80 mm long) float for approximately one to two years on the Gulf Stream before arriving on the coasts of Europe, Iceland and North Africa. Here, they metamorphose into aptly named glass eels; they are still transparent but are now a recognisable eel shape. Some will remain in the brackish waters of the estuary, but many will begin to travel up into rivers where they develop into their next life cycle stage, the elver (see **Figure 2**).

Moving upstream en masse (once known as the elver run), the pigmented elvers disperse into freshwater habitats where many will spend the majority of their life, growing over many years as yellow eels. As they mature, they begin to transform into silver eels. Silver eels only reach full maturity during the six-month journey back to the Sargasso Sea; this downstream migration of the sea-bound silver eel happens in the autumn.

It took hundreds of years of research to piece together the puzzle of the eel's life, and it was not until 1920 that Johannes Schmidt discovered the probable location of where European eels spawn.[1] He trawled the Atlantic Ocean over many years looking for smaller larvae until he established that their life must begin within the Sargasso Sea. Much of the eel's life is still a mystery to scientists; no one has ever seen them mate or successfully tracked an adult eel's return migration all the way back to where it is believed they spawn.

▲ **Figure 3. ObstacEELS volunteers and obstacles to eel migration being surveyed. (© Action for the River Kennet and Thames21)**

BOX 1. SARGASSO SEA

The only sea in the world without any land borders. It is found in the west of the Atlantic Ocean and is defined by ocean currents. It is characterised by the abundance of sargassum, a brown seaweed that floats within the area.

WHY ARE THEY ENDANGERED?

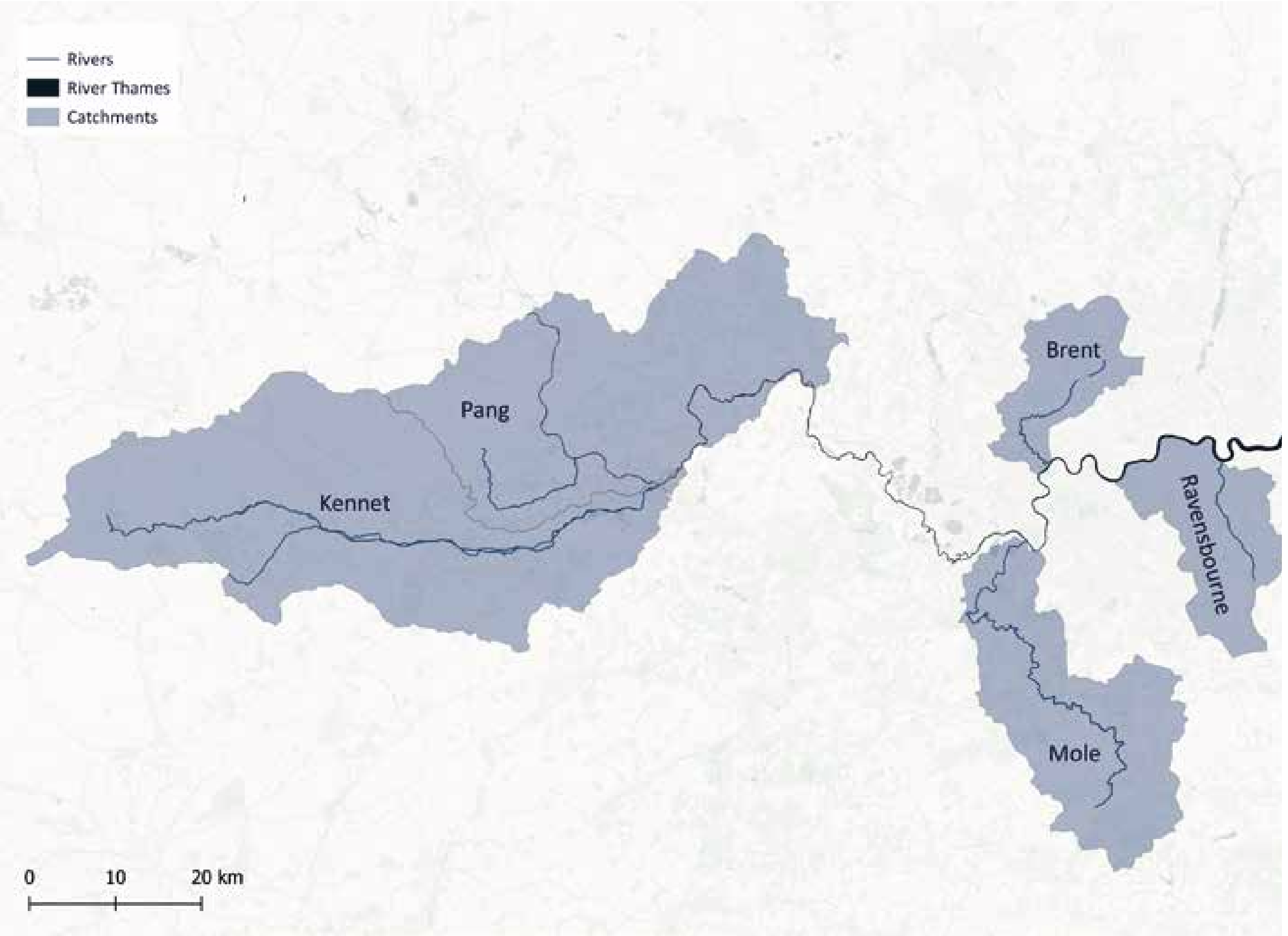
The European eel has been listed as critically endangered on the IUCN Red List[2] since 2008 due to dramatic declines in abundance recorded across all stages of its life cycle and much of its natural range. For instance, monitoring of the upstream migration shows that recruitment of young eel into the River Thames and other European rivers is only at approximately 10 per cent of what it was prior to the 1980s.

The eel's life cycle is complex, involving both freshwater and marine phases (diadromous). As such, eels are subjected to a range of threats that include the loss of habitat in freshwater due to barriers to migration, historic drainage of wetlands, pollution, hydropower developments and unsustainable fisheries. In addition, some studies have shown that oceanic and climatic variability impact the transport of larvae and recruitment of glass eels. It is likely that, in combination, these pressures are responsible for the recent alarming decline in eel populations.

OBSTACEELS: MAPPING OBSTACLES TO EEL MIGRATION

Weirs, sluices, locks and other man-made structures litter rivers; the Thames catchment has thousands which cause major problems for many fish species, including the eel. One of the key conservation objectives in fresh water for eel and other fish is to restore migratory pathways by removing redundant structures and adding fish and eel passes to those structures that cannot be removed. In order to do this, we first need to know where all the structures are and assess their impact on migrating fish. This is the purpose of ObstacEELS.

ObstacEELS was developed as a new citizen science project, piloted within the Thames Catchment Community Eels Project and initially targeting five rivers. For this project, the River Obstacles app, originally released in 2016, was updated to capture data specific to eels. Project officers from the three river trusts attended a one-day train-the-trainer workshop with ZSL to enable efficient training of volunteers. A volunteer Eel Force was then recruited and trained by the river trusts' project officers. Volunteers learnt how to use the app and how to identify and classify obstacles using ZSL's eel barrier assessment tool (EBAT), which creates a passability score. These citizen scientists were then co-ordinated by their project officer and worked in small teams to walk riverbanks and survey stretches of



▲ **Figure 4. Map of the rivers being surveyed to inform strategic evidence-based conservation planning. (© Thames Estuary Partnership)**

their local rivers, ground truthing existing datasets and logging previously unmapped barriers (see **Figure 3**).

The pilot ran until the end of September 2021 and the results will be publicly available through the Thames Estuary Partnership's Fish Migration Roadmap. The findings will inform the Thames River Basin District Eel Management Plan and contribute to the management plans of the catchment partnerships; it will also inform strategic plans for practical river improvement projects, such as weir removals, eel passes and eel monitoring.

INITIAL FINDINGS

The Thames Catchment Community Eels Project has a baseline barrier dataset consisting of barrier data from the Adaptive Management of Barriers in European Rivers (AMBER) project, Catchment Based Approach (CaBA), Environment Agency (EA) and existing data in the River Obstacles app. In addition, data from stakeholders of the relevant catchments were also gathered.

The Thames Catchment Community Eels Project has a far reach, currently running across five river catchments (see **Figure 4**). Full reports from each partner will be available in 2022, but initial findings are as follows:

The Kennet. The River Kennet is a chalk stream 72 km long and is the largest tributary to the River Thames. The Lower Kennet has been canalised in parts, meaning locks are the most significant barrier to eels. Often there are side streams around a lock where water flows.

While an eel could swim around the obstacle in the side stream, some are too steep to navigate. The Lower Kennet surveys found 63 barriers, of which 44 were not recorded in the baseline dataset. This demonstrates the value of the survey, highlighting that existing data were out of date and needed ground truthing.

The Pang. The Pang is a small chalk stream river that runs for approximately 37 km from its source near the village of Compton to its confluence with the River Thames at Pangbourne. The Action for the River Kennet-trained ObstacEELS volunteers have enjoyed access to the privately owned stretches of river for barrier surveying. So far, they have identified 14 barriers, eight of which were not in the baseline dataset. When out surveying, the historic data showed nine additional barriers which volunteers observed were no longer present. These barriers were likely removed to improve fish passage.

The Mole. The River Mole is approximately 80 km long with the final 5 km forming the Lower Mole Flood Alleviation Scheme, a complex series of large barriers many of which have eel passes in place. One of these structures, Island Barn Weir, is where volunteer citizen scientists are monitoring elver numbers migrating into the catchment. Data from this season show promising numbers of eels are present, highlighting the importance of the work to record barriers and ultimately open up more habitat to eels. Upstream of here, ObstacEELS surveys are showing that previous data seem to be incomplete, with previously unrecorded barriers submitted by volunteers.

The Brent. At its confluence with the River Thames, the River Brent has a number of large locks, given the river has been completely channelised into the Grand Union Canal. These represent significant barriers to eels and have been previously assessed with some eel passes already installed. Further upstream, surveys found that much of the existing barrier data were completely out of date. During one survey it was found that there were three new barriers in place which were not listed in any datasets and one barrier had been removed but not been updated in any records.

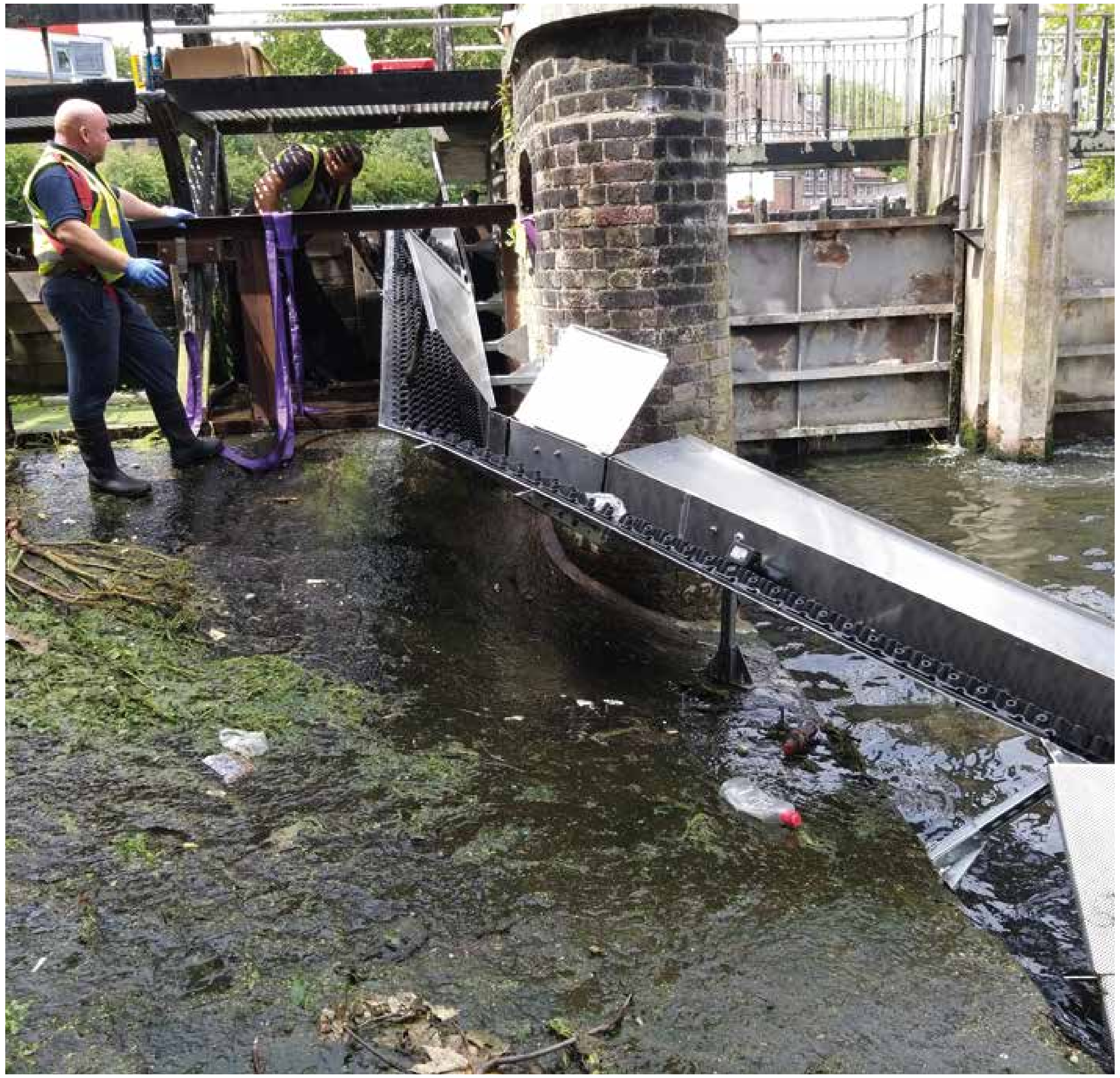
The Ravensbourne. The majority of this catchment runs through a highly urbanised area with a population of 1.25 million people. Three rivers make up the core of this catchment: the Ravensbourne, Pool and Quaggy, and each river has been highly adapted with much of the catchments encased in concrete. Weirs were by far the dominant obstacle. In the lower half of the catchment (approximately 15 km of waterways), 100 per cent of barriers were weirs, with a total of 26 in place. Eel research has been minimal in this catchment and it is an area where eel monitoring is required.

The number of barriers surveyed to date (12 October 2021) compared to the baseline dataset is illustrated in **Figure 5.**

Number of barriers surveyed as part of the project, showing how many of these are present in the project's baseline dataset

▲ **Figure 5. Graph showing data from the five rivers targeted in this project: the number of barriers surveyed, the number of barriers present in the project's baseline data and the number of new barriers, 'new' being not present in the baseline dataset. The data shown are correct as of 12 October 2021. (Source: Thames Estuary Partnership)**

CASE STUDY



▲ Figure 6. An eel pass. (© Zoological Society of London)

DATA ANALYSIS AND THE FISH MIGRATION VISION

The barrier data collected during the ObstacEELS surveys will be added to the existing Fish Migration Roadmap. The data will also be used to help the five individual catchments to develop their own catchment-specific roadmap which will include:

- Fish migratory barriers with data on fish/eel passes and EBAT;
- River connectivity data;
- River habitat data; and
- Other local data such as flood areas, development opportunity areas, land ownership etc.

The catchment-specific roadmaps will then be used to help develop a fish migration vision for each catchment. The fish migration vision is a shared long-term goal that envisions what a healthy and connected river corridor could be when there is collective action within a catchment. It relies on expert knowledge-based reprioritisation of existing barriers for the development of eel-ready proposals that will target unnecessary barriers and achieve the greatest environmental and social benefits possible. For example, a proposal involving the local council and local community may be developed to remove an impassable barrier and make a diverse habitat upstream more accessible. Activities could include educational programmes about fish and eel migration and surveying fish and eel passage (through citizen science programmes) before and after barrier removal to measure impact.

Data analysis is led by the Thames Estuary Partnership which is feeding the citizen scientists' work into an overall Fish Migration Roadmap for the River Thames.

THE FUTURE

Using the data gathered during the Thames Catchment Community Eels Project, up-to-date information on river fragmentation will be visualised and shared to target improvements on the ground. Such improvements could include:

- Eel passes (see **Figure 6**);
- Obstacle removal;
- Habitat restoration;
- Eel monitoring; and
- Increased awareness and understanding.

Community buy-in is vital to the successful delivery of environmental projects. Increasing awareness and understanding of a species, in this case the European eel, can lead to increased value of a local river to residents, as well as support within a community for practical restoration work and involvement (e.g. volunteering and contributing ideas). The principles of connecting people with nature underpin the ethos of many of the partners on this project. The project has developed a suite of resources and is delivering a series of free community engagement activities to complement the future river improvement works.

Offerings include eel classroom and riverside workshops, eel talks and community riverbank eel walks. The walks and talks are also available to groups, clubs and organisations and are open to participants of all ages.

The project partners are currently developing a partnership legacy project to expand ObstacEELS to other rivers, create new partnerships and use the new mapping data together with stakeholder engagement to carry out eel habitat improvements. ES

Anna Forbes is the Project Manager of the Thames Catchment Community Eels Project for Thames Rivers Trust. She has a background in leading river restoration projects, citizen science training and co-ordination, river education and community engagement.
info@thamesriverstrust.org.uk
@Thames_RvrsTrst

Oli Back is a Project Officer for Thames21. His work focuses on community engagement and improving urban rivers.
oli.back@thames21.org.uk
@thames21

Mia Ridler is a Project Officer for Action for the River Kennet, running the Thames Catchment Community Eels Project in the Kennet and Pang catchments, including ObstacEELS surveys.
mia@riverkennet.org
@ARKennet

Jess Mead is a Project Officer at the South East Rivers Trust. Her role focuses on community engagement and volunteering activities, including coordination of the trust's citizen science initiatives. Jess is leading the ObstacEELS surveying and elver migration monitoring on the River Mole.
jess@southeastriverstrust.org
@SE_Rivers_Trust

Wanda Bodnar is an Assistant Manager at the Thames Estuary Partnership. She develops, oversees and manages the Fish Migration Roadmap project. As part of the Thames Catchment Community Eels Project, she helps with barrier data management and visualisation.
w.bodnar@ucl.ac.uk
@ThamesEstPart

Joe Pecorelli is a ZSL Conservation Project Manager. In 2005, he helped set up the Thames Eel Conservation Project, which has continued to expand and develop. He now works on a broad suite of freshwater conservation projects with national impact.
Joe.Pecorelli@zsl.org
@ZSLMarine

REFERENCES

1. Schmidt, J. (1923) IV.—The breeding places of the eel. *Philosophical Transactions of the Royal Society of London.* Series B, Containing Papers of a Biological Character, 211 (382–390), pp. 179–208. https://royalsocietypublishing.org/doi/10.1098/rstb.1923.0004 (Accessed: 17 September 2021).
2. Pike, C., Crook, V. and Gollock, M. (2020) Anguilla anguilla. *The IUCN Red List of Threatened Species 2020:* e.T60344A152845178. https://www.iucnredlist.org/species/60344/152845178 (Accessed: 17 September 2021).

FEATURE

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How well do we understand the migratory habitats and needs of freshwater fish?

Mark Everard considers the importance of river, lake and wetland connectivity for freshwater fish migration.

Maybe the term 'migratory fish' conjures images of the weir-leaping salmon or the ocean-wandering tuna.

Amongst British and European freshwater fish species, in vernacular, but also in some other, more expert, discourse, salmonids have historically been considered migratory with most coarse fish species generally overlooked and implicitly assumed not to migrate.

Migration is defined as deliberate, temporally predictable translocation in space. On that basis – spoiler alert – virtually *all* freshwater fish migrate!

NIGHT AND DAY

Many smaller freshwater fish species exploit different habitats on a diel (24-hour) basis, adapting to changing conditions. One such example of 'small fry' (fish rarely longer than 12 cm) is the stone loach (*Barbatula barbatula*), a species of temperate rivers and lakes that tends to live under stones and woody debris by day, emerging to forage for food by night. Studies have shown that foraging activity in stone loach remains significantly higher during the night compared to twilight and daytime even when fish were experimentally starved, and all daytime foraging ceased when a predator was introduced.[1] This diurnal pattern balances feeding requirements with predation risk, especially important for small benthic (bottom-dwelling) species with low swimming speeds and therefore low potential to escape faster-moving predators.

Different diurnal habitat use is also observed in larger and more agile coarse fish species. One example is the dace (*Leuciscus leuciscus*), a shoaling, rheophilic, lithophilic cyprinid fish of moderate size (rarely longer than 30 cm). Radio-telemetry studies of dace recorded diel movements between different, clearly defined daytime and night-time habitats in the summer, with individual dace returning, predictably, to previously occupied locations at dawn and dusk, suggesting differential habitat suitability related to light intensity similar in some respects to roosting behaviour in birds.[2] Pike (*Esox lucius*), the principal fish predators of dace, are also known from tracking experiments to migrate on a predictable cycle making use of different habitats by day and night.

SEASONAL MIGRATIONS

It has been widely and long known that many riverine benthic invertebrates with aerial adult life stages undertake upstream flights on emergence, prior to breeding, partially compensating for the downstream drift of eggs and larvae.[3]

It should not then be surprising to learn that many coarse fish species also undertake upstream migrations prior to spawning. This may also be to access suitable spawning habitat, such as gravels and vegetation flushed by stronger flows that may be less favourable for the needs of these species during the rest of the year. Studies of freshwater fish species from a range of families – including roach (*Rutilus rutilus*), perch (*Perca fluviatilis*) and pike – found varying degrees of upstream spawning migrations in rivers or in more favourable locations in lakes, ranging from tens of metres to several kilometres or in some cases hundreds of kilometres. Access to better-oxygenated waters that may tend to warm faster than deeper reaches downstream can enable earlier spawning and shorten the hatching time of eggs, resulting in higher survival of resultant juveniles compared to those of fish that spawn lower down in catchments.

Seasonal migrations relate not only to spawning but also to predator evasion. An extensive field telemetry study found that tagged roach commonly migrate from lakes to streams during winter, and that this confers a significant survival benefit from predation by piscivorous birds, specifically cormorants (*Phalacrocorax carbo* spp.), based on recovery of transponder tags found at communal cormorant roosts derived from the fish that these birds had consumed.[4] In this study, roach were found to significantly reduce predation risk from cormorants by migrating into streams; the probability that they were preyed upon by cormorants was positively related to the time individuals spent in the lake during winter.

Fish species such as dace and roach are also known to move downstream in autumn and winter, forming aggregations in deeper and slower reaches, even into tidal sections, apparently to evade strong spate flows and to conserve energy in maintaining station in the river.

LATERAL MIGRATION

The rivers of Britain and lowland Europe, as indeed much of the world, are very far from natural. The lowland rivers in which many fish species evolved would not only naturally meander within wider corridors but, in the absence of widespread human channel reinforcement and floodplain drainage, would evolve as braided systems. As trees fall obstructing existing channels, perhaps through the actions of Eurasian beavers *(Castor fiber)*, diverted water would form new channels also sweeping clear floodplain landscapes kept open for some time by the grazing activity of aurochs and other herbivores, though subject to successional processes. Over time, braids would form, reticulating the river corridor with channels of varied flow regimes and creating diverse wetland types. Whilst this type of dynamic, wild landscape may not be fully attainable as a conservation goal in today's highly populated and exploited world, it does nonetheless reflect the needs of fish and other organisms that evolved in landscapes with those characteristics.

A key feature of such a natural historic landscape is connectivity of diverse habitats, including different flow regimes across and between braided channels but critically also laterally to wetlands of various types upon which, in particular, the spawning needs of many species and their juvenile life stages most depend. Yet lateral connectivity not only to rich channel edge habitats but with linked floodplain wetland systems is a rarity in our much drained, farmed, built and otherwise encroached-on floodplains. Many things can be done to soften river edges and floodplains, informed by the spawning, nursery, feeding and refuge needs of fish. Such changes would also yield wider societal benefits such as enhanced flood and drought buffering, water purification, nutrient and carbon cycling, aesthetic enhancement, and habitat provision for many types of wildlife.[5]

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The ultimate canary in the coalmine of the loss of lateral connectivity is the burbot (*Lota lota*), once native to eastern-flowing rivers in England from the Skerne and Esk in the north, down to smaller Norfolk and Suffolk rivers in the south but extinct since around 1970 (the last verified specimen was captured in 1969). A curious fish, the burbot is the only freshwater member of the Gadiformes (the order of cod-like species of fish), spawning in the cold water of winter. A lazy assumption is that climate change is to blame for its demise, but this is to ignore the ecology of the genetic strain of small lowland European river burbot. The closest genetic match to the extinct British population are the extant burbot populations in western European rivers. Although burbot are widely distributed across cool freshwaters of the northern hemisphere from Alaska, Canada and some northern states of the USA, across Northern Europe and Northern Asia, many of these fish are of larger genetic strains inhabiting still waters and spawning under ice.

The western European strain of burbot is not only smaller but largely riverine and occurs where ice lakes are absent, inhabiting lower river reaches as well as upstream trout-type habitat. This smaller riverine western European genetic strain of burbot consequently spawns in inundated floodplains in midwinter, sometimes migrating up to hundreds of kilometres upstream and then laterally into floodplain wetlands. Typical of other cod-like species, burbot release a very high abundance of tiny non-sticky eggs – large females can release up to 3.5 million eggs – that then settle in the near-static waters of riparian wetlands.

The hatching larvae enter the plankton to grow before metamorphosing into juveniles that embark on a benthic lifestyle that continues into their adult life. To complete their life cycle, riverine burbot need suitable floodplain wetlands that are inundated for at least two months in the winter. It is exactly this landscape that has been virtually expunged from lowland Britain and much of lowland Europe, starting from Roman times but completed under aggressive land drainage programmes driven by the overriding food security policy priority following the Second World War.

Fenland, formerly a landscape of around 1,500 square miles that was neither fully wet nor fully dry, now contains just a few hundred hectares of remnant fen. It is no coincidence that burbot also went into precipitous decline in these rivers after long-term decreases in numbers that were also far from coincidentally proportionate with previous land drainage. It is also no coincidence that salmon and sea trout were also lost from these rivers during the same period, although, of course, salmonids, unlike burbot, are able to repopulate from their sea-going phases. The 1950s to 1970s was a cool cycle in the climate, further undermining the oft-repeated assumption that climate change was the major culprit.


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River habitat restoration has played a key part in the successful reintroduction or recovery of the western European strain of burbot in Belgium, Germany and the Netherlands, at latitudes far further south than the eastern English rivers from which they were lost. There are almost no rivers left in lowland Britain in which floodplain habitats are diverse, connected and inundated for at least two months in winter, though one site is being investigated for a potential British reintroduction. (For more on the ecology and conservation of burbot, see Everard.[6])

In addition to physical survival, habitat loss and fragmentation can have severe impacts on the genetic diversity and, consequently, future population trajectories of freshwater fish.[7]

RIVER CONNECTIVITY FOR FISH AND PEOPLE

There are costs to fish undertaking migratory behaviours, including energy expenditure in locomotion, reduced foraging opportunities and increased predation risk. Consequently, there must be evolutionary advantages. Based on spatiotemporal variations in their abundance and distribution, the 2008 book *Migration of Freshwater Fishes*[8] challenged previously held assumptions that many freshwater fish species do not move between habitats. In fact, virtually all freshwater fish species regularly move on seasonal or other bases for spawning, feeding and refuge, in many cases in ways that are fundamental for the successful completion of life cycles.

River connectivity matters for all species of fish for their daily, seasonal, feeding, spawning, nursery, refuge and other needs. This includes both longitudinal connectivity (up and down rivers) as well as laterally (across channels and across the floodplain into connected wetlands). Whilst the EU Water Framework Directive is driving thinking about improving longitudinal connectivity – bypassing or removing weirs and other impoundments that often serve no important purpose – lateral connectivity remains a regulatory blind spot. Yet, functional floodplains not only host wide biodiversity, including helping support natural regeneration and diversification of fish populations by catering for the temporally variable needs of their various life stages, but also provide a great richness of wider ecosystem services.[9] In that sense, catering for the migratory needs of fish is far from an altruistic measure; it is responding to an indicator of wider catchment functioning and the wealth of societal benefits that this provides.

We need to know more about the migratory habits and habitat needs of all species of fish. Most investment to date has been targeted at commercially important species, particularly trout and salmon[10] although there are also some studies of eels, shad and other recognised migratory fish. But, above all, we need to account for all fish in the ways we manage, regulate and incentivise rivers and landscapes as bioindicators of the viability of catchment functioning and the multiple benefits that this confers as a key building block of sustainable development. ES

Dr Mark Everard is an ecosystems consultant and an Associate Professor of Ecosystem Services at the University of the West of England (UWE Bristol). He has a background in freshwater ecosystems and has been a champion of the development of ecosystems thinking and its application for over 40 years across academic, policy-development, NGO and business environments in both the developed and the developing world. Mark is also a Vice-President of the IES and a prolific author and broadcaster.
mark.everard@uwe.ac.uk; mark@pundamilia.co.uk

REFERENCES

1. Fischer, P. (2003) Nocturnal foraging in the stone loach (*Barbatula barbatula*): Fixed or environmentally mediated behavior? *Journal of Freshwater Ecology*, 19 (1), pp. 77–85. https://doi.org/10.1080/02705060.2004.9664515 (Accessed: 16 September 2021).
2. Clough, S. and Ladle, M. (2005) Diel migration and site fidelity in a stream-dwelling cyprinid, Leuciscus leuciscus. *Journal of Fish Biology*, 50 (5), pp. 1117–1119. https://doi.org/10.1111/j.1095-8649.1997.tb01635.x (Accessed: 16 September 2021).
3. Elliott, J.M. (1970) Upstream movements of benthic invertebrates in a Lake District stream. *Journal of Animal Ecology*, 40 (1), pp. 235–252. https://doi.org/10.2307/3339 (Accessed: 16 September 2021).
4. Skov, C., Chapman, B.B., Baktoft, H., Brodersen, J., Brönmark, C., Hansson, L-A., Hulthén, K. and Anders Nilsson, P. (2013) Migration confers survival benefits against avian predators for partially migratory freshwater fish. *Biology Letters*, 9 (2), pp. 1–4. https://doi.org/10.1098/rsbl.2012.1178 (Accessed: 16 September 2021).
5. Everard, M. (2015) *River Habitats for Coarse Fish: How Fish Use Rivers and How We Can Help Them*. Sheffield: Old Pond Publishing.
6. Everard, M. (2021) *Burbot: Conserving the Enigmatic Freshwater Codfish*. 5M Books.
7. Pavlova, A., Beheregaray, L.B., Coleman, R., Gilligan, D., Harrisson, K.A., Ingram, B.A., Kearns, J., Lamb, A.M., Lintermans, M., Lyon, J., Nguyen, T.T.T., Sasaki, M., Tonkin, Z., Yen, J.D.L. and Sunnucks. P. (2017) Severe consequences of habitat fragmentation on genetic diversity of an endangered Australian freshwater fish: A call for assisted gene flow. *Evolutionary Applications*, 10 (6), pp. 531–550. https://doi.org/10.1111/eva.12484 (Accessed: 16 September 2021).
8. Lucas, M. and Baras, E. (2008) *Migration of Freshwater Fishes*. John Wiley & Sons.
9. Rothero, E., Lake, S. and Gowing, D. (eds) (2016) *Floodplain Meadows – Beauty and Utility. A Technical Handbook*. Milton Keynes, Floodplain Meadows Partnership.
10. Brönmark, C., Skov, C., Brodersen, J., Anders Nilsson, P. and Hansson, L-A. (2008) Seasonal migration determined by a trade-off between predator avoidance and growth. *PLoS One*, 3 (4), e1957. https://doi.org/10.1371/journal.pone.0001957 (Accessed: 16 September 2021).

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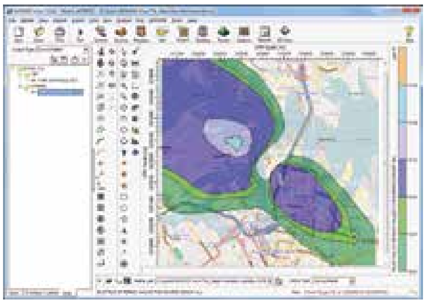

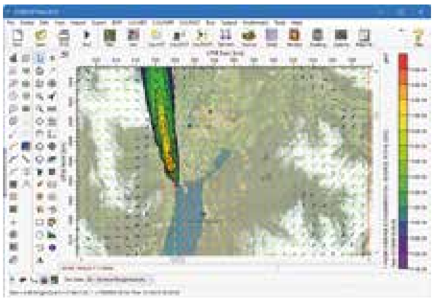

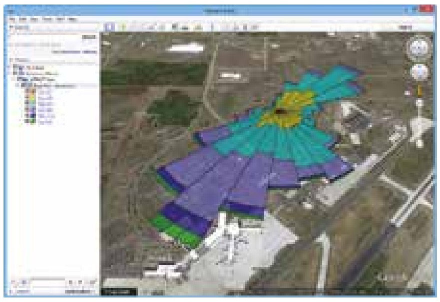

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