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Research Article

Flyways Beyond Migratory Pathways: The Case of Waterbird Conservation

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Abstract

For almost a century, the term 'flyways' has been used to order relations over time and space. It has been used to coordinate scientific research and communication as well as monitoring and management efforts for waterbird conservation. In this article, we revisit the concept of 'boundary object' (Star and Griesemer 1989) to investigate how this term 'flyways' has been central to common efforts while also having multiple meanings for the actors it connects. The article discusses both contemporary and historical achievements of the term by analysing its underlying knowledge infrastructure. We account for the complex assemblages of social, material, natural, and technical systems that shape how the term 'flyway' has been functioning as a boundary object and how this has changed over time. By discussing how the term 'flyways' as a boundary object and its underlying knowledge infrastructure shape each other, we empower the actors to define, visualise, communicate, and imagine flyways in more purposeful ways. Our analysis contributes to the literature on boundary objects and knowledge infrastructures by expanding their original definitions, arguing for a co-productive relation between them.

Keywords: Boundary object, knowledge infrastructure, conservation, flyways, definition, transdisciplinary collaboration

INTRODUCTION

Migratory birds, like many other species, are affected by human intrusions. Intensive agricultural systems and the overuse of natural resources are considered to be the most insidious threats to bird species that seasonally move between breeding and non-breeding grounds (UNEP/CMS 2012: 18). Many types of actions aiming to end or minimise the suffering of migratory birds—ranging from formalised international conventions to more direct conservation projects in the field—have been coordinated around the term 'flyways'. The term was initially put forward to define the pathways that migratory birds take during their seasonal migration (Lincoln 1935). Most recently, a widely cited definition of a flyway is "the totality of the ecological systems that are necessary to enable a migratory waterbird to survive and fulfil its annual cycle" (Boere and Stroud 2006: 45). The changing meanings of flyways is the impetus for this article.

A decline in the number of migratory birds does not just mean the loss of some bird species. It indicates that the ecological systems they encounter during their life cycle have deteriorated to such an extent that they can no longer support these species (Bauer and Hoye 2014). The suffering of migratory birds is thus a sign of the state of ecological systems on which other species, including humans, depend and will eventually be affected. Efforts to know about flyways, or to what extent ecological systems support migratory waterbirds, are the backbone of important achievements for

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the conservation of resources that are as valuable to migratory birds in the short term as they are to humans in the long term. Such achievements include hunting regulations, nature reserves, and agri-environmental schemes compensating farmers for measures that conserve species breeding or feeding on their lands. In other words, knowing about the conditions of the flyways of migratory birds is a prerequisite for effective interventions to minimise damaging impacts not only on birds but on ecological systems as a whole.

As noted above, 'flyways' currently has a widely accepted definition. But its use on the ground varies over time and across actors. While the lack of a precise definition leads to frustration for some actors and concerns about vagueness, the term has facilitated collaboration not only between different contemporary actors holding different understandings but also between different sets of actors who have changed over time. In this article, we investigate how the term has aligned various worlds and facilitated collaboration over the past century. We examine how the term is used to order relations over space and time and how different knowledge infrastructures support flyways to coordinate scientific research and communication, monitoring efforts, and management (political and administrative) for waterbird conservation purposes. We focus on waterbird flyways rather than, for example, migratory raptors, land-birds or seabirds because waterbird flyway work has tended to be at the forefront of flyway science and conservation.

The primary contemporary actors involved in coordinating actions to improve the conditions of migratory birds by engaging with the term 'flyways', include 1) scientists collecting data to produce and communicate scientific knowledge about flyways; 2) conservation practitioners contributing to long-term monitoring and conservation projects at various scales; and 3) various governmental and nongovernmental administrative and policy actors involved in setting up and implementing international conservation agreements as well as providing support to both the scientists and practitioners.

To study this transdisciplinary collaboration, we revisit the concept of "boundary object" (Star and Griesemer 1989), coined to make sense of collaborations achieved in spite of the lack of a single, uniform understanding of terms used. Star (2010), however, reminds her readers on multiple occasions what makes something a boundary object is not only the fact that it can afford multiple meanings for different social worlds but also that it actually enables actors from different worlds to achieve common goals.

In this article, we first argue how flyways is currently used to order research, monitoring and management efforts, not despite, but thanks to the presence of multiple definitions. This multiplicity is what allows the actors to recontextualise an abstract, decontextualised and thus standardised term for their own purposes. Accordingly, it prevents the actors from feeling a disconnection between their contextual experiences of the phenomenon (waterbird migration dynamics) and what the standardised term of flyways loosely represents (ecological systems supporting waterbirds).

After demonstrating the contemporary context-specific definitions that an abstract term with fuzzy boundaries allows at a single point in time, we move to a historical analysis. In this second part, we discuss how a standardised definition of flyways that allows different sets of actors to achieve common goals can evolve over time. We provide evidence for this point by documenting the knowledge infrastructures and their changing socio-technical, material, and ecological dynamics that enable the term to achieve its changing common functions. This analysis demonstrates how, following the definition of boundary objects, these processes of abstraction and decontextualisation of a phenomenon into standard terms are essential if actors of transdisciplinary collaborations with different prioritisations are to work together towards a common goal.

With such a twofold analysis, we first aim to draw attention to the value of dynamic boundaries of abstract terms like flyways for transdisciplinary collaborations. Second, by making explicit that flyways have already been made, unmade, and remade over time, we show actors that boundary objects can be a resource to intervene more purposefully in the way flyways function—both their contextualised and decontextualised definitions. This means seeing the multiplicity of flyways not as a frustrating lack of precision nor as an invitation to normative fixations but rather as a resource that can help enact better futures for migratory birds and other species and habitats that are entangled with them. In the final part of the article, we consider how actors might be supported by concrete suggestions on the potential of this approach to help actors shape flyways more purposefully.

BOUNDARY OBJECTS AND KNOWLEDGE INFRASTRUCTURES

The concept of boundary objects (Star and Griesemer 1989) was developed to make sense of the cooperation mechanisms of scientific knowledge production and exchange systems in the absence of consensus. Based on their ethnographic and historical data, Star and Griesemer (1989: 393) showed that effective collaborations in the absence of consensus tend to be built around boundary objects because such objects are "plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites".

As Star (2010) later insisted, along with interpretive flexibility, the functioning of boundary objects depends on two other conditions: 1) material and organisational structures underlying boundary objects, enabling them to satisfy the information and work requirements of the actors and 2) the possibility of boundary objects to oscillate between their ill-defined and context-tailored meanings or their general and specific versions. In other words, "not all ambiguous [ill-defined] objects are boundary objects" (Lainer-Vos 2013: 516). That ambiguity has to have a function and alternate with clearer, more precise meanings and context-tailored versions.

The concept of boundary objects travelled across disciplines such as policy and innovation studies, management, educational science, and design, as mapped out in several reviews (Oswick and Robertson 2009; Trompette and Vinck 2009). Ecology was the primary case for the development of the concept in the course of the study of collection practices for a natural history museum (see Star and Griesemer 1989). But only recently, ecologists and conservation scientists have also embraced boundary objects to analyse the coherence and coordination mechanisms among scientists, conservation practitioners, administrators and the public for issues related to sustainability and biodiversity (Brand and Jax 2007; Goldman 2009; Garmendia et al. 2016; Hoogstra-Klein et al. 2017; Amundsen and Hermansen 2020).

Across this work, terms like ecosystem services, green transformation, green infrastructure, and multi-use forestry were analysed as boundary objects. However, in these analyses, the efforts are concentrated mostly on showing how these terms can have different meanings for different actors. Some analyses (Brand and Jax 2007; Garmendia et al. 2016; Amundsen and Hermansen 2020) even explicitly question whether boundary objects can ever fulfil the promise of facilitating a collaboration without consensus. The argument is that while boundary objects help keep the debate on the agenda by affording multiple meanings, they seem to put at risk the conceptual clarity and precision in the debate or water down its aims. Accordingly, in these analyses much less attention is paid to the ill-defined but common meanings of those terms and their relations to the context-tailored meanings. In the first part of the analysis (Section: Contemporary Achievements of Flyways as a Boundary Object), we focus on how the decontextualised, loosely defined abstract term of flyways has allowed different actors to recontextualise and define it in their specific contexts to achieve their own goals while at the same time maintaining a common standardised identity so that actors can still work together to achieve common goals. In other words, the first part argues that the term flyways functions as a boundary object.

In the second part of the analysis, we examine, in turn, what underlies the term flyways, enabling it to achieve its functions. We examine this question because once the underlying dynamics of flyways are made visible, the actors using the term can more purposefully give shape to its context-tailored and ill-defined versions. To examine this question, instead of focusing merely on the material and organisational structures, or information infrastructures (IIs), as the term originally suggests, we broaden our scope of analysis to knowledge infrastructures (KIs). KIs are initially defined as "networks of people, artefacts, and institutions that generate, share and maintain specific knowledge about the human and natural world" (Edwards 2010: 17), and further fuelled scholarship (Beaulieu and Estalella 2012; Borgman et al. 2020; Beaulieu 2022). Unlike IIs that refer to infrastructures supporting data creation and ordering processes, KIs "accounts for the presence of political considerations, values and other invisibles that work to allow the exchange and proliferation of knowledge" (Slota and Bowker 2017: 539). By broadening our scope of analysis to KIs, we draw attention to complex assemblages of material, organisational, social and technical dynamics supporting the whole knowledge production cycle, encompassing not only the processes of data creation and ordering, but also problem-framing, agenda setting and knowledge exchange. In the second part, we then argue that KIs support boundary objects to oscillate between context-specific and ill-defined but common meanings. By unpacking the KIs that support boundary objects, we more comprehensively show the dynamics shaping the boundary objects, which is an insight that can potentially help actors intervene more precisely in the shaping of boundary objects when needed.

METHOD

In this article, we draw on complementary empirical sources: professional experience and document analysis. While not used extensively, the insights of ethnographic fieldwork pursued by the first two authors during the writing of this article as part of a multi-year collaboration with a group of bird ecologists (see Eren & Beaulieu 2023) further supported the analysis. In addition, Piersma and Crockford have decades-long first-hand experience with various scientific research and conservation projects on migratory waterbirds. This experience laid the groundwork for understanding collaborations and the periodisation of the historical analysis of the KIs supporting and shaping flyways.

To select material, we focused on the documents and websites where the term flyways is explicitly used in relation to migratory waterbirds. The documents we analysed include books on the history of American and British ornithology, glossy highly illustrated books on bird migration, reports and websites of international agreements on migratory species, and non-governmental conservation organisations (for instance, Wetlands International and BirdLife International), as well as opinion pieces, journal articles and Twitter accounts of ecologists.

CONTEMPORARY ACHIEVEMENTS OF FLYWAYS AS A BOUNDARY OBJECT

The term 'flyways' has one widely-cited definition, at least since the early twenty-first century: "the totality of the ecological systems that are necessary to enable a migratory waterbird to survive and fulfil its annual cycle" (Boere and Stroud 2006: 45). This definition allows 'flyways' to remain an ill-defined or imprecise term, in contrast to its specific versions discussed later. Such imprecision is neither accidental nor the result of insufficient rigour, but it is essential for flyways to function as a boundary object. Such imprecision allows actors to tailor the term to specific contexts as needed while maintaining a common meaning. Therefore, there are multiple versions of flyways at different scales, according to the needs of the actors (UNEP/CMS 2014: 59), and multiple visual representations for different contexts. Below, we first discuss three context-tailored versions of flyways as 1) chains of ecosystems; 2) individual trajectories; and 3) chains of administrative units. In the final section, we briefly discuss how the context-tailored versions and their achievements culminate in what the ill-defined but shared version of flyways aims to achieve: protecting the systems that enable waterbirds and human societies to cohabit. In this way, flyways function as a boundary object oscillating between context-tailored and ill-defined versions, and in so doing, bridging different social worlds with different priorities.

In the definition of flyways, at least two ill-defined parts can be identified and organised at different scales, depending on aims and context: ecological systems and migratory waterbirds. The phrase ‘ecological systems’ is ill-defined in at least two ways: first, in terms of boundaries, there is no single authoritative map showing the definitive boundaries of the relevant flyways. This can be exemplified by the approximate and overlapping boundaries of the eight broad flyways visible in Figure 1. Also, depending on the number of individuals they represent, flyways can become either a single trajectory with much narrower boundaries or a chain of areas with wider boundaries. Second, in terms of their geographical extent, flyways can cover different ecosystems like mudflats, agricultural lands, tundra, or administrative units at different scales, like nation-states or sub-national regions. The phrase ‘migratory waterbirds’ is also ill-defined in at least two ways: first, in terms of the scale to which it refers, a flyway can be represented at an individual, population, and species scale. Second, in terms of the species to which it refers, a flyway can represent the entire range of a single migratory waterbird species or a combined range of different species (see Boere and Dodman 2010: 56).

The combination of these different ways of defining ecological systems and migratory birds, therefore, yields a variety of context-tailored meanings of the term flyways. Depending on the context of use, flyways become either more biological or political/administrative phenomena and stress different scales at which birds can be studied or protected. As such, flyways as a boundary object provide a shared way of being relevant to different kinds of actors with different kinds of concerns.

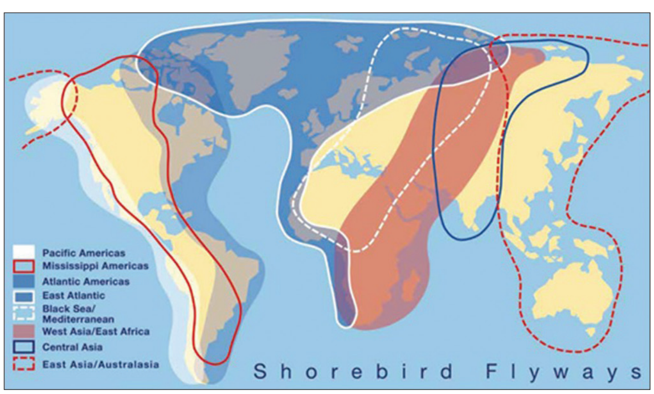

Figure 1
Major flyways of migratory land and waterbirds. Reproduced from Boere and Stroud (2006) with the permission of David Stroud

Flyways as Chains of Ecosystems Enabling Scientific Research and Development

Scientists tailor the term flyways as different chains of ecosystems at various scales to advance their scientific understanding of the species that use such flyways. For instance, ecologists very recently realised that the Pacific Ocean is actually an “ecological corridor rather than a barrier” (Gill et al. 2009). While Ancient Polynesians already knew about this flyway, the knowledge is now supported by the types of evidence that scientific knowledge prescribes. This means that the geographical characteristics of this overlooked flyway over the Pacific Ocean now trigger new research questions on that flyway: “How do birds manage many days of nonstop exercise apparently without sleep? (…) How do such extreme migrations evolve? (Piersma et al. 2022: 1).

Furthermore, not only how flyways are conceptualised and delineated but also how they are depicted and visualised equips scientists to advance their research. With the advent of tracking devices, satellite imagery, and online databases, certain flyways can be visualised digitally on maps based on location data points collected from various tracking devices. The visual representation of flyways in the research context—initially constructed based on the re-sighting of unique ring combinations placed on birds’ legs—is currently being re-constructed digitally based on location data points.

Overlaying such digital visual representations of flyways at the population or species level with other datasets on the same map can provide new perspectives and insights into birds and their migration conditions (see globalflywaynetwork.org). For instance, if data regarding various pollution level on land or areas designated for renewable energy infrastructures can be overlaid with distributions of birds on their flyways, researchers and policymakers can gain new insights on the relation between migration strategies and pollution conditions as well as potential impacts of energy infrastructures on birds (see avistep.birdlife.org). Efforts are also ongoing in a number lines of research to add climate variable layers to such mapping efforts. Therefore, flyways as visualised chains of ecosystems can enable researchers to ask new questions and develop new hypotheses and/or indicators to evaluate conservation solutions.

Despite what it enables scientists and policymakers to achieve, this context-tailored version of flyways also has limitations. As we further discuss in the next section, not all species’ journeys and their context can be equally well depicted digitally due to the anatomy and behaviour of certain species and the limitations of datasets on relevant socio-environmental conditions.

Flyways as Individual Trajectories Supporting Science and Conservation Communication

Where scientists, conservation practitioners, and field assistants who collect data on birds in the field meet citizens, we see these actors tailoring the meaning of flyways to achieve another specific purpose: science and conservation communication. In this context, flyways are often represented at the individual scale rather than the species scale used in the research context. The trajectory of a single bird is visualised and used as a storytelling tool by scientists, field assistants, and practitioners to communicate science and conservation needs to interested citizens. Given the urgency in tackling sustainability-related problems dependent on transdisciplinary collaborations, such storytelling is a growing strategy.

For instance, on Twitter, many bird ecologists and practitioners use individual trajectories to narrate birds' individual seasonal journeys. Depending on the project birds are a part of, individuals are given actual names (Amelia) or a combination of numbers and letters referring to bands (B2BRLY). This helps scientists and practitioners refer to specific individuals while narrating their journeys. The actors mainly aim to attract broader attention to the problems birds face during their journeys due to the climate crisis or other human-induced activities like intensified agriculture, construction, and recreational activities. To allude to the potential impact of a specific ecosystem on the journey, they use captions such as: '(...) Has she accumulated enough fuel at #WaddenSea [to continue her migration]?' (Tweet GlobalFlyway, August 2, 2020). Through stories of achievement and suffering along a migratory path, visualised flyways as individualised trajectories are used to mobilise citizens and policymakers for conservation actions.

Another example can be found in the communication between local actors and the field assistants/researchers collecting data in the field. For some research projects, local actors such as farmers and land management organisations are essential to provide access to the fields where birds nest. In addition, these local actors are often important sources of observations and data. Having relations of trust with these actors can be a crucial factor in creating the highest quality data and, ultimately, in management interventions that benefit the birds. For instance, one of the field assistants once shared with the first author during the ethnographic encounter as part of her multi-year collaboration with a group of bird ecologists that she was regularly updating the farmer she was in contact with about 'his bird's journey back to The Netherlands'—referring to the fact that the bird was captured and ringed on his land while breeding there, and will probably return there to breed again (A field assistant pers. comm. Spring 2021). Using flyways in this form can be instrumental in developing attachment of the farmers to the birds who nest in their fields, and in the demonstration that birds can be attached to specific fields.

By sharing the migration stories of specific individuals, researchers get local actors familiarised with their habitual but overlooked 'neighbours', and get them interested in collaboration. Such relations are expected to achieve broader and stronger collaborations between scientists, conservationists, and the societal actors, that are needed for better data, more accurate scientific outcomes, and more relevant and supported conservation policies and interventions.

Flyways as Chains of Administrative Units Re-ordering Borders

Migratory birds defy human-made borders of nation-states, regions, and even continents. For this reason, it is pivotal for the conservation of endangered migratory species that research collaborations, monitoring projects, and management efforts are organised internationally along migratory routes. We then see conservation practitioners as well as administrative and policy actors tailoring the meaning of flyways for their purpose as chains of administrative units at different scales. In this context, flyways bind together disconnected units by re-ordering conventional national borders (see Figure 2).

This context-tailored version shapes the kinds of knowledge produced and the kinds of data required. In order to know about the population size and status of a migratory species, it is not sufficient to have a snapshot of its conditions in only a specific territory along the migration route. For instance, such snapshots are not sufficient for adaptive harvest management. Regulation of harvest by just one country of the flyway in isolation, based only on national data, is considered unlikely to yield robust results. It is impossible to ensure the 'sustainable use' of migratory bird populations unless the full range of population parameters along the flyway is understood. Equally, in order for conservation policies to work effectively for a migratory population, it is not sufficient that only the countries in the breeding areas care for and invest in improving the conditions of their land. If a population suffers low levels of food sources in their stop-over areas, those individuals are unable to fuel their migration, even if they have ideal conditions both in breeding and 'wintering' areas.

Because of the need to consider what is going on across regions and countries, in the second part of the twentieth century flyways are constructed as global objects that need to be measured and known at global scale. This is how they began to bind actors scattered across multiple institutions and nation-states together through transnational research consortia, monitoring projects, and conservation initiatives, as well as through international agreements with different convening and enforcement powers.

For instance, the International Waterbird Census (IWC) is an achievement of scientists, conservation practitioners and volunteer birdwatchers enacting flyways as chains of administrative units that re-order the borders of disconnected institutions and nation-states, to monitor waterbirds' population size together since 1967. In the 1970s, data collected by IWC along flyways fed into the discussions leading to international conventions that bind various nation-states and align their conservation management efforts, such as the Ramsar and Bonn Conventions (Boere 2003). Re-ordered borders for monitoring projects through flyways, then determined geographical sites of ecological and biodiversity significance, supported research and monitoring efforts, and provided the rationale behind the international management efforts for waterbirds. Although flyways "challenge our all-too-humancentric conceptions of space, borders, and movement" (Barry and Suliman 2022: 1), it is also important to consider that there is a constant tension between these re-ordered borders through flyways and political borders driven by development projects of nation-states and nationalism.

Flyways as Boundary Object to Achieve Common Goals

Having discussed three context-tailored meanings and versions of flyways for the purposes of different actors, we end this section by briefly discussing how these actors can still achieve a common goal through the ill-defined, standard but shared meaning of flyways: improving 'ecological systems' of 'migratory waterbirds'.

To illustrate this dynamic, we focus on the Tagus estuary, Portugal's most important wetland for migratory waders (Nightingale et al. 2023). The area is currently under threat, with plans for a new commercial airport. After permission for the airport was given, mainly on the basis of national considerations for Portugal's economic development, a flyway approach helped demonstrate to the Portuguese government that this airport would affect bird populations shared with more than 30 other countries and more than 300 protected areas. Thus, scientific research and monitoring activities underpinned by this flyway approach have enabled researchers and practitioners to produce evidence discrediting the favourable Environmental Impact Statement issued by the Portuguese government (Verhoeven 2021). Meanwhile, on Twitter, local researchers have been narrating the stories of (individual) waders that use the estuary to fuel their northward migrations, particularly highlighting what would happen to them if this habitat on their migration route in the East Atlantic Flyway (EAF) could not support them anymore. The construction plans for the airport triggered conservation organisations in the Netherlands to draw up a petition against the plan and spurred a letter-writing campaign by conservation organisations along the EAF (SPEA 2020). Meanwhile, a national lawsuit has been filed to stop the proposed airport through the compliance mechanisms of relevant intergovernmental agreements initiated by concerned conservation organisations united along the EAF.

We see 'flyways' at work as a boundary object. The specific meanings include the chain of habitats giving the rationale behind research and monitoring efforts that are used to show the importance of the estuary in the chain; the individual trajectories used to narrate birds' suffering from a potential airport and to make this suffering relatable to wider audiences, and the chain of administrative units that shares the same birds across countries. These different meanings that fall under flyways are channelled into one common aim of conserving multiple waterbird species migrating along the East Atlantic Flyway. They enabled the creation of data, attention, and administrative rationale for international action while re-ordering research, monitoring, and management efforts along the chain.

HISTORICAL CHANGES IN INFRASTRUCTURES AND FLYWAYS

The term 'flyways' has enabled collaboration as a boundary object between contemporary actors and changing sets of actors with different priorities over a century. Having considered contemporary collaboration around flyways, we now turn to the KIs that have underpinned (what is known about) flyways since the term was first coined. More specifically, we discuss how the ill-defined, standardised meaning of the term flyways and its commonly shared functions have evolved and how KIs have shaped such meanings by supporting certain relations and functions over time.

Flyways Coined to Manage Harvestable Species

The roots of the first standardised definition coined in the 1930s can be traced back to the late nineteenth century. At this time, North American scientific ornithologists were collecting as many dead specimens as possible to analyse, measure, describe and classify (Barrow 2000). To investigate the migration routes and the distribution of species, the technique called banding became prominent in the 1920s among ornithologists based at the Bureau of Biological Survey in the US (Benson 2017). Early banders marked birds in the hope that someone would eventually find and report the band when the bird died, for example, by being hunted (Hawkins et al. 1984; Barrow 2000). Ornithologists then closely collaborated with hunters and natural history specimen dealers to collect banded birds. Later, to increase the probability of receiving such reports, some banders marked birds with coloured bands so that they could be recognised from afar, without waiting for them to die, be killed or recaptured. The increasing numbers of hobbyist birdwatchers, the advent of field identification guides, and field glasses further facilitated the collection of data through sightings of coloured bands (Barrow 2000; Benson 2017).

However, until the first decades of the twentieth century, ornithologists rejected such field reports on the presence/absence of a species not backed by the collected specimen, as they were mere observations and not "tangible" enough (Barrow 2000: 173). The professionalisation of the scientific discipline of ornithology partly explains the ornithologists' strong preference for collecting dead specimens over field observations as their data source. In the late nineteenth and early twentieth centuries, museums like the American Museum of Natural History provided a living for most of the ornithologists, while expecting them to return from their expeditions with specimens to enrich the collections and exhibit halls (Barrow 2000: 172-173). Colonial, extractivist relations to nature drove these practices.

Another reason behind the preference for collected specimens was the accuracy problems in the sighting records. For a community that "firmly believed in shooting first and answering questions later", sight identification of species was considered to be subject to "countless vagaries and a great deal of individual interpretation" (Barrow 2000: 175).

Although some criteria were established over time to ensure the quality of observations, not every birdwatcher was interested in upholding such scientifically relevant criteria. Some, and according to Barrow (2000), even the majority, were into birdwatching as a recreational escape to nature in an increasingly urbanised industrial society, or a chance to compete with others to report as many species as possible in a given time. Thus, we see that the initial infrastructural configuration underlying the term flyways aimed at taxonomic classification with maximum certainty based on hands-on physical examination of specimens, and at exhibiting as many species as possible.

It was only after the 1920s and the 1930s that the controversy over the scientific credibility of field notes taken by birdwatchers with a variety of motivations eased due to several developments. Among these were the further systematisation in the field identification techniques, the increasing difficulty for scientists to get legal permission to hunt for scientific purposes due to the observed decrease in population sizes, and a growing interest in new research questions supported by newly emerging positions in wildlife management bureaus and universities. Finally, the gatekeeping practices that scientists were able to establish to police volunteers' field behaviours and control the quality of their field notes helped establish greater trust in data from field observations (Barrow 2000: 175-180). As a result of these developments, banding and field notes filled with sighting records gained increased scientific standing.

The first bird group for which Frederick C. Lincoln (1935) coined the term flyways in North America was the migratory waterfowl due to their importance as harvested species. Originally, the term refers to "highway roads through the air", also known as migration routes (Clarke 2014: 20), that blend or come together in a definite geographic region (Lincoln 1935: 2). The primary function of the term was then to help manage and control hunting activities in order to prevent a decrease in population size of specific species (Hawkins et al. 1984). Mapping out the migration routes and knowing where birds spend their time throughout the year are crucial to managing the population, since knowing important sites helps to plan how best to count the birds and estimate the population size. The first large waterfowl banding programme was used to map out the first four North American flyways. It was made possible by Lincoln's development of the waterlily-leaf trap in 1922, and built on the data coming from distributed networks of birdwatchers (Hawkins et al. 1984).

These developments between the late-nineteenth century and the early twentieth century shaped the KIs that, in turn, shaped the initial definition of flyways articulated in the 1930s. A number of elements contributed to the emergence of this term: from novel funding and managerial regimes of the discipline of ornithology to new hunting regulations, to changing socio-cultural norms about nature activities fed by urbanisation and industrialisation, as well as new techniques that facilitate data collection, and standards that ensure the data quality of field notes.

Flyways to Conserve Globally Endangered Species

From the 1960s onwards, the need to collaborate with hunters to collect data was further reduced, not only due to the growing concerns regarding wildlife conservation status and intrinsic valuation of nature leading to hunting bans but also thanks to the emergence of new techniques like dye-marking, mist-nets and cannon-nets (see Boere and Piersma 2012). While new types of nets enabled large scale (re-)catching and ringing efforts for the first time, marking birds by dying feathers further facilitated identification from a distance without recapturing the birds. With these new techniques, researchers were even less dependent on reports or recaptures from hunters, while they came to rely even more on volunteer birdwatchers to study the distribution and population size of species along flyways.

Developing specific techniques or mobilising and training large numbers of volunteers and ornithologists were not the only facilitating factors behind the large-scale bird censuses. Animal behaviour and environment also facilitated these since it is easier to count large number of birds where their distribution is concentrated in a few restricted and accessible geographical areas with unobstructed visibility (Altenburg et al. 1982; Piersma et al. 1987). Such distribution is characteristic of coastal waders that gather during the non-breeding season on open mudflats or agricultural lands—but not woodland songbirds that tend to be more dispersed across forested areas. Thus, species and the habitats they live in also play an important role in shaping which migratory species' flyways can be better known.

The colonial past, and the relations it normalises between geographies that are politically separated and hierarchised but are actually connected by migratory birds, has also played a role in the infrastructural configurations leading to certain understandings of flyways. For instance, 'Expeditions' of European ornithologists in the 1980s to countries of the Global South were crucial in determining birds' distribution and abundance (Altenburg et al. 1982). Such expeditions were made possible not only by the maps compiled from surveys of colonial powers like British Admiralty Charts (Tye 1987) but also supported by the 'invisible' fieldwork of locals for the foreign researchers. Some of these asymmetries endure in contemporary 'collaborations' and continue to shape data inequities (Horn et al. 2023), as well as the data that shapes flyways.

These new relations between birds, habitats, volunteer birdwatchers, invisible locals, ecologists, conservation organisations, and certain techniques of catching as well as data collection, storage, and analysis techniques enabled large-scale waterbirds counts. A notable example, started in 1967, is the IWC. It has provided crucial data to develop international cooperation on wetland habitat and waterbird conservation, like the Ramsar Convention in 1971 and the Bonn Convention in 1979 (Boere 2003). Large-scale waterbird counts have since been shaping not only (what is known about) the flyways of waterbirds in the world but also how these flyways can be enforced through national and international policies (see Boere and Piersma 2012). In other words, the KIs of the post-1950s, where scientific institutions and practices in different parts of the world became increasingly connected, together with the growing importance of international governance practices and global political actors such as the United Nations, made it possible to understand certain objects of study, such as climate, biodiversity and flyways, as a global object rather than a fragmented object of study that differed geographically (Miller 2004; Edwards 2010; Beaulieu 2022).

Halfway through the twentieth century, we see the function of the term 'flyways' shifting from managing harvestable species to coordinating global conservation efforts and policies for migratory birds. Meanwhile, the scientific definition of the term also started to change by including the birds' breeding, wintering, and stopover areas used during annual migration (Smit and Piersma 1989: 24). By linking land areas to the airways, the definition no longer evokes migration routes passively used by birds. Instead, it evokes geographical regions where the birds' life journeys are actively enabled or hindered. Therefore, 'flyways' began to indicate more than some routes for researchers to follow to understand global population distribution and sizes better. It was incorporating the conditions that affect the status of populations.

Flyways to Transform Everyday Practices with the Help of Birds as Sentinels

The use of telemetry and remote sensing technologies in data collection became widespread in the twenty-first century. This signalled another wave of change in KIs underlying flyways, including new actors and new relations of dependence between them. During the first decade of the century, the size of tracking devices progressively miniaturised, which made it possible to track a wider range of smaller species with geolocators, radio tags, and satellite tags (UNEP/CMS 2014; van de Kam et al. 2016). The inclusion of tracking devices in KIs increased the role that birds, as well as national investment, global technologies (such as satellites), and scientific funding regimes play in shaping flyways.

For instance, which migratory routes can be studied and which questions can be answered for populations using those routes through such devices are dependent on alignment between the technical infrastructures required for tags to work and the infrastructures of the countries that those birds pass through or land in. Also, since tracking tags that have better resolution for location data are still very expensive and unaffordable for most research groups based in universities, this creates hierarchies between institutions and gaps in flyway knowledge. Finally, what can be studied and known about flyways also depends on another alignment among tracking devices, habitats, and the characteristics of the species. For instance, radio-telemetry is not suitable for use in dense vegetation or mountainous areas (Benson 2010: 138), although it is a relatively cheaper device compared to GPS tags. Finally, some birds are either too light to carry the devices or, have feathers that cover solar-powered tags while flying because of their anatomy, thereby rendering the tags inactive (Benson 2010; A senior researcher pers. comm. Spring 2021).

New alignments between species, habitats, national investment, and scientific funding regimes, as well as new technologies, techniques and expertise—including isotope analysis, environmental DNA, and image recognition—in the twenty-first-century have further nuanced the emergent boundaries and functions of flyways (see Chan et al. 2019; Piersma et al. 2022). For instance, for some time, stopping sites along flyways were considered to be important re-fuelling sites where birds mainly stop to replenish energy stores. However, new studies using lightweight tags can also provide insight into non-fuelling behaviours, such as information gathering and social interactions at such sites (Lagarde and Piersma 2021; Linscott and Senner 2021). This opens up a new avenue for further research and conservation practices.

During this period, we see different co-management practices based on different human-bird relations, featuring the participation of local actors and birds as sentinels. They aim not only to increase bird populations but also transform everyday practices (especially agricultural ones) that are damaging ecosystems. The increasing availability of tracking devices, facilitating transformative everyday practices have made it possible for researchers to "give voice to the voiceless" (Safina 2002: 98) and to see the conditions of landscapes from the birds' eyes (Piersma and Lindström 2004) so that agricultural practices can be adjusted accordingly. Thanks to this "transformation of perception" (Benson 2010: 191), new infrastructural alignments of the twenty-first century then contribute to creating new types of stories of flyways where birds are the protagonists (see Piersma et al. 2021) sensing the environment, showing the way towards better soils and habitats, and thus, connecting humans to the earth they inhabit. Flyways produced through these alignments also contribute to new collaborations between scientists and artists. They represent and communicate flyways to raise public awareness through affective and aesthetic registers (EAAFP Secretariat 2021; Janet n.d.).

In this second part of the analysis (Section: Historical Changes in Infrastructures and Flyways), we delved into how different configurations of KIs, with changing social, material, technical, and ecological alignments, enabled actors to monitor, research and manage multiple 'flyways' for a century. While some of the changing alignments are contingent, others are effortful and directed. For example, although GPS tags were not specifically being produced to advance flyway work, once their potential was understood when tested on larger birds, demands to produce lightweight tags for smaller birds or tags that can measure more variables beyond location were increasingly recognised as a potential market. Then, this alignment between tags and birds, which is initially contingent and later purposeful, further drove new alignments between research questions, birds and tags, thus, to new meanings and functions of flyways.

With this analysis, summarised in Table 1, we aim to highlight how the ill-defined, standardised meaning of flyways and its commonly shared functions have evolved over decades. In this second part (Section: Historical Changes in Infrastructures and Flyways), we have therefore discussed how various components of KIs have shaped what can be known as and achieved with flyways. This is not to dismiss any potential agency needed to make new alignments or to align what is not aligned. It is rather to empower the actors to understand better which parts of KIs can be redesigned within existing limitations. As such, flyways can gain new meanings and functions to advance further research, monitoring, and conservation efforts necessary to improve the conditions for migratory birds.

CONCLUSION

In this article, we investigated how the term ‘flyways’ has been used to order relations over space and time to coordinate scientific research and communication, monitoring projects and management for conservation purposes. In the first part (Section: Contemporary Achievements of Flyways as a Boundary Object), we showed that the term functions as a boundary object with the examples from the contemporary fields of action, and showed how the imprecision of its current standardised definition allows different actors to strive for a common aim of conserving migratory waterbirds by achieving specific aims in their contexts. Specifically, we showed how the term ‘flyways’ allows actors to create and/or order (new) conceptual, socio-environmental and administrative relations over space.

In the second part (Section: Historical Changes in Infrastructures and Flyways), we moved to a historical analysis of how the term ‘flyways’ has been functioning as a boundary object over time. For this purpose, we focused not only on IIs, contrary to what Trompette and Vinck (2009) suggest, but rather on KIs, arguing that a broader scope of analysis of how knowledge about flyways is produced is more effective for understanding what underlies it. We saw how certain changes in the KIs led to shifts in the standardised definition and commonly shared functions of the term and played a role in making, unmaking, and remaking flyways. With these two parts of analysis, we then mapped the co-productive relation between boundary objects and KIs. There is great value in making explicit this co-productive relation since it shows how boundary objects can constitute a resource for transdisciplinary collaboration.

Based on such a two-fold analysis, supported by the ethnographic work of the first two authors in collaboration with a group of bird ecologists (see Eren & Beaulieu 2023), this article expands the Edwards’ (2010) definition of KIs as a network of people, artefacts and institutions by drawing attention to the role of animals and habitats in knowledge-making. In other words, our presentation of the definition adds nature to the network. Second, it contributes to the use of boundary objects to make sense of the collaborations around environmental problems by showing how the concept has been used in the literature with a very partial focus that mainly emphasises its interpretive flexibility, leading only to specific achievements. Third, by focusing on how underlying infrastructures enable the boundary object’s specific and common achievements, the article fruitfully expands the concept’s original scope of analysis from IIs to KIs.

Besides the theoretical contributions, we first make visible how collaboration is possible not just despite such vagueness but actually thanks to it. This insight is especially relevant for actors involved with flyways work who are concerned about the vagueness of the term. Our analysis shows that beyond frustration at such vagueness, there is much value in seeing its potential. The multiple recontextualisations, that such vagueness allows, actually extend the temporal and spatial reach of the term’s epistemic and practical achievements.

Secondly, for all flyway actors, we foreground not only how certain configurations of their KIs are shaped by flyways to advance research, monitoring and management efforts but also which type of infrastructural configurations and affordances shape flyways. By making such configurations visible, we also aim to empower the actors first to define and visualise flyways more explicitly, taking into account how they can serve to

Table 1

Summary of the highlights of the gradual changes in social, material, technical, and ecological relations in knowledge infrastructures, leading to shifts in the functions of the term flyways over time. Note that this table does not imply a discontinuity between time periods but rather foregrounds what is characteristic of a particular period.

	1800s	1920s—1950s	1960s—2000s	2000s onwards
Main tools and techniques	Shooting and collecting, field observations	More systematic field observations, bird catching and banding/ringing techniques	Mass catching and ringing techniques, computer card systems and calculators, statistical analysis	Telemetry through geolocators and satellite tags, databases, isotope analysis
Main actors	Scientific ornithologists, collectors, hunters, taxidermists, museums, colonial traders	Scientific ornithologists, local policymakers, hunters, volunteer bird watchers, often invisible local fieldworkers	Ecologists, environmental scientists, bird watchers, intergovernmental policy organisations, national and international conservation NGOs	Additional to the previous period, artists, farmers, data curators, technology companies
Dominant human-bird relation	Birds as specimens to capture, identify and categorise	Birds as a resource to exploit responsibly	Birds having intrinsic value, to be protected from humans	Birds as sentinels connecting humans to the world
Flyways’ function	Only emerging	To manage harvestable species	To conserve globally endangered migratory bird species	To transform agricultural practices & land management

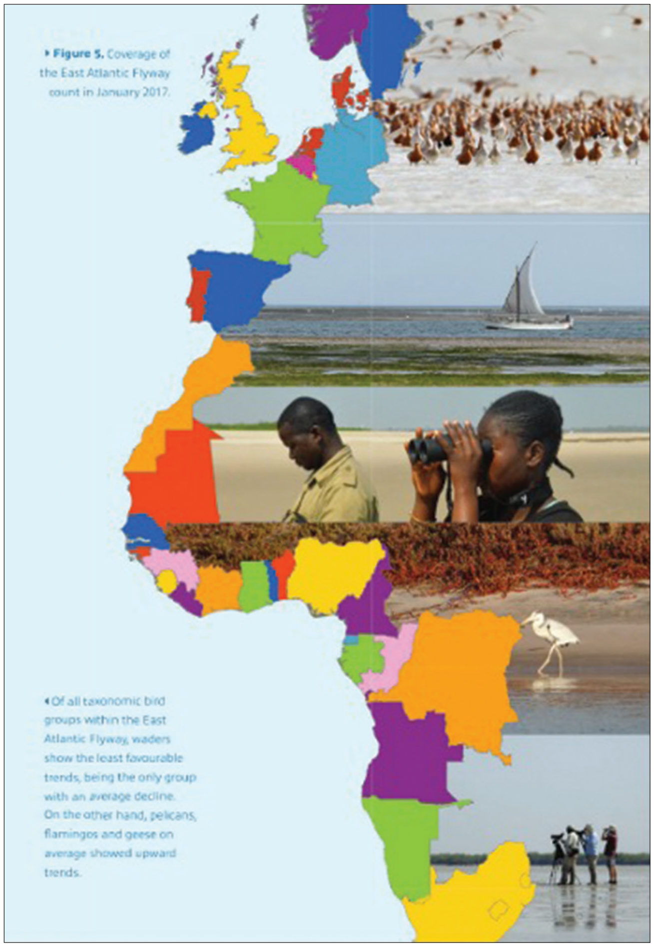

Figure 2
The coverage of East Atlantic Flyway Count in January 2017 (Koffijberg and van Roomen 2019), re-ordering borders as a specific chain of administrative units

ask new research questions, come up with new hypothesis or conservation solutions, and build new affective, institutional and administrative alliances. While it is not our place to indicate which directions such uses should take, this article can contribute to the important realisation that boundary objects and infrastructural configurations are potential resources that can be purposefully put to use in accordance with changing stakes, needs and priorities of actors.

Such purposeful interventions in the shaping of flyways might include, within the existing social, material, technical, and ecological alignments of the current knowledge infrastructures, a less flat version of flyways, a version that accounts for the varying degrees of knowledge, budget, political support, investments distributed over space that they cover, to create an even more effective boundary object, ordering attention and efforts more purposefully towards where they are needed across the flyways.

However, it could also be worthwhile to make visible the limitations of the current flyways derived from certain alignments and to work towards different infrastructural configurations. For instance, currently, flyways are agglomerations of individual stories. The tags individualise the flocks that the birds live and socialise in by orienting our attention to the behaviours and decisions of individuals. Another example could be how too much focus on satellite data—in which individual points move on an X and Y coordinate system—comes at the expense of field observations that can give more context to the tracked birds and their environment. Thus, different data infrastructures, supported by different assumptions, research agendas, values and technologies, can situate flyway stories in richer inter- and multi-species relations. On the basis of this analysis of how ‘flyways’ emerge at the intersection of boundary objects and knowledge infrastructures, we have shown that flyways are a key site where new meanings, forms and functions unfold. Insight into these dynamics can help enhance our understanding of the past and present and enrich our infrastructural imagination so that knowledge infrastructures can be developed to support better liveable futures for migratory waterbirds.

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Conception or design of the work: Selen Eren, Anne Beaulieu, Theunis Piersma, Nicola Crockford
Data collection: Selen Eren, Theunis Piersma
Data analysis: Selen Eren
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Critical revision of the manuscript: Selen Eren, Anne Beaulieu, Theunis Piersma, Nicola Crockford
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Declaration of competing/conflicting interests

The authors declare no competing interests in the conduct of this research.

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Data Availability

Data analysed for this article are in the public domain, as they are scientific journal articles, books, reports, websites, and tweets.

NOTES

1. We use the term practitioners over the term conservationists, not only to emphasise the applied work that needs to be done in the fields but also because of the overlapping identities between scientists and conservationists.
2. The practice of attaching individually numbered metal or plastic tags to birds' legs tends to be called 'banding' in North America and Australia and 'ringing' in Europe and in parts of Latin America.

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