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RESEARCH ARTICLE

Agreements for conserving migratory shorebirds in the Asia–Pacific are better fit for addressing habitat loss than hunting

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Abstract A full-life cycle approach is a tenet of migratory species conservation, yet the degree to which this is achieved remains largely unassessed. This knowledge gap can be addressed using the concept of social-ecological fit, understood as the match between governance and ecological dimensions. Here, we assess the social-ecological fit for conserving migratory shorebirds in the Asia–Pacific, focusing on habitat loss and hunting. We identify the governance architectures for addressing these two threats and then assess the coordinating capacity of each architecture, measure institutional coverage for each species across their range, and determine the degree of institutional connectivity along their migratory network. We find that social-ecological fit is higher for the governance of habitat designation than for hunting management, with implications for governance practice. Analyses of social-ecological fit thus provide critical insights on the potential effectiveness of governance and therefore are a useful first step for migratory species conservation.

Keywords East Asian–Australasian Flyway · Global environmental governance · Migratory species · Social-ecological fit · Transboundary conservation · Waterbirds

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INTRODUCTION

Migratory species conservation often requires governance mechanisms, such as institutional arrangements, to ease problems associated with jurisdictional fragmentation (Boardman 2006). Institutional arrangements can be understood as agreements of prescribed behaviour between two or more actors (Ostrom 2005). These mechanisms are a central part of governance, which in turn can be understood as coordination for collective action among actors (Chhotray and Stoker 2009). For instance, encoded in institutional arrangements, the commercial exploitation of migratory species has been managed through the recognition of property rights (Barrett 2003), and the conservation of their habitats has been promoted through networks of protected areas over large spatial scales (Xu et al. 2022). Animal migrations, including their full-life cycle, can span more than single political jurisdictions, which can range from subnational to national. For example, the pronghorn (*Antilocapra americana*) migration in mountainous western USA does not cross international borders, but nevertheless requires mechanisms to overcome domestic jurisdictional fragmentation (Middleton et al. 2020). Other species, such as the leatherback turtle (*Dermochelys coriacea*), require accounting for political jurisdictions across countries and even the high seas (Harrison et al. 2018). Consequently, a full-life-cycle approach has become a central tenet of migratory species conservation (Young 2002; Boere and Stroud 2006), as these animals are important to humans and are declining (Wilcove and Wikelski 2008). However, the degree to which this is accomplished in practice remains largely unassessed. Within this context, migratory shorebirds warrant scholarly attention as they complete their life cycle across multiple countries, and despite the development of various institutional arrangements for their conservation, their populations continue to decline (Studds et al. 2017; Gallo-Cajiao et al. 2019a).

Despite their importance (Bauer and Hoye 2014), migratory species have been declining around the world and across taxa due to multiple threats. Notably, such trends have not only included biodiversity loss from a compositional perspective (i.e. species extinction), but also from a functional standpoint (i.e. ecological processes; Noss 1990). Examples of declining populations of migratory species include the southern bluefin tuna (*Thunnus maccoyii*; Caton 1991) and the Mongolian gazelle (*Procapra gutturosa*; Milner-Gulland and Lhagvasuren 1998). Some migratory species declines have resulted in extinction (Hornaday 1913), such as the great auk (*Pinguinus impennis*) and the Labrador duck (*Camptorhynchus labradorius*). In other instances, species have not necessarily become extinct, but some populations have become sedentary, with the implied loss of migration as a biological phenomenon (Satterfield et al. 2015). Animal migrations usually entail the use of habitats spanning multiple political jurisdictions, such that threats associated with different environmental, socio-economic, and political contexts operate along the life cycle of individual organisms. Specifically, threats to these species include habitat loss, barriers to migration, overexploitation, incidental mortality, invasive species, and climate change, amongst others (Wilcove and Wilkelski 2008).

The governance for conserving migratory species that complete their life cycle beyond a single country can be a set of transboundary institutional arrangements with various degrees of spatial and functional overlap (Boardman 2006; Conte et al. 2023). Institutional arrangements between countries, understood as international governance, have included multilateral (e.g. Convention on Migratory Species) and bilateral (e.g. USA–Canada International Porcupine Caribou Agreement) memberships. In other cases, institutional arrangements have included participation of state and non-state actors (e. g. Western Hemisphere Shorebird Reserve Network), known as hybrid governance. Additionally, some institutional arrangements can have exclusive participation of non-state actors (e.g. Southern Cone Grassland Alliance), regarded as transnational governance. Some migratory species are conserved through multiple, and different types of (e.g. international, hybrid, and transnational), institutional arrangements that address various threats (e.g. Wilson 2008). The resulting set of coexisting institutional arrangements can be framed as a governance architecture (Biermann et al. 2009a), and the phenomenon of expansion of participating actors in transboundary settings beyond the nation state as global environmental governance (Pattberg and Widerberg 2015). The rationale for such institutional arrangements is underpinned by a centralisation imperative across political jurisdictions to address the weakest link paradigm, uneven capacity of actors, and population-level effects that result from aggregate impacts scattered throughout migratory ranges (Farber 1997; Boardman 2006; Albers et al. 2023). Against this background, social-ecological fit, understood as the match between governance and ecological dimensions of a conservation problem (Holling and Sanderson 1996), provides a suitable concept to evaluate empirically the extent to which migratory species are being conserved, at least prescriptively, throughout their entire full-life cycle.

A growing body of empirical scholarship has focused on social-ecological fit using spatial data on animal distributions and movements (Sayles et al. 2019). Within the context of migratory species, Sayles and Baggio (2017) considered social-ecological fit for salmon conservation, accounting for migratory movements using proxies (i.e. hydrological units) and focusing on the freshwater section of their life cycle. Additionally, studies by Runge et al. (2015), Li et al. (2019), and Zhang et al. (2023) assessed social-ecological fit for conserving migratory bird taxa in relation to the match between protected areas and species occurrence. A study by Thirgood et al. (2004) also took on a full-life-cycle approach and accounted for migratory connectivity of ungulates in relation to protected areas across two countries in Eastern Africa. However, while progress for assessing social-ecological fit has been made within the context of migratory species conservation, empirical analyses of social-ecological fit at the macro-level incorporating a full-life-cycle approach remain limited.

Migratory shorebirds, a cosmopolitan group of waterbirds, have a governance architecture for their conservation in the Asia–Pacific (Gallo-Cajiao et al. 2019a), but no study has yet appraised its socio-ecological fit. Many migratory shorebird species have been declining across this region, known as the East Asian–Australasian Flyway (EAAF), due chiefly to habitat loss (Studds et al. 2017) and hunting (Gallo-Cajiao et al. 2020a). Other threats operating in the region include pollution, invasive species, incidental mortality, climate change, and disturbance, understood as disruption to time budgets for feeding and resting (Harding et al. 2007; Studds et al. 2017; Liang et al. 2023). Evaluating social-ecological fit in the EAAF does not only have the potential to contribute directly to the conservation agenda of these species, but also to provide conceptual and methodological insights for assessing and improving the social-ecological fit of governance architectures for conserving other migratory species.

Here we present a single case study of social-ecological fit of the governance architecture for conserving migratory shorebirds in the EAAF, whereby we ask: (i) what are the specific governance architectures for habitat designation and hunting management in terms of actors and institutional arrangements?, (ii) how does the coordinating capacities of the habitat designation and hunting management governance architectures differ?, (iii) how does the institutional coverage for each migratory shorebird species across their corresponding range states differ in relation to habitat designation and hunting management?, and (iv) how does the degree of connectivity of the migratory network for select taxa differ in relation to the governance architectures for habitat designation and for hunting management? We analysed the governance architectures for habitat designation and hunting management using comparative and mixed methods with an interdisciplinary perspective drawing on environmental governance and spatial ecology. In so doing, we adopted a hierarchical approach to social-ecological level of analysis, from the entire flyway as a single ecological unit, through species occurrence at range state level, to explicit bird movements between range states (Fig. S1). We consider social-ecological level of analysis as the intersection of social (e.g. institutional arrangements, political jurisdiction of actors) and ecological (e.g. occurrence, movements) spatial variables used to observe the phenomenon of enquiry.

THEORETICAL FRAMEWORK

Social-ecological fit and network analysis

The concept of fit has origins in the environmental governance literature developed through an interweaving process of two strands of scholarship working at different spatial scales and levels of governance (Ostrom 1990; Holling and Sanderson 1996; Young 2002). 'Fit', albeit contested, is an analytical and normative tool for understanding the match between governance and ecological processes. Social-ecological fit is considered an important condition, but not the only one, for achieving sustainability of social-ecological systems (Young 2011; Epstein et al. 2015). Thus, empirical analyses of fit have become a paradigm to appraise proxies of the effectiveness of governance systems (Young 2011). Institutional arrangements, as key components of governance systems, with rules and actors that account for ecological processes temporally and spatially are indicative of potentially high problem-solving capacity. This concept has become a paradigm in the literature on social-ecological systems, generally applied at meso- to micro-levels (Ostrom 1990; Ekstrom and Young 2009), even though it also has roots in regime analysis, where it has been generally applied at the macro-level (Young 2002). The definition and operationalisation of the concept for empirical studies have been varied and idiosyncratic, resulting in a lack of conceptual consensus when applied (Epstein et al. 2015). Hence, for the purpose of our study, we consider social-ecological fit as the match between migratory species occurrence and their movements across their entire life cycle with institutional arrangements for their conservation, both spatially (i.e. where they operate) and functionally (i.e. what they do).

Recent integration of network analysis for the study of social-ecological fit presents untapped research potential within the context of migratory species conservation. Network analysis has enabled the operationalisation of empirical research of social-ecological fit in a more rigorous manner. Perhaps one of the key advantages of this approach lies in the possibility of representing *vis-à-vis* social and biophysical phenomena and processes (Sayles et al. 2019). Importantly, the use of network analysis to evaluate social-ecological fit is enabled by the consideration of node and edge-level traits as well as the configuration of nodes and edges (i.e. topology). Within this context, governance architectures can be represented as networks, whereby actors and institutional arrangements are represented as nodes, whilst membership to institutional arrangements is represented as edges, also known as ties (Kim 2019; Morrison et al. 2023). In turn, networks can also be used to represent ecological processes and phenomena, as already considered for the case of migratory species, whereby species occurrence is represented by nodes and movement between discrete areas of occurrence is represented by edges (Iwamura et al. 2013). These variables can be used to represent and analyse key features of global environmental governance for conserving migratory species by matching governance (e.g. actors and membership to institutional arrangements) and ecological dimensions (e.g. occurrence and movements). Node-level traits include the importance of nodes within a given network based on their number of ties to other nodes, known as degree centrality. Edge-level traits include the number of connections between any given dyad of nodes, known as edge degree. The resulting configuration based on the relation between nodes and edges determine the influence, or coordinating capacity, of any given node within a network, which is known as betweenness centrality. This analytical approach becomes particularly useful for the assessment of social-ecological fit of environmental issues that include multiple institutional arrangements, as is the case of migratory shorebirds in the EAAF (Gallo-Cajiao et al. 2019a).

Problem structure

Migratory connectivity is fundamentally important to understanding threats to migratory species, and eventually to conserving them. This concept refers to the connections across space given by migratory movements of individual animals as they complete their entire life cycle, known as full-life cycle, as part of the same population (Webster et al. 2002). Hence, migratory connectivity critically underpins conservation of such taxa throughout their full-life cycle, known as full-life-cycle approach, allowing the identification and amelioration of threats at particular stages of a species' life cycle (Marra et al. 2011). For this study, we focus on two major threats to migratory shorebird taxa, namely habitat loss (Studds et al. 2017) and hunting (Gallo-Cajiao et al. 2020a). Migratory connectivity can be conceptualised as a network, whereby sites, represented by nodes, are linked by migratory movements, represented by edges. Hence, habitat loss can potentially disrupt to various degrees the flow of individual animals as they move through the network (Iwamura et al. 2013). Likewise, hunting can have population-level effects, since discrete harvesting events at different nodes accumulate throughout the network. Both of these threats can drive population declines. Hence, migratory connectivity is pivotal to conceptualise conservation as demographic processes that need to be accounted for spatially at a network level. With this background, we advance the following propositions in relation to rule-setting for each institutional arrangement: (a) the gold standard for addressing habitat loss (i.e. habitat designation) is the explicit establishment of a flyway-wide network of site-based management initiatives that account for the network structure of migration underpinned by site-based designation criteria (Xu et al. 2022) and (b) the gold standard for addressing hunting (i.e. hunting management) is the explicit adoption of a framework for quota allocation underpinned by assessments of aggregate levels of take at a flyway level and different demographic impacts depending upon life-history stages (Baldasarre and Bolen 1994). Ultimately, threats to migratory species can be considered as human-induced mechanisms that result in loss of migratory connectivity, due to either reduced carrying capacity (e.g. habitat loss) or increased mortality (e.g. hunting).

STUDY SYSTEM

The focus of this study is the EAAF, located in the Asia–Pacific, which can be considered as a social-ecological system. The range states of this flyway are considered as all countries that are part of the life cycle of migratory shorebirds in the Asia–Pacific following Bamford et al. (2008) and the East Asian–Australasian Flyway Partnership (Table S1). We additionally include Taiwan as part of the EAAF, because regardless of political status, or recognition, this island is a geographical part of the life cycle of some migratory shorebird species. In all, 58 species of migratory shorebirds (Aves: Charadriiformes) complete their life cycle along this flyway, comprising Alaska, Northeast Asia, East Asia, Southeast Asia, and Australasia (Fig. S2). Breeding grounds for migratory shorebirds are generally located at high latitudes in the northern hemisphere with non-breeding grounds primarily near the equator and in the southern hemisphere. Of these taxa, 18 are considered of conservation concern for being either listed globally as Near Threatened or threatened (BirdLife International 2023). The overarching governance architecture for conserving these species in this region includes 28 institutional arrangements that have different memberships, spatial scopes, and provisions. Actors in these institutional arrangements represent levels of governance ranging from subnational to supranational (Gallo-Cajiao et al. 2019a). Here, we consider those subsets of institutional arrangements with specific provisions for (i) habitat designation and (ii) hunting management.

MATERIALS AND METHODS

Data collection

Institutional dimensions

We adopted an exploratory sequential mixed-methods design, with qualitative data leading to quantitative data (Creswell and Clark 2018). The habitat designation and hunting management architectures were first identified and characterised using qualitative methods. We consider those two architectures as subsets of the overarching governance architecture for migratory shorebird conservation in the EAAF (Gallo-Cajiao et al. 2019a), which encompasses additional institutional arrangements that focus on neither habitat designation nor hunting management. In this context, we focused exclusively on institutional arrangements, which we consider here as document-based explicitly agreed rules, norms, courses of action, and decision-making procedures (Ostrom 2005) between at least two actors across national borders for attaining a specific common goal. Institutional arrangements were only included if at least one of their actors, or aims, has jurisdiction within the EAAF, as well as whether shorebird conservation is relevant to them considering the two major imminent threats to those species (i.e. habitat loss and hunting) in the region. Institutional arrangements were initially identified through searches focused on key references (i.e. Anonymous 1996; Asia–Pacific Migratory Waterbird Conservation Committee 2001; Boardman 2006; CMS 2014) and three treaty databases (i.e. ECOLEX, FAOLEX, and the International Environmental Agreements Database Project). Keywords used for database searches included: "biodiversity", "wetland*", "environment*", "migratory bird*", "wildlife", and "coast*".

To expand the scope of data collection, we conducted fieldwork as a complement to desktop-based approaches. The initial identification of 14 relevant institutional arrangements was expanded and refined through interviews, participant observation, and document analysis allowing additionally for data saturation and methodological triangulation (Yin 2011). All data collection was conducted under institutional human research ethics approval number 2015001625 issued by the University of Queensland. EGC carried out semi-structured and unstructured interviews of key informants representing state and non-state actors using purposive and snowball sampling (Cox 2015). Interviews were conducted between March 2014 and November 2016 in Australia, Canada, China, Japan, Republic of Korea, and the USA (Tables S2, S3). Interviews focused on the relevance of different institutional arrangements for conserving migratory shorebirds including in relation to habitat designation and hunting management, membership, their level of formality, as well as whether they were active or inactive. Formality was operationalised by determining whether each institutional arrangement is legally or non-legally binding following the Vienna Convention on the Law of Treaties (1969). Legally binding institutional arrangements are those for which actors, countries in this case, need to undergo ratification after signature whereby they must seek domestic approval to be bound. Conversely, non-legally binding institutional arrangements are those where ratification through a legislative procedure is not required. We defined as active those institutional arrangements for which there was evidence of current programmatic activities at the time, as well as regular consultative meetings (e.g. Conference of the Parties). Key informants were mostly senior officials with expertise, and conservation experience, on at least one of the following topics: wetlands, waterbirds, policy, or coastal environmental issues. A total of 34 interviews were conducted (in-person: 23; phone: 5; email: 6; Table S4), and in some cases audio recorded (n = 19), representing actors from six countries (Australia, China, New Zealand, Republic of Korea, Russia, and the USA; local government: 3, national government: 12, national NGO: 5, research organisation: 4), as well as some that operate across multiple countries (corporate: 1, intergovernmental organisation: 6; international NGO: 3). Semi-structured interviews lasted between 30 and 120 min. Likewise, we further explored, and confirmed, the relevance of institutional arrangements through participant observation conducted at key international fora (Table S3). Additionally, key documents (n = 11), such as work plans and media clips, were examined to confirm the relevance of institutional arrangements for conserving migratory shorebirds based on their currency and programmatic activities.

Ecological dimensions

Ecological dimensions of migratory shorebird species included spatially explicit data drawing on secondary sources. First, data on occurrence at a range state level was considered for each species of migratory shorebird as presence–absence based on country profiles available from BirdLife International Datazone (2019). The list of species occurring in the EAAF was initially taken from Bamford et al. (2008) and subsequently refined at the subspecies level based on the Handbook of the Birds of the World (del Hoyo et al. 2019). This approach aimed to ensure only taxa migrating within the EAAF were considered in relation to each range state. For instance, the whimbrel is a species that migrates within the EAAF, but the subspecies that occurs regularly in Alaska (*Numenius phaeopus hudsonicus*) migrates within the Americas Flyways, so the occurrence of this species in the USA was excluded for the purpose of this study. Second, data on migratory connectivity were gathered and transformed from Iwamura et al. (2013), a study that focused on effects of sea-level rise under climate change on such taxa. That study presents migratory networks for select shorebird taxa within the EAAF (Table S5) drawing on multiple data sources, including expert opinion and various tracking methods of individual birds (i.e. bands, leg flags, satellite tags, and geolocators). The nodes of such networks were presented through an ecological lens; consequently, they can represent regions that span more than one country, or represent regions at a subnational level. Because our level of analysis is at country-to-country institutional ties, we transformed the connectivity data from Iwamura et al. (2013) by pooling together nodes at the subnational level into national-level nodes, as well as by splitting ecological nodes that span across more than one country into country-level nodes. Likewise, all ties (i.e. edges) between nodes at the subnational level, or across more than one country, were transformed into connections exclusively at the national level. We built an aggregate country-level connectivity network accounting for northbound and southbound migration that includes all taxa considered by Iwamura et al. (2013).

Data analysis

(i) What are the specific governance architectures for habitat designation and hunting management in terms of actors and institutional arrangements?

Data collected on institutional arrangements through various methods allowed us to characterise the habitat designation and hunting management architectures. To that end, interview transcripts, participant observation notes, and key documents were compiled and coded using qualitative data analysis software (QDA Miner Lite; Yin 2011). The coding framework (Table S6) for the analysis of interviews and participant observation was developed inductively using a topic-oriented approach building to themes according to the different institutional arrangements in relation to our research questions (Saldaña 2009). This process resulted in a list of all institutional arrangements deemed relevant and active for conserving migratory shorebirds in the Asia–Pacific in relation to habitat designation and hunting management. We used document analysis to identify those institutional arrangements with provisions for addressing two of the major threats to migratory shorebirds (i.e. habitat loss and hunting) through designation of habitat areas for conservation and hunting management. In the case of habitat conservation, we considered provisions with reference to the designation of areas that include amongst their goals, waterbird habitat conservation, involving areas ranging from multiple-use to strict protection (keywords: “protected area*”, “conservation area*”, “park*”, “refuge*”, “sanctuary*”). In the case of hunting, we considered provisions that focus on species conservation, as well as on their sustainable use (keywords: “take”, “hunt*”, “harvest*”, “sustainable use”).

Subsequently, we built corresponding attribute tables for actors and institutional arrangements to conduct further analysis. The attribute table for actors (A; Appendix S1) includes the governance level at which they primarily operate (i.e. subnational, national, and supranational) and whether they are state (SA) or non-state actors (NSA). The attribute table for institutional arrangements (IA; Appendix S2) includes level of formality (i.e. legally binding vs non-legally binding), membership (bilateral: A = 2; multilateral: $A \geq 3$), provisions (i.e. habitat designation and hunting management), and issue scope (i.e. specialised, generic). The latter attribute was evaluated based on whether each institutional arrangement includes or not taxonomic appendices that contain migratory shorebirds to which provisions apply.

The governance architecture for conserving migratory shorebirds in the EAAF was analysed with a focus on problem structure. We used a quantitative network analysis approach, in which each architecture (i.e. habitat designation, hunting management) is considered as a bipartite directed network graph, with actors having affiliation to institutional arrangements (i.e. $A \rightarrow IA$; Robins 2015). Two types of nodes were considered, institutional arrangements and actors, while edges represent membership of actors to institutional arrangements. For this purpose, an adjacency matrix was compiled for each architecture using a sequential coding for actors (SA_i: state actors, NSA_i: non-state actors; IA_j: institutional arrangements), where $A_{ij} = 1$ when actor i is a member to institutional arrangement j and $A_{ij} = 0$ otherwise. For the adjacency matrices, membership was considered as accession, which in this context refers to the year of signature in the case of non-legally binding institutional arrangements and to the year of ratification, or actual accession, in the case of legally binding institutional arrangements. The membership of all institutional arrangements included in this study is presented as of December 2016. Based on the attribute table of institutional arrangements (Appendix S2) and the corresponding adjacency matrices (Appendices S3, S4), we visualised each architecture for habitat designation and hunting management through network graphs using NodeXL.

Some nodes in the adjacency matrix were considered as both institutional arrangements and actors, resulting in a multi-level network at the macro-level (Robins 2015). Institutional arrangements (e.g. international environmental agreements) typically include decision-making bodies through member representation (e.g. Conference of the Parties) and international bureaucracies (e.g. secretariats; Churchill and Ulfstein 2000). In turn, these bureaucracies can be considered as agencies with some degree of permanence set up by members to pursue a policy (Biermann et al. 2009b). Within this context, the distinction between bureaucracies, as actors, and agreements, as institutional arrangements, has been an area of debate (Biermann and Siebenhüner 2009) and represents an empirical challenge for analysis in global environmental governance (O’Neill et al. 2013). On the one hand, these bureaucracies have been considered as largely lacking autonomy, because they may be understood as mere structures through which states advance their own interests (Biermann and Siebenhüner 2009). On the other hand, international bureaucracies can also be considered discrete actors, because they can shape the course of institutions (North 1990) and are usually established under their own international legal personality (Churchill and Ulfstein 2000; Biermann et al. 2009b).

Consequently, for our network analysis, we consider membership of five relevant international bureaucracies as memberships of intergovernmental organisations (IGOs) to another institutional arrangement (i.e. East Asian–Australasian Flyway Partnership; EAAFP). We define IGOs as institutional arrangements that include international bureaucracies and a normative framework that is established by and is effective on the member states (Biermann and Siebenhüner 2009). Typically, international bureaucracies are subordinate to the decision-making bodies of institutional arrangements (Churchill and Ulfstein 2000). Likewise, international bureaucracies act on behalf of their members following their mandate, but can also make decisions that can bind individual members with or even without their consent (Newell et al. 2012). Whilst we acknowledge the degree of autonomy held by these bureaucracies (Bauer et al. 2012), we also understand their capacity to exert cognitive, normative, and executive influence over their very own institutional arrangements (Biermann et al. 2009b; Eckhard and Ege 2016). Furthermore, international bureaucracies include under their purview entering additional institutional arrangements (Churchill and Ulfstein 2000). Our analytical approach is further supported by the document of constitution of the EAAFP, which requires members to support its objectives and actions. Therefore, we consider the mandate of this partnership to influence such IGOs through their international bureaucracies.

(ii) How does the coordinating capacity of the habitat designation and hunting management governance architectures differ?

The coordinating capacity of each governance architecture was assessed through quantitative and qualitative network analysis using metrics at a node and topology level. This analysis assumed the entire EAAF to be a single spatial unit from an ecological standpoint. Hence, the relative coordinating capacity of institutional arrangements within each architecture was appraised using betweenness centrality. This parameter is considered for any given node as the number of shortest paths that pass through such a node when every possible pair of nodes within the network are connected (Robins 2015). In social network theory, nodes with high betweenness centrality are considered to have a brokerage capacity, and hence bear coordinating properties. The betweenness centrality of a node v is given by the expression:

$$g = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

where σ_{st} is the total number of shortest paths from node s to node t and $\sigma_{st}(v)$ is the number of paths that pass through v. When calculating betweenness centrality, we considered each node as representing an institutional arrangement within each corresponding adjacency matrix including all actors, whereby the network was still bipartite but undirected. This conceptualisation assumes that institutional arrangements facilitate coordination by allowing flows of information, norms, and rules throughout the network in either direction considering their ties to actors. Betweenness centrality was calculated using R Studio version 3.2.4 and the igraph package (Csárdi and Nepusz 2006). Additionally, we considered whether each institutional arrangement was specialised or generic, assuming the former tend to have higher coordinating capacity given their narrower taxonomic focus compared to the latter. The overall capacity of each governance architecture to allow coordination amongst all actors was assessed using density (D). From a social network theory perspective, density describes how much social activity occurs within a system (Robins 2015). This parameter is defined as the proportion of ties relative to the total number of possible ties between nodes and is given by:

$$D = \frac{m}{n(n-1)/2}$$

where m is the total number of actual edges in the network and n is the total number of possible nodes in the network. Consequently, the maximum value of D is 1 when a network presents nodes fully connected to one another. To that end, we considered each architecture as a unipartite and undirected network graph whereby all nodes represent state actors at the national level. We adopted this simplified conceptualisation considering the jurisdiction and external sovereignty of the nation state, as well as the constraints on possible ties imposed by the membership of institutional arrangements (i.e. bilateral, multilateral). Hence, we calculated density (D) for each graph after converting all institutional ties (i.e. actors to institutional arrangements) into country-to-country ties (i.e. deconstructed network), whereby if $A_{ij} = 1$, then it follows that $A_{ii} = 1$ (A_i: actors; IA_j: institutional arrangements). Density was calculated using R Studio version 3.2.4 and the igraph package (Csárdi and Nepusz 2006). These network graphs were also visualised with NodeXL and analysed with plotted histograms of edge degree distribution.

(iii) How does the institutional coverage for each migratory shorebird species across their corresponding range states differ in relation to habitat designation and hunting management?

This spatially explicit analysis took into consideration the occurrence of migratory shorebird species in relation to the density of institutional arrangements. First, we determined the range states in which each taxon occurs and consequently built a binary matrix of presence-absence. Subsequently, we compiled the number of institutional arrangements to which each range state is a member according to provisions for habitat designation (Appendix S5) and hunting management (Appendix S6). We then calculated the mean institutional coverage per species for each governance architecture across their corresponding range states, followed by the mean values of institutional coverage across all species for the habitat designation and hunting management architectures. Last, we ran a simple regression analysis to explore the relationship between the number of range states and the mean institutional coverage per species, with one analysis for each governance architecture (i.e. habitat designation, hunting management).

(iv) How does the degree of connectivity of the migratory network for select taxa differ in relation to the governance architectures for habitat designation and for hunting management?

We adopted a spatially explicit approach to social-ecological fit accounting for institutional arrangements to which range states have entered and the actual movements of migratory shorebird taxa between range states. A migratory network was compiled for each shorebird taxon at a range state level considering northbound and southbound movements. Each network was represented as unipartite and undirected through an adjacency matrix, whereby nodes represent range states and edges represent migratory movements between range states (i.e. migratory ties), such that $RS_{ii} = 1$ (RS: range state) when range state i is connected to range state i by migratory movements of shorebird taxa j and $RS_{ii} = 0$ otherwise. Subsequently, we combined all individual networks of each migratory shorebird taxa into a single migratory network for the EAAF. Based on the simplified country-to-country institutional network, we calculated the edge degree of institutional ties overlapping each migratory tie for each architecture (i.e. Appendix S7: habitat designation; Appendix S8: hunting management). We visualised each overlapping migratory governance network using NodeXL and plotted histograms to explore edge degree distribution.

Limitations

This study necessarily entailed simplification of network attributes both institutionally and ecologically given limitations of data availability. First, all actors and institutional arrangements are considered equal from an analytical perspective when performing network analyses, with variables such as power or legitimacy not being accounted for. Instead, there was only consideration of node attributes, both for actors and institutions, given by the quantitative network parameters described above. Second, the migratory network does not include weighted edges that reflect the strength of migratory connectivity (Runge et al. 2015), neither at the community level (i.e. number of species) nor at the population level (i.e. number of individuals). This simplification stems from the dearth of data accounting for a more complete set of species, as well as for population flows between range states. Third, ecologically, nodes and country-level occurrence were all considered with the same demographic importance, which is a simplification as the migratory range structure for some species makes some nodes bear more importance within the full-life cycle given the spatial distribution of life-history stages. Fourth, threats were not considered as spatially explicit from an analytical perspective, but rather as if they operate across the entire region, hence requiring institutional arrangements equally throughout the entire flyway. Fifth, the relative effect of habitat loss and hunting in driving population declines remains unclear. Last, non-state actors were not considered analytically from a spatial perspective because they pose a challenge given their lack of external sovereignty when compared to range states.

RESULTS

(i) What are the specific governance architectures for habitat designation and hunting management in terms of actors and institutional arrangements?

The habitat designation and hunting management architectures cover almost the entire flyway, but they nevertheless differ in the number of institutional arrangements and actors. First, the habitat designation architecture comprises 19 institutional arrangements, 6 of which are generic and 13 specialised. Regarding membership within this architecture, 13 institutional arrangements are bilateral and 6 are multilateral, including 36 actors across various levels of governance (subnational = 5.5%, national = 66.6%, supranational = 27.7%) and sectors of society (state actors = 63.9%, non-state actors = 36.1%; Fig. 1). Second, the hunting management architecture includes 16 institutional arrangements, 4 being generic and 12 specialised. Regarding membership of this architecture, 13 institutional arrangements are bilateral and 3 are multilateral, which include exclusively state actors at the national level (Fig. 1). Both architectures include 22 of the 23 range states (95.6%) in the EAAF, with Taiwan not being a member to any institutional arrangement. Furthermore, when each architecture is decomposed in country-to-country ties, there are 229 range state dyads ($D = 0.991$) with 617 institutional ties for habitat designation and 213 range state dyads ($D = 0.922$) with 278 institutional ties for hunting management (Fig. 2).

(ii) How does the coordinating capacity of the habitat designation and hunting management governance architectures differ?

The results showed that the habitat designation architecture has higher coordinating capacity than the hunting management architecture. This was illustrated by the

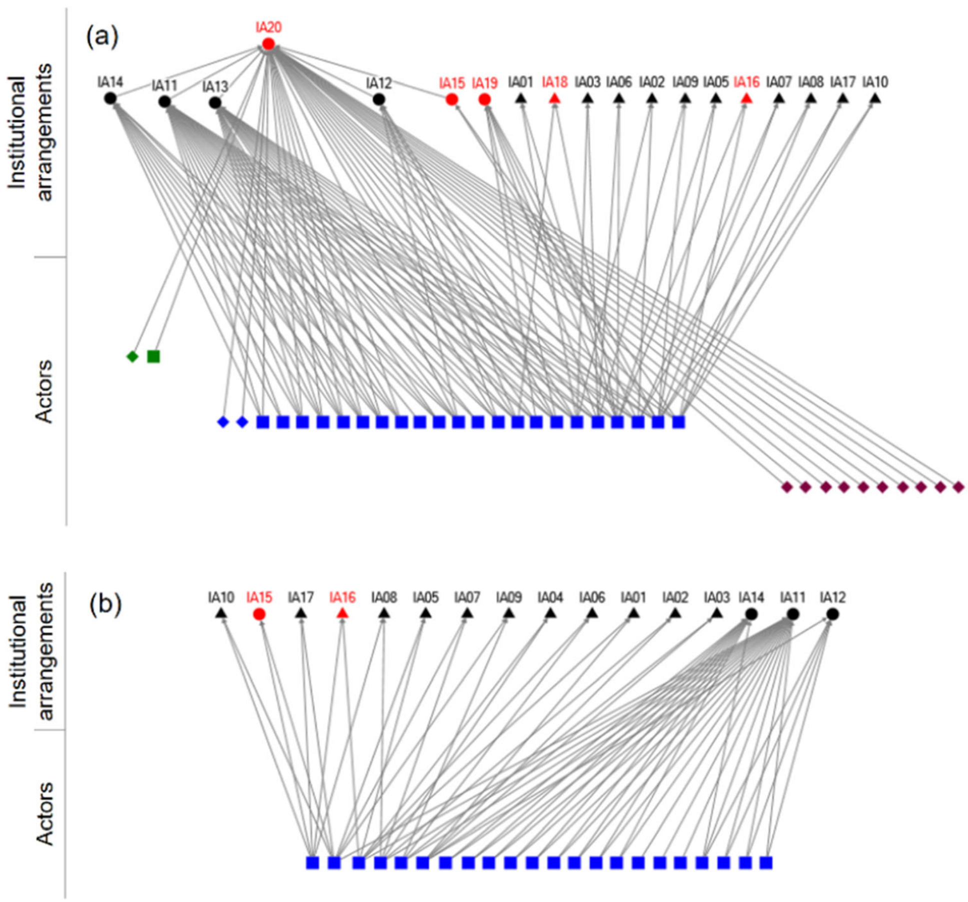

Fig. 1 Governance architecture for **a** habitat designation and **b** hunting management. Upper nodes represent institutional arrangements (triangle: bilateral membership; circle: multilateral membership; black: legally binding status; red: non-legally binding status; for codes of institutional arrangements refer to Table 1), lower nodes represent actors (colours represent levels of governance. Green: subnational; blue: national; purple: supranational. Shapes represent type of actor. Square: state actor; diamond: non-state actor), and lines with arrows represent membership of actors to institutional arrangements

betweenness centrality, which was generally higher for institutional arrangements for habitat designation ($\bar{x}$ = 69.373, sd = 194.95; Table 1) when compared to hunting management ($\bar{x}$ = 37.437, sd = 116.86; Table 1). Based on betweenness centrality, the EAAFP is the institutional arrangement with highest coordinating capacity for habitat designation ($g(v)$ = 855.278; Table 1). This institutional arrangement is specialised and includes an explicit mandate to develop a network of sites for habitat conservation, known as the Flyway Site Network, accounting for their relative importance to migratory shorebirds at a flyway level based on abundance but not accounting for migratory connectivity (Xu et al. 2022). By contrast, the Convention on Biological Diversity has the highest coordinating capacity for hunting management ($g(v)$ = 489.632; Table 1). Notably, this institutional arrangement is generic and does not provide a framework for quota allocation underpinned by assessments of aggregate levels of take at a flyway level and different demographic impacts depending upon life-history stages. These results indicate that while both architectures are similar in that they bring all countries together, habitat designation does so more robustly than hunting management by having a high-coordinating specialised institutional arrangement, additional actors beyond the nation state, and more institutional arrangements.

(iii) How does the institutional coverage for each migratory shorebird species across their corresponding range states differ in relation to habitat designation and hunting management?

The institutional coverage of range states for habitat designation is generally higher than for hunting management for each species. Most species of migratory shorebirds are widespread within the EAAF, species occur on average in 15.66 range states (68%), with most species (75%) occurring across at least half of range states ($\geq$ 11) and a quarter

Table 1 Betweenness centrality of institutional arrangements for habitat designation and hunting management for conserving migratory shorebirds in the East Asian–Australasian Flyway

Code/Institutional arrangement	Issue scope	Betweenness centrality	
		Habitat	Hunting
IA01/Australia–China Bilateral Migratory Bird Agreement	S	1.558	4.188
IA02/Australia–Japan Bilateral Migratory Bird Agreement	S	1.140	3.902
IA03/Australia–Republic of Korea Bilateral Migratory Bird Agreement	S	0.983	2.460
IA04/China–Japan Bilateral Migratory Bird Agreement	S	N/A	3.971
IA05/China–Russia Bilateral Migratory Bird Agreement	S	1.976	5.723
IA06/China–Republic of Korea Bilateral Migratory Bird Agreement	S	1.268	3.471
IA07/Japan–Russia Bilateral Migratory Bird Agreement	S	1.297	4.861
IA08/Japan–USA Bilateral Migratory Bird Agreement	S	1.400	10.065
IA09/Russia–Republic of Korea Bilateral Migratory Bird Agreement	S	1.399	5.740
IA10/Russia–USA Bilateral Migratory Bird Agreement	S	1.091	6.464
IA11/Convention on Biological Diversity	G	235.283	489.632
IA12/Convention on Migratory Species	S	5.008	9.506
IA13/Ramsar Convention	S	159.823	N/A
IA14/ASEAN Centre for Biodiversity	G	29.131	24.000
IA15/Conservation of Arctic Flora and Fauna Working Group	G	1.091	6.464
IA16/USA–China Protocol on Field of Conservation of Nature	G	2.247	12.088
IA17/USA–Russia Agreement in the Field of the Environment and Natural Resources	G	1.091	6.464
IA18/China–New Zealand arrangement for migratory shorebird conservation	S	0.877	N/A
IA19/Framework for North-East Asian Cooperation	G	16.159	N/A
IA20/East Asian–Australasian Flyway Partnership	S	855.279	N/A

G generic, *S* specialised, *N/A* not applicable

(25%) occurring across almost all range states (≥ 20; ≥ 86.9%). Two species are the most widespread, occurring across all range states (i.e. Pacific golden plover, *Pluvialis fulva*; red-necked stint, *Calidris ruficollis*), and one the least, occurring across only two range states (i.e. double-banded plover, *Charadrius bicinctus*). Average institutional coverage for each species generally declines as the number of range states in which it occurs increases, with a similar pattern for institutional arrangements for habitat designation (r = -– 0.679; r^2 = 0.4616; Fig. 3) and hunting management (r = -0.662; r^2 = 0.438; Fig. 3). Average institutional coverage for habitat designation ($\bar{x}$ = 4.85, sd = 0.66) is higher than for hunting management ($\bar{x}$ = 2.9, sd = 0.505) across all species (Fig. 4), a pattern maintained for each species including those of conservation concern (Fig. 5, Table 2). The rock sandpiper (*Calidris ptilocnemis*) is the species with the highest average institutional coverage for both habitat designation and hunting management, whereas the Australian pratincole (*Stiltia isabella*) is the species with the lowest average institutional coverage.

(iv) How does the degree of connectivity of the migratory network for select taxa differ in relation to the governance architectures for habitat designation and for hunting management?

The migratory network for select shorebird taxa is more comprehensively connected by the habitat architecture than the hunting architecture (Fig. 6). The migratory network for select shorebird taxa includes 14 range states (i.e. nodes) and 43 migratory ties (i.e. edges) between countries spanning the full latitudinal spectrum of the EAAF accounting for northbound and southbound migration. When considering the combined migratory network for such taxa, the frequency distribution of edge degree tended to be higher for the habitat designation architecture (≥ 3) when compared to the hunting management architecture (≤ 2). Additionally, the habitat designation architecture presented edge gaps (i.e. absence of institutional arrangements) between two range state dyads (i.e. 4.6.%; China–Taiwan, Taiwan–Australia), whilst the hunting management architecture presented institutional gaps between five range state dyads (i.e. 11.6%; China–Taiwan, Taiwan–Australia, Republic of Korea–USA,

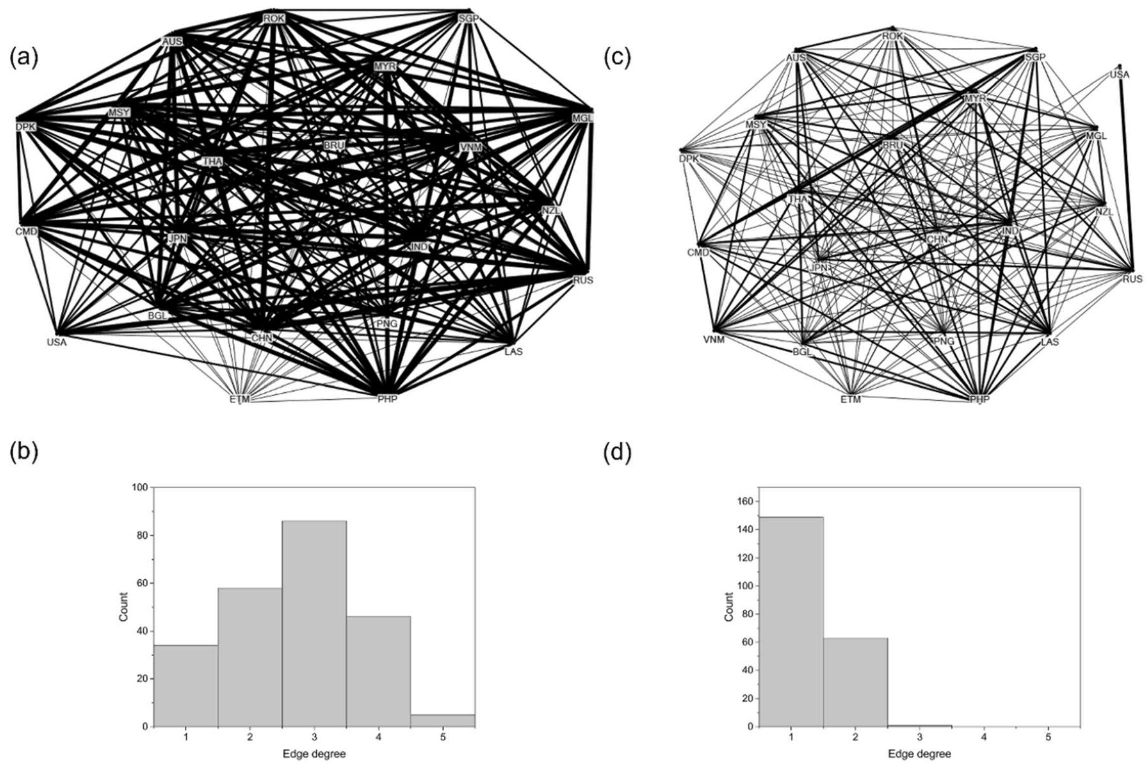

Fig. 2 Decomposed country-to-country network of institutional arrangements (top) and edge degree distribution (bottom) for habitat designation (**a, b**) and hunting management (**c, d**). Taiwan is not included in these network graphs since this range state has not entered any institutional arrangement included in this analysis (see Table S1 for country abbreviations)

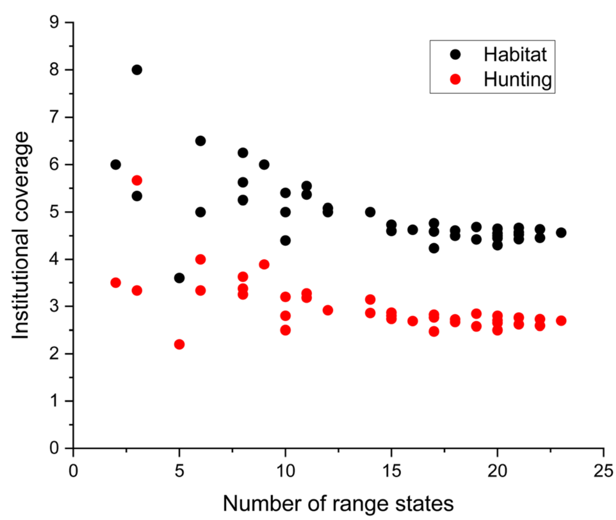

Fig. 3 Average institutional coverage per species for habitat designation (solid black circles) and hunting management (solid red circles) as a function of number of range states in which it occurs

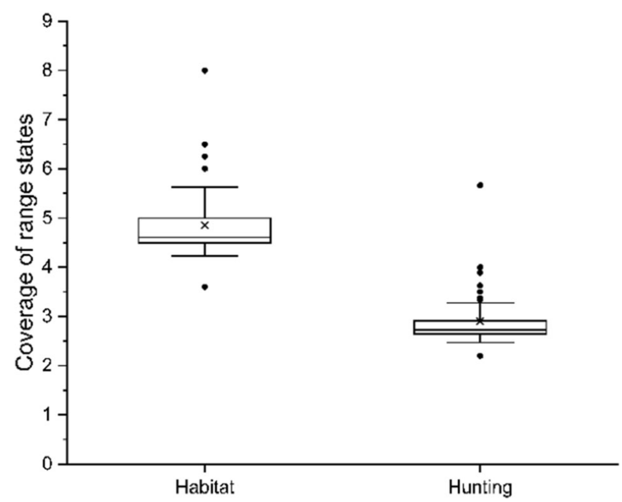

Fig. 4 Box plot of average institutional coverage for habitat designation and hunting management per species in relation to their range states

Australia–USA, New Zealand–USA). These gaps are relevant for two migratory shorebird taxa according to their individual migratory networks, curlew sandpiper (*Calidris ferruginea*) with two dyads (China–Taiwan, Taiwan–Australia) and bar-tailed godwit *baueri* (*Limosa lapponica baueri*) with three range state dyads (Republic of Korea–USA, Australia–USA, New Zealand–USA).

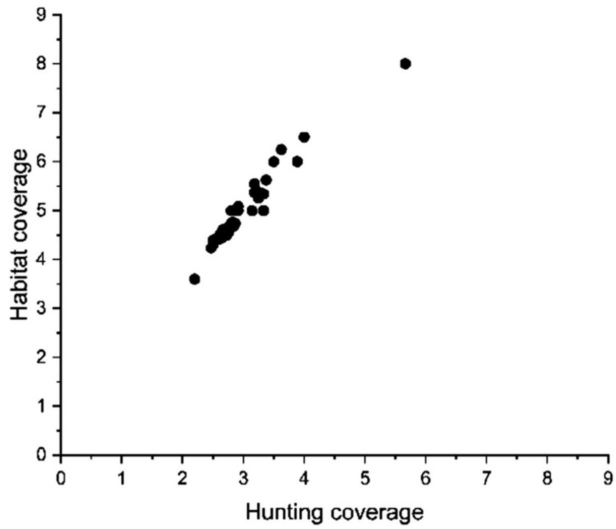

Fig. 5 Correlation between the average institutional coverage for habitat designation and hunting management per species in relation to their range states

DISCUSSION

We discovered relatively higher social-ecological fit for habitat designation compared to hunting management for migratory shorebird conservation in the EAAF across three different social-ecological levels of analysis (i.e. flyway, country occurrence, migratory network). Surprisingly, migratory species conservation has received little empirical attention in a social-ecological fit context despite being an environmental issue identified as a fertile ground for quite some time (Young 2002). Thus, this study is a contribution to the growing quantitative scholarship on social-ecological fit, which has so far focused on smaller spatial scales than the one considered here (Thirgood et al. 2004; Sayles et al. 2019). Despite both governance architectures covering almost the entirety of the EAAF, we also found that the governance architecture for habitat designation is more complex than the hunting management architecture given by the inclusion of more institutional arrangements and participation of actors beyond the nation state. The institutional coverage for habitat designation was also generally higher than for hunting management across all migratory shorebird species. We discovered that the average institutional coverage for each species generally declines as the number of range states increases, with a similar pattern for institutional arrangements for habitat designation and hunting management. Additionally, the migratory network for select shorebird taxa is more comprehensively connected by the habitat designation architecture than the hunting management architecture. These results are significant for informing governance processes for conserving migratory shorebirds in this flyway, as they provide insights to decide whether priority should be on implementation or

Table 2 Average institutional coverage for habitat designation (Habitat) and hunting management (Hunting) for species of conservation concern (BirdLife International 2023) in relation to their range states (for scientific names refer to Appendix S5)

English name	IUCN status	Habitat	Hunting
Asian dowitcher	NT	4.5 (± 2.5)	2.65 (± 1.8)
Bar-tailed godwit	NT	4.7 (± 2.5)	2.7 (± 1.8)
Black-tailed godwit	NT	4.5 (± 2.5)	2.6 (± 1.8)
Curlew sandpiper	NT	4.5 (± 2.5)	2.7 (± 1.8)
Double-banded plover	NT	6 (± 1.4)	3.5 (± 2.1)
Eurasian curlew	NT	4.6 (± 2.4)	2.6 (± 1.7)
Eurasian oystercatcher	NT	5.6 (± 3.2)	3.3 (± 2.5)
Far Eastern curlew	EN	4.6 (± 2.6)	2.7 (± 1.9)
Great knot	EN	4.5 (± 2.6)	2.7 (± 1.9)
Grey-tailed tattler	NT	4.7 (± 2.6)	2.8 (± 1.9)
Latham’s snipe	NT	5 (± 3.7)	3.3 (± 2.7)
Northern lapwing	NT	5.1 (± 2.7)	2.9 (± 2.1)
Red knot	NT	4.7 (± 2.5)	2.8 (± 1.9)
Red-necked stint	NT	4.5 (± 2.4)	2.6 (± 1.8)
Sharp-tailed sandpiper	VU	5 (± 3.0)	3.1 (± 2.2)
Spoon-billed sandpiper	CR	5.0 (± 2.9)	2.8 (± 2.2)
Spotted greenshank	EN	4.7 (± 2.6)	2.8 (± 1.9)
Wood snipe	VU	5.3 (± 3.2)	3.3 (± 2.3)
Average departure from mean		0.33	0.23

institution building given conservation requires resource allocation within limited capacities (Victor et al. 1998; Bottrill et al. 2008; Muñoz et al. 2009). Moreover, this study extends previous research on social-ecological fit for migratory species conservation within the context of large-scale social-ecological systems across the jurisdiction of multiple countries.

Variation in social-ecological fit across functional areas has also been found in other social-ecological systems within the context of migratory species conservation. For instance, the relatively higher social-ecological fit for habitat designation compared to hunting management for migratory shorebirds in the Asia–Pacific was also found for seabirds in the South Pacific, although that study should be considered as preliminary (Gallo-Cajiao et al. 2020b). Conversely, using a spatially explicit approach based on occurrence at a lower social-ecological level of analysis focusing on protected areas, Runge et al. (2015) and Zhang et al. (2023) discovered high spatial misfit across migratory bird taxa at a global level. A similar pattern was found by Li et al. (2019) for migratory shorebirds in the EAAF. Hence, the relatively higher level of fit for habitat designation found in our study needs to be taken cautiously regarding effective conservation because it considered social-ecological fit at a higher social-ecological level of analysis (i.e. flyway level, country level, migratory network level). Such a difference could be driven by the fact that country-level analyses can smooth and overrepresent species occurrence at smaller spatial scales, such as protected areas. This contrasting pattern may indicate the need to reflect carefully on the various analytical approaches adopted when comparing levels of social-ecological fit across functional areas and social-ecological systems.

Given the time and effort required for institution building (Muñoz et al. 2009), we recommend strengthening the implementation process of existing institutional arrangements for habitat conservation. In particular, the high-coordinating capacity of the EAAFP, as shown quantitatively, is also backed by its mandate, which includes supporting the implementation of other institutional arrangements captured in our analysis, such as the Ramsar Convention, the Convention on Migratory Species, the Convention on Biological Diversity, and all the bilateral migratory bird agreements from this flyway. Indeed, implementation of the EAAFP has been identified as an issue requiring attention in the context of its subsidiary Flyway Site Network, whereby sites are designated but their on-ground conservation has remained a challenge (Gallo-Cajiao and Fuller 2015; Gallo-Cajiao et al. 2017, 2019b; Wauchope et al. 2022). Importantly, this implementation deficit has started being addressed through a US$1.5 billion conservation initiative supported by the Asian Development Bank in 2021.[1] The implementation of this investment could potentially benefit from the use of optimal resource allocation frameworks (Martin et al. 2007). Beyond implementation, the Flyway Site Network could still be improved by means of accounting explicitly for the migratory network of movements undertaken by individual birds (Xu et al. 2022; Navedo and Piersma 2023; Zhang et al. 2023).

Considering the ineffectiveness of governance architectures with gaps of social-ecological fit, we suggest a continued focus on institution building in the case of hunting management. Notably, the governance architecture for hunting management lacks an overarching specialised institutional arrangement that includes hunting with a functional mandate for migratory shorebird conservation at a flyway level. This shortcoming is further highlighted by the lack of a flyway-level mechanism to monitoring hunting of migratory shorebirds in this flyway (Gallo-Cajiao et al. 2020a). The recent development of task forces for addressing illegal hunting under the Convention on Migratory Species and the EAAFP are promising steps, yet likely not sufficient (Gallo-Cajiao et al. 2019b). The most recent Meeting of the Partners (MoP 11) of the EAAFP, held in March 2023, indicated that while these task forces have the potential to contribute to problem solving by, *inter alia*, promoting implementation of existing hunting-focused institutional arrangements, they still lack the overarching coordinating capacity to drive sustainable hunting at a flyway level as they exclude legal hunting. Only time will tell whether these two efforts become fully fledged institutional arrangements capable of filling this institutional gap, including the concern for unregulated and legal hunting as they can also drive additive mortality.

The difference in social-ecological fit detected at a flyway level between the two governance architectures is also reflected across all species, being likely modulated by the number of range states involved. Without exception, all species considered as part of the EAAF have higher institutional coverage for habitat designation compared to hunting management. Importantly, this pattern is maintained for those species of conservation concern. Hence, as much as this result signals a system-wide issue, it also indicates that a well-devised approach to correcting this shortcoming may be impactful across many species. Furthermore, when considering the gradient of range states per species, we found that institutional coverage generally decreases as the number of range states involved increases for both architectures. Hence, our analysis supports empirically the proposition that collective action becomes more difficult in the international system as the number of

[1] https://www.adb.org/projects/55056-001/main [accessed on 1st March, 2023]

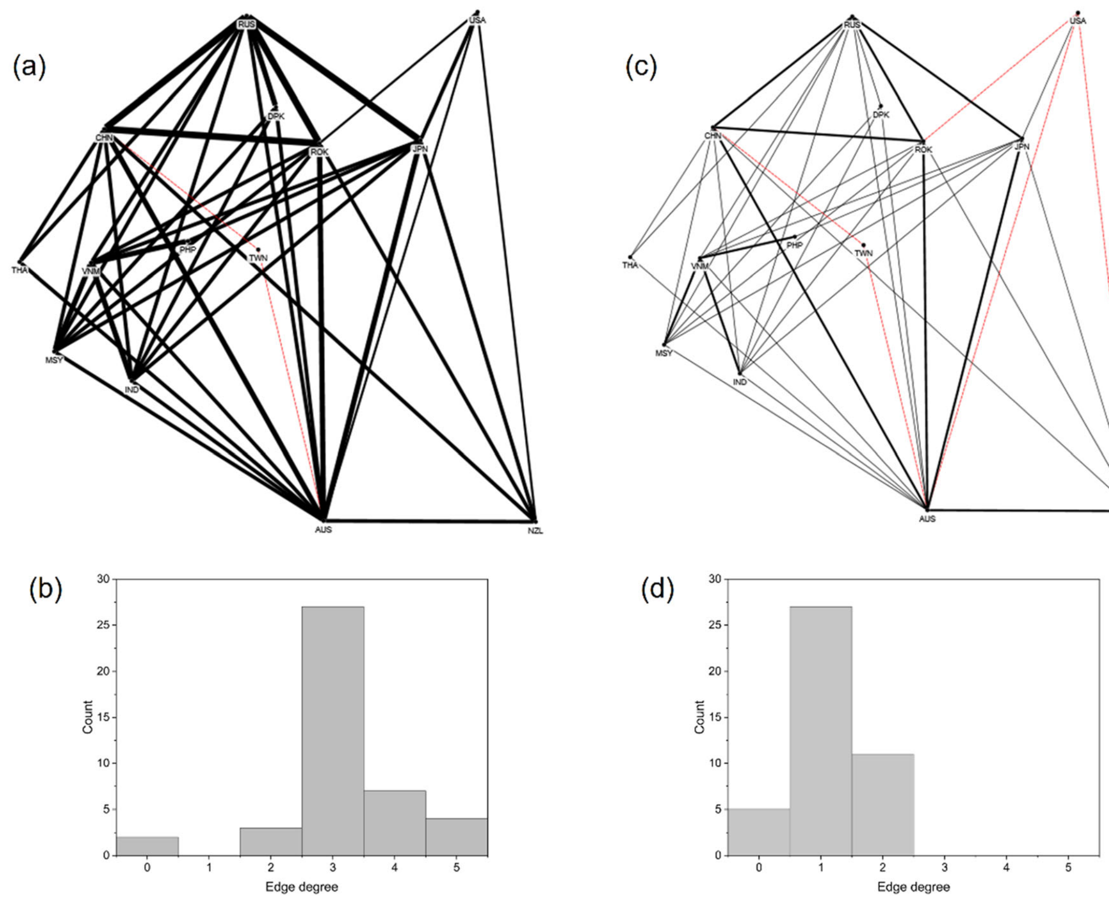

Fig. 6 Connectivity of the migratory network for select shorebird taxa (top), including edge degree distribution (bottom), by the architecture for habitat designation (**a, b**) and hunting management (**c, d**) for conserving migratory shorebirds in the East Asian–Australasian Flyway. Red colour in network graphs indicates migratory ties with no overlapping institutional ties. (See Table S1 for country abbreviations)

actors increases (Snidal 1995). This proposition is also in line with the trade-off between depth and breadth, whereby larger memberships are generally associated with more generic institutional arrangements, whereas more specialised institutional arrangements are more likely associated with smaller memberships (Young 2017). Hence, the difference in social-ecological fit found in our study indicates that the depth and breadth trade-off may have been overcome for habitat designation but not yet for hunting management.

Regarding migratory ties not accounted for by institutional ties, there are two species for which this emerges as a concern given they are both listed as Near Threatened. That is the case of the bar-tailed godwit (*Limosa lapponica*), a polytypic species, and the curlew sandpiper (*Calidris ferruginea*), a monotipic species. In the case of the bar-tailed godwit, the subspecies *baueri* breeds in Alaska, which represents a range state (i.e. USA) missing institutional ties to address hunting management with the Republic of Korea, Australia, and New Zealand. While hunting is unlikely to be currently a concern in the Republic of Korea and Australia, it may represent a real cumulative threat in the case of New Zealand and the USA, where hunting has happened until relatively recently illegally in the former and continues to happen legally in the latter (Gallo-Cajiao et al. 2020a). Additionally, current hunting levels of this taxon in Alaska alone are likely to reach the flyway-wide threshold for sustainable harvest (Naves et al. 2019), which means that any take beyond that level, anywhere else, is likely to result in additive mortality and hence population declines. In the case of the curlew sandpiper, institutional dyadic ties including China–Taiwan and Taiwan–Australia are missing for both habitat designation and hunting management. Given hunting is currently very unlikely to affect shorebirds in Taiwan and Australia (Gallo-Cajiao et al. 2020a), the main concern is related to habitat (Murray et al. 2014; Studds et al. 2017). This institutional gap is given by the lack of recognition of Taiwan as a country by the United Nations due to the One-China policy, which prevents its participation in international institutional arrangements (Gallo-Cajiao et al. 2019a). Interestingly, despite this shortcoming, Taiwan has taken up domestically principles from key institutional arrangements for habitat designation, such as the Ramsar Convention (Su 2014). Additionally, non-state actors may play a key role circumventing geopolitical barriers, as in the case of the Taiwan Wild Bird Federation, a bird conservation-focused NGO that has a flyways program including international cooperation approaches.

The governance architectures for habitat designation and hunting management operate at the node (i.e. sites) level, but do not provide protection at the edge level. This condition means that the corresponding institutional arrangements do not supply structural connectivity between sites, which is usually given by so-called corridors. Instead, sites present functional connectivity likely as a result of the high altitudes at which shorebirds undertake their migratory flights (Newton 2008; Albers et al. 2023). That said, considering the tridimensional migrations of these taxa, some sources of mortality at high altitudes, such as bird-aircraft strikes (Burger 1985), should not be ruled out and could be considered as a potential institutional gap. Importantly, this source of mortality should not be underestimated given the potential aggregate effects across a region with some of the busiest flight paths in the world.[2]

Having multiple institutional arrangements governing a particular issue and functional area may create opportunities and challenges to advance conservation for migratory shorebirds. As for opportunities, more institutional ties may mean potential for more flows of information, norms, resources, innovation, and values, which can subsequently diffuse through the governance architectures to other institutional arrangements and actors (Ostrom 2010). Fora associated with multiple institutional arrangements can also be used strategically by non-state actors, including NGOs and researchers, for venue shopping, whereby they raise agenda items and seek political buy-in to influence the policy process at different policy levers (Pralle 2003). In a region with complex geopolitics, such as the EAAF, having the opportunity for venue shopping can be advantageous, because different institutional arrangements bring together different constituencies (Gallo-Cajiao et al. 2019a). The existence of more than one institutional tie across all range-state dyads can also provide the governance architectures with resilience, since potential removal of institutional ties due to withdrawal from institutional arrangements would not necessarily result in institutional gaps. Within this context, resilience is higher for the habitat designation architecture than the hunting management architecture. As an example of resilience, Russia has become politically isolated from international cooperation for biodiversity conservation in the wake of the invasion of Ukraine. In particular, the Arctic Council, which is part of the governance architectures for habitat designation and hunting management, has now been paused and will exclude Russia when some activities resume in the future, leaving it out of Arctic Council cooperation, which includes efforts for migratory shorebird conservation (Gallo-Cajiao et al. 2023). Despite political isolation, Russia is close to other countries within the region, such as China. These two countries have a bilateral migratory bird agreement that includes work on migratory shorebirds, so this institutional arrangement could potentially provide opportunities to keep working with Russia at a flyway level through brokerage with China. In relation to challenges, multiple institutional arrangements can result in treaty fatigue, whereby actors' capabilities are overstretched by increasing financial and technical requirements, such as meeting attendance and reporting (Muñoz et al. 2009). Furthermore, this condition can create problems of accountability, inefficiencies, and exacerbation of power imbalances between countries (Zürn and Faude 2013; Morrison et al. 2020).

[2] https://openflights.org/

Further research

The analysis presented here opens additional paths for empirical and theoretical enquiry. First, the higher social-ecological fit for habitat designation compared to hunting management seems to be an emerging pattern beyond migratory shorebirds in the EAAF. Hence, researching the likely drivers explaining such a variation would help to unlock potential barriers for correcting issues of social-ecological fit. Second, qualitative research focusing on institutional interplay, understood as cases in which the operation of one institutional arrangement is affected by another one (Oberthür and Stokke 2011), would enrich the empirical basis of the quantitative approach adopted in this study. Third, the burgeoning field of migratory ecology using fine-resolution tracking devices, though still with remaining gaps, has resulted in improved understanding of migratory patterns creating opportunities to conduct additional studies of social-ecological fit based on other migratory taxa, social-ecological systems, as well as social-ecological levels of analysis that can potentially feed into conservation policy (Kays et al. 2015; Dunn et al. 2019; Kauffman et al. 2021; Scarpignato et al. 2023). Fourth, studies of implementation of institutional arrangements in cases where social-ecological fit seems high become paramount, for well-designed rules, need to be ultimately translated into actions on-the-ground to be effective. Last, the institutional dynamics of the governance architectures for habitat designation and hunting management in the EAAF could be studied using the dataset presented here as a baseline, as some institutional arrangements have subsequently become part of them, such as the World Heritage Convention,[3] while others have been disrupted by the Russian invasion of Ukraine (Gallo-Cajiao et al. 2023).

CONCLUSION

Social-ecological fit is not the only factor accounting for effectiveness of governance architectures to conserve biodiversity, but it is certainly a necessary condition. If true implementation of institutional arrangements has become a common mantra for attainment of conservation goals (Brown-Weiss and Jacobson 2000), governance architectures with social-ecological misfit are likely doomed to fail no matter how strictly they are implemented. Hence, assessments of social-ecological fit should be considered a key initial step to be undertaken in conducting institutional analyses to improve conservation governance outcomes. The analysis presented here uncovered how social-ecological fit for habitat designation is higher than for hunting management in the case of migratory shorebird conservation in the EAAF. Based on our results, we recommend prioritising implementation in the case of habitat designation and fostering further institution building in the case of hunting management. While both governance architectures include most range states, the habitat designation architecture is more robust, including an overarching institutional arrangement with spatially explicit provisions. Considering that collective action for biodiversity conservation in transboundary social-ecological systems becomes more challenging as the number of participating countries increases, migratory shorebirds represent one of the biggest challenges of migratory species conservation given their often trans-equatorial migrations involving many countries (Colwell 2010). Hence, it is imperative we take advantage of the golden era of animal tracking technology to further advance empirical and theoretical approaches for studying social-ecological fit of governance systems for conserving migratory species (Katzner and Alettaz 2019).

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[3] https://whc.unesco.org/en/list/1606/ [accessed 1st March 2023].

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Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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