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Identifying the wetlands of international importance in Beibu Gulf along the East Asian – Australasian Flyway, based on multiple citizen science datasets

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The Beibu Gulf (Gulf of Tonkin, Vinh Bac Bo in Vietnamese), located midway along the East Asian-Australasian Flyway (EAAF), is a critical stopover and wintering region for migratory waterbirds. This transboundary coastal region, spanning between China and Vietnam, harbors diverse wetland habitats that provide refuge to waterbird species, including highly threatened species such as the spoon-billed sandpiper (CR) and the black-faced spoonbill (EN). However, the scarcity of comprehensive assessments regarding waterbird abundances, distribution, key wetland habitats, and regional threats hinders our understanding of its conservation significance at the flyway level. Further research is needed to address these knowledge gaps and facilitate effective conservation efforts in the Beibu Gulf. By synthesizing accessible citizen science datasets and published records from wetland sites in south China and northeast Vietnam, we concluded that at least 97 waterbird species used the Gulf's wetlands during their annual cycle. Among surveys conducted from 2014 to 2022, 5 and 11 waterbird species were considered as first and second class protected species under the National Key Protected Wild Animal List in China; 2 species were listed as Critically Endangered on the IUCN Red List, 4 as Endangered and 2 as Vulnerable, underlying the critical importance of the Beibu Gulf for the survival of these

species. Our study identified 25 sites in the Beibu Gulf that met the criteria for designation as internationally important wetlands. Alarming, less than a quarter ($n = 5$, or 20%) of these sites benefit from national or international protection. Localized threats, including aquatic resource harvesting, hunting, and aquaculture/fisheries, were widespread in the region. This study provides a crucial scientific baseline for continued waterbird monitoring, site prioritization, and the development of effective habitat management plans to conserve vital coastal wetland habitats in the Beibu Gulf in China and Vietnam.

KEYWORDS

waterbird, bird conservation, the Gulf of Tonkin, conservation priorities, East Asian-Australasian Flyway (EAAF), citizen science

1 Introduction

Animal migration is a global phenomenon (Dingle and Drake, 2007). Migratory animals, particularly birds, play indispensable ecological roles across multiple ecosystems worldwide (Bauer and Hoye, 2014). Their remarkable journeys, spanning vast distances across large spatial scales and often crossing diverse habitats, contribute to the interconnectedness and functioning of various ecosystems. Throughout their annual cycles, avian species require a sequence of connected sites along their migration routes where they can rest, forage, and accumulate energy reserves (Alerstam and Lindström, 1990). The presence of intact fueling sites along migratory flyways is of paramount importance for migratory birds, as they are essential for refueling and replenishing energy reserves. As among the largest of 9 global flyways, the East Asian-Australasian Flyway (EAAF) stretches at a continental scale from the Arctic Circle across East and Southeast Asia, to Australia and New Zealand and supports over 50 million migratory waterbirds from more than 250 different populations (access by June 25, 2023; <https://www.eaaflyway.net>). Waterbirds, particularly shorebirds (order Charadriiformes), strongly depend on coastal wetlands along their migratory routes as critical habitats. Unfortunately, these waterbird populations are facing alarming declines primarily attributable to a multitude of threats, such as hunting (Gallo-Cajiao et al., 2020), pollution (Ma et al., 2022), and habitat loss (Zhang et al., 2018) and degradation (Ma et al., 2014; Studds et al., 2017) and other forms of unsustainable use such as wetland reclamation (Yang et al., 2020). The imperative to ensure the conservation of migratory bird populations and effectively address the challenges faced by transboundary migrants calls for the urgent establishment of a comprehensive continental network of wetland sites. Relying solely on the protection of a few selected key sites proves insufficient in providing an adequate framework to safeguard these avian species and their habitats (Runge et al., 2014; Dhanjal-Adams et al., 2017; Xu et al., 2020).

The identification and protection of important wetlands for waterbirds will ensure an effective conservation 'safety net' for many species and the long-term survival of migratory waterbirds within the EAAF (Dinerstein et al., 2023). The Convention on Wetlands of

International Importance, also known as the Ramsar Convention, provides internationally recognized criteria to identify wetlands of international importance (Ramsar sites) during the past 50 years (Stroud and Davidson, 2022). Further, some of the sites are already inscribed on the World Heritage List (UNESCO) due to Outstanding Natural Values (e.g., https://whc.unesco.org/en/list/1606/multiple=1&unique_number=2304), as well as the sites identified by the Convention of Migratory Species (CMS) and other international agreements and institutional arrangements (i.e., East Asian–Australasian Flyway Partnership, hereafter as 'EAAFP'), base recognition on the 2 criteria specifically related to waterbird populations. So far, 152 sites, spread over 19 countries, have been included in this Flyway Site Network of EAAFP (access by June 25, 2023; <https://www.eaaflyway.net>). In particular, priority sites along the EAAF, such as those located within the Yellow/Bohai Sea and Australia, and their ecological importance to migratory waterbirds are relatively well studied, profiled, and monitored (Barter, 2002; China Coastal Waterbird Census Group, 2011; Clemens et al., 2016; Wang et al., 2022), and in 2019, several wetland sites such as Yancheng and Dafeng Milu National Nature Reserves were inscribed as UNESCO World Heritage Sites (UNESCO, 2019). Yet, the comprehensive conservation of migratory waterbirds hinges upon the adequate protection of interconnected sites spanning the entire EAAF, including regions such as southern China and Southeast Asia. Despite the importance of these regions, they have often received relatively less attention from conservationists and researchers (Chan et al., 2019; Yong et al., 2022).

The Beibu Gulf (also known as the Gulf of Tonkin, Vịnh Bắc Bộ as it is known in Vietnam; 北部湾 in Chinese) spans the frontiers of China and Vietnam and serves as one of the most important migration stopover and wintering areas for many waterbirds at the interface of Southeast Asia and south China along the EAAF, including critically endangered species such as spoon-billed sandpiper *Calidris pygmaea* (Pedersen et al., 1996; Chang et al., 2020; Nguyen et al., 2021). It is a large, semi-enclosed bay located northwest of the South China Sea, drained by several major rivers such as the Nanliu in China and the Red River in Vietnam. In China, it is bounded by the provinces of Guangxi and Guangdong

and the island province of Hainan. In Vietnam to the south-west of the Bay, it is bounded by several provinces of northeast and central Vietnam from Quang Binh to Quang Ninh. With coastal habitats such as bare tidal flats, salt marshes, mangroves, reefs, and seagrasses, the Beibu Gulf is rich in marine biodiversity, supports key fisheries and aquaculture activities, recreation and tourism, ports, as well as a wide range of ecological services, e.g., storm surges (MacKinnon et al., 2012; United Nations Environment Programme (UNEP), 2014; Teng et al., 2022). More specifically, this region provides nursery habitats for “living fossils”, namely horseshoe crabs (Kwan et al., 2021), and critical habitats for migratory species such as black-faced spoonbill *Platalea minor*, spoon-billed sandpiper and spotted greenshank *Tringa guttifer* (Nguyen et al., 2021; Nguyen et al., 2023). Despite the ecological importance of the Beibu Gulf, research on migratory waterbirds in this part of the EAAF remains relatively limited. Based on the ringing and flag resighting records in Guangxi, Yi et al. (2023) demonstrated the migration connectivity between the Beibu Gulf and Tasmania in Australia, Chukotka in Russia, and Jiangsu in China. In Vietnam, Xuan Thuy National Park (NP) has been well recognized for its importance to the black-faced spoonbill and spoon-billed sandpiper and has been regularly surveyed since the 1990s (Pedersen and Nielsen, 1998). Besides, there are substantial knowledge gaps in Southeast Asia, including Vietnam (Choi et al., 2016; Yong et al., 2022; Nguyen et al., 2023). Vietnam has a well-established network of protected areas, but very few coastal wetlands are included (Rambaldi et al., 2001). According to Yong et al. (2022), Vietnam has 13 coastal Important Bird and Biodiversity Areas (IBAs), supporting 12 threatened bird species. Globally threatened species, such as Saunders’s gull *Saundersilarus saundersi*, have been recorded in the Red River Delta of north Vietnam (Pedersen and Nielsen, 1998), while great knot *Calidris tenuirostris* and spoon-billed sandpiper were recorded in the Mekong Delta, Southern Vietnam (Zöckler et al., 2016; Nguyen et al., 2023).

The densely populated Beibu Gulf has historically played a vital role in the economies of China and Vietnam, being particularly important for the production of seafood for both countries while supporting important biodiversity, including waterbirds (Qiu et al., 2008; Teng et al., 2022). Given an accelerating pace of development in both countries, particularly with the implementation of the Beibu Gulf Economic Rim, there is an urgent need to synthesize the distribution and abundance of waterbirds across the Gulf based on emerging knowledge and data and expand the identification of priority sites in the Beibu Gulf to guide effective conservation actions. Although 4 sites within the Gulf have been recognized as IBAs or Ramsar sites in China and several more in Vietnam (see Pedersen et al., 1996), recent bird surveys have indicated or discovered that additional sites may be important, and these sites should be included in the protected area network. Thus far, the absence of systematic waterbird survey data poses a significant challenge in accurately demarcating and defining the important coastal wetlands within the Beibu Gulf. This data gap hampers the implementation of effective conservation plans and policies to preserve these ecologically significant areas. Compounding the issue is the limited accessibility of related publications, which are predominantly available in vernacular languages. This language

barrier impedes the smooth exchange of information and hinders effective communication and collaboration among international stakeholders (Amano et al., 2023).

In this study, we compile survey data from multiple sources of citizen science datasets across both countries and apply these data against internationally recognized criteria of the Ramsar Convention and the East Asian-Australasian Flyway Partnership. We delineate several new sites of significance to waterbird conservation. Based on all citizen science and open-access records collected from China and Vietnam, we aim to: 1) review the priority sites for waterbird conservation based on waterbird abundance and distribution; 2) identify the threats and conservation status of these sites in the region.

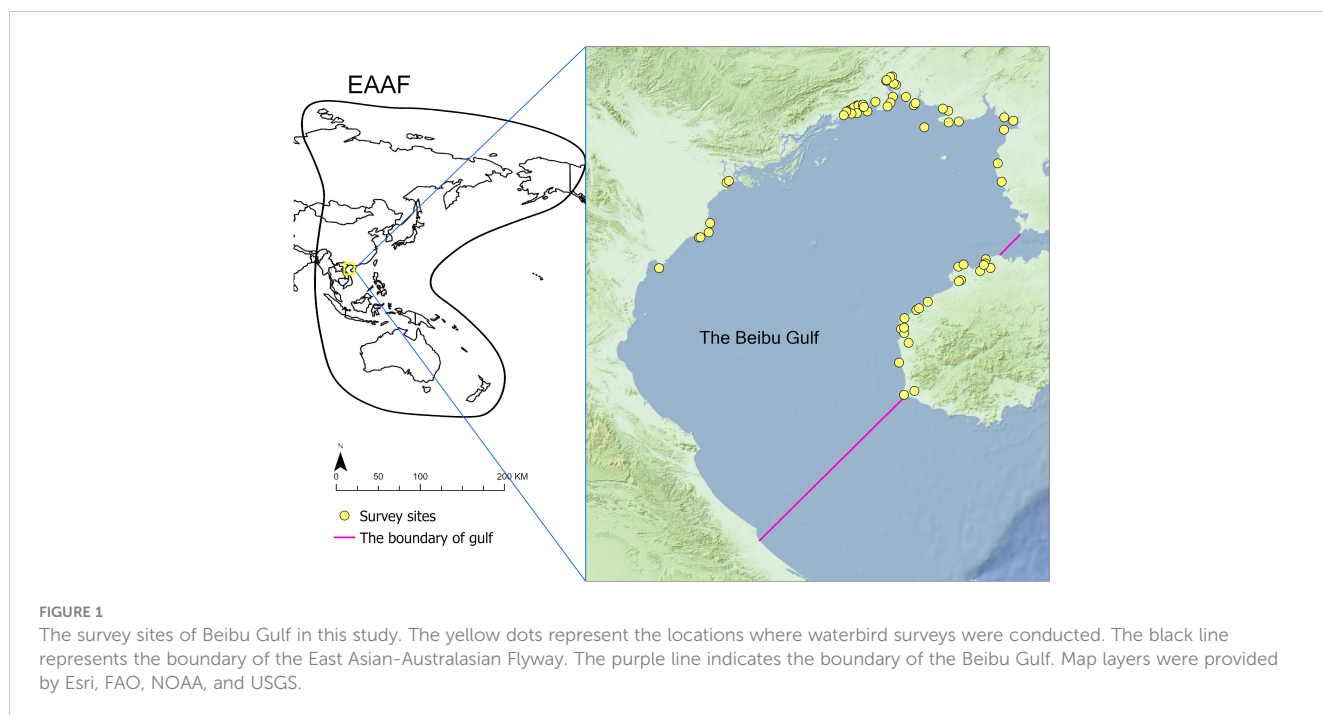
2 Methods

2.1 Study area

The Beibu Gulf is a semi-enclosed bay in the northwest of the South China Sea, bounded to the north by southeast China (Leizhou Peninsula, Qiongzhou Strait, and Hainan Island) and to the south by the provinces of northeast and central Vietnam (Figure 1, Zou, 2005). It covers an area of approximately $12.8 \times 10^4 \text{ km}^2$. Being an important node of the EAAF, the Beibu Gulf provides crucial stopover, wintering, and staging grounds, including temporary resting places and foraging areas sites for migratory waterbirds.

2.2 Data sources and processing

The data used in this study were obtained from the Guangxi Biodiversity Research and Conservation Association, the Zhanjiang Mangrove National Nature Reserve in Guangdong Province, Haikou Duotan Wetlands Institute & Hainan Bird Watching Society in China. In Vietnam, data was compiled from Xuan Thuy National Park and ongoing projects from Vietnam National University, BirdLife International and Vietnam Nature Conservation Centre (Viet Nature). The dataset covers the years from 2014 to 2022, with survey data from Guangxi province for 6 years (2017–2022), data from Hainan Island for 2021 and 2022, and data from Zhanjiang in Guangdong Province for 2019, 2020, and 2022. Data from northern Vietnam ranged from 2014 to 2022, covering sites including Xuan Thuy National Park, Thai Binh Wetland Conservation Area (now administratively merged with a part of Tien Hai Nature Reserve), An Hai IBA (2021), Tien Hai IBA (2021), and Tra Co IBA (2014, 2016 and 2017). Generally, one or two surveys were conducted in each site per year, details see Table S1. Based on the data from the Guangxi Biodiversity Research and Conservation Association’s public monitoring report on the biodiversity of coastal wetlands from 2014 to 2020 and research on the threats faced by coastal wetlands in Vietnam, as well as data in the published literature (Li et al., 2020), we summarized the threats within this region. The data was analyzed using Python (3.10.6; Python Software Foundation, 2022) tools, including Panda (1.4.2; Pandas Development Team, 2022) and Numpy (1.23.1;



Harris et al., 2022), and the spatial information was integrated and analyzed using ArcGIS Pro 3.0.2 (Esri, 2018).

2.3 Criteria for areas of significance for waterbird conservation

In this study, the criteria for wetlands of international importance under the Ramsar Convention were employed to assess the significance of sites for the conservation of waterbirds. If a site met at least one of the criteria at any point, it was considered significant for waterbird conservation. By applying these criteria, we aimed to identify and prioritize sites that are crucial in supporting waterbird populations and their conservation efforts. Specifically, based on the Ramsar Convention Secretariat (2016), two criteria related to waterbirds and one to species and ecological communities, namely ‘A wetland should be considered internationally important if it supports vulnerable, endangered, or critically endangered species or threatened ecological communities (Criteria 2)’, ‘A wetland should be considered internationally important if it regularly supports 20,000 or more waterbirds (Criteria 5)’ and ‘A wetland should be considered internationally important if it regularly supports 1% of the individuals in a population of one species or subspecies of waterbird (Criteria 6)’.

3 Results

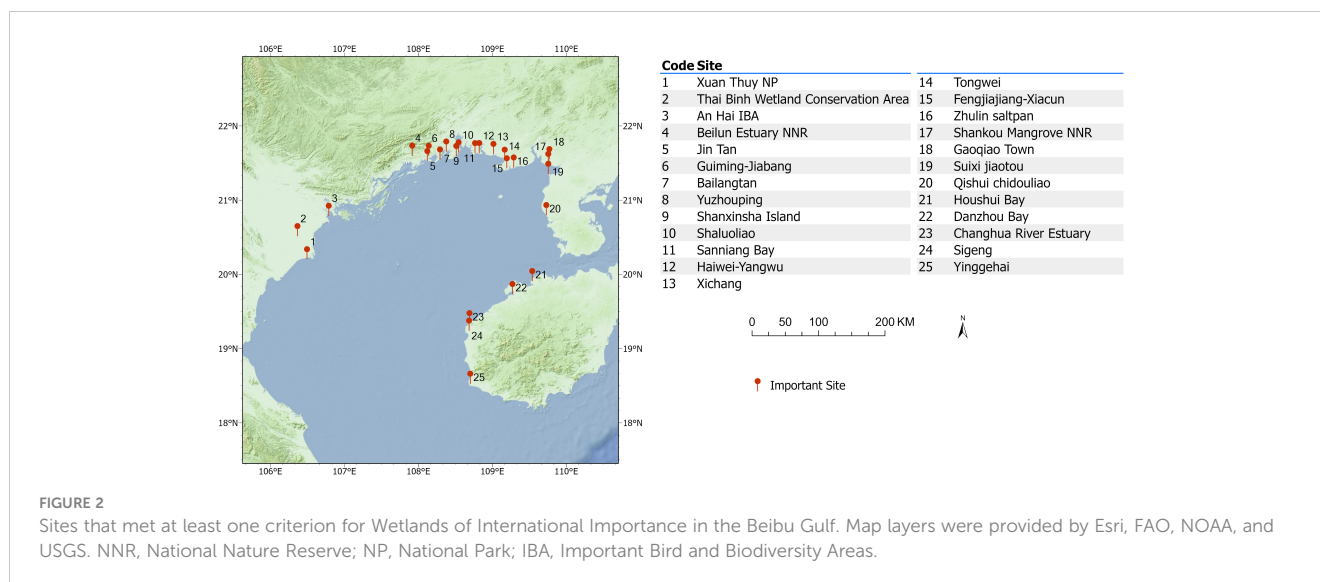
3.1 Identification of sites of International Importance

From October 2014 to January 2022, a total of 66 sites were surveyed in the Beibu Gulf, with a total of 4571 records noted. Based

on the criteria, 25 sites were identified as of Importance and met either Criteria 2 or Criteria 6, as no site met Criteria 5 (Figure 2, details can be found in Table 1). Specifically, 7 Chinese sites (Jintan, Bailangtan, Shaluoliao, Haiwei-Yangwu, Xichang, Fengjiajiang-Xiacun, Danzhou Bay) and 2 Vietnamese sites (Xuan Thuy NP and An Hai IBA) satisfied two criteria. The site of Zhulin Saltpan fulfilled Criteria 6, while the other 15 sites (Thai Binh Wetland Conservation Area, Beilun Estuary NNR, Guiming-Jiabang, Yuzhouping, Shanxinsha Island, Sanniang Bay, Tongwei, Shankou, Gaoqiao Town, Suixi Jiaotou, Qishui Chidouliao, Houshui Bay, Changhua River Estuary, Sigeng, Yinggehai) met Criteria 2. Besides, Xuan Thuy NP (in 2021 and 2022), Shaluoliao (years from 2020 to 2022), and Shanxinsha Island (in 2021 and 2022) qualified as important sites for more than two years.

3.2 Species abundance and distribution along the Beibu Gulf

According to the comprehensive analysis of survey data, a total of 97 bird species were observed and documented (refer to Table S2). Considering the highest recorded count for each species, the findings revealed several noteworthy avian species that exhibited a significant level of abundance within the observed area. The most abundant species, based on their maximum recorded counts from a single survey at specific site, included black-headed gull *Chroicocephalus ridibundus* ($n = 4710$, Haiwei-Yangwu, 2018), lesser sand plover *Charadrius mongolus* ($n = 4200$, Danzhou Bay, 2022), Kentish plover *Charadrius alexandrinus* ($n = 3151$, Fengjiajiang-Xiacun, 2022), black-tailed godwit *Limosa limosa* ($n = 2900$, An Hai IBA), and dunlin *Calidris alpina* ($n = 2200$, Haiwei-Yangwu, 2021). These findings highlighted the significance



of the surveyed sites for these species in the Beibu Gulf. Five of the 97 observed bird species belonged to the first class, while 11 fell under the second class of the National Key Protected Wild Animal List of China. Notably, the IUCN Red List (IUCN, 2023) provided valuable insights into the conservation status of certain bird species. The spoon-billed sandpiper and Christmas Island frigatebird *Fregata andrewsi* were categorized as Critically Endangered (CR), indicating an extremely high risk of extinction. Additionally, four species, namely the black-faced spoonbill, Far Eastern curlew *Numenius madagascariensis*, great knot, and spotted greenshank, were classified as Endangered (EN), denoting a significantly high risk of extinction. Furthermore, two species, the Saunders's gull and black-legged kittiwake *Rissa tridactyla*, were designated as Vulnerable (VU). These findings underscored the significance of the Beibu Gulf in safeguarding the survival and well-being of wintering and/or staging populations of these species, emphasizing the urgent need for conservation efforts. The species and their distribution can be found in Table 1.

A noteworthy observation emerged recently as 11 species exhibited population sizes surpassing the 1% threshold (The specific observed year and survey data see Table S3). Specifically, the lesser sand plover in Danzhou Bay in Hainan, China, reached 2.1% of its flyway population. With respect to criterion 2, which focuses on threatened species (Table 2), notable sightings were recorded for the spoon-billed sandpiper (IUCN, 2023, CR) and the black-faced spoonbill (IUCN, 2023, EN). The spoon-billed sandpiper was observed in 9 sites, while the black-faced spoonbill was sighted in 11 sites. It is worth highlighting that Xichang in Guangxi, China, was found to support a population of spoon-billed sandpipers ($n = 8$) exceeding 1% of its global population estimate. Using the most conservative 1% estimate, thus 4 individuals instead of 8 for spoon-billed sandpipers (Green et al., 2021), the number of sites qualified as internationally important remains the same. But an additional seven sites (Bailangtan, Shanxinsha Island, Haiwei-Yangwu, Shaluoliao, Danzhou Bay, Xuan Thuy NP and An Hai IBA) should be considered as important to the conservation of this species. Similarly, Saunders's gull populations exceeding 1% of its

global population estimate were observed in these regions. Moreover, Xuan Thuy NP in Vietnam supports a wintering congregation of black-faced spoonbills surpassing the 1% threshold. These findings underscored the significance of these specific sites in supporting these threatened bird species.

3.3 Conservation Status

Out of the 25 designated wetland sites recognized as internationally significant, three sites located in China have been designated as national nature reserves, namely Sigeng located in Sibi Bay National Wetland, Beilun Estuary NNR, and Shankou Mangrove NNR. In Vietnam, 2 of these important wetland sites are protected, namely Xuan Thuy NP and Thai Binh Wetland Conservation Area (including Thai Thuy and Tien Hai, which were defined formerly as separate IBAs). These collective efforts contribute to the conservation and protection of wetland habitats in the region. Yet, the remaining 20 sites (80%) are located outside the national protected area system. 13 unprotected areas in China (Jintan, Bailangtan, Shanxinsha Island, Shaluoliao, Sanning Bay, Haiwei-Yangwu, Gaoqiao Town, Suixi Jiaotou, Qishui Chidouliao, Houshui Bay, Danzhou Bay, Changhua River Estuary, and Yinggehai, Figure S1) were located within or close to Ecological Redline boundaries (Choi et al., 2022), which is a spatial planning framework to protect areas that provide essential ecosystem services while biodiversity conservation could be a byproduct, thus providing some level of protection to these unprotected sites. In Vietnam, An Hai IBA, which overlaps with the major city of Hai Phong, supports some of the most extensive intertidal flats left in north Vietnam, but remains unprotected and is now being partly reclaimed for development (Nguyen et al., 2023).

Two unprotected sites located in Guangxi, China, namely Xichang and Haiwei-Yangwu, and An Hai IBA in Vietnam were of particular concern (Tables 2, S3). The urgency stems from the fact that these sites host a populations of threatened bird species that exceed the 1% threshold. More specifically, surveys in Xichang

TABLE 1 Summarized details of sites identified as of Importance in Beibu Gulf.

Code	Site	Chinese/ Vietnamese	Longitude	Latitude	Fulfilled criteria	Species	Threats	References
1	Xuan Thuy NP*	Vườn quốc gia Xuân Thủy	106.49502	20.196527	C2,C6	black-faced spoonbill (80), Kentish plover (1050), spoon-billed sandpiper (4) , spotted greenshank (1)	Not applicable	
2	Thai Binh Wetland Conservation Area* (formerly Thai Binh and Tien Hai IBAs respectively)	Khu bảo tồn đất ngập nước Thái Bình	106.653056	20.608061	C2	black-faced spoonbill (1)	Fishing, killing and harvesting aquatic resources; Storms and flooding; Increased fragmentation within protected area; Agricultural and forestry effluents; Aquaculture/fisheries; Disturbance to birds; hunting (mist net and gun)	Thai Thuy_ecosystem Health Index_methodology_EN
3	An Hai IBA*	IBA An Hải	106.78919	20.781943	C2,C6	black-tailed godwit (2900), broad-billed sandpiper (930), Kentish plover (1093), spotted redshank (300), great knot (370) , spoon-billed sandpiper (4) , Saunders's gull (40)	Illegal hunting (mist nets and traps); land reclamation and infrastructure expansion	
4	Beilun Estuary NNR	北仑河口国家级自然保护区	107.91759	21.592412	C2	black-faced spoonbill (1)	Not applicable	
5	Jintan	金滩	108.12175	21.518719	C2,C6	Kentish plover (1319), Saunders's gull (6)	Harvesting aquatic resources; tourism; Habitat fragmentation	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
6	Guiming-Jiabang	贵明-佳邦	108.14083	21.590397	C2	spotted greenshank (1) , Saunders's gull (1)	Verchle disturbance, Aquaculture/fisheries; hunting (mist net)	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
7	Bailangtan	白浪滩	108.29303	21.539825	C2,C6	Caspian tern (265), spoon-billed sandpiper (4) , great knot (6) , spotted greenshank (1)	Harvesting aquatic resources; tourism; habitat fragmentation	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
8	Yuzhouping	渔洲坪	108.37771	21.647684	C2	great knot (50)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; Habitat fragmentation, plastic debris; pollution; Loss and fragmentation of habitat	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
9	Shanxinsha Island	山心沙岛	108.51315	21.587464	C2	spoon-billed sandpiper (7) , great knot (250) , black-legged kittiwake (1) , Saunders's gull (20)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; Habitat fragmentation, plastic debris; pollution; Loss and fragmentation of habitat	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)

(Continued)

TABLE 1 Continued

Code	Site	Chinese/ Vietnamese	Longitude	Latitude	Fulfilled criteria	Species	Threats	References
10	Shaluoliao	沙螺寮	108.54464	21.636425	C2,C6	grey plover (1200), spoon-billed sandpiper (5), great knot (155), black-legged kittiwake (1), Saunders's gull (25)	Not applicable	
11	Sanniang Bay	三娘湾	108.76697	21.625484	C2	black-faced spoonbill (9)	Not applicable	
12	Haiwei-Yangwu	海尾-杨屋	108.82326	21.626847	C2,C6	Caspian tern (395), kentish plover (2400), lesser sand plover (2204), Saunders's gull (500), spoon-billed sandpiper (5), Far Eastern curlew (11), great knot (350), spotted greenshank (1), black-faced spoonbill (9)	Not applicable	
13	Xichang	西场	109.01563	21.615008	C2,C6	Kentish plover (1500), spoon-billed sandpiper (8), Saunders's gull (30)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat, Spartina invasion	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
14	Tongwei	峒尾	109.16816	21.53705	C2	Christmas Island frigatebird (1)	Habitat fragmentation, plastic debris; pollution; Loss and fragmentation of habitat, Spartina invasion	
15	Fengjiajiang-Xiacun	冯家江-下村	109.19611	21.421667	C2,C6	Kentish plover (3151), sanderling (575), spoon-billed sandpiper (1), spotted greenshank (1)	Not applicable	
16	Zhulin Saltspan	竹林盐场	109.29008	21.432297	C6	Kentish plover (2706)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat, Spartina invasion	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
17	Shankou	山口	109.75697	21.479992	C2	Saunders's gull (2)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat, Spartina invasion	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
18	Gaoqiao Town	高桥镇	109.77182	21.545079	C2	black-faced spoonbill (2)	Harvesting aquatic resources	Zhang et al. (2013)
19	Suixi Jiaotou	遂溪角头	109.75663	21.347464	C2	Saunders's gull (2)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat, Spartina invasion	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
20	Qishui Chidouliao	企水赤豆寮	109.73076	20.791424	C2	black-faced spoonbill (5), great knot (32)	Harvesting aquatic resources	

(Continued)

TABLE 1 Continued

Code	Site	Chinese/ Vietnamese	Longitude	Latitude	Fulfilled criteria	Species	Threats	References
21	Houshui Bay	后水湾	109.54024	19.902695	C2	black-faced spoonbill (46)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat	Li et al. (2020)
22	Danzhou Bay	儋州湾	109.27283	19.727545	C2,C6	broad-billed sandpiper (305), lesser sand plover (4200), Caspian tern (421), spotted greenshank (2) , great knot (79) , spoon-billed sandpiper (6) , black-faced spoonbill (38)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); plastic debris; pollution	Public Report on Coastal Wetland Biodiversity; Monitoring in the Beibu Gulf, China (2019-2020; 2014-2019)
23	Changhua River Estuary	昌化江口	108.6917	19.335443	C2	great knot (21)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat	Li et al. (2020)
24	Sigeng	四更	108.68649	19.23434	C2	black-faced spoonbill (47) , Far Eastern curlew (1)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat	
25	Yinggehai	莺歌海	108.70255	18.519624	C2	black-faced spoonbill (7)	Harvesting aquatic resources; Aquaculture/ fisheries; hunting (mist net); miscatch; plastic debris; pollution; Loss and fragmentation of habitat	

*: sites belong to Vietnam. Species in bold indicated species on the IUCN redlist ([IUCN, 2023](#)).

TABLE 2 Globally threatened waterbirds reported at the identified sites, Beibu Gulf.

Common name	Scientific name	IUCN status	Number of sites with record	Identified Site >1% population
spoon-billed sandpiper	<i>Calidris pygmaea</i>	CR	9	Xichang, Guangxi, China
Christmas Island frigatebird	<i>Fregata andrewsi</i>	CR	1	
black-faced spoonbill	<i>Platalea minor</i>	EN	11	Xuan Thuy NP, Vietnam
Far Eastern curlew	<i>Numenius madagascariensis</i>	EN	2	
great knot	<i>Calidris tenuirostris</i>	EN	9	
spotted greenshank	<i>Tringa guttifer</i>	EN	6	
black-legged kittiwake	<i>Rissa tridactyla</i>	VU	2	
Saunders's gull	<i>Chroicocephalus saundersi</i>	VU	9	Haiwei-Yangwu, Guangxi, China

has documented the presence of 8 spoon-billed sandpipers and 1500 Kentish plovers, while Haiwei-Yangwu has reported sightings of 2400 Kentish plovers, 2204 lesser sand plovers, and 500 Saunders's gulls. In Vietnam, the An Hai IBA is estimated to support populations of 2900 black-tailed godwits *Limosa limosa*, 1093 Kentish plovers, 930 broad-billed sandpipers *Calidris falcinellus*, 370 great knots, 300 spotted redshanks, 4 spoon-billed sandpipers, and 40 Saunders's gulls. These numbers highlight the significance of these sites for the survival and conservation of these threatened species (details see Table 2).

3.4 Threats to sites in the Beibu Gulf

By far, the most severe and irreversible threat to biodiversity in this gulf is anthropogenic disturbances. We identified 15 types of threats. The most common ones included harvesting aquatic resources (16 sites), hunting (14 sites), and aquaculture/fisheries (13 sites; Tables 1, S4). Hunting through bycatch (mainly reported in Guangxi, China); illegal mistnetting (e.g., in An Hai, Vietnam; multiple sites in Hainan, China) also threaten waterbirds in the region.

4 Discussion

Coastal wetlands surrounding the Beibu Gulf are important wintering and stopover areas for threatened migratory waterbird species, particularly the spoon-billed sandpipers. The Beibu Gulf, along with the Leizhou Peninsula (Leung et al., 2022), represents the northernmost wintering region for the spoon-billed sandpipers. Notably, 4 flagged spoon-billed sandpipers were repeatedly re-sighted at Xichang between 2016 and 2019, indicating the importance of this site in connecting with birds in Chukotka in Russia and Jiangsu in China where the birds are usually tagged (Yi et al., 2023). Consistent with this finding, Xichang supported >1% population of spoon-billed sandpipers for their stopover. The Beibu Gulf region also supports the wintering or stopover populations of three other endangered shorebird species, namely Far Eastern curlew (present in at least 2 sites), great knot (9 sites), and spotted

greenshank (6 sites). The region is probably the most north-easterly wintering region for all these species and probably a newly identified wintering region for Far Eastern curlews (Higgins and Davies, 1996; Zöckler et al., 2018). Furthermore, the Beibu Gulf is a well-known, important wintering region for the endangered black-faced spoonbills, with records from 11 sites. This region is considered one of the southernmost wintering regions for this species. Given its location at the northern and southern limits of the wintering ranges for several migratory waterbird species, continuous long-term monitoring of these waterbirds in the gulf can provide insights into their responses to climate change (Lehikoinen et al., 2021). The conservation of these endangered waterbird species and their habitats within the Beibu Gulf is of utmost importance for their long-term survival, in parallel with ongoing work to understand the impacts of environmental changes on migratory waterbird populations.

Following the criteria for wetlands of international importance defined by the Ramsar Convention Secretariat (2016), we identified 25 sites that met the criteria of significance to waterbird conservation along the Chinese and Vietnamese coasts of the Beibu Gulf through the integration of citizen science data. Over three-quarters of these important sites were located outside the existing Ramsar or protected areas. In 2014, China introduced the Ecological Conservation Redline (ECRL) policy, which holds exceptional national significance and has a proven history of effective enforcement by regional and local governmental authorities (Bai et al., 2016). Examining the implications of the ECRL, it becomes evident that 13 sites fall within or near the designated redline areas. This indicates the potential for these sites to receive protection under the ECRL policy, as development activities are prohibited in ECRL. The ECRL policy provides a framework for safeguarding these sites and underscores their importance in conserving ecological integrity and promoting sustainable development practices. In 2022, Vietnam passed the directive, 'urgent tasks and solutions to conserve wild and migratory birds', which provides new and important guidance to address conservation issues for migratory species such as hunting, and strengthening the national framework of policies and legislation addressing the protection of threatened species (Directive 4/CT-TTg, 2022; Nguyen et al., 2023).

Our results reinforce the need for urgent protection of important waterbird habitats in the Beibu Gulf to avert further declines of waterbird populations along the EAAF. Increasingly efficient harvesting tools and approaches for seafood products cause greater harvests of invertebrates that may lead to reduced food availability and increased energy cost for waterbirds due to disturbances, while heightening the risk of bycatches (Verhulst et al., 2004; Yasué, 2005; Yasué, 2006). Many areas of intertidal flats are actively being used for the fishery (Verhulst et al., 2004), therefore putting migratory birds in direct conflict with fisheries in both China and Vietnam. Livestock, poultry, and aquaculture were identified as dominant sources of pollutants, e.g., antibiotics in the Beibu Gulf (Wu et al., 2022). Furthermore, other pollutants, including heavy metals and organic contaminations are reported in this region, posing an ecological risk to waterbird species foraging here (Gan et al., 2013; Li et al., 2015). Besides, to reduce the dependency on imported fossil fuels in the Beibu Gulf, wind energy infrastructures can be expected to become more common in the near future. In addition, coastal wetlands along Guangxi province were reclaimed and caused significant habitat fragmentation due to infrastructure needs (e.g., port), commercial developments and coastal engineering (Liu et al., 2023). Similar changes are ongoing in An Hai, Vietnam (Nguyen et al., 2023). Therefore, a sustainable economic development policy balancing environmental protection is urgently needed (Chen et al., 2020).

The protection of the coastal wetland ecosystem and bird habitats in the Beibu Gulf is of utmost importance and requires collaborative efforts from governments, agencies, businesses, and citizens. Strengthening cooperation among these stakeholders is crucial to effectively conserve and manage the ecological environment of the region (Yong et al., 2018). Recent studies utilizing satellite tracking methods have initiated efforts to address these research gaps (Chan et al., 2019). These studies serve as a valuable complement to ground-based field surveys (Putra et al., 2019; Nguyen et al., 2021). However, there is an ongoing and pressing need for further field-based research to address several critical aspects of waterbird conservation in Beibu Gulf. Firstly, understanding the habitat use and local movement by various bird species in different sites is crucial. Secondly, investigating migratory routes and establishing knowledge about migratory connectivity among waterbird populations is imperative. Such research outcomes can guide the identification of priority sites, including IBAs, and inform the planning and establishment of protected areas. Continued field-based investigations are therefore necessary to address these research objectives effectively. Lastly, sustainable development practices that prioritize the preservation of intertidal and supratidal habitats (Jackson et al., 2020) in the Beibu Gulf and ensure the safety of bird populations should be considered and implemented. This includes measures to minimize habitat degradation, pollution, and disturbance. Additionally, efforts should be made to promote the diversity of bird species by conserving their habitats and addressing any potential threats they may face. By fostering collaboration and implementing environmentally friendly practices, it is possible to strive towards the long-term protection and sustainable management of the coastal wetland ecosystem and bird habitats in the Beibu Gulf.

It is important to note that relatively few surveys were conducted in Vietnam (60 sites in China; 6 sites in Vietnam were surveyed). Additionally, some sites, such as IBAs of Tien Hai and Tra Co, were only surveyed once, thus, our limited datasets due to low survey capacity could be a reason why some former important sites appeared to support insignificant waterbird congregations. On the other hand, sites such as Sanning Bay met the important wetland criteria only once, thus, long-term monitoring is needed to see if the record of large number of waterbirds was a rare incident or the site indeed supports a substantial number of waterbirds regularly. Furthermore, the data used in this study encompassed a combination of citizen science observations, publicly available bird records, and unpublished data from local observers. The quality of the data is influenced not only by the resources and capabilities but also by the skills and expertise of the observers. As information about the observers was often lacking, the verification of certain data points may have been challenging, potentially impacting the overall data quality. To address these limitations, future research, monitoring, and conservation effort should consider providing training and learning opportunities for local surveyors, enhancing the resources available to conservation and research organizations in both countries, and promoting transboundary collaboration between researchers, managers, and local observers. Moreover, the information collected in local languages, predominantly Chinese and Vietnamese, should be translated, analyzed, and published to facilitate accessibility and foster effective transboundary conservation efforts for migratory waterbirds (Liu et al., 2020; Amano et al., 2021; Fuller et al., 2021).

In conclusion, the Beibu Gulf, situated along EAAF and shared between China and Vietnam, is a vital stopover and wintering region for migratory waterbirds. Our study, which synthesized citizen science datasets and published records from wetland sites in both countries, revealed the presence of at least 97 waterbird species in the Gulf during the migration period. Among these species, some are highly threatened, such as the spoon-billed sandpiper and the black-faced spoonbill, are highly threatened and face significant conservation challenges. In addition, our research identified 25 sites within the Beibu Gulf that qualify as internationally important wetlands, including many for the first time and therefore underscoring the region's significance for waterbird conservation. However, it is concerning that only a small fraction of these sites receive adequate protection, with less than a quarter benefiting from national or international protection and recognition. This study also shed light on localized threats faced by these waterbird habitats, including aquatic resource harvesting, hunting, and aquaculture/fisheries, which are widespread in the region. Addressing these threats is essential to ensure the survival and well-being of the diverse waterbird species that rely on the gulf's wetlands. With the findings from this study, we emphasize the urgent need for continued waterbird monitoring, effective site prioritization, and the development of comprehensive habitat management plans. By bridging knowledge gaps and implementing conservation measures, stakeholders in both China and Vietnam can work collaboratively to protect and preserve the critical waterbird habitats in the Beibu Gulf, securing the future of these migratory species and maintaining the ecological integrity of this important coastal region.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary Material](#). Further inquiries can be directed to the corresponding authors.

Author contributions

C-YC and YM contributed to the conception and design of the study. CA, CC, GL, FL, HN, QN, TL, SW, and TH participated in data collection through fieldwork in their respective countries. NT, SL, YY, LL, and PQ organized and analyzed the database. YM performed the statistical analysis. NT and YM wrote the first draft of the manuscript. DY and C-YC edited the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

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Conflict of interest

Author QN is employed by WildTour Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at <https://www.frontiersin.org/articles/10.3389/fmars.2023.1222806/full#supplementary-material>

SUPPLEMENTARY TABLE 1

Summary of survey sites and survey effort along the Beibu Gulf.

SUPPLEMENTARY TABLE 2

Recorded avian species and their maximum counts observed during a survey at a specific site in the Beibu Gulf.

SUPPLEMENTARY TABLE 3

Waterbird species exhibited population sizes surpassing the 1% threshold.

SUPPLEMENTARY TABLE 4

Summary of threats recorded in the Beibu Gulf.

SUPPLEMENTARY FIGURE 1

Sites within or close to Ecological Redline boundaries.

References

- Alerstam, T., and Lindström, Å. (1990). "Optimal bird migration: the relative importance of time, energy, and safety," in *Bird migration: physiology and ecophysiology*. Ed. E. Gwinner (Berlin, Heidelberg: Springer Berlin Heidelberg), 331–351. doi: 10.1007/978-3-642-74542-3_22
- Amano, T., Berdejo-Espinola, V., Akasaka, M., de Andrade Junior, M. A. U., Blaise, N., Checco, J., et al. (2023). The role of non-English-language science in informing national biodiversity assessments. *Nat. Sustain.* 6, 845–854. doi: 10.1038/s41893-023-01087-8
- Amano, T., Berdejo-Espinola, V., Christie, A. P., Willott, K., Akasaka, M., Báldi, A., et al. (2021). Tapping into non-English-language science for the conservation of global biodiversity. *PLoS Biol.* 19, e3001296. doi: 10.1371/journal.pbio.3001296
- Bai, Y., Jiang, B., Wang, M., Li, H., Alatalo, J. M., and Huang, S. (2016). New ecological redline policy (ERP) to secure ecosystem services in China. *Land. Use Policy* 55, 348–351. doi: 10.1016/j.landusepol.2015.09.002
- Barter, M. (2002). *Shorebirds of the Yellow Sea: Importance, threats and conservation status*. Canberra, Australia: Wetlands International Global Series 9, International Wader Studies 12.
- Bauer, S., and Hoyer, B. J. (2014). Migratory animals couple biodiversity and ecosystem functioning worldwide. *Science* 344, 1242552. doi: 10.1126/science.1242552
- Chan, Y., Tibbitts, T. L., Lok, T., Hassell, C. J., Peng, H., Ma, Z., et al. (2019). Filling knowledge gaps in a threatened shorebird flyway through satellite tracking. *J. Appl. Ecol.* 56, 2305–2315. doi: 10.1111/1365-2664.13474
- Chang, Q., Syroechkovskiy, E. E., Yakushev, N., Anderson, G. Q. A., Insua-Cao, P., Green, R. E., et al. (2020). Post-breeding migration of adult Spoon-billed Sandpipers. *Wader Study* 127, 200–209. doi: 10.18194/ws.00201
- Chen, X., Foley, A., Zhang, Z., Wang, K., and O'Driscoll, K. (2020). An assessment of wind energy potential in the Beibu Gulf considering the energy demands of the Beibu

- Gulf Economic Rim. *Renew. Sustain. Energy Rev.* 119, 109605. doi: 10.1016/j.rser.2019.109605
- China Coastal Waterbird Census Group (2011). China coastal waterbird census report 1.2008-12.2009. (Hong Kong Bird Watching Society). Available at: <https://cms.hkbws.org.hk/cms/en/resource/publication/regional-publication/category/41-cwcc-report-en>.
- Choi, C.-Y., Rogers, K. G., Gan, X., Clemens, R., Bai, Q.-Q., Lilleyman, A., et al. (2016). Phenology of southward migration of shorebirds in the East Asian-Australasian Flyway and inferences about stop-over strategies. *Emu - Austral Ornithol.* 116, 178–189. doi: 10.1071/MU16003
- Choi, C., Shi, X., Shi, J., Gan, X., Wen, C., Zhang, J., et al. (2022). China's Ecological Conservation Redline policy is a new opportunity to meet post-2020 protected area targets. *Conserv. Lett.* 15, e12853. doi: 10.1111/conl.12853
- Clemens, R., Rogers, D. I., Hansen, B. D., Gosbell, K., Minton, C. D. T., Straw, P., et al. (2016). Continental-scale decreases in shorebird populations in Australia. *Emu - Austral Ornithol.* 116, 119–135. doi: 10.1071/MU15056
- Dhanjal-Adams, K. L., Klaassen, M., Nicol, S., Possingham, H. P., Chadès, I., and Fuller, R. A. (2017). Setting conservation priorities for migratory networks under uncertainty. *Conserv. Biol.* 31, 646–656. doi: 10.1111/cobi.12842
- Dinerstein, E., Joshi, A. R., Vynne, C., Lee, A. T. L., Pharend-Deschênes, F., França, M., et al. (2023). A “Global Safety Net” to reverse biodiversity loss and stabilize Earth's climate. *Sci. Adv.* 6, eabb2824. doi: 10.1126/sciadv.abb2824
- Dingle, H., and Drake, V. A. (2007). What is migration? *Bioscience* 57, 113–121. doi: 10.1641/B570206
- Directive 4/CT-TTg (2022). Available at: [https://en.Vietnamplus.vn/government-takes-action-to-protect-wild-birds/229319.vnp#:~:text=Hanoi%20\(VNA\)%20%2D%20Deputy%20Prime,important%20bird%20regions%20and%20seven](https://en.Vietnamplus.vn/government-takes-action-to-protect-wild-birds/229319.vnp#:~:text=Hanoi%20(VNA)%20%2D%20Deputy%20Prime,important%20bird%20regions%20and%20seven).
- Esri (2018). *ArcGIS pro (Version 3.0.2)* (Redlands, CA: Environmental Systems Research Institute).
- Fuller, R. A., Jackson, M. V., Amano, T., Choi, C.-Y., Clemens, R. S., Hansen, B. D., et al. (2021). Collect, connect, upscale: Towards coordinated monitoring of migratory shorebirds in the Asia-Pacific. *Aust. Zool.* 41, 205–213. doi: 10.7882/AZ.2020.027
- Gallo-Cajiao, E., Morrison, T. H., Woodworth, B. K., Lees, A. C., Naves, L. C., Yong, D. L., et al. (2020). Extent and potential impact of hunting on migratory shorebirds in the Asia-Pacific. *Biol. Conserv.* 246, 108582. doi: 10.1016/j.biocon.2020.108582
- Gan, H., Lin, J., Liang, K., and Xia, Z. (2013). Selected trace metals (As, Cd and Hg) distribution and contamination in the coastal wetland sediment of the northern Beibu Gulf, South China Sea. *Mar. Pollut. Bull.* 66, 252–258. doi: 10.1016/j.marpolbul.2012.09.020
- Green, R. E., Syroechkovskiy, E. E., Anderson, G. Q. A., Chang, Q., Chowdhury, S. U., Clark, J. A., et al. (2021). New estimates of the size and trend of the world population of the spoon-billed sandpiper using three independent statistical models. *Wader. Study.* 128, 22–35. doi: 10.18194/ws.00218
- Harris, C. R., Millman, K. J., van der Walt, S. J., Gommers, R., Virtanen, P., Cournapeau, D., et al. (2022) *Array programming with NumPy (Version 1.23.1)*. Available at: <https://numpy.org/>.
- Higgins, P. J., and Davies, S. J. F. (Eds.) (1996). *Handbook of Australian, New Zealand & Antarctic birds. Volume 3, snipe to pigeons* (Melbourne: Oxford University Press).
- IUCN. (2023). *The IUCN red list of threatened species. Version 2022-2*. Available at: www.iucnredlist.org (Accessed January 14, 2023).
- Jackson, M. V., Choi, C.-Y., Amano, T., Estrella, S. M., Lei, W., Moores, N., et al. (2020). Navigating coasts of concrete: Pervasive use of artificial habitats by shorebirds in the Asia-Pacific. *Biol. Conserv.* 247, 108591. doi: 10.1016/j.biocon.2020.108591
- Kwan, K. Y., Bopp, J., Huang, S., Chen, Q., Wang, C. C., Wang, X., et al. (2021). Ontogenetic resource use and trophic dynamics of endangered juvenile *Tachypleus tridentatus* among diversified nursery habitats in the northern Beibu Gulf, China. *Integr. Zool.* 16, 908–928. doi: 10.1111/1749-4877.12495
- Lehikoinen, A., Lindström, Å., Santangeli, A., Sirkiä, P. M., Brotons, L., Devictor, V., et al. (2021). Wintering bird communities are tracking climate change faster than breeding communities. *J. Anim. Ecol.* 90, 1085–1095. doi: 10.1111/1365-2656.13433
- Leung, K.-S. K., Choi, C.-Y., Clark, N. A., He, T., Martinez, J., Ren, X., et al. (2022). A closed-population mark-resighting estimate of the number of Spoon-billed Sandpipers at Leizhou Peninsula, Guangdong Province, China during the boreal winter. *J. Asian Ornithol.* 38, 22–28. doi: 10.17863/CAM.78585
- Li, F., Lu, G., Chan, B. P. L., Zheng, X., Zhou, Z.-Q., and Mo, Y.-N. (2020). Status of wintering waterbirds on Hainan Island: results of annual waterbird surveys between 2008-2020. *Forktail* 36, 79–89.
- Li, P., Xue, R., Wang, Y., Zhang, R., and Zhang, G. (2015). Influence of anthropogenic activities on PAHs in sediments in a significant gulf of low-latitude developing regions, the Beibu Gulf, South China Sea: Distribution, sources, inventory and probability risk. *Mar. Pollut. Bull.* 90, 218–226. doi: 10.1016/j.marpolbul.2014.10.048
- Liu, J., Yi, C., Tang, S., Zhang, W., Wen, K., Qin, C., et al. (2023). Impact of coastal island restoration engineering and subsequent tourism on migratory waterbirds: a 3-year case from Southern China. *Restor. Ecol.*, e13974. doi: 10.1111/rec.13974
- Liu, J., Yong, D. L., Choi, C.-Y., and Gibson, L. (2020). Transboundary frontiers: an emerging priority for biodiversity conservation. *Trends Ecol. Evol.* 35, 679–690. doi: 10.1016/j.tree.2020.03.004
- Ma, Y., Choi, C. Y., Thomas, A., and Gibson, L. (2022). Review of contaminant levels and effects in shorebirds: Knowledge gaps and conservation priorities. *Ecotoxicol. Environ. Saf.* 242, 113868. doi: 10.1016/j.ecoenv.2022.113868
- Ma, Z., Melville, D. S., Liu, J., Chen, Y., Yang, H., Ren, W., et al. (2014). Rethinking China's new great wall. *Science* 346, 912–914. doi: 10.1126/science.1257258
- MacKinnon, J., Verkuil, Y., and Murray, N. (2012). IUCN situation analysis on East and Southeast Asian intertidal habitats, with particular reference to the Yellow Sea (including the Bohai Sea). Available at: <https://www.iucn.org/content/iucn-situation-analysis-east-and-southeast-asian-intertidal-habitats-particular-reference-yellow-sea-including-bohai-sea-0>.
- Nguyen, H. B., Le, T. T., Phan, V. T., Bui, T. T., Nguyen, V. T., Nguyen, H. Q., et al. (2023). The present status and distribution of the Critically Endangered Spoon-billed Sandpiper *Calidris pygmaea* in Vietnam. *Wader Study* 130, 1–13. doi: 10.18194/ws.00292
- Nguyen, H. B., Nguyen, H. Q., Nguyen, V. T., Bui, T. T., Phan, V. T., and Yong, D. L. (2021). New site in the Gulf of Tonkin coast of northern Vietnam for Spoon-billed Sandpiper *Calidris pygmaea*. *Spoon-billed. Sandpiper. Task. Force. Bull.* 24, 17–19.
- Pandas Development Team. (2022). *pandas: Powerful data analysis toolkit (Version 1.4.2)*. Available at: <https://pandas.pydata.org/>.
- Pedersen, A., and Nielsen, S. S. (1998). The status and conservation of threatened and near-threatened species of birds in the Red River Delta, Vietnam. *Bird. Conserv. Int.* 8, 31–51. doi: 10.1017/S0959270900003610
- Pedersen, A., Thang, N. H., Dung, V. V., and Hoang, T. T. (1996). The conservation of key coastal wetland sites in the Red River Delta. *Hanoi. BirdLife. Int. Vietnam. Program.*
- Putra, C. A., Hikmatullah, D., Zöckler, C., Syroechkovskiy, E. E., and Hughes, B. (2019). Spoon-billed Sandpiper: a new species for Indonesia. *Wader. Study.* 126, 60–63. doi: 10.18194/ws.00135
- Python Software Foundation. (2022). *Python language reference, version 3.10.6*. Available at: <https://www.python.org/doc/3.10.6/>.
- Qiu, Y. S., Zeng, X. G., Chen, T., Yuan, W., and Wang, Y. (2008). Fishery resources and management in South China Sea.
- Rambaldi, G., Bugna, S., and Geiger, M. (2001). Review of the protected area system of Vietnam. *Asean. Biodivers.* 1, 43–51.
- Ramsar Convention Secretariat (2016). *An introduction to the Ramsar convention on wetlands* (Gland, Switzerland: Ramsar Convention Secretariat).
- Runge, C. A., Martin, T. G., Possingham, H. P., Willis, S. G., and Fuller, R. A. (2014). Conserving mobile species. *Front. Ecol. Environ.* 12, 395–402. doi: 10.1890/130237
- Stroud, D. A., and Davidson, N. C. (2022). Fifty years of criteria development for selecting wetlands of international importance. *Mar. Freshw. Res.* 73, 1134–1148. doi: 10.1071/MF21190
- Studds, C. E., Kendall, B. E., Murray, N. J., Wilson, H. B., Rogers, D. I., Clemens, R. S., et al. (2017). Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nat. Commun.* 8, 14895. doi: 10.1038/ncomms14895
- Teng, W., Chunhou, L., Yong, L., and Ren, Z. (2022). Biodiversity and conservation of fish in the beibu gulf. *Pakistan J. Zool.*, 1–62. doi: 10.17582/journal.pjz/20220301040305
- UNESCO. (2019). *World Heritage Committee Decision: 43 COM 8B3—Migratory Bird Sanctuaries along the coast of Yellow Sea-Bohai Gulf of China (Phase 1) (China)*. Available at: <https://whc.unesco.org/en/decisions/7358/>.
- United Nations Environment Programme (UNEP). (2014). *The importance of mangroves to people: A call to action* (Nairobi: UNEP).
- Verhulst, S., Oosterbeek, K., Rutten, A. L., and Ens, B. J. (2004). Shellfish fishery severely reduces condition and survival of oystercatchers despite creation of large marine protected areas. *Ecol. Soc.* 9 (1), 7. doi: 10.5751/ES-00636-090117
- Wang, X., Chen, Y., Melville, D. S., Choi, C.-Y., Tan, K., Liu, J., et al. (2022). Impacts of habitat loss on migratory shorebird populations and communities at stopover sites in the Yellow Sea. *Biol. Conserv.* 269, 109547. doi: 10.1016/j.biocon.2022.109547
- Wu, Q., Xiao, S.-K., Pan, C.-G., Yin, C., Wang, Y.-H., and Yu, K.-F. (2022). Occurrence, source apportionment and risk assessment of antibiotics in water and sediment from the subtropical Beibu Gulf, South China. *Sci. Total. Environ.* 806, 150439. doi: 10.1016/j.scitotenv.2021.150439
- Xu, Y., Si, Y., Takekawa, J., Liu, Q., Prins, H. H. T., Yin, S., et al. (2020). A network approach to prioritize conservation efforts for migratory birds. *Conserv. Biol.* 34, 416–426. doi: 10.1111/cobi.13383
- Yang, Z., Lagassé, B. J., Xiao, H., Jackson, M. V., Chiang, C. Y., Melville, D. S., et al. (2020). The southern Jiangsu coast is a critical moulting site for Spoon-billed Sandpiper *Calidris pygmaea* and Nordmann's Greenshank *Tringa guttifer*. *Bird. Conserv. Int.* 30 (4), 649–660. doi: 10.1017/S0959270920000210
- Yasué, M. (2005). The effects of human presence, flock size and prey density on shorebird foraging rates. *J. Ethol.* 23, 199–204. doi: 10.1007/s10164-005-0152-8
- Yasué, M. (2006). Environmental factors and spatial scale influence shorebirds' responses to human disturbance. *Biol. Conserv.* 128, 47–54. doi: 10.1016/j.biocon.2005.09.015
- Yi, C., Zhang, W., and Jiang, A. (2023). Analyzing the migration patterns of banded waterbirds based on citizen science data: a case study of the coastal area of beibu gulf, Guangxi, southern China. *Chin. J. Wildl.* 44 (01), 118–124. doi: 10.12375/ydxwb.20230113
- Yong, D. L., Jain, A., Liu, Y., Iqbal, M., Choi, C.-Y., Crockford, N. J., et al. (2018). Challenges and opportunities for transboundary conservation of migratory birds in the East Asian-Australasian flyway. *Conserv. Biol.* 32, 740–743. doi: 10.1111/cobi.13041

- Yong, D. L., Kee, J. Y., Aung, P. P., Jain, A., Yeap, C.-A., Au, N. J., et al. (2022). Conserving migratory waterbirds and the coastal zone: the future of South-east Asia's intertidal wetlands. *Oryx* 56, 176–183. doi: 10.1017/S0030605320001374
- Zhang, S. D., Ma, Z., Choi, C. Y., Peng, H. B., Bai, Q. Q., Liu, W. L., et al. (2018). Persistent use of a shorebird staging site in the Yellow Sea despite severe declines in food resources implies a lack of alternatives. *Bird. Conserv. Int.* 28, 534–548. doi: 10.1017/S0959270917000430
- Zhang, W., Yu, N., and Liu, J. (2013). Waterbirds monitoring and status of resources in zhanjiang mangrove reserve. *Wetl. Sci. Manag* 9, 1, 69–71.
- Zöckler, C., Beresford, A. E., Bunting, G., Chowdhury, S. U., Clark, N. A., Fu, V. W. K., et al. (2016). The winter distribution of the Spoon-billed Sandpiper *Calidris pygmaeus*. *Bird. Conserv. Int.* 26, 476–489. doi: 10.1017/S0959270915000295
- Zöckler, C., Li, D., Chowdhury, S. U., Iqbal, M., and Yu, C. (2018). Winter distribution, habitat and feeding behaviour of Nordmann's Greenshank *Tringa guttifer*. *Wader Study* 125 (1), 7–14. doi: 10.18194/ws.00106
- Zou, K. Y. (2005). The sino-Vietnamese agreement on maritime boundary delimitation in the gulf of tonkin. *Ocean Development & International Law* 36, 1, 13–24. doi: 10.1080/00908320590904920