TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 80/2026

A New Decade for Social Changes

Technium Social Sciences Journal
Vol. 80, 296-305, February, 2026
ISSN: 2668-7798
www.techniumscience.com

Adaptations of Migratory Birds Wintering in the East Asian–Australasian Flyway to Climate Change

Joy Min

Chadwick International School, South Korea

joymin0608@gmail.com

Abstract. The East Asian-Australasinan Flyway (EAAF) is home to over 50 million migratory waterbirds annually, many of which rely on stopover habitats like the tidal flats in Songdo, South Korea. The rapid loss of tidal flats in the Yellow Sea region that affects carbon dioxide sinks, paired with rising global temperatures and shifting seasonal patterns, threatens these migratory birds. According to the study by Murray et al. (2018), 16 percent of the world's tidal flats have disappeared and two-thirds of South Korea's tidal flats have been used to expand the city. In some cases, the loss of tidal flats has created significant population declines. For example, the Great Knot's population has suffered a 24% decline with estimates of the death of 90,000 birds [12]. Others have shown resilience to the changing climate, especially larger birds that show more resiliency by shifting migratory pathways to include fewer stopovers or relocating stopovers to less disrupted areas [9]. Differences in migration timing have also been recorded [3]. In order to protect migratory bird populations, protection and conservation efforts should be aimed at preserving a network of stopovers.

Keywords. East Asian–Australasian Flyway, Tidal Flat Loss, Migratory Shorebirds, Stopover Sites, Climate Change

1. Introduction

Songdo is a district located on the west coast of South Korea, with a population of approximately 100,000 to 180,000 residents (KPF). It is selected as a focal site in this research not for its urban characteristics but because it sits within the Yellow Sea, a biogeographic bottleneck of the East Asian–Australasian Flyway where a disproportionate share of migratory shorebirds concentrate during migration, making ecological change at this location especially consequential at the flyway scale. It is widely recognized as a meticulously planned "smart city," characterized by modern infrastructure and sustainability-oriented design. However, just over two decades ago, this area consisted of expansive tidal flat ecosystems along one of the world's most significant migratory bird routes. These tidal flats are characterized by fine-grained, organic-rich sediments that support dense communities of benthic invertebrates, such as polychaete worms, bivalves, and crustaceans, which form the primary food source for migratory shorebirds. The regular inundation and exposure driven by tidal cycles creates highly productive foraging conditions, while the open, low-vegetation landscape offers unobstructed visibility that reduces predation risk. In addition, the Yellow

Sea's coastal geomorphology and prevailing wind patterns provide favorable atmospheric conditions that facilitate energy-efficient flight and predictable stopover timing, making the ecosystem especially compatible with long-distance migration. Each year, hundreds of thousands of shorebirds, including endangered species such as the black-faced spoonbill and the great knot—depend on the Songdo tidal flats as critical resting and feeding sites during their long migrations between breeding grounds in Siberia and wintering habitats in Southeast Asia and Australia. Rapid urban development, shifting climatic conditions, and increasing human intervention have since transformed both the physical landscape and the migratory behavior of these birds [10] [13].

Migratory birds are among the most sensitive indicators of climate and land-use change because their survival depends on a geographically dispersed yet tightly connected network of habitats. Along the EAAF, more than 50 million waterbirds rely on a limited number of coastal stopover sites to refuel during long-distance migrations between Arctic breeding grounds and Australasian wintering areas [14][11]. Climate change has begun to disrupt the environmental cues that govern migration timing, such as temperature thresholds, photoperiod-linked food emergence, and wind regimes, while rapid coastal development has simultaneously reduced the availability and quality of critical stopover habitats [10][7]. Long-term phenological datasets show that rising spring temperatures in East Asia have advanced invertebrate emergence and peak primary productivity, creating temporal mismatches between food availability and bird arrival [3]. At the same time, altered wind patterns associated with climate warming have increased the energetic costs of migration for some species, narrowing the margin for error during long-distance flights (Klaassen et al., 2014).

This convergence of climatic and anthropogenic pressures has prompted a growing body of research examining how migratory birds adapt through altered timing, reduced stopovers, or route reconfiguration [9][3]. However, scholars disagree on whether these behavioral adjustments indicate resilience or instead conceal accumulating physiological stress and long-term population decline. Consequently, understanding how specific stopover sites function within a broader migratory network has become a central concern in avian conservation science. This review presents an intervention that focuses on preserving and restoring a network of stopover habitats in response to changes in the birds' migratory patterns, including reductions in the number of stopovers and shifts in the timing of departure or arrival. This intervention is grounded in evidence that stopover suitability depends on specific biophysical conditions, such as organic-rich sediments that sustain high benthic prey densities, predictable tidal inundation cycles, and favorable wind regimes that reduce flight energy expenditure, which cannot be rapidly replicated once degraded or reclaimed [13][11] Klaassen et al., 2014). Examining stopover sites as interconnected components of a migratory system, rather than as isolated conservation units, is essential for addressing the compound effects of climate change and habitat loss on migratory birds.

This review presents an intervention that focuses on preserving and restoring a network of stopover habitats in response to changes in the birds' migratory patterns, including reducing the number of stopovers and changing the timing of departure or arrival. Examining stopover sites as interconnected components of a migratory system, rather than as isolated conservation units, is essential for addressing the compound effects of climate change and habitat loss on migratory birds.

2. Literature review

In the following sections, a range of studies are surveyed and analyzed how climate change and habitat loss interact to reshape migratory behavior through three distinct geographic lenses. First, the South Korean coastline is analyzed for the direct physical impact of tidal flat reclamation on bird density and energetic carrying capacity. Second, Hong Kong's migratory habitat is discussed to explore how urbanization degrades habitat quality and water chemistry, even when space remains partially protected. Finally, the Coastal China is discussed to analyze the flyway as a whole, investigating how birds reconfigure their migratory routes across a network of stopovers. Collectively, these case studies address the core question of avian adaptation by demonstrating that survival depends not just on finding any landing spot but on the functional integrity and connectivity of specific ecological nodes.

2.1.1. *South Korea: Tidal Flat Loss and Carrying Capacity Compression.* Research on South Korea's west coast has consistently highlighted the outsized importance of Yellow Sea tidal flats for migratory shorebirds. Using global remote-sensing data, Murray et al. (2019) estimate that over 16% of the world's tidal flats have disappeared since the mid-20th century [11]. In South Korea specifically, large-scale reclamation accelerated from the late 1980s through the early 2000s, with major projects such as Saemangeum and the development of Songdo removing extensive intertidal areas within a few decades. Within approximately 10–20 years of these reclamation efforts, monitoring data began to record sharp declines in shorebird abundance and reduced stopover duration, indicating a rapid ecological response to habitat loss. This loss has direct implications for migratory birds' energetic balance.

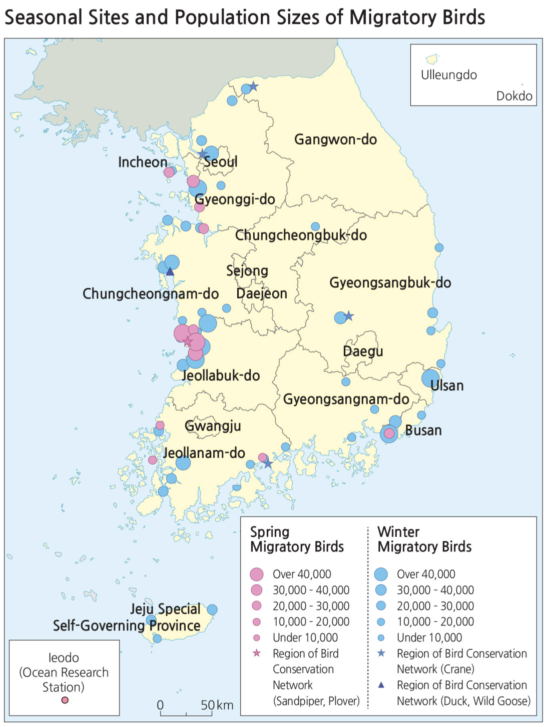

Fig.1: Map of migratory bird population distribution per season in South Korea [12]

Fig. 2: Garolim Bay Tidal Flat in Chungcheongnam-do, South Korea [2]

Research on South Korea’s west coast has consistently highlighted the outsized importance of Yellow Sea tidal flats for migratory shorebirds, as illustrated by the concentration of avian populations across the peninsula’s western coastline (Fig. 1). These environments, such as the Garolim Bay tidal flat (Fig. 2), provide the essential benthic resources necessary for migratory refueling. Using global remote-sensing data, Murray et al. (2019) estimate that over 16% of the world’s tidal flats have disappeared since the mid-20th century [11]. In South Korea specifically, large-scale reclamation accelerated from the late 1980s through the early 2000s, with major projects such as Saemangeum and the development of Songdo removing extensive intertidal areas within a few decades. Within approximately 10–20 years of these reclamation efforts, monitoring data began to record sharp declines in shorebird abundance and reduced stopover duration, indicating a rapid ecological response to habitat loss. This loss has direct implications for migratory birds’ energetic balance.

Technium Social Sciences Journal
Vol. 80, 296-305, February, 2026
ISSN: 2668-7798
www.techniumscience.com

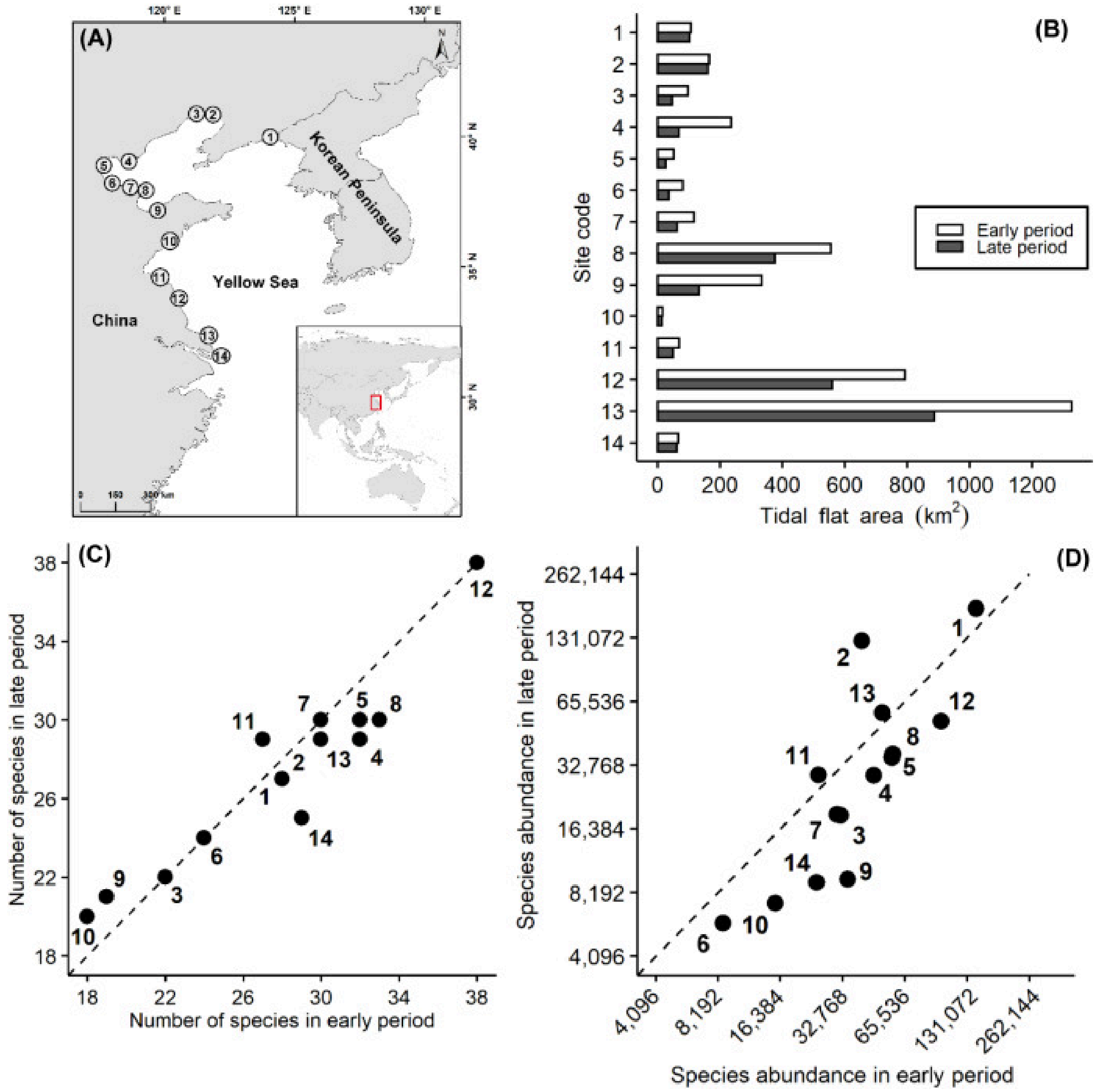

Fig. 3: Distribution (A), tidal flat areas (B), number of species (C) and species abundance (D) of the 14 stopover sites along China's Yellow Sea coast. Site codes: 1: Yalu Estuary, 2: Liaohe Estuary, 3: Jinzhou, 4: Northern Bohai Bay, 5: Tianjin, 6: Southwest Bohai Bay, 7: Southern Bohai Bay, 8: Yellow River Delta, 9: Laizhou Bay, 10: Jiaozhou Bay, 11: Lianyungang, 12: Yancheng, 13: Nantong, and 14: Chongming Dongtan [15].

The quantitative data provided by Wang et al. (2022) in Figure 3 provides the necessary empirical bridge between the localized observations in South Korea and the broader flyway dynamics. Panels B, C, and D of Figure 3 reveal a clear linear relationship between the physical scale of a stopover and its biological richness: sites with the largest remaining tidal flat areas, such as the Yalu Estuary (Site 1) and Yancheng (Site 12), serve as the primary anchors for the population, supporting both the highest number of species and the greatest total abundance. By contrast, smaller sites (such as Jiaozhou Bay, Site 10) show significantly diminished ecological metrics. This data reinforces the "carrying capacity" theory discussed earlier: the physical footprint of the habitat directly dictates the maximum number of birds that can effectively refuel. When reclamation reduces these footprints across the network, the resulting "carrying capacity compression" creates the density-dependent stress mentioned in the South Korean context, as birds from lost habitats are forced to compete for dwindling resources in smaller, overcrowded foraging grounds.

However, while these studies provide robust quantitative evidence of density-dependent stress, they often assume relative stability in migration routes. As climate change accelerates, this assumption becomes increasingly tenuous, raising questions about whether observed declines result primarily from habitat loss or from the interaction between habitat loss and shifting migratory strategies. It is important to address this gap because attributing population declines solely to spatial habitat loss risks overlooking other mechanisms, such as habitat quality degradation and ecological functionality, that may equally constrain birds' ability to refuel and adapt under changing climatic conditions. The following case study from Hong Kong directly engages with this gap by examining how stopover effectiveness can deteriorate even when spatial extent is partially maintained.

2.1.2. Hong Kong: Urbanization, Water Quality, and Partial Protection. On the other hand, research from Deep Bay, Hong Kong complicates a purely crisis-oriented narrative by revealing species-specific responses and partial ecological buffering. Ecologically, Deep Bay is a semi-enclosed estuarine system composed of intertidal mudflats, mangrove forests, and shallow subtidal waters influenced by freshwater discharge from the Pearl River, as seen in the coastal landscape of Ha Pak Nai (Fig. 4) and the spatial layout of protected zones (Fig. 5).

Fig. 4: Ha Pak Nai, Hong Kong [5]

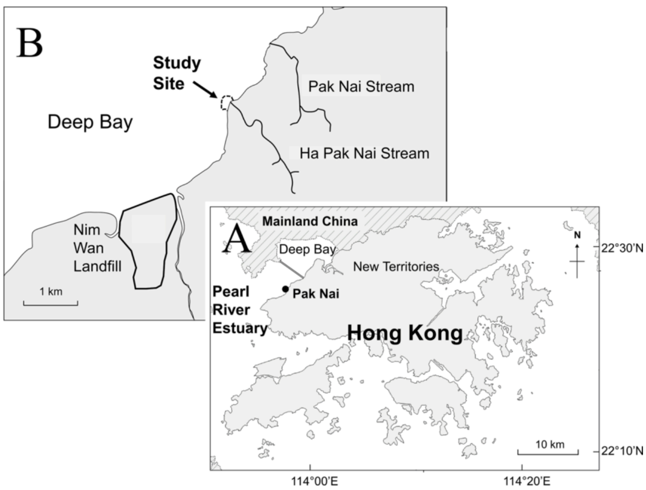

Fig. 5: Map of migratory bird habitats in Deep Bay, Hong Kong [1]

Its fine, silty sediments and nutrient-rich conditions historically supported high benthic productivity, particularly polychaete worms, small bivalves, and crustaceans, making it a critical wintering and stopover habitat for migratory shorebirds along the East Asian–Australasian Flyway. Leung et al. (2024) document how rapid urbanization around Deep Bay has degraded water quality, reducing benthic prey biomass and driving declines in benthic-feeding waterbirds [8]. Urban expansion and intensified wastewater discharge in the Deep Bay catchment increased markedly from the 1990s onward; within roughly two to three decades, nutrient loading and sediment contamination altered benthic community composition, shifting the system from one dominated by invertebrate-rich mudflats to a more degraded estuarine environment less capable of supporting benthic-feeding migrants. Notably, this occurred despite the site's partial legal protection, suggesting that conservation status alone is insufficient when broader catchment-level processes are ignored.

In conversation with Wang et al. (2022) [15], Leung et al.'s findings shift attention from habitat quantity to habitat quality. While South Korean studies emphasize spatial loss and crowding, the Hong Kong case demonstrates that functional degradation, mediated through pollution and hydrological alteration, can similarly undermine stopover effectiveness. At the same time, the observed shift toward water-column feeders indicates a degree of community reassembly rather than uniform collapse [8]. Perhaps, effective conservation must look beyond passive legal "protection" (the prevention of physical building) and move toward active "management," which involves strictly regulating catchment-level industrial runoff and maintaining the chemical balance of the water to ensure the biological productivity of the mudflats remains intact.

2.1.3. Coastal China: Network Dependence and Migration Reconfiguration. Extending beyond individual sites, studies from coastal China underscore the importance of viewing stopovers as nodes within a migratory network (Fig. 6). Studds et al. (2017), using population modeling across multiple Yellow Sea sites—a shallow semi-enclosed marginal sea characterized by extensive intertidal mudflats (Fig. 7), high sediment deposition from major rivers such as the Yellow and Yangtze, and exceptionally high benthic productivity—show that declines in a small number of key stopovers can drive flyway-wide population collapses. This network sensitivity helps explain why some species exhibit abrupt declines even when alternative habitats appear available. In other words, the apparent presence of substitute sites does not guarantee functional redundancy, because the loss of strategically important nodes can disrupt migratory connectivity and energy balance across the entire flyway.

Technium Social Sciences Journal
Vol. 80, 296-305, February, 2026
ISSN: 2668-7798
www.techniumscience.com

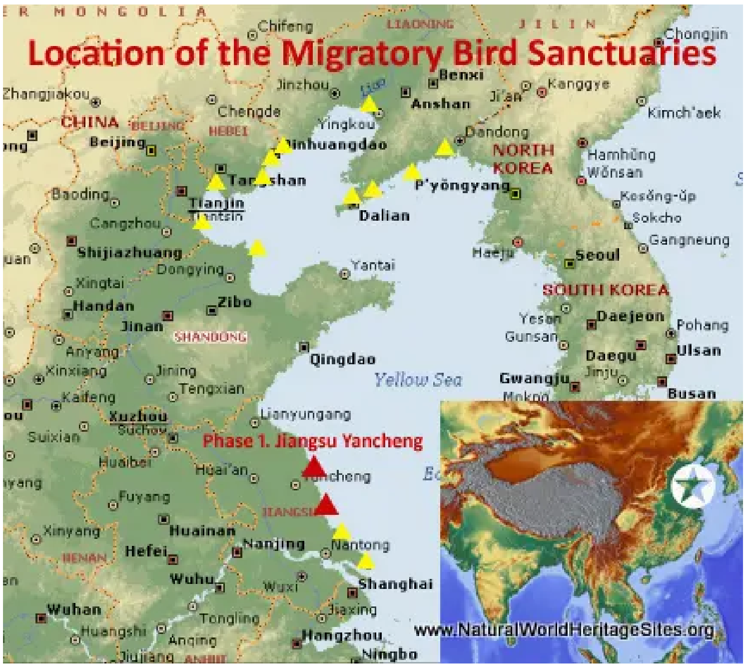

Fig. 6: Map or migratory bird sanctuaries in the Yellow Sea [12]

Fig. 7: Tidal flat, an important shorebird site, in Jiangsu province, China [4]

At the same time, tracking studies suggest that not all species respond uniformly. Lisovski et al. (2024) find that larger-bodied species, such as bar-tailed godwits, demonstrate greater resilience by undertaking longer nonstop flights or reducing the number of stopovers altogether [9]. This contrast is largely driven by physiological and aerodynamic differences: larger-bodied birds can store proportionally greater fat reserves, achieve higher flight efficiency, and better exploit favorable wind assistance, allowing them to bridge longer distances between remaining habitats. In contrast, smaller species with limited fuel capacity, higher mass-specific metabolic rates, and narrower aerodynamic margins remain constrained to traditional routes and frequent refueling, making them disproportionately vulnerable to localized habitat loss [15].

Taken together, these studies align with climate-driven migration research showing shifts in departure timing and route selection [3][7], yet they also reveal a methodological limitation: many models infer resilience from movement data without directly measuring long-term fitness or reproductive outcomes.

References

[1] Chan, Y.-H., Piersma, T., Rogers, D. I., Huig, N. J., Gosbell, K. B., Hassell, C. J., Weston, M. A., et al. (2019). Persistence of shorebird populations in a disturbed and restored habitat. *Animal Conservation, 22*(2), 138–150. https://doi.org/10.1111/acv.12444

[2] Chungcheongnam-do Provincial Government. (2025, February 7). Garolim Bay applies for “World Heritage” listing (Seosan Area). *Chungnam English Media*. https://www.chungnam.go.kr/english/media/article/view.do?articleNo=MD0003113175&menuNo=700023&articleSectNo2=500197

[3] Damba, I., Zhang, J., Yi, K.-I., et al. (2021). Seasonal and regional differences in migration patterns and conservation status of swan geese (*Anser cygnoides*) in the East Asian flyway. *Avian Research, 12*, 73. https://doi.org/10.1186/s40657-021-00308-y

[4] East Asian–Australasian Flyway Partnership. (2026). Invasive Spartina and tidal flat loss in China. *EAAFlyway.net*. https://eaaflyway.net/invasive-spartina-and-tidal-flat-loss-in-china/

[5] Hong Kong Tourism Board. (2026). Ha Pak Nai: Hong Kong’s romantic sunset spot. *Discover Hong Kong*. https://www.discoverhongkong.com/ca/explore/great-outdoor/ha-pak-nai-romantic-sunset-spot.html

[6] Hua, N., Ma, Z., & Piersma, T. (2015). Coastal management and shorebird conservation in China. *Journal of Applied Ecology, 52*(3), 690–695. https://doi.org/10.1111/1365-2664.12423

[7] Kumar, S., Kler, T. K., Sekhon, G. S., & Sahni, T. (2024). Impacts on avian migratory patterns due to climate change and hormonal disruption: A review. *Mitigation and Adaptation Strategies for Global Change, 29*, 69. https://doi.org/10.1007/s11027-024-10163-z

[8] Leung, F. C. C., Doherty, P. D., Liu, M., Metcalfe, K., Godley, B. J., & Lee, S. Y. (2024). Rise and fall of an avian oasis: Tracking the impacts of land use change in a key coastal wetland in the world’s largest megalopolis. *Science of the Total Environment, 906*, 167231. https://doi.org/10.1016/j.scitotenv.2023.167231

[9] Lisovski, S., Hoye, B. J., Conklin, J. R., Battley, P. F., Fuller, R. A., Gosbell, K. B., Klaassen, M., Lee, C. B., Murray, N. J., & Bauer, S. (2024). Predicting resilience of migratory birds to environmental change. *Proceedings of the National Academy of Sciences, 121*(19), e2311146121. https://doi.org/10.1073/pnas.2311146121

[10] Ma, Z., Cai, Y., Li, B., & Chen, J. L. (2014). Managing wetlands for waterbirds: A review. *Wetlands Ecology and Management, 22*(6), 849–865. https://doi.org/10.1007/s11273-014-9383-2

[11] Murray, N. J., Phinn, S. R., DeWitt, M., Ferrari, R., Johnston, R., Lyons, M. B., Clinton, N., et al. (2019). The global distribution and trajectory of tidal flats. *Nature, 565*(7738), 222–225. https://doi.org/10.1038/s41586-018-0805-8

[12] National Atlas of Korea. (2026). Tidal flats. *Nationalatlas.ngii.go.kr*. http://nationalatlas.ngii.go.kr/pages/page_1424.php

[13] Piersma, T., Bruinzeel, L. W., Drent, R., Kersten, M., Koolhaas, J. A., Dekinga, A., van Gils, S., & Piersma, T. (2016). Migratory shorebirds integrate refuge quality and predation risk into their annual scheduling. *Proceedings of the Royal Society B, 283*(1834), 20160272. https://doi.org/10.1098/rspb.2016.0272

[14] Studds, C. E., Piersma, T., Mugerwa, M. J. D., Rogers, D. I., et al. (2017). Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites. *Nature Communications, 8*, 14895. https://doi.org/10.1038/ncomms14895

[15] Wang, X., Chen, Y., Melville, D. S., Choi, C.-Y., Tan, K., Liu, J., Li, J., Zhang, S., Cao, L., & Ma, Z. (2022). Impacts of habitat loss on migratory shorebird populations and communities at stopover sites in the Yellow Sea. *Biological Conservation, 269*, 109547. https://doi.org/10.1016/j.biocon.2022.109547