OFFSHORE SEAWEED AQUACULTURE PROVIDES KEY WINTER ROOSTING HABITATS FOR BLACK-TAILED GULLS *LARUS CRASSIROSTRIS* IN SOUTHWEST KOREA

DAE-HAN CHO[1,2], SANG-MIN JUNG[2], DONG-HYUN KIM[2,3], TAE-WAN KIM[2,4], SI-WAN LEE[2], & HA-CHEOL SUNG[5]*

[1]*School of Biological Sciences and Biotechnology, Chonnam National University, Gwangju, Republic of Korea*
[2]*Korea Institute of Environmental Ecology, Daejeon, Republic of Korea*
[3]*Department of Geography, Jeju National University, Jeju, Republic of Korea*
[4]*Faculty of Science Education, Jeju National University, Jeju, Republic of Korea*
[5]*Department of Biological Sciences, Institute of Sustainable Ecological Environment, Chonnam National University, Gwangju, Republic of Korea *(shcol2002@jnu.ac.kr)*

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ABSTRACT

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Roosts are sites that birds repeatedly use and that provide ecological benefits. Many coastal roosting sites for gulls, however, are increasingly being lost or degraded due to land reclamation and human disturbance. This degradation has created a need for gulls to seek alternative roosting opportunities. The province of Jeollanam-do, in South Korea, supports offshore aquaculture, characterized by floating infrastructure that may offer stable resting substrates. We evaluated whether these aquaculture structures function as floating roost sites for the Black-tailed Gull *Larus crassirostris* and assessed their potential to complement degraded coastal roost habitats. From 2021 to 2024, we tracked 38 adult Black-tailed Gulls using GPS loggers. Roosting behavior was defined as stationary location fixes with a movement speed of 0 km hr^{-1}. Each roosting fix was initially assigned to a land-cover habitat category and subsequently overlaid with spatial polygons representing aquaculture facilities. We classified fixes according to the corresponding aquaculture category and the underlying land-cover type. Statistical analysis showed that during winter, roosting activity was concentrated on offshore aquaculture structures, particularly floating seaweed farms. In contrast, roosting during spring and summer was dominated by terrestrial and intertidal habitats. Diel patterns differed markedly, with daytime roosting primarily occurring in intertidal habitats and nighttime roosting shifting toward marine waters and floating seaweed farms. Overall, our findings identify offshore aquaculture as a roosting resource for Black-tailed Gulls and highlight an underrecognized ecological function of floating seaweed farms. Managing human disturbance and maintaining floating infrastructure during periods of peak winter use may therefore help sustain roosting opportunities in rapidly changing coastal landscapes.

Key words: Black-tailed Gull, offshore aquaculture, seaweed farms, floating roost habitat, GPS tracking, wintering ecology

INTRODUCTION

Roosts are sites where birds settle to rest or sleep, often repeatedly and for extended periods (Eiserer, 1984). Communal roosting is widely thought to confer multiple benefits, including reduced thermoregulatory demands, decreased predation risk (through safety-in-numbers effects), and enhanced foraging efficiency via social information transfer (Beauchamp, 1999; Bijleveld et al., 2010; Eiserer, 1984; Ward & Zahavi, 1973). Because roost-site selection involves trade-offs, the availability and quality of roost sites can influence individual fitness and, ultimately, population persistence (Pearse et al., 2017; Walsberg, 1986). Roost-site selection is typically shaped by a balance among predator avoidance, proximity to foraging areas, and exposure to human disturbance (Clark, DeStefano, et al., 2016; Cresswell, 1994; Rogers et al., 2006; Webb & Blumstein, 2005). Many seabirds use communal roosts, forming aggregations that range from small groups to thousands of individuals (Beauchamp, 1999; Eiserer, 1984). Within the family Laridae, large communal roosts on inland and coastal waters are widespread and may include thousands to tens of thousands of individuals (Gosler et al., 1995; Rao & Babu, 2021).

The Black-tailed Gull *Larus crassirostris* is commonly reported to roost in coastal environments that provide high accessibility to foraging areas and relatively safe conditions, such as marine waters and intertidal flats, as well as port infrastructure and other coastal structures (e.g., piers, breakwaters, and seawalls; Kim et al., 2021; Rao & Babu, 2021; Vernon & Walsh, 1966). Consistent with this pattern, roost-site modeling for Ring-billed Gulls *Larus delawarensis* and European Herring Gulls *Larus argentatus* has indicated that selection is associated with water-body size and proximity to an individual's final daytime location (Clark, Koenen, et al., 2016). However, many coastal zones are increasingly exposed to multiple threats, including land reclamation, pollution, and human disturbance, which may reduce both the availability and suitability of sites (Hua et al., 2015; Ma et al., 2019; Santos et al., 2023). In particular, the southwestern coast of South Korea has experienced substantial losses of potential roosting habitat due to reclamation and coastal construction, and remaining sites are frequently subject to anthropogenic disturbance (Koh & Khim, 2014; Lee et al., 2018). Accordingly, increasing emphasis has been placed on efforts to provide alternative roosting opportunities.

Under these circumstances, floating offshore roosting sites have been proposed as a means of supplementing available roost habitat in areas that may be less affected by coastal development, thereby offering seabirds more stable roosting conditions (East Asian–Australasian Flyway Partnership, 2020; Watchorn et al., 2022).

South Korea is a peninsula with extensive coastline, providing favorable conditions for coastal use, coastal development, and offshore aquaculture (Hwang & Park, 2020; Jo, 2011). In particular, the province of Jeollanam-do on the southwestern coast supports intensive offshore aquaculture, with 5,501 licensed aquaculture operations covering a total area of 121,725 ha (1,217.25 km^2) as of 2024 and producing a wide range of taxa, including seaweed and shellfish (Ministry of Oceans and Fisheries, 2025). Floating aquaculture practiced in deeper waters typically involves the extensive deployment of surface structures, such as buoys and cages, which can provide stable roosting substrates for seabirds using offshore waters and therefore have the potential to function as roosting sites. Consistent with this potential, gulls have frequently been observed roosting on aquaculture buoys across multiple systems (Comeau et al., 2009; Hong & Lee, 2011; Kim et al., 2021; Roycroft et al., 2007). Moreover, aquaculture types that are accessible to seabirds have been reported to be associated with higher seabird abundance and diversity (Scridel et al., 2020). Nevertheless, although aquaculture may represent a poorly understood hotspot for seabird biodiversity, evidence-based evaluations of its conservation value remain limited (Barrett et al., 2019; Kirk et al., 2007).

The Black-tailed Gull is a medium-sized seabird widely distributed across the East Asian–Australasian Flyway (EAAF), with all life-history stages—including breeding, wintering, and non-breeding periods—occurring in coastal or marine areas of Korea, China, Japan, and Russia (Kang et al., 2024; Kazama et al., 2013; Lee & Lee, 2024; Xia et al., 2023). The species is also among the most common seabirds observed in coastal and marine waters of the Yellow Sea, making it a suitable model for evaluating changes in coastal habitat availability and offshore space use (Kim et al., 2014; Moores, 2012; Yang et al., 2011). However, the extent to which offshore aquaculture structures function as seasonal roosts for Black-tailed Gulls in the Yellow Sea, as well as the conditions under which they are used, remains poorly quantified.

Accordingly, this study evaluates whether offshore aquaculture in Jeollanam-do can function as a seasonal roosting habitat for Black-tailed Gulls. Specifically, we assess the potential for these aquaculture structures to serve as floating roosting sites (i.e., stable roosting substrates at sea) and examine their role as offshore roosting habitats that may complement limited or disturbed coastal roosts.

METHODS

From 2021 to 2024, we captured 38 adult Black-tailed Gulls along the western coast of the Korean Peninsula. All captures were of adults and were conducted using a cannon net. Following capture, each bird was placed individually in a cloth bag and immediately transported to the nearest handling station. There, we weighed each bird and attached a solar-powered GPS logger (WT-300; KoEco Inc., Daejeon, South Korea) weighing < 5% of body mass to minimize potential adverse effects (Kenward, 2000). Loggers were mounted as backpacks using a harness made of Teflon ribbon. All birds were released within 30 min of capture and exhibited normal behavior after release. GPS fix intervals were programmed at 1 hr (n = 1), 2 hr (n = 35), and 4 hr (n = 2). To improve positional accuracy, we excluded GPS fixes with a dilution of precision (DOP) value > 5 (Moen et al., 1997; Rempel et al., 1995). Roosting behavior was inferred by classifying GPS fixes with a recorded speed of 0 km hr^{-1} that occurred within suitable roosting habitat as roosting fixes.

To assess whether offshore aquaculture structures function as roosting sites in the marine waters of Jeollanam-do, we extracted tracking locations occurring between the Jeollanam-do coastline and the boundary of South Korea's territorial sea. Offshore aquaculture facilities in the region were categorized into seaweed, shellfish, and integrated farms based on data for 2023 provided by the Korea Hydrographic and Oceanographic Agency (Fig. 1). Because aquaculture methods differ in their capacity to provide perching surfaces, facilities were further classified into the following types: seaweed farms (floating type), seaweed farms (stilt type), shellfish farms (floating type), shellfish farms (bottom type), integrated farms (floating type), and integrated farms (bottom-stilt type). Floating types typically include buoy-based structures and/or cages that provide exposed surfaces suitable for perching (e.g., buoys and cage frames), whereas stilt- or bottom-based methods generally do not provide suitable perching substrates (Fig. 2). Accordingly, each roosting fix was assigned to an aquaculture type when the location fell within the boundaries of an aquaculture facility.

To examine monthly and diel (day–night) differences in roost-habitat use, we reclassified the land-cover map for 2023 provided by the Korean Ministry of Environment (MOE) into nine habitat categories: built-up, agriculture, bare land, grassland, tree cover, wetland, intertidal, freshwater, and marine water. For each roosting fix, the underlying land-cover class was first extracted and then overlaid with a spatial layer of aquaculture facilities (Fig. 3). If a fix overlapped an aquaculture feature that provided above-water perching structures, we assigned it to the corresponding aquaculture type. Fixes overlapping aquaculture features considered unsuitable for perching (e.g., stilt or bottom types) were not assigned an aquaculture category and were instead classified according to the underlying land cover (intertidal or marine water). Because sunrise and sunset times vary seasonally, we defined day and night using daily sunrise and sunset times (Korea Standard Time) calculated with the *getSunlightTimes* function in the "suncalc" package of R (Thieurmel & Elmarhraoui, 2019). Daytime was defined as the period between sunrise and sunset, and nighttime as the period between sunset and the subsequent sunrise.

We used chi-square tests of independence to assess whether the composition of roost-habitat types differed among months and between day and night. When significant differences were detected, we conducted pairwise post hoc comparisons using the *pairwiseNominalIndependence* function in the "rcompanion" package of R to identify month pairs and diel periods that differed in habitat use (Mangiafico, 2017).

RESULTS

The habitat-type composition of roosting fixes differed significantly among months (χ^2 = 32,702, df = 121, p < .001; Fig. 4). Post hoc pairwise comparisons indicated significant differences in habitat-type composition among multiple month pairs (all p < .05). Standardized residuals revealed pronounced seasonal shifts in roost-

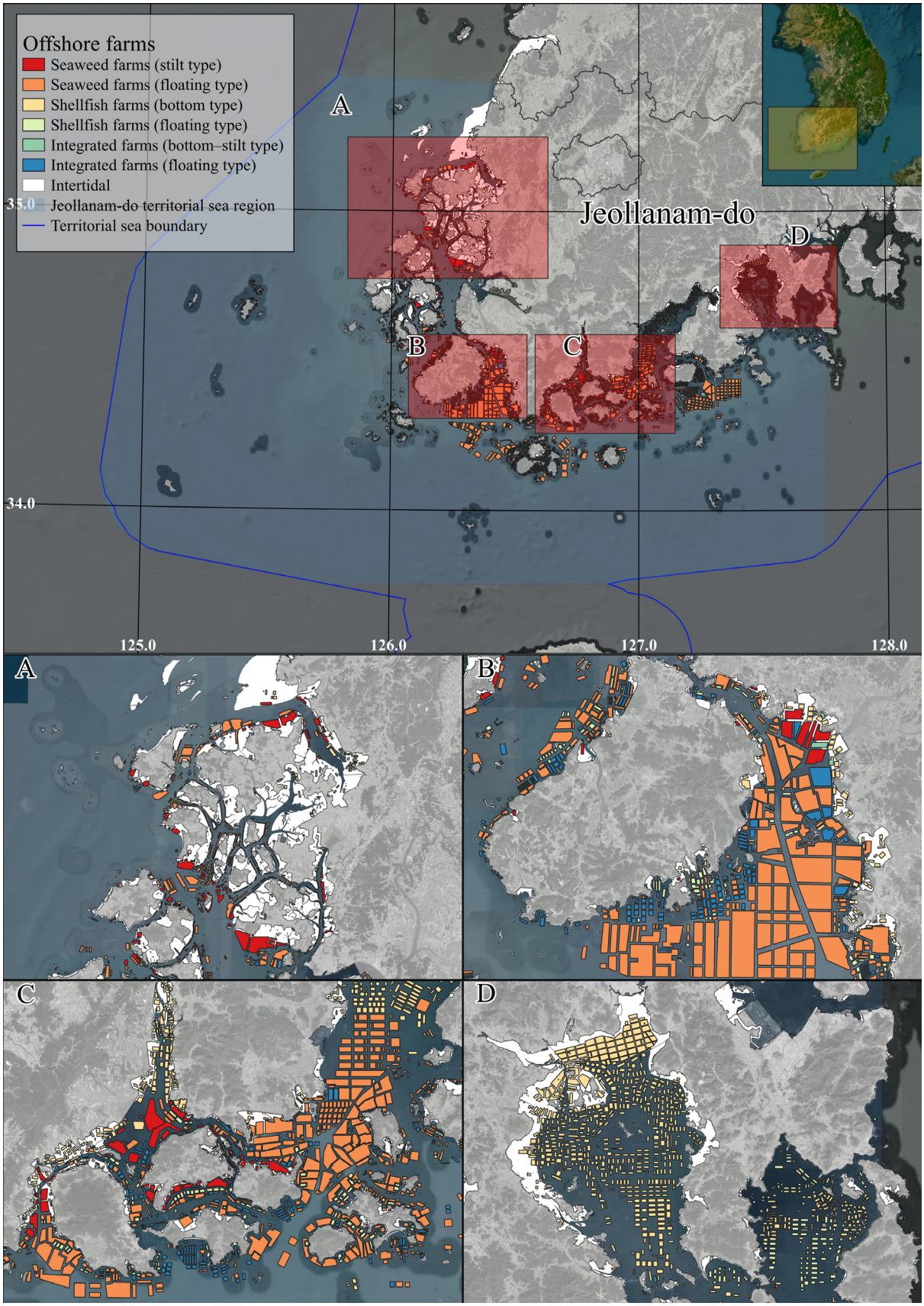

Fig. 1. Spatial distribution of offshore aquaculture farms within the territorial sea of Jeollanam-do, South Korea, in 2023 (top); the inset map at top right shows the region in relation to South Korea. Aquaculture types are distinguished by color: seaweed farms (stilt and floating), shellfish farms (bottom and floating), and integrated farms (bottom-stilt and floating). Panels A–D (bottom) present enlarged views of selected hotspots, illustrating fine-scale farm configurations.



Fig. 2. Photographs of representative offshore aquaculture farm structures in the study area in Jindo-gun, Jeollanam-do, South Korea, taken in December 2024. (A) Seaweed farm (floating type), (B) Seaweed farm (stilt type), and (C) Shellfish farm (floating type). Shellfish farms (bottom type) are not shown because this method relies on intertidal seeding (broadcasting) and lacks above-water structures. Integrated farms are omitted because their surface structures are not readily distinguishable in photographs. Photo credits: Dae-Han Cho

habitat use. Grassland was strongly overrepresented in April and May (standardized residuals = +43.83 and +55.09, respectively; Fig. 4). Intertidal habitat use peaked in July and August (standardized residuals = +30.24 and +42.98, respectively; Fig. 4). In contrast, floating seaweed farms were markedly overrepresented during winter (November–February; standardized residuals = +23.18 to +54.63; Fig. 4) and strongly underrepresented from spring to early autumn (April–September; standardized residuals = −22.99 to −41.69; Fig. 4).

Habitat-type composition also differed significantly between day and night (χ^2 = 19,283, *df* = 11, $p < .001$; Fig. 5). Daytime roosting fixes

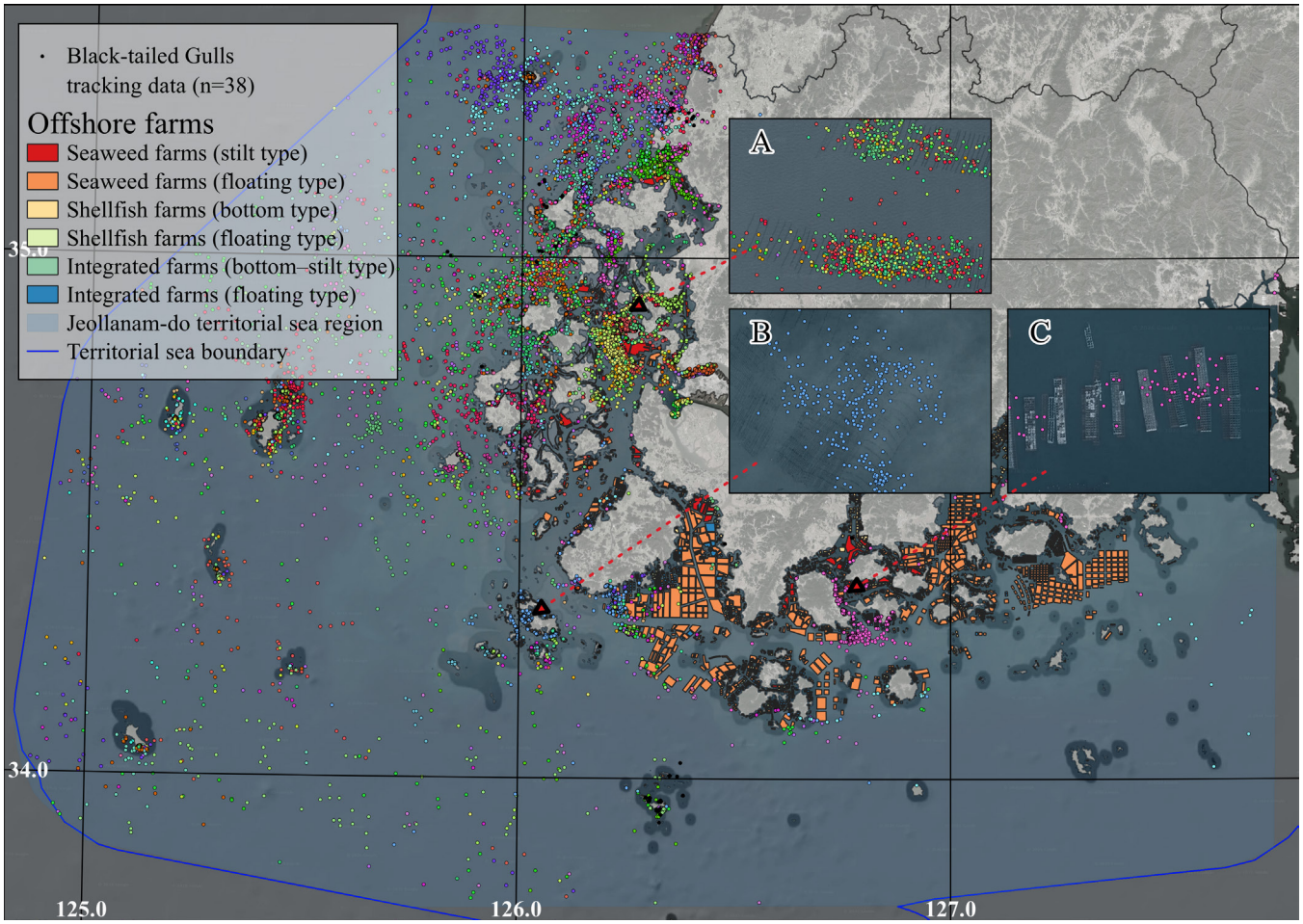

Fig. 3. GPS locations of Black-tailed Gulls *Larus crassirostris* (*n* = 38) recorded from June 2021 to December 2024 within the territorial sea of Jeollanam-do, South Korea, overlaid on offshore aquaculture farms. Panels A–C show representative examples of gull locations associated with floating-type farms: (A) seaweed farms, (B) integrated farms, and (C) shellfish farms.

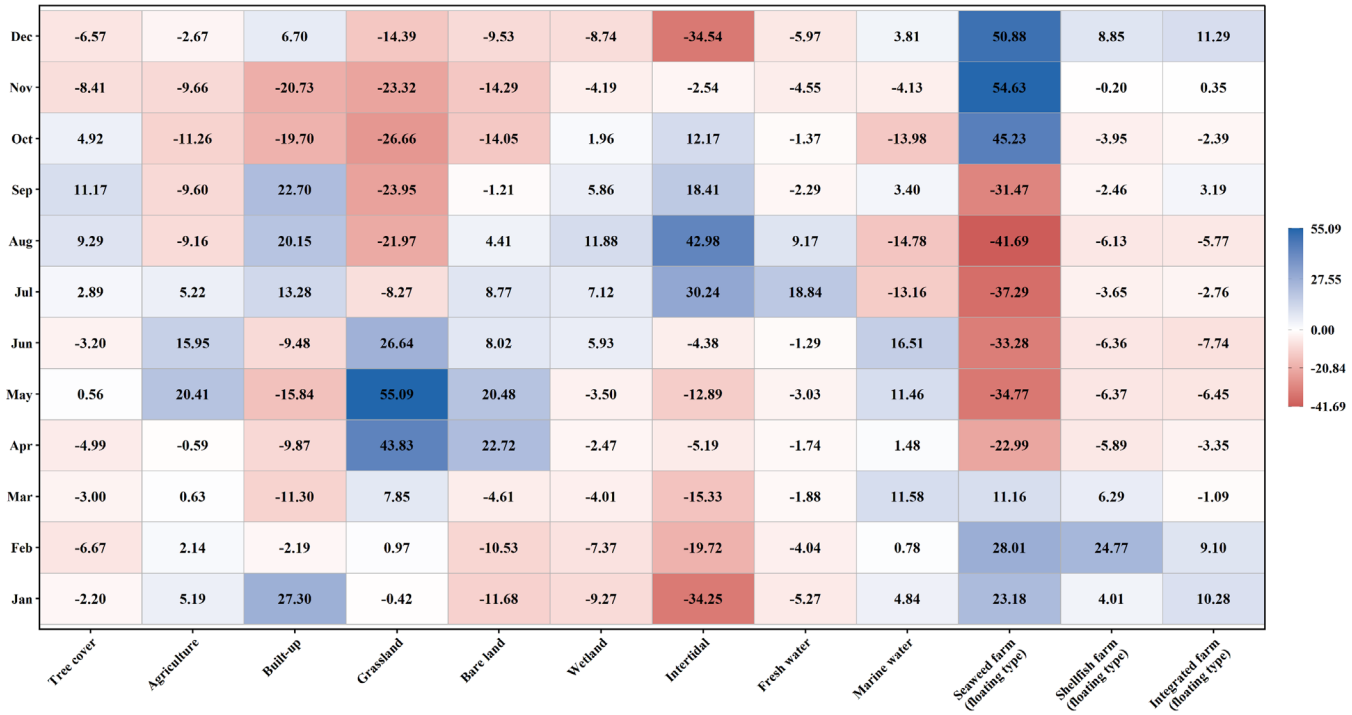

Fig. 4. Heatmap of the standardized residuals from the chi-squared test of independence based on the contingency table between months and habitat types. Residuals of habitat use by Black-tailed Gulls *Larus crassirostris* in the Jeollanam-do, South Korea, study area within each month are displayed in the cells, with blue indicating positive residuals (observed > expected), near-white indicating residuals close to zero (observed ≈ expected), and red indicating negative residuals (observed < expected). Color intensity increases with the absolute value of the residual, reflecting the relative contribution of each cell to the overall chi-squared statistic.

were strongly overrepresented in intertidal habitats (standardized residual = +109.19; Fig. 5). In contrast, nighttime roosting fixes were overrepresented in marine waters (standardized residual = +82.06) and floating seaweed farms (standardized residual = +67.01; Fig. 5).

DISCUSSION

Most studies of roost-site use have relied on visual surveys of known or suspected roosts, which are effective for characterizing sites that are already recognized. In contrast, satellite telemetry enables the tracking of individual gulls across broad spatial and temporal scales, thereby revealing both known roosts and previously undocumented roosting areas (Clark, DeStefano, et al., 2016). Using this approach, we documented previously underreported use of offshore aquaculture structures by Black-tailed Gulls and demonstrated that this use varies seasonally and extends into the nocturnal period. Our analyses revealed a clear temporal structure in roost-habitat use by Black-tailed Gulls in the marine environment of Jeollanam-do. The habitat-type composition of roosting fixes differed markedly among months and between day and night, indicating that roosting is not confined to a single habitat class but instead shifts predictably across the annual cycle and diel period.

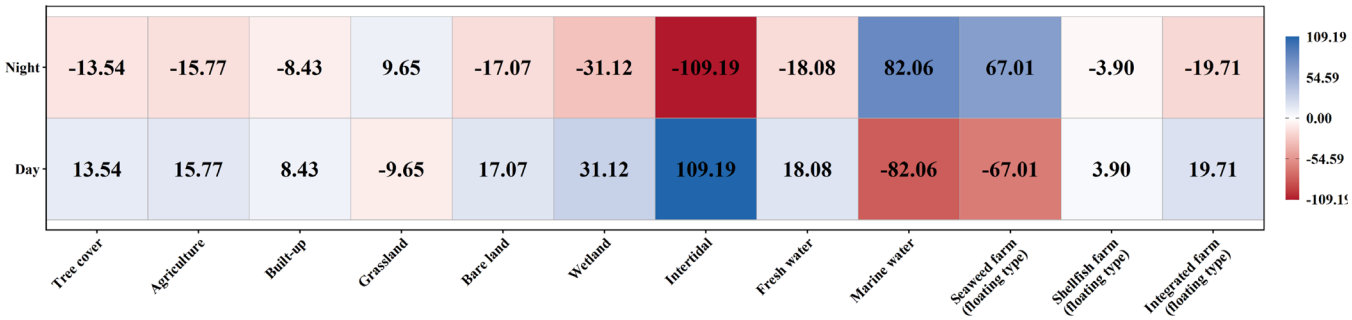

Fig. 5. Heatmap of the standardized residuals from the chi-squared test of independence based on the contingency table between diel period and habitat types. Residuals of habitat use by Black-tailed Gulls *Larus crassirostris* in the Jeollanam-do, South Korea, study area within each diel period are displayed in the cells, with blue indicating positive residuals (observed > expected), near-white indicating residuals close to zero (observed ≈ expected), and red indicating negative residuals (observed < expected). Color intensity increases with the absolute value of the residual, reflecting the relative contribution of each cell to the overall chi-squared statistic.

The pronounced seasonal shifts in roost-habitat use likely reflect both seasonal variation in habitat availability and the advantages of minimizing commuting costs between foraging and roosting areas. Proximity to major feeding grounds is a key determinant of roost site selection because it directly constrains the time and energy budgets associated with daily movements (Clark, DeStefano, et al., 2016; Rogers et al., 2006). For example, roost-site modeling of Ring-billed Gulls and European Herring Gulls demonstrated that roost selection was associated with water-body size and proximity to an individual's final daytime location, highlighting the importance of minimizing movement costs when selecting roost sites (Clark, DeStefano, et al., 2016).

April–May corresponds to the breeding season of Black-tailed Gulls, during which individuals typically forage in nearby coastal and marine areas and return to breeding sites to rest (Orians & Pearson, 1979; Ronconi et al., 2022). Accordingly, the relatively high use of bare land and grassland during April–May likely reflects increased use of breeding-site habitats. However, some stationary fixes (speed = 0 km hr^{-1}) recorded during this period may represent a mixture of resting and breeding-related behaviors, such as incubation or chick-rearing. July–August corresponds to the post-breeding season, and the increased use of intertidal habitats during this period likely reflects the importance of intertidal flats as foraging areas during the non-breeding stage. *Larus* gulls are known to forage extensively on intertidal flats during the post-breeding period, where prey such as small fish and benthic invertebrates are often abundant and relatively predictable (O'Hanlon et al., 2022; Xia et al., 2023). Staying close to these intertidal foraging grounds may allow individuals to combine feeding and roosting while reducing commuting costs, thereby supporting energetic recovery and maintenance of body condition following breeding.

In contrast, during winter, many gulls forage predominantly offshore, often exploiting fishery-related resources by following fishing vessels (Gimeno et al., 2023; Sommerfeld et al., 2016). For individuals that forage far from land, using floating structures at sea as roosting substrates may reduce commuting distances and associated time and energetic costs compared with returning to coastal roosts. This mechanism is likely reinforced by the seasonal availability of offshore aquaculture infrastructure. In Korea, seaweed aquaculture typically begins when seawater temperatures fall below approximately 22 °C (with regional variation, often in late October), and surface structures are maintained through winter into early spring (Hwang & Park, 2020). This operational cycle increases the winter availability of exposed above-water structures, such as buoys and frames, potentially providing stable and predictable resting substrates at sea. Accordingly, the strong winter association with floating-type seaweed farms observed in our study likely reflects the suitability of these structures as offshore roosting sites.

Daytime roosting was concentrated in intertidal habitats, whereas nighttime roosting was more strongly associated with marine waters and floating-type seaweed farms. This elevated nocturnal use of offshore habitats is consistent with previous findings (Lee et al., 2023). The observed diel differences may reflect constraints imposed by reduced visibility. Gulls rely heavily on visual cues to locate food and detect potential predators (Beauchamp, 2009; Cantlay et al., 2025; Lucas et al., 2024). During daylight, gulls can more readily perceive and avoid anthropogenic disturbance and predation risk, whereas at night, limited visual information may increase perceived risk near land and promote greater use of offshore areas (Hébert & McNeil, 1999; Rock et al., 2016; Shamoun-Baranes et al., 2011). In addition, some gulls continue to forage at night, and artificial light, such as fishing-vessel lights used to attract fish, can facilitate visually guided foraging under otherwise low-light conditions (Arcos & Oro, 2002; Garthe & Hüppop, 1993; Poot, 2003). Accordingly, individuals that forage offshore at night may reduce commuting to land and instead rest on nearby floating structures at sea, including seaweed-farm infrastructure. Therefore, the nighttime association with marine waters and floating-type seaweed aquaculture structures observed in our study likely reflects a combination of reduced exposure to land-based disturbance or predation risk and, for some individuals, proximity to nocturnal foraging opportunities.

In contrast, gulls used shellfish and integrated aquaculture types more frequently during the daytime. This daytime association may reflect both direct predation on farmed organisms and indirect increases in foraging opportunities resulting from the aggregation of fish and invertebrates around aquaculture structures. For example, opportunistic seabirds, including gulls, have been reported as common predators around finfish sea-cage farms, and predator presence can vary temporally in relation to farm activities such as harvesting (Barrett et al., 2019; Díaz López, 2017). More broadly, shellfish and finfish farms may attract wild fish and generate locally enhanced prey fields, potentially increasing the attractiveness of aquaculture sites to opportunistic seabirds (Callier et al., 2018; Veggerby et al., 2024). However, further research is needed to identify the dominant mechanisms underlying this daytime association and to evaluate its ecological consequences, ideally by integrating behavioral observations with diet analyses and prey-field assessments.

We found that Black-tailed Gulls concentrated their use of floating-type seaweed farms during winter. Together, these patterns indicate that offshore aquaculture structures, particularly floating seaweed-farm infrastructure, can function as seasonally important roosting habitat that complements coastal roost options. This role may be especially important in regions where coastal roost sites are increasingly constrained by land reclamation, coastal development, and human disturbance, such that offshore structures can partially offset seasonal limitations in coastal roost availability. Because Black-tailed Gulls typically roost in flocks (Gosler et al., 1995; Rao & Babu, 2021), the number of individuals using these structures is likely greater than the number detected in our telemetry sample. Therefore, minimizing disturbance to floating seaweed-farm infrastructure during winter may help maintain stable communal roosting opportunities.

It is plausible that Black-tailed Gulls have used offshore aquaculture structures as roosting sites for many years. Under the "win–stay, lose–switch" rule, animals continue to return to familiar sites until they experience a negative outcome, after which they shift to alternative sites (Switzer, 1993). This behavioral rule is particularly evident in long-lived seabirds and provides strong empirical support for experience-based site fidelity (Danchin et al., 1998; Robert et al., 2014). Given the high site fidelity often observed in gulls, individuals may repeatedly use the same aquaculture structures during winter. Such fidelity can confer fitness advantages under stable or predictable environmental conditions, thereby promoting individual survival and population growth (Piper, 2011). However, strong reliance on familiar sites can become a liability when habitat quality declines or sites are lost, potentially limiting behavioral

flexibility and increasing vulnerability to rapid environmental change (Merkle et al., 2022; Regan et al., 2024). Therefore, conserving and managing currently used aquaculture structures and surrounding waters in Jeollanam-do may contribute to maintaining stable roosting opportunities for Black-tailed Gulls.

Incentive-based management approaches, such as payments for ecosystem services, have been proposed as mechanisms to compensate aquaculture operators for ecosystem services, including habitat-related benefits, and could potentially enhance the conservation value of offshore aquaculture infrastructure by incentivizing the retention of floating structures beyond harvest. For example, Dai et al. (2021) reported that an eco-compensation program enabled the temporary rental and water-level management of aquaculture ponds during non-farming periods, resulting in positive responses in waterbird abundance and diversity with relatively simple interventions. Building on this principle, retaining floating seaweed-farm structures beyond the harvest period may provide additional roosting opportunities not only for gulls but also for migratory shorebirds during spring and autumn. Preliminary observations from the Jeung-do tidal flat (in Jeollanam-do) suggest that up to 94% of shorebirds present during high tide roosted on floating-type seaweed-farm structures in March and that the number of individuals declined markedly following structure removal in early April (Cho, 2024). Although these patterns require formal validation, they highlight the potential for offshore aquaculture infrastructure to function as an important roosting resource for seabirds.

Although studies of seabirds in aquaculture systems have generally focused on nonlethal deterrence to reduce predation and associated economic losses (Ross et al., 2001; Scridel et al., 2020; Varennes et al., 2013), our results indicate that aquaculture structures can also function as important roosting sites. We therefore encourage future research to quantify the broader conservation implications of aquaculture structures across seabird taxa.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

ETHICS APPROVAL

The procedures for capturing, handling, and tagging the birds complied with applicable national laws and relevant guidelines and regulations and were approved by the Institutional Animal Care and Use Committee (IACUC). Animal ethics training was completed prior to fieldwork (KoEco certificate numbers 2021-001, 2022-001, 2023-001, and 2024-001).

AUTHOR CONTRIBUTIONS

DHC: Writing—original draft, visualization, methodology, investigation, formal analysis, data curation, conceptualization. SMJ: Validation, investigation. DHK: Data curation, methodology. TWK: Data curation, visualization. SWL: Funding acquisition, project administration. HCS: Writing—review & editing, supervision.

REFERENCES

Arcos, J., & Oro, D. (2002). Significance of nocturnal purse seine fisheries for seabirds: A case study off the Ebro Delta (NW Mediterranean). *Marine Biology*, *141*(2), 277–286. https://doi.org/10.1007/s00227-002-0828-3

Barrett, L. T., Swearer, S. E., & Dempster, T. (2019). Impacts of marine and freshwater aquaculture on wildlife: A global meta-analysis. *Reviews in Aquaculture*, *11*(4), 1022–1044. https://doi.org/10.1111/raq.12277

Beauchamp, G. (1999). The evolution of communal roosting in birds: Origin and secondary losses. *Behavioral Ecology*, *10*(6), 675–687. https://doi.org/10.1093/beheco/10.6.675

Beauchamp, G. (2009). Sleeping gulls monitor the vigilance behaviour of their neighbours. *Biology Letters*, *5*(1), 9–11. https://doi.org/10.1098/rsbl.2008.0490

Bijleveld, A. I., Egas, M., Van Gils, J. A., & Piersma, T. (2010). Beyond the information centre hypothesis: Communal roosting for information on food, predators, travel companions and mates? *Oikos*, *119*(2), 277–285. https://doi.org/10.1111/j.1600-0706.2009.17892.x

Callier, M. D., Byron, C. J., Bengtson, D. A., Cranford, P. J., Cross, S. F., Focken, U., Jansen, H. M., Kamermans, P., Kiessling, A., Landry, T., O'Beirn, F., Petersson, E., Rheault, R. B., Strand, Ø., Sundell, K., Svåsand, T., Wikfors, G. H., & McKindsey, C. W. (2018). Attraction and repulsion of mobile wild organisms to finfish and shellfish aquaculture: A review. *Reviews in Aquaculture*, *10*(4), 924–949. https://doi.org/10.1111/raq.12208

Cantlay, J. C., Portugal, S. J., & Martin, G. R. (2025). Visual fields, foraging and collision vulnerability in gulls (Laridae). *Ibis*, *167*(2), 386–396. https://doi.org/10.1111/ibi.13360

Cho, D.-H. (2024). *Changes in shorebird use of roosting sites in the Sinan Tidal Flats* [Unpublished raw data].

Clark, D. E., DeStefano, S., MacKenzie, K. G., Koenen, K. K. G., & Whitney, J. J. (2016). Roost site selection by ring-billed and herring gulls. *The Journal of Wildlife Management*, *80*(4), 708–719. https://doi.org/10.1002/jwmg.1066

Clark, D. E., Koenen, K. K. G., Whitney, J. J., MacKenzie, K. G., & DeStefano, S. (2016). Fidelity and persistence of Ring-billed (*Larus delawarensis*) and Herring (*Larus argentatus*) Gulls to wintering sites. *Waterbirds*, *39*(Suppl. 1), 220–234. https://doi.org/10.1675/063.039.sp120

Comeau, L. A., St-Onge, P., Pernet, F., & Lanteigne, L. (2009). Deterring coastal birds from roosting on oyster culture gear in eastern New Brunswick, Canada. *Aquacultural Engineering*, *40*(2), 87–94. https://doi.org/10.1016/j.aquaeng.2008.11.003

Cresswell, W. (1994). Flocking is an effective anti-predation strategy in redshanks, *Tringa totanus*. *Animal Behaviour*, *47*(2), 433–442. https://doi.org/10.1006/anbe.1994.1057

Dai, W., Goodale, E., He, R., Mammides, C., Liu, S., Zhou, L., Tang, S., Su, B., Lao, X., & Jiang, A. (2021). An eco-compensation policy increases shorebird diversity during the non-farming period for aquaculture. *Wetlands*, *41*(1), Article 4. https://doi.org/10.1007/s13157-021-01397-7

Danchin, E., Boulinier, T., & Massot, M. (1998). Conspecific reproductive success and breeding habitat selection: Implications for the study of coloniality. *Ecology*, *79*(7), 2415–2428. https://doi.org/10.1890/0012-9658(1998)079[2415:CRSABH]2.0.CO;2

Díaz López, B. (2017). Temporal variability in predator presence around a fin fish farm in the Northwestern Mediterranean Sea. *Marine Ecology*, *38*(1), Article e12378. https://doi.org/10.1111/maec.12378

East Asian–Australasian Flyway Partnership. (2020, March 6). *Floating roost for weary migratory shorebirds on trial in Republic of Korea*. https://eaaflyway.org/floating-roost-trial-in-ro-korea/

Eiserer, L. A. (1984). Communal roosting in birds. *Bird Behavior*, *5*(2–3), 61–80.

Garthe, S., & Hüppop, O. (1993). Gulls and Fulmars following ships and feeding on discards at night. *Ornis Svecica*, *3*(3–4), 159–161. https://doi.org/10.34080/os.v3.23040

Gimeno, M., García, J. A., Afán, I., Aymí, R., Montalvo, T., & Navarro, J. (2023). Age-related differences in foraging behaviour at sea and interactions with fishing vessels in an opportunistic urban gull. *ICES Journal of Marine Science*, *80*(9), 2405–2413. https://doi.org/10.1093/icesjms/fsac120

Gosler, A., Kenward, R. E., & Horton, N. (1995). The effect of gull roost deterrence on roost occupancy, daily gull movements and wintering wildfowl. *Bird Study*, *42*(2), 144–157. https://doi.org/10.1080/00063659509477160

Hébert, P. N., & McNeil, R. (1999). Nocturnal activity of Ring-billed Gulls at and away from the colony. *Waterbirds*, *22*(3), 445–451. https://doi.org/10.2307/1522122

Hong, S., & Lee, I. (2011). The visitation aspect of black-tailed gull (*Larus crassirostris*) in the long period at Nakdong Estuary, Busan, Republic of Korea. *Korean Journal of Ornithology*, *18*, 1–10.

Hua, N., Tan, K., Chen, Y., & Ma, Z. (2015). Key research issues concerning the conservation of migratory shorebirds in the Yellow Sea region. *Bird Conservation International*, *25*(1), 38–52. https://doi.org/10.1017/S0959270914000380

Hwang, E. K., & Park, C. S. (2020). Seaweed cultivation and utilization of Korea. *Algae*, *35*(2), 107–121. https://doi.org/10.4490/algae.2020.35.5.15

Jo, M.-H. (2011). Measuring the quantities of aquaculture farming facilities for seaweed, ear shell and fish using high resolution aerial images - A case of the Wando region, Jeollanamdo. *Journal of the Korean Association of Geographic Information Studies*, *14*(2), 147–161. https://doi.org/10.11108/kagis.2011.14.2.147

Kang, T., Kim, S. S., Cho, D., Kim, T. W., Paek, W. K., & Lee, S.-W. (2024). Characteristics of wintering habitat use by Black-tailed Gulls (*Larus crassirostris*) on the West Coast of Korea. *Proceedings of the National Institute of Ecology of the Republic of Korea*, *5*(2), 37–42. https://doi.org/10.22920/PNIE.2024.5.2.37

Kazama, K., Hirata, K., Yamamoto, T., Hashimoto, H., Takahashi, A., Niizuma, Y., Trathan, P. N., & Watanuki, Y. (2013). Movements and activities of male black-tailed gulls in breeding and sabbatical years. *Journal of Avian Biology*, *44*(6), 603–608. https://doi.org/10.1111/j.1600-048X.2013.00103.x

Kenward, R. E. (2000). *A manual for wildlife radio tagging*. Academic Press.

Kim, H. W., Kim, Y. H., An, Y.-R., Park, K. J., & An, D. H. (2014). Seabird distribution patterns by strip transect in the Yellow Sea in spring. *Korean Journal of Fisheries and Aquatic Sciences*, *47*(6), 973–977. https://doi.org/10.5657/KFAS.2014.0973

Kim, M., Hong, M., & Kwon, Y. (2021). First report of habitat ranges in Black-tailed Gulls (*Larus crassirostris*) breeding on Hongdo Island, Hallyeohaesang National Park. *Journal of National Park Research*, *12*(2), 59–66. https://doi.org/10.54406/jnpr.2021.12.2.059

Kirk, M., Esler, D., & Boyd, W. S. (2007). Morphology and density of mussels on natural and aquaculture structure habitats: Implications for sea duck predators. *Marine Ecology Progress Series*, *346*, 179–187. https://doi.org/10.3354/meps07046

Koh, C.-H., & Khim, J. S. (2014). The Korean tidal flat of the Yellow Sea: Physical setting, ecosystem and management. *Ocean & Coastal Management*, *102*, 398–414. https://doi.org/10.1016/j.ocecoaman.2014.07.008

Lee, J. K., Chung, O.-S., Park, J.-Y., Kim, H.-J., Hur, W.-H., Kim, S.-H., & Kim, J.-H. (2018). Effects of the Saemangeum Reclamation Project on migratory shorebird staging in the Saemangeum and Geum Estuaries, South Korea. *Bird Conservation International*, *28*(2), 238–250. https://doi.org/10.1017/S0959270916000605

Lee, S., & Lee, W.-S. (2024). Comparing spatial differences in behavioral pattern transition of Black-tailed gull during post breeding season in the Korean peninsula. *Scientific Reports*, *14*(1), Article 19527. https://doi.org/10.1038/s41598-024-70330-9

Lee, S., Park, J., Jeong, I., Yoo, J., & Lee, W. (2023). The diurnal and nocturnal home range differences of Black-tailed Gulls (*Larus crassirostris*). *Korean Journal of Ornithology*, *30*(2), 116–124. https://doi.org/10.30980/KJO.2023.12.30.2.116

Lucas, E. A., Martin, G. R., Rocamora, G., & Portugal, S. J. (2024). A seabird's eye view: Visual fields of some seabirds (Laridae and Procellariidae) from tropical latitudes. *The Science of Nature*, *111*(4), Article 40. https://doi.org/10.1007/s00114-024-01926-4

Ma, T., Li, X., Bai, J., & Cui, B. (2019). Habitat modification in relation to coastal reclamation and its impacts on waterbirds along China's coast. *Global Ecology and Conservation*, *17*, Article e00585. https://doi.org/10.1016/j.gecco.2019.e00585

Mangiafico, S. (2017). *rcompanion: Functions to Support Extension Education Program Evaluation* (Version 2.5.1) [R package]. CRAN package repository. https://cran.r-project.org/package=rcompanion

Merkle, J. A., Abrahms, B., Armstrong, J. B., Sawyer, H., Costa, D. P., & Chalfoun, A. D. (2022). Site fidelity as a maladaptive behavior in the Anthropocene. *Frontiers in Ecology and the Environment*, *20*(3), 187–194. https://doi.org/10.1002/fee.2456

Moen, R., Pastor, J., & Cohen, Y. (1997). Accuracy of GPS telemetry collar locations with differential correction. *The Journal of Wildlife Management*, *61*(2), 530–539. https://doi.org/10.2307/3802612

Ministry of Oceans and Fisheries. (2025). *Statistical yearbook of oceans & fisheries*. Ministry of Oceans and Fisheries of the Republic of Korea.

Moores, N. (2012). *The distribution, abundance and conservation of avian biodiversity in Yellow Sea habitats in the Republic of Korea* [Doctoral thesis, University of Newcastle, Australia]. Open Research Newcastle. https://hdl.handle.net/1959.13/930392

O'Hanlon, N. J., Thaxter, C. B., Burton, N. H., Grant, D., Clark, N. A., Clewley, G. D., Conway, G. J., Barber, L. J., McGill, R. A. R., & Nager, R. G. (2022). Habitat selection and specialisation of herring gulls during the non-breeding season. *Frontiers in Marine Science*, *9*, Article 816881. https://doi.org/10.3389/fmars.2022.816881

Orians, G. H., & Pearson, N. E. (1979). On the theory of central place foraging. In D. J. Horn, G. R. Stairs, & R. D. Mitchell (Eds.), *Analysis of ecological systems* (pp. 155–177). Ohio State University Press.

Pearse, A. T., Krapu, G. L., & Brandt, D. A. (2017). Sandhill crane roost selection, human disturbance, and forage resources. *The Journal of Wildlife Management*, *81*(3), 477–486. https://doi.org/10.1002/jwmg.21215

Piper, W. H. (2011). Making habitat selection more "familiar": A review. *Behavioral Ecology and Sociobiology*, *65*(7), 1329–1351. https://doi.org/10.1007/s00265-011-1195-1

Poot, M. (2003). Offshore foraging of Mediterranean Gulls *Larus melanocephalus* in Portugal during the winter. *Atlantic Seabirds*, *5*(1), 1–12.

Rao, G. B., & Babu, S. (2021). Roost-site selection and population assessment of gulls wintering along India's west coast reveals the importance of conserving coastal habitats. *Ornithological Science*, *20*(2), 161–174. https://doi.org/10.2326/osj.20.161

Regan, C. E., Bogdanova, M. I., Newell, M., Gunn, C., Wanless, S., Harris, M. P., Lopez, S. L., Benninghaus, E., Bolton, M., Daunt, F., & Searle, K. R. (2024). Seabirds show foraging site and route fidelity but demonstrate flexibility in response to local information. *Movement Ecology*, *12*(1), Article 46. https://doi.org/10.1186/s40462-024-00467-9

Rempel, R. S., Rodgers, A. R., & Abraham, K. F. (1995). Performance of a GPS animal location system under boreal forest canopy. *The Journal of Wildlife Management*, *59*(3), 543–551. https://doi.org/10.2307/3802461

Robert, A., Paiva, V. H., Bolton, M., Jiguet, F., & Bried, J. (2014). Nest fidelity is driven by multi-scale information in a long-lived seabird. *Proceedings of the Royal Society B*, *281*(1793), Article 20141692. https://doi.org/10.1098/rspb.2014.1692

Rock, P., Camphuysen, C. J., Shamoun-Baranes, J., Ross-Smith, V. H., & Vaughan, I. P. (2016). Results from the first GPS tracking of roof-nesting Herring Gulls *Larus argentatus* in the UK. *Ringing & Migration*, *31*(1), 47–62. https://doi.org/10.1080/03078698.2016.1197698

Rogers, D. I., Piersma, T., & Hassell, C. J. (2006). Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological Conservation*, *133*(2), 225–235. https://doi.org/10.1016/j.biocon.2006.06.007

Ronconi, R. A., Lieske, D. J., McFarlane Tranquilla, L. A., Abbott, S., Allard, K. A., Allen, B., Black, A. L., Bolduc, F., Davoren, G. K., Diamond, A. W., Fifield, D. A., Garthe, S., Gjerdrum, C., Hedd, A., Mallory, M. L., Mauck, R. A., McKnight, J., Montevecchi, W. A., Pollet, I. L., . . . Wilhelm, S. I. (2022). Predicting seabird foraging habitat for conservation planning in Atlantic Canada: Integrating telemetry and survey data across thousands of colonies. *Frontiers in Marine Science*, *9*, Article 816794. https://doi.org/10.3389/fmars.2022.816794

Ross, B. P., Lien, J., & Furness, R. W. (2001). Use of underwater playback to reduce the impact of eiders on mussel farms. *ICES Journal of Marine Science*, *58*(2), 517–524. https://doi.org/10.1006/jmsc.2000.1025

Roycroft, D., Kelly, T. C., & Lewis, L. J. (2007). Behavioural interactions of seabirds with suspended mussel longlines. *Aquaculture International*, *15*(1), 25–36. https://doi.org/10.1007/s10499-006-9065-y

Santos, C. D., Catry, T., Dias, M. P., & Granadeiro, J. P. (2023). Global changes in coastal wetlands of importance for non-breeding shorebirds. *Science of the Total Environment*, *858*, Article 159707. https://doi.org/10.1016/j.scitotenv.2022.159707

Scridel, D., Utmar, P., Franzosini, C., Segarich, M., Menon, S., Burca, M., Diviacco, P., Ciriaco, S., del Negro, P., & Spoto, M. (2020). Sink or swim? Modernization of mussel farming methods may negatively impact established seabird communities. *Biological Conservation*, *243*, Article 108458. https://doi.org/10.1016/j.biocon.2020.108458

Shamoun-Baranes, J., Bouten, W., Camphuysen, C. J., & Baaij, E. (2011). Riding the tide: Intriguing observations of gulls resting at sea during breeding. *Ibis*, *153*(2), 411–415. https://doi.org/10.1111/j.1474-919X.2010.01096.x

Sommerfeld, J., Mendel, B., Fock, H. O., & Garthe, S. (2016). Combining bird-borne tracking and vessel monitoring system data to assess discard use by a scavenging marine predator, the lesser black-backed gull *Larus fuscus*. *Marine Biology*, *163*(5), Article 116. https://doi.org/10.1007/s00227-016-2889-8

Switzer, P. V. (1993). Site fidelity in predictable and unpredictable habitats. *Evolutionary Ecology*, *7*(6), 533–555. https://doi.org/10.1007/BF01237820

Thieurmel, B., & Elmarhraoui, A. (2019). *suncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase* (Version 0.5) [R package]. CRAN package repository. https://cran.r-project.org/package=suncalc

Varennes, É., Hanssen, S. A., Bonardelli, J., & Guillemette, M. (2013). Sea duck predation in mussel farms: The best nets for excluding common eiders safely and efficiently. *Aquaculture Environment Interactions*, *4*(1), 31–39. https://doi.org/10.3354/aei00072

Veggerby, K. B., Scheuerell, M. D., Sanderson, B. L., Kiffney, P. M., & Ferriss, B. E. (2024). Shellfish aquaculture farms as foraging habitat for nearshore fishes and crabs. *Marine and Coastal Fisheries*, *16*(2), Article e210282. https://doi.org/10.1002/mcf2.10282

Vernon, J. D. R., & Walsh, T. P. (1966). The Common Gull in the Severn Estuary in relation to feeding areas, roost sites and behaviour. *Proceedings of the Bristol Naturalists' Society*, *31*(2), 173–184. http://www.biodiversitylibrary.org/page/46698755

Walsberg, G. E. (1986). Thermal consequences of roost-site selection: The relative importance of three modes of heat conservation. *The Auk*, *103*(1), 1–7. https://doi.org/10.1093/auk/103.1.1

Ward, P., & Zahavi, A. (1973). The importance of certain assemblages of birds as "information-centres" for food-finding. *Ibis*, *115*(4), 517–534. https://doi.org/10.1111/j.1474-919X.1973.tb01990.x

Watchorn, D. J., Cowan, M. A., Driscoll, D. A., Nimmo, D. G., Ashman, K. R., Garkaklis, M. J., Wilson, B. A., & Doherty, T. S. (2022). Artificial habitat structures for animal conservation: design and implementation, risks and opportunities. *Frontiers in Ecology and the Environment*, *20*(5), 301–309. https://doi.org/10.1002/fee.2470

Webb, N. V., & Blumstein, D. T. (2005). Variation in human disturbance differentially affects predation risk assessment in Western Gulls. *The Condor*, *107*(1), 178–181. https://doi.org/10.1093/condor/107.1.178

Xia, H., Nilsson, C., Thorup, K., Jia, C., & Lei, F. (2023). Non-breeding movements of the Black-tailed Gull (*Larus crassirostris*). *Avian Research*, *14*, Article 100103. https://doi.org/10.1016/j.avrs.2023.100103

Yang, H.-Y., Chen, B., Barter, M., Piersma, T., Zhou, C.-F., Li, F.-S., & Zhang, Z.-W. (2011). Impacts of tidal land reclamation in Bohai Bay, China: Ongoing losses of critical Yellow Sea waterbird staging and wintering sites. *Bird Conservation International*, *21*(3), 241–259. https://doi.org/10.1017/S0959270911000086