Spatial ecology of little egret (*Egretta garzetta*) in Hong Kong uncovers preference for commercial fishponds

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Many natural wetlands have been converted to human-influenced wetlands. In some instances, human-influenced wetlands could provide complementary habitats for waterbirds, compensating for the loss of natural wetlands. Inner Deep Bay in Hong Kong is composed of both natural and human-influenced wetlands and is under immense development pressure. From an ecology perspective, we need to understand if different wetland types play the same ecological role. To achieve this, we tracked nine little egrets (*Egretta garzetta*) using GPS loggers for 14 months to study their spatial ecology, home range, movement and habitat use. We found that over 88% of the home range of all individuals comprised of wetlands (commercial fishponds, mangrove, *gei wai*, channel, and intertidal mudflat). Among these wetland types, nearly all (seven of nine) individuals preferred commercial fishponds over other habitats in all seasons. Little egrets exhibited seasonal movement and habitat use among seasons, with largest home range, greatest movement, and most frequent visits to fishponds in winter compared to spring and autumn. Our results highlight the significant role of commercial fishponds, providing a feeding ground for little egrets. However, other wetland types cannot be ignored, as they were also used considerably. These findings underscore the importance of maintaining a diversity of wetland types as alternative foraging and breeding habitats.

Title

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ABSTRACT

Many natural wetlands have been converted to human-influenced wetlands. In some instances, human-influenced wetlands could provide complementary habitats for waterbirds, compensating for the loss of natural wetlands. Inner Deep Bay in Hong Kong is composed of both natural and human-influenced wetlands and is under immense development pressure. From an ecology perspective, we need to understand if different wetland types play the same ecological role. To achieve this, we tracked nine little egrets (*Egretta garzetta*) using GPS loggers for 14 months to study their spatial ecology, home range, movement and habitat use. We found that over 88% of the home range of all individuals comprised of wetlands (commercial fishponds, mangrove, *gei wai*, channel, and intertidal mudflat). Among these wetland types, nearly all (seven of nine) individuals preferred commercial fishponds over other habitats in all seasons. Little egrets exhibited seasonal movement and habitat use among seasons, with largest home range, greatest movement, and most frequent visits to fishponds in winter compared to spring and autumn. Our results highlight the significant role of commercial fishponds, providing a feeding ground for little egrets. However, other wetland types cannot be ignored, as they were also used considerably. These findings underscore the importance of maintaining a diversity of wetland types as alternative foraging and breeding habitats.

Keywords

Bird, GPS tracking, habitat use, home range, sustainable land-use management, wetland conservation

INTRODUCTION

In recent centuries, over half of natural wetlands have been lost, and a large proportion have been converted to human-influenced wetlands (Davidson 2014; Gong et al. 2010). Such conversion is typically considered detrimental to biodiversity, since many waterbirds rely on natural wetlands as foraging and breeding grounds (Bellio et al. 2009; Ma et al. 2004; Sebastián-González & Green 2016). However, some studies have found that human-influenced wetlands could provide alternative, complementary habitats for some species (Fidorra et al. 2016; Giosa et al. 2018; Kloskowski et al. 2009; Li et al. 2013; Márquez-Ferrando et al. 2014). In some cases, the transformation from natural to human-influenced wetlands has increased bird diversity due to enhanced habitat heterogeneity (Murillo-Pacheco et al. 2018). Also, aquaculture ponds can provide essential feeding grounds for waterbirds (Navedo et al. 2015; Ramirez et al. 2012). A high number of birds are attracted when fishponds are periodically drained for harvest; the draining practice opens up opportunities for waterbirds to forage concentrated preys with reduced water depth (Navedo et al. 2015). To understand the ecological role of different wetland types (natural and human-influenced), studies are needed comparing the suitability of different wetlands to waterbirds, particularly in parts of the world where diverse waterbird communities are being threatened by destruction of wetlands.

The Inner Deep Bay, a Ramsar site in Hong Kong, is an important site for migratory waterbirds, housing over 40,000 birds each winter, including threatened species (Hong Kong Bird Watching Society 2018). The area is a complex landscape with a variety of wetlands (e.g. commercial fishponds, mangrove, and intertidal mudflats) and urban settlements. This area has been under high pressure for housing development (Morton 2016; Young 1998) and wetlands have declined by 53% between 1986 and 2007 (Ren et al. 2010). Among wetland types, commercial fishponds are particularly vulnerable because most are located outside the designated Ramsar site and have limited legal protection against development. Data on the habitat use of waterbirds in the area can be used to evaluate the ecological role of different wetland types, thereby providing a basis for wetland conservation and informing land-use management.

Recently, with the technological advancement of tracking devices, tracking studies have been widely used to study the spatial ecology of birds. Advanced tracking methods (e.g., ARGOS or GPS tracking) gather real-time data with accurate location information that traditional bird surveys cannot provide. The resolution of these data can account for variation in movement and habitat use (Koczur et al. 2018; Takano & Haig 2004), thereby enhancing our ability to evaluate the habitat quality for birds and yield data to guide habitat management and conservation (e.g. El-Hacen et al. 2013; Mitchell et al. 2016).

In this study, we used GPS tracking to study the spatial ecology of little egrets (*Egretta garzetta*) in the Inner Deep Bay, Hong Kong. In the area, little egrets are present throughout the year with a population peaks in winter (1000–2000 in January) (Carey et al., 2001). Since they inhabit a diversity of wetlands, little egrets provide an ideal study system to compare the ecological role of different wetland types (Martínez-Vilalta et al. 2019; Young 1998). Further, although the little egret is one of the most widespread ardeid species worldwide (Martínez-Vilalta et al. 2019), there has yet been a tracking study—little is known about their spatial ecology. This study's objectives were to determine home range sizes, movement and habitat use of little egrets. Specifically, we aim to see if little egrets exhibit a preference for certain habitats, and understand how seasonal draining of commercial fishponds affects home range sizes, movement and habitat use. Since drained commercial fishponds with reduced water depth allow waterbirds to forage concentrated prey (Navedo et al. 2015), usually October–May in the Inner Deep Bay (Young 1998). These data will contribute to the conservation of waterbirds in Hong Kong and guide habitat management in landscape mosaics consisting of natural and human-influenced wetlands worldwide.

MATERIALS AND METHODS

Study area

This study was carried out in the Inner Deep Bay of the Hong Kong Special Administrative Region, China (22°29' N 114°02' E). The area consists of a natural, shallow estuarine bay with extensive intertidal mudflats connected to mangroves and human-influenced wetlands, including *gei wais* (tidal shrimp ponds), drainage channels and commercial fishponds. The commercial fishponds form a continuous wetland habitat of approximately 460 ha. Individual fishponds are generally 1–3 hectares in size, and contain polycultures of commercial freshwater fish, including grass carp *Ctenopharyngodon idellus*), grey mullet (*Mugil cephalus*) and tilapia (*Oreochromis* sp.).

Bird capturing and tracking data collection

From January–December 2018, we captured nine individuals of little egret (*Egretta garzetta*) using clap nets (1.5 m and 2 m in diameter) with fish bait. We put each individual into a covered, large laundry hampers. They are soft enough for the birds from getting hurt, but strong enough for retaining the birds. For each bird, we attached a solar-charged GPS-UHF logger [model PICA (5.5 g in weight) or HARRIER (12 g), Ecotone Telemetry, Poland]), using Teflon tape and a backpack harness. The captured birds weighed 290–495 g. The weight of the loggers and harnesses were <3% of the birds' weights. All birds were released within two hours at the site of capture. We programmed the loggers to record data (location and speed) hourly from 5 am (around sunrise, before the egrets leave their roosting sites) to 7 pm (after sunset, returning to roost). Data were automatically stored on the loggers, and were remotely downloaded every two weeks using a hand-held base station with unidirectional antenna. We included data collected between 30 Jan 2018 and 22 Mar 2019 in the analysis. All procedures were approved by the Agricultural Fisheries and Conservation Department of the Hong Kong Government [permit number: (43) AF GR CON 09/51 Pt. 6, (99) AF GR CON 09/51 Pt. 6, (166) AF GR CON 09/51 Pt. 6, (79) AF GR CON 09/51 Pt. 7].

Habitat availability

To determine habitat availability in the study area, we first mapped the study area using QGIS 3.6.1 (QGIS Development Team 2016). Next, we delineated and classified the area into six habitat types using Google Earth: commercial fishponds, *gei wais* (tidal shrimp ponds), mangroves, intertidal mudflat, drainage channels and human settlement). Subsequently, we conducted fieldwork to ground-truth the habitat type. Further, we collected the draining schedules of 591 commerical fishponds from their owners throughout the study period, which covers 81.5% of all commercial fishponds in the entire Deep Bay area.

Data analysis

We performed all statistical analyses in R (R Core Team 2019), using the packages 'BBMM' and 'adehabitatHR' for home range analysis (Calenge 2011; Nielson et al. 2013); 'adehabitatHS' for habitat selection analysis (Calenge 2011); 'lme4' for model fitting (Bates et al. 2014) and 'ggplot2' for graphic production (Wickham 2016).

We applied three methods to calculate the home range of individuals. First, given that the location was recorded regularly each hour, we used the Brownian bridge movement model (BBMM) to report the 50% and 95% home range as the core area and overall home range, respectively (Fischer et al. 2013). Based on our preliminary field testing, we set 20 meters as the location errors for BBMM. We also calculated home range using fixed kernel density estimation (50% and 95% kernel) (Worton 1989) and minimum convex polygon (MCP) (Mohr 1947). For kernel, we used the h_{ref} kernel density estimators (Calenge 2011).

To determine if little egrets exhibit habitat preference, we used compositional analysis, which compares the point habitat occurrence data with habitat availability across the entire home range of each individual (Aebischer et al. 1993). We defined the 100% minimum convex polygon (MCP) of each individual as their maximum home range, and then calculated the proportion of each habitat type as the habitat availability (Whisson et al. 2015). We then assigned their relocations to the corresponding habitat and calculated the proportion of used habitat. Second, we performed Wilk's Lambda statistic to determine their overall selection of habitat. If preferences were found, we used randomization tests to conduct pair-wise comparisons of resource types (Aebischer et al. 1993). Consequently, we used the eigenanalysis of selection ratios to examine individual variations in habitat use in different seasons (Calenge & Dufour 2006).

We tested the seasonal effect on daily home ranges, daily travel distance and proportion of daily occurrence in fishponds (i.e. the proportion of GPS fixes on fishponds among all habitats during the daylight period) using Linear Mixed Model (LMM) and Generalized Linear Mixed Model (GLMM) followed by analysis of variance (Bolker et al. 2009). For daily home range and daily travel distance, LMMs were applied and fitted with Gaussian distribution. For the proportion of the daily occurrence in fishponds, we constructed GLMMs fitted with binomial distribution and log-linked function. We could only collect data from two indivduals in the summer (June to August), so we excluded summer data from this analysis. We set bird identity as a random effect and season as a fixed effect in the model (spring: March to May; autumn: September to November; winter: December to February). Daily home range was calculated as the daily 50% and 95% utilization distribution (UD) of each individual, using the fixed Kernel Density Estimation (KDE) method (Seaman & Powell 1996; Worton 1989). We calculated daily travel distance by summing the travel distance between each successive location on each tracking day. We excluded data collected from 351 tracking days that had missing data.

RESULTS

Between January 2018 and March 2019, we received 18839 GPS fixes (1296 tracking bird-days) from nine individuals (Table 1). For individuals, the mean (± SD) number of tracking days was 154 ± 41 and GPS fixes was 2093 ± 567.

The mean (± SD) overall home range (95% BBMM) and core area (50% BBMM) were 9.40 km^2 ± 7.68 (range = 0.85–20.62) and 1.31 km^2 ± 1.26 (range = 0.14–3.70), respectively (Table 1; Fig. 1). The length of the entire tracking duration of each individual did not correlate with the home range size (Pearson's correlation; 50% core area, $t = 0.16$, df = 7, $p = 0.87$; 95% home range, $t = 0.48$, df = 7, $p = 0.65$).

The home range of all tracked individuals was dominated by fishponds (overall home range = 46.8%; core area = 54.3%), intertidal mudflats (overall home range = 11.4%; core area = 12.5%)

and mangroves (overall home range = 13.8%; core area = 7.6%) (Table 2). These three habitat types constituted over 70% of the home ranges of all individuals.

Proportion of habitats used by the little egret (excluding summer) differed from the availability (Wilk's $\lambda = 0.032$, $p < 0.05$ in all cases). Commercial fishponds were the most preferred habitats, followed by mangrove, *gei wais*, channel and intertidal mudflat, in preferential order (Table 3). Non-wetland habitats (categorized as 'Others') were the least utilized. However, the eigenanalysis of selection ratios showed individual variation in habitat preference across seasons (Fig. 2). The first two axes explained 87.0% (spring), 100% (summer), 87.6% (autumn) and 86.9% (winter) of the information. Seven of the nine individuals preferred fishponds across all seasons (Fig. 2).

With data from summer excluded, the size of daily home ranges, daily travel distance, and the proportion of daily occurrence in fishponds differed between seasons (Fig. 3, Table 4, Table S1). During winter, little egrets displayed the greatest movement, with largest home range and longest traveling distance; they also visited fishponds more often. The activities declined in spring and reached minimum levels in autumn.

DISCUSSION

In this study, we examined the spatial ecology of little egrets in the Inner Deep Bay, a complex landscape with a variety of wetlands and urban settlements. We found that little egrets rarely utilized non-wetland habitats (0.1% of all point locations, Table 2), indicating the species is a wetland specialist in the area. We found that little egrets selected habitats nonrandomly and preferred fishponds, and they displayed seasonal differences in movement and habitat use. We discuss the ecological and conservation implication of these findings below.

Preference of fishponds

The preference of the little egret for fishponds matches other studies on ardeids (Fidorra et al. 2016). The preference of fishponds is probably associated with the draining practices that enhance food availability and accessibility (Fidorra et al. 2016; Rocha et al. 2017). In the Inner Deep Bay, the fishponds are drained for fish harvesting, between October and May (Fig. 4). In drained fishponds, a high density of prey (e.g. fish and invertebrates) become accessible to birds in shallow water (Young 1998). Our data showed that most little egrets rely on fishponds as the major foraging habitat from autumn to spring. Other wetland birds likely also have preference for fishponds, such as the endangered black-faced spoonbill (*Paltalea minor*), which are often seen feeding alongside little egrets in fishponds (Yu & Swennen 2004). In light of the high development pressure on fishponds, our findings reinforce the importance of preserving commercial fishponds in the Inner Deep Bay.

Importance of other wetlands

Despite an obvious preference of commercial fishponds, our data indicate that other wetland types are also important to little egrets as breeding and foraging habitats (>41% of point locations in other wetland types, Table 2). In Hong Kong, little egrets mainly nest in mangrove, coastal shrubs and trees (Wong et al. 1999). One individual (PIC09) shifted from using commercial fishponds in other seasons to mangroves in the summer (breeding season). With fishponds being the major habitat for feeding, channels, g*ei wai*, and intertidal mudflat act as an alternative feeding grounds to little egrets when there are few drained fishponds. Notably, we detected individual variation in habitat use. One individual (PIC07) had distinctive habitat use, preferring a channel over other wetlands (including commercial fishponds) across all seasons (Fig. 2). In the channel where this individual frequented (located at Nam Sang Wai), an ecological-friendly design was implemented, including an unlined earth bottom and mangrove plantation, which has attracted a high number of ardeids and ducks (Lai et al. 2007). Overall, our findings suggest that the coexistence of different wetlands is crucial to little egrets, accommodating their need across seasons and of different individuals.

Other wetland types (channel, *gei wai*, mangrove and intertidal mudflat) were used considerably, supported by our data that each type constituted about 10% of point locations. Although we could not directly test the impact of habitat heterogeneity on movement and habitat use, the use of a variety of wetlands by individuals implies wetland heterogeneity is vital to little egrets. Similar studies on other waterbird species would help us understand the impact of habitat heterogeneity on waterbird diversity, in turn informing land developers and governments how to best integrate biodiversity conservation into sustainable development plans.

Seasonal variation in habitat use and movement

We detected significant seasonal differences in habitat use and movement in autumn, winter and spring. Since data were only collected from two individuals in the summer, we were unable to include it in our analysis. The largest home range, greatest movement and highest occurrence in fishponds occurring in winter. We suggest this seasonal pattern is due to the plentiful, but unpredictable and transient nature of food availability in commercial fishponds. Winter in Hong Kong (December to February) conincides with core of the drainage schedule of commercial fishponds (October to May). Drained commercial fishponds are likely preferred because they contain a large amount of accessible prey. However, food resources in drained fishponds are usually exhausted in a few days (Rocha et al. 2017). Searching for resource-rich drained fishponds is probably frequent, but unpredictable (based on fish farmer's preference), which would increase movement and home range during winter. Conversely, food resources in natural wetlands are more predictable.

Compared to winter, more fishponds were drained in spring in the study period (Fig. 4), however, we found lower proportion of daily occurrences in fishpond in spring than winter and autumn (Fig. 3), which contradicts our prediction. This hints that movement and habitat use of little egrets are shaped by a balance between foraging and reproduction. In Hong Kong, the reproductive season of little egrets starts in March and April (Carey et al. 2001). When they begin sitting on nests and rearing youngs in mangrove, foraging time and movements get limited (Maccarone & Brzorad 2005), and hence they may not be able to search for and feed in drained fishponds. Tracking more little egrets in summer and areas without fishponds will help elucidate the factors influencing the temporal changes in their habitat use and movement.

CONCLUSION

Besides improving our understanding of the spatial ecology of little egrets, our results reiterate the importance of preserving wetlands, particularly commercial fishponds, in the Inner Deep Bay. Human-influenced wetlands can provide not only suitable but preferable habitats for wildlife. Further, the coexistence of different types of wetlands, natural and human-influenced, is important in increasing habitat heterogeneity and providing alternative foraging and breeding habitats for little egrets and other waterbird species. In light of the high development pressure on wetlands in Hong Kong, we hope that this study can become a springboard for similar studies to inform us how to better integrate biodiversity conservation into sustainable development plans.

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REFERENCES

Aebischer NJ, Robertson PA, and Kenward RE. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74:1313–1325.

Bates D, Maechler M, Bolker B, and S W. 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1–7. *Available at http://cran.r-project.org/package=lme4* (accessed 12 Mar 2017).

Bellio MG, Kingsford RT, and Kotagama SW. 2009. Natural versus artificial- wetlands and their waterbirds in Sri Lanka. *Biological Conservation* 142:3076–3085.

Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, and White J-SS. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution* 24:127–135.

Calenge C, and Dufour AB. 2006. Eigenanalysis of selection ratios from animal radio-tracking data. *Ecology* 87:2349–2355.

Calenge C. 2011. Exploratory analysis of the habitat selection by the wildlife in R: the adehabitatHS package. *Available at* [*https://trac.faunalia.it/animove/*](https://trac.faunalia.it/animove/) (accessed 13 Dec 2019).

Carey GJ, Chalmers ML, Diskin DA, Leader PJ, Leven MR, Lewthwaite MR, Melville DS, Turnbull M, and Young L. 2001. *The avifauna of Hong Kong*. Hong Kong: Hong Kong Bird Watching Society.

Davidson NC. 2014. How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research* 65:934–941.

El-Hacen E-HM, Overdijk O, Lok T, Olff H, and Piersma T. 2013. Home range, habitat selection, and foraging rhythm in Mauritanian Spoonbills (*Platalea leucorodia balsaci*): a satellite tracking study. *Waterbirds* 36:277–286.

Fidorra JC, Frederick PC, Evers DC, and Meyer KD. 2016. Selection of human-influenced and natural wetlands by great egrets at multiple scales in the southeastern USA. *The Condor* 118:46–56.

Fischer JW, Walter WD, and Avery ML. 2013. Brownian bridge movement models to characterize birds' home ranges. *The Condor* 115:298–305.

Giosa E, Mammides C, and Zotos S. 2018. The importance of artificial wetlands for birds: A case study from Cyprus. *PloS one* 13:e0197286.

Gong P, Niu Z, Cheng X, Zhao K, Zhou D, Guo J, Liang L, Wang X, Li D, Huang H, Wang Y, Wang K, Li W, Wang X, Ying Q, Yang Z, Ye Y, Li Z, Zhuang D, Chi Y, Zhou H, and Yan J. 2010. China's wetland change (1990–2000) determined by remote sensing. *Science China Earth Sciences* 53:1036–1042.

Hong Kong Bird Watching Society. 2018. Mai Po Inner Deep Bay Ramsar Site waterbird monitoring programme 2017-18. Report by the Hong Kong Bird Watching Society to the Agriculture, Fisheries and Conservation Department, Hong Kong SAR Government. *Available at* *http://www.hkbws.org.hk/web/chi/documents/report/summer_report_2017.pdf* (accessed 1 March 2020).

Kloskowski J, Green AJ, Polak M, Bustamante J, and Krogulec J. 2009. Complementary use of natural and artificial wetlands by waterbirds wintering in Doñana, south-west Spain. *Aquatic Conservation: Marine and Freshwater Ecosystems* 19:815–826.

Koczur LM, Kent GM, Ballard BM, Meyer KD, and Green MC. 2018. Space use and movements of adult reddish egrets (*Egretta rufescens*) during winter. *Waterbirds* 41:1–15.

Lai PCC, Lee WH, and Wong BSF. 2007. Construction of a drainage channel at Inner Deep Bay, Hong Kong: mitigating ecological and landscape impact through an environmentally friendly design. *Landscape and Ecological Engineering* 3:179–185.

Li D, Chen S, Lloyd H, Zhu S, Shan K, and Zhang Z. 2013. The importance of artificial habitats to migratory waterbirds within a natural/artificial wetland mosaic, Yellow River Delta, China. *Bird Conservation International* 23:184–198.

Ma Z, Li B, Zhao B, Jing K, Tang S, and Chen J. 2004. Are artificial wetlands good alternatives to natural wetlands for waterbirds? – A case study on Chongming Island, China. *Biodiversity and Conservation* 13:333–350.

Maccarone AD, and Brzorad JN. 2005. Foraging microhabitat selection by wading birds in a tidal estuary, with implications for conservation. *Waterbirds* 28:383–391.

Márquez-Ferrando R, Figuerola J, Hooijmeijer JCEW, and Piersma T. 2014. Recently created man-made habitats in Doñana provide alternative wintering space for the threatened Continental European black-tailed godwit population. *Biological Conservation* 171:127–135.

Martínez-Vilalta A, Motis A, Christie DA, and Kirwan GM. 2019. Little Egret (*Egretta garzetta*). In: del Hoyo J, Elliott A, Sargatal J, Christie DA, and de Juana E, eds. *Handbook of the Birds of the World Alive*. Barcelona, Spain: Lynx Edicions.

Mitchell C, Griffin L, Maciver A, Minshull B, and Makan N. 2016. Use of GPS tags to describe the home ranges, migration routes, stop-over locations and breeding area of Taiga Bean Geese *Anser fabalis fabalis* wintering in central Scotland. *Bird study* 63:437-446.

Mohr CO. 1947. Table of equivalent populations of North American small mammals. *The American Midland Naturalist* 37:223–249.

Morton B. 2016. Hong Kong's mangrove biodiversity and its conservation within the context of a southern Chinese megalopolis. A review and a proposal for Lai Chi Wo to be designated as a World Heritage Site. *Regional studies in marine science* 8:382–399.

Murillo-Pacheco J, López-Iborra GM, Escobar F, Bonilla-Rojas WF, and Verdú JR. 2018. The value of small, natural and man-made wetlands for bird diversity in the east Colombian Piedmont. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28:87–97.

Navedo JG, Fernandez G, Fonseca J, and Drever MC. 2015. A potential role of shrimp farms for the conservation of Nearctic shorebird populations. *Estuaries and Coasts* 38:836–845.

Nielson R, Sawyer H, and McDonald T. 2013. BBMM: Brownian bridge movement model. R package version 3.0.

QGIS Development Team. 2016. QGIS Geographic Information System. Open Source Geospatial Foundation Project. *Available at http://qgis.osgeo.org*.

Ramirez F, Navarro J, Afan I, Hobson KA, Delgado A, and Forero MG. 2012. Adapting to a changing world: unraveling the role of man-made habitats as alternative feeding areas for slender-billed gull (*Chroicocephalus genei*). *PloS one* 7:e47551.

R Core Team. 2019. R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. *Available at https://www.R-project.org/* (accessed 21 October 2017).

Ren H, Wu X, Ning T, Huang G, Wang J, Jian S, and Lu H. 2010. Wetland changes and mangrove restoration planning in Shenzhen Bay, Southern China. *Landscape and Ecological Engineering* 7:241–250.

Rocha AR, Ramos JA, Paredes T, and Masero JA. 2017. Coastal saltpans as foraging grounds for migrating shorebirds: an experimentally drained fish pond in Portugal. *Hydrobiologia* 790:141–155.

Seaman DE, and Powell RA. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77:2075–2085.

Sebastián-González E, and Green AJ. 2016. Reduction of avian diversity in created versus natural and restored wetlands. *Ecography* 39:1176–1184.

Takano LL, and Haig SM. 2004. Seasonal movement and home range of the Mariana common moorhen. *The Condor* 106:652–663.

Whisson DA, Weston MA, and Shannon K. 2015. Home range, habitat use and movements by the little raven (*Corvus mellori*) in a coastal peri-urban landscape. *Wildlife Research* 42:500–508.

Wickham H. 2016. *ggplot2: elegant graphics for data analysis*. New York: Springer.

Wong LC, Corlett RT, Young L, and Lee JSY. 1999. Foraging flights of nesting egrets and herons at a Hong Kong egretry, south China. *Waterbirds* 22:424–434.

Worton BJ. 1989. Kernel methods for estimating the utilization distribution in home-range

studies. *Ecology* 70:164–168.
Young L. 1998. The importance to ardeids of the Deep Bay fish ponds, Hong Kong. *Biological Conservation* 84:293–300.
Yu YT, and Swennen C. 2004. Habitat use of the Black-faced Spoonbill. *Waterbirds* 27:129–134.

Figure 1

50% core areas and 95% overall home ranges of nine little egrets in the Inner Deep Bay, Hong Kong, using Brownian bridge movement model.

A) CHI01, B) HUN01, C) HUN02, D) HUN03, E) HUN04, F) PIC05, G) PIC06, H) PIC07, I) PIC09.

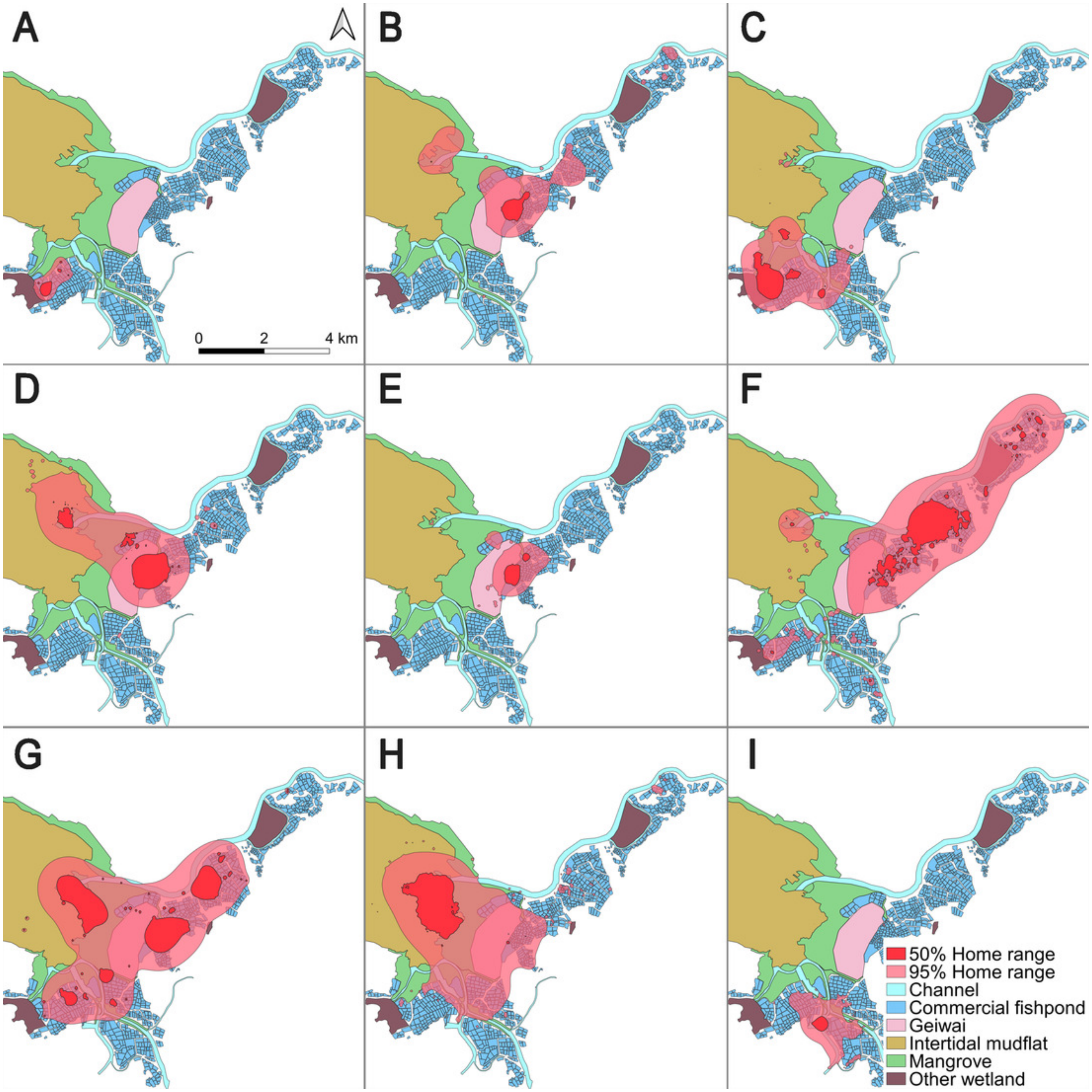
A
B
C
D
E
F
G
H
I
0
2
4 km
50% Home range
95% Home range
Channel
Commercial fishpond
Geiwai
Intertidal mudflat
Mangrove
Other wetland

Figure 2

Eigen analyses of selection ratios of habitat selection of nine little egrets in six habitat types in different seasons.

Habitat types loadings on the first two factorial axes and individual scores on the first factorial plant were displayed by seasons. A–B, Spring; C–D, Summer; E–F, Autumn; G–H, Winter. The numbers correspond to the animals. 1, CHI01; 2, HUN01; 3, HUN02; 4, HUN03; 5, HUN04; 6, PIC05; 7, PIC06; 8, PIC07; 9, PIC09.

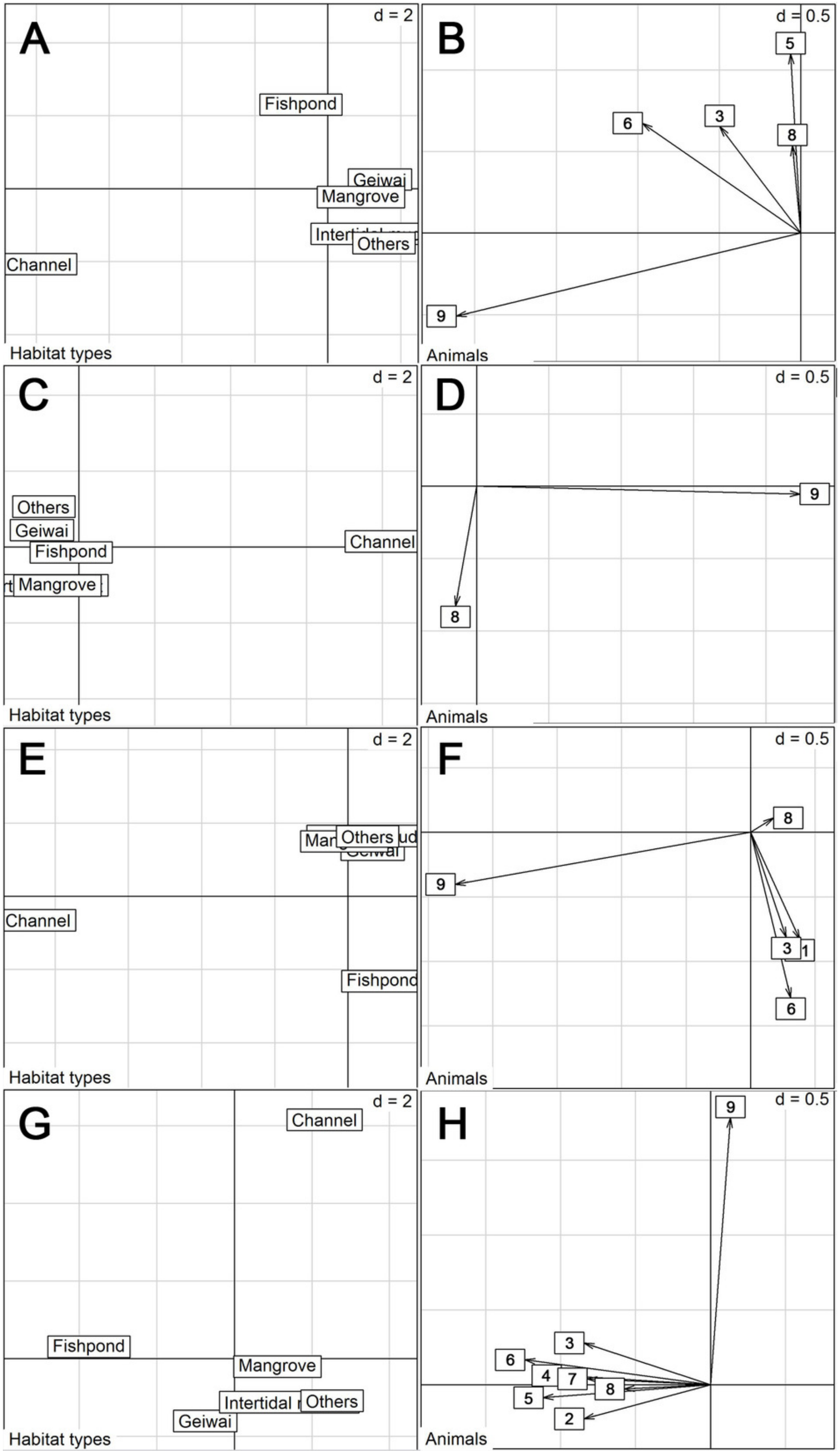
A
d = 2
Fishpond
Geiwai
Mangrove
Others
Channel
Habitat types
B
d = 0.5
5
6
3
8
9
Animals
C
d = 2
Others
Geiwai
Fishpond
Channel
Mangrove
Habitat types
D
d = 0.5
9
8
Animals
E
d = 2
Others
Channel
Fishpond
Habitat types
F
d = 0.5
8
9
3
1
6
Animals
G
d = 2
Channel
Fishpond
Mangrove
Others
Geiwai
Habitat types
H
d = 0.5
9
3
6
4
7
8
5
2
Animals

Figure 3

The effect sizes of season on the little egret activities.

(A) home range size (black: log daily 50% core area; grey: log daily 95% home range), (B) daily travel distances in the LMM models and (C) occurrence frequency on fishponds of little egrets in the GLMM model. Autumn was set as the reference level. Error bars represent standard errors.

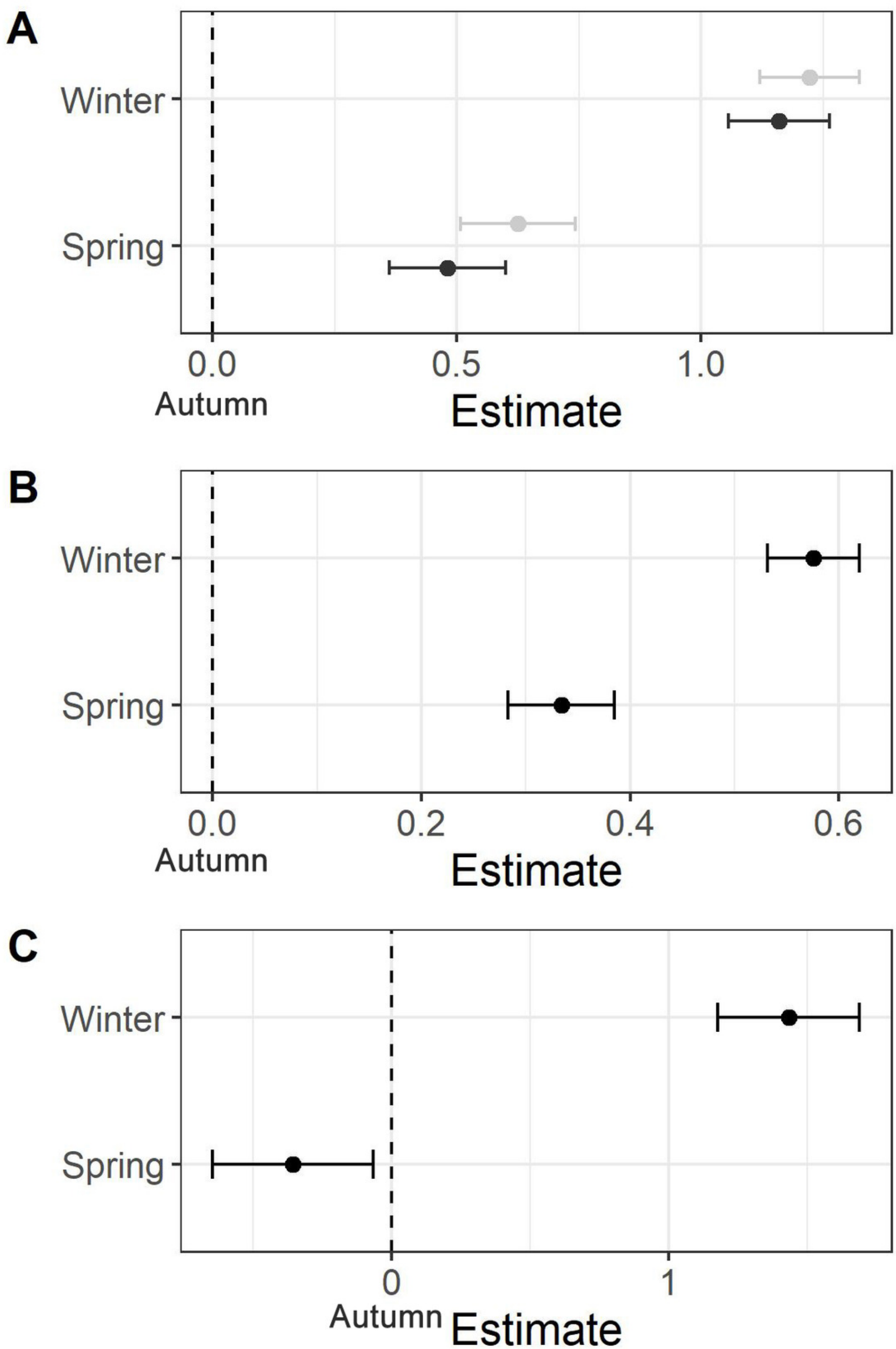
A
Winter
Spring
0.0
0.5
1.0
Autumn
Estimate
B
Winter
Spring
0.0
0.2
0.4
0.6
Autumn
Estimate
C
Winter
Spring
0
1
Autumn
Estimate

Figure 4

Number of commercial fishponds that were drained according to season in the Inner Deep Bay, Hong Kong in 2018-2019.

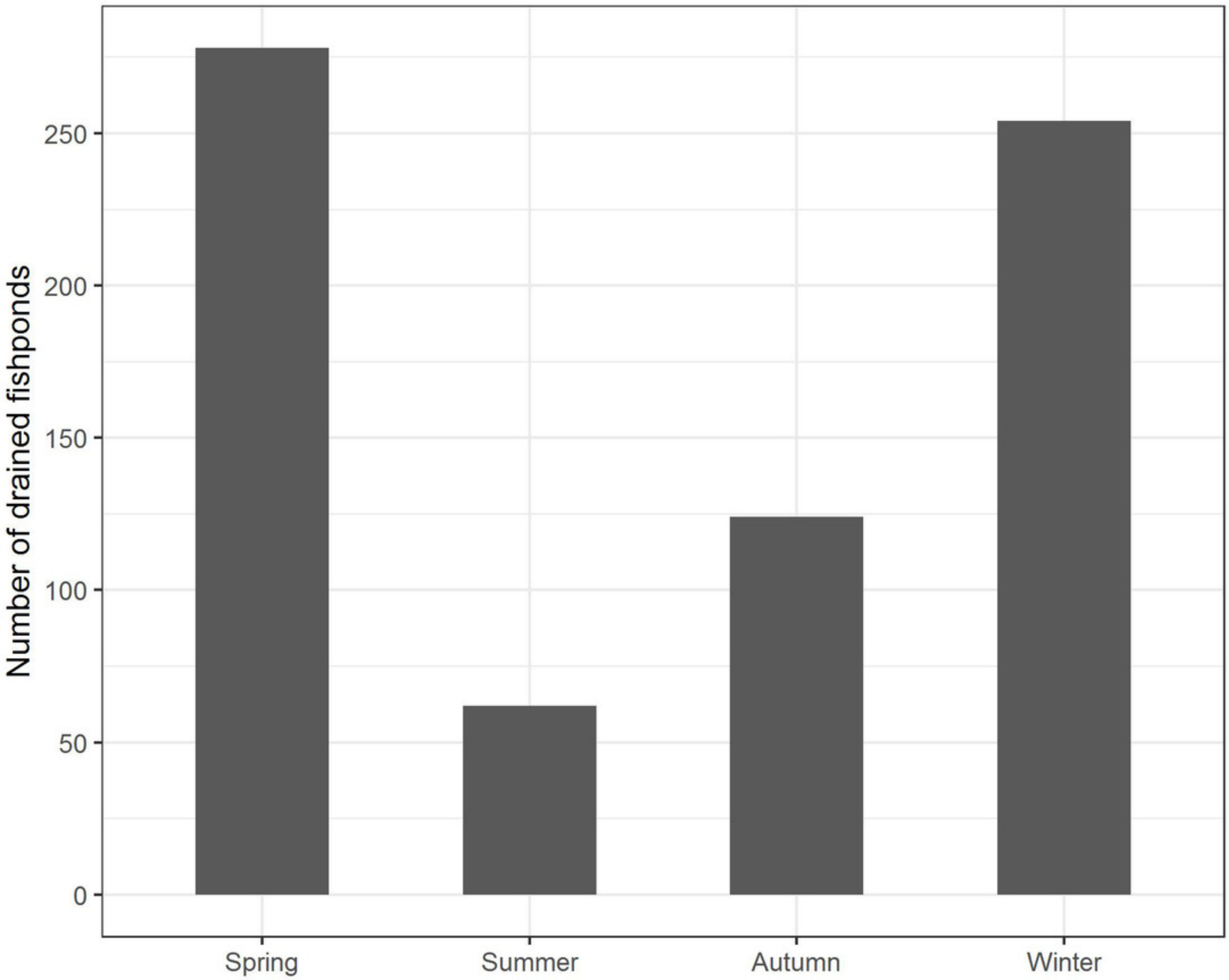

Table 1(on next page)

Home range of little egrets in the inner Deep Bay area, Hong Kong.

Table 1. Home range of little egrets in the Inner Deep Bay, Hong Kong.

ID	Tracker model	Start date of tracking	Last date of signal received	Tracking duration (day)	Home range (km²)				
					100% MCP	50% Kernal	95% Kernal	50% BBMM	95% BBMM
CHI01	PICA	28/09/18	15/11/18	49	1.54	0.13	0.79	0.14	0.85
HUN01	HARRIER	01/12/18	08/02/19	70	26.11	0.76	7.95	0.40	5.85
HUN02	HARRIER	18/10/18	22/03/19	156	12.97	1.03	5.73	0.97	6.33
HUN03	HARRIER	01/12/18	14/02/19	76	16.16	1.53	10.28	1.37	10.17
HUN04	HARRIER	01/12/18	22/03/19	112	17.52	0.33	1.30	0.30	2.25
PIC05	PICA	30/01/18	08/02/19	217*	38.38	3.90	24.61	2.58	20.05
PIC06	PICA	30/01/18	28/02/18	30	25.57	7.55	27.29	3.70	20.62
PIC07	PICA	30/01/18	27/02/19	394	41.04	2.03	15.32	2.20	15.81
PIC09	PICA	30/01/18	21/03/19	289*	24.72	0.10	1.62	0.15	2.68

* PIC05 migrated out of Hong Kong from 13/05/18 to 05/08/18 and PIC09 migrated from 29/03/18 to 01/08/2018. Data obtained in this period were excluded in the analysis.

Table 2(on next page)

Proportion (SE) of habitat types within the home ranges for the tracked little egrets, and the proportion of little egret locations within each habitat type in the Inner Deep Bay, Hong Kong.

Table 2. Proportion (SE) of habitat types within the home ranges for the tracked little egrets, and the proportion of little egret locations within each habitat type in the inner Deep Bay, Hong Kong.

Habitat types	100% MCP	95% BBMM home range	50% BBMM home range	Point locations
Channel	6.8 (0.4)	5.5 (1.6)	7.5 (5.2)	9.5 (7.3)
Fishpond	31.3 (2.7)	46.8 (6.7)	54.3 (10.4)	58.7 (9.5)
Gei wai	7.4 (1.3)	11.4 (3.8)	11.9 (5.7)	9.7 (4.5)
Mangrove	19.9 (2.5)	13.8 (2.5)	7.6 (2.6)	11.9 (3.4)
Intertidal mudflat	14.0 (2.6)	11.4 (4.3)	12.5 (8.3)	10.2 (5.2)
Others	20.5 (3.9)	11.1 (3.6)	6.2 (2.7)	0.1 (0.0)

Table 3(on next page)

The ranking matrix for habitat selection of the nine little egrets. The matrix compares the proportion of used habitat based on the relocations and 100% MCP (available habitat).

+, preference, -, avoidance, a triple sign indicates significant deviation from random at $p < 0.05$. The ranking list ranges from 0 (most avoided) to 5 (most selected).

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	Fishpond	Mangrove	*Gei wai*	Channel	Intertidal mudflat	Others	Rank
Fishpond		+++	+++	+++	+++	+++	5
Mangrove	−−−		+	+	+	+++	4
Gei wai	−−−	−		+	+	+++	3
Channel	−−−	−	−		+	+++	2
Intertidal mudflat	−−−	−	−	−		+++	1
Others	−−−	−−−	−−−	−−−	−−−		0

Table 4(on next page)

Statistical summary of ANOVA following Linear Mixed Models (LMM) and Generalized Linear Mixed Model (GLMM) for the effects of season on the activities of little egrets.

Table 4. Statistical summary of ANOVA following Linear Mixed Models (LMM) and Generalized Linear Mixed Model (GLMM) for the effects of season on the activities of little egrets.

Source of variation	Model	d.f.	SS	MS	F-ratio	*p*
Log daily 50% home range	LMM	2	222.8	111.4	67.5	<0.001
Log daily 95% home range	LMM	2	237.4	118.7	73.8	<0.001
Log daily travel distance	LMM	2	51.7	25.9	85.0	<0.001
Occurrence frequency in fishponds	GLMM	2	86.4	43.2	43.2	<0.001