Change in nest site and population size of great cormorants (*Phalacrocorax carbo*) in relation to different Ardeidae species in inland breeding sites in Korea

Hyun-Jeong Lee[1], Jin-Hee Yi[2] and Ha-Cheol Sung[3*]

Abstract

We investigated the changes in the population size and inter-specific space usage for breeding in mixed breeding sites of the great cormorant (*Phalacrocorax carbo*), grey heron (*Ardea cinerea*), great egret (*Ardea alba modesta*) and intermediate egret (*Egretta intermedia*) in Gammul-myeon, Goesan-gun, Chungcheongbuk-do, South Korea, in 2016–2017. These species bred in two adjacent habitats (site A and site B). The number of breeding pairs of all species and the size of the breeding area at site B increased in 2017. In 2017, great cormorants at site B occupied the breeding sites previously occupied by the other species in 2016, while the grey heron and great egret occupied the sites around the great cormorant breeding site. The heights of nest trees and nests of great cormorant and grey heron did not differ temporally, but these heights in site B were significantly higher than those in site A for great cormorants. For great egrets, these greatly decreased in site B in 2017. Thus, the great cormorant either moved to favourable nest sites for breeding success or selected nest sites used by the herons in the previous year. Further studies of these two possibilities are necessary.

Keywords: *Phalacrocorax carbo*, Ardeidae, Mixed breeding sites, Nest height, Nest tree height

Background

Changes in population size of bird species are affected by habitat conditions (Kushlan 1993; Zöckler 2005; Sekercioglu 2006) including the physical environment (type, height and girth of nest trees, nest height built in the tree, distances between nests, food location, etc.) and the biological environment (species sharing the nest tree, intra- and inter-specific interactions, time of arrival at the breeding sites, etc.), which affect the survival and reproductive success of the breeding species. Thus, to ensure breeding success, birds are expected to respond to changes in habitat conditions.

Most waterbirds such as gulls, cormorants, and egrets are collectively breeding (Rolland et al. 1998; Valera et al. 2003). More than two species breed together in the same breeding site (e.g. sharing nest trees), and the interactions among these breeding populations can affect the breeding period, behaviour, and habitat selection (Rosenberger 2015; Lee 2018). On the one hand, group breeding helps to choose good-quality habitats and increases the likelihood of finding food resources (Zicus and Hennes 1989; Hoi and Hoi-Leitner 1997; Somers et al. 2007). In addition, it alerts the animals to approaching predators and provides opportunities to avoid predators or to continue feeding even in the presence of other species (Nuechterlein 1981; Wojczulanis et al. 2005). On the other hand, inter-specific competition or aggressive interactions can have negative effects on reproduction (Burger 1984; Ellis and Good 2006; Somers et al. 2007). For example, inter-specific competition during the breeding period for selecting nest site or for food resources could result in one of the species not being able to reproduce successfully. Competition for site selection

* Correspondence: shcol2002@jnu.ac.kr
[3]Research Center of Ecomimetics, Department of Biological Sciences, College of Natural Sciences, Chonnam National University, Gwangju 61186, Korea
Full list of author information is available at the end of the article

occurs in the early days of breeding, which may lead to giving up the optimal breeding sites to other species and being pushed to the less favourable sites in the surrounding area (Valera et al. 2003; Ellis and Good 2006; Somers et al. 2007). At the same time, the excreta of great cormorants increases the acidity of the soil and the imbalance of nutrients, resulting in defoliation of the trees (Cuthbert et al. 2002; Kolb et al. 2010; Hebert et al. 2014). This causes loss of habitat and reduction in the number of breeding waterbirds (Hebert et al. 2005; Somers et al. 2007; Dorr et al. 2010). Thus, intra- and inter-specific interactions between breeding waterbirds could affect the selection of breeding sites and the number of breeding populations.

The great cormorant is a species of the order Pelecaniformes (family: Phalacrocoracidae) that is found throughout the world except in South America and Antarctica (Del Hoyo et al. 1992; Park and Seo 2008). According to a survey in 2008 in Korea, a large number of great cormorants bred along the Han River estuary and the islands off the west coast (Park and Seo 2008; Lee et al. 2010). After that, their breeding sites have expanded to inland areas such as Soyangho Lake in Chunchoen and Jokjado near Paldangho Lake (Park 2014). Our study area, located in Gammul-myeon, Goesan-gun, Chungcheongbuk-do, has been reported to be an early breeding site for species of the family Ardeidae (National Environmental Science Institute 2012), and from 2013, great cormorants have begun to settle in and share the breeding sites with these species.

Therefore, in this study, in the mixed breeding sites of the great cormorants and the species of the Ardeidae family in Gammul-myeon, we investigated the changes in the inter-specific population size and the spatial use of the study area for breeding from 2016 to 2017. We observed the movement patterns of these birds to choose nest trees within the breeding sites, and we predicted the cause of change across years to be one of the following: (1) to improve breeding success, the great cormorants will move to places with good nest tree that were of sufficient height to build nests at optimal heights, and girth (measured as the diameter at breast height, DBH); (2) because the defoliation rate of nest trees is high, there is a possibility that the great cormorants will move to an area with trees experiencing low defoliation; and (3) regardless of the nest tree conditions, they would have moved, influenced directly or indirectly by the existence of other species rather than selecting breeding sites by themselves. In order to reveal the cause of population change, we examined (1) the spatial use of breeding nest sites by year and species, and (2) the characteristics of the breeding site that was selected by the study species in each year of the study. The characteristics that were examined were nest tree and nest height, DBH of the nest trees and status of nest trees (i.e., live tree (LT) or dead tree (DT)).

Materials and methods
Study sites
We performed this study in the forested area near a large reservoir located in our study area. We located nest sites and trees of each pair of species and measured their nest and tree heights and DBH from end-May to end-September in 2016 and 2017. The breeding sites were divided into two large habitats (site A and site B), which existed across the valley separated by about 30 m (Fig. 1). While false acacia (*Robinia pseudoacacia*) and sawtooth oak (*Quercus acutissima*) trees were the dominant species at site A, false acacia and oriental white oak (*Quercus aliena*) were at site B (Lee et al. 2017).

Breeding site characteristics
After breeding of all species, we measured the nest tree height, nest height, DBH, LT/DT, size of breeding area, and population size of each species. Nest locations were recorded using a GPS and were displayed on the map of the study area. We used binoculars (10 × 32, Carl Zeiss Terra ED) and a field scope (LEPOLD WindRiver 20–60 × 80S) to identify the nest trees of each species, a digital range finder (Leica DISTO^{TM} X310) to measure the height of the nest tree and the height of the nests, and a Diameter Rule (F10-02DM/KDS) to measure the DBH. We counted the number of pairs of species in the breeding area at site A and at site B and measured the size of breeding areas in 2016 and 2017 using the coordinate information of the nests obtained from the National Geographic Information Service (http://www.ngii.go.kr).

Statistical analysis
All data were tested for normality (one-sample Kolmogorov-Smirnov test, $P > 0.05$) and once normality was confirmed, two-way ANOVA was used to analyse the effects of nest tree height, nest height, and DBH of great cormorants and the species belonging to Ardeidae by year and by breeding sites. All statistical analyses were performed using the SPSS statistical package (IBM SPSS version 20.0).

Results
The breeding area and the number of breeding pairs in site A and site B in the study area were compared between 2016 and 2017. First, both the breeding area and the number of breeding pairs of great cormorants and the three Ardeidae species (grey heron, great egret and intermediate egret) decreased in site A in 2017 compared to 2016, but
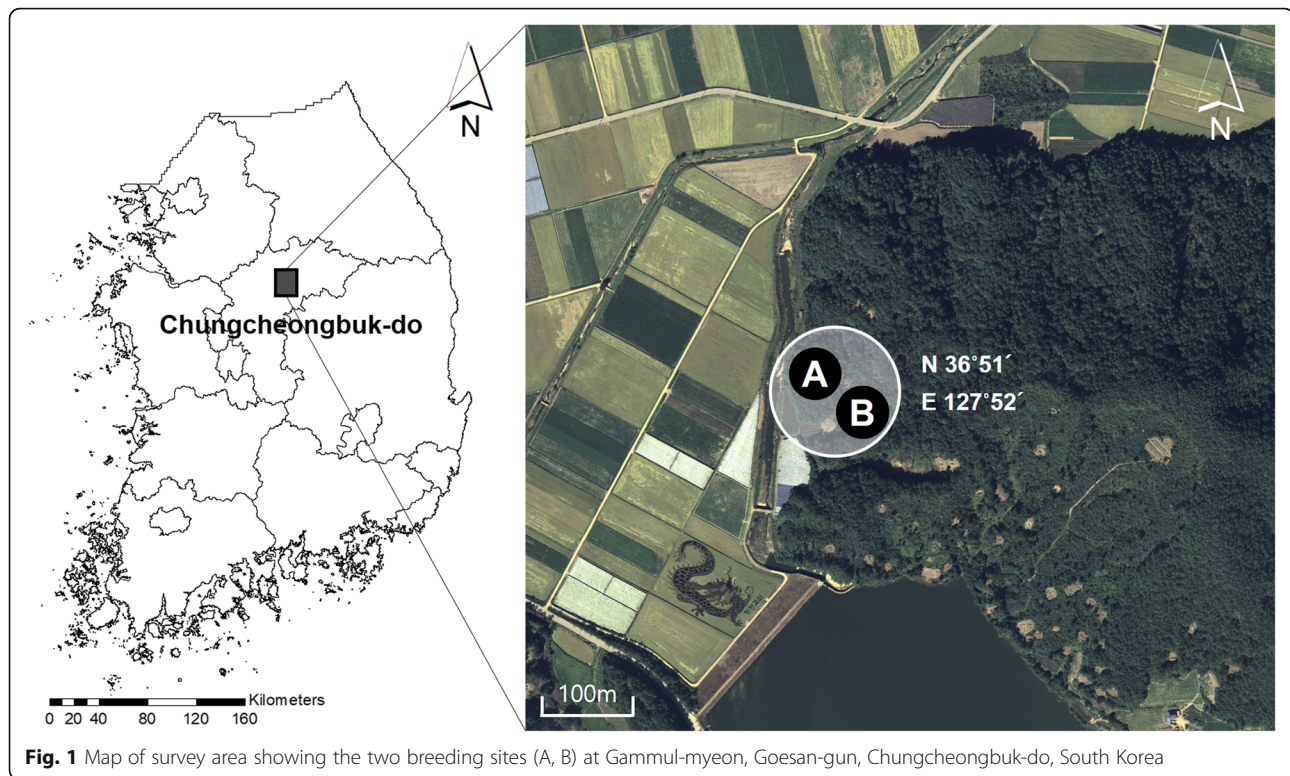
Fig. 1 Map of survey area showing the two breeding sites (A, B) at Gammul-myeon, Goesan-gun, Chungcheongbuk-do, South Korea

they increased in site B (Fig. 2, Table 1, Table 2). Second, in 2017, a large number of great cormorants in site B took up the central part of the habitat, which was the main breeding ground for the Ardeidae species in 2016. Furthermore, the Ardeidae species also increased in site B in 2017 when compared with the numbers in 2016, but these birds settled around the major breeding sites of great cormorants. Third, the great egrets and the intermediate egrets bred in site A and B in 2016, but both did not breed in site A and the intermediate egret did not breed in site B either in 2017.

In terms of the height of the nest trees, while there was a significant interaction between the years and the breeding sites of the great cormorants ($F_{1,128} = 9.395$, $P = 0.003$), and a significant difference between sites (site A, site B; $F_{1,128} = 18.153$, $P < 0.001$), we found no difference between the years (2016, 2017), where the mean value of the height of the nest tree at site A increased and site B decreased in 2017 (Fig. 3a). In 2017, the number of great cormorants occupying site B was more than site A, and they selected taller nest trees in 2017 than in 2016. Grey herons showed no significant difference between sites and between years (Fig. 3b). In 2017, the great egret had no breeding pairs in site A while the intermediate egret had none in both sites A and B. At site B, the height of nest trees of the great egrets in 2017 was significantly lower than in 2016 ($F_{1,75} = 5.232$, $P = 0.025$; Fig. 3c).

In terms of the nest height, there was a significant interaction between the years and the sites of breeding

for the great cormorants ($F_{1,233} = 10.170$, $P = 0.002$). It differed significantly between sites (site A, site B; $F_{1,233} = 8.867$, $P = 0.003$), but showed no difference between the years (2016, 2017), where the mean value of the nest height at site A increased and site B decreased in 2017 (Fig. 4a). The number of great cormorants occupying site B was more than at site A in 2017. The height at which their nests were built was higher in 2017 than in 2016. Grey heron showed no significant difference either spatially (between sites) or temporally (between years) (Fig. 4b). However, in site B, the nest height of the great egrets in 2017 was significantly lower than in 2016 ($F_{1,150} = 12.577$, $P = 0.001$; Fig. 4c).

In terms of DBH, there was significant interaction between the years and the sites of breeding for the great cormorants ($F_{1,128} = 8.992$, $P = 0.003$). However, no significant differences were seen between sites (site A, site B) and between years (2016, 2017). There were no significant differences in all analyses for the grey herons and no difference between years for the great egrets.

In 2016, the percentage of living trees in site A was 92% while that of dead trees was 8%. In site B, the percentage of living trees was 100%, while no dead trees were used for nesting.

Discussion

Our results indicate that there were inter-specific interactions in the selection of breeding sites between

Fig. 2 Size of breeding areas and the number of breeding pairs of great cormorants and the three Ardeidae species in sites A and B: **a** 2016 and **b** 2017

the great cormorants and birds belonging to the family Ardeidae. At site A in 2017, while the breeding area and the number of breeding pairs of great cormorants largely decreased, only two pairs of grey heron bred around the breeding site of great cormorants, and the great egret and the intermediate egret

Table 1 Size of the breeding areas of great cormorants and birds of the family Ardeidae in site A and site B (in the years 2016 and 2017)

Species	Size of breeding areas (m²)			
	2016		2017	
	Site A	Site B	Site A	Site B
Great cormorant	1811.43	202.16	948.87	1049.44
Ardeidae species	415.67	1475.09	233.66	1792.25
Total	2227.10	1677.25	1182.53	2841.69

Table 2 Number of breeding pairs of great cormorants and birds of the family Ardeidae in site A and site B (in the years 2016 and 2017)

Species	Number of breeding pairs			
	2016		2017	
	Site A	Site B	Site A	Site B
Great cormorant	84	18	44	91
Grey heron	39	9	2	60
Great egret	4	64	0	85
Intermediate egret	13	13	0	0
Total	140	104	46	236

did not breed at all. At site B, the breeding area and the number of breeding pairs of the great cormorants, grey herons, and great egrets increased in 2017. In particular, the great cormorants, in 2017, occupied the places where grey heron, great egret, and intermediate egret had bred in 2016, and the grey herons and great egrets moved to areas located around the breeding sites of great cormorants in 2017. Three possible causes for the movement of these waterbirds to another breeding site and changes in their population size over the 2 years of this study (i.e. better conditions to ensure breeding success, lower defoliation rates and breeding site selected by other species) were highlighted in the introduction section of this paper. Based on our results, we evaluate each of these, below.

The first possible cause for the movement and changes in the population size of the great cormorants that we observed in our study is that the site B was a better breeding site. The heights of the nesting trees at site B were greater than those in site A in both years, while the height of the nests of the great cormorants was greater at site B in 2017 than at site A in 2016. Earlier studies have concluded that the higher the nest tree height, the higher is the breeding success rate (Childress and Bennun 2000; Park et al. 2011). Thus, it is possible that the great cormorants moved to areas

with taller nest trees. On the contrary, grey herons did not show significant differences between breeding years and sites, while the height of the nest tree and nest of great egrets were significantly lower in site B in 2017 than in 2016. Similar to results from a previous study (Park et al. 2011), nest tree and nest height of great egrets were lower than those of grey herons, which was probably influenced by the competition for nest sites between these species. Therefore, at site B in 2017, great cormorants selected taller trees for nesting and the height of their nests was higher than in site A in 2016, and the nest and nest tree heights of the grey herons and great egrets seem to have been influenced by the selection of great cormorants.

The second possible cause is the defoliation rate of the nest trees. The defoliation rate of those used in site A in 2016 was high enough to make it unstable for nesting. It is known that the double-crested cormorants (*Phalacrocorax auritus*) often prefer nearby sturdy trees because the branches of defoliated tree are less stable when building nests (Rippey et al. 2002; Hebert et al. 2005). By abandoning dead and dying trees and selecting a living tree, the double-crested cormorants tended to expand breeding sites (Hebert et al. 2005). However, in this study area, the
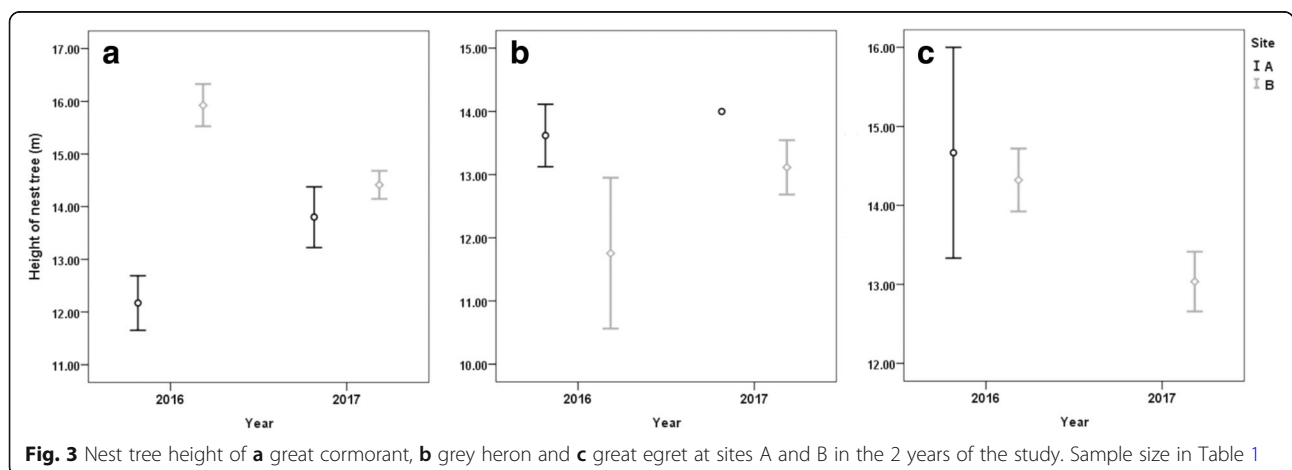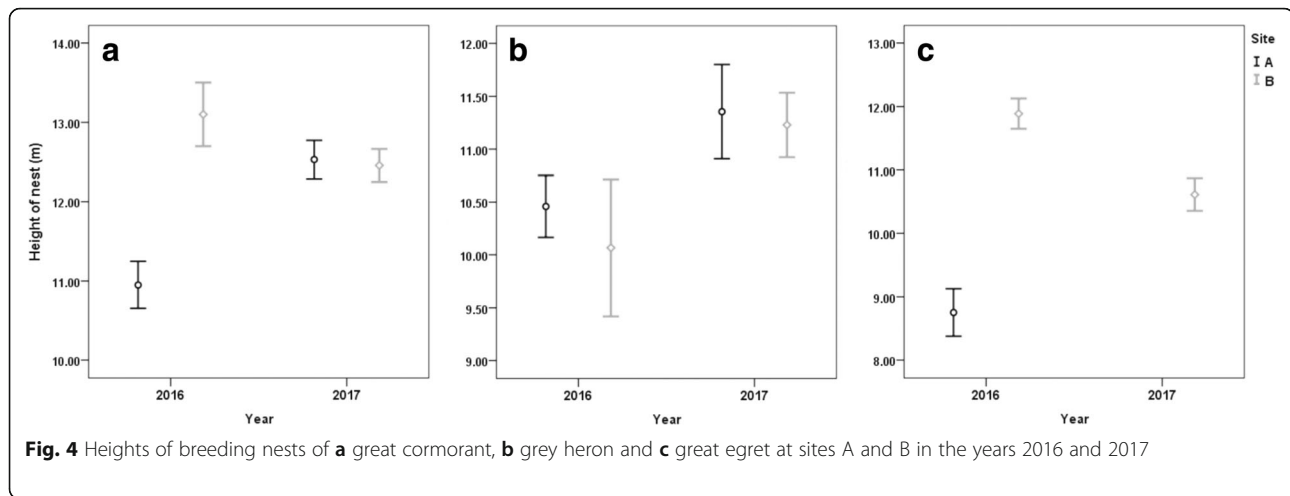

Fig. 3 Nest tree height of **a** great cormorant, **b** grey heron and **c** great egret at sites A and B in the 2 years of the study. Sample size in Table 1

Fig. 4 Heights of breeding nests of **a** great cormorant, **b** grey heron and **c** great egret at sites A and B in the years 2016 and 2017

defoliation rate of the nest trees in site A was 8% in 2016, while dead trees were not used for nesting in site B in 2016. Compared to our study, Lafferty et al. (2016) reported that, although the ratio of live to dead trees used for nesting by the double-crested cormorant varied throughout the breeding area, in general, about 50% of the nest tree were dead. Further, 50% of the nest trees of the great blue herons (*Ardea herodias*) found breeding along with it were also dead. Our results show that even though the defoliation rate of the nest trees in site A was only about 8%, many breeding species moved to the surrounding area, implying that, the possibility of defoliation rate driving the changes is low.

The third possible cause for the change in the breeding sites of the great cormorants from site A to B is because of the presence of the birds belonging to the Ardeidae family. In 2016, the nest trees of the great cormorants was located in the centre of the habitat in site A, while in 2017, in site B, great cormorants bred in most places where the Ardeidae species had bred in 2016, which in turn had moved to areas around the breeding sites of the great cormorants. The changes show a high possibility that great cormorants moved breeding sites along with Ardeidae. Similar results have been reported in the mixed breeding double-crested cormorant and black-crowned night heron (*Nycticorax nycticorax*) populations in Tommy Thompson Park, Ontario, Canada (Jarvie et al. 1997), where the black-crowned night herons abandoned their breeding sites and moved to adjacent habitats during the 1993–1995 survey periods and the double-crested cormorants continued to expand its distribution to the area where the black-crowned night herons had earlier bred. Further, the double-crested cormorants used the nest trees of the black-crowned night herons in the following years. In addition, the double-crested cormorant colonies in the US Great Lakes island initially followed herons for new nesting areas, where about 3% of cormorants started to nest in new areas without any other waterbirds (Wires and Cuthbert 2009). So heron presence might be used as an indicator of habitat quality of the cormorants (Forbes and Kaiser 1994). In this study, however, more detailed observations are needed to reveal how the great cormorant directly or indirectly interacts with other Ardeidae in the future.

Conclusion

We can conclude that two of the three possible causes suggested (the first possible cause, i.e. requirement for a good quality site to ensure reproductive success, and the third possible cause, i.e. influence of site-choice made by other species in the mixed breeding group) are likely to have driven the changes in the breeding sites and in the population size of the great cormorants and birds of the Ardeidae family between the 2 years and the two sites. Further detailed and long-term studies are necessary on the reproductive success of the breeding species and the initial breeding site selection process and behaviour in order to determine whether changes occurred as a result of selection of good quality breeding nest sites or just as a result of breeding site selection of different Ardeidae species.

Authors' contributions
HJL and JHY were involved in the data collection and analysis. HJL and HCS were involved in the writing of the manuscript. All authors read and approved the final manuscript.

Availability of data and materials
The datasets during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author details
[1]School of Biological Sciences and Biotechnology, Chonnam National University, Gwangju 61186, Korea. [2]Pulip Ecology Research Institute, Namyangju-si, Gyeonggi-do 12128, Korea. [3]Research Center of Ecomimetics, Department of Biological Sciences, College of Natural Sciences, Chonnam National University, Gwangju 61186, Korea.

References
Burger J. Grebes nesting in gull colonies: protective associations and early warning. Am Nat. 1984;123:327–37.

Childress RB, Bennun LA. Nest size and location in relation to reproductive success and breeding timing of tree-nesting great cormorants. Waterbirds. 2000;23:500–5.

Cuthbert FJ, Wires LR, McKearnan JE. Potential impacts of nesting double-crested cormorants on great blue herons and black-crowned night-herons in the US Great Lakes region. J Great Lakes Res. 2002;28:145–54.

Del Hoyo J, Elliott A, Sargatal J. Handbook of the birds of the world, vol. 1. Barcelona: ICBP. Lynx Edicions; 1992.

Dorr BS, Aderman T, Butchko PH, Barras SC. Management effects on breeding and foraging numbers and movements of double-crested cormorants in the Les Cheneaux Islands, Lake Huron, Michigan. J Great Lakes Res. 2010;36:224–31.

Ellis JC, Good TP. Nest attributes, aggression, and breeding success of gulls in single and mixed species subcolonies. The Condor. 2006;108:211–9.

Forbes SL, Kaiser GW. Habitat choice in breeding seabirds: when to cross the information barrier. Oikos. 1994;70:377–84.

Hebert CE, Duffe J, Weseloh DC, Senese ET, Haffner GD. Unique islands habitats may be threatened by double-crested cormorants. J Wildlife Manag. 2005;69:68–76.

Hebert CE, Pasher J, Weseloh DC, Dobbie T, Dobbyn S, Moore D, Duffe J. Nesting cormorants and temporal changes in island habitat. J Wildlife Manag. 2014;78:307–13.

Hoi H, Hoi-Leitner M. An alternative route to coloniality in the bearded tit: females pursue extra-pair fertilizations. Behav Ecol. 1997;8:113–9.

Jarvie S, Blokpoel H, Chipperfield T. A geographic information system to monitor nest distributions of double-crested cormorants and blackcrowned night-herons at shared colony sites near Toronto, Canada. In: Symposium on Double-crested Cormorants: population status and management issues in the Midwest. ME Tobin: Ed.). USDA/APHIS Technical Bulletin; 1997.

Kolb GS, Ekholm J, Hambäck PA. Effects of seabird nesting colonies on algae and aquatic invertebrates in coastal waters. Mar Ecol Prog Ser. 2010;417:287–300.

Kushlan JA. Colonial waterbirds as bioindicators of environmental change. Colon Waterbirds. 1993;16:223–51.

Lafferty DJ, Hanson-Dorr KC, Prisock AM, Dorr BS. Biotic and abiotic impacts of double-crested cormorant breeding colonies on forested islands in the southeastern United States. For Ecol Manag. 2016;369:10–9.

Lee HJ. Breeding behavior and habitats of great cormorant (*Phalacrocorax carbo*) in inland mixed breeding sites with Ardeidae [master's thesis. Gwangju: Chonnam National University; 2018.

Lee HJ, Yi JH, Baek CR, Han YS, Sung HC. The mixed breeding site of great cormorant (*Phalacrocorax carbo*) and birds in the family Ardeidae in inland of South Korea. Korean J Ornithol. 2017;24:89–100.

Lee SW, Kim YH, Kang TH, Song MJ. Ecological importances of Jangbongdo coastal wetland protected area as a habitat of macro-benthic fauna and waterbirds. Korean J Ornithol. 2010;17:149–62.

National Environmental Science Institute. Egrets and herons in Korea. Seoul: Econature; 2012.

Nuechterlein GL. 'Information parasitism' in mixed colonies of western grebes and Forster's terns. Anim Behav. 1981;29:985–9.

Park JG. Identification guide to birds of korea. Seoul: Econature; 2014.

Park JG, Seo JH. A photographic guide to the birds of Korea (Water bird). Seoul: Econature; 2008.

Park SR, Kim KY, Chung H, Choi YS, Sung HC. Vertical nest stratification and breeding success in a six mixed-species heronry in Taeseong, Chungbuk, Korea. Animal Cells Syst. 2011;15:85–90.

Rippey E, Rippey JJ, Dunlop JN. Increasing numbers of pied cormorants breeding on the islands off Perth, Western Australia and consequences for the vegetation. Corella. 2002;26:61–4.

Rolland C, Danchin E, Fraipont MD. The evolution of coloniality in birds in relation to food, habitat, predation, and life-history traits: a comparative analysis. Am Nat. 1998;151:514–29.

Rosenberger LC. Analysis of duoble-crested cormorant nest spatial patterns in single and mixed-species colonies and their effect on cormorant behaviour and on black-crowned night heron spatial patterns [master's thesis]. Toronto: York University; 2015.

Sekercioglu CH. Increasing awareness of avian ecological function. Trends Ecol Evol. 2006;21:464–71.

Somers CM, Lozer MN, Quinn JS. Interactions between double-crested cormorants and herring gulls at a shared breeding site. Waterbirds. 2007;30:241–51.

Valera F, Casas-Crivillé A, Hoi H. Interspecific parasite exchange in a mixed colony of birds. J Parasitol. 2003;89:245–51.

Wires LR, Cuthbert FJ. Characteristics of double-crested cormorant colonies in the U.S. Great Lakes island landscape. J Great Lakes Res. 2009;36:232–41.

Wojczulanis K, Jakubas D, Stempniewicz L. Exploitation by the grey heron of fish regurgitated by cormorants. Waterbirds. 2005;28:225–30.

Zicus MC, Hennes SK. Nest prospecting by common goldeneyes. The Condor. 1989;91:807–12.

Zöckler C. Migratory bird species as indicators for the state of the environment. Biodiversity. 2005;6:7–13.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.