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Moran, Leah L.K.; Dorr, Brian S.; Hanson-Dorr, Katie C.; Moore, R. J.; and Rush, Scott A., "Space Use and Movements of Southeastern Breeding Double-Crested Cormorants (*Nannopterum auritum*) in the United States" (2023). *USDA Wildlife Services - Staff Publications*. 2637.

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Article

Space Use and Movements of Southeastern Breeding Double-Crested Cormorants (*Nannopterum auritum*) in the United States

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Abstract: Seasonal movements of Double-crested Cormorants (*Nannopterum auritum*) have been studied at breeding and wintering sites in the southeastern United States, but little information exists on the movements of these birds within and from their southern breeding sites in lacustrine systems. Since 2001, cormorants have established nesting colonies on islands in Guntersville Reservoir in Alabama, USA. Following the movements of tagged cormorants using satellite telemetry, we found that the mean home range during the 2017 breeding season (May–August) was 41.76 km², with a core use area of 6.36 km². The mean home range used by these birds was largest during the period coinciding with incubation: 9–30 May: (98.86 ± 80.64 km²) compared with the chick-rearing 31 May–4 July: 18.30 ± 22.56 km²), and the post-fledge periods (5 July–15 August: 42.04 ± 30.95 km²). There was no significant difference in the metrics of movement and space use between male and female cormorants assessed in this study. Differences in space used by cormorants breeding in Alabama relative to their northern breeding grounds may be explained by landscape characteristics and availability of prey.

Keywords: Alabama; breeding; movements; reservoir; satellite telemetry; space use



Citation: Moran, L.L.K.; Dorr, B.S.; Hanson-Dorr, K.C.; Moore, R.J.; Rush, S.A. Space Use and Movements of Southeastern Breeding Double-Crested Cormorants (*Nannopterum auritum*) in the United States. *Diversity* **2023**, *15*, 453. <https://doi.org/10.3390/d15030453>

Academic Editors: Thomas Göttert and Michael Wink

Received: 30 January 2023

Revised: 13 March 2023

Accepted: 15 March 2023

Published: 18 March 2023



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1. Introduction

A conservation success story, the abundance of Double-crested Cormorants (*Nannopterum auritum*, cormorants) has been increasing since the late 1970's across North America after a federal ban on DDT and sustainable management [1]. From around 32,000 pairs of breeding pairs in the late 1970's to 1–2 million individuals in 2005, the number of breeding cormorants has increased, particularly in the interior portion of North America [1]. Additionally, the number of cormorants wintering in the southeastern United States has also increased from 10,000 birds in 1996 to 31,000 birds in 2005 [2]. Increased cormorant abundance has heightened conflict between cormorants and humans, specifically manifested through concerns over the impacts of these birds on sport fishing, economic loss from depredation on aquaculture ponds, and the degradation of natural resources on breeding sites [3]. Sustainable management and thorough research are critical for the continued conservation of cormorants and the habitats they use.

Various studies have assessed cormorant movements during migration, wintering, and breeding seasons. Understanding these movements provides insight into resources used by these birds during different periods within a full annual cycle. However, with the advent of cormorant populations steadily increasing and utilizing new areas for breeding sites in the southeastern United States [1,4,5], we know less about how these birds are using these relatively novel ecosystems. Therefore, it is important to evaluate how cormorants

that may not leave the southeastern United States use these ecosystems and how the use of these resources may lead to heightened conflicts among stakeholders.

Water depth, distance from shore and proximity to loafing/staging areas are all factors known to affect how cormorants use aquatic systems during winter and breeding seasons [6,7]. Water depth can significantly affect cormorant movements, with birds typically capturing prey between 1–10 m (m) deep [8]. Loafing or staging areas are also important for movement, with birds using small islands or channel markers to rest and dive for prey. Cormorants require suitable daytime loafing areas as well as nighttime roosts during all seasons with channel markers, floating debris, and low-lying wires and trees being used throughout their seasonal ranges [7]. Islands or inlets 3 km (km) from the mainland are often used as winter roosts and breeding sites as a response for predator avoidance [9], with foraging distance typically within 20 km from these roosting or breeding sites [10,11].

During winter, cormorants that nest in North America's Great Lakes region migrate south to coastal inlets or to aquaculture-producing areas throughout the southeastern United States [12,13]. Geographically, the Lower Mississippi Valley and the northern Gulf of Mexico are wintering locations for cormorants within the southeastern United States [14]. Yet movements between these locations differ, with cormorants overwintering on lakes and coasts using an average home range of 81 km² while those in aquaculture ponds average a home range of 2760 km² [15]. King et al. (2012) also calculated home ranges and core use areas for wintering cormorants throughout the Lower Mississippi Alluvial Valley and estimated average home ranges of 17,490 km² and a mean core use area of 1550 km². Conversely, cormorants breeding in Lake Ontario and wintering in this same region used a mean home range and core use area of only 4609 km² and 566 km², respectively, less than half of what was reported for the Lower Mississippi Alluvial Valley [16].

During the breeding season, variable movement patterns have been observed among cormorants throughout the Great Lakes. Cormorants nesting in Lake Ontario had home ranges and core use areas of 4646 and 820 km², respectively [17]. Conversely, cormorants tagged in the Mississippi Alluvial Valley that bred throughout the Great Lakes had home ranges and core use areas almost triple the size seen in Lake Ontario [16,18]. This variability in both wintering and breeding seasons has been explained through differences in the management of these birds in both their breeding and wintering areas with measures to control populations implemented in the forms of egg-oiling, roost dispersal, and lethal management in some locations [15,17]. Simple depletion of suitable prey species could also account for these differing mean home ranges and core use areas plus individual variability between breeding and wintering years [17,19]. Regardless of intra-seasonal variability, differences between wintering and breeding cormorants are also apparent.

Our objective for this study was to measure home ranges and core use areas for individual cormorants for a breeding season (May–August 2017) and explore relationships in cormorant movements and space use. Additionally, we wanted to evaluate existing theories derived from populations of these birds breeding on North America's Great Lakes relative to recent breeding areas on a lacustrine system in the southeastern United States (Figure 1). Our prediction was that cormorants breeding on this lacustrine system in the southeastern United States will use a smaller area around nesting sites due to the smaller geographic footprint, shallower bathymetry, and distribution of resources in proximity to nesting sites within this system as compared to birds that breed on North America's Great Lakes.

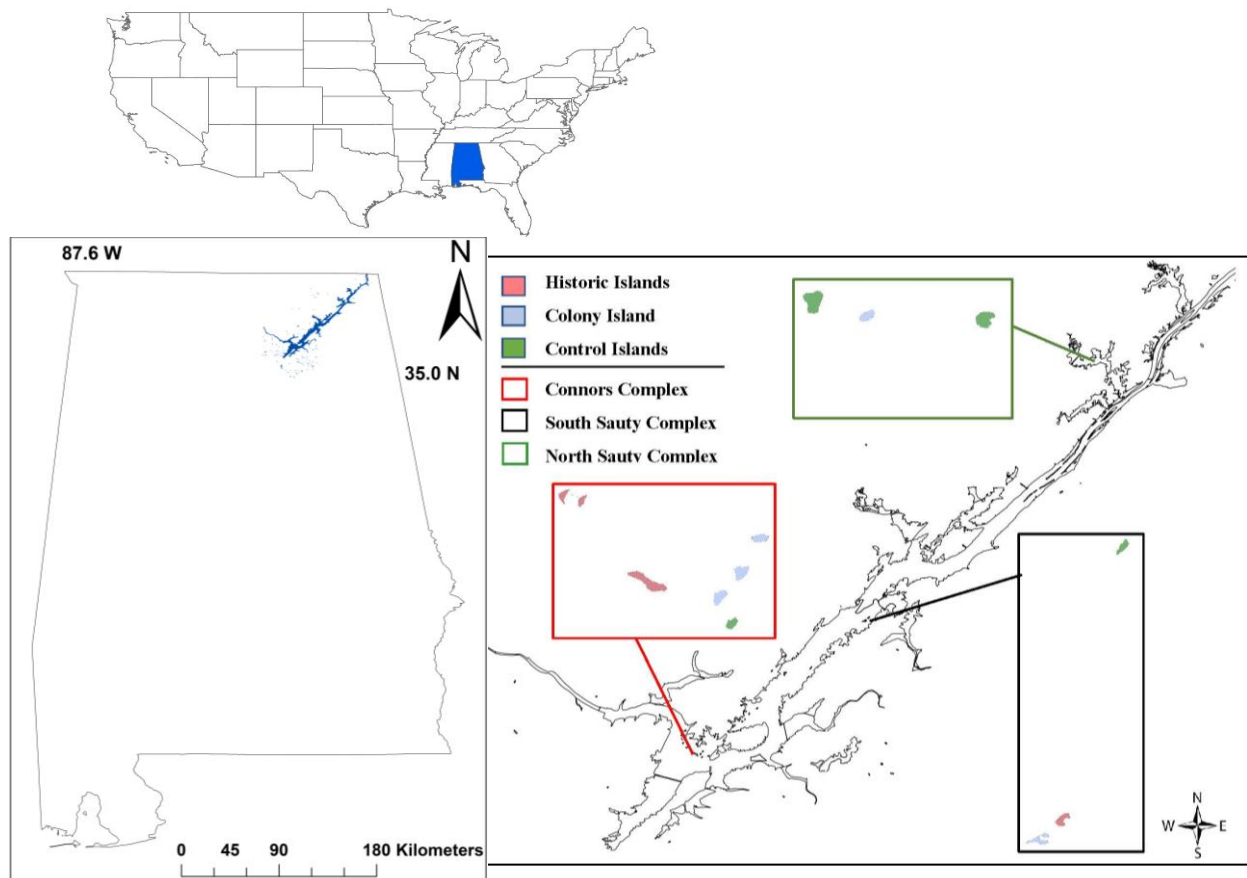


Figure 1. Guntersville Reservoir within Alabama with map at right showing islands colonized, abandoned, and not used by nesting Double-crested Cormorants during March–August 2017.

2. Materials and Methods

This study was conducted on Guntersville Reservoir in Marshall and Jackson counties in northeast Alabama, USA (Figure 1). Guntersville Reservoir was created by damming the Tennessee River in 1935 with reservoir hydrology controlled by the Guntersville Dam and has a water surface area of 27,478 hectares and a mean water depth of 18.3 m (m) within the main channel but only 4.6 m outside of the main channel [20]. Guntersville Reservoir is situated in a temperate zone and is more eutrophic and productive than northern lakes and reservoirs year-round due to high nutrient inputs from natural and agricultural sources [21,22]. Temperature and climate are temperate with summers averaging 27 °C and winters around 15 °C [23]. Deciduous hardwoods, such as oak (*Quercus* spp.) and hickory (*Carya* spp.), and coniferous trees such as red cedar (*Juniperus virginiana*) and loblolly pine (*Pinus taeda*) are all prevalent within the reservoir system [23]. Fish communities within the reservoir include a multitude of baitfish species such as gizzard (*Dorosoma cepedianum*) and threadfin shad (*D. petenense*), skipjack herring (*Alosa chrysochloris*) and sportfish such as bass species (*Micropterus salmoides* and *M. dolomieu*), sauger (*Sander canadensis*), bluegill (*Lepomis macrochirus*), crappie (*Pomoxis* spp.), and catfish (*Siluriformes*) [24], with bluegill, crappie, and shad the most common prey during a diet study of cormorants feeding within Guntersville Reservoir (Dorr et al., unpublished data).

The number of cormorants using Guntersville Reservoir (Figure 1) during the breeding season (March–August: Dorr et al., 2014) has increased since signs of nesting were first documented in 2001 [4]. A systemic survey conducted in 2017 by USDA Wildlife Services estimated a total of 1620 cormorants nesting on islands within the reservoir. Little is currently known about how cormorants move within Guntersville Reservoir during their breeding season. It is theorized that cormorants that breed in the southeastern United States may be year-round residents with seasonal immigration augmenting overwintering

populations [25,26]. Cormorants breeding on Guntersville is currently limited to island colonies [4,5]. Islands are present throughout the reservoir (Figure 1). The southernmost part of Guntersville has the highest number of breeding colonies of cormorants which currently include Connors Islands and South Sauty with one island within mid-Guntersville, North Sauty (Figure 1). Some islands around current breeding colonies were once colonized but have subsequently been abandoned after trees and vegetation died off [27] and a few islands (Control) have not been colonized by cormorants as of the completion of this study.

The management of cormorants on Guntersville Reservoir has been conducted since evidence of breeding was detected in 2001 [4]. Both lethal and non-lethal methods have been employed to disperse birds during the breeding season, with Connors and South Sauty and surrounding waterways the site of the greatest management effort (Figure 1). After the Public Resource Depredation Order was rescinded in 2016 [28], most management was ceased for the foreseeable future including the year all cormorants were tagged for this study.

To determine the cormorant home range and core use areas we targeted Connor Island and South Sauty island due to the highest density of breeding birds in these colonies. North Sauty has recorded nests but logistically trapping in the area was not possible due to water depths < 0.2 m. Adult cormorants were targeted for telemetry deployment, but all birds were banded and processed if captured. Spring-loaded leg hold traps were modified and used to capture cormorants from May–July 2017. A rubber buffer was installed inside the clamps of each leg-hold trap to decrease the chance of injury as well as replacing factory coil springs with weaker springs to reduce the closing force on the leg [29]. The factory chain was replaced with an aircraft cable and elastic shock cord to minimize injury when the captured bird lunged to escape [29]. Leg hold traps were placed on known loafing areas such as downed logs or debris sticking out of the water so that when the target cormorant stepped on the trap, a spring switched to “hold” the captured leg of the cormorant without injury or escape.

All captured birds were banded with an individually numbered aluminum leg band (USGS permit # 23835) as well as a uniquely coded plastic leg band. We collected a small sample of blood from each adult cormorant to genetically determine the sex of that bird. A 25-gauge syringe needle was used to pierce the right, medial metatarsal vein of each bird and a blood sample (~20–50 uL) was collected and applied to a PermaCode Card for genetic sexing (Animal Genetics, Inc., Tallahassee, FL USA).

A backpack satellite transmitter (GeoTrak Inc., Apex, NC, USA, model number GT-22GS-GPS) was placed on each cormorant using methods described by King and Tobin (2000) and Dunstan (1972). Transmitters were positioned on each bird using a backpack harness [30] with the transmitter affixed externally and secured using Teflon ribbon, with small metal bird bands crimped to secure the harness to the bird (Figure 2). So that any harsh edges from the metal band would not adversely affect the cormorant, shrink tubing covered these attachment sites using a standard soldering iron.

Each GPS tag weighed 22 gram (g) and had a proportional mass of 1.1% relative to bird weight. Each tag was equipped with a solar panel that supplied a voltage of 3.6 to 4.2 volts DC providing continuous battery life to the transmitter. Sensor data from each GPS PTT unit were checked every other day to ensure each unit was not experiencing a significant loss of power. If a unit was found to be relaying GPS coordinates consistently from one location for more than 3 days, or a transmitter had not transmitted for more than 3 days, the unit was tracked via the VHF device attached to the tag until the device was recovered. Argos data were uploaded every 48 h through the Argos system.



Figure 2. Picture illustrating placement of transmitter on an adult Double-crested Cormorant secured using a Teflon ribbon.

Telemetry data were subset into five temporal categories for analysis based on breeding periods: (1) incubation, (2) chick-rearing, (3) post-fledge, (4) breeding season, and (5) all movements. The incubation period was delineated as 9–30 May (21–28 days), [7]. Since capture was delayed, a week was cut from this period to make up for Gunterville birds nesting earlier than their Great Lake counterparts. Chick-rearing was defined as from 31 May to 4 July (28–30 days) [7], and the post-fledge period was defined as from 5 July to 15 August. Because cormorants nested in Gunterville from late March through early June, we combined incubation and chick-rearing into one time period. All movements described the complete time that the individual was tracked. Home range and core use areas were calculated for all movements of these individuals.

All analyses for this study were completed using Program R [31]. Home range and core use areas were calculated by finding the utilization distribution (UD) of individuals through kernel density estimation, with no limit for the number of points used [32]. Kernel method estimation of the UD does not hold estimates to parametric assumptions so can more accurately estimate densities of any shape by smoothing locations to not over or underestimate distributions [33,34]. For tagged cormorants in this study, bivariate normal kernel functions were placed over each relocation point, with all functions averaged for a kernel density estimation of the UD for that individual. A smoothing parameter, h , was also applied to the estimation to control the width of the kernel function placed over the point used. The ad hoc method, or reference bandwidth, was calculated as the h for each point. The home range was found by using the 95% use of the individual while the core use area was found by using the 50% use area. We present results as mean \pm standard deviation throughout the manuscript and attached tables. Due to a small sample size ($n = 8$), analyses by sex were not run but mean home range and core use areas were calculated for summary statistics to show differences in ranges between sexes and also by colony affiliation.

3. Results

During May–July 2017, 10 Solar GPS PTT tags equipped with a VHF device were deployed, with 2916 locations recorded for all birds, 1775 locations from the breeding season and 1140 locations from the post-fledge season. One tag, ID 129279, was deployed twice on two separate cormorants, due to bird mortality on the first bird on 17 July 2017. Three tags were deployed on juvenile birds. Information derived from these tags was not included in this study.

The mean home range for all cormorants for the entire breeding season was $41.8 \pm 33.2 \text{ km}^2$. When separated into periods, the mean home range for the incubation period was $98.9 \pm 80.6 \text{ km}^2$, for the chick-rearing period mean home range size was $18.3 \pm 22.6 \text{ km}^2$ and for the post-fledge period, the mean home range size was $42.0 \pm 31.0 \text{ km}^2$. Combining incubation and chick-rearing into one period provided a mean home range of $40.2 \pm 32.3 \text{ km}^2$ (Table 1). Home range overlap within breeding periods was within a 3 km radius. The mean home ranges for all movements between males and females were $27.6 \pm 31.3 \text{ km}^2$ and $55.9 \pm 32.5 \text{ km}^2$, respectively, and for breeding season was $30.95 \pm 24.9 \text{ km}^2$ for males and $52.5 \pm 31.6 \text{ km}^2$ for females. Looking at colony affiliation, South Sauty had a mean home range of $59.1 \pm 26.8 \text{ km}^2$ and $60.1 \pm 25.1 \text{ km}^2$ for all movements and breeding seasons, respectively, while Connors was $12.8 \pm 5.5 \text{ km}^2$ and $13.7 \pm 5.0 \text{ km}^2$ for the same periods (Table 2). Mean home ranges for breeding sub periods can also be found for cormorant sex and colony affiliation in Table 3.

Table 1. Ninety-five percent home ranges (km^2) measured for all movements of Double-crested Cormorants ($n = 8$ birds) on Guntersville Reservoir, Alabama in 2017. Breeding season ($n = 7$) is incubation ($n = 6$) and chick-rearing periods ($n = 6$), combined. Post-fledge ($n = 4$), colony affiliation refers to a nesting site. Dashes indicate no data for that time period.

Sex	Colony Affiliation	Breeding Season	Incubation	Chick-Rearing	Post-Fledge	All Movements
		May–July	9–30 May	31 May–4 July	5 July–15 August	
Male	South Sauty	73.8	106.8	55.8	-	73.8
Male	South Sauty	17.2	40.7	6.3	16.0	6.8
Female	South Sauty	-	-	-	82.1	82.1
Female	South Sauty	80.8	172.3	36.6	62.0	64.6
Female	South Sauty	68.4	216.2	2.2	-	68.4
Male	Connors	12.3	27.3	7.6	8.1	9.5
Female	Connors	8.4	8.4	-	-	8.4
Male	Connors	20.5	29.8	1.3	-	20.5
$\bar{x} =$		40.2 ± 32.3	98.9 ± 80.6	18.3 ± 22.6	42.0 ± 31.0	41.8 ± 33.2

Table 2. Means and standard deviation (SD) of 95% home range (km^2) of Double-crested Cormorants on Guntersville Reservoir for female, male, and colony affiliation by breeding periods (in bold first column and top rows).

	Breeding Season	Incubation	Chick-Rearing	Post-Fledge	All Movements
	May–July	9–30 May	31 May–4 July	5 July–15 August	
Female	52.5 ± 31.6	132.3 ± 89.4	19.4 ± 17.2	72.1 ± 10.1	55.9 ± 32.5
Male	30.95 ± 24.9	51.15 ± 32.5	17.75 ± 22.1	12.05 ± 4.0	27.6 ± 31.3
South Sauty	60.1 ± 25.1	134 ± 66.5	25.2 ± 22.1	53.4 ± 27.7	59.1 ± 26.8
Connors	13.7 ± 5.0	21.8 ± 9.6	4.5 ± 3.2	8.1 ± 0	12.8 ± 5.5

Table 3. Fifty percent home ranges (km²) measured for all movements of Double-crested Cormorants (*n* = 8 birds) in Guntersville Reservoir, Alabama in 2017. Breeding season (*n* = 7) is incubation (*n* = 6) and chick-rearing periods (*n* = 6), combined. Post-fledge (*n* = 4), colony affiliation refers to a nesting site. Dashes indicate no data for that time period.

Sex	Colony Affiliation	Breeding Season	Incubation	Chick-Rearing	Post-Fledge	All Movements
		May–July	9–30 May	31 May–4 July	5 July–15 August	
Male	South Sauty	11.3	16.9	10.8	-	11.4
Male	South Sauty	1.6	6.3	0.5	1.5	1.0
Female	South Sauty	-	-	-	13.1	13.1
Female	South Sauty	7.2	25.1	3.3	5.7	5.4
Female	South Sauty	8.2	30.1	0.3	-	8.2
Male	Connors	1.6	3.6	1.4	1.7	1.6
Female	Connors	1.2	1.2	-	-	1.2
Male	Connors	3.7	5.6	0.2	-	3.7
\bar{x} =		5.0 ± 4.0	14.6 ± 11.2	2.8 ± 4.1	5.5 ± 4.7	6.4 ± 5.9

The mean core use area for cormorants for all movements was 6.4 ± 5.9 km². When separated into periods, the mean core use area for the: Incubation period was 14.6 ± 11.2 km²; chick-rearing was 2.8 ± 4.1 km²; post-fledging was 5.5 ± 4.7 km² (Table 3). Combining incubation and chick-rearing into one breeding period revealed the mean core use area for this combined time period was 5.0 ± 4.0 km² (Table 3). Core use overlaps within breeding periods within a 2 km radius. The mean core use areas for all movements between males and females were 5.4 ± 4.8 km² and 7.0 ± 5.0 km², respectively, and for the breeding season, it was 4.6 ± 4.6 km² for males and 5.5 ± 3.8 km² for females. Looking at colony affiliation, South Sauty had a mean home range of 7.8 ± 4.3 km² and 7.1 ± 3.5 km² for all movements and breeding seasons, respectively, while Connors was 2.2 ± 1.1 km² for both breeding season and all movements (Table 4). The mean core use areas for breeding sub periods can also be found for cormorant sex and colony affiliation in Table 4.

Table 4. Means and standard deviation (SD) of 50% core use areas (km²) of Double-crested Cormorants on Guntersville Reservoir for female, male and colony affiliation by breeding periods (in bold first column and top rows).

	Breeding Season	Incubation	Chick-Rearing	Post-Fledge	All Movements
	May–July	9–30 May	31 May–4 July	5 July–15 August	
Female	5.5 ± 3.8	18.8 ± 12.6	3.2 ± 4.4	9.4 ± 3.7	7.0 ± 5.0
Male	4.6 ± 4.6	8.1 ± 5.2	1.8 ± 1.5	1.6 ± 0.1	5.4 ± 4.8
South Sauty	7.1 ± 3.5	19.6 ± 9.0	3.7 ± 4.3	6.8 ± 4.8	7.8 ± 4.3
Connors	2.2 ± 1.1	3.5 ± 1.8	0.8 ± 0.6	1.7 ± 0	2.2 ± 1.1

Mean home ranges for female cormorants for all movements and during the breeding season, respectively, were 55.9 ± 32.5 and 52.5 ± 38.7 km² while for males they were 27.6 ± 30.9 and 31.3 ± 28.7 km² (Table 2). Core use areas for female cormorants for all movements was 7.0 ± 5.0 km² and for males was 5.4 ± 4.8 km². For the breeding season core use areas were 5.5 ± 3.8 km² and 4.6 ± 4.6 km², respectively (Table 4).

4. Discussion

Compared to previous studies of home ranges of northern breeding cormorants, home ranges on Guntersville Reservoir were much smaller. Studies of cormorants tagged near aquaculture facilities in the Mississippi Delta region report a mean home range of

$30,547 \pm 6197 \text{ km}^2$ during the summer on their northern breeding grounds [16] compared to a mean 95% home range of just $41.8 \pm 33.2 \text{ km}^2$ on Gunterville Reservoir. This was similar in core use areas where cormorants tagged in the Mississippi Delta and breeding up north used over two times the area as cormorants in Gunterville Reservoir [16]. Cormorants breeding in Lake Huron foraged in areas of around 3000 km^2 , over double that of birds breeding on Gunterville, though birds breeding on Lake Huron were actively dispersed and subject to egg oiling over the course of the breeding season [15]. Additionally, cormorants tagged in the greater Great Lakes area from 2004 to 2007 revealed a mean home range of $1937 \pm 5297 \text{ km}^2$ and were also subject to harassment and management [6]. Conversely, cormorants breeding in eastern Lake Ontario had 95% kernel home ranges of 42 ± 44 and $75 \pm 13 \text{ km}^2$ in 2000 and 2001, respectively, with ongoing egg oiling management [17]. Compared to the Great Lakes, Gunterville Reservoir is a small aquatic system and therefore cormorants in this reservoir do not have to travel far for prey. Moreover, since cormorants tend to forage in waters $<10 \text{ m}$ in depth [10], cormorants in the Great Lakes must find appropriate prey on shorelines or areas of shallow depth. Gunterville Reservoir is shallow, with depths no deeper than 10.6 m outside of the main channel.

For cormorants breeding in the southeastern U.S., island size and distance from the mainland may not be significant drivers of home range as water depth and available loafing areas are readily available and the size of the lentic bodies is much smaller than for other populations such as those that nest on the Great Lakes [16]. Additionally, many breeding colonies in the southeast are situated in the same or similar ecosystems to those used as wintering roosting spots [2,7,35,36]. It is hypothesized that cormorants that started breeding in the southeastern United States reflect birds that historically migrated through this area but changed their migratory behavior as food resources became available year-round [1,7,25]. Cormorant foraging seems to coordinate in areas of possible *Lepomis* breeding habitats that are present at Gunterville Reservoir. Though different in size, water depth is likely just as important in the southeastern United States as it is in the Great Lakes, for optimal foraging as well as loafing areas to dry off and rest between foraging sessions [7,37]. The smaller home range size may be more a function of foraging on an inland reservoir that is smaller than the geographic extent of aquaculture in the MS Delta or areas of the Great Lakes.

Within Gunterville Reservoir, the size of cormorant home ranges differed among the defined periods of incubation, chick-rearing, and post-fledge though the areas used by individual cormorants did not differ and were consistent, within 2.5 km , throughout the season. Cormorants had the largest home ranges during the incubation period while the smallest home ranges were observed during the chick-rearing period across all colony types and sex (Table 1). These differences could be accounted for by the sex of the cormorants tracked. Studies have suggested that male cormorants forage farther from colonies during incubation than females and vice versa for females during chick rearing [18,38]. This was not apparent in our study, where females foraged almost twice as far as males during incubation and had similar distances for chick-rearing (Tables 3 and 4). Additional energy constraints may affect females more than males as the energy needed for building nests and laying and incubating eggs rests largely on the adult female [18,38]. Parents could be foraging closer to the nest during chick rearing and make shorter trips for fish to feed chicks, accounting for the lower home ranges during this period. Overall, the mean home range and core use area of males ($27.6 \pm 31.3 \text{ km}^2$) for all movements on Gunterville Reservoir were smaller than that of females ($55.9 \pm 32.5 \text{ km}^2$; Table 3). Additionally, colony affiliation may have accounted for some of these large differences in home range size, with South Sauty birds having larger home range ($59.1 \pm 26.8 \text{ km}^2$) and core use areas ($7.8 \pm 4.3 \text{ km}^2$) than their Connors Island counterparts ($12.8 \pm 5.5 \text{ km}^2$ and $2.2 \pm 1.1 \text{ km}^2$), though some individual birds varied within these areas (Figures 1 and 3 and Tables 1–4). This may be explained due to Connors having a larger breadth of water to forage on, and depths of 0.3 m compared to 4.5 m around surrounding colonies such as South Sauty. Conversely, South Sauty is situated in a much narrower area within Gunterville and birds may travel farther north or south to forage, though water depths do not differ between these two sites.

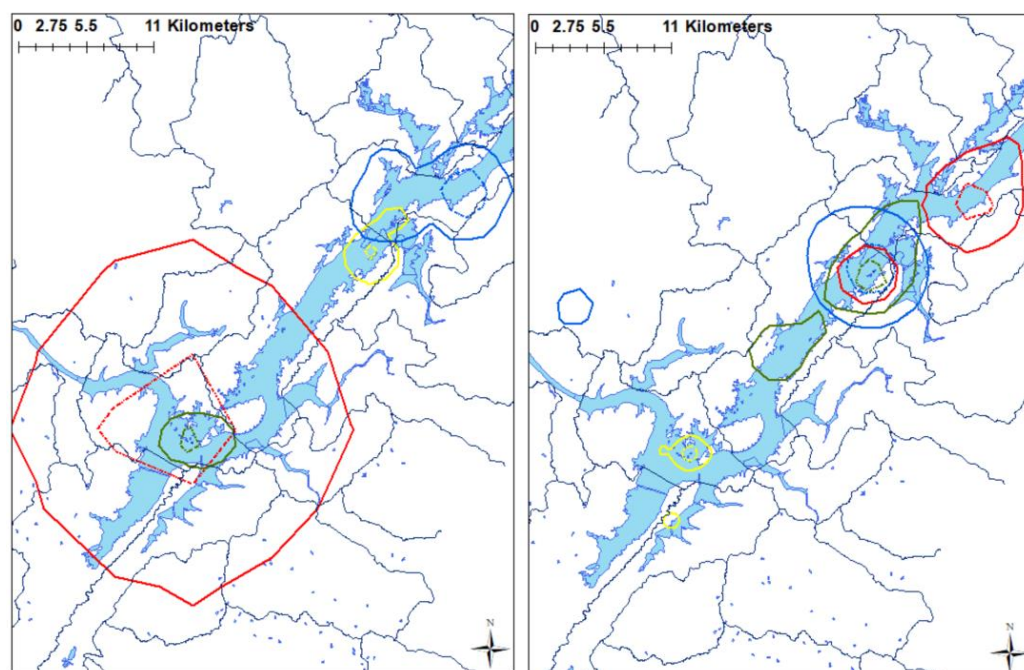


Figure 3. Home range and core use areas of for male Double-crested Cormorants at breeding colonies on the left ($n = 4$) and females on the right ($n = 4$) for the complete period of study March–August 2017. Different color lines differentiate individual birds and line types differentiate 95% (solid line) or 50% (dotted line) home range.

5. Conclusions

Managers in the southeastern United States who are monitoring and controlling expanding cormorant populations on reservoirs can use data derived from telemetered birds to understand how these birds move on the landscape and what characteristics are present in their home ranges. Knowing that cormorants breeding on Guntersville reservoir use smaller areas than northern birds nesting in the Great Lakes helps managers focus on a much smaller and precise scope to manage cormorants and implement solutions for better and sustainable conservation. Additionally, our results support current data that cormorants forage in shallow water, depths ≤ 5 m, and take advantage of loafing areas scattered around colony sites, relationships similar for cormorants nesting in the Great Lakes. These contrasts between southern and northern breeding birds are pivotal in managing and understanding not only the behavior and movements of cormorants but also gives insight into the expanding range of cormorants in southeastern reservoirs.

Author Contributions: Conceptualization, R.J.M. and S.A.R.; Data curation, L.L.K.M.; Formal analysis, L.L.K.M.; Funding acquisition, B.S.D., R.J.M. and S.A.R.; Investigation, L.L.K.M. and K.C.H.-D.; Methodology, L.L.K.M., B.S.D., K.C.H.-D. and S.A.R.; Resources, B.S.D. and R.J.M.; Supervision, B.S.D., R.J.M. and S.A.R.; Visualization, R.J.M.; Writing—original draft, L.L.K.M.; Writing—review & editing, B.S.D. and S.A.R. All authors have read and agreed to the published version of the manuscript.

Funding: Funding for this research was provided by the Tennessee Valley Authority, U.S. Department of Agriculture National Wildlife Research Center agreements #16-7428-1276 and 17-7428-1276, National Institute of Food and Agriculture, and McIntire-Stennis project under accession number MISZ-082100, U.S.G.S. permit number 23835, AL permit # 2018083624868680, and IACUC 16-603.

Institutional Review Board Statement: All applicable ethical guidelines for the use of birds in research have been followed, including those presented in the Ornithological Council’s “Guidelines to the Use of Wild Birds in Research”. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are archived at the USDA, Wildlife Services, National Wildlife Research Center, Fort Collins, CO, USA, www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/programs/nwrc/sa_about/ct_contacts_nwrc.

Acknowledgments: We would like to thank the Tennessee Valley Authority (TVA) who allowed us to conduct this research on their lands and who let us use equipment and facilities throughout the duration of this project. We also want to extend our appreciation to USDA-National Wildlife Research Center and USDA-Alabama-Wildlife Services staff for their time, equipment, and assistance in the capture and telemetry attachment of birds for this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wires, L.R.; Cuthbert, F.J. Historic Populations of the Double-crested Cormorant (*Phalacrocorax auritus*): Implications for Conservation and Management in the 21st Century. *Waterbirds* **2006**, *29*, 9–37. [CrossRef]
2. Dorr, B.; King, D.T.; Tobin, M.E.; Harrel, J.B.; Smith, P.L. Double-crested Cormorant movements in relation to aquaculture in eastern Mississippi and western Alabama. *Waterbirds* **2004**, *27*, 147–154. [CrossRef]
3. Dorr, B.S.; Fielder, D.G. Double-Crested Cormorants: Too Much of a Good Thing? *Fisheries* **2017**, *42*, 468–477. [CrossRef]
4. Barras, S.C. *Double-Crested Cormorants in Alabama*; USDA National Wildlife Research Center-Staff Publications: Washington, DC, USA, 2004; p. 77.
5. Lafferty, D.J.; Hanson-Dorr, K.C.; Priscock, A.M.; Dorr, B.S. Biotic and abiotic impacts of Double-crested cormorant breeding colonies on forested islands in the southeastern United States. *For. Ecol. Manag.* **2016**, *369*, 10–19. [CrossRef]
6. Guillaumet, A.; Dorr, B.; Wang, G.; Taylor, J.D.; Chipman, R.B.; Scherr, H.; Bowman, J.; Abraham, K.F.; Doyle, T.J.; Cranker, E. Determinants of local and migratory movements of Great Lakes double-crested cormorants. *Behav. Ecol.* **2011**, *22*, 1096–1103. [CrossRef]
7. Dorr, B.S.; Hatch, J.J.; Weseloh, D.V. Double-crested Cormorant (*Phalacrocorax auritus*), version 2.0. In *Birds of North America*; Cornell Lab of Ornithology: Ithaca, NY, USA, 2014.
8. Coleman, J.T.; Richmond, M.E.; Rudstam, L.G.; Mattison, P.M. Foraging location and site fidelity of the Double-crested Cormorant on Oneida Lake, New York. *Waterbirds* **2005**, *28*, 498–510. [CrossRef]
9. Wires, L.R.; Cuthbert, F.J. Characteristics of Double-crested Cormorant colonies in the U.S. Great Lakes island landscape. *J. Great Lakes Res.* **2010**, *36*, 232–241. [CrossRef]
10. Stapanian, M.A. Interspecific Interactions, Habitat Use, and Management of Double-crested Cormorants (*Phalacrocorax auritus*) in the Laurentian Great Lakes: An Introduction. *J. Great Lakes Res.* **2002**, *28*, 119–124. [CrossRef]
11. Coleman, J.T.; Richmond, M.E. Daily foraging patterns of adult Double-crested Cormorants during the breeding season. *Waterbirds* **2007**, *30*, 189–198. [CrossRef]
12. Glahn, J.F.; Reinhold, D.S.; Sloan, C.A. Recent population trends of Double-crested Cormorants wintering in the delta region of Mississippi: Responses to roost dispersal and removal under a recent depredation order. *Waterbirds* **2000**, *23*, 38–44.
13. Burr, P.C.; Avery, J.L.; Street, G.M.; Strickland, B.K.; Dorr, B.S. Historic and contemporary use of catfish aquaculture by piscivorous birds in the Mississippi Delta. *Condor* **2020**, *122*, duaa036. [CrossRef]
14. King, D.T.; Blackwell, B.F.; Dorr, B.S.; Belant, J.L. Effects of aquaculture on migration and movement patterns of Double-crested Cormorants. *Hum.-Wildl. Interact.* **2010**, *4*, 77–86.
15. Scherr, H.; Bowman, J.; Abraham, K.F. Migration and Winter Movements of Double-Crested Cormorants Breeding in Georgian Bay, Ontario. *Waterbirds* **2010**, *33*, 451–460. [CrossRef]
16. King, D.T.; Strickland, B.K.; Radomski, A. Winter and summer home ranges and core use areas of Double-crested Cormorants captured near aquaculture facilities in the southeastern United States. *Waterbirds* **2012**, *35*, 132–137. [CrossRef]
17. Dorr, B.S.; Taylor, J.D.; Werner, S.J.; King, D.T.; Farquhar, J.F.; Mazzocchi, I.M.; McCullough, R.D. Summer and Migrational Movements of Satellite-Marked Double-Crested Cormorants from a Breeding Colony Managed by Egg-Oiling in Lake Ontario, USA. *Waterbirds* **2012**, *35*, 114–123. [CrossRef]
18. Dorr, B.S.; Aderman, T.; Butchko, P.H.; Barras, S.C. 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*, 224–231. [CrossRef]
19. Ashmole, N.P. The regulation of numbers of tropical oceanic birds. *IBIS* **1963**, *103b*, 458–473. [CrossRef]
20. Encyclopedia of Alabama. Guntersville Dam and Lake. 2015. Available online: <http://encyclopediaofalabama.org/ARTICLE/h-2621> (accessed on 27 December 2022).
21. Sawyer, C.N. Basic concepts of eutrophication. *Water Pollut. Control Fed.* **1966**, *38*, 737–744.
22. Olin, M.; Rask, M.; Ruuhijärvi, J.; Kurkilahti, M.; Ala-Opas, P.; Ylönen, O. Fish community structure in mesotrophic and eutrophic lakes of southern Finland: The relative abundances of percids and cyprinids along a trophic gradient. *J. Fish Biol.* **2002**, *60*, 593–612. [CrossRef]
23. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online: <https://websoilsurvey.nrcs.usda.gov> (accessed on 23 October 2016).

24. Tennessee Wildlife Resource Agency. (n.d.); Tennessee State Government—TN.gov. Gunterville Reservoir Fishing. Available online: <https://www.tn.gov/twra/fishing/where-to-fish/cumberland-plateau-r3/guntersville-reservoir.html> (accessed on 27 December 2022).
25. Moran, L.K.; Dorr, B.S.; Hanson-Dorr, K.C.; Moore, R.J.; Rush, S.A. Stable isotope analyses of movement and pre usage of Double-crested Cormorants in a reservoir system of the southeastern United States. *Food Webs* **2022**, *31*, e00220. [[CrossRef](#)]
26. Sheehan, K.L.; Esswein, S.T.; Dorr, B.S.; Yarrow, G.K.; Johnson, R.J. Using species distribution models to define nesting habitat of the eastern metapopulation of Double-crested Cormorants. *Ecol. Evol.* **2017**, *7*, 409–418. [[CrossRef](#)] [[PubMed](#)]
27. Veum, L.M.; Dorr, B.S.; Hanson-Dorr, K.; Moore, R.J.; Rush, S. Double-crested Cormorant colony effects on soil chemistry, vegetation structure and avian diversity. *For. Ecol. Manag.* **2019**, *453*, 117588. [[CrossRef](#)]
28. *Migratory Bird Permits; Removal of Depredation Orders for Double-crested Cormorants to Protect Aqua-Culture Facilities and Public Resources*; 83 Fed. Reg. 32805 (codified as 50 CFR 21); Fish and Wildlife Service: Washington, DC, USA, 2018.
29. King, D.T.; Tobin, M.E. Capture and telemetry techniques for Double-crested Cormorants (*Phalacrocorax auritus*). *Proc. Vertebr. Pest Conf.* **2000**, *19*, 54–57. [[CrossRef](#)]
30. Dunstan, T.C. A harness for radio-tagging raptorial birds. *Inland Bird Band. News* **1972**, *44*, 4–8.
31. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2017. Available online: <https://www.R-project.org/> (accessed on 26 November 2017).
32. Calenge, C. The package “adehabitat” for the R software: A tool for the analysis of space and habitat use by animals. *Ecol. Model.* **2006**, *197*, 516–519. [[CrossRef](#)]
33. Worton, B.J. Kernel methods for estimating the utilization distribution in home-range studies. *Ecology* **1989**, *70*, 164–168. [[CrossRef](#)]
34. Seaman, D.E.; Powell, R.A. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* **1996**, *77*, 2075–2085. [[CrossRef](#)]
35. Glahn, J.F.; May, A.; Bruce, K.; Reinhold, D. Censusing Double-crested Cormorants (*Phalacrocorax auritus*) at their winter roosts in the Delta Region of Mississippi. *Colonial Waterbirds* **1996**, *19*, 73–81. [[CrossRef](#)]
36. King, D.T. Movements of Double-crested Cormorants among winter roosts in the Delta Region of Mississippi. *J. Field Ornithol.* **1996**, *67*, 205–211.
37. Enstipp, M.R.; Grémillet, D.; Jones, D.R. The effects of depth, temperature and food ingestion on the foraging energetics of a diving endotherm, the Double-crested Cormorant (*Phalacrocorax auritus*). *J. Exp. Biol.* **2006**, *209*, 845–859. [[CrossRef](#)]
38. Anderson, C.D.; Roby, D.D.; Collis, K. Foraging patterns of male and female Double-crested Cormorants nesting in the Columbia River estuary. *Can. J. Zool.* **2004**, *82*, 541–554. [[CrossRef](#)]

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