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Note

Seasonal Habitat Selection and Movements by Mottled Ducks

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ABSTRACT Mottled ducks (*Anas fulvigula*) were released by the South Carolina Department of Natural Resources (SCDNR) in South Carolina, USA, during 1975–1983 and expanded into Georgia, USA, in the 1990s. Banding data suggest that birds marked in Georgia are often harvested in other states. Because the South Carolina reintroduced population was able to expand into Georgia via long-distance dispersal, a more thorough understanding of mottled duck spatial ecology in Georgia and South Carolina is needed to direct future management decisions to accommodate expanding duck populations. We used global positioning system (GPS) telemetry to investigate movements and habitat selection by 47 mottled ducks (17 males, 30 females) during 4 seasons from 2013–2016. Mean seasonal home ranges varied from 2,002–4,598 ha across sexes and seasons. We found mean distances moved within seasonal ranges varied from 3.5–11.3 km/day for birds captured in Georgia, and 1.3–5.6 km/day for those captured in South Carolina. We observed 23 excursions, in which individuals left established seasonal ranges for >6 hours and moved ≥5 km; these excursions ranged from 5 km to 139.5 km. We documented 5 dispersals ranging from 52.6 km to 245.8 km. We also documented several long-distance movements, with 7 birds captured in Georgia moving to South Carolina and 2 moving to Florida, USA. These movements suggest mottled ducks in South Carolina and Georgia may constitute a single population. Notably, we observed dispersal and long-distance movements only from birds marked in Georgia, suggesting that habitat may be a limiting factor along the Georgia coast. We quantified third-order selection for mottled ducks and found seasonal selection for managed impoundments and avoidance of palustrine emergent marsh during breeding and teal seasons. Managed impoundments were limited to 4 river systems along coastal Georgia and South Carolina, resulting in much of the coastal wetlands in both states being unused by mottled ducks. We suggest the Georgia Department of Natural Resources (GADNR) and SCDNR work cooperatively to manage mottled ducks and their habitats by focusing efforts to create and manage impoundments throughout the Santee, Savannah, Altamaha, and Ashepoo-Combahe-Edisto (ACE) river basins in coastal Georgia and South Carolina where we documented use. © 2018 The Wildlife Society.

KEY WORDS *Anas fulvigula*, excursion, Georgia, habitat selection, home range, mottled duck, South Carolina.

Mottled ducks (*Anas fulvigula*) are a non-migratory waterfowl species with populations endemic to the Western Gulf Coast (WGC) and peninsular Florida, USA (Stutzenbaker 1988, Bielefeld et al. 2010). A third population was established by the South Carolina Department of Natural Resources (SCDNR) during 1975–1983 by releasing 1,285 individuals in coastal South Carolina, USA (Shipes 2014, Kneece 2016). Individuals released in South Carolina were translocated from Florida, Louisiana, and Texas, USA (Kneece 2016). With that expansion, individuals have been consistently found in coastal Georgia, USA, since the mid-1990s (G. D. Balkcom, Georgia Department of Natural Resources, Wildlife Resources Division [GADNR], unpublished data). Although movements and habitat use of mottled ducks are understood in Florida and the WGC, there is a lack of information available for mottled ducks in South Carolina and Georgia. Notably, coastal habitats of these states are atypical of Florida and the WGC, instead being dominated by bottomland hardwoods, maritime forests, hammock islands, tidal fresh and brackish marshes,

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and saltmarshes (SCDNR 2017). Tidal influences can also range from 1.4–2.4 m (National Oceanic and Atmospheric Administration [NOAA] 2017*a,b*) in comparison to the Gulf Coast, which experiences <1 m tides (Dardeu et al. 1992). Consequently, habitat conditions for mottled ducks are variable across coastal Georgia and South Carolina, necessitating a more detailed assessment of habitat use by mottled ducks at broader spatial scales.

Mottled duck populations in coastal Georgia presumably expanded from either Florida or South Carolina and it is currently unknown how habitat selection, seasonal space use, and long-distance movements by ducks influenced this expansion. In portions of its range in the WGC and Florida, mottled ducks are generally a resident species that use various habitats, including non-tidal fresh to brackish marshes, flooded rice fields, and inland prairies of the WGC (Stutzenbaker 1988, Zwank et al. 1989, Haukos et al. 2010, Moon 2014). Mottled ducks in Florida also use freshwater lakes and ponds associated with urban areas (Varner et al. 2014) and freshwater emergent wetlands and wet prairies (Johnson et al. 1991, Bielefeld et al. 2010). Previous research in South Carolina noted that water depth <25 cm (Weng 2006), and managed wetland impoundments and brackish wetlands (Shipes et al. 2015) were important to mottled ducks.

As resident species, habitat selection and space use by mottled ducks are key behaviors for understanding the distribution and persistence of local populations. Indeed, previous studies reported considerable variation in space use patterns that make identifying generalities in spatial requirements difficult. For example, mean annual home ranges for females in Florida vary from 2,050–95,000 ha (Bielefeld et al. 2010). Varner et al. (2014) reported that individuals living in urban areas had ranges of 232–598 ha, whereas individuals living in rural areas used ranges from 32,573–88,101 ha. In southeast Texas, breeding season home ranges of female mottled ducks varied from 650–4,200 ha (Rigby 2008) compared to coastal Texas where female breeding season home ranges varied 42.5–132 ha (Weeks 1969). Most recoveries of mottled duck bands in Florida and Texas were within 56.5 km and 78.9 km, respectively, of their banding sites (Baldassarre 2014). However, after the GADNR began banding mottled ducks in 2006, band returns indicated the species is highly mobile with 7 of 24 bands being recovered out of state (G. D. Balkcom, unpublished data). Previous research has also documented dispersal distances from 44 km to 197 km (Davis 2012, Moon et al. 2015), with a mean distance moved per week of 2.7 km (Moon et al. 2015), suggesting mottled ducks may move greater distances than previously reported.

Given the considerable differences in landscape structure from South Carolina and Georgia relative to Florida and the WGC, we hypothesized that mottled ducks exhibit different habitat selection and space use patterns that warrant unique management strategies. Knowledge of mottled duck spatial ecology in South Carolina and Georgia will enable land managers to make decisions to ensure sustainable populations in these states. Our objectives were to document movements, space use, and seasonal home ranges, and evaluate habitat selection at multiple spatial scales for mottled ducks in South Carolina and Georgia.

STUDY AREA

We conducted our study from 2013–2016 on the Altamaha Wildlife Management Area (WMA) located in McIntosh county, Georgia and surrounding marshes and islands owned by GADNR and public and private lands in the Ashepoo-Combahee-Edisto (ACE) and Santee river basins of South Carolina. Altamaha consisted of 1,248 ha of managed wetland impoundments and 11,000 ha of backwater tupelo swamps and hardwood bottomlands along the Altamaha River near Darien, Georgia (Fig. 1). Coastal Georgia contained 160 km of coastline and 153,000 ha of saltmarsh and provided one of the most extensive and productive natural marsh systems in the United States (NOAA 2016). The Santee River Basin included the Santee Coastal Reserve WMA and areas around McClellanville, which included 4,600 ha of managed wetland impoundments. Bear Island WMA near Green Pond, and Nemours Wildlife Foundation Plantation near Yemassee were capture sites in the ACE Basin, which included 1,880 ha and 805 ha of managed wetland impoundments, respectively (Beaufort, Charleston, and Colleton counties; Fig. 1). Our study sites were located in the Coastal Plain physiographic regions and contained intensively managed wetland impoundments, which provided varying salinities and a diversity of plant life including cattails (*Typha* spp.), panic grasses (*Panicum* spp.), smartweed (*Polygonum* spp.), sedges (*Cyperus* spp.), rice cutgrass (*Leersia oryzoides*), smooth cordgrass (*Spartina alterniflora*), and saltmarsh bulrush (*Scirpus robustus*). This diversity of

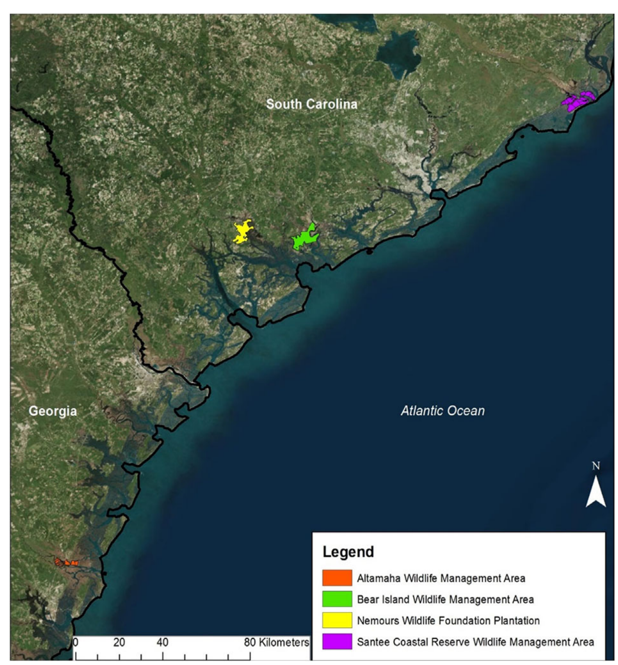

Figure 1. Mottled duck capture sites in Georgia and South Carolina, USA, including Altamaha Wildlife Management Area (WMA), Bear Island WMA, Nemours Wildlife Foundation Plantation, and Santee Coastal Reserve WMA, 2013–2016.

plants and salinities helped fulfill management objectives of providing quality wintering habitat to migratory waterfowl and waterfowl hunting opportunities to the public. During the study, mean temperature on our Georgia study area was 19.8°C (range = 15–30°C) and mean temperature on our South Carolina study area was 17.9°C (range = 16.5–34.1°C; https://usclimatedata.com/). Mean elevation for McIntosh County, Georgia was 4.9 m (range: 0–16 m; Georgia GIS Clearninghouse 2018). In McIntosh County, Georgia, the land cover consisted of 24.1% open water, 23.5% emergent herbaceous wetlands, 20.9%, evergreen forest, 20.4% woody wetlands, 5.0% shrub-scrub, 3.6% urban, 2.3% agriculture, 0.1% mixed forest, and <0.1% deciduous forest (Homer et al. 2015). Mean elevation among Beaufort, Charleston, and Colleton counties in South Carolina was 8.3 m (range: −1.5–41.9 m; South Carolina GIS Database 2018). Among Beaufort, Charleston, and Colleton counties in South Carolina, the land cover consisted of 26.8% woody wetlands, 20.7% emergent herbaceous wetlands, 19.3%, evergreen forest, 9.5% urban, 8.7% shrub-scrub, 7.8% agriculture, 5.7% open water, 1.0% mixed forest, and 0.6% deciduous forest (Homer et al. 2015).

To evaluate seasonal movement and habitat selection of mottled ducks, we first adapted seasons from Varner et al. (2014) but adjusted them to reflect the hunting seasons in Georgia and South Carolina as follows: breeding (1 Feb–30 Jun), molt and post-breeding (1 Jul–9 Sep), teal hunting season (10 Sep–19 Nov), and hunting season (20 Nov–31 Jan). We based teal and hunting seasons on the earliest opening date for those respective hunting seasons from 2013–2016.

METHODS

Duck Capture and Monitoring

We captured mottled ducks in Georgia between 8–14 August 2014, 11 August–13 October 2015, on 7 April 2016, and 7 July–11 August 2016 using the night-lighting technique from an airboat in managed wetland impoundments of the Altamaha WMA (Merendino and Lobpries 1998). We also used a net gun deployed from a helicopter to capture mottled ducks during 11–14 August 2015 (Dragonfly Aviation, Laredo, TX, USA). All capture and processing techniques that occurred in Georgia were approved by the University of Georgia Institutional Animal Care and Use Committee (permit A2014-03-007-R1). Mottled ducks in South Carolina were captured by SCDNR and Nemours Wildlife Foundation staff on 8 October 2013, 5–7 August 2014, and 23 July 2015 via night lighting from an airboat (Federal Bird Banding Permit 23417).

Once captured, we aged mottled ducks (after-hatch year [AHY] or hatch year [HY]), recorded sex and weight, and outfitted them with a United States Geological Survey (USGS) aluminum band. In Georgia, we fitted individuals weighing >750 g with a platform transmitter terminal (PTT)-100 (hereafter, PTT) 22-g Solar Argos-global positioning system (GPS) transmitter, whereas we fitted those captured in South Carolina with 25-g GPS-Groupe Spécial Mobile (GSM) solar transmitters (Microwave Telemetry, Columbia, MD, USA; Caccamise and Hedin 1985). We attached transmitters using 4.8-mm-wide braided Teflon tape (Bally Ribbon Mills, Bally, PA, USA) and cyanoacrylate glue, using methodology akin to Miller et al. (2005). We released individuals onto the wetland where we captured them.

The PTT radios recorded 4 locations per day on a seasonal schedule at 0000, 0800, and 1200 year-round, at 1600 from 1 October–30 April, and at 1800 1 May–30 September. They also emitted a universal high frequency (UHF) signal that allowed real-time tracking of individuals. Secure Global System for Mobile (SGSM) transmitters recorded GPS locations based on available battery voltage. Fully charged units were capable of recording a location every minute; at night, the units could record a location every 30 minutes to 4 hours.

Seasonal Home Ranges and Movements

Prior to data analysis, we filtered GPS data to remove locations outside the study areas and those associated with an error reading. We further filtered data recorded by the SGSM units using speed between subsequent locations; we removed all locations with a speed >10 km/hour because we assumed these locations were a result of GPS error. Although this filter likely removed valid locations (i.e., in-flight locations), we filtered only 2% of locations using this approach.

To estimate seasonal home ranges (95%) and core areas (50%), we used auto-correlated kernel density estimators (AKDE) in the ctmm package (Fleming and Calabrese 2016) for Program R (version 3.1.3, R Core Team, Vienna, Austria). We included an error rate of 15 m for PTT and the SGSM units (Pollander 2017). We required transmitters to record a location on ≥50% of the days in the season for a range to be calculated. We combined all seasonal ranges for PTT- and SGSM-marked birds to calculate mean range size across seasons because AKDEs are robust to variation in sampling schedules (Fleming et al. 2015). We did not attempt to assess differences in space use across years, states, or sexes because sample sizes were small in some years and varied across years. Likewise, our sample of mottled ducks from South Carolina included only females.

For our movement analysis, we defined 3 categories of movements (local, excursions, and dispersals) based on location relative to the seasonal range of a bird and duration of the movement outside this range. We defined local movements as those occurring within the seasonal range with occasional movements outside the range lasting <6 hours. To quantify and compare these movements, we summed the distance for all days with ≥3 locations and plotted distances across the length of the season. Because of the volume of data recorded by the SGSM units, we reported local movements for SGSM- and PTT-marked birds separately. We felt the increased volume of data from the SGSM units had the potential to better describe local movements; therefore, we chose not to subsample to make comparisons between transmitter type. We defined an excursion as any movement >5 km round trip, outside the seasonal range lasting

≥6 hours. To detect excursions, we used ArcMap 10.4 (Environmental Systems Research Institute, Redlands, CA, USA) to identify locations outside the seasonal range. We determined duration and distance of an excursion from the last point inside the home range prior to the excursion to the first location inside the home range (i.e., post-excursion). We defined dispersal movements as those where an individual left one watershed and established a new area of use in another watershed (i.e., established new home range). We calculated linear distance traveled from the last point in the original home range to the first point in the new home range and duration for such movements.

We documented long-distance movements for individuals with insufficient data to estimate a seasonal range, in which the individual moved to a new wetland for ≥12 hours. In cases where we observed this long-distance movement behavior, we calculated total distance moved, duration, season, and classified the movement as an excursion or dispersal-type behavior.

Seasonal Habitat Selection

To investigate habitat selection, we examined selection at the seasonal home range scale (third order selection; Johnson 1980). We based seasonal habitat availability on the 95% seasonal home range estimates calculated in the previous section. However, because of variation in sampling schedules between the SGSM and PTT units, we standardized datasets to 4 locations per day collected within 2 hours of when PTT units recorded locations, producing comparable datasets suitable for habitat selection modeling.

We used Coastal Change Analysis Program (C-CAP; NOAA 2010) land cover data and National Agriculture Imagery Program (NAIP; U.S. Department of Agriculture [USDA] 2016) aerial imagery to identify available marsh habitat. The C-CAP data identified estuarine emergent marshes, which included tidal wetlands with ≥80% cover of herbaceous hydrophytes and ocean derived salt content ≥0.5%. Likewise, C-CAP data identified palustrine emergent marshes, which included tidal and nontidal marshes with ≥80% cover in persistent emergent vascular plants, emergent mosses, or lichens while maintaining <0.5% ocean-derived salt content (NOAA 2010). We used NAIP imagery to create a vector layer of managed wetlands impoundments (i.e., impoundments) by visually identifying such areas in the imageries of coastal South Carolina and Georgia. We identified marsh as an impoundment if we found complete external levees, which could control hydroperiod, internal canals used to flood and drain soils, and vegetation that appeared more diverse than the surrounding marshes. We incorporated the impoundment layer with the C-CAP data into a 30-m resolution raster. Additionally, we classified the Confined Disposal Facility (CDF) of the Savannah Harbor units as managed impoundments because they were functionally serving as a managed impoundment during our study. We then used the Euclidean distance tool in ArcMap 10.4 to calculate the distance from any pixel within the study area to the nearest pixel of palustrine emergent wetlands, estuarine emergent wetlands, or impoundments.

We used a distance-based resource selection function to identify habitats selected by mottled ducks at the third order (within the seasonal home range; Johnson 1980), following Design III described by Manly et al. (2002). Within the seasonal home range, we characterized habitat availability using 3 random locations for each used location. We then extracted distance to habitat variables (i.e., palustrine emergent wetlands, estuarine emergent wetlands, impoundments) for all used and random locations and used generalized linear mixed effect models in Program R to evaluate habitat selection with a use versus availability framework. We categorized used and available locations as binary, where we assigned a used location 1 and available (random) locations 0. Because of uneven sampling rates, we used duck identification number as a random effect in our models. Additionally, we included study area (Savannah, ACE, Santee, or Altamaha) as a random effect in our models to account for variation among sites (Gillies et al. 2006).

Prior to analysis, we scaled all distance values for used and available locations by dividing the linear distance by 2,500 m to reduce model convergence issues. We identified correlations between habitat variables using Pearson pair-wise correlations and variance inflation factors (VIF). We then constructed full generalized linear mixed effect models for each season because we assumed that habitat selection varied because of inherent changes in mottled duck behavior during the annual cycle (Davis 2012). Likewise, our sample of marked birds varied across seasons; therefore, we did not include a season effect in our models. We considered variables where $\alpha \leq 0.05$ significant. We calculated scaled odds ratios and 95% confidence intervals and considered any confidence intervals that included 1 as not informative. We then validated our seasonal home range models by using k-fold cross-validation ($k = 10$ folds; Boyce et al. 2002).

RESULTS

We monitored 47 mottled ducks (Georgia, $n = 17$ males, 18 females; South Carolina, $n = 12$ females) during 2013–2016. In Georgia, we monitored 2, 11, 15, and 5 birds during breeding, molting, teal season, and hunting seasons, respectively. In South Carolina, we monitored 6, 5, 7, and 5 birds during the same seasonal periods, respectively. The PTT transmitters on ducks in Georgia collected 11,297 GPS locations and SGSM transmitters on ducks in South Carolina collected 176,501 GPS locations. We monitored birds captured in Georgia an average of 93.1 ± 14.5 (SE) days, whereas we monitored birds captured in South Carolina an average of 209.1 ± 48.4 days. Because of a limited number of males and females in each season, we grouped all individuals in Georgia together to evaluate movements and habitat selection.

Seasonal Home Ranges and Movements

Given the sample size, and spatial scale of seasonal home ranges, we combined all mottled ducks from Georgia and South Carolina into 1 group. Mean home ranges were 2.3 times larger during breeding season (4,598 ha), 2.0 times larger during teal season (4,001 ha), and 1.2 times larger during hunting season (2,479 ha) relative to molting season (2,002 ha; Table 1). Mean core areas were 2.6 times larger during breeding season (969 ha), 2.1 times larger during teal season (789 ha), and 1.2 times larger during hunting season (446 ha) relative to molting season (379 ha; Table 1).

Because of the different sampling schedules between the PTT and SGSM, estimates of mean daily distance moved

Table 1. Seasonal range (95%) and core area (50%) sizes for male (M) and female (F) mottled ducks captured in Georgia or South Carolina from 2013–2016. Age is indicated by after-hatch year (AHY) or hatch year (HY). Season is indicated by molting (M, 1 Jul–9 Sep), teal (T, 10 Sep–19 Nov), hunting (H, 20 Nov–31 Jan), and breeding (B, 1 Feb– 30 Jun).

Duck identification	Seasonal range (ha)	SE	Core area (ha)	SE	Year	Age	Sex	Season
GA 01	2,725		242		2016	HY	M	M
GA 03	273		41		2016	AHY	F	M
GA 04	1,273		149		2016	HY	M	M
GA 05	3,458		350		2016	HY	F	M
GA 07	1,584		217		2015	HY	F	M
GA 10	12,024		2,776		2015	HY	F	M
GA 11	6,706		1,498		2015	HY	M	M
GA 12	52		12		2016	AHY	F	M
GA 15	284		46		2015	AHY	M	M
GA 18	293		56		2016	HY	M	M
GA 29	24		5		2016	HY	F	M
SC 236	790		171		2014	AHY	F	M
SC 238	1,504		271		2014	AHY	F	M
SC 244	116		20		2015	AHY	F	M
SC 249	891		196		2014	AHY	F	M
SC 250	33		7		2015	AHY	F	M
$\bar{x}$	2,002	789	379	183				M
GA 02	14,054		1,831		2014	AHY	M	T
GA 03	996		129		2016	AHY	F	T
GA 04	2,071		471		2016	HY	M	T
GA 05	2,685		528		2016	HY	F	T
GA 06	894		170		2015	AHY	F	T
GA 07	962		157		2015	HY	F	T
GA 08	33		6		2015	HY	F	T
GA 10	1,662		428		2015	HY	F	T
GA 11	264		54		2015	HY	M	T
GA 12	3,432		632		2016	AHY	F	T
GA 13	270		47		2014	HY	M	T
GA 14	4,945		1,037		2014	HY	M	T
GA 15	1,301		174		2014	HY	M	T
GA 17	4,787		1,079		2014	HY	M	T
GA 19	2,952		485		2014	HY	M	T
SC 236	7,388		1,737		2014	AHY	F	T
SC 238	24,812		5,646		2013	AHY	F	T
SC 242	2,014		400		2014	AHY	F	T
SC 244	3,414		552		2014	AHY	F	T
SC 247	4,466		876		2014	AHY	F	T
SC 250	700		80		2015	AHY	F	T
SC 253	3,916		833		2014	AHY	F	T
$\bar{x}$	4,001	1,190	789	255				T
GA 06	337		61		2015	AHY	F	H
GA 11	257		42		2015	HY	M	H
GA 16	4,266		903		2014	HY	M	H
GA 15	1,169		237		2014	HY	M	H
GA 13	1,176		295		2014	HY	F	H
SC 236	1,479		281		2013	AHY	F	H
SC 238	1,692		380		2013	AHY	F	H
SC 244	1,438		240		2014	AHY	F	H
SC 247	12,464		1,951		2014	AHY	F	H
SC 250	513		71		2015	AHY	F	H
$\bar{x}$	2,479	1,166	446	185				H
GA 03	5,610		740		2015	AHY	F	B
GA 16	1,301		174		2016	AHY	F	B
SC 236 (2014)	13,220		2,981		2014	AHY	F	B
SC 236 (2015)	1,780		359		2015	AHY	F	B
SC 238	769		110		2014	AHY	F	B
SC 242	356		74		2015	AHY	F	B
SC 244	2,218		335		2015	AHY	F	B
SC 247	15,276		3,782		2015	AHY	F	B
SC 250	856		163		2016	AHY	F	B
$\bar{x}$	4,598	1,902	969	466				B

could be affected by biases associated with the respective schedules; therefore, we separated Georgia and South Carolina ducks for reporting purposes. In Georgia, mean distance moved for mottled ducks was 3.5 ± 0.3 km/day during molting and 5.7 ± 0.2 km/day during teal season. During the hunting season, mean distance moved was 4.1 ± 0.2 km/day, whereas mean distance moved during breeding was 11.3 ± 0.4 km/day. In South Carolina, mean distance moved was 1.3 ± 0.1 km/day during molting season. Movements during teal season were 4.8 ± 0.3 km/day. Movements during the hunting season were 3.5 ± 0.2 km/day, whereas during breeding season mean distance moved was 5.6 ± 0.2 km/day. Movements during breeding season were approximately 2.5 times and 1.9 times greater compared to the other seasons for mottled ducks in Georgia and South Carolina, respectively.

We documented 21 excursions (Table S1, available online in Supporting Information). Five individuals captured in South Carolina completed 12 different excursions, with 1 individual completing 5 separate movements, whereas birds captured in Georgia completed 11 excursions. The farthest excursion was completed by a hatch year female (GA 10) who traveled 139.5 km over 32 hours from the Altamaha to the marshes south of Savannah during the molting season. The farthest excursion during teal season was completed by a hatch year male (GA 15) who traveled 28.7 km over 20 hours from his seasonal range in the western portion of the Altamaha to the natural marshes to the north. The only excursion during the hunting season was completed by an adult female (SC 236), who traveled 9.4 km over 44 hours. The farthest breeding season excursion was 24.8 km over 14 hours, completed by an adult female (SC 250), who visited natural and managed impoundments south of her seasonal range.

We documented 5 dispersal movements, all by birds captured in Georgia during molting and breeding seasons. The farthest was completed by an adult male (GA 15) who traveled 245.8 km from his established range near the Altamaha WMA to Cape Romaine National Wildlife Refuge (NWR) in slightly more than 20 hours during the breeding season (Fig. S1, available online in Supporting Information). This same male completed a second dispersal later in the breeding season and traveled 48.7 km over 42 hours to Santee Coastal Reserve WMA. The next farthest dispersal was by a hatch year male (GA 18) who traveled from Altamaha WMA to the St. Johns River in Jacksonville, Florida, before moving northwest over 44 hours to Waverly, Georgia. We observed an after-hatch year female (GA 03) disperse to Florida, moving 109 km from Altamaha WMA to ponds in a suburban community of Jacksonville over 102 hours (Fig. S2, available online at Supporting Information). The last dispersal we observed was from a hatch year male (GA 11) who traveled 52.6 km over 12 hours from Altamaha WMA to Savannah NWR and the Confined Disposal Facilities of the Savannah Harbor.

We observed 6 noteworthy long-distance movements during molt and teal seasons. We documented 2 males (a hatch year and adult), traveling 183.3 km and 131.8 km one way from the Altamaha to Savannah over 42 hours and 18 hours, respectively, during the molt season. Later in the molting season, the adult male traveled 183.3 km round trip from Savannah to Bear Island WMA in South Carolina over 102 hours. An after-hatch year male (GA 02) traveled 176.2 km from the Altamaha to Nemours Wildlife Foundation Plantation over 62 hours. Lastly, a hatch year male (GA 30) traveled a straight-line distance of 187.9 km over 48 hours to Lulu, Florida, before being found dead. The single long-distance movement during teal season was by an after-hatch year female (GA 26) who moved 31.4 km from the Altamaha WMA to Black Beard Creek over 1.75 days, at which point the transmitter ceased reporting and status of the bird was unknown.

Seasonal Habitat Selection

Given the resolution of our landcover data, sample size, and spatial scale of seasonal habitat selection, we combined all mottled ducks from Georgia and South Carolina into 1 group. We retained all variables in our modeling efforts because no variables were highly correlated ($|r| < 0.6$, VIF < 1.3). During the breeding season, individuals selected for impoundments but avoided palustrine emergent wetlands (Table 2). During the molting season, individuals selected for impoundments and palustrine emergent wetlands and avoided estuarine emergent wetlands (Table 2). During teal season, individuals selected for impoundments but avoided palustrine emergent wetlands (Table 2). During the hunting season, individuals selected for impoundments (Table 2), whereas selection of estuarine emergent wetlands and palustrine emergent wetlands were not significant (Table 2). Our *k*-fold cross-validation correctly classified 74.6%, 74.9%, 75.0%, and 75.5% of the locations for the seasonal home range models for breeding, molting, teal, and hunting seasons, respectively.

DISCUSSION

In general, we observed differential seasonal habitat selection, home range and core area size, and movements of mottled ducks in Georgia and South Carolina relative to Florida. We found that mottled ducks exhibited strong selection for managed impoundments within established home ranges during all seasons, similar to Shipes et al. (2015). Managed impoundments offer stable water depths not affected by normal tidal fluctuations, and foraging resources important to waterfowl (Gordon et al. 1989). We were not able to assess salinity across the managed impoundments used by individuals in our study, but Shipes et al. (2015) noted that mottled ducks selected impoundments that were brackish rather than fresh or saline in the ACE Basin. We documented individuals using small islands in the Atlantic Ocean in the Altamaha and Santee areas, along with managed wetlands west of the saltwater demarcation line (U.S. Highway 17) in the ACE, Savannah, and Altamaha areas. These observations suggest that mottled ducks are capable of using wetlands with a wide gradient of salinities. Locations of our marked birds did cluster around the saltwater demarcation line, but we suspect this was due to

Table 2. Seasonal habitat selection coefficients and odds ratios for mottled ducks based on distance metrics (m) at the seasonal home range (95% auto-correlated kernel density) spatial scale in South Carolina and Georgia, USA, 2013–2016. Negative values indicate selection and positive values indicate avoidance of the specific habitat type.

Habitat	Season[a]	β	SE	Z	P	Odds ratio	Lower 95%	Upper 95%
Managed impoundments	Breeding	−1.718	0.085	−20.11	<0.001	0.407	0.152	0.212
	Molt	−0.359	0.032	−11.20	<0.001	0.699	0.656	0.744
	Teal	−1.134	0.071	−16.02	<0.001	0.322	0.280	0.370
	Hunting	−0.461	0.151	−3.05	0.002	0.631	0.469	0.848
Estuarine emergent wetlands	Breeding	0.113	0.095	1.19	0.234	1.120	0.930	1.349
	Molt	3.623	0.162	22.40	<0.001	37.468	27.279	51.461
	Teal	−0.111	0.083	−1.33	0.185	0.895	0.760	1.054
	Hunting	−0.018	0.136	−0.13	0.894	0.982	0.752	1.282
Palustrine emergent wetlands	Breeding	0.210	0.184	3.86	<0.001	2.034	1.419	2.916
	Molt	−0.892	0.175	−5.10	<0.001	0.410	0.291	0.577
	Teal	0.967	0.128	7.58	<0.001	2.631	2.048	3.378
	Hunting	0.479	0.277	1.73	0.084	1.614	0.937	2.779

[a] Seasons: breeding (1 Feb–30 Jun), molt (1 Jul–09 Sep), teal (10 Sep– 19 Nov), and hunting (20 Nov–31 Jan).

the close juxtaposition of managed impounds to this water interface rather than the actual salinity levels.

Estimates of home ranges and core areas for birds from our study were similar to estimates for birds in the Chenier Plain of Texas ($\bar{x}$ home range = 6,566 ha and core areas = 1,516 ha; Moon 2014). Our estimates for Georgia and South Carolina mottled ducks were greater than for birds using urban areas but less than for birds using rural areas in Florida (Varner et al. 2014). We also found that mottled ducks avoided estuarine emergent wetlands during the molt season but selected for managed impoundments in all seasons; 72% of all locations recorded were in managed impoundments. This likely reflects the need for stable water depths and habitat, particularly when a bird is undergoing remigial molt. Tidal marshes clearly do not offer this, reinforcing the importance of impoundments. Similarly, previous research has demonstrated the importance of impoundments to mottled ducks (Shipes et al. 2015) and surveys completed by SCDNR have noted that 99% of all mottled ducks were located in managed impoundments (Shipes 2014).

We examined movements of PTT-marked birds (Georgia) and SGSM-marked birds (South Carolina) separately because the PTT recorded 4 locations per day, whereas the SGSM units collected locations based on available battery. Although variation between individuals and study areas contribute most to the total variance in home range size (Börger et al. 2006), we assumed that the increase in data provided by SGSM units would better describe individual movement paths (Cagnacci et al. 2010). For example, during teal season, we found little difference in mean daily movements between mottled ducks in Georgia and South Carolina. We observed the greatest difference in daily movements during the breeding season when birds in Georgia moved, on average, greater distances than South Carolina birds. We suspect this observed difference was due to sample size rather than any biologically relevant differences in bird behavior because we monitored only 3 individuals in Georgia during breeding (1 was male), whereas all birds monitored in South Carolina during breeding were female.

We documented birds from both states completing excursions outside their seasonal ranges. The longest excursion was 44 hours, with a mean duration of 18 ± 1.6 hours, indicating that although these birds did leave their ranges, they did so infrequently and for brief time periods. Excursions are commonly documented in other taxa (Hodder et al. 1998, Kolodzinski et al. 2010, Hawkes et al. 2011, Krone et al. 2013, Deuel et al. 2017), but the underlying factors influencing excursions are poorly understood. For example, white-tailed deer (*Odocoileus virginiaus*) make excursions during all seasons of the annual cycle (Beier and McCullough 1990, Kolodzinski et al. 2010, Simoneaux 2015, Jacobsen 2017) and numerous explanations have been offered for these movements, ranging from finding mates, food, minerals, and refugia to pre-dispersal exploration (Holzenbein and Marchinton 1992, Karns et al. 2011). We documented an excursion by an adult female (SC 250) to natural marshes southeast of her molt season range. The following teal season, she incorporated this excursion location into her home range, suggesting that perhaps this female used an excursion to explore areas for future use. Notably, her excursion occurred during 24–25 August 2015, but she did not revisit this area again until 3 October 2015. Regardless, exploratory excursions may give increased familiarity with surrounding areas and thereby increase the rate of success in dispersal attempts (Conradt et al. 2001).

Long-distance movements and dispersals completed by mottled ducks in Georgia have implications for managers charged with managing habitats because dispersal patterns suggest that mottled ducks from South Carolina and Georgia constitute a single population. For example, we documented 5 dispersal movements ranging from 52.6–245.8 km and 5 one-way long-distance movements varying from 31.4–183.3 km, all completed by birds captured in Georgia. These movements align with band return data from GADNR in which 7 of 24 were recovered out of state (G. D. Balkcom, unpublished data) but were greater distances than those reported for most mottled ducks in Florida and Texas (Baldassarre 2014). Being that most movements were between Georgia and South Carolina, we assumed South Carolina, instead of Florida, was the source of mottled ducks currently found in Georgia. Similar to other studies, we suggest that extensive movements are likely required for mottled ducks to find ideal foraging, breeding, and molting habitats (Stutzenbaker 1988, Moon 2014) because we observed dispersal and long-distance movements only from birds captured in Georgia, suggesting that habitat along the Georgia coast may be a limiting factor. In South Carolina, locations tended to be clustered around river systems with large complexes of managed wetland impoundments, such as the Santee and ACE river basins. Therefore, the distribution of managed wetlands appears to limit mottled duck occurrence in coastal Georgia, potentially forcing individuals to complete dispersal and long-distance movements in search of suitable habitat.

Hydrologic regimes and management schemes may influence use of impoundments by mottled ducks as water levels, vegetation communities, and salinities vary through time (Gordon et al. 1989). We documented 1,077 locations (72% of all locations in the Savannah River basin) in the CDF of the Savannah Harbor. These impoundments were managed by the Army Corps of Engineers to hold dredge materials removed from the Savannah River and were not managed to provide waterfowl habitat. Our resource selection function suggests these impoundments potentially provide beneficial vegetation types for mottled ducks. If conditions of the CDF were altered, this habitat could be restricted or removed, limiting mottled duck habitat along the Savannah River, and potentially causing birds to leave or use less suitable habitat.

Historically, tidal impoundments were created in tidal areas close to freshwater because rice production was most successful in those areas (Gordon et al. 1989). Although we were not able to assess the importance of salinity in habitat selection, intuitively salinity affects mottled duck habitat selection because the species is limited to coastal regions (Shipes et al. 2015). Stutzenbaker (1988) reported that WGC mottled ducks consumed high volumes of seeds and plants only available in brackish marshes, and Stieglitz (1972) reported that mottled ducks in brackish marshes of Florida consumed considerably more animal material than birds in freshwater marshes. We suggest future research investigate potential effects of salinity and water depth on habitat selection and diets.

MANAGEMENT IMPLICATIONS

We suggest SCDNR and GADNR cooperate on future mottled duck projects including research, species, and habitat management efforts. Mottled duck movements out of Georgia may be related to relatively poor quality (i.e., limited beneficial vegetation types) or direct lack of habitat. We suggest efforts to increase the amount of high quality habitat for mottled ducks near the Altamaha WMA and across coastal Georgia, namely through the establishment of managed impoundments. If successful, improved habitat conditions for mottled ducks in Georgia should result in reduced dispersal of birds from the state.

We noted the importance of managed impoundments to mottled ducks. Mottled ducks selected habitats limited to the Santee, ACE, Savannah, and Altamaha river basins and failed to use any areas outside of these basins. Therefore, we suggest that agencies create and manage impoundments within and between these 4 river systems, thereby increasing available habitat. We also suggest that larger managed impoundments, such as those found on Rhetts Island of Altamaha WMA, could be divided into smaller units, allowing for a diversity of management opportunities.

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