MOVEMENTS, SPACE USE, AND HABITAT SELECTION OF THE MOTTLED DUCK IN GEORGIA AND SOUTH CAROLINA

by

KAYLEE MARIE POLLANDER

(Under the Direction of Michael J. Chamberlain)

ABSTRACT

A non-native population of resident mottled ducks (*Anas fulvigula*) exists in coastal South Carolina and Georgia, but little is known about their ecology and behavior. I used GPS telemetry to document movements, space use, and habitat use of 47 individuals between 2013 – 2016. Mean seasonal home ranges varied from 2002 to 4598 ha. Individuals made 23 excursions outside of established ranges varying from 5 km to 139.5 km, 5 dispersal movements varying from 52.6 km to 245.8 km, and 6 long-distance movements. Mottled ducks selected for managed impoundments at multiple spatial scales. My findings indicate that mottled ducks in Georgia and South Carolina are likely one population, and are highly dependent on impounded wetlands. I recommend state and federal agencies create and manage impounded wetlands to benefit mottled ducks across the South Carolina and Georgia coasts.

INDEX WORDS: Mottled duck, movements, GPS telemetry, home range, habitat, managed impoundment, South Carolina, Georgia

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by

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DEDICATION

This work is dedicated to my family. They made me the person I am today and have constantly supported me as I chased ducks, far and wide. Without their love and encouragement, this never would have been possible.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Understanding movements, space use, and habitat selection is important components of waterfowl ecology and management. Movements and habitat use are well documented for species such as the mallard (*Anas platyrhyncos;* Merendino and Ankney 1994, Kessler et al. 2014, Lancaster et al. 2015) and northern pintail (*Anas acuta*; Cox and Afton 1997, Miller et al. 2005, Haukos et al. 2006). As these species are migratory, habitat availability on the breeding and wintering grounds are equally important (Smith et al. 1989, Batt 1992). By comparison, non-migratory species such as the mottled duck (*Anas fulvigula*) require all annual needs met locally (Stutzenbaker 1988, Bielefeld et al. 2010). Mottled ducks will use non-tidal fresh to brackish marshes, flooded rice fields, and inland prairies of Louisiana and Texas in the Western Gulf Coast (WGC; Stutzenbaker 1988, Zwank et al. 1989, Haukos et al. 2010, Moon 2014) and freshwater lakes and ponds associated with urban areas (Varner et al. 2014) and freshwater emergent wetlands and wet prairies of Florida (Johnson et al. 1991, Bielefeld et al. 2010), where the species is endemic. Based on band return data, most individuals were recovered 56.5 – 78.9 km from initial banding sites in Florida and the WGC, respectively (Baldassarre 2014). Despite being resident, movements of up to 105.5 (Davis 2012) and 197.5 km (Moon 2014) have been documented, and Stutzenbaker (1988) stated that individuals could move 400 km during drought conditions to find ideal molting habitat.

Because mottled ducks are a resident species, moving among habitats in localized areas, home ranges estimates are appropriate and useful. In Florida, mean annual home ranges (95%

Kernel estimator) for females were 2050 ha, whereas estimates using minimum convex polygons (MCP) ranged from 17,000 to 95,000 ha (Bielefeld et al. 2010). Additionally, individuals living in urban areas maintained ranges of 232 – 598 ha, whereas individuals living in rural areas maintained ranges from 32,573 – 88,101 ha (Varner et al. 2014). Conversely, mottled ducks in Texas maintained considerably smaller ranges (95% 6,566 ha; Moon 2014).

In addition to the historic endemic and genetically distinct mottled duck populations of the WGC and Florida, a third population exists. The South Carolina Department of Natural Resources (SCDNR) released 1,285 individuals from the WGC and Florida between 1973 – 1985 (Shipes et al. 2015, Kneece 2016). Recent estimates (2009-2011) found the mottled duck population around 23,000 ducks in South Carolina (Kneece 2016). Since the mid-1990s, mottled ducks have been consistently found in coastal Georgia, having presumably expanded from either Florida or South Carolina. The Georgia Department of Natural Resources (GADNR) began banding mottled ducks in 2006, and band returns indicate the species is highly mobile as 7 of 24 bands were recovered out of state (GADNR unpublished data). Beyond this coarse scale band data, little is known about location, permanence, and timing of movements.

Although studies of habitat use have been conducted in endemic ranges, there is little information for the mottled duck in Georgia and South Carolina. Coastal areas 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, and saltmarshes (SCDNR 2017). Additionally, tidal influences in Georgia and South Carolina can range from 1.4 m – 2.4 m (NOAA 2017*a, b*) in comparison to the Gulf Coast, which experiences < 1 m tides (Dardeu et al. 1992). Previous research in South Carolina found water depth < 25 cm (Weng 2006), and managed wetland impoundments and brackish wetlands were important to mottled ducks (Shipes et al. 2015). These studies (Weng 2006 and Shipes et al. 2015) only investigated habitats in small study areas, each limited to one river drainage system, therefore an analysis of habitats across Georgia and South Carolina would better inform management agencies.

Methods for monitoring waterfowl have recently improved with the advent of Global Positioning System (GPS) telemetry, replacing very-high frequency (VHF) and satellite (i.e. ARGOS) telemetry. Use of GPS telemetry has substantially increased accuracy and volume of locations recorded (Byrne et al. 2014) as it uses a network of satellites that provides 24-hour worldwide coverage (Rodgers et al. 1996), allowing for nearly limitless data collection. Although useful, VHF has proven labor intensive, weather dependent, and road-biased (Guthrie et al. 2011, Fischer et al. 2013). Satellite telemetry can have locational errors that range from a few to several thousand meters, and is affected by satellite orbits, behaviors of radio-marked individuals, transmitter altitude, topography, and weather conditions (Harris et al. 1990, White and Garrott 1990, Rodgers 2001, Miller et al. 2005). Thus, VHF and satellite telemetry have limited data collection, restricted life history and ecology research for many waterfowl species. Despite the efficacy of GPS technology, questions remain regarding their locational accuracy. Frequently, information regarding device accuracy is not included or discussed (Namgail et al. 2011, Perez-Garcia et al. 2013; but see Sheaffer and Malecki 2009) despite error distances increasingly being incorporated into home range estimators (Fleming and Calabrese 2016, Kranstauber and Smolla 2016), or the manufacturer specifications are used because an independent estimation of accuracy does not exist (Fischer et al. 2013, Hawkes et al. 2013). Therefore, information regarding the accuracy of GPS units suitable for waterfowl research is needed.

OBJECTIVES

My primary objectives were to document space use and movements, and quantify habitat selection at multiple spatial scales for mottled ducks in Georgia and South Carolina. Secondarily, I evaluated locational accuracy of GPS transmitters used to fulfill my primary objectives.

THESIS FORMAT

This thesis is in manuscript format. Chapter 1 is an introduction and literature review regarding mottled duck space use, movements, habitat use, and GPS telemetry. Chapter 2 focuses on movements and space use of mottled ducks in Georgia and South Carolina. Chapter 3 outlines habitat selection at multiple spatial scales. Chapter 4 presents an assessment of locational accuracy of GPS transmitters used to describe movements, space use, and habitat selection in this study. Chapter 5 outlines conclusions and management implications. Chapters 2 and 3 will be submitted to a peer-reviewed journal for publication.

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CHAPTER 2

MOVEMENTS AND SPACE USE OF MOTTLED DUCKS IN GEORGIA AND SOUTH CAROLINA[1]

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ABSTRACT

Limited information exists regarding movements and space use of mottled ducks (*Anas fulvigula*) in South Carolina, where the species was released by the South Carolina Department of Natural Resources (SCDNR) between 1975 – 1983. Mottled ducks expanded into coastal Georgia in the 1990s, and banding data suggest that birds captured in Georgia are often harvested in other states. Hence, there is a need to more thoroughly understand movement ecology of mottled ducks in Georgia and South Carolina. We used GPS telemetry to investigate movements and space use of mottled ducks during 2013-2016. Overall estimates of space use using minimum convex polygons varied from 8 to 12,046 ha, whereas seasonal ranges varied between 2002 – 4598 ha estimated using mean adaptive kernel density estimates. 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 hrs and moved ≥ 5 km; these excursions ranged from 5 to 139.5 km. We documented 5 dispersal movements which covered distances ranging from 52.6 km to 245.8 km. We also documented various long distance movements, with 7 birds captured in Georgia moving to South Carolina and 2 moving to Florida. Our findings suggest that mottled ducks inhabiting the South Carolina and Georgia coasts are essentially a single population. Notably, we only observed dispersal and long-distance movements from birds captured in Georgia, suggesting that habitat may be limited along the Georgia coast, prompting birds to move long distances or abandon previously established ranges. We suggest the Georgia Department of Natural Resources (GADNR) and SCDNR work cooperatively to manage mottled ducks and their habitats. Additionally, GADNR should consider increasing the availability of quality habitats along the Georgia coast.

INDEX WORDS: mottled duck, movements, home range, *Anas fulvigula*, Georgia, South Carolina, dispersal, excursion

INTRODUCTION

Movements and space use of waterfowl are well studied, lending insight into migration ecology, behavior, and habitat use. This knowledge allows wildlife professionals to make informed decisions regarding management and conservation. Previous studies have described evening foraging flights (Tamisier 1976, Baldassarre and Bolen 1984, Cox and Afton 1996), spring and fall migrations (LaGrange and Dinsmore 1989, Krementz et al. 2011, Miller et al. 2005), and molt migrations (Yarris et al. 1994) for migratory species such as the northern pintail (*Anas acuta*), green-winged teal (*A. carolinensis*), and mallard (*A. platyrhynchos*). Space use during breeding (Pöysä 2001, Mack et al. 2003) and non-breeding (Hestbeck 1993, Legagneaux et al. 2008, Lancaster et al. 2015) seasons have also been well documented.

The mottled duck (*A. fulvigula*), a close relative of the mallard, is primarily found in 2 distinct populations, the Western Gulf Coast (WGC) of Texas and Louisiana and peninsular Florida (Bielefeld et al. 2010, Baldassarre 2014). A third introduced population was established by the South Carolina Department of Natural Resources (SCDNR), who released 1,285 individuals from the WGC and Florida to coastal South Carolina between 1973 – 1985 (Shipes 2015, Kneece 2016). Recent estimates (2009-2011) put the mottled duck population in South Carolina around 23,000 ducks (Kneece 2016). Since the mid-1990s, mottled ducks have been consistently found in coastal Georgia, having presumably expanded from either Florida or South Carolina. The Georgia Department of Natural Resources (GADNR) began banding mottled ducks in 2006, and band returns indicate the species is highly mobile as 7 of 24 bands were recovered out of state (GADNR unpublished data). Mottled ducks are considered a resident species, as most band recoveries in Florida were within 56.5 km of their banding site whereas in Texas, most were recovered within 78.9 km of banding sites (Baldassarre 2014). Davis (2012) found that maximum distance moved annually varied from 44, 105.5, and 81.2 km between 2007 – 2009, whereas Moon (2015) found that female mottled ducks dispersed a maximum of 197.5 km and moved a mean distance of 2.72 km/week on the Texas Chenier Plain. Currently, little is known about movements of mottled ducks in the introduced South Carolina and Georgia population.

Being that mottled ducks are residents, analyses of home range and space use could improve our understanding of species ecology. In east-central Florida, mean annual home ranges (95% Kernel estimator) for females were 2050 ha, whereas estimates obtained using minimum convex polygons (MCP) ranged from 17,000 to 95,000 ha (Bielefeld et al. 2010). Additionally, individuals living in urban areas maintained ranges of 232 – 598 ha, whereas individuals living in rural areas maintained ranges from 32,573 – 88,101 ha (Varner et al. 2014). Conversely, mottled ducks in Texas maintained considerably smaller ranges (95% 6,566 ha; Moon 2014). During the breeding season in southeast Texas, females had 650 ha to 4200 ha home ranges, depending on the method used to estimate range size (Rigby 2008). In coastal Texas, breeding ranges were between 42.5 and 132 ha (Weeks 1969). Outside of the breeding season, there is no published information regarding seasonal home range sizes, and there is no information about space use and home range size for mottled ducks in South Carolina and Georgia. Our objectives were to document movements, space use, and seasonal home ranges for mottled ducks in South Carolina and Georgia.

STUDY AREA

In Georgia, we captured mottled ducks on the Altamaha WMA and surrounding marshes and islands owned by GADNR. 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 (Figure 2.1, GADNR 2016). The intensively managed wetland impoundments 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 plants and salinities helped fulfill management objectives of providing quality wintering habitat to migratory waterfowl and waterfowl hunting opportunities to the public. Being the only actively managed wetlands in coastal Georgia, the Altamaha was widely considered the best waterfowl hunting in the state (GADNR 2014). Additionally, coastal Georgia boasts 160 km of coastline and 153,000 ha of saltmarsh and is considered one of the most extensive and productive natural marsh systems in the United States (NOAA 2016).

In South Carolina, mottled duck capture occurred on public and private lands in the Ashepoo, Combahee, Edisto (ACE) and Santee River Basins. This capture was conducted by staff of Nemours Wildlife Foundation in cooperation with SCDNR. Lands targeted in the Santee River Basin were 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 and 805 ha of managed wetland impoundments, respectively.

METHODS AND MATERIALS

Field Methods

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 by night lighting from an airboat in the managed wetland impoundments of the Altamaha WMA (Merendino and Lobpries 1998).

Additionally, a net gun deployed from a helicopter was used to capture mottled ducks during 11 – 14 August 2015 (Dragonfly Aviation, Laredo, Texas, 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 by night lighting from an airboat (Federal Bird Banding Permit 23417).

Once captured mottled ducks were aged, sexed, weighed, and outfitted with a USGS aluminum band. We fitted individuals captured in Georgia with a mass > 750 g with a PTT-100 22 g Solar Argos/GPS transmitter, whereas those captured in South Carolina were outfitted with the 25 g GPS/GSM Solar transmitters (Microwave Telemetry, Inc., Columbia, Maryland, USA; Caccamise and Hedin 1985). Transmitters were attached using 4.8 mm wide braided Teflon tape (Bally Ribbon Mills, Bally, Pennsylvania, USA; sold as 3/16") and cyanoacrylate glue, using methodology akin to Miller et al. (2005). Once outfitted, individuals were promptly released onto the wetland where they were captured.

The PTT-100 22 g Solar Argos/GPS (hereafter PTT-100) recorded 4 locations per day. The units recorded locations at 0000, 0800, ad 1200 hrs, year-round. Evening locations were recorded at 1600 hours from 1 October – 30 April, and at 1800 hrs from 1 May – 30 September. Locational data recorded by PTT-100s were uploaded to the Argos satellite every third day (CLS America Inc., Lanham, Maryland, USA) and made available online. Once available, we downloaded data from the CLS America website. We processed these files using the Argos-GPS Parser software (Microwave Telemetry, Inc., Columbia, Maryland, USA). Additionally, the PTT-100 was outfitted with a UHF signal, allowing for real time tracking of marked individuals.

The 25 g GPS/GSM Solar (hereafter SGSM) transmitters recorded GPS locations dynamically based on available battery voltage. According to the manufacturer, fully charged units exposed to the sun could record a location every minute; at night, the units could record a location every 30 minutes to 4 hours. Data were uploaded once daily via Groupe Spécial Mobile (GSM) wireless networks. Individual units could store up to 258,000 locations onboard. When a unit was outside GSM coverage, data were stored onboard until the unit returned to an area of coverage. All new and previously recorded locations were uploaded daily. Once transmitted, data were made available by email. If the PTT-100 and the SGSM transmitters were unable to record a location and the battery was not depleted, the date, time, and an error reading indicating the reason for the missed fix were reported. If either transmitter type was unable to record a location due to insufficient battery power, either battery drain or low voltage errors were reported.

If a transmitter stopped communicating, we attempted to get to the last recorded location to search for the carcass and transmitter. Transmitters from hunter harvested birds taken in Georgia were recovered by GADNR staff, whereas SCDNR facilitated recovery in South Carolina.

Statistical Methods

We filtered GPS data to remove locations outside the study areas, where altitudes were > 1000 m, and that were associated with an error reading. Data recorded by the SGSM units were further filtered using speed between subsequent locations; we removed all locations with a speed > 10 km/hr as we believed these locations were a result of GPS error. Although this filter likely removed valid locations (i.e. in flight locations), we only removed 2% of locations using this approach.

We adapted seasons from Varner et al. (2014), but adjusted them to reflect the hunting seasons in Georgia and South Carolina as follows: breeding (Feb 1-June 30), molt/post-breeding (July 1-Sept 9), teal hunting season (Sept 10-Nov 19), and general hunting season (Nov 20-Jan 31). We based teal and general hunting seasons on the earliest opening date for those respective hunting seasons from 2013-2016.

We used auto-correlated kernel density estimators (AKDE; Fleming et al. 2016) to estimate seasonal ranges (95%) and core areas (50%) to better understand variation in space use across seasons. We used program R and the ctmm package (Fleming and Calabrese 2016) to calculate ranges, and an error rate of 15 m for both units based on a static test conducted in 2015 (see Chapter 4). Transmitters must have recorded a location on ≥ 50% of the days in the season for a range to be calculated. We combined all seasonal ranges for PTT-100 and SGSM marked birds to calculate mean range size across seasons, as AKDEs are insensitive to variation in sampling schedules (Fleming et al. 2016). We did not attempt to assess differences in space use across years, states, or sexes, as sample sizes were small in some years and also varied across years. Likewise, our sample of mottled ducks from South Carolina only included females.

To analyze movements, we first grouped them into excursions, dispersals, and what we believed to be typical movements. We defined an excursion as any movement > 5 km round trip, outside the seasonal range lasting ≥ 6 hrs. To detect excursions, we used ArcMap 10.4 (ESRI, Redlands, CA, USA) to identify locations outside the seasonal range. We determined duration and distance of an excursion from the last point inside the range prior to the excursion to the first location post-excursion inside the range. We defined dispersal movements as those where an individual left one watershed and settled into another watershed. We calculated distance and duration for such movements.

We defined typical movements as those occurring within the seasonal range with occasional movements outside the range lasting < 6 hrs. 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. Due to the volume of data recorded by the SGSM units, we reported typical movements for SGSM and PTT-100 marked birds separately. We felt the increased volume of data from the SGSM units had the potential to better describe typical movements, therefore we chose not to subsample to make comparison between transmitter type.

We documented long-distance movements for individuals with insufficient data to estimate a seasonal range, in which the individual moved to a new wetland system for ≥ 12 hr. When we observed these movements, we calculated total distance moved, duration, season, and whether the movement was one-way, where the bird moved to a new area and stayed, or round trip, where the bird went to a new area then returned.

We used minimum convex polygons (MCP) to estimate space use for all individuals that were tracked continuously for ≥ 26 days (Mohr 1947), producing results comparable to estimates available in the literature. We used Program R (version 3.1.3, R Core Team, Vienna, Austria) and the adehabitatHR (Calenge 2015) package to calculate 95% MCPs. If dispersal was documented, we calculated an MCP for the area where the bird was tracked the longest, so as not to inflate MCP sizes due to movements associated with birds relocating to a new range.

RESULTS

In Georgia, we captured and outfitted 35 mottled ducks with PTT-100 transmitters, collecting 11,297 GPS locations. In South Carolina, 12 after-hatch year females were outfitted with SGSM transmitters, which recorded 176,501 locations. We monitored birds captured in Georgia an average of 93.1 days (SE = 14.5), whereas birds captured in South Carolina were monitored an average of 209.1 days (SE = 48.4). MCP sizes ranged from 8 ha to 12,046 ha for all birds (Table 2.1).

Space Use

Of 47 birds captured, we obtained sufficient data from 16 birds during molting that maintained a mean range of 2002 ha (SE = 789) and a mean core area of 379 ha (SE = 183, Table 2.2). During teal season, we obtained sufficient data from 22 individuals whose mean range was 4001 ha (SE = 1190) and mean core area was 789 ha (SE = 255). During the general hunting season, 11 birds maintained mean ranges of 2254 ha (SE = 1079) and core areas of 406 ha (SE = 172). During the breeding season, the mean consisted of ranges from 8 individuals; one bird was tracked across 2 years, resulting in 9 ranges. Mean breeding range was 4598 ha (SE = 1902) and core area was 969 ha (SE = 466). We tracked an additional bird (GA 15) who completed 2 dispersal movements during the breeding season, resulting in 3 separate seasonal ranges. These ranges were maintained from 1 February 2015 – 9 April 2015, 9 April 2015 – 26 May 2015, and 26 May 2015 – 30 June 2015. Range sizes were 298, 1,427, and 25,798 ha, whereas core areas were 58, 348, and 5996 ha, respectively.

Movements

For birds captured in Georgia, mean distance moved was 3.5 km/day (SE = 0.3, Figure 2.2) during molting and 5.7 km/day (SE = 0.2, Figure 2.3) during teal season. During the general hunting season, mean distance moved was 4.1 km/day (SE = 0.2) whereas mean distance moved during breeding was 11.3 km/day (SE = 0.4, Figure 2.4).

For the females captured in South Carolina, mean distance moved was 1.3 km/day (SE = 0.1, Figure 2.5) during molt season. Movements during teal season were 4.8 km/day (SE = 0.3, Figure 2.6). Movements during the general hunting season were 3.0 km/day (SE = 0.2, Figure

2.7), whereas during breeding season mean distance moved was 5.6 km/day (SE = 0.2, Figure 2.8).

We documented 21 excursions (Table 2.3). Five individuals captured in South Carolina completed 12 different excursions, with one individual completing 5 separate movements, whereas birds captured in Georgia completed 11 excursions. The farthest was completed by a hatch year female (GA 10) who traveled 139.5 km over 32 hrs from the Altamaha to the marshes south of Savannah during the molt season. The farthest excursion during teal season was completed by GA 15, a hatch year male, 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 general hunting season was completed by an adult female (SC 236), who traveled 9.4 km over 44 hrs. The farthest breeding season excursion was 24.8 km over 14 hrs, 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 molt 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 to Cape Romaine National Wildlife Refuge (NWR) in slightly more than 20 hrs during the breeding season (Figure 2.9). This same male completed a second dispersal later in the breeding season and traveled 48.7 km over 42 hrs to Santee Coastal Reserve WMA. The next farthest dispersal was by a hatch year male (GA 18) who traveled from Altamaha WMA to St Johns River in Jacksonville, FL, before moving northwest over 44 hrs to Waverly, GA. We observed GA 03, an after-hatch year female, disperse to Florida, moving 109 km from Altamaha WMA to ponds in a suburban community of Jacksonville over 102 hours. The last dispersal we observed was from a hatch year male (GA 11) who traveled 52.6 km over

12 hrs 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 (GA 13, GA 31), traveling 183.3 and 131.8 km one way from the Altamaha to Savannah, over 42 and 18 hrs, respectively, during the molt season. Later in the molt season, GA 31 moved 183.3 km round trip from Savannah to Bear Island WMA in South Carolina over 102 hrs. An after-hatch year male (GA 02), moved 176.2 km from the Altamaha to Nemours Wildlife Foundation Plantation over 62 hrs. Lastly, GA 30, a hatch year male, traveled straight-line distance of 187.9 km over 48 hrs to Lulu, Florida, before being found dead (Figure 2.10). The single long-distance movement during teal season was by GA 26, an after-hatch year female, who moved 31.4 km from the Altamaha to Black Beard Creek over 1.75 days, at which point the transmitter ceased reporting and status of the bird was unknown. Although not a focus of our work, we documented known fates of some marked birds; 4 birds captured in Georgia were harvested by hunters during the 2014 – 2015 waterfowl season, and GA 16, an after-hatch year female, was recaptured in 2016 without a transmitter. No birds captured in South Carolina were reported by hunters or recovered in the field.

DISCUSSION

We documented space use and movements of mottled ducks in Georgia and South Carolina. Prior to this work, there was limited understanding of movements through band return data and no information regarding space use for this species outside of Florida and the WGC. We found that mean range size across seasons varied from 2002 – 4598 ha, whereas mean core areas ranged from 379 – 969 ha. Using a similar estimation method, Varner et al. (2014) found urban dwelling mottled ducks in Florida maintained 232 – 598 ha annual ranges, whereas rural individuals maintained 32,573 – 88,101 ha annual ranges. Hence, our range estimates were larger than for urban Florida birds and smaller than birds located in rural areas. Our estimates were similar to Moon (2014), who found mean home ranges were 6,566 ha and mean core areas were 1,516 ha. Both Moon (2014) and Varner et al. (2014) noted considerable variation among individuals, which we also observed.

When using MCPs, we documented highly variable space use across individual birds. Specifically, we noted that 4 birds had especially small range estimates (GA 18, GA 27, GA 29, GA 33; see Table 2.1). Of these birds, all were captured and monitored during the molt season and one hatch year female (GA 27) was caught before her flight feathers had developed. The remaining 3 individuals were captured in 2016 in the same wetland, and their movements were highly localized excepting 1 to 3 locations where each individual left the one impoundment and went elsewhere before returning. Because we calculated 95% MCPs, these few points were excluded from analysis, resulting in very small MCP estimates. Additionally, we removed locations associated with a long-distance movement by GA 18 when he abandoned his localized range and moved to Florida, before traveling to inland Georgia. We acknowledge these 4 ranges appear as outliers, but we offer that they demonstrate how little mottled ducks may move within the molting season.

We examined movements of PTT-100 marked birds (Georgia) and SGSM marked birds (South Carolina) separately, as the PTT-100 recorded 4 locations per day whereas the SGSM units collected locations dynamically based on available battery. We assumed that the increase in data provided by SGSM units would better describe individual movements. However, we noted similar movements between transmitter type, although birds captured in Georgia and marked with PTT-100 transmitters tended to exhibit greater mean movements. During teal season, we documented birds captured in Georgia moving a mean of 5.7 km/day whereas birds captured in South Carolina moved 4.8 km/day, a difference of only 0.9 km/day. The greatest difference we observed was during the breeding season, in which birds captured in Georgia moved 11.3 km/day and birds captured in South Carolina moved 5.6 km/day. We suspect this observed difference was due to sample size rather than any biologically relevant differences in bird behavior; we only monitored 3 individuals in Georgia during breeding (1 was male) whereas all birds monitored in South Carolina birds during breeding were female. In an analysis similar to ours, Moon (2014) documented mottled ducks on the Texas Chenier Plain traveled an average of 2.72 km/week, which was considerably lower than our estimates. This difference was likely due to how data were collected, as Moon (2014) used satellite telemetry with a duty cycle that limited relocations, and likely underestimated distances moved.

We documented birds from both states completing excursions outside their seasonal ranges. The longest excursion was 44 hrs, with a mean duration of 18 hrs (SE = 1.6), indicating that although these birds did leave their ranges, they did so infrequently and for brief time periods. Excursions have been documented in other avian species, such as the common buzzard (*Buteo buteo*; Hodder et al. 1998), but the underlying factors influencing excursions are poorly understood. White-tailed deer (*Odocoileus virginiaus*) are known to make excursions during all seasons of the annual cycle (Beier and McCullough 1990, Kolodzinski et al. 2010, Simoneaux 2015, Jacobsen 2017). Numerous explanations have been offered for these movements, ranging from finding mates, food, minerals, and refugia to pre-dispersal exploration (Hölzenbein and Marchinton 1992, Karns et al. 2011). We documented an adult female (SC 250) make an excursion 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.

Most mottled ducks in Florida and Texas were recovered within 56.5 and 78.9 km of their banding sites, respectively (Baldassarre 2014). 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 (unpublished data). Being that most movements were between Georgia and South Carolina, we assume South Carolina is the source of mottled ducks currently found in Georgia. Additionally, with the volume of movements we saw between the states, Georgia and South Carolina likely hold one larger population of mottled ducks, rather than 2 separate populations as previously thought.

The long-distance movements and dispersals completed by birds captured in Georgia have implications for managers charged with managing habitats for mottled ducks. After documenting movements similar to ours, Moon (2014) speculated that dispersal and long distance movements were related to resource availability. Similarly, Stutzenbaker (1988) stated that mottled ducks could travel up to 400 km during droughts to find ideal molting habitat. While we did not see movements of that distance, we only saw dispersal and long distance movements 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 (See Chapter 3). Managed wetlands are limited in coastal Georgia, potentially forcing individuals to complete dispersal and long distance movements in search of suitable habitat.

MANAGEMENT IMPLICATIONS

Movements indicated that South Carolina and Georgia likely have one continuous population of mottled ducks. Based on this, we suggest SCDNR and GADNR work cooperatively on future research projects and openly communicate about changes in species management and regulations, as the actions of one agency could affect mottled ducks inhabiting both states. Additionally, the long-distance movements we documented may have been triggered by a lack of habitat in Georgia. Increasing the amount of available habitat near the Altamaha WMA and across coastal Georgia, would likely reduce the number of dispersal and long distance movements from Georgia into South Carolina or Florida.

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Table 2.1. Minimum convex polygon (MCP) area, number of locations used to generate the MCP, and days tracked for all mottled ducks outfitted with PTT-100 22 g Solar Argos/GPS (PTT-100) in Georgia and 25 g GPS/GSM Solar (SGSM) transmitters in South Carolina with ≥ 26 days of data during 2013 – 2016.

Duck ID	MCP area (ha)	Days tracked	Location count
GA 01	4455	57	238
GA 02	3983	126	499
GA 03	3906	172	691
GA 04	3228	81	335
GA 05	2482	81	333
GA 06	700	171	402
GA 07	1954	216	461
GA 08	713	105	305
GA 09	1205	72	205
GA 10	7334	172	448
GA 11	3139	158	385
GA 12	359	81	334
GA 13	591	143	455
GA 14	12046	134	380
GA 15	8543	235	809
GA 16	4123	354	857
GA 17	2543	230	541
GA 18	21	47	199
GA 19	7510	127	491
GA 24	4137	26	112
GA 25	1038	56	144
GA 26	412	34	137
GA 27	36	32	74
GA 28	871	75	193
GA 29	8	42	175
GA 31	6356	42	164
GA 33	11	33	143
GA 35	1391	42	175
SC 236	11233	638	39581
SC 238	1741	343	57303
SC 239	143	57	894

SC 241	104	40	1024
SC 242	301	310	7339
SC 244	6733	416	33600
SC 247	7505	330	22157
SC 249	1336	69	1967
SC 250	3509	291	10172
SC 253	1794	178	11314

Table 2.2. Seasonal range and core area sizes for mottled ducks outfitted with PTT-100 22 g Solar Argos/GPS (PTT-100) in Georgia or 25 g GPS/GSM Solar (SGSM) units in South Carolina that recorded data for ≥ 50% of the season from 2013 – 2016. Age is indicated by after-hatch year (AHY) or hatch year (HY). Season is indicated by molt (M, 01 JULY – 09 SEPT), teal (T, 10 SEPT – 19 NOV), hunt (H, 20 NOV – 31 JAN), and breed (B, 01 FEB – 30 JUNE).

Duck ID	Entire (ha)	SE	Core (ha)	SE	Year	Age	Sex	Season
GA 01	2725	-	242	-	2016	HY	M	M
GA 03	273	-	41	-	2016	AHY	F	M
GA 04	1273	-	149	-	2016	HY	M	M
GA 05	3458	-	350	-	2016	HY	F	M
GA 07	1584	-	217	-	2015	HY	F	M
GA 10	12024	-	2776	-	2015	HY	F	M
GA 11	6706	-	1498	-	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	1504	-	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
Mean	2002	789	379	183	-	-	-	M
GA 02	14054	-	1831	-	2014	AHY	M	T
GA 03	996	-	129	-	2016	AHY	F	T
GA 04	2071	-	471	-	2016	HY	M	T
GA 05	2685	-	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	1662	-	428	-	2015	HY	F	T
GA 11	264	-	54	-	2015	HY	M	T
GA 12	3432	-	632	-	2016	AHY	F	T
GA 13	270	-	47	-	2014	HY	M	T
GA 14	4945	-	1037	-	2014	HY	M	T

GA 15	1301	-	174	-	2014	HY	M	T
GA 17	4787	-	1079	-	2014	HY	M	T
GA 19	2952	-	485	-	2014	HY	M	T
SC 236	7388	-	1737	-	2014	AHY	F	T
SC 238	24812	-	5646	-	2013	AHY	F	T
SC 242	2014	-	400	-	2014	AHY	F	T
SC 244	3414	-	552	-	2014	AHY	F	T
SC 247	4466	-	876	-	2014	AHY	F	T
SC 250	700	-	80	-	2015	AHY	F	T
SC 253	3916	-	833	-	2014	AHY	F	T
Mean	4001	1190	789	255	-	-	-	T
GA 06	337	-	61	-	2015	AHY	F	H
GA 11	257	-	42	-	2015	HY	M	H
GA 16	4266	-	903	-	2014	HY	M	H
GA 15	1169	-	237	-	2014	HY	M	H
GA 13	1176	-	295	-	2014	HY	F	H
SC 236	1479	-	281	-	2013	AHY	F	H
SC 238	1692	-	380	-	2013	AHY	F	H
SC 244	1438	-	240	-	2014	AHY	F	H
SC 247	12464	-	1951	-	2014	AHY	F	H
SC 250	513	-	71	-	2015	AHY	F	H
Mean	2479	1166	446	185	-	-	-	H
GA 03	5610	-	740	-	2015	AHY	F	B
GA 16	1301	-	174	-	2016	AHY	F	B
SC 236 (2014)	13220	-	2981	-	2014	AHY	F	B
SC 236 (2015)	1780	-	359	-	2015	AHY	F	B
SC 238	769	-	110	-	2014	AHY	F	B
SC 242	356	-	74	-	2015	AHY	F	B
SC 244	2218	-	335	-	2015	AHY	F	B
SC 247	15276	-	3782	-	2015	AHY	F	B
SC 250	856	-	163	-	2016	AHY	F	B
Mean	4598	1902	969	466	-	-	-	B

Table 2.3. Excursions, outside seasonal ranges, by mottled ducks outfitted with PTT-100 22 g Solar Argos/GPS (PTT-100) in Georgia or 25 g GPS/GSM Solar units (SGSM) in South Carolina. Age is indicated by after-hatch year (ahy) or hatch year (hy). Season is indicated by molt (M, 01 JULY – 09 SEPT), teal (T, 10 SEPT – 19 NOV), hunt (H, 20 NOV – 31 JAN), and breed (B, 01 FEB – 30 JUNE).

Duck ID	Date initiated	Date finished	Season	Distance (km)	Duration (hrs)	Age	Sex
GA 04	8/26/2016 18:00	8/27/2016 18:00	M	24.3	24	HY	M
GA 05	8/17/2016 4:00	8/17/2016 22:00	M	26.3	18	HY	F
GA 07	8/5/2015 10:00	8/6/2015 10:00	M	22	24	HY	F
GA 10	8/14/2015 10:00	8/15/2015 18:00	M	139.5	32	HY	F
SC 250	8/30/2015 0:01	8/30/2015 11:31	M	10.4	12	AHY	F
SC 250	8/24/2015 22:34	8/25/2015 11:42	M	12.7	13	AHY	F
GA 02	9/15/2014 22:00	9/16/2014 18:00	T	12.4	20	AHY	M
GA 11	9/9/2015 22:00	9/10/2015 18:00	T	8.2	20	HY	M
GA 13	9/15/2014 22:00	9/16/2014 18:00	T	21.5	20	HY	M
GA 14	9/20/2014 4:00	9/20/2014 22:00	T	8.7	18	HY	M
GA 15	10/13/2014 2:00	10/13/2014 22:00	T	28.7	20	HY	M
SC 247	9/22/2014 22:45	9/23/2014 11:48	T	13.9	13	AHY	F
SC 253	9/22/2014 23:19	9/23/2014 11:30	T	5	12	AHY	F
SC 236	12/23/2013 21:34	12/25/2013 17:37	H	9.4	44	AHY	F
GA 16	2/8/2015 5:00	2/9/2015 5:00	B	20.2	24	AHY	F
SC 236	6/23/2015 21:23	6/24/2015 10:58	B	11.9	14	AHY	F
SC 242	3/5/2015 6:45	3/5/2015 17:51	B	5.8	11	AHY	F
SC 247	5/17/2015 23:34	5/18/2015 11:33	B	20.7	12	AHY	F
SC 250	4/2/2016 22:50	4/3/2016 8:42	B	16.5	10	AHY	F
SC 250	3/13/2016 23:35	3/14/2016 11:35	B	19.9	12	AHY	F
SC 250	4/8/2016 23:15	4/9/2016 13:17	B	24.8	14	AHY	F

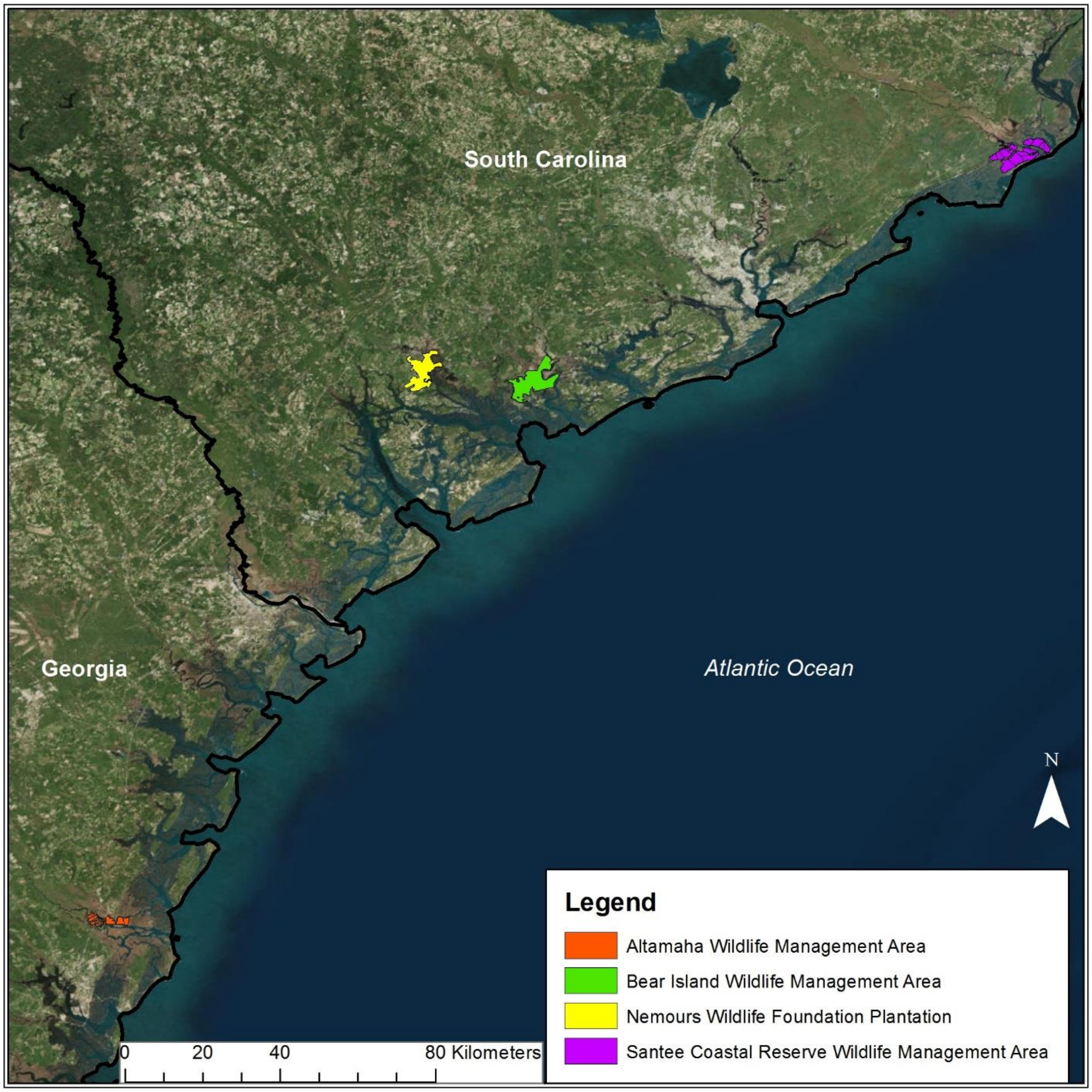


Figure 2.1. Capture sites for mottled ducks 2013 – 2016 Georgia and South Carolina, including Altamaha Wildlife Management Area (WMA), Bear Island WMA, Nemours Wildlife Foundation Plantation, and Santee Coastal Reserve WMA.

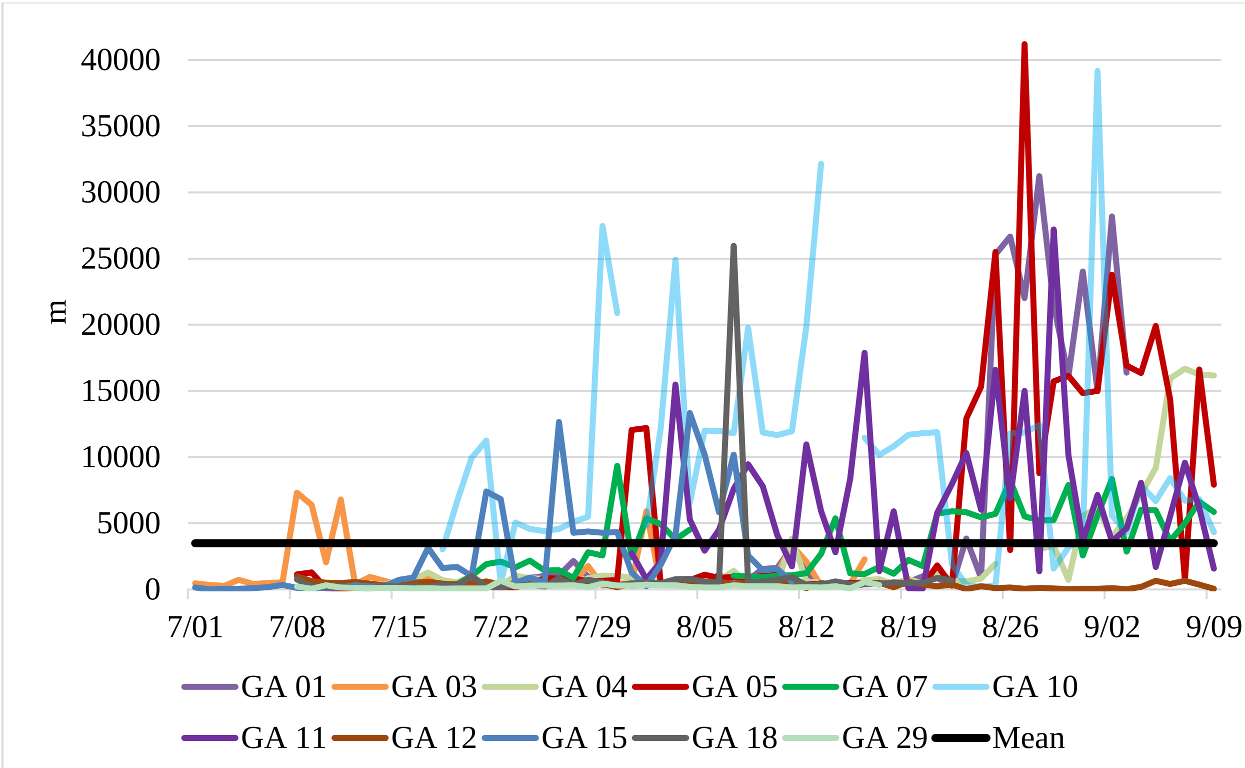


Figure 2.2. Total daily distance moved per day by mottled ducks captured in Georgia from 2014 – 2016 during the molt season (01 July – 09 September). Mean distance was 3.5 km/day (SE = 0.3).

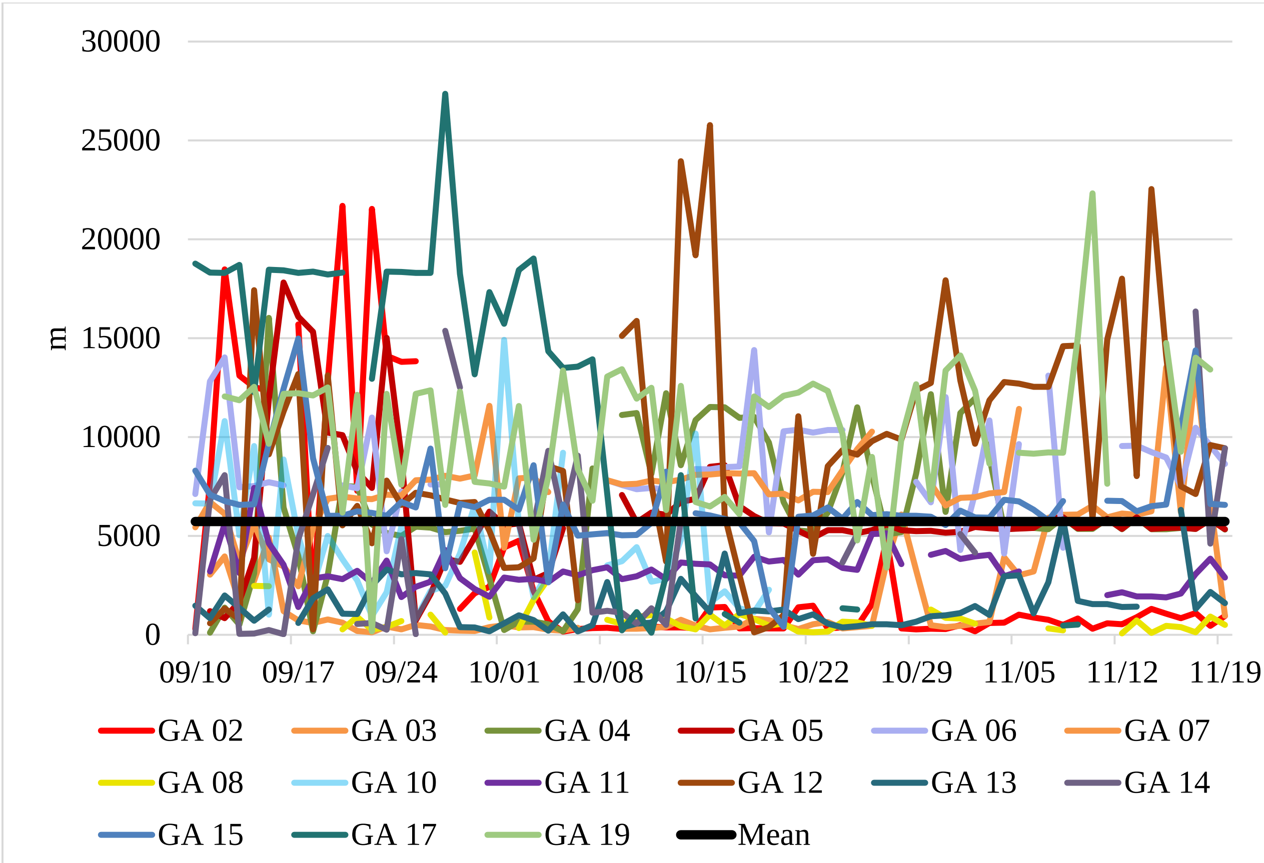
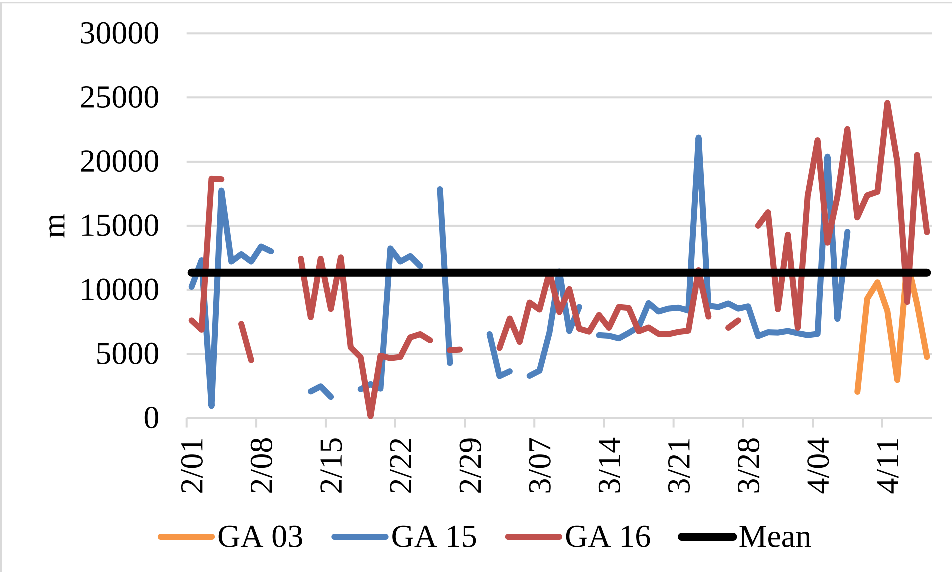


Figure 2.3. Total daily distance moved per day by mottled ducks captured in Georgia from 2014 – 2016 during the teal season (10 September – 19 November). Mean distance was 5.7 km/day (SE = 0.2).

A.



B.

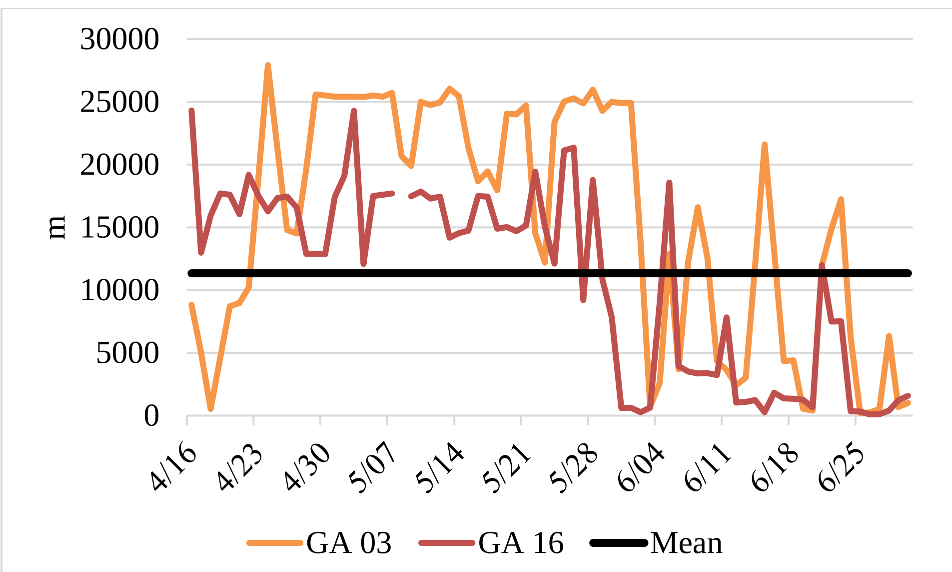


Figure 2.4. Total daily distance moved per day by mottled ducks captured in Georgia from 2014 – 2016 during breeding season, separated into early (A; 01 February – 15 April) and late breeding season (B; 16 April – 30 June). Mean distance was 11.3 km/day (SE = 0.4).

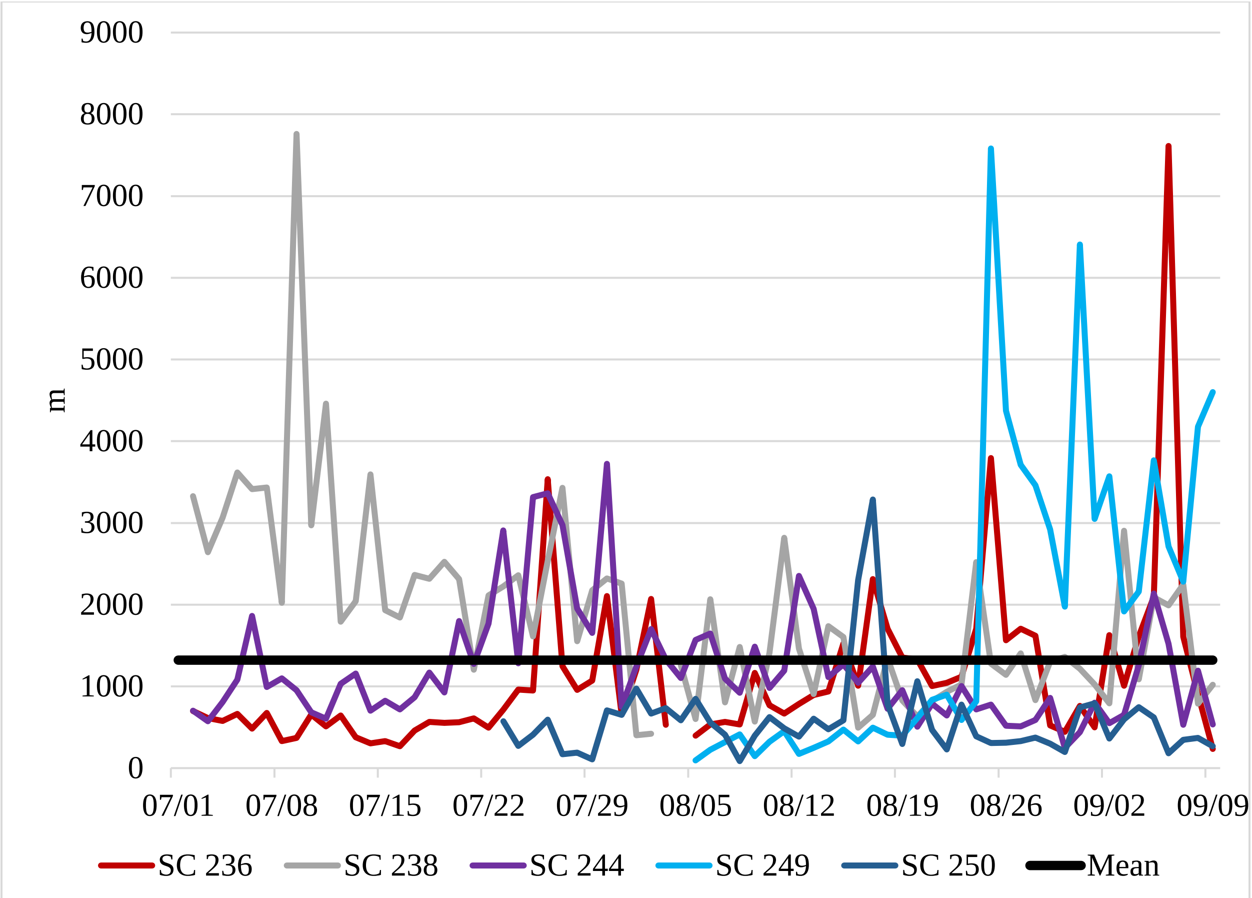


Figure 2.5. Total daily distance moved per day by mottled ducks captured in South Carolina from 2013 – 2016 during the molt season (01 July – 09 September). Mean distance was 1.3 km/day (SE = 0.1).

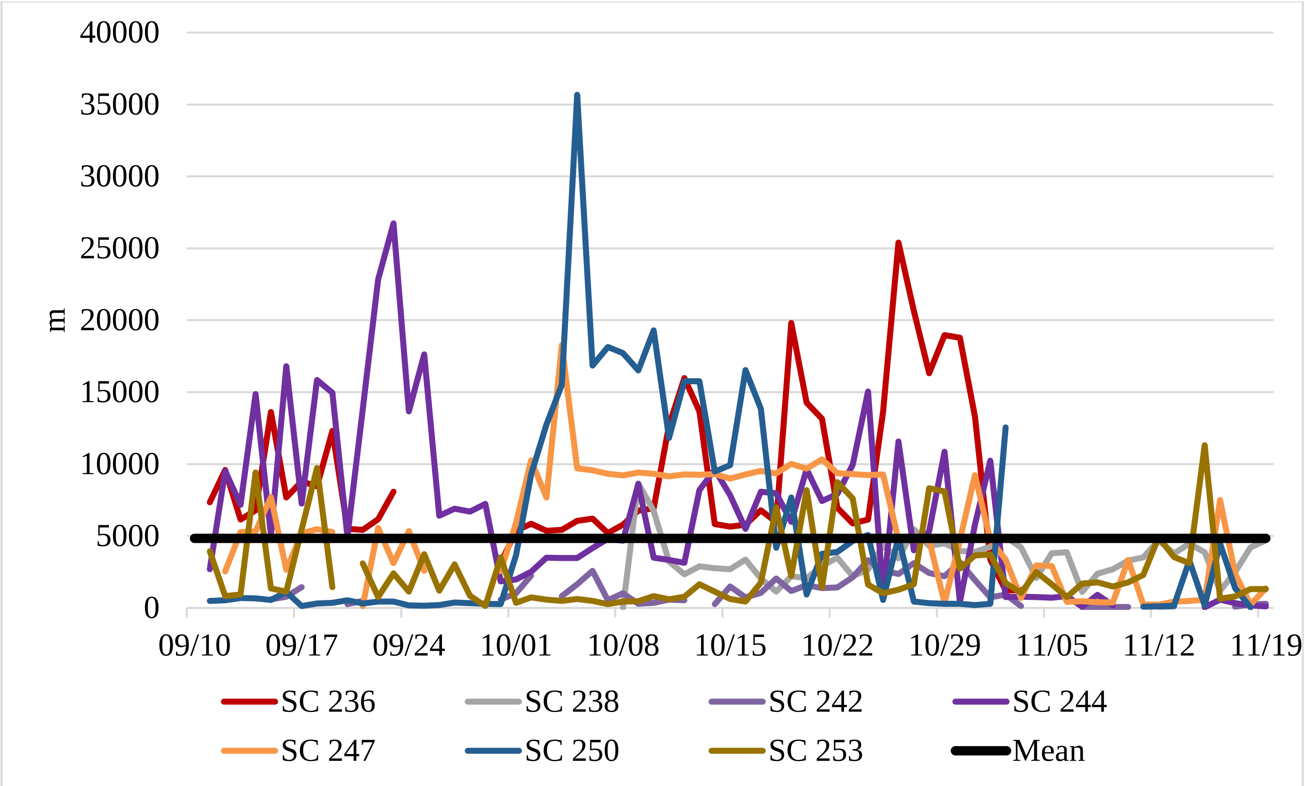


Figure 2.6. Total daily distance moved per day by mottled ducks captured in South Carolina from 2013 – 2016 during teal season (10 September – 19 November). Mean distance was 4.8 km/day (SE = 0.3).

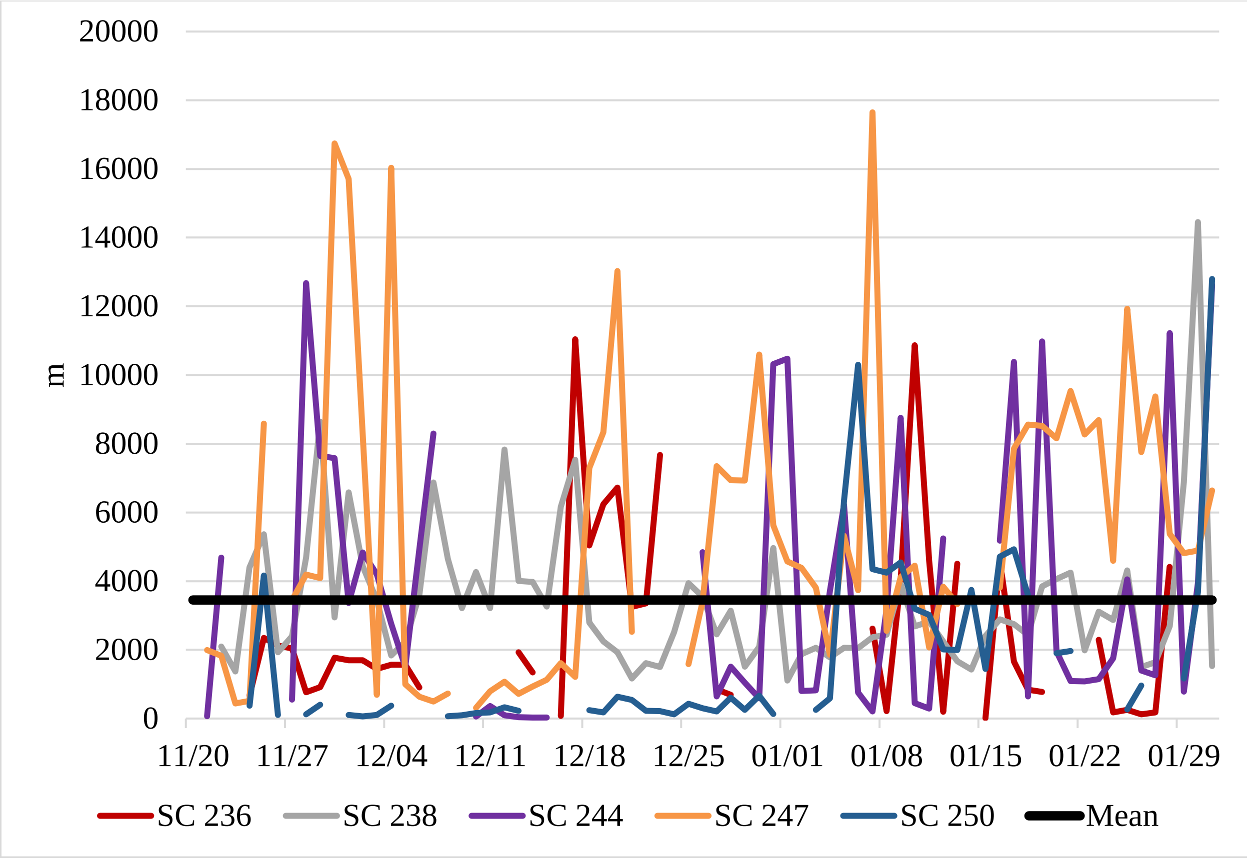
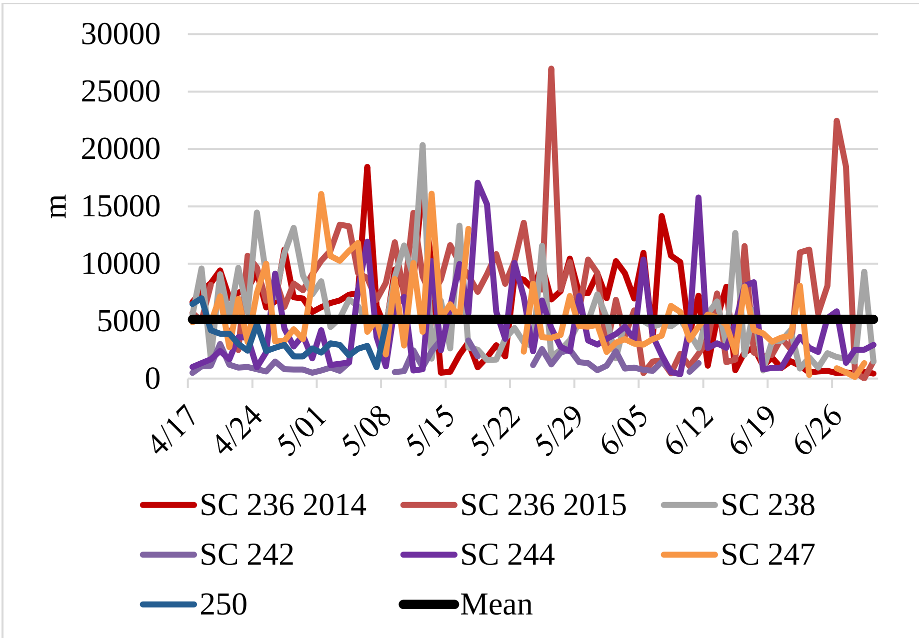


Figure 2.7. Total daily distance moved per day by mottled ducks captured in South Carolina from 2013 – 2016 during the general hunting season (20 November – 31 January). Mean distance was 3.5 km/day (SE = 0.2).

A.



B.

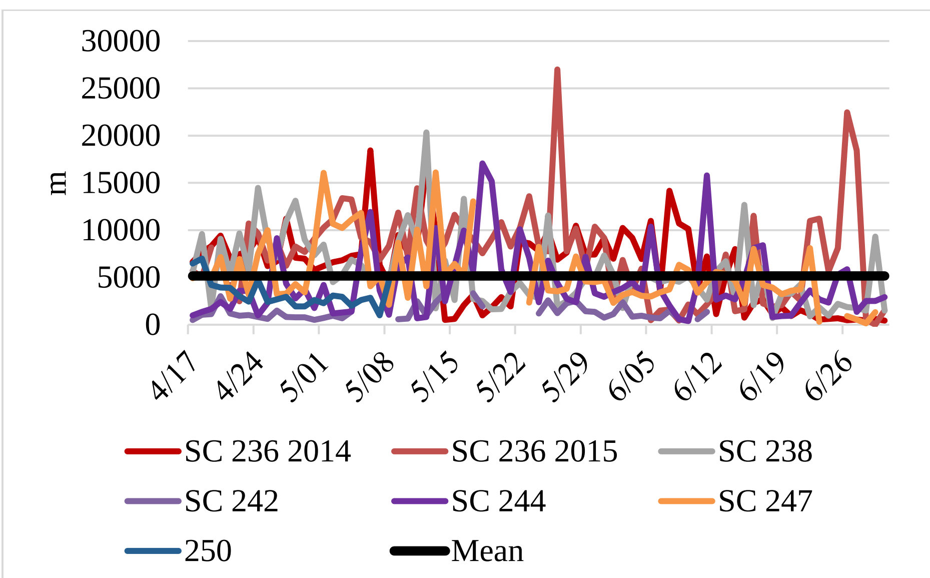


Figure 2.8. Total daily distance moved per day by mottled ducks captured in South Carolina from 2013 – 2016 during breeding season, separated into early (A; 01 February – 15 April), and late breeding season (B; 16 April – 30 June). Mean distance was 5.6 km/day (SE = 0.2).

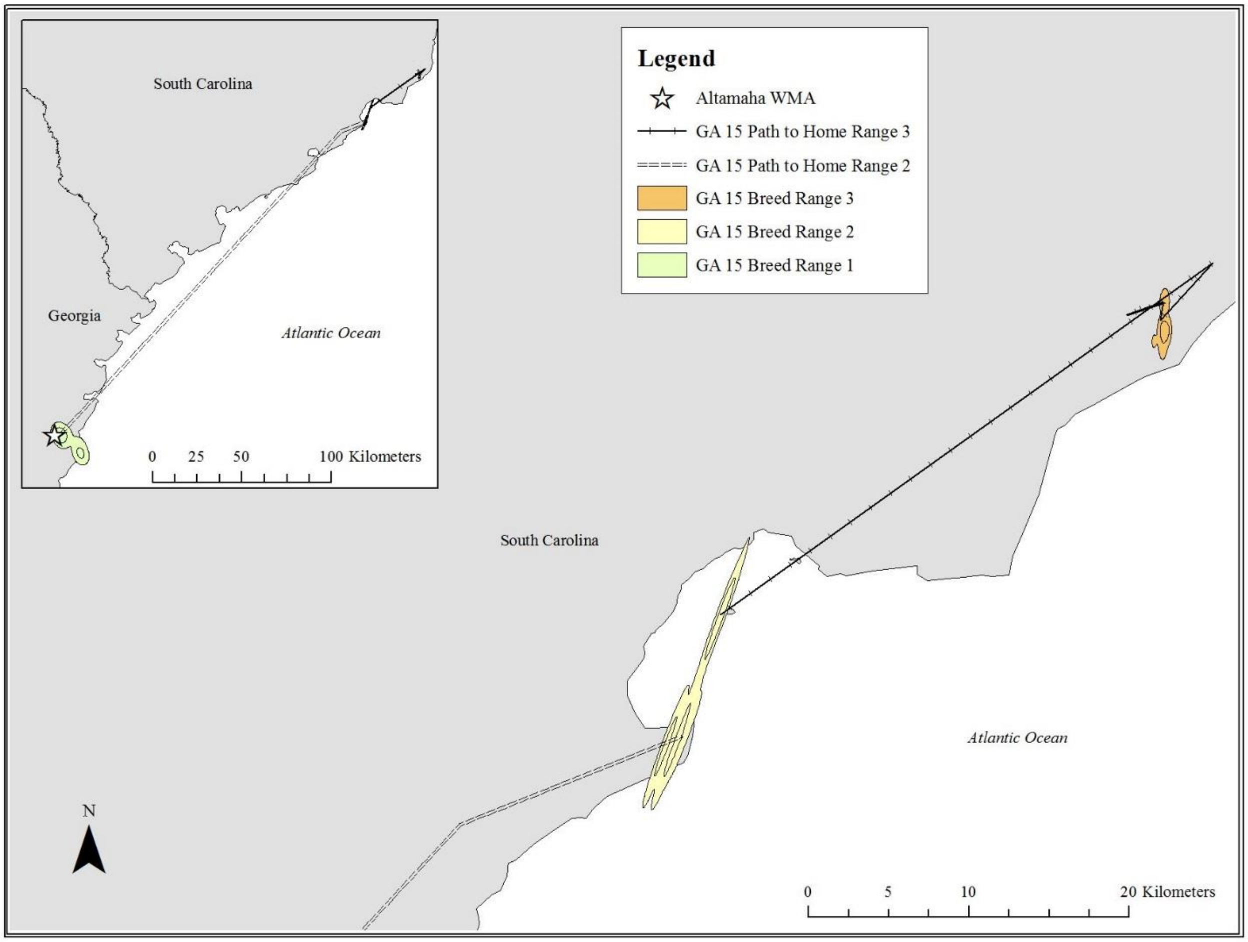


Figure 2.9. Home ranges and dispersals documented for individual GA 15, an after-hatch year male mottled duck outfitted with a PTT-100 22 g Solar Argos/GPS (PTT-100) transmitter during the breeding season (01 FEB – 30 JUNE) of 2015. The dispersal from breed range 1 to breed range 2 took 20 hours and 245.8 km. The dispersal from breed range 2 to breed range 3 took 42 hours and 48.8 km.

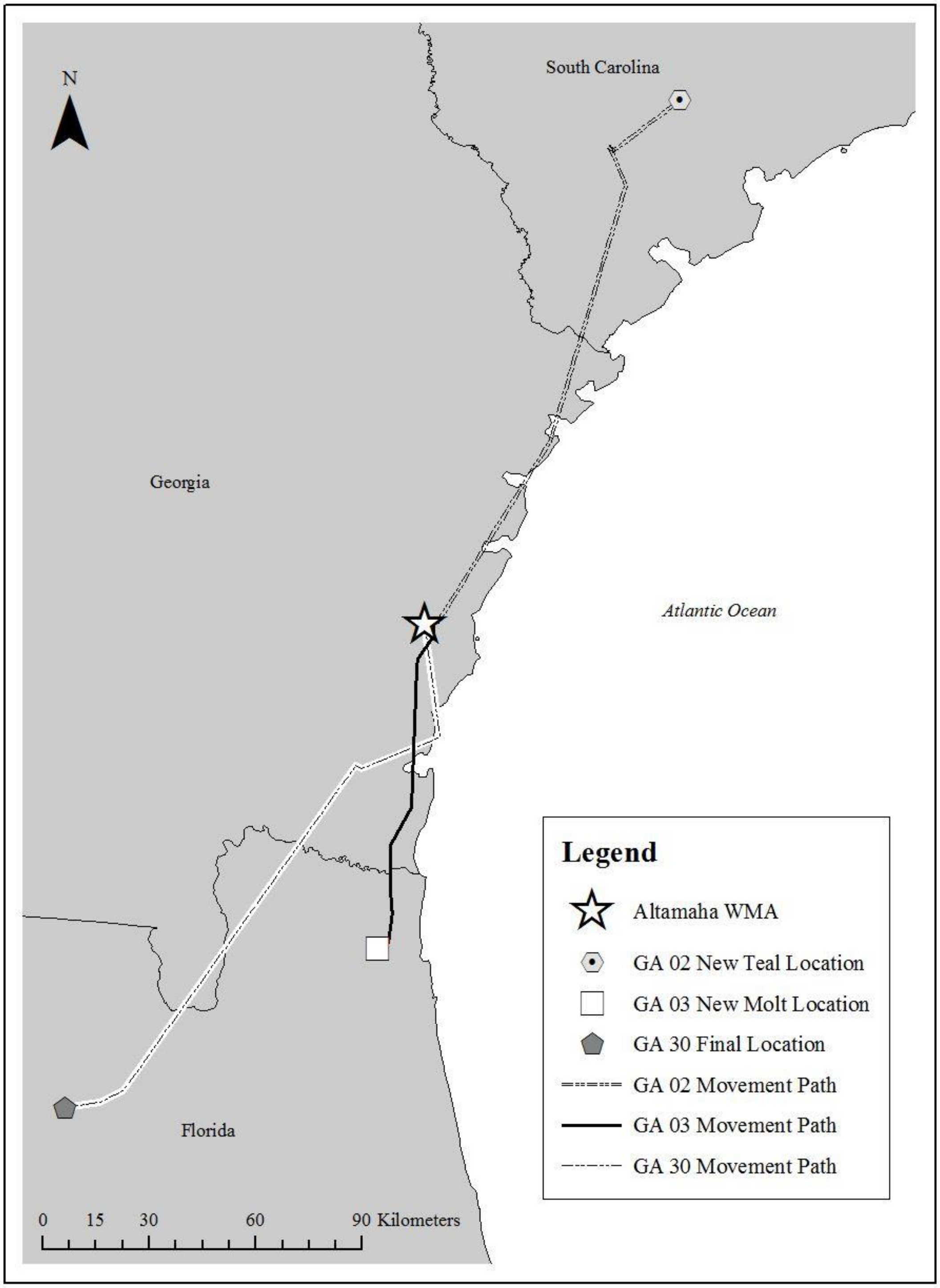


Figure 2.10. Various dispersal and long-distance movements documented from mottled ducks originally captured on Altamaha Wildlife Management Area (WMA), Darien, GA, USA from 2014 – 2016.

CHAPTER 3

HABITAT SELECTION OF MOTTLED DUCKS IN SOUTH CAROLINA AND GEORGIA[1]

1. Pollander, K. M., A. R. Little, G. D. Balkcom, and M. J. Chamberlain. To be submitted to *Journal of Wildlife Management.*

ABSTRACT

Managed wetland impoundments of Georgia and South Carolina are important to migrating waterfowl and shorebirds. Although management of these wetlands has focused on providing habitat for wintering waterfowl, non-native, resident mottled ducks (*Anas fulvigula*) also use these wetlands throughout the annual cycle. Previous research in South Carolina identified water depths < 25 cm and brackish managed impoundments as important across all seasons. Mottled ducks banded in Georgia are known to use habitats in South Carolina, and to date no research has been conducted documenting habitat selection by mottled ducks in Georgia. Hence, our objectives were to document habitat use at multiple spatial scales for mottled ducks in South Carolina and Georgia during 2013 – 2016. We found that mottled ducks selected managed impoundments and palustrine wetlands at the study area scale. During breeding (Feb 1 – June 30), molt (July 1 – Sept 9), teal (Sept 10 – Nov 19), and general hunting seasons (Nov 20 – Jan 31), mottled ducks selected for managed impoundments and against palustrine emergent marshes during breeding and teal seasons. During molt season, palustrine emergent marshes were selected for whereas estuarine emergent marshes were selected against. Managed impoundments were important to mottled ducks at both spatial scales we assessed, but were limited to 4 river systems along coastal Georgia and South Carolina. We observed that considerable portions of coastal habitats in both states were essentially unused. To increase available habitat for mottled ducks, we suggest agencies create and manage impoundments throughout coastal areas of both states, focusing efforts around the Altamaha, Savannah, ACE, and Santee river systems where we documented use.

INDEX WORDS: mottled duck, *Anas fulvigula*, Georgia, South Carolina, habitat, managed impoundment

INTRODUCTION

The wetlands of coastal South Carolina historically provided important habitat for wintering and migrating waterfowl and shorebirds (Tomkins 1986, Weber and Haig 1996, Gordon et al. 1998). Between 1954 and 1987, approximately 30% of dabbling ducks migrating in the Atlantic Flyway wintered in South Carolina (Gordon et al. 1989). Specifically, managed wetland impoundments were important as they provided diverse salinities and food resources, unlike those available in natural marshes (Shipes 2014). Historically, these wetlands produced rice (*Oryza* spp.), but with the disappearance of the industry, management focused on providing wintering waterfowl habitat and hunter opportunity (Gordon et al. 1989). Although frequently managed to provide habitat for wintering waterfowl, resident and regional migrants, such as the wood duck (*Aix sponsa*), mottled ducks (*Anas fulvigula*), and black-bellied whistling-ducks (*Dendrocygna autumnalis*), also benefit from these managed wetlands (Gordon 1998, Shipes et al. 2015).

The mottled duck is a non-migratory species found in 2 distinct populations along the Western Gulf Coast (WGC) and peninsular Florida (Stutzenbaker 1988, Bielefeld et al. 2010). In native portions of its range, mottled ducks are known to 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, Moon 2014, Haukos et al. 2010). In Florida, mottled ducks 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).

A third mottled duck population was established by the South Carolina Department of Natural Resources (SCDNR), who released 1,285 individuals in coastal South Carolina between 1975-1983 (Shipes 2014, Kneece 2016). Recent estimates (2009-2011) put the mottled duck population at 23,000 individuals (Kneece 2016). With that expansion, individuals have been consistently found in coastal Georgia since the mid-1990s (Georgia Department of Natural Resources [GADNR] unpublished data). Although habitat use is understood in Florida and the WGC, there is a lack of information available for mottled ducks in South Carolina and Georgia. Notably, coastal areas 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, and saltmarshes (SCDNR 2017). Additionally, tidal influences can range from 1.4 m – 2.4 m (NOAA 2017*a, b*) in comparison to the Gulf Coast, which experiences < 1 m tides (Dardeu et al. 1992).

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. Habitat conditions across coastal Georgia and South Carolina are highly variable, therefore a more detailed assessment of habitat use by mottled ducks at broader spatial scales is warranted. Therefore, our objectives were to evaluate habitat selection at multiple spatial scales, giving land managers and natural resource agencies a more extensive understanding of mottled duck habitat requirements.

STUDY AREA

In Georgia, we captured mottled ducks on the Altamaha WMA and surrounding marshes and islands owned by GADNR. 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 (Figure 2.1, GADNR 2016). The intensively managed wetland impoundments 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 plants and salinities helped fulfill management objectives of providing quality wintering habitat to migratory waterfowl and waterfowl hunting opportunities to the public. Being the only actively managed wetlands in coastal Georgia, the Altamaha was frequently considered the best waterfowl hunting in the state (GADNR 2014). Additionally, coastal Georgia boasts 160 km of coastline and 153,000 ha of saltmarsh and is considered one of the most extensive and productive natural marsh systems in the United States (NOAA 2016).

In South Carolina, mottled duck capture occurred on public and private lands in the Ashepoo, Combahee, Edisto (ACE) and Santee River Basins. This capture was conducted by staff of Nemours Wildlife Foundation in cooperation with SCDNR. Lands targeted in the Santee River Basin were 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 and 805 ha of managed wetland impoundments, respectively.

METHODS AND MATERIALS

Field Methods

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 by night lighting from an airboat in managed wetland impoundments of the Altamaha WMA (Merendino and Lobpries 1998). Additionally, a net gun deployed from a helicopter was used to capture mottled ducks during 11 – 14 August 2015 (Dragonfly Aviation, Laredo, Texas, 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 by night lighting from an airboat (Federal Bird Banding Permit 23417).

Once captured mottled ducks were aged, sexed, weighed, and outfitted with a USGS aluminum band. We fitted individuals captured in Georgia with a mass > 750 g with a PTT-100 22 g Solar Argos/GPS transmitter, whereas those captured in South Carolina were outfitted with the 25 g GPS/GSM Solar transmitters (Microwave Telemetry, Inc., Columbia, Maryland, USA; Caccamise and Hedin 1985). Transmitters were attached using 4.8 mm wide braided Teflon tape (Bally Ribbon Mills, Bally, Pennsylvania, USA; sold as 3/16") and cyanoacrylate glue, using methodology akin to Miller et al. (2005). Once outfitted, individuals were promptly released onto the wetland where they were captured.

The PTT-100 22 g Solar Argos/GPS (henceforth PTT-100) recorded 4 locations per day on a seasonal schedule. The units recorded locations at 0000, 0800, and 1200 hrs, year-round. Evening locations were recorded at 1600 hours from 1 October – 30 April, and at 1800 hrs from 1 May – 30 September. Locational data recorded by PTT-100s were uploaded to the Argos satellite every third day (CLS America Inc., Lanham, Maryland, USA) and made available online. Once available, we downloaded data from the CLS America website. We processed these files using the Argos-GPS Parser software (Microwave Telemetry, Inc., Columbia, Maryland, USA). Additionally, the PTT-100 was outfitted with a UHF signal, allowing for real time tracking of marked individuals.

The 25 g GPS/GSM Solar (henceforth SGSM) transmitters recorded GPS locations dynamically based on available battery voltage. According to the manufacturer, fully charged units exposed to the sun could record a location every minute; at night, the units could record a location every 30 minutes to 4 hours. Data were uploaded once daily via Groupe Spécial Mobile (GSM) wireless networks. Individual units could store up to 258,000 locations onboard. When a unit was outside GSM coverage, data were stored onboard until the unit returned to an area of coverage. All new and previously recorded locations were uploaded daily. Once transmitted, data were made available by email. If the PTT-100 and the SGSM transmitters were unable to record a location and the battery was not depleted, the date, time, and an error reading indicating the reason for the missed fix were reported. If either transmitter type was unable to record a location due to insufficient battery power, either battery drain or low voltage errors were reported.

Statistical Methods

We filtered GPS data to remove locations outside the study areas, where altitudes were > 1000 m, and that were associated with an error reading. Data recorded by the SGSM units were further filtered using speed between subsequent locations; we removed all locations with a speed > 10 km/hr as we believed these locations were a result of GPS error. Although this filter likely removed valid locations (i.e. in flight locations), we only filtered 2% of locations using this approach.

We calculated 100% minimum convex polygons (MCP) around used locations in the Altamaha, Savannah, ACE, and Santee River basins to estimate available habitat. We chose this approach because most of the South Carolina and Georgia coasts were not used by our marked sample and < 2% of locations were outside these MCPs. To assess seasonal habitat selection, 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 (Feb 1-June 30), molt/post-breeding (July 1-Sept 9), teal hunting season (Sept 10-Nov 19), and general hunting season (Nov 20-Jan 31). Teal and general hunting seasons were based on the earliest opening date for those respective hunting seasons from 2013-2016. We based seasonal habitat availability on an individual's seasonal home range estimate, which was calculated using 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), and error rate of 15 m for PTT-100 and the SGSM units (see Chapter 4). Transmitters must have recorded a location on ≥ 50% of the days in the season for a seasonal range to be calculated. We used full datasets from SGSM marked individuals to calculate seasonal ranges because AKDEs are insensitive to sampling schedule and autocorrelation in the data (see Chapter 2, Fleming et al. 2015). However, to assess habitat selection within ranges (see below), we standardized datasets to 4 locations per day collected within 2 hours of when PTT-100 units recorded locations, producing comparable datasets suitable for modeling.

We used Coastal Change Analysis Program (C-CAP, NOAA 2010) land cover data and National Agriculture Imagery Program (NAIP, USDA 2016) aerial imagery in ArcMap 10.4 (ESRI, Redlands, CA) 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 visually identify and create a vector layer of managed wetland impoundments (hereafter impoundments) in coastal South Carolina and Georgia. Marsh was identified 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. The impoundment layer was then incorporated with the C-CAP data into a 30-m resolution raster. We then used the Euclidean distance tool in ArcMap 10.4 (ESRI, Redlands, CA, USA) 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 habitat types selected by mottled ducks at the 2^{nd} order (study area scale) and 3^{rd} order (within the home range; Johnson 1980), following Design II and III described by Manly et al. (2002). At the study area scale, we evaluated available non-random habitat selection with a ratio of 1 random point for each used location within the MCP. Within the seasonal home range, we characterized habitat availability using 3 random locations for each used location. We then extracted distance to habitat variables for all used and random locations using ArcMap 10.4. We used generalized linear mixed effect models in program R to evaluate habitat selection with a use versus availability framework (Manly et al. 2002). We categorized used and available locations as binary, where a used location was assigned 1 and available (random) locations were assigned 0. Due to uneven sampling rates, we used duck identification number as a random effect in both 2^{nd} and 3^{rd} order models. Additionally, MCP location (Savannah, ACE, Santee, or Altamaha) was also incorporated as a random effect in 2^{nd} order models, but we were not interested in evaluating potential differences in habitat selection across these sites. Prior to analysis, we scaled all variables 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 observed correlation values $< |0.6|$ and VIF values remained < 1.3, hence we retained all variables. We then constructed full models for 2^{nd} and 3^{rd} order habitat selection separately. We assumed that habitat selection was variable across seasons due to inherent changes in mottled duck behavior during the annual cycle. Likewise, our sample of marked birds varied considerably across seasons, hence 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 assessed our models using *k*-fold cross validation (Boyce et al. 2002). In so doing, data were binned into *k* equally sized subsamples ($k = 10$) and *k* iterations of training and validation occurred, during which we withheld a different subsample of data for validation and used the remaining subsamples for training.

RESULTS

In Georgia, we captured and outfitted 35 mottled ducks with PTT-100 transmitters, collecting 11,297 GPS locations between 2014 – 2016. In South Carolina, 12 after hatch year females were outfitted with SGSM transmitters, which recorded 176,501 locations. After we standardized the datasets similar to PTT-100 units, we used 8,808 locations from ducks marked with SGSM units. We did not observe any significant correlations among variables, therefore we retained all in our subsequent models. Mean distances from used locations at all scales were closer to managed impoundments than at available locations (Table 3.1). At the study area scale, mottled ducks selected for managed impoundments ($\beta = -0.630$, $P < 0.001$, OR = 0.533) and palustrine emergent wetlands ($\beta = -1.186$, $P < 0.001$, OR = 0.306), but against estuarine emergent marshes ($\beta = 0.788$, $P < 0.001$, OR = 2.199, Table 3.2, Figure 3.2).

At the home range scale during the breeding season, we recorded sufficient data from 8 individuals, one of which was tracked for 2 breeding seasons, resulting in 9 seasonal ranges. Birds selected for impoundments ($\beta = -1.718$, $P < 0.001$, OR = 0.407) but against palustrine emergent wetlands ($\beta = 0.210$, $P < 0.001$, OR = 2.034). We found no difference in selection of estuarine emergent wetlands ($P = 0.234$, Table 3.3). We recorded sufficient locations to estimate 16 ranges during the molt season. Individuals selected against estuarine emergent wetlands ($\beta = 3.623$, $P < 0.001$, OR = 37.468) and for impoundments ($\beta = -0.359$, $P < 0.001$, OR = 0.699) and palustrine emergent wetlands ($\beta = -0.892$, $P < 0.001$, OR = 0.410). We recorded adequate data to estimate 21 ranges during teal season. Individuals selected for impoundments ($\beta = -1.134$, $P < 0.001$, OR = 0.322) and against palustrine emergent wetlands ($\beta = 0.967$, $P = < 0.001$, OR = 2.631). Selection of estuarine emergent marsh was not significant ($P = 0.185$). We recorded sufficient data to estimate ranges during general hunting season for 11 birds. Individuals selected for impoundments ($\beta = -0.461$, $P = 0.002$, OR = 0.631), whereas selection of estuarine emergent wetlands ($P = 0.894$) and palustrine emergent wetlands were not significant ($P = 0.084$).

Our *k*-fold cross validation correctly identified 64.2% of locations at the study area scale. At the home range scale, our models correctly identified 74.6%, 74.9%, 75.0%, and 75.5% for the breeding, molt, teal and general hunting seasons, respectively.

DISCUSSION

We used location data from GPS-transmitted mottled ducks in South Carolina and Georgia to model habitat use at the study area and seasonal home range scale. At both spatial scales, mottled ducks selected managed impoundments. We found that 72% of all locations recorded were in managed impoundments, indicating that mottled ducks rely heavily on this habitat. In comparison, we found that birds were 37 times less likely to select a location for every 2500 m closer to estuarine emergent wetlands during molt season. 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. Likewise, previous research has demonstrated 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). Notably, the MCPs we created that defined available habitat contained 74% of the 25,466 ha of managed impoundments we identified in coastal Georgia and South Carolina.

Hydrologic regimes and management schemes may influence use of impoundments by mottled ducks as water levels, vegetative communities, and salinities vary through time (Gordon et al. 1989). Weng (2006) noted that mottled ducks had been confirmed breeding at Savannah NWR since 1997, yet we only recorded 8 locations at that site. Conversely, we documented 1,077 locations (72% of all locations in the Savannah River basin) in the Confined Disposal Facility (CDF) of the Savannah Harbor. Because of this use, we classified the CDF units as managed impoundments, as they were functionally serving as a managed impoundment during our study (K. Pollander personal observation). In reality, 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 predicted these impoundments as potentially providing medium, medium-high, and high use habitats (Figure 3.3). If conditions of the CDF were changed, this habitat could be restricted or removed, limiting mottled duck habitat along the Savannah River, potentially causing birds to leave or use less suitable habitat.

In addition to managed impoundments, we found that mottled ducks selected palustrine emergent wetlands at the study area scale. We suspect this selection was an artifact of the distribution of palustrine wetlands across our study sites, relative to availability of managed impoundments. We noted that managed impoundments were frequently bordered by palustrine emergent wetlands. In Santee, we found extensive use of this habitat adjacent to a managed impoundment on the southeast end of Murphy's Island (Figure 3.4). In the ACE Basin, Savannah, and Altamaha areas, mottled ducks selected locations in relic impoundments, which the C-CAP data classified as palustrine emergent wetlands. These areas, likely remnants from the rice production era, appeared to have features such as linear canals and interior levees, but hydrology was not controlled because of breaks in the exterior levees, based on aerial imagery. One location where we noted use of a relic impoundment was on Broughton Island, along the Altamaha River (Figure 3.5). The extensive use of this area, which accounted for 51.1% of locations in palustrine emergent wetlands across Georgia and South Carolina, coupled with the fact that palustrine emergent wetlands only accounted for 7.9% of available habitats across the 4 river drainages, likely contributed to the resource selection function identifying palustrine emergent wetlands as being important to mottled ducks. This habitat, although not used to the same extent as managed impoundments, may have been especially important in the Altamaha as managed impoundments were limited when compared to other river drainages. The ACE and Santee areas held 7,413 ha and 7,470 ha of managed impoundments, respectively, whereas Savannah had 2,892 ha and the Altamaha had 1,248 ha. The varying management schemes used on the Altamaha, and impoundments in general, potentially further reduced the volume of suitable habitat for mottled ducks, possibly causing them to use places such as Broughton Island.

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). Mottled ducks also likely benefit from habitat management for shorebirds, as the shallow water required by many species is also attractive to mottled ducks (Weng 2006). 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 (US 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. Frequently, we noted that mottled duck locations were clustered around the saltwater demarcation line, but we suspect this likely reflected the presence of managed impoundments rather than salinity.

Historically, impoundments were created in tidal areas close to freshwater, as 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 is a driver of mottled duck habitat selection because the species is limited to coastal regions. Stutzenbaker (1988) found that WGC mottled ducks consumed high volumes of seeds and plants only available in brackish marshes, and Stieglitz (1972) found that mottled ducks in brackish marshes of Florida consumed considerably more animal material than birds in freshwater marshes. We suggest future research investigate potential impacts of salinity and water depth on habitat selection and food habits.

MANAGEMENT IMPLICATIONS

We noted the importance of managed impoundments to mottled ducks across multiple spatial scales. Mottled ducks selected habitats limited to the Santee, ACE, Savannah, and Altamaha river basins and failed to use any habitats outside of these areas. Hence, we suggest that agencies create and manage impoundments within and between these 4 river systems, thereby increasing available habitat. Furthermore, we noted broad expanses habitat in the Altamaha that our resource selection function classified as low quality. We offer that this stems from the limited availability of managed impoundments. Hence, we suggest the GADNR consider identifying areas where additional impoundments could be created. Additionally, we suggest that larger managed impoundments, such as those found on Rhetts Island of the Altamaha, could be divided into smaller units, allowing for a diversity of management opportunities. Managing a series of smaller impoundments with varying water depths and vegetative communities would provide a mosaic of habitats beneficial to mottled ducks.

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Table 3.1. Mean distance (m) to habitats at used and available locations for mottled ducks in Georgia and South Carolina at the study area and seasonal home range scales during 2013 – 2016. Seasons were breeding (01 February – 30 June), molt (01 July – 09 September), teal (10 September – 19 November), and general hunting (20 November – 31 January).

	Mean distance (m)									
	Study area		Home range - Breeding		Home range - Molt		Home range - Teal		Home range - Hunt	
	Used	Available	Used	Available	Used	Available	Used	Available	Used	Available
Managed impoundment	1057.6	2738.0	267.3	666.5	712.7	1224.6	1328.3	1595.8	1336.2	1415.7
Palustrine emergent wetlands	375.4	537.1	319.6	367.2	442.9	476.6	368.5	383.6	358.2	351.3
Estuarine emergent wetlands	495.9	349.8	559.8	528.2	563.5	422.6	428.2	428.1	540.8	541.6

Table 3.2. Parameter estimates for 2nd order habitat selection of mottled ducks in coastal Georgia and South Carolina.

Habitat	β	SE	Z	P	Odds ratio	Lower 95%	Upper 95%
Managed impoundment	-0.630	0.013	-48.32	<0.001	0.533	0.519	0.547
Estuarine emergent wetlands	0.788	0.055	14.41	<0.001	2.199	1.976	2.448
Palustrine emergent wetlands	-1.186	0.067	-17.58	<0.001	0.306	0.268	0.349

Table 3.3. Seasonal 3rd order parameter estimates for mottled ducks in South Carolina and Georgia as described by generalized linear mixed models. Seasons were breeding (01 February – 30 June), molt (01 July – 09 September), teal (10 September – 19 November), and general hunting (20 November – 31 January).

Habitat	Season	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	-11.2	< 0.001	0.699	0.656	0.744
	Teal	-1.134	0.071	-16.02	< 0.001	0.322	0.28	0.37
	General 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	1.12	0.93	1.349
	Molt	3.623	0.162	22.4	< 0.001	37.468	27.279	51.461
	Teal	-0.111	0.083	-1.33	0.185	0.895	0.76	1.054
	General Hunting	-0.018	0.136	-0.13	0.894	0.982	0.752	1.282
Palustrine emergent wetlands	Breeding	0.21	0.184	3.86	< 0.001	2.034	1.419	2.916
	Molt	-0.892	0.175	-5.1	< 0.001	0.41	0.291	0.577
	Teal	0.967	0.128	7.58	< 0.001	2.631	2.048	3.378
	General Hunting	0.479	0.277	1.73	0.084	1.614	0.937	2.779

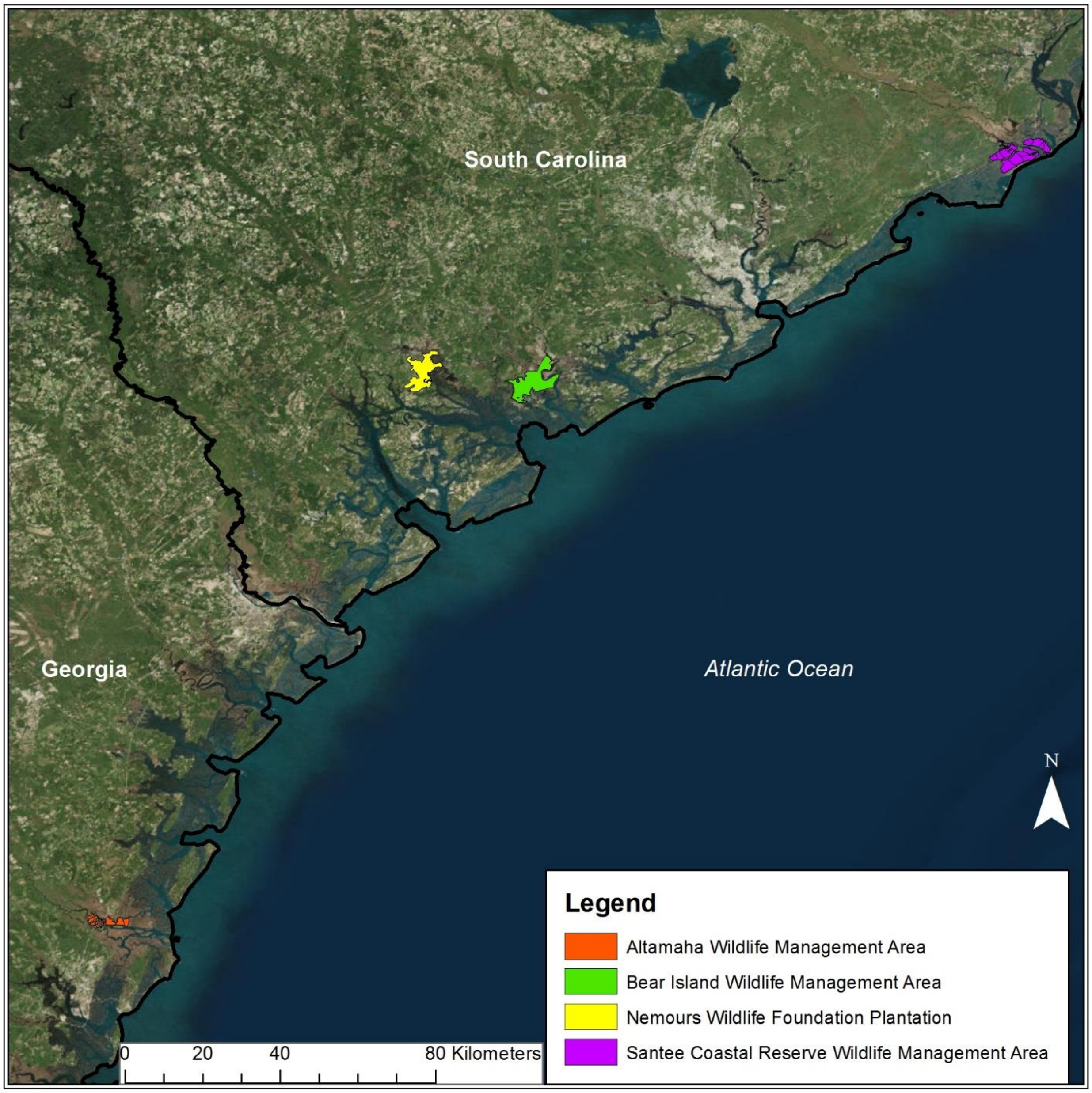

Figure 3.1. Capture sites for mottled ducks from 2013 – 2016 in Georgia and South Carolina, including Altamaha Wildlife Management Area (WMA), Bear Island WMA, Nemours Wildlife Foundation Plantation, and Santee Coastal Reserve WMA.

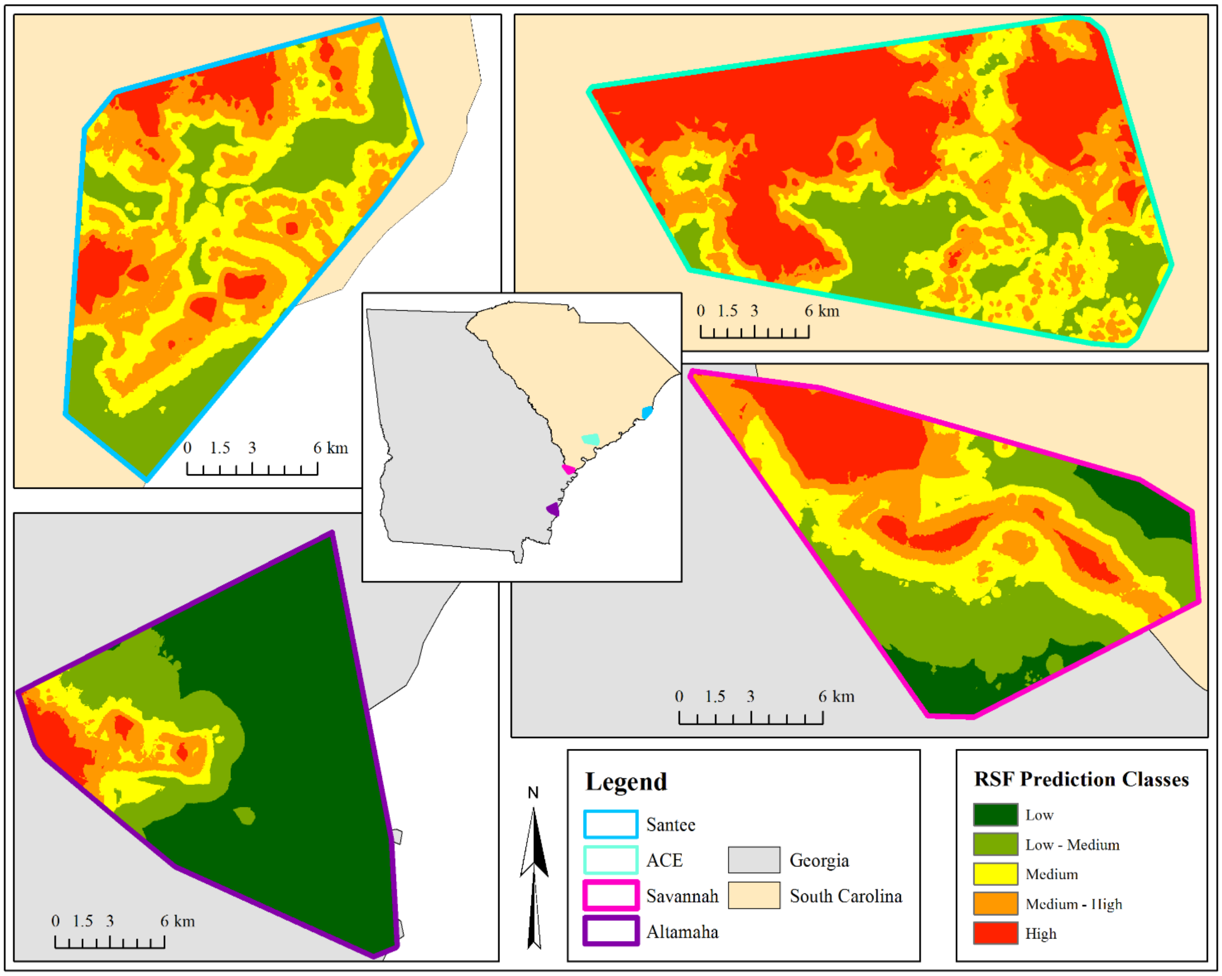

Figure 3.2. Resource Selection Function (RSF) predictions for 2nd order (Johnson 1980) habitat selection for mottled ducks from 2013 – 2016 in the Santee, Savannah, Altamaha, and ACE (Ashepoo, Combahe, Edisto) River basins in coastal Georgia and South Carolina.

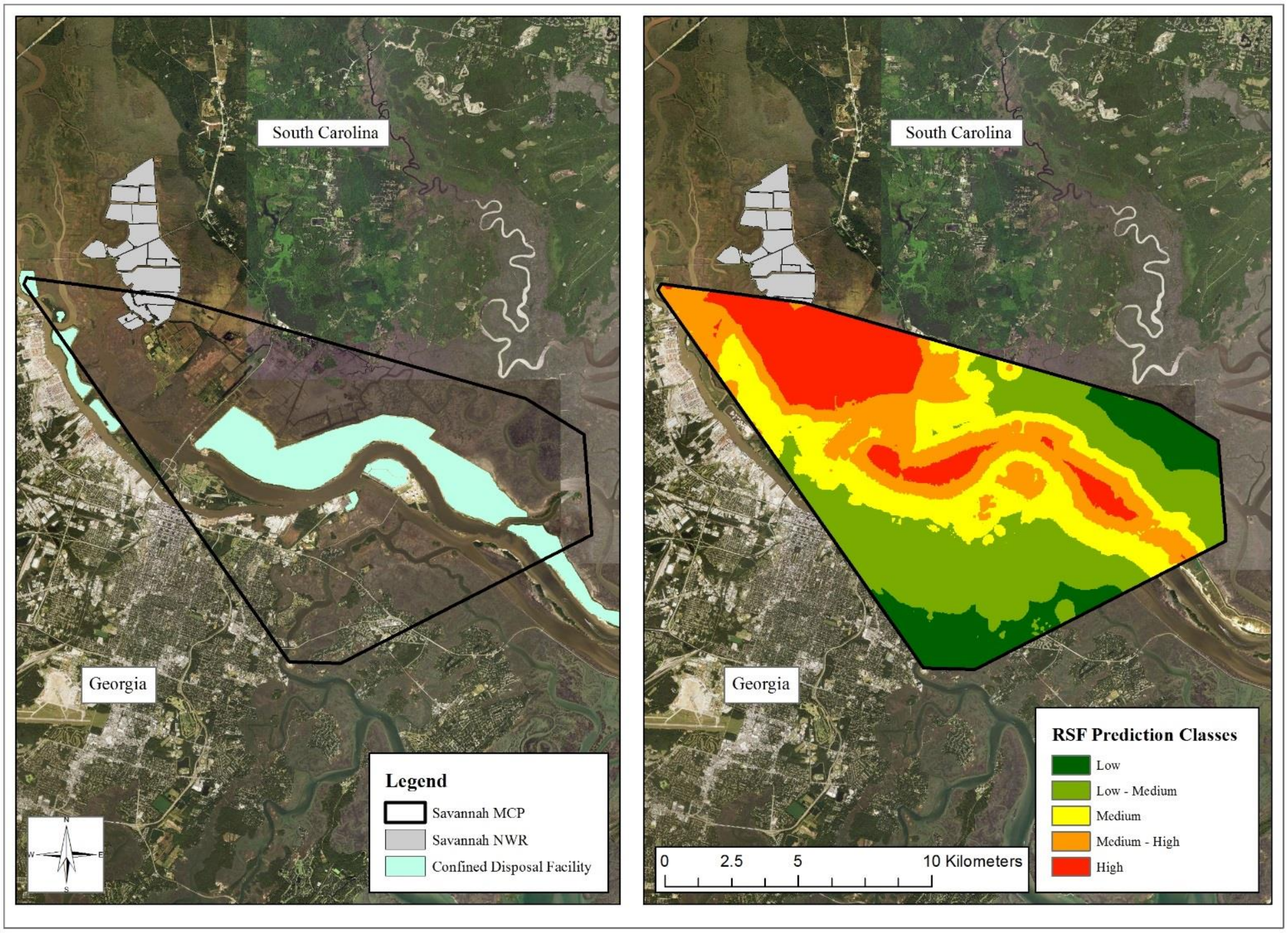

Figure 3.3. Resource selection function predicting that the Confined Disposal Facility (CDF) of the Savannah Harbor provides medium, medium-high, and high use habitats.

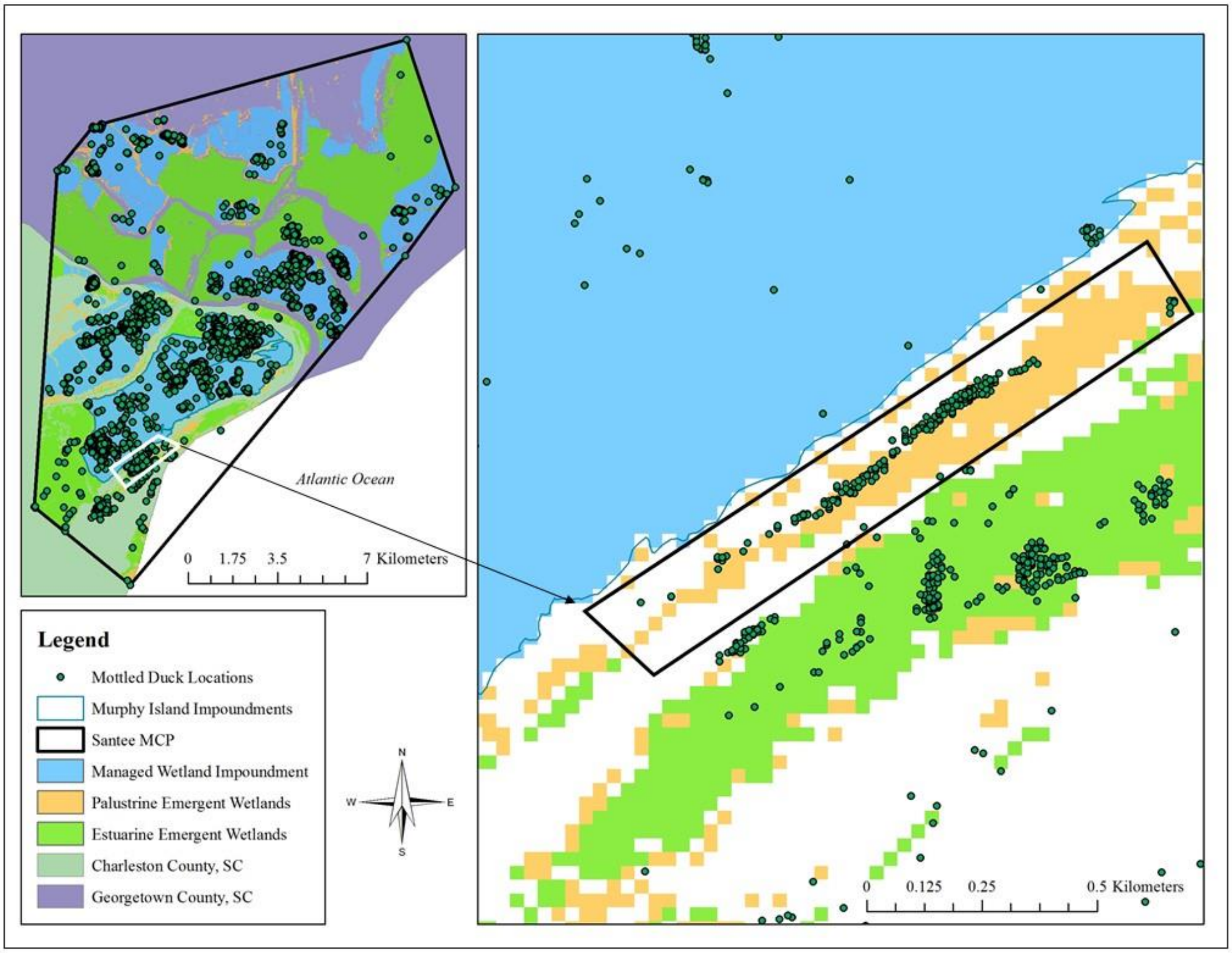

Figure 3.4. Mottled duck locations from 2013 – 2016 in palustrine emergent wetlands, outside of a managed impoundment on Murphy's Island, part of the Santee Coastal Wildlife Management Area, within the Santee Minimum Convex Polygon (MCP) in Georgetown and Charleston Counties, South Carolina.

Figure 3.5 Mottled duck locations from 2014 – 2016 in palustrine emergent wetlands of Broughton Island, near the Altamaha Wildlife Management Area, within the Altamaha Minimum Convex Polygon (MCP) in Glynn and McIntosh Counties, Georgia.

CHAPTER 4

EVALUATION OF TWO GPS TRANSMITTERS: IMPLICATIONS FOR WATERFOWL RESEARCH[1]

1. Pollander, K. M., J. W. Hinton, and M. J. Chamberlain. To be submitted to *Wilson Bulletin*

ABSTRACT

Global position system (GPS) telemetry improves upon very-high frequency (VHF) and satellite (i.e. ARGOS) telemetry by using a network of satellites that allows for nearly limitless data collection. Like VHF and satellite telemetry, error distances for GPS transmitters are frequently unreported or manufacturer estimates of error are used. We estimated the altitudinal and location accuracy of 2 GPS transmitters suitable for waterfowl research to fill this knowledge gap. We conducted a 13-day static test in Athens, Georgia to estimate the GPS and altitudinal accuracy of the PTT-100 22 g Solar Argos/GPS (PTT-100) and the 25 g GPS/GSM Solar (SGSM) transmitters. The PTT-100 transmitters collected 309 locations and had a mean error distance of 14.6 m (SE = 0.3), whereas SGSM units collected 47,127 locations of which 91.3% were within 5 m of accurate, despite having a mean error distance of 104.9 m (SE = 28.4). Our data suggest that both transmitters are accurate enough for waterfowl research, depending on research objectives. We offer that the limited data collection capabilities of the PTT-100 makes it ideal for documenting space use and broad-scale movements, whereas with data filtering the SGSM units can supply high volume datasets capable of documenting fine-scale movements and habitat use.

INDEX WORDS: accuracy, altitude, Global Positioning System, GPS, movement ecology, telemetry, waterfowl

INTRODUCTION

The development of Global Positioning System (GPS) backpacks suitable for waterfowl has enabled biologists to study movements of many species over space and time (Namgail et al. 2011, Hawkes et al. 2013, Kesler et al. 2014). Previous technology, such as very-high frequency (VHF) radiotelemetry and satellite telemetry (i.e. ARGOS), were used to track waterfowl such as mallards (*Anas platyrhynhcos*; Talent et al. 1982, Lancaster et al. 2015), gadwalls (*A. strepera*; Sayler and Willms 1997), and northern pintails (*A. acuta*; Miller et al. 2005, Haukos et al. 2006). These monitoring techniques have greatly contributed to our understanding of waterfowl ecology.

Despite their popularity and utility, VHF and satellite telemetry have numerous drawbacks. VHF has proven labor intensive, weather dependent and road-biased (Guthrie et al. 2011, Fischer et al. 2013). Thus, accuracy and volume of information has limited the scope of management plans and restricted research on life history and ecology for many species of waterfowl. Satellite telemetry can have locational errors that range from a few to several thousand meters, and number of locations recorded per day can vary greatly (Keating et al. 1991, Green et al. 2002, Miller et al. 2005). Additionally, reliability and locational error of satellite telemetry can be affected by satellite orbits, behaviors of radio-marked individuals, transmitter altitude, topography, and weather conditions (Harris et al. 1990, White and Garrott 1990, Rodgers 2001).

Replacing VHF and satellite telemetry with GPS telemetry has substantially increased accuracy and volume of locations recorded (Byrne et al. 2014). The reduction in locational error occurs because the transmitter receives signals from 3 or more satellites of known location, from which latitude and longitude can be calculated, unlike satellite telemetry which uses Doppler shift (Rodgers 2001). The network of satellites used by a GPS provide 24-hour worldwide coverage (Rodgers et al. 1996), allowing for nearly limitless data collection. In addition to recording location, GPS transmitters can record altitude when the unit receives signals from 4 or more satellites (Rodgers 2001). To better understand migration over the Himalayan Mountains, bar-headed geese (*Anser indicus*) were outfitted with GPS transmitters that documented migration from the breeding grounds in Mongolia, northern China, and the Tibetan Plateau, to wintering grounds in India. The median height flown by geese during migration was 3152 m, but notably one individual flew at 7290 m (Hawkes et al. 2013). Additionally, GPS telemetry linked the presence of avian influenza H5N1 in rural Mongolia, to the migration of bar-headed geese and ruddy shelducks (*Tadorna ferruginea*) from China (Prosser et al. 2009). Understanding altitudinal and migrational patterns could further increase our understanding of physiology, biomechanics, and disease spread in waterfowl.

Despite the efficacy of GPS technology, questions still remain regarding their locational accuracy. Error distances are important for field biologists trying to locate sites visited by marked individuals. Additionally, error distances are increasingly being incorporated into home range estimators (Fleming and Calabrese 2016, Kranstauber and Smolla 2016). Traditionally, observers using VHF radiotelemetry were tested for accuracy using beacon tests, in which a test transmitter was placed in field conditions and observers located them in the same manner they would locate a radio marked animal (Withey et al. 2001). Bearing errors were then calculated using the actual location of the test transmitter and the bearings and locations recorded by observers (White and Garrott 1990). Individual observers naturally vary in their ability to accurately triangulate test transmitters (Withey et al. 2001). Similarly, GPS transmitters, which essentially replace observers, should be tested, but such information is frequently not included

(Namgail et al. 2011, Perez-Garcia et al. 2013; but see Sheaffer and Malecki 2009), or the manufacturer specifications are used because an independent estimation of accuracy does not exist (Fischer et al. 2013, Hawkes et al. 2013). To better understand the accuracy of GPS transmitters used to conduct waterfowl research, we sought to describe the spatial and altitudinal accuracy, and reporting rates, for two GPS transmitters with varying collection schedules.

STUDY AREA

We conducted a static test at the University of Georgia Turfgrass Research and Education Center in Athens, GA, USA. We used a 1.8 ha open field with an unobstructed view of the southern sky, >50 m from all buildings, with low-growing (5-20 cm), herbaceous vegetation. Elevation of the study area was 215-220 m.

METHODS AND MATERIALS

We tested the PTT-100 22 g Solar Argos/GPS and the 25 g GPS/GSM Solar transmitters (Microwave Telemetry, Inc., Columbia, Maryland, USA; Figure 4.1). During assembly, PTT-100 22 g Solar Argos/GPS transmitters (henceforth PTT-100) were outfitted with an ultra-high frequency (UHF) radio, permitting ground tracking. This capability taxed the battery so that only 4 locations per day could be recorded. The PTT-100s had 3 different seasonal schedules in which they recorded locations. During the static test, units recorded locations at 0000, 0800, 1200, and 1800 hours, and altitude was recorded in 10 m intervals.

Locational data recorded by PTT-100s were uploaded to the Argos satellite (CLS American Inc., Lanham, Maryland, USA) and made available online. All location data were stored onboard the PTT-100 between communication intervals with the Argos Satellite. Once available online, data were downloaded from the CLS America website (https://www.cls.fr/en/). We then processed these files using Argos-GPS Parser software (Microwave Telemetry, Inc., Columbia, Maryland, USA). Date, time, latitude, longitude, speed, course, and altitude for all locations taken were then available.

The 25 g GPS/GSM Solar (henceforth SGSM) transmitters recorded GPS locations dynamically based on available battery voltage. Per the manufacturer, fully charged units exposed to the sun could record a location every minute; at night, they could record a location every 30 minutes to 4 hours. Data were uploaded once daily via Groupe Spécial Mobile (GSM) wireless networks. Individual units could store 258,000 locations onboard. When units were outside GSM coverage, data were stored onboard until units returned to an area of coverage. All new and previously recorded locations were uploaded daily. Once transmitted, data were made available by email. Transmission files included date, time, latitude, longitude, speed, course, altitude, horizontal dilution of precision, and vertical dilution of precision readings. If the PTT-100 and the SGSM transmitters were unable to record a location and the battery was not depleted, the date, time, and an error reading indicating the reason for the missed fix were reported. If either transmitter type was unable to record a location due to insufficient battery power, either battery drain or low voltage errors were reported.

We conducted a static test to estimate locational and altitudinal accuracy and reporting rates of PTT-100 and SGSM transmitters. Six units of each transmitter type were attached to individual stakes 30 cm above the ground, approximating the height of a mallard-sized dabbling duck's back. We affixed transmitters using a 4.8 mm braided Teflon ribbon (Bally Ribbon Mills, Bally, Pennsylvania, USA) and black vinyl tape as needed. As recommended by the manufacturer, transmitters were tilted 15° towards the ground so that the antenna was elevated above the solar panel, the units were south facing, and were >1 m apart. To approximate actual altitudes and locations, we used a handheld Garmin eTrex 20x to record 101-102 locations and altitudes at each test location. We calculated the mean location and altitude for each transmitter and considered it to be the known testing location and altitude (Oderwald and Boucher 2003).

We used hourly weather data collected by a weather station at the Athens-Ben Epps Airport, 6.8 km northeast of the study site in Athens, GA, and made available online (NOAA 2015). Mean daytime and night-time temperatures, cloud cover, and total precipitation were recorded during the static test.

We calculated the distance between testing locations and those recorded by PTT-100 and SGSM transmitters to estimate accuracy using the distances function of the aspace package (Bui et al. 2012) in program R (version 3.1.3, R Core Team, Vienna, Austria). Altitudinal error was the difference between the known testing altitude and altitude recorded by the units. We only used 3D GPS fixes, which had latitude, longitude, and altitude, in our analysis. We recorded total number of locations taken, and mean and standard error of altitudinal and locational error measurements for all PTT-100 and SGSM units. We describe below weather conditions that occurred during transmitter testing.

RESULTS

The static test spanned 13 days between 28 May and 9 June 2015. Mean daytime temperature was 25.7° C, whereas mean nighttime temperature was 20.0° C. Precipitation totaled 6.4 cm. Cloud coverage ranged between 0% and 100%, but because no transmitter reported low voltage or battery drain readings, we assumed it had no effect on unit performance.

The PTT-100 transmitters recorded 309 of 312 scheduled fixes (Table 4.1); one transmitter did not record 3 scheduled fixes or report error readings. The most accurate unit had a mean altitude reading 0.2 m (SE = 0.9) above the actual testing location, whereas the least accurate unit was 16.2 m (SE = 14.2) above the known test location. The unit with the most accurate GPS fixes had a mean error of 11.9 m (SE = 0.6) from the known test location, whereas the least accurate unit had a mean error of 17 m (SE = 0.6, Figure 4.2). Mean GPS error was 14.6 m (SE = 0.3) and ranged from 2.8 - 28.9 m. Half (49.5%) of all locations were <15 m from testing locations (Table 4.2). Mean altitudinal error for units was 5.1 m (SE = 2.4), and ranged from 29 m below to 742 m above the actual testing location.

The 6 SGSM transmitters acquired 47,127 locations during the static test, 98% of which were recorded during daylight hours (Figure 4.3). The most accurate and least SGSM transmitter had a mean altitude of 3.2 m (SE = 0.7) and 108.3 m (SE = 13.2) above the known test location (Table 4.3). Two transmitters were most accurate with a mean GPS error of 2.9 m (SE = 0.1, SE = 0) from the test location (Figure 4.4), whereas the least accurate had a mean GPS error of 325.9 m (SE = 95.5). Across all locations recorded the mean GPS error distance was 104.9 m (SE = 28.4), and ranged from 0.3 m to 61.1 km, despite 91.3% of locations being <5 m of test locations. Mean altitudinal error for all locations was 41.1 m (SE = 4.1) above testing locations, and ranged from 307 m below to 32,213 m above testing locations.

DISCUSSION

Prior to our static test, the only information available on accuracy of these GPS units came from the manufacturer (Fischer et al. 2013). We found slight variation in GPS and altitudinal accuracy among the PTT-100 units, whereas these same metrics varied greatly among SGSM units. Although human error is removed when using a GPS transmitter as compared to VHF telemetry, we still suggest that users test transmitters similarly to beacon tests conducted on VHF observers. These procedures could help identify transmitters with accuracy flaws prior to deployment.

Our experiment was conducted under nearly optimal field conditions with little rain (6.4 cm), limited cloud coverage, ample sun, and vegetation that remained below the height of transmitters. Under these conditions, the units could readily charge and communicate with the Argos and GPS satellites (Rodgers 2001). We recognize that these field conditions are rarely representative of those encountered by most waterfowl, especially fall and winter in North America. Hence, our estimates of accuracy should be considered ideal. We encourage other researchers to test units in more inclement weather and realistic habitat conditions to further refine expectations of accuracy for field studies (see Rempel et al. 1995).

Based on our testing, the best GPS unit to select will depend on study objectives. The PTT-100s recorded limited data, but had a mean GPS accuracy of 14.6 m with little variation among units. When outfitted with a UHF radio, the PTT-100 offers researchers the opportunity to recover units, allowing for redeployment and data collection associated with mortalities in the field. Removal of the UHF radio, the unit could record 5 locations per day, so inclusion of the UHF only reduces collection of a single location daily. Additionally, the PTT-100 can transmit data worldwide via communication with the Argos satellite. Hence, we offer that the PTT-100 seems appropriate when researchers are trying to describe space use and coarse-scale movements, i.e. 2^{nd} and 3^{rd} order selection (Johnson 1980).

In contrast to the PPT-100s, the SGSM units collected substantial datasets, but most relocations (98%) were recorded during diurnally. Likewise, mean GPS error distance was highly variable among units, ranging from 2.9 m to 325.9 m. Despite great varibility among units, we noted that 91.3% of fixes were <5 m from testing locations. Data filtering (see chapter 2, 3) would likely assist, removing inaccurate locations, providing researchers with a high volume of accurate relocations, capable of quantifying diurnal fine-scale movements and habitat use, i.e. 4^{th} order selection (Johnson 1980). However, a challenge presented by the SGSM units was the data transmission system, as the GSM network is frequently unavailable in rural landscapes where many species of waterfowl breed, such as northern boreal forests and the Arctic. Additionally, we cannot speak to the efficacy of these units on dabbling ducks that use forested wetlands during the wintering months or the impact that cold and inclement weather would play. Deploying SGSM transmitters on a species in remote or densely-vegetated habitats may result in sporadic data acquisition as individuals pass into areas with GSM coverage.

MANAGEMENT IMPLICATIONS

Our results indicate that the PTT-100 and SGSM transmitters are sufficiently accurate to improve our understanding of waterfowl behavior and ecology, especially in open habitat, such as prairie grasslands. Selecting the ideal transmitter will ultimately depend on objectives of individual research projects. The PTT-100 provided a limited dataset but with little variability in error among units. Hence, we suggest they can be used to provide estimates of space use and broad-scale movements. Conversely, SGSM transmitters provided substantial datasets that if filtered, could quantify fine-scale movements and habitat use. However, the availability of GSM network coverage may limit the feasibility of using SGSM transmitters in certain locales. Regardless, prior to deployment we suggest transmitters be tested in varying field conditions representative of environments the study species inhabits to ensure that data collected by the units can answer the desired research questions.

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Table 4.1. Mean altitude and Global Positioning System (GPS) error distance ($\bar{x}$ + SE) for the static test of the PTT-100 22 g Solar Argos/GPS (PTT-100) transmitters for each unique unit (ID) tested during 2015, Athens, GA, USA.

ID	Number of locations recorded	Test site altitude (m)	Altitude (m) above test location		GPS error (m) from test location	
			$\bar{x}$	SE	$\bar{x}$	SE
44	52	216	2.7	0.6	13.9	0.0
46	52	216	4.6	0.6	12.6	0.6
47	52	219	0.2	0.9	15.7	1.0
48	52	216	2.5	0.7	16.5	0.6
53	52	218	16.2	14.2	11.9	0.6
61	49	215	4.4	0.7	17.0	0.6

Table 4.2. The Global Positioning System (GPS) error distance in 5 m increments for all locations recorded by PTT-100 22 g Solar Argos/GPS (PTT-100) and 25 g GPS/GSM Solar (SGSM) transmitters tested during 2015, Athens, GA, USA.

	PTT-100		SGSM	
GPS error (m)	Count of GPS fixes	Percent of total	Count of GPS fixes	Percent of total
<5	3	1.0	43031	91.3
5-10	33	10.7	3881	8.2
10-15	153	49.5	119	0.3
15-20	75	24.3	19	0
20-25	37	12.0	11	0
25-30	8	2.6	7	0
30-35	0	0	4	0
35-40	0	0	2	0
>40	0	0	53	0.1
Total	309	100	47127	100

Table 4.3. Mean altitude and Global Positioning System (GPS) error distance ($\bar{x}$ + SE) for the static test of the 25 g GPS/GSM Solar (SGSM) transmitters for each unique unit (ID) tested during 2015, Athens, GA, USA.

			Altitude (m) above test location		GPS error (m) from test location	
ID	Locations recorded	Test site altitude (m)	$\bar{x}$	SE	$\bar{x}$	SE
237	7017	213	3.2	0.7	2.9	0.1
243	6235	217	23.5	8.5	6.6	3.3
245	12270	215	108.3	13.2	325.9	95.5
248	7295	218	7.6	4.5	2.9	0.0
250	7176	217	22.5	7.1	31.4	28.6
252	7134	218	31.0	8.4	89.3	85.6

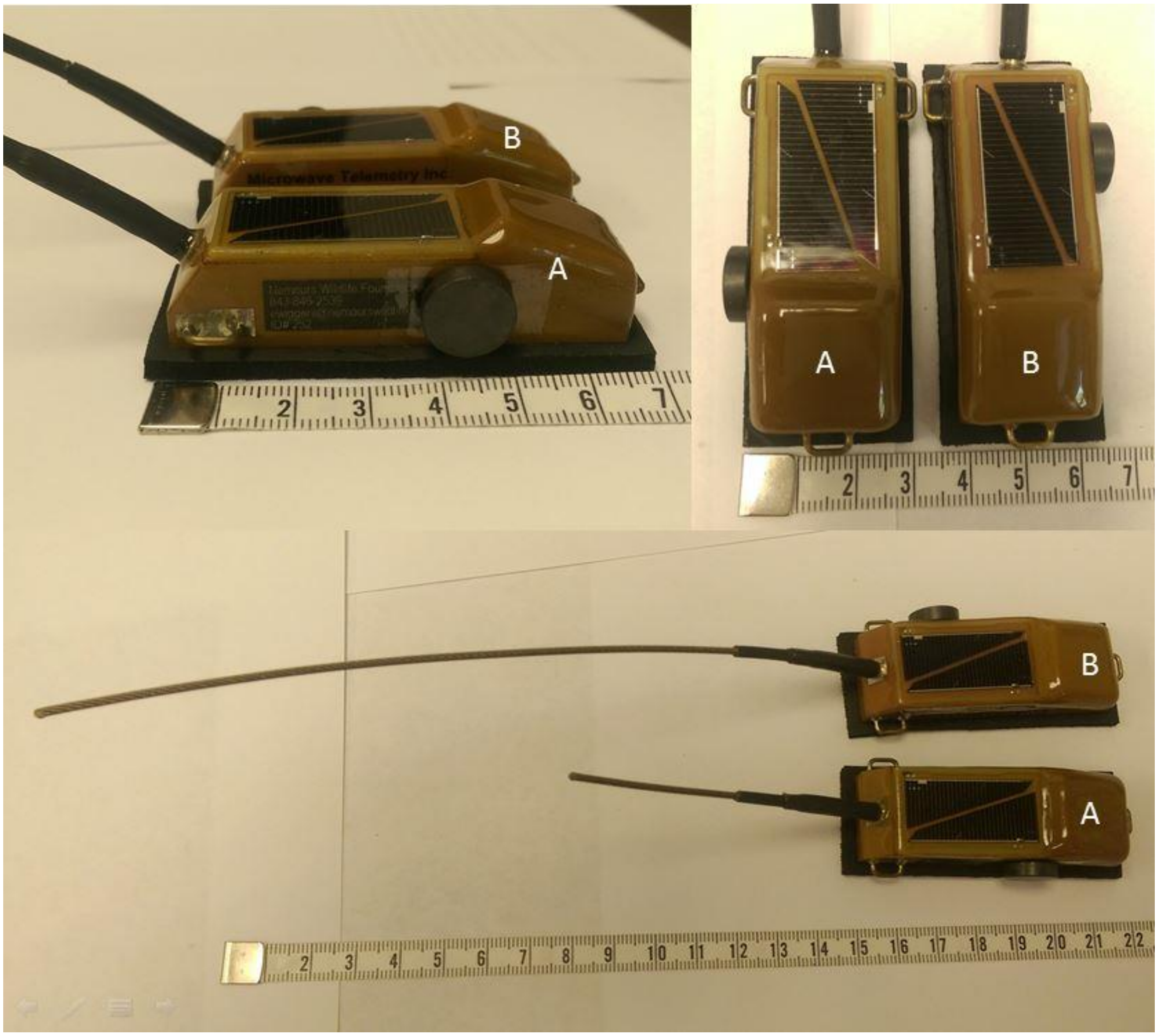

Figure 4.1. The 25 g GPS/GSM Solar (SGSM; A) and PTT-100 22 g Solar Argos/GPS (PTT-100; B) transmitters. Both measured 6.5 cm × 2.3 cm × 1.5 cm excluding antennas. The SGSM transmitter had 7.6 cm antenna and the PTT-100 transmitter had a 17.7 cm antenna.

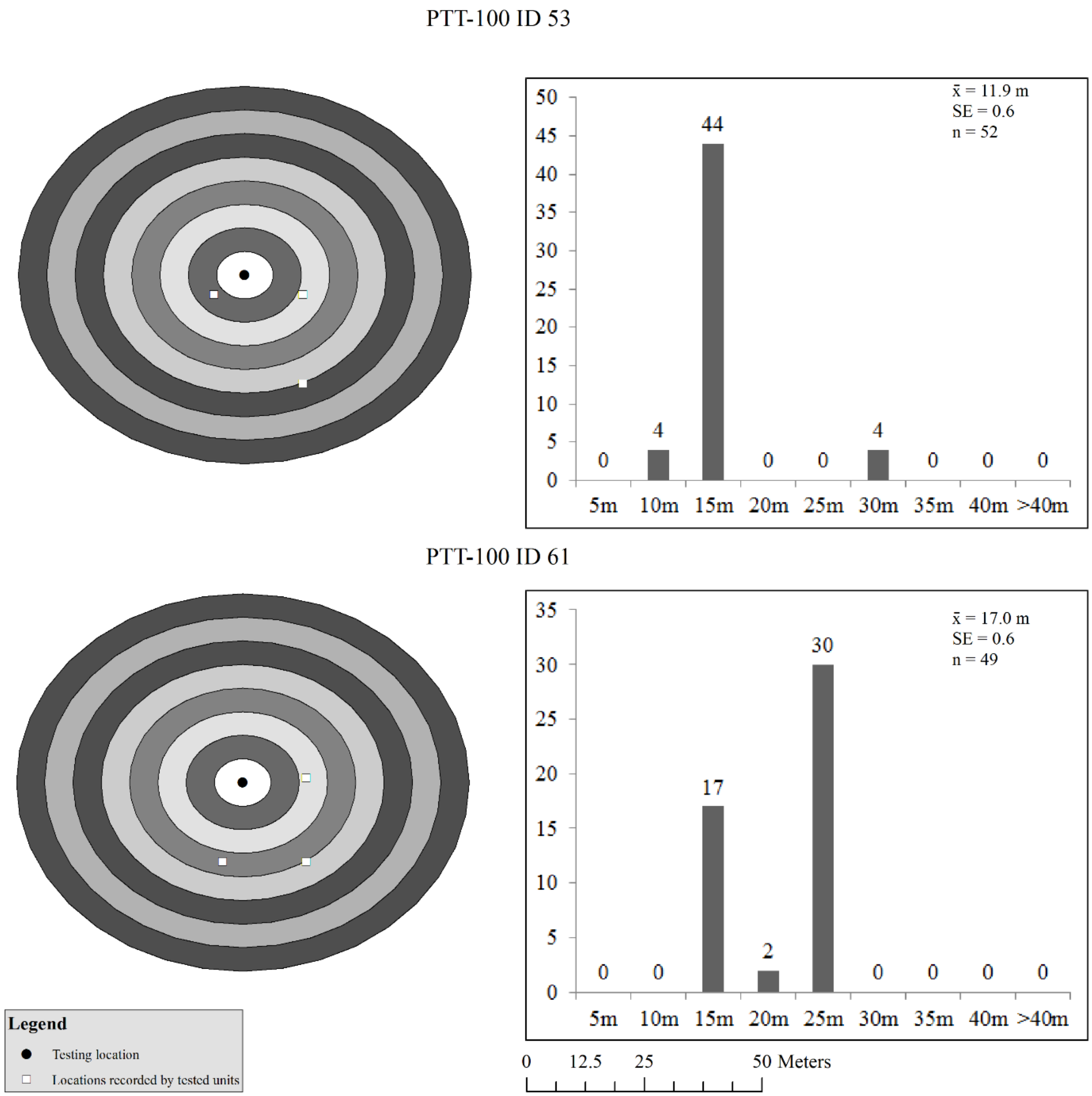

Figure 4.2. The Global Positioning System (GPS) locations and the static testing locations mapped in 5 m increments, locations (*n*), and mean GPS error ($\bar{x}$ + SE) for PTT-100 22 g Solar Argos/GPS (PTT-100) transmitters with the highest and lowest mean GPS error distances.

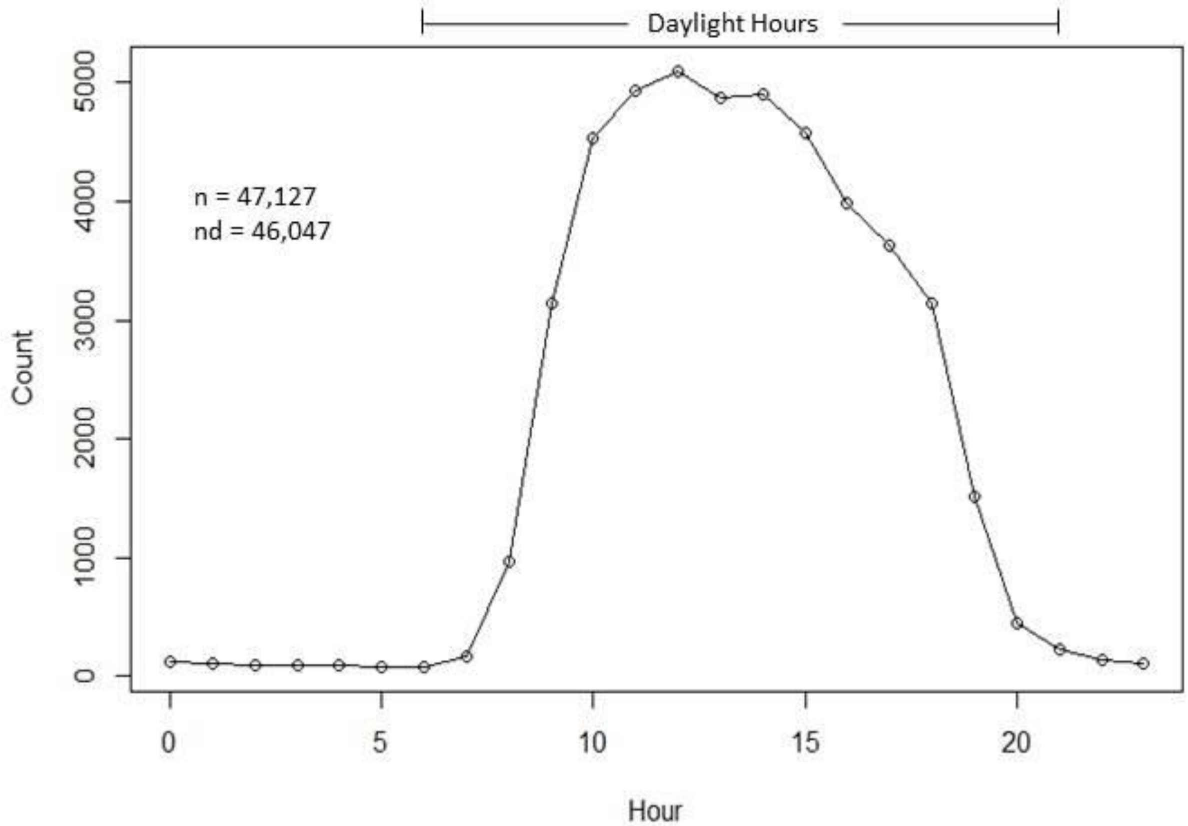

Figure 4.3. Count of locations recorded (n) by hour for all 25 g GPS/GSM Solar (SGSM) transmitters recorded during the 13-day static test and number GPS locations recorded during 0600 and 2100, which constituted daylight hours (nd).

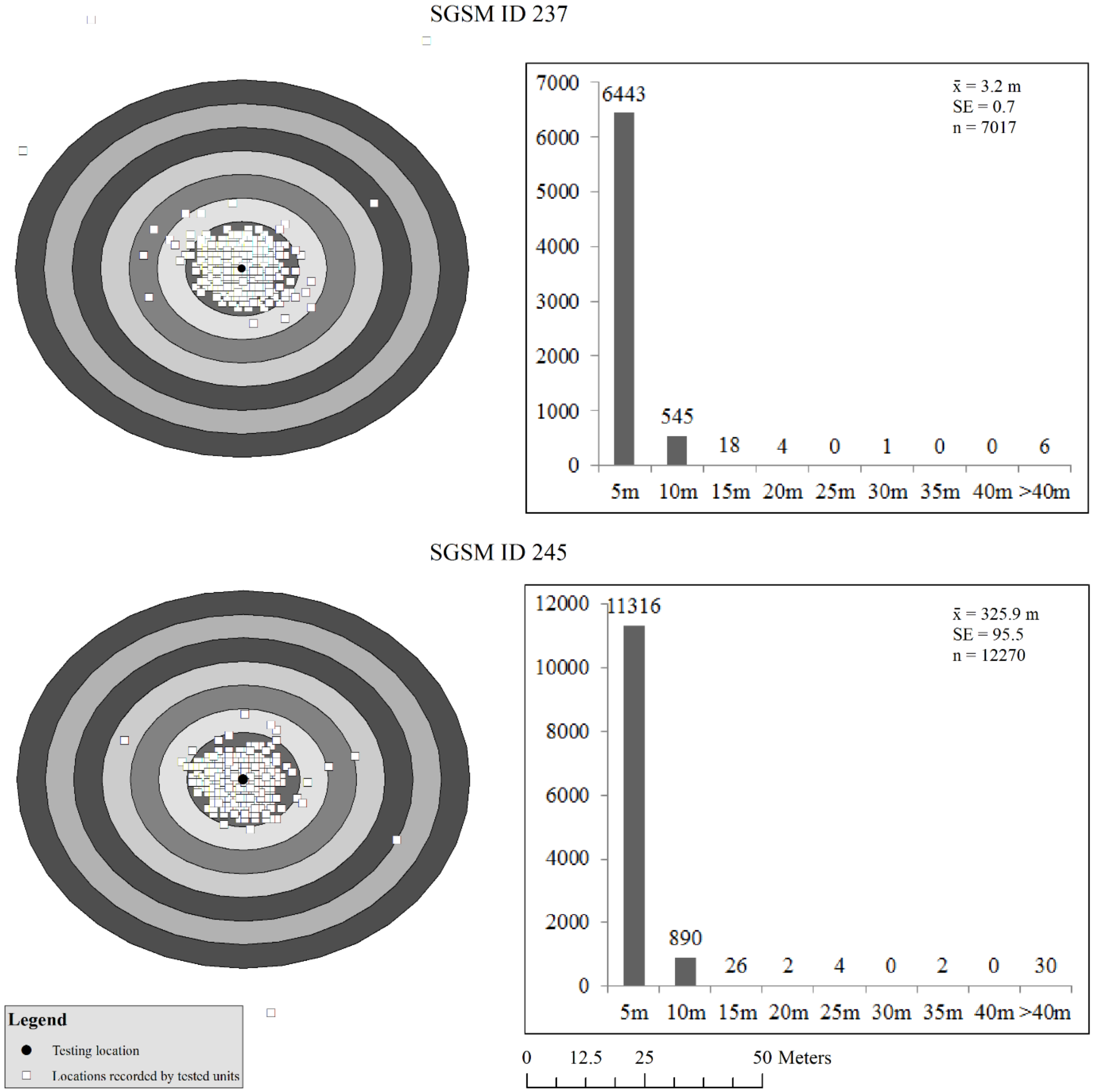

Figure 4.4. The Global Positioning System (GPS) locations and the static testing locations mapped in 5 m increments, locations (*n*), and mean GPS error ($\bar{x}$ + SE) for 25 g GPS/GSM Solar (SGSM) transmitters with the highest and lowest mean GPS error distances.

CHAPTER 5

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

I documented excursions where mottled ducks left established home ranges for > 6 hrs and traveled ≥ 5 km. Although the underlying mechanisms influencing these excursions are unclear, I speculate that these movements were likely conducted in search of resources (e.g., foraging sites, loafing sites, roost areas). I documented dispersal and long-distance movements, resulting in 5 individuals captured in Georgia moving to South Carolina. These movements indicate that South Carolina and Georgia likely have one continuous population of mottled ducks. I only observed long-distance movements from birds captured in Georgia, hence I speculate that habitat may be limited for mottled ducks around the Altamaha.

I found that mottled ducks selected for managed impoundments and palustrine emergent wetlands at the study area scale, and selected for managed impoundments in all seasons at the home range scale. Impoundments are likely important to mottled ducks because they provide diverse food resources and stable water depths, unlike natural saltmarshes that are tidally influenced. I suspect that birds may have selected palustrine emergent wetlands when impoundments were flooded > 25 cm, as mottled ducks prefer water depths below this level. Alternatively, palustrine wetlands may have provided food resources unavailable in managed impoundments. Future studies should describe food habits of mottled ducks, which are poorly understood for this non-native population.

I suggest that the South Carolina Department of Natural Resources and Georgia Department of Natural Resources work collaboratively on management and future research involving the mottled duck. Additionally, I suggest that both agencies create and manage impoundments within and between the Altamaha, Savannah, ACE (Ashepoo, Combahee, and Edisto) and Santee River systems, thereby increasing available habitat. Specifically, I suggest impoundments between Savannah and the Altamaha are needed. Potential sites exist along the North and South Newport Rivers and Harris Neck National Wildlife Refuge, or near the Jerico River. Additional opportunities may exist on Sapelo and Ossabaw Islands. Furthermore, I recommend that large managed impoundments, such as those found on Rhetts Island of the Altamaha, may better serve mottled ducks if they are separated into smaller units, providing a diversity of management opportunities. Managing a series of smaller impoundments with varying water depths and vegetative communities would provide a mosaic of habitats beneficial to mottled ducks.

This project was unable to assess the importance of salinity on mottled duck habitat selection. Clearly, salinity is an important determinant to habitat selection by mottled ducks, as the species is found almost exclusively in coastal areas. It is unclear what range of salinities are most selected by mottled ducks, but understanding ideal salinity levels would allow agencies to better manage existing impoundments and create new impoundments at locations most attractive to the species. Likewise, forage selection is likely tied to salinity, so understanding food habits would allow for more tailored habitat management, likely increasing the quality of available habitat.

I was unable to quantify was reproduction. Despite tracking 8 females during the breeding seasons, one which we tracked for 2 years, I was unable to document movement behavior that suggested nesting activity. Previous researchers have noted that mottled ducks likely have a low nesting propensity. Additionally, it has been speculated that transmitters negatively affect individuals, potentially preventing them from nesting. Alternatively, it is possible that they did attempt to nest and I was unable to detect it, despite getting high volumes of locations for birds outfitted with SGSM transmitters. I venture that the latter is unlikely, so I suggest future work use a different approach, such as using geolocators. Geolocators use the sun to document location of the bird. If placed around the leg of the bird, like a band, a geolocator will document a dark period, when the bird is sitting on a nest, as she is blocking light from the unit. This approach, applied over both South Carolina and Georgia would improve our understanding of mottled duck nesting ecology.