Survival and Recovery of Mottled Ducks in Coastal South Carolina, 2008–2018

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Abstract: Mottled ducks are typically geographically separated into two sub-species: peninsular Florida (*Anas fulvigula fulvigula*) and the western Gulf Coastal (WGC) (*A. f. maculosa*). Between 1975 and 1983, >1,200 mottled ducks were introduced to coastal South Carolina primarily from the WGC range. A late summer banding program was initiated in 2008 within the Santee Delta and the Ashepoo, Combahee, and Edisto Rivers Basin in South Carolina to estimate mottled duck survival and harvest probability. We acquired 3,594 banding and 525 recovery records of mottled ducks banded between 2008–2018. We used the dead recovery model with Brownie parametrization in Program MARK to estimate annual survival (*S*) and recovery probabilities (*f*) among combinations of age, sex, year, and band material (aluminum or stainless steel). Annual survival was greatest for adult males (0.60 ± 0.03 [SE]), followed by adult females (0.57 ± 0.04), juvenile females (0.44 ± 0.13), and juvenile males (0.32 ± 0.07). Recovery and harvest probabilities were greatest for juvenile males (0.10 ± 0.02; 14% [harvest probability assuming 73% reporting]) followed by adult males (0.08 ± 0.01; 11%), juvenile females (0.05 ± 0.01; 7%), and adult females (0.05 ± 0.01; 6%). The band material variable was absent from competing models suggesting that retention or inscription attrition did not impact recovery probabilities of individuals banded with aluminum bands. Relative to other occupied regions, juvenile male survival and recovery probabilities for South Carolina mottled ducks were low suggesting either poor post-breeding season survival probabilities or high dispersal rates. Survival probabilities for other age and sex classes were well within previously reported ranges and appear sufficient to maintain populations with continued recruitment.

Key words: *Anas fulvigula*, band material, harvest probability, recovery probability, retention, stainless steel, survival probability

Journal of the Southeast. Association of Fish and Wildlife Agencies 7: 189–194

Mottled ducks (*Anas fulvigula*) are one of five nonmigratory duck species in North America. The two genetically distinct subspecies are endemic to two areas: coastal wetlands and associated habitats of the Western Gulf of Mexico Coast (*A. f. maculosa*), and urban/suburban areas of peninsular Florida (*A. f. fulvigula*) (McCracken et al. 2001, Williams et al. 2005, Bielefeld et al. 2010, Ford et al. 2017). Mottled ducks are not endemic to South Carolina or Georgia (Bielefeld et al. 2010). However, given the reverence for the bird by hunters and bird watchers in endemic ranges, the South Carolina Department of Natural Resources (SCDNR) released mottled ducks in the state between 1975–1983. More than 1,200 mottled ducks were captured in Texas, Louisiana, and Florida and translocated into the coastal marshes of the Santee River Delta and the Ashepoo, Combahee, and Edisto rivers (ACE) basin (SCDNR, unpublished data). Although a rigorous population estimate is lacking, the South Carolina population appears to have increased based on successful banding efforts (i.e., >1,000 in 2010) and anecdotal observations by wetlands managers at many coastal wetlands (Shipes 2014). Mottled ducks currently are found along the entire South Carolina Coast and have been recorded in select coastal counties of North Carolina. Moreover, despite no introduction efforts, Georgia now contains mottled ducks which likely originated from an expanding South Carolina population (Weng 2006, Balkcom and Mixon 2015). Mottled ducks are commonly observed throughout the year in coastal South Carolina and are coveted by waterfowl hunters (Shipes et al. 2015). Given the rise in stakeholder interest of this species in South Carolina, the SCDNR initiated a collective banding program in 2008 to monitor survival and recovery probabilities and intra- and inter-state connectivity in these birds.

Long-term banding programs in endemic regions provide robust benchmarks of survival and recovery probabilities for mot-

1. Current: South Carolina Department of Natural Resources, 420 Dirleton Road, Georgetown, SC 29440.
2. Current: Gulf Coast Joint Venture, 700 Cajundome Blvd., Lafayette, LA 70506.
3. Retired

tled ducks with which to compare South Carolina demographics (Johnson et al. 1995, Haukos 2015). Mottled ducks have been and continue to be banded in Florida since 1977, whereas Louisiana and Texas established programs in 1994 and 1997, respectively (Johnson et al. 1995, Haukos 2015). Given apparent range expansion of mottled ducks along the eastern seaboard, Georgia conceived a mottled duck banding program in 2006 (Balkcom and Mixon 2015). Generally, previous research has revealed disparate annual survival among age and sex combinations in the species, with adult males experiencing greatest annual survival and juvenile males having greatest recovery probabilities (Johnson et al. 1995, Johnson 2009, Balkcom and Mixon 2015, Haukos 2015). Haukos (2015) also detected great variability in annual survival of mottled ducks banded in Texas and Louisiana ranging from <20%–80% across age and sex classes. Excluding biologically improbable estimates, the range in contemporary survival probabilities of mottled ducks across their range (i.e., 35%–62%) is comparable to estimated probabilities for mallards (e.g., 0.48–0.68) reported by Nichols and Hines (1987) and Smith and Reynolds (1992). Balkcom and Mixon (2015) reported recovery probabilities (i.e., 14%–16%) for Georgia mottled ducks which were nearly double compared to birds in their endemic range, which translates to low annual survival (~35%) of all age and sex combinations. Several factors may have influenced the lower survival probabilities of Georgia mottled ducks, including high alligator populations or high harvest due to capture and banding on a heavily hunted public use area and potential errors in parameter values due to small sample size or poor retention of aluminum bands (Balkcom and Mixon 2015).

Bands made of aluminum alloy, a relatively soft metal, become illegible or deteriorate over time, possibly leading to band loss in long-lived water birds under certain environmental conditions (e.g., brackish water; Haramis et al. 1982, DuWors et al. 1987, Schreiber and Mock 1998, Gaston et al. 2013). Often, illegibility of aluminum bands can be ameliorated with chemical-etching techniques conducted by the U.S. Geological Survey (USGS) Bird Banding Laboratory (BBL), and data can be read. However, some hunters are hesitant to mail these illegible bands to the BBL which is essentially equivalent to an unreported band. Band loss can result in biased estimation of survival and recovery (Brownie et al. 1985), especially for species with high survival probabilities (Lensink 1988, Breton et al. 2006). For this reason, Hickey (1952:24) cautioned against the use of waterfowl banding data >5 years following band attachment. Lensink (1988) reported 100% loss of aluminum bands on Black Brant (*Branta bernicla nigricans*) recaptured ≥6 years after double marking with monel, a hard nickel and copper alloy material. Anecdotally, Balkcom and Mixon (2015) cited discoloration and tarnishing of aluminum bands that had become nearly illegible on mottled ducks and black-bellied whistling ducks (*Dendrocygna autumnalis*) recaptured mere weeks following initial banding. Given that both soft- and hard-metal materials were used in the banding of mottled ducks in South Carolina between 2008 and 2018, we were able to compare recovery probabilities between band types.

Our objectives for this study were to estimate annual survival and recovery probabilities of South Carolina banded mottled ducks and to investigate whether recovery probabilities differed between band materials. Given existing estimates of survival and recovery probabilities from other regions, we predicted differences would occur among age and sex cohorts, with greatest annual survival for adult males, greatest recovery probabilities for juvenile males, and annual survival probabilities near 50%. Moreover, if discoloration or deterioration of aluminum bands impacted retention or reporting probabilities, we expected to observe a lower recovery probability for mottled ducks banded with aluminum materials. Rigorous survival and recovery estimates will provide state and regional managers with demographic parameters needed for enhanced conservation and management of mottled ducks in South Carolina.

Methods

We captured mottled ducks on managed tidal impoundments of the ACE Rivers Basin and Santee River Delta of coastal South Carolina. Primary capture locations were: 1) Bear Island Wildlife Management Area (WMA) located in the ACE Basin that contained 2,100 ha of managed tidal impoundments; 2) Santee Coastal Reserve WMA, which contained 6,100 ha of managed tidal impoundments in the Santee River Delta; and 3) approximately four private properties adjacent to WMAs in years when bird distribution, wetland conditions, and consent allowed. All capture sites contained managed tidal impoundments that were brackish and produced aquatic plant communities of widgeongrass (*Ruppia maritima*), saltmarsh bulrush (*Scirpus robustus*), dwarf spikerush (*Eleocharis parvula*), and giant cordgrass (*Spartina cynosuroides*).

We captured mottled ducks via night-lighting techniques with airboats from July–September 2008–2017 (Cummings and Hewitt 1964). We concentrated capture events around nocturnal periods lacking moonlight (i.e., new moon), generally corresponding with the species' remigial molt (Merendino et al. 2005, Mills et al. 2011, Shipes et al. 2015). We conducted banding operations under USGS BBL permit 06658.

Following capture, we classified mottled ducks by age (AHY [after-hatch-year; banded >1 year after hatch] or HY [hatch-year; banded in year of hatching]) and sex classes using morphometric characteristics or cloacal examination (Carney 1992). During

Table 1. Annual number of mottled duck banding and recovery records by band material used in survival analysis of South Carolina mottled ducks (*Anas fulvigula*), 2008–2018.

Banding/ Recovery Year	Stainless Steel		Aluminum	
	Banded	Recovered	Banded	Recovered
2008–09	–	–	199	11
2009–10	–	–	352	29
2010–11	752	41	333	39
2011–12	302	52	10	29
2012–13	402	56	16	17
2013–14	963	101	1	5
2014–15	88	57	–	5
2015–16	116	48	–	0
2016–17	39	15	–	0
2017–18	21	18	–	2
Total	2,683	388	911	137

our study, USGS BBL amended reporting method inscriptions on bands from toll-free/write-in (hereafter; toll-free) to toll-free/web-address (hereafter; web-address). Moreover, following concerns that aluminum bands may become illegible over time because mottled ducks frequent coastal wetlands, the SCDNR began transitioning to stainless-steel bands in 2010. These approaches resulted in four banding scenarios for mottled ducks in our study (Table 1): 1) an aluminum toll-free band from 2008–2009, 2) either an aluminum toll-free or stainless-steel web-address band in 2010; 3) either an aluminum or stainless-steel web-address band from 2011–2013; or 4) a stainless-steel web-address band from 2014–2017.

We obtained from the BBL all normal banding records (status code 300) for mottled ducks captured in South Carolina between 2008–2017 and unsolicited recovery (i.e., shot or found dead) records of those birds during hunting seasons from 2008–2009 to 2017–2018. We considered normal records as mottled ducks captured during July–September and solely marked with a standard numbered USGS leg-band. We excluded individuals marked with an auxiliary marking device (e.g., radio-transmitter) as part of independent research, as such markers may differentially influence survival or reporting probabilities compared to only banded individuals (Murray and Fuller 2000). We also removed those records which did not indicate age or sex at time of banding, records where the harvested bird was described as a mallard, and also one report which lacked a recovery date.

We used the dead recovery model with Brownie parametrization in Program MARK to estimate annual survival (*S*) and recovery probabilities (*f*) among combinations of age, sex, year, and band material (aluminum or stainless steel; recovery only) (Brownie et al. 1985). With the age category models, individuals marked as juveniles were assigned the same survival and recovery probabilities as adults ≥1 year after marking. Recovery probability is the product of the individual probabilities that a banded bird is killed, retrieved, and reported to the USGS BBL. Boomer et al. (2013) reported no evidence that inscription (toll-free or web-address) impacted reporting probabilities for mallards from 2007–2010. Moreover, since band material should not influence the probability that a bird is killed nor retrieved, we assumed that any potential variation in recovery probabilities between band materials stemmed from disparate band retention or inscription attrition. We ranked models using quasi-Akaike's Information Criterion ($QAIC_c$) adjusted for overdispersion using a variance inflation factor ($\hat{c} = 1.39$) calculated from 1,000 bootstrap simulations of the saturated model (Burnham and Anderson 2002, Balkcom and Mixon 2015). We addressed multi-model uncertainty by model averaging survival and recovery estimates among competing models ($\Delta QAIC_c \leq 2$; Burnham and Anderson 2002). We used reporting probabilities (λ) of 0.73 (Garrettson et al. 2014) and 0.65 (P. R. Garrettson, USFWS, personal communication; Haukos 2015) to derive harvest probabilities (K*c*) from recovery probabilities (*f*) using the equation $f / \lambda = Kc$. The 73% reporting probability was derived by Garrettson et al. (2014) from mallards in the eastern population marked with toll-free inscription reward-bands and has been used as a fitting mottled duck reporting probability on the east coast (Balkcom and Mixon 2015); the 65% reporting probability was derived from a sample of mottled ducks banded in 2007–2008 in the Western Gulf Coast.

Results

Between 2008 and 2017, 3,594 mottled ducks were banded in South Carolina which yielded 525 recoveries, 260 (50%) of which were direct recoveries, that is, they occurred in the hunting season immediately following banding (Table 1). There were four competing models ($\Sigma w_i = 0.72$; Table 2) that contained combinations of two survival and two recovery parameterizations. The survival parameter was represented by models containing variation among age and sex classes, or variation solely by age (Table 2). Variation in the recovery parameter was best estimated among age and sex classes or sex only (Table 2). We found a lack of support for annual variation in either survival ($\Delta QAIC_c \geq 17.0$) or recovery parameters ($\Delta QAIC_c \geq 18.8$), nor evidence that band material impacted recovery probabilities ($\Delta QAIC_c \geq 2.3$; Table 2).

Model averaged parameters revealed that annual survival was greatest for adult males (0.60 ± 0.03 [SE]), followed by adult females (0.57 ± 0.04), juvenile females (0.44 ± 0.13), and juvenile males (0.32 ± 0.07). Recovery probabilities were greatest for ju-

Table 2. Competitive model selection results of survival (*S*) and recovery (*f*) of mottled ducks (*Anas fulvigula*) banded in South Carolina, 2008–2018. Number of parameters (*K*), model weight (w_i), and quasi-deviance (Qdev) are displayed with the difference in second order Quasi-Akaike's Information Criterion compared to the top-ranked model ($\Delta QAIC_c$). In age models, individuals marked as juveniles were assigned the same survival and recovery rates as adults ≥1 year after marking.

Model	*K*	$\Delta QAIC_c$	w_i	Qdev
$S_{Sex*Age}\,f_{Sex*Age}$	8	0.00	0.23	3158.73
$S_{Age}\,f_{Sex*Age}$	6	0.34	0.19	3163.08
$S_{Age}\,f_{Sex}$	4	1.40	0.11	3168.15
$S_{Sex*Age}\,f_{Sex}$	6	1.47	0.11	3164.21
$S_{Sex*Age}\,f_{Sex*Age + BndType}$	9	2.00	0.08	3158.71
$S_{Sex*Age}\,f_{Sex*Age + BndType*YSM(<5,\geq 5)}$ [a]	11	2.19	0.08	3154.88
$S_{Age}\,f_{Sex*Age + BndType}$	7	2.33	0.07	3163.07
$S_{Age}\,f_{Sex + BndType}$	5	3.22	0.05	3167.97
$S_{Sex*Age}\,f_{Sex + BndType}$	7	3.30	0.04	3164.03
$S_{Sex*Age}\,f_{Sex*Age + BndType*YSM(<6,\geq 6)}$ [a]	11	4.01	0.03	3156.71
$S_{.}\,f_{.}$	2	42.99	0.00	3213.75

a. Post-hoc models where years since marking (YSM) was classified into two levels indicated in parentheses.

venile males (0.10 ± 0.02) followed by adult males (0.08 ± 0.01), juvenile females (0.05 ± 0.01), and adult females (0.05 ± 0.01). Using the two reporting probabilities of 73% and 65%, we estimated harvest probabilities of 6.3% and 7.0% for adult females, 7.2% and 8.0% for juvenile females, 11.0% and 12.3% for adult males, and 13.9% and 15.6% for juvenile males, respectively.

Discussion

Annual survival of South Carolina mottled ducks banded from 2008–2017 was within the range of reported estimates from their endemic range (Johnson et al. 1995, Balkcom and Mixon 2015, Haukos 2015, McClinton et al. 2019). As predicted, annual survival was greatest for adults with only slight differences between sexes. However, there was substantial disparity in survival probabilities between juvenile males and females; in fact, male juveniles had the lowest reported annual survival probabilities for the species. A contributing factor may have been that our juvenile male recovery probability was twice that of juvenile females. However, the annual survival probability of juvenile males in South Carolina was similar to that found in Georgia despite a nearly 50% lower recovery probability in South Carolina. Differences in these values between the two studies suggests that mortality of juvenile males in South Carolina may be occurring between the period of banding and hunting season, that juvenile males in South Carolina dispersed to areas with less susceptibility to harvest mortality, or that natural mortality rates of juvenile males may be greater in South Carolina for some reason which is at this time unknown.

Mottled ducks typically fulfill their annual requirements within a relatively small range, but males will occasionally make longer movements. In coastal Georgia and South Carolina, for example, Pollander et al. (2019) found seasonal home ranges to be <5,000 ha, with longest seasonal mean daily movements <12 km/day during the breeding season. Such long-distance movements are uncommon during the post-breeding period, but have been observed primarily before molt (Moon et al. 2015) or following major weather events (Davis 2012). Pollander et al. (2019) reported six long distance movements, of which five were made by males (2 HY, 3 AHY). Marty et al. (2018) reported that two male mottled ducks banded in southwest Louisiana were harvested in North Dakota (i.e., >1990 km). Moreover, Haukos (2015) found that 35% of direct recoveries of juvenile male mottled ducks banded in Texas were recovered in Louisiana, suggesting that juvenile males are the cohort most likely to disperse. Among inter-state recoveries of mottled ducks used in our survival analysis, 78% (21 of 27) were males (24% hatch-year, 76% after-hatch-year). Little is known about movements of juvenile male mottled ducks because most previous work focused on adult females, which appear to have lower dispersal rates than males (Davis 2012, Moon 2014, Haukos 2015). High dispersal and potentially increased mortality during dispersal of juvenile males between the banding and hunting season may explain low survival and recovery probabilities for that cohort of birds.

Bielefeld and Cox (2006) found adult females in east-central Florida were most susceptible to mortality during the post-breeding period. Moreover, Moon et al. (2017) found increased mortality of adult female mottled ducks during special teal (*Spatula discors* and *Anas crecca*) hunting seasons in 2 of 3 years. Special harvest opportunities exist for teal in South Carolina in mid-September. This period tends to coincide with cessation of the remigial molt for mottled ducks following any capture-banding efforts but prior to the main hunting season, a period when mortality is assumed to be zero in survival estimation. However, experimental teal hunting seasons in South Carolina have been controversial and were nearly eliminated in 2003 due to >25% harvest or attempted harvest of non-target species (e.g., wood ducks [*Aix sponsa*] or mottled ducks) (Migratory Bird Hunting 50 CFR § 20 2003). Thus, possible illegal non-target harvest of mottled ducks may go unreported by hunters, causing a recovery probability that is biased low, despite removal of those birds from the population (Moon et al. 2017). If this illegal harvest disproportionately removes juvenile males from the population, because they are making more and longer movements, this may explain relatively low recovery probability together with high mortality probabilities.

Contrary to prediction, our best supported models did not contain evidence that band material impacted recovery probabilities of South Carolina mottled ducks. Mottled duck recovery probabilities remained relatively high (i.e., >5%) and may have masked any small differences in recovery probabilities between materials that may be clearer when the overall recovery probability is low. Moreover, Gaston et al. (2013) stated that the choice between soft- or hard-metal bands should be made based on the longevity of the species regardless of the primary environment (i.e., saltwater) it may occupy. In our analyses, a post-hoc heavily parameterized and uncompetitive model ($\Delta AIC_c = 3.0$) suggested that the odds of recovering an aluminum banded mottled duck was 56% (-17%–83%) lower than one banded with stainless steel ≥5 years after banding. Using adult male annual survival probabilities (i.e., greatest value recorded) and assuming constant daily survival, mean life expectancy of South Carolina mottled ducks is ~2 years. It then seems plausible mottled ducks may not live long enough to be impacted by band retention and wear. Nonetheless, all mottled ducks banded in South Carolina since 2014 have been banded with hard-metal bands, so there should be no question whether band retention or inscription attrition impact survival or recovery probabilities in the future.

In 2008–2010, we used toll-free inscribed aluminum bands; whereas, web-address inscriptions were used exclusively thereafter regardless of band material. Although Boomer et al. (2013) found no evidence for disparate harvest reporting probabilities for mallards by band inscription, Sanders and Otis (2012) reported greater reporting probabilities for web-address inscription bands on mourning doves (*Zenaida macroura*). If reporting probabilities of mottled ducks increased with the introduction of web-address bands in 2011, greater mottled duck harvest probabilities may have occurred but been masked by lower reporting probabilities in 2008–2010. Moreover, harvest probabilities reported herein are subject to assumptions of published reporting probabilities for Western Gulf Coast mottled ducks or mallards (i.e., 65% and 73%) such that any positive deviation in reporting probability for South Carolina mottled ducks would result in lower harvest probabilities and vice versa. However, these standard reporting probabilities allow comparison across the endemic and introduced range of mottled ducks.

Our results provide estimated mottled duck survival and recovery probabilities for South Carolina that can be used by biologists to assess sensitivity of factors affecting population growth, provide a baseline for comparison to future probabilities, and identify future research needs. Future research should focus on seasonal juvenile male survival and dispersal rates to identify time periods, wetland types, or mortality sources that may contribute to lower survival and may be ameliorated by targeted habitat restoration or wetland management. Although juvenile male survival probabilities were low, there has been no indication that male survival has limited pair formation or have any negative effect on population growth rates (Kneece 2016). Moreover, managers should determine reliable estimates of total mottled duck harvest among age and sex classes to provide needed data to inform Lincoln estimators (i.e., Lincoln 1930, Alisauskas et al. 2014) and allow for estimation of mottled duck population size in South Carolina to further improve the understanding of this species. Because of mottled duck exchange between South Carolina and Georgia, and apparent isolation from Florida and the WGC, managers may wish to combine estimates from the two states to derive a population estimate for introduced mottled ducks along the Atlantic coast.

Acknowledgements

We are grateful for financial and logistical support from Nemours Wildlife Foundation, South Carolina Department of Natural Resources, Mississippi State University (MSU) College of Forest Resources, and the James C. Kennedy Endowed Chair in Waterfowl and Wetlands Conservation at MSU. The authors also thank Bob Gitzen, associate editor and Greg Balkcom, Pam Garrettson, and an anonymous reviewer for their thoughtful comments that improved this manuscript. This publication is a contribution of the Forest and Wildlife Research Center, Mississippi State University.

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