Duckling Survival, Fecundity, and Habitat Selection of Mottled Duck Broods on the Upper Texas Gulf Coast

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Abstract: Mottled ducks (*Anas fulvigula*) on the western Gulf Coast have exhibited a steep population decline since the mid 1990s. Low rates of breeding incidence and nest success have been implicated in this decline, but duckling survival and the habitat needs of broods have not been previously investigated in this region. We fitted mottled duck ducklings and adult females with radio transmitters and tracked broods to estimate duckling survival and brood habitat selection on the upper Texas Gulf Coast. Duckling survival to 30 days was high (range among models 0.354 – 0.567) compared to other dabbling duck species. Estimated fecundity was low, (range among models 0.398 – 0.634) however, indicating that overall reproductive output is low. Within coastal marsh, broods selected home ranges with more water cover and less upland and fresh marsh landcover than was available in the study area. Within coastal marsh home ranges, broods selected for water cover relative to other landcover types, and there was some evidence that broods avoided unvegetated landcover. Although high quality brood habitat is undeniably important, management efforts to increase mottled duck population growth on the western Gulf Coast may best be spent on increasing nesting habitat quality to increase nest success and breeding incidence.

Key words: Anas fulvigula, brood, duckling survival, fecundity, habitat, mottled duck

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Mottled ducks (*Anas fulvigula*) are year-round residents of marshes along the Gulf of Mexico coast and peninsular Florida (Bielefeld et al. 2010). The western Gulf Coast population of Texas and Louisiana is considered genetically distinct from the Florida population (McCracken et al. 2001); hereafter, we will only consider the western Gulf Coast population. Unlike the many migrant waterfowl that winter along the Gulf Coast, mottled ducks rely on the coastal marshes for their entire life cycle, including breeding, molting, and wintering there (Bielefeld et al. 2010). Gulf coastal marshes face a number of threats, including subsidence (White and Tremblay 1995), development (Morton and Paine 1990), sea-level rise, and changes in hydrology (Moon 2014). A sea-level rise model, for example, predicted that irregularly flooded marsh (the habitat type used most by mottled ducks in that study) would decline from 60% of landcover within mottled duck home ranges to 32% by 2100 (Moon 2014).

Without a long-term, range-wide survey, population trends for Gulf Coast mottled ducks are based on a variety of regional surveys and banding data. Metapopulation dynamics between Texas and Louisiana are largely unknown, but some movement of adults between states is likely. Bielefeld et al. (2010) concluded the weight of evidence suggests a long-term steep population decline in Texas and a stable long-term trend in Louisiana with a stable or slightly decreasing long-term trend for the population as a whole.

A steep decline in the mottled duck population was indicated by an analysis of band recovery data and age ratios from wings of hunter-killed birds in Texas and Louisiana (Johnson 2009). A matrix population model using available vital rates indicated a population growth rate of $\lambda = 0.54$ (Rigby and Haukos 2014), much less than the $\lambda = 1$ necessary for a stable population. An annual aerial breeding pair survey of Texas National Wildlife Refuges (NWRs) estimated a density of 1.04 mottled duck pairs / km^2 in 2012, representing a decline of 65% from the 26-year long-term average of 3.38 pairs/km^2 (U.S. Fish and Wildlife Service 2013). The Midwinter Waterfowl Survey (MWS, which includes mottled ducks in Texas and Louisiana and extends beyond NWRs) estimated 18,096 mottled ducks in surveyed areas in Texas in 2012, a 30% decline from the 28-year long-term average (U.S. Fish and Wildlife Service 2013). Mottled ducks surveyed in Louisiana did not appear to share the decline, showing a 0.8% annual increase over the long term (U.S. Fish and Wildlife Service 2013).

Most of the research into mottled duck population dynamics has focused on nest success (e.g., Holbrook et al. 2000, Walters et al. 2001, Durham and Afton 2003, Finger et al. 2003) and estima-

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tion of adult survival from band recoveries (Haukos 2010) or telemetry (Rigby and Haukos 2012, Moon 2014). Several population vital rates, however, have not been investigated, even though any stage of the life cycle can affect population growth rate (Johnson et al. 1992). Ducklings are particularly vulnerable to mortality, but survival during this period is seldom investigated due to the difficulty of tracking ducklings and broods (Johnson et al. 1992, Sedinger 1992). Nesting vital rates may provide an index to fecundity, but the correlation between those rates is often poor (Etterson et al. 2011). To accurately estimate fecundity, defined as the number of offspring produced per female for a pre-defined period (Etterson et al. 2011), an estimate of duckling survival is essential.

Although habitats used by adults (Haukos et al. 2010, Moon 2014) and nesting females (Walters et al. 2001, Durham and Afton 2003, Rigby and Haukos 2012) have been documented for mottled ducks, information on brood habitat use is lacking. Investigating brood habitat selection in coastal marsh would increase our knowledge of the suite of habitats required by the species throughout its life cycle and aid managers' efforts to create and maintain habitat for broods. Our objectives for mottled ducks on the upper Texas Gulf Coast were to (1) estimate duckling survival, (2) estimate fecundity, and (3) determine habitat selection by broods in coastal marsh.

Study Site

Mottled duck broods were studied during the breeding seasons of 2006–2008 on Anahuac NWR in Chambers County, Texas (29°28′N – 29°41′N, 94°21′W – 94°37′W). The 139-km^2 refuge included coastal marsh and prairie and managed moist-soil units (MSUs) and was situated on the Chenier Plain, which contains the greatest density of mottled ducks on the western Gulf Coast (Bielefeld et al. 2010). Hurricane Rita affected habitat conditions when it made landfall approximately 68 km east of Anahuac NWR on 24 September 2005 (Knabb et al. 2006). The storm surge inundated much of the refuge with saltwater. A subsequent drought resulted in high salinities and low water levels in many areas, which lasted until late-season precipitation in June 2006. Conditions in 2007 were wetter, with higher water levels and lower salinity. These conditions persisted until precipitation decreased in spring 2008, resulting in a late breeding season drought (Rigby 2008).

Methods

Capture and Radio-Telemetry

We caught mottled duck ducklings from airboats at night, keeping all brood members together during handling. Captures occurred in both managed freshwater moist-soil units and across types of coastal marsh (fresh, intermediate, brackish, and saline). All duckling captures occurred between 25 April and 27 June. Each captured duckling was aged according to Gollop and Marshall (1954) and Stutzenbaker (1988), weighed with a spring scale (g), and banded with a U.S. Geological Survey aluminum leg band (if sufficient size to retain a band). We randomly selected two ducklings from each brood and fitted each with an A2430 transmitter (Advanced Telemetry Systems [ATS], Isanti, Minnesota) with an expected battery life of 72 days. The transmitters weighed 1.4–1.7 g, which was <5% of body weight as recommended by Samuel and Fuller (1994). In 2006 and 2007, transmitters were attached to the plucked interscapular area with cyanoacrylate glue, as recommended by ATS. In 2008, we used sutures (Wheeler 1991) in addition to the glue, to increase transmitter retention time. Trapping and handling procedures followed guidelines set by permits from the Texas Tech University Animal Care and Use Committee (06026-06) and U.S. Fish and Wildlife Service.

Ducklings were tracked daily with an ATS model R4000 radio receiver via a 3-element hand-held AF Antronics, Inc. yagi antenna. Visual observations were obtained every 3 days. To minimize brood disturbance, duckling survival was considered confirmed on days without visual observation if the position of the radio signal had moved at least 30 m since the previous day. Mortality was determined by discovery of a duckling carcass; lost signals were right-censored in analysis.

To increase sample size of duckling home ranges and habitat selection in coastal marsh, we also captured and radio-transmitted adult females to follow their broods. Adult females in coastal marsh were captured prior to nesting using swim-in traps baited with rice or a mixture of rice, molasses, and sweet potatoes and decoy traps baited with a live mallard (*Anas platyrhynchos*). We weighed and banded each female with a U.S. Geological Survey aluminum leg band. We then fitted each female with a 23-g Advanced Telemetry Systems A1800 back-mounted radio transmitter (ATS Inc., Isanti, Minnesota). Adult females were tracked on foot via homing (Mech 1983) and visually observed every 3–4 days. Adult female locations were classified as brood locations if the female was seen with ducklings or if the female displayed brood behavior (not flushing when approached and/or splashing or quacking to distract the observer from the brood) after a previous visual observation with ducklings.

Analysis

We used the Known Fate Procedure of Program MARK (White and Burnham 1999) to estimate daily duckling survival from encounter data. Due to small sample size within years, we did not estimate survival among years, instead pooling data across years. We tested 3 models for the 70-day encounter period: constant survival with and without a mean-centered body mass covariate and survival differing by week. Models were ranked by Akaike's information criterion for small sample sizes (AIC_c, Burnham and Anderson 2002).

Due to low nesting densities of mottled ducks in Texas, we were unable to track broods from nests to brood-rearing habitat. Thus, our duckling survival estimate cannot account for duckling mortalities during this period, a time known for high duckling mortality (Johnson et al. 1992). Few data exist regarding this period for mottled ducks, but Baker (1983) followed 5 radio-transmittered females and their broods from the nest to brood-rearing habitat in Cameron Parish, Louisiana. Three of the 5 broods took 2 days for the journey, 1 brood was lost on the first day, and 1 brood finished the trip in 1 day. We used the Known Fate procedure of Program MARK to estimate daily duckling survival during those 2 days from Baker's (1983) data.

We calculated duckling survival to 30 days post-hatch as $D = \Pi D_i$, where D_i = daily duckling survival on day *i* ($i = 1, 2, \ldots, 30$). We assumed the daily duckling survival estimate from Baker (1983) represented D_i during the trip from the nest to brood-rearing habitat and the model-averaged daily duckling survival estimate from our data represented D_i thereafter up to 30 days. Due to uncertainty regarding the length of the trip from nest to brood-rearing area, we calculated D for 3 possible trip lengths (1, 2, and 3 days). We used the Delta method (Powell 2007, 2012) to estimate D and associated standard errors from the daily survival estimates for the 3 trip length scenarios.

We used Etterson et al.'s (2011) framework to guide our estimation of fecundity (F),

$$F = Y \times S \times N \times P,$$

where Y = expected number of young per successful nest raised to a specified level of development (here, 30 days), S = expected probability that a nest fledges at least one fledgling (nest success), N = expected number of nest attempts per breeding female, and P = probability that a female attempts to breed in a season (breeding propensity or breeding incidence).

Y can be viewed as a product of vital rates. We used

$$Y = C \times Q \times D,$$

where C = clutch size, Q = the proportion of eggs that hatch, or hatchability, and D = duckling survival to 30 days. N requires a precise estimate of renesting effort, which is not available for mottled ducks. Instead, we drew on Cowardin and Johnson's (1979) approximation for hen success (H), a product of nest success and renesting effort. They used

$$H = S \times e^{(1-S)^\wedge 2},$$

so we assumed $H = S \times N$, making $N = e^{(1-S)^\wedge 2}$. Our final equation for fecundity was therefore

$$F = C \times Q \times D \times S \times e^{(1-S)^\wedge 2} \times P.$$

We estimated variation in fecundity via Monte Carlo simulation (Thomopoulos 2013). We ran simulations under 5 models of duckling survival to 30 days post-hatch (Table 1). For models 1, 2, and 3, trip length was constant at 1, 2, or 3 days, respectively. For model 4, trip length was 1, 2, or 3 days with equal probability of each trip length. For model 5, trip length was 1, 2, or 3 days with Pr(trip length = 1 day) = 0.25, Pr(trip length = 2 days) = 0.5, and Pr(trip length = 3 days) = 0.25.

We calculated process variance ($\sigma_{process}$, White 2000) for vital rates for which >2 estimates were available (C, S, P). We estimated variation for Q using the binomial distribution (Snedecor and Cochran 1968: 207) and report the standard error for Q as a weighted average of estimates. We transformed apparent nest success reported in Finger et al. (2003) to approximate Mayfield nest success (Green 1989, Johnson 1991). We assigned probability distributions to each vital rate in the fecundity estimation equation (above) and parameterized them with previously reported estimates of those vital rates (Table 2) and our duckling survival estimates. We assumed

Table 1. Duckling survival for mottled ducks on the western Gulf Coast was modeled using 5 probability distributions for the trip length from nest to brood-rearing area. Fecundity was then estimated using previously reported vital rates (Table 2) and model-averaged duckling survival to 30 days.

Model	Pr(Trip length = 1 day)	Pr(Trip length = 2 days)	Pr(Trip length = 3 days)	Estimated fecundity (F)	SE(F)
1	1	0	0	0.634	0.00147
2	0	1	0	0.504	0.00118
3	0	0	1	0.398	0.000946
4	0.33	0.33	0.33	0.512	0.00126
5	0.25	0.5	0.25	0.512	0.00125

Table 2. Estimates of vital rates for mottled ducks on the western Gulf Coast were extracted from previous literature (rates also used by Rigby and Haukos 2014). Rates include: C = clutch size, Q = hatchability (the proportion of eggs that hatch), S = nest success, and P = breeding incidence. Process variance ($\sigma_{process}$, White 2000) was calculated for vital rates for which >2 estimates were available (C, S, P). We estimated variation for Q using the binomial distribution (Snedecor and Cochran 1968: 207) and report the standard error for Q as a weighted average of estimates.

Vital rate	Mean	$\sigma_{process}$ or SE	Sources
C	9.214	0.583	Johnson et al. 2002, Finger et al. 2003, Durham and Afton 2006
Q	0.947	0.0106	Finger et al. 2003, Stutzenbaker 1988
S	0.158	0.0758	Holbrook et al. 2000, Walters et al. 2001, Durham and Afton 2003, Finger et al. 2003[a]
P	0.420	0.214	Finger et al. 2003, Rigby and Haukos 2012

[a] Apparent nest success reported in Finger et al. (2003) was transformed to approximate Mayfield nest success (Green 1989, Johnson 1991).

C was normally distributed. We assumed Q, D, S, and P were beta-distributed, as these vital rates are logically bounded between 0 and 1. We used the estimated mean ($\bar{x}$) and standard error (SE) or process variation (σ_{process}) to calculate shape parameters α and β for the beta distribution, where $\alpha = \bar{x}\,[\bar{x}(1-\bar{x})/\sigma_{\text{process}}^{2} - 1]$ and $\beta = (1-\bar{x})\,[\bar{x}(1-\bar{x})/\sigma_{\text{process}}^{2} - 1]$. For each of 100,000 iterations, we generated a value for each vital rate from the assigned probability distribution and calculated fecundity using program R version 3.0.2 (R Core Development Team 2013).

We tested coastal marsh habitat selection by mottled duck broods rather than ducklings, because locations for individual ducklings were not independent. Broods caught in managed moist-soil units (MSUs) were excluded because we suspected roads, levees, and disparate upland habitat surrounding MSUs might present barriers to movement, and we were primarily interested in selection within coastal marsh habitat. Brood locations included either all locations for the duckling with the longest telemetry history or all locations for a transmittered female between the first and last sightings of her ducklings. We performed a compositional analysis of habitat use (Aebischer et al. 1993), using brood locations and a spatial vegetation inventory. The inventory covered 93.3 km^2 of coastal marsh on Anahuac NWR and was constructed using multi-spectral ortho-rectified digital 0.5 m imagery, acquired on 14 March 2008 (P. Donnelly, U.S. Fish and Wildlife Service, unpublished data). In April 2008, 34 vegetation types on the refuge were classified in the field to the upper most floristic level (Alliance) of the National Vegetation Classification Standard (NVCS, Federal Geographic Data Committee 2008). Field data were used to train the classification model, including 1028 training and 263 accuracy assessment plots. The overall accuracy of the classification was 92.4% and the kappa statistic was 0.978. Landcover types were grouped into 7 categories based on salinity requirements and taxonomy of dominant species (Table 3). Because vegetation alliance A.1481 (Spartina patens and Distichlis spicata) covered >30% of the study area, we also performed the analysis using only that alliance as an 8th landcover category. Significant results of that analysis did not differ from the 7 category analysis, so we present results for the 7 landcover categories only (Table 3).

In the compositional analysis, we compared habitat use in coastal marsh to availability at 2 scales as defined by Johnson (1980): 2nd order selection (selection of home ranges within the study area) and 3rd order selection (brood locations within home ranges). We used the extent of the vegetation inventory as the habitat selection study area and eliminated ducklings captured outside that area from the habitat selection analysis. The vegetation inventory included coastal marshes and prairies with a range of salinities. Home ranges were estimated using a 95% kernel utilization distribution, calculated with the least-squares cross validation method (LSCV) method for h, the smoothing factor (Worton 1989). We carried out the analysis using package adehabitatHS (Calenge 2011) for program R version 3.0.2 (R Core Development Team 2013). Aebischer et al. (1993) recommended using at least 30 locations for each animal to avoid bias in home range size due to number of locations, but that sample size was precluded in

Table 3. Landcover types were combined into categories by salinity and hydrological needs for dominant species on Anahuac National Wildlife Refuge for 2008. Categories were informed by Visser et al. (2000).

Landcover category	NVCS Alliance	Vegetation type	Percentage of study area
Brackish / intermediate marsh	A.1481	*Spartina patens – (Distichlis spicata)*	30.64
	A.1390	*Spartina patens*	15.85
	A.1344	*Paspalum vaginatum*	2.30
	A.1274	*Spartina patens – (Schoenoplectus pungens)*	0.04
	Total		*48.83*
Fresh marsh	A.1472	*Typha (angustifolia, domingensis)*	2.61
	A.1436	*Typha (angustifolia, latifolia) – (Schoenoplectus* spp.)	2.17
	A.1990	*Eleocharis quadrangulata – Sagittaria* spp.	1.98
	A.1431	*Phragmites australis*	0.82
	A.1375	*Juncus effusus*	0.22
	A.1984	*Nymphaea odorata* – Nuphar spp.	0.11
	A.1395	*Zizaniopsis miliacea*	0.10
	TCP-01	Early successional floaton *(Leersia, Eleocharis* spp., *Alternanthera, Ludwigea, Hydrocotyle, Limnobium)*	0.02
	Total		*8.03*
Intermediate *Shoenoplectus* spp.	A.2007	*Schoenoplectus americanus*	16.22
	A.1434	*Schoenoplectus robustus*	1.11
	A.1173	*Schoenoplectus tabernaemontani*	0.27
	A.1171	*Schoenoplectus californicus*	0.03
	Total		*17.63*
Unvegetated	Road	Road	0.38
	Unclassified	Unclassified	0.10
	VII.C.4.N.b.	Intermittently flooded mud flats	0.05
	VII.C.2.N.b.	Intermittently flooded sand beaches and shores	0.03
	VII.C.3.C.b.	Non-agriculture disturbed areas	0.02
	VII.C.2.N.c.	Temporarily flooded sand flats	0.01
	Total		*0.58*
Saline marsh	A.1882	*Distichlis spicata*	5.06
	A.1471	*Spartina alterniflora*	0.43
	A.1475	*Juncus roemerianus*	0.22
	Total		*5.71*
Upland	A.1230	*Spartina spartinae*	5.92
	A.1888	*Tamarix* spp.	0.14
	A.1015	*Baccharis halimifolia*	0.09
	A.1483	*Spartina spartinae*	0.06
	A.257	*Triadica sebifera*	<0.01
	Total		*6.22*
Water	Water	Water	13.00

our study due to transmitter retention time and following broods only to age 30 days. We tested for an effect of number of telemetry locations on the size of home ranges using linear regression. The relationship was very weak ($F_{10} = 0.32$, $P = 0.58$), so we estimated brood home range size using all available brood locations for broods with ≥5 locations. Because habitats types were often finely enmeshed, the finest scale of habitat composition was estimated within a 10-m radius around brood locations rather than the singular habitat type in which the brood was found (e.g., 45% of a 10-m circle was Habitat A and 55% was Habitat B, rather than a single designation (A or B) as in Aebischer et al. (1993)). Fresh marsh was not used as a habitat category in 3rd order selection analysis because it was only available in the home range of 1 brood.

Results

We captured and tracked a total of 59 ducklings: 7 ducklings from 4 broods in 2006, 43 ducklings from 23 broods in 2007, and 9 ducklings from 5 broods in 2008. Mean body mass for all captured ducklings across all years was 259.6 g (SE = 20.0) and mean brood size was 4.3 (SE = 2.7). Duckling age at capture ranged from class IA-IIB (Gollop and Marshall 1954); 14 broods were class I and 18 were class II. Transmitter attachment was problematic in all years; transmitter retention was <15 days for all ducklings. Average transmitter retention lasted 4.1 days, with 239 overall exposure days available for survival estimation. Two ducklings were found dead, both in 2007. We captured and radio-tagged 47 females over 3 years. Four female mottled ducks had broods inside the study area with enough brood locations to contribute to the compositional analysis of habitat use in coastal marsh.

Of the 3 duckling survival models we compared in Program MARK, only models with constant survival showed evidence of support (Table 4). Including duckling mass at capture as a covariate did not improve the model ($\Delta\text{AIC}_c = 0.81$). For the top-

Table 4. Model selection results for duckling survival of mottled ducks on the upper Texas Gulf Coast, 2006-2008.

Model	AIC_c	ΔAIC_c	AIC_c Weight	Model likelihood	Parameters
Constant survival	23.3	0	0.60	1	1
Constant survival with body mass covariate	24.1	0.8	0.40	0.67	2
Survival differs by week	37.8	14.5	<0.001	<0.001	10

Table 5. Simplified compositional analysis results for mottled duck brood use of 7 habitat types on Anahuac National Wildlife Refuge, Texas, 2006–2008. We examined (a) 2nd-order habitat selection of home ranges within the study area and (b) 3rd-order habitat selection of brood locations within home ranges. For row *i*, column *j*, the sign indicates if habitat *i* was selected more than habitat *j*. A double sign indicates a significant result at α = 0.1 and a triple sign indicates a significant result at α = 0.05. Fresh habitat was not examined for 3rd-order selection because it was only available within the home range of 1 brood.

a) Home range (95% kernel utilization density) vs. total study area

	Unvegetated	Upland	Saline marsh	Water	Brackish and intermediate marsh	Intermediate *Schoenoplectus*	Fresh marsh
Unvegetated		++	–	–––	–	–	+++
Upland	––		–––	–––	–––	–––	+++
Saline	+	+++		–––	+	+	+++
Water	+++	+++	+++		+++	+++	+++
Brackish and intermediate marsh	+	+++	–	–––		+	+++
Intermediate *Schoenoplectus*	+	+++	–	–––	–		+++
Fresh	–––	–––	–––	–––	–––	–––	

b) Brood locations vs. home range (95% kernel utilization density)

	Unvegetated	Upland	Saline marsh	Water	Brackish and intermediate marsh	Intermediate *Schoenoplectus*
Unvegetated		–	––	–––	–	––
Upland	+		–	–––	–	–
Saline	++	+		–––	+	–
Water	+++	+++	+++		+++	+++
Brackish and intermediate marsh	+	+	–	–––		–
Intermediate *Schoenoplectus*	++	+	+	–––	+	

ranked model, estimated daily duckling survival was $D_i = 0.987$ (SE = 0.00937); model-averaged daily duckling survival was $D_i = 0.989$ (unconditional SE = 0.00954). Using Baker's (1983) data, we estimated daily duckling survival during the trip from the nest to brood-rearing habitat as $D_i = 0.782$ (SE = 0.0467). Duckling survival to 30 days was D = 0.567 (SE = 0.162) assuming a 1-day trip length from nest to brood-rearing area, D = 0.448 (SE = 0.133) for a 2-day trip length, and D = 0.354 (SE = 0.113) for a 3-day trip length. Mean fecundity was greatest for the model with a 1-day trip length (F= 0.634, SE = 0.00147) and smallest for the model with 3-day trip length (F = 0.398, SE = 0.000946) (Table 1).

Of the 32 transmittered broods, 17 were captured in coastal marsh and were eligible for habitat selection analysis. Habitat selection was not estimable for 4 broods captured in the Alice Jackson White unit due to a lack of aerial imagery for that area. In all, 12 broods had sufficient locations (≥5) for assessment of habitat selection within coastal marsh: 8 broods tracked via transmittered ducklings and 4 broods with tracked via transmittered adult females. Mean number of locations per brood was 8.1 (SE = 0.83). Mean home range size for broods was 0.698 km^2 (SE = 0.173 km^2). The compositional analysis showed broods selected home ranges with more water cover and less fresh and upland landcover than was available in the study area (Table 5). Within home ranges, broods selected locations with more water landcover. There was some evidence ($0.1 > P > 0.05$) that broods selected against unvegetated landcover when choosing locations within home ranges.

Discussion

Although mottled duck duckling survival was moderate to high in our study, estimated fecundity for the population was low due to low estimates of nest success and breeding incidence. The disparity between duckling survival and overall fecundity for mottled ducks emphasizes the importance of examining multiple stages of the life cycle when evaluating population status. When mottled duck vital rates spanning the life cycle were examined in a matrix population model, the population growth rate was $\lambda = 0.54$, indicating a steep population decline (Rigby and Haukos 2014). Nest success and breeding incidence were low and responsible for the most variation in λ (Rigby and Haukos 2014).

Mottled duck duckling survival to 30 days (mean range among models 0.354 – 0.567) was consistent with Finger et al.'s (2003) estimate for ducklings on the mid-coast of Texas (D = 0.41). Both estimates are moderate to high compared to other dabbling duck studies. Recent estimates of duckling survival to 30 days for mallards include: D = 0.40 in southern Ontario, Canada (Hoekman et al. 2004, range among sites 0.07 – 0.50), D = 0.25 in California (Chouinard and Arnold 2007), and D = 0.26 and D = 0.16 for 2 years in North Dakota (Amundson and Arnold 2011, range among site-years = 0.007 – 0.34). Largely contiguous coastal marshes on the western Gulf Coast differ structurally when compared to northern freshwater wetlands (prairie potholes) where most North American dabbling ducks breed, and the risks and resources for mottled duck ducklings may differ too. Additional investigation into mottled duck survival during the first week of life would help increase the precision of survival estimates and reveal hazards that broods face.

Despite high duckling survival on the upper and mid- Texas Gulf Coast, mottled duck fecundity was low when estimated using vital rates obtained across the western Gulf Coast (range among models 0.398 – 0.634)). Hoekman et al. (2006) estimated mallard recruitment of female young surviving to 30 days in Ontario, Canada, with a range of 0.08 – 0.99, and 4 of 5 sites had recruitment ≥0.79. If a 1:1 duckling sex ratio is assumed, their recruitment estimates can be doubled and compared to our fecundity estimate (range 0.16 – 1.98, with 4 of 5 sites having fecundity ≥1.58). Mauser and Jarvis (1994) estimated mallard recruitment of female young with range 0.31 – 1.26 in northeastern California (0.62 – 2.52 when doubled for comparison to our fecundity estimate). The high duckling survival found in our study is insufficient to produce high fecundity when rates of breeding incidence and nest success are low (Rigby and Haukos 2014).

Mottled duck broods selected water cover over all other landcover types at both scales. The study area included finely interspersed water and emergent vegetation, so broods in water were seldom far from emergent vegetation to use for foraging and cover from predators. Broods selected against upland landcover when choosing home ranges, instead using open wetlands as brood-rearing habitat.

The avoidance of fresh marsh by broods in coastal marsh was unexpected (recall, however, that our habitat analysis only examined broods in coastal marsh habitats to the exclusion of managed freshwater MSUs, which were used by many broods). We have 2 hypotheses that might explain fresh marsh avoidance within coastal marsh. First, 69.7% of fresh coastal marsh on the study area was vegetated by cattail (*Typha* spp.) and *Phragmites australis*. These species can grow 1.5 – 4 m tall and form thick stands (Stevens and Hoag 2004, Magee 2013), which may be an obstacle to broods. Second, fresh marshes may have higher abundances of brood predators (such as alligators (*Alligator mississippiensis*), which prefer freshwater) than other coastal marsh cover types. Broods could therefore avoid choosing home ranges in these areas as a way to avoid predation.

High salinity (≥9 ppt) is known to be detrimental to mottled duck duckling health (Moorman et al. 1991), but we found no avoidance of saline landcover. Salinity in coastal marshes varies on a faster time scale than changes in vegetation assemblage, so it is possible mottled ducks use these habitats when salinities are sufficiently low to meet their needs.

Although broods chose home ranges independently of unvegetated landcover, there was some evidence they selected against unvegetated landcover within those home ranges. Because roads made up most unvegetated landcover, this finding suggests mottled duck broods are able to use habitats with some human development, but may avoid human development at a fine scale.

If the high duckling survival found in our study holds true across the region, management efforts to increase the western Gulf Coast mottled duck population may be best spent on increasing nesting habitat quality in association with potential brood habitat. Increases in nest success and breeding incidence due to increased nesting habitat quality have the greatest potential to increase population growth (Rigby and Haukos 2014). Nesting habitat must be located within reach of brood habitat, however, for the life cycle to be completed. If managers working in the narrow band of coastal marsh along the Gulf of Mexico wish to encourage persistence of this species, we suggest providing habitats for all life stages, including adults, nesting females, and broods. Future population analyses for this species should consider survival during all life stages. Additional research into seasonal survival, including molt and winter survival, would greatly aid our understanding of mottled duck population dynamics. Investigating duckling survival and brood habitat use at a regional scale across the western Gulf Coast would expand our knowledge across a wider spatial range and could reveal how these factors vary spatially.

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