Habitat selection by Mottled Duck *Anas fulvigula* broods

ANASTASIA KRAINYK[1,3], RICHARD S. FINGER[1,4], BART M. BALLARD[1,*], M. TODD MERENDINO[2,5], DAVID B. WESTER[1] & RUSSEL H. TERRY[1,6]

[1]Caesar Kleberg Wildlife Research Institute, Texas A & M University-Kingsville, Kingsville, Texas 78363, USA.
[2]Texas Parks and Wildlife Department, 1700 7th St. Bay City, Texas 77414, USA.
[3]Current address: Patuxent Wildlife Research Center, 12311 Beech Forest Rd, Laurel, Maryland 20708, USA.
[4]Current address: Washington Department of Fish and Wildlife, 1550 Alder St. NW, Ephrata, Washington 98823, USA.
[5]Current address: Ducks Unlimited, Inc., Texas Field Office, 915 Front Street, Richmond, Texas 77469, USA.
[6]Current address: Ducks Unlimited, Inc. Great Lakes/Atlantic Regional Office, 1220 Eisenhower Place, Ann Arbor, Michigan 48108, USA.
*Correspondence author. E-mail: bart.ballard@tamuk.edu

Abstract

The western coast of the Gulf of Mexico provides important habitat for migrating and resident waterfowl, including the Mottled Duck *Anas fulvigula*, which relies on this region for all of its life-cycle events. The Western Gulf Coast (WGC) population has been in decline since the 1970s, primarily because of loss and degradation of large tracts of wetlands and coastal prairies due to human activities. The Mottled Duck Conservation Plan, developed by academics involved in Mottled Duck research, state and federal biologists, U.S. Fish and Wildlife Service migratory bird staff, flyway council representatives, and others, suggested that increasing recruitment is essential for the recovery of the population. Management and preservation of brood-rearing habitats are crucial for increasing recruitment rates. However, gaps still exist in knowledge of the species' ecological requirements, and relatively little research has been conducted on wetland habitat selection by female Mottled Ducks with broods. This study investigated habitat selection by 82 Mottled Duck broods from six replicate surveys of 300 wetlands in 1994 and 330 wetlands in 1995 along the Texas coast, and by tracking the movements of 14 radio-marked Mottled Duck females with broods in 2001. Brood-rearing Mottled Ducks selected palustrine unconsolidated bottom, palustrine aquatic bed, palustrine emergent, and estuarine intertidal aquatic bed wetlands. The average distance between the nest site and the wetland first used by Mottled Duck broods was 1,073 m, and the median longest daily movement by female Mottled Ducks throughout the brood-rearing period was 1,497 m. These results indicate that the proximity of nesting habitat to brood-rearing habitat is an important landscape variable to consider for future management strategies. Brood survival is a major factor driving Mottled Duck recruitment; creating or managing wetlands for these key characteristics therefore may help increase recruitment rates and stabilise the WGC Mottled Duck population.

Key words: *Anas fulvigula*, coastal marsh, Mottled Duck, Western Gulf Coast.

The Mottled Duck *Anas fulvigula* is a non-migratory dabbling duck, which inhabits the coastal marshes along the Gulf of Mexico from Alabama to the northeast coast of Mexico and peninsular Florida (Baldassarre 2014). Birds from the Western Gulf Coast (WGC) population are genetically distinct from those in the Florida population, and the two populations are geographically separate with minimal to no gene flow (McCracken *et al.* 2001; Williams *et al.* 2005); therefore, they are managed separately. Mid-winter waterfowl surveys from 1971–2009, and breeding pair surveys on national wildlife refuges from 1985–2009, indicate a long-term decline of WGC Mottled Ducks in Texas and a stable to slight decline in Louisiana (Texas Parks & Wildlife Department, unpubl. data; Louisiana Game and Fish Department, unpubl. data; Bielefeld *et al.* 2010). The most recent estimates of the Florida population indicate a weak increasing trend in spring densities from 1985–2006 (Bielefeld *et al.* 2010), but survey numbers also include Mallard *Anas platyrhynchos* × Mottled Duck hybrids (Bielefeld 2008). The WGC population of Mottled Duck is strongly associated with coastal habitats and adjoining agricultural areas throughout its range (Grand 1988; Zwank *et al.* 1989; Baldassarre 2014), whereas the Florida population largely occurs on inland freshwater and urban/suburban areas (Johnson *et al.* 1991; Bielefeld 2008). Anthropogenic activities, such as canal and dike construction, and agricultural and urban expansion along the western Gulf Coast have caused significant loss and degradation of nesting and brood-rearing habitats (Moulton *et al.* 1997; Kennish 2001; Morton *et al.* 2004; Dahl & Stedman 2013), whilst hunting and drought conditions reduce adult survival rates (Moon *et al.* 2017). Nest success (Holbrook *et al.* 2000; Walters *et al.* 2001; Durham & Afton 2003) and brood survival (Finger *et al.* 2003; Rigby 2008) vary with habitat quality. Thus, the loss of high quality brood-rearing and nesting habitat is thought to be one of the main drivers of the population decline (Wilson 2007). Previous studies have found high duckling survival rates (Rigby & Haukos 2012), and it has been suggested that improving the quality of nesting and brood-rearing habitats have the greatest potential to increase population growth (Rigby & Haukos 2014), so information on the habitat selection throughout the breeding season is required to inform appropriate management for the species.

The type of wetland habitat used has the potential to affect predator avoidance and the nutrient availability for broods (Voigts 1976; Longcore *et al.* 2006; Raven *et al.* 2007). The quality of habitats used by broods influences their growth and survivorship and is an important aspect of understanding population dynamics (Batt *et al.* 1992). There has been relatively little investigation of Mottled Ducks during the brood-rearing period (Allen 1981; Durham & Afton 2003; Finger *et al.* 2003; Rigby 2008). Consequently, this is perhaps the least known aspect of their reproductive ecology, although recent studies have found that within coastal marshes broods select home ranges with more water cover and there was some evidence that broods avoided unvegetated landcover (Rigby & Haukos 2015). According to the Mottled Duck Conservation Plan (Wilson 2007), providing brood-rearing habitat in association with nesting habitat is a key objective to increase the declining WGC Mottled Duck population (Wilson 2007). With knowledge of habitat types vital to brood-rearing activities of Mottled Ducks, managers can focus their time and resources in areas where improvement of brood-rearing habitat will most benefit the population.

This paper aims to provide further information on habitat use and selection by Mottled Duck females during the brood-rearing period. Two years of survey and one year of radio-telemetry data, recorded in 1994, 1995 and 2001 respectively, are analysed to test the hypothesis that females with broods select for specific wetland-types in heterogeneous wetland matrices along the Texas coast. The results are compared with those of other studies to synthesis knowledge on the species' breeding ecology.

Methods

Study area

This research took place along the Texas coast inclusive of the upper, central, and lower coast regions (Fig. 1). The Texas Gulf Coast stretches nearly 600 km with about 2,300 km of shoreline along bays, and estuaries (Brown *et al.* 1980). Climatic conditions vary greatly along a latitudinal gradient, from warm and humid with average annual precipitation of 150 cm along the upper coast of Texas to sub-humid and semi-arid conditions with 60 cm of rainfall annually along the lower coast (Fulbright & Bryant 2004; NOAA 2011). Texas Gulf Coast summers are generally hot (mean high = 33°C, mean low = 24°C) and humid, the winters are mild (mean high = 18°C, mean low = 8°C; NOAA 2011), and tropical storms occur periodically in the region which can have an impact on vital waterfowl habitats (Conner *et al.* 1989; Couvillion *et al.* 2011). This variation in climate across the region results in variation in the quantity and quality of habitats available for Mottled Duck brood-rearing (Krainyk & Ballard 2014).

The Texas Gulf Coast has experienced significant changes in habitat over the last century (Moulton *et al.* 1997). Historically, tall- and mid-grass prairies, as well as cordgrass *Spartina* sp. marshes, made up a major portion of the coastal landscape. However, loss and degradation of these communities, primarily because of

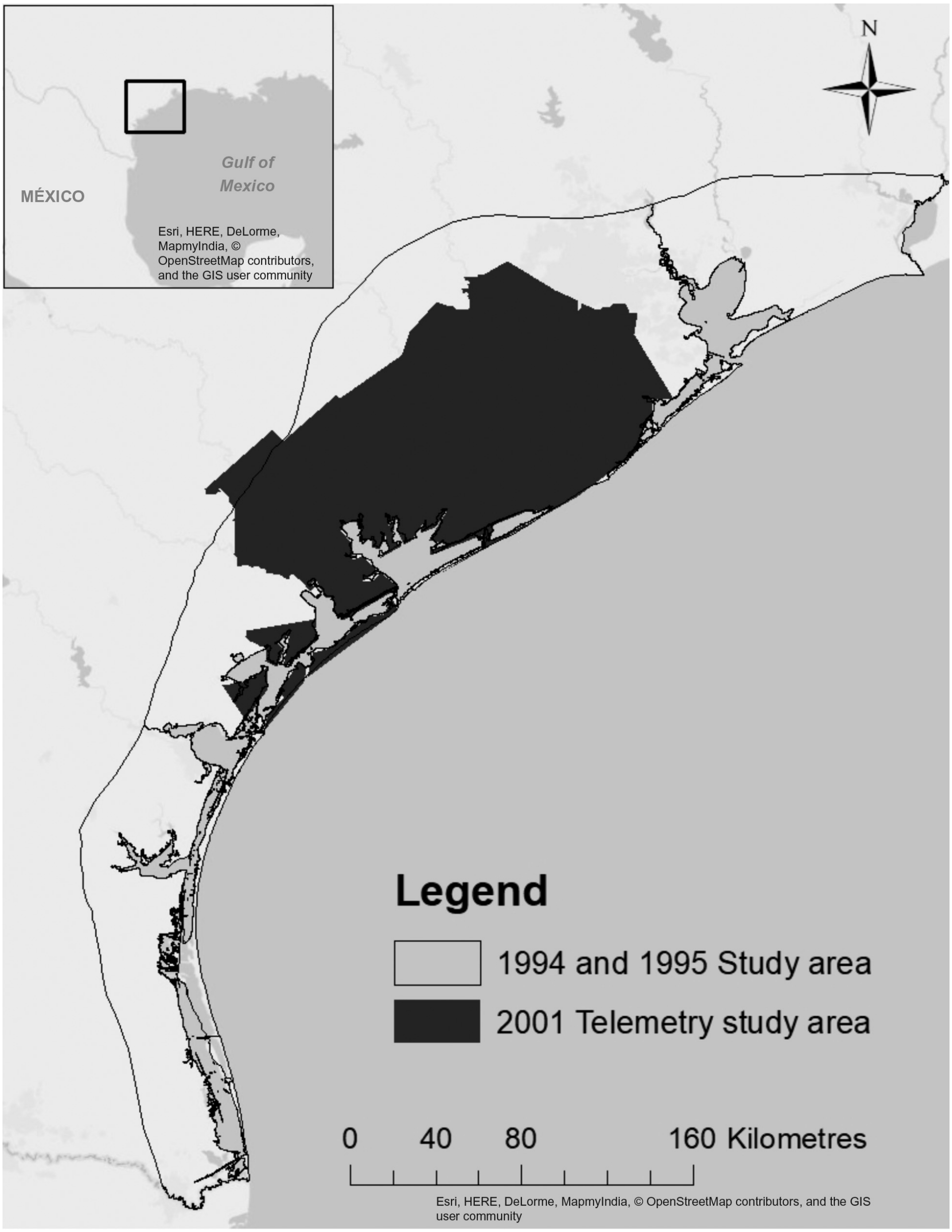

Figure 1. Map of Texas, United States. Area outlined in black depicts the study area for 1994 and 1995 wetland surveys. The region shaded in dark grey depicts the study area for the 2001 telemetry study.

agricultural practices, have fragmented the landscape and decreased its utility to waterfowl (Dahl & Stedman 2013). The human population has grown by 34% along the Texas Coast over the last 20 years, resulting in an increase in urbanisation and waterfowl habitat loss (Texas A. & M. Natural Resources Institute 2016). Additionally, recent changes in land use, particularly in rice-growing regions of the coast, have likely influenced the attractiveness of these areas to Mottled Ducks (Durham & Afton 2006). Mottled Ducks nesting in agricultural regions of the western Gulf Coast are often associated with managed rice fields (Durham & Afton 2003, 2006), but rice production in Texas declined by 50% between 1990 and 2016 (USDA 2016). Among other challenges, recent changes to current water allocation rules from river authorities along the Texas coast have caused many farmers to convert to dryland row crops, such as corn, sorghum and cotton, which do not provide the same benefits to Mottled Ducks as flooded rice fields (Esslinger & Wilson 2001; Durham & Afton 2003, 2006). Managed and fallow rice fields provide valuable waterfowl habitat (Durham & Afton 2006; Anderson 2008) and the consequences of the loss of this habitat along the Texas coast to the future of the Mottled Duck population in Texas are unknown (Wilson 2007). Moreover, coastal wetlands are less suited than inland areas to agricultural practices and high-density development, but channelisation projects have affected overland sheet flow and hydrological functions of wetlands historically used by many waterfowl species in North America (Ricketts *et al.* 1999).

Data collection and analysis

A stratified (by wetland type) sample of 300 wetlands in 1994 and 330 wetlands in 1995, comprising 34 wetland types known to be used by ducks along the Texas coast, was selected at random and allocated in proportion to the distribution of wetland types along the lower, central and upper coasts of Texas (Anderson 1994; Muehl 1994; Tacha *et al.* 1993). Initial wetland types in the selection process were based on National Wetland Inventory (NWI; www.fws.gov/wetlands/) classification and included wetland types in the estuarine, lacustrine, riverine and palustrine systems. Wetlands were surveyed for Mottled Duck broods once each month from March through August. Each wetland was surveyed for broods first by scanning the site using a 10–60× spotting scope and then by walking along the shoreline and inspecting any emergent vegetation to increase the likelihood of observing broods. The number and age of ducklings in each Mottled Duck brood observed at each of the wetlands surveyed was recorded. Duckling age was estimated based on size and plumage characteristics (Gollop & Marshall 1954). During each survey, habitat attributes were estimated visually by the observer to aid in wetland classification, in case wetland type changed between visits or was different from original NWI classification. Observers made ocular estimates of proportional composition of emergent and submergent vegetation (including dominant species), open water and bare substrate. Based on these estimates, wetlands visited during each survey were classified following Cowardin *et al.* (1979).

The Palmer Drought Severity Index (PDSI) and total available surface water were used as indicators of breeding habitat conditions for each year. PDSI data for the surveyed area were obtained from the National Oceanic and Atmospheric Administration (NOAA, https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/) for each of six months (March–August) for 1994 and 1995. Average PDSI values indicated that 1994 was slightly drier (-0.39) than 1995 (0.02). Measures of available surface water were modelled using the Thematic Satellite Imagery (*i.e.* remote sensing data) and the Normalized Difference Water Index (McFeeters 1996). There was a 4% difference in surface water availability between the two survey years. The years 1994 and 1995 were analysed independently as PDSI and surface water availability indicated a slight difference in breeding habitat conditions. The method of Neu *et al.* (1974) was used to test whether Mottled Duck broods were using habitats in proportion to their availability in the landscape each year.

In 2000–2001, 110 female Mottled Ducks were caught using decoy traps and baited rocket nets during January–March, prior to nesting, and each fitted with a 20 g abdominal implant transmitter (ATS model 203 and Holohil model AI-2) with an external antenna, using procedures described by Korschgen *et al.* (1996). Transmitters were 1.9–3.0% of female Mottled Duck body mass and had an expected life of > 180 days. Of 110 transmitters, eight failed prematurely or the females moved out of the study area or died, and 21 females were recovered dead prior to brood-rearing. Thus, 81 radio-marked females were tracked within the study area throughout the brood-rearing period. All transmitters had mortality sensors, which indicated when a transmitter was stationary for ≥ 8 h. Movements of radio-tagged females were monitored throughout the agriculture lands and coastal marsh zone of the Central Coast of Texas (*i.e.* the Aransas, Brazoria, Calhoun, Fort Bend, Jackson, Matagorda, Victoria and Wharton counties), and females known to have broods were tracked daily during brood-rearing, using a null-array system (zeroed weekly) and following procedures described by Samuel and Fuller (1994). LOAS™ (Location of a Signal) software was used to estimate locations and to assess immediately error ellipses of triangulations. Additional bearings were taken if error ellipses were > 10,000 m^2. Female dabbling ducks occasionally leave broods (Ringelman *et al.* 1982; Talent *et al.* 1983), and radio-tagged females were assumed to be on brood-rearing breaks (Paulus 1984) when they were located > 1 km from their previous location and returned to within 300 m of that previous location within 2 h. These movements were not included in brood movement analysis. Females were assumed to have lost their brood if repeatedly found using many wetlands over a large area (> 2 km^2) (Rotella & Ratti 1992a). Distances from successful nest sites to brood-rearing habitat were estimated using GPS coordinates of successful nest sites and locations of the first wetland used by radio-tagged female Mottled Ducks with broods. All distance measurements were performed using ArcGIS software (ESRI 2011).

In 2000, the study area received < 50% of average precipitation and experienced severe drought (PDSI average = –3.80; NOAA source as above) during the brood-rearing period. As a result, only two clutches hatched and neither brood survived long enough to be included in the analyses. In 2001, there was near-normal rainfall and an average PDSI value of 0.79 (NOAA source as above) during the brood-rearing period. Of all clutches that hatched (n = 15), 14 provided enough information (> 3 locations) for analysis. GPS location data for the radio-tagged females with broods was imported into ArcGIS and spatially displayed using x and y coordinate fields. The NWI dataset (USFWS 2015) was used in combination with available surface water to identify wetland types used by Mottled Duck broods and considered available within the landscape around brood locations. To determine if a wetland basin was inundated during the brood-rearing period, surface water was identified using the Normalized Difference Water Index (NDWI; proposed by McFeeters 1996) to delineate non-urban water associated with wetlands. LANDSAT 7 thematic mapper satellite images were downloaded from USGS (http://earthexplorer.usgs.gov/) for July 2001 and a surface water extraction model was built in "model builder" ERDAS Imagine software (ESRI 2011) using band combinations (spectral bands 1, 4 and 7/spectral bands 1, 2 and 3) defined by McFeeters (1996), which indicates surface water presence on the landscape.

The median of the longest daily movements by the 14 broods was calculated and this value (1,496.7 m) used as a radius to designate a circular landscape of potentially available habitat around each brood location. Because of the relatively limited mobility of broods, we felt that a typical assessment of home range was not appropriate and used this movement distance to provide a more realistic measure of what was available to Mottled Duck broods over smaller temporal scales. An intersect model was developed in ArcGIS Model Builder (ESRI 2011) that produced a dataset of wetland types and their areas for each of the daily circular landscapes. Based on NWI classification (Cowardin *et al.* 1979), 49 wetland types occurred within the circular landscapes of radio-tagged Mottled Duck broods in 2001, and were considered available for use. Within each of these landscapes, we calculated the area (in hectares) of each wetland type that was available to the Mottled Duck brood on that particular day, and recorded the wetland type that was used by the brood during monitoring. This information was used to calculate the proportion each wetland category represented of total available wetland area and these wetlands types were considered available to Mottled Duck broods during the telemetry study.

The 34 wetland types recorded during the wetland surveys, and the 49 wetland types within the circular landscapes around brood locations were grouped into 13 broader wetland categories (Tables 1–3) to reduce the number of wetland types with no brood observations. The broader wetland categories were based on similarities in classification characteristics (Cowardin *et al.* 1979). This resulted in all 13 of the categories being available during surveys in 1994 and 1995, and 11 of the categories were available within the circular landscapes. The total area of each wetland category was calculated and these categories were considered to be the wetland types available to Mottled Duck broods during the respective monitoring.

Individual observations (locations) of a given Mottled Duck brood likely are not independent, and lack of independence violates a basic assumption in contingency-table based tests of hypotheses (Conover 1999) such as the approach of Neu *et al.* (1974). To address this issue, we incorporated a re-sampling protocol in our analysis. We selected a single random location from each of our 14 broods and classified it according to the habitat occupied; this resulted in a 1 × 11 contingency table of observed frequencies. Expected frequencies were calculated under the assumption that use was proportional to availability. Following Neu *et al.* (1974), we used a χ^2 statistic with (h–1) d.f., where h = number of habitats, to test the null hypothesis that habitat use was proportional to availability. This process was repeated 1,000 times with independent re-sampling of the dataset. For each analysis, when the null hypothesis was rejected, we estimated 95% confidence intervals for the proportion of use for each habitat. When a given confidence interval included the expected value, we declare that use was proportional to availability for the associated habitat; habitat selection was declared when the lower bound of the interval exceeded the expected value, and habitat avoidance was declared when the upper bound interval was less than the expected value. Although this method prevents analysis of within-season changes in habitat use, it removes problems of non-independence among locations, and allows a more appropriate estimate of habitat availability.

Results

The analyses included 82 brood observations during surveys of wetlands along the Texas coast, and 289 brood locations of 14 broods radio-tracked daily across the brood-rearing period along the central Texas coast (Tables 1–3). During surveys, Mottled Duck broods selected estuarine intertidal aquatic bed (E2AB in Tables 1–3), palustrine unconsolidated bottom (PUB) and palustrine aquatic bed (PAB) wetlands. Radio-tagged females with broods selected palustrine emergent (PEM) wetlands. No wetland types were selected in all years. Wetland types avoided by females with broods in all years included riverine (R), lacustrine limnetic (L1), palustrine unconsolidated shore (PUS) and palustrine scrub-shrub – palustrine forested (PSS/PFO) wetlands. Estuarine intertidal emergent (E2EM) wetlands were used in proportion to their availability during the driest and wettest year (1994 and 2001, respectively), but were avoided in the medial year (1995) (Tables 1–3). PEM wetlands were avoided in the driest year (1994), used in proportion to their availability in 1995 and selected by Mottled Duck broods in the wettest year (2001). PAB wetlands were used in proportion to their availability in the driest of three years, selected in the near normal precipitation year, and avoided by broods in the wettest of the three years (Table 1–3).

Table 1. Wetland Survey of 300 wetlands in 1994 consisted of 34 wetland types grouped into 13 wetland categories according to Cowardin *et al.* (1979). Total area of each wetland category and the number of Mottled Duck broods observed on each wetland category were recorded, and analysis of use *vs.* availability was undertaken following Neu *et al.* (1974). Overall $\chi^2_{12} = 315.27$, $P < 0.001$. For each analysis, when the null hypothesis was rejected ($\alpha = < 0.05$), we estimated 95% confidence intervals (CI) for the proportion of use for each habitat, to determine whether use was proportional to availability for the associated habitat, as described in the Methods.

[1]Wetland category	Area (ha)	Proportion of area	No. broods observed	No. broods expected	Proportion observed	Lower CI	Upper CI	Decision
E1	545.2	0.13	0	5.74	0	0	0	Avoided
E2AB	**310.5**	**0.08**	**10**	**3.27**	**0.23**	**0.11**	**0.36**	**Selected**
E2US	566.2	0.14	0	5.97	0	0	0	Avoided
E2EM/E2SS	301.4	0.07	4	3.18	0.09	0.01	0.18	Proportion
R	52.5	0.01	0	0.55	0	0	0	Avoided
L1	717.1	0.18	0	7.56	0	0	0	Avoided
L2RB/L2UB	860.5	0.21	8	9.07	0.19	0.07	0.30	Proportion
L2AB	258.7	0.06	7	2.73	0.16	0.05	0.27	Proportion
PUB	**39.5**	**0.01**	**11**	**0.42**	**0.26**	**0.13**	**0.39**	**Selected**
PAB	56.2	0.01	2	0.59	0.05	–0.02	0.11	Proportion
PUS	40.6	0.01	0	0.43	0	0	0	Avoided
PEM	280.8	0.07	1	2.96	0.02	–0.02	0.07	Avoided
PSS/PFO	52.4	0.01	0	0.55	0	0	0	Avoided
TOTAL	**4,081.6**	**1**	**43**	**43**	**1**			

[1]E1: Estuarine Subtidal, E2AB: Estuarine Intertidal Aquatic Bed, E2US: Estuarine Intertidal Unconsolidated Shore, E2EM/E2SS: Estuarine Intertidal Emergent/Estuarine Intertidal Scrub-Shrub, R: Riverine, L1: Lacustrine Limnetic, L2RB/L2UB: Lacustrine Littoral Rock Bottom/Lacustrine Littoral Unconsolidated Bottom, L2AB: Lacustrine Littoral Aquatic Bed, PUB: Palustrine Unconsolidated Bottom, PAB: Palustrine Aquatic Bed, PUS: Palustrine Unconsolidated Shore, PEM: Palustrine Emergent, PSS/PFO: Palustrine Scrub-Shrub/Palustrine Forested.

Table 2. Wetland Survey of 330 wetlands in 1995 consisted of 34 wetland types grouped into 13 wetland categories according to Cowardin *et al.* (1979). Total area of each wetland category and the number of Mottled Duck broods observed on each wetland category was recorded, and analysis of use *vs.* availability assessed following for Neu *et al.* (1974). Overall $\chi^2_{12} = 112.25$, $P < 0.001$. For each analysis, when the null hypothesis was rejected ($\alpha = < 0.05$), we estimated 95% confidence intervals (CI) for the proportion of use for each habitat to determine whether use was proportional to availability for the associated habitat, as described in the Methods.

[1]Wetland category	Area (ha)	Proportion of area	No. broods observed	No. broods expected	Proportion observed	Lower CI	Upper CI	Decision
E1	361.1	0.09	0	3.32	0	0	0	Avoided
E2AB	394.1	0.09	8	3.63	0.21	0.08	0.33	Proportion
E2US	1,590.3	0.38	11	14.63	0.28	0.14	0.42	Proportion
E2EM/E2SS	322.6	0.08	1	2.97	0.03	–0.02	0.08	Avoided
R	69.3	0.02	0	0.64	0	0	0	Avoided
L1	395.2	0.09	0	3.64	0	0	0	Avoided
L2RB/L2UB	487.1	0.11	7	4.48	0.18	0.06	0.30	Proportion
L2AB	82.9	0.02	1	0.76	0.03	–0.02	0.08	Proportion
PUB	169.7	0.04	1	1.56	0.03	–0.02	0.08	Proportion
PAB	**79.0**	**0.02**	**9**	**0.73**	**0.23**	**0.10**	**0.36**	**Selected**
PUS	80.9	0.02	0	0.74	0	0	0	Avoided
PEM	158.5	0.04	1	1.46	0.03	–0.02	0.08	Proportion
PSS/PFO	47.7	0.01	0	0.44	0	0	0	Avoided
TOTAL	**4,238.4**	**1**	**39**	**39**	**1**			

[1]E1: Estuarine Subtidal, E2AB: Estuarine Intertidal Aquatic Bed, E2US: Estuarine Intertidal Unconsolidated Shore, E2EM/E2SS: Estuarine Intertidal Emergent/Estuarine Intertidal Scrub-Shrub, R: Riverine, L1: Lacustrine Limnetic, L2RB/L2UB: Lacustrine Littoral Rock Bottom/Lacustrine Littoral Unconsolidated Bottom, L2AB: Lacustrine Littoral Aquatic Bed, PUB: Palustrine Unconsolidated Bottom, PAB: Palustrine Aquatic Bed, PUS: Palustrine Unconsolidated Shore, PEM: Palustrine Emergent, PSS/PFO: Palustrine Scrub-Shrub/Palustrine Forested.

Table 3. Radio-telemetry of 14 female Mottled Ducks and their broods in 2001 consisted of 49 wetland types grouped into 11 wetland categories according to Cowardin *et al.* (1979). Individual observations (locations) of a given Mottled Duck brood likely are not independent, and lack of independence violates a basic assumption in contingency-table based tests of hypotheses (Conover 1999) such as the approach of Neu *et al.* (1974). To address this issue, we incorporated a re-sampling protocol in our analysis. Following Neu *et al.* (1974), we used a χ^2 statistic with (*h*-1) d.f. to test the null hypothesis that habitat use was proportional to availability. This process was repeated 1,000 times with independent re-sampling of the data set (1,000 χ^2 statistics). For each analysis, when the null hypothesis was rejected, we estimated 95% confidence intervals (CI) for the proportion of use for each habitat. When a given CI included the expected value, we declared that use was proportional to availability for the associated habitat; habitat selection was declared when the lower bound of the interval exceeded the expected value, and habitat avoidance was declared with the upper bound of the interval was less than the expected value.

[1]Wetland Category	Area (ha)	Avoided	Proportional	Selected	Decision
E1	13,968.5	137	419	0	Proportion
E2EM/E2SS	77,350.1	140	416	0	Proportion
E2US	355.4	372	184	0	Avoided
R	561.7	556	0	0	Avoided
L1	745.3	407	0	0	Avoided
L2RB/L2UB	292.1	545	0	0	Avoided
PUB	160.2	98	458	0	Proportion
PAB	67.5	485	0	0	Avoided
PUS	57.6	535	0	0	Avoided
PEM	**71,000.2**	**1**	**530**	**25**	**Selected**
PSS/PFO	181.2	556	0	0	Avoided

[1]E1: Estuarine Subtidal, E2US: Estuarine Intertidal Unconsolidated Shore, E2EM/E2SS: Estuarine Intertidal Emergent/Estuarine Intertidal Scrub-Shrub, R: Riverine, L1: Lacustrine Limnetic L2RB/L2UB: Lacustrine Littoral Rock Bottom/Lacustrine Littoral Unconsolidated Bottom, PUB: Palustrine Unconsolidated Bottom, PAB: Palustrine Aquatic Bed, PUS: Palustrine Unconsolidated Shore, PEM: Palustrine Emergent, PSS/PFO: Palustrine Scrub-Shrub/Palustrine Forested.

Estuarine subtidal (E1) wetlands were used in proportion to their availability only in the wettest of three years (2001) and avoided in 1994 and 1995.

The other four wetland types (R, L1, PUS and PSS/PFO), where Mottled Duck broods were not detected during the brood surveys (1994 and 1995), comprised > 23%

of wetland area but accounted for only 1.3% of wetlands within the landscapes around the 289 brood locations recorded during the telemetry study (2001), suggesting that Mottled Duck broods choose landscapes dominated by particular wetland types presumably favourable to the species. To provide further support for this hypothesis, the wetland type (PEM) selected by radio-tagged female Mottled Ducks and their broods comprised almost half (43%) of the available wetland habitat within the landscapes around their locations.

The mean distance travelled by Mottled Duck broods from the nest site to the first wetland used was 1,073 m (range = 60–3,761 m), and 92% of all broods made movements of ≤ 1,580 m. The median of the longest daily distances moved by radio-tagged female Mottled Ducks and their broods throughout the brood-rearing period was 1,497 m (range = 847–3,761 m).

Discussion

Habitat conditions, driven by precipitation, appear to be a primary driver of the types of wetland habitats used by Mottled Duck broods. For instance, Mottled Duck broods selected palustrine emergent (PEM) wetlands when conditions were wetter, and avoided this wetland type when conditions were relatively dry. This is consistent with recent findings by Moon (2014), who suggested that annual rainfall was a main factor influencing habitat use by female Mottled Ducks during the breeding period. The amount of wetness, as well as its effects on salinity, likely has an influence on the quality of habitat provided by a specific wetland type (Moon 2014). It is well established that changes in hydrology have large impacts on the resulting wetland vegetation (Mitsch & Gosselink 2007), and these changes can influence food resources and the degree of protection provided to breeding waterbirds by emergent vegetation (Poiani *et al.* 1995; Murkin & Ross 2000; Fitzsimmons *et al.* 2012). Another indication that habitat conditions influence the types of wetlands used by Mottled Duck broods was that the birds' use of estuarine intertidal emergent (E2EM) wetlands was higher in the driest year (1994), whereas they were avoided in the two wetter years (1995 and 2001). This may have been the result of more preferred wetland types, such as less saline habitats, not being available in the drier years. E2EM wetlands are also important habitats for moulting female Mottled Ducks (Wehland 2012) that have similar nutritional requirements and similar vulnerability to depredation as ducklings (Stutzenbaker 1988). Mottled Duck ducklings exhibit a salinity threshold of around 9 ppt for drinking water, however, above which mortality increases quickly (Moorman *et al.* 1991). Estuarine subtidal (E1) wetlands were avoided in the driest years, which was consistent with findings of Rigby and Haukos (2015), but were used in proportion to availability during the wettest year, indicating that changes in salinity during years of above average precipitation may render these habitats useable to Mottled Duck broods. Moreover, previous Mottled Duck studies have demonstrated high use of coastal marshes with a large freshwater component (Grand 1988; Haukos *et al.* 2010; Rigby & Haukos 2015). Thus, in dry years when salinities can elevate in the coastal marsh, these habitats may be suboptimal for Mottled Duck broods unless there is access to freshwater drinking sites.

It appeared that female Mottled Ducks and broods selected landscapes dominated by favourable wetland types as the habitats within landscapes around brood locations (used) contained a greater proportion of selected habitat types than the sample of wetlands surveyed along the coast (indication of availability). These results were consistent with findings that Mottled Duck broods selected areas finely interspersed with water and emergent vegetation (Rigby & Haukos 2015). Brood-rearing female Mallard and American Black Duck *Anas rubripes* also select landscapes dominated by wetland types known to be productive brood-rearing habitats (Ringelman & Longcore 1982; Belanger & Couture 1988; Rotella & Ratti 1992a, b). Given the highly dynamic nature of wetlands, occupying landscapes with abundant brood-rearing habitat allows options to access productive sites as wetland conditions change.

The avoidance of palustrine aquatic bed (PAB) wetlands during the telemetry study was unexpected, because submerged vegetation is one of the defining plant types in aquatic bed wetlands and plays a key role in supporting aquatic invertebrate communities that are critical for duckling nutrition (Kaminski & Prince 1981; Murkin *et al*. 1991). Voigts (1976) showed that maximum numbers of aquatic invertebrates occurred where beds of submerged vegetation were interspersed with stands of emergent vegetation. PAB comprised only 0.04% of the available wetland area, however, so the probability of a Mottled Duck brood occurring on this wetland type was small (one observation in 2,410). The apparent avoidance of PAB wetlands therefore is likely to be an artifact of the extremely low availability of this habitat in the landscape.

Palustrine unconsolidated bottom (PUB) wetlands were selected in the driest year, and were used in proportion to their availability in the other two years. This wetland type is characterised by relatively deeper wetlands with shallow peripheries containing emergent vegetation. Thus, in drier years, these freshwater wetlands may provide more reliable brood-rearing habitat than other shallower wetland types (Poysa 1983; Krapu & Reinecke 1992; Murkin *et al*. 1997). Selection for wetland permanence may also vary seasonally according to duckling age (Rotella & Ratti 1992b). Young broods tend to select relatively shallow water areas (< 10 cm), whereas older ducklings are able to forage in deeper water (< 25 cm; Paulus 1984).

The results of this study are consistent with those of other studies on similar species in indicating that Mottled Duck broods avoid deep-water and riverine wetlands, as well as those dominated by woody vegetation (Ringelman & Longcore 1982; Paulus 1984; Moorman & Gray 1994). Mottled Duck ducklings tend to use shallow water wetlands (Paulus 1984; Rigby 2008) where foods such as seeds and invertebrates are available to support the energy and protein needs of growing ducklings (Poysa 1989). Dabbling Duck ducklings < 2 weeks of age feed predominantly on invertebrates (Swanson & Bartonek 1970; Stutzenbaker

1988), and spend most of their time foraging (Hickey & Titman 1983; Ringelman & Flake 1980). Therefore, selection of wetland types by Mottled Duck females and their broods is critical for the growth and survival of ducklings.

The findings presented here reinforce the conclusions of other studies that a distance of 1,600 m from nesting habitat to brood-rearing habitat is generally the maximum distance that should be used in landscape conservation to promote brood survival (Wilson 2007; Moon *et al*. 2015). Vegetation type, structure and density of the grassland landscape may increase time of overland travel, affecting the distance travelled by broods to brood-rearing habitat (Dzus & Clark 1997; Rotella & Ratti 1992a, b). Female Mallard choose nest sites that are proximal to brood-rearing wetlands as overland distance from nest site to brood-rearing habitat is positively related to duckling mortality (Ball *et al*. 1975; Rotella & Ratti 1992b). Therefore, conservation of brood-rearing wetlands must be in tandem with management of surrounding grassland habitats. The potential quality of nesting habitat for Mottled Ducks should consider the availability of brood-rearing habitat in the proximal landscape (Wilson 2007; Krainyk & Ballard 2014). Reducing the distance travelled over land to quality brood-rearing habitat in the first day after hatching is vital to duckling survival because of the relative lack of mobility and high vulnerability to predators at this time (Ball *et al*. 1975; Rotella & Ratti 1992b). Hence, we suggest that management of wetlands for brood-rearing activities by Mottled Ducks should focus on seasonally and temporarily flooded emergent vegetated palustrine and estuarine wetlands that exist in a matrix of quality nesting habitat.

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References

Allen, J.A. 1981. Nesting and productivity of Mottled Ducks in the marshlands of southwestern Louisiana. M.Sc. thesis, Louisiana State University, Baton Rouge, Louisiana, USA.

Anderson, J.T. 1994. Wetland use and selection by waterbirds in coastal Texas. M.Sc. thesis, Texas A & M University-Kingsville, Kingsville, Texas, USA.

Anderson, J.T. 2008. Survival, habitat use, and movements of female northern Pintails wintering along the Texas coast. M.Sc. thesis, Texas A & M University-Kingsville, Kingsville, Texas, USA.

Baldassarre, G.A. 2014. *Ducks, Geese and Swans of North America*. Johns Hopkins University Press, Baltimore, USA.

Ball, I.J., Gilmer, D.S., Cowardin, L.M. & Riechmann, J.H. 1975. Survival of Wood

Duck and Mallard broods in north central Minnesota. *Journal of Wildlife Management* 39: 776–780.

Batt, B.D., Afton, A.D., Anderson, M.G., Ankney, C.D., Johnson, D.H., Kadlec, J.A. & Krapu, G.L. 1992. *Ecology and Management of Breeding Waterfowl*. University of Minnesota Press, Minneapolis, USA.

Belanger, L. & Couture, R. 1988. Use of man-made wetlands by dabbling duck broods. *Journal of Wildlife Management* 52: 718–723.

Bielefeld, R.R. 2008. Mottled duck survey report. Fish and Wildlife Research Institute. Florida Fish and Wildlife Conservation, Commission, St. Petersburg, USA.

Bielefeld, R.R., Brasher, M.G., Moorman, T.E. & Gray, P.N. 2010. Mottled Duck (*Anas fulvigula*), version 2.0. *In* A.F. Poole (ed.), *The Birds of North America*. Cornell Laboratory of Ornithology, Ithaca, New York, USA. Available at: https://doi.org/10.2173/bna.81 (last accessed 23 June 2018).

Brown, L.F., Jr., Brewton, J.L., Evans, T.T., McGowan, J.H., White, W.A., Groat, C.G. & Fisher, W.L. 1980. *Environmental Geologic Atlas of the Texas Coastal Zone-Brownsville-Harlingen Area*. Bureau of Economic Geology, Austin, USA.

Conner, W.H., Days, J.W., Baumann, R.H. & Randall, J.M. 1989. Influence of hurricanes on coastal ecosystems along the northern Gulf of Mexico. *Wetland Ecology and Management* 1: 45–56.

Conover, W.J. 1999. *Practical Nonparametric Statistics. 3rd edition*. John Wiley and Sons, Hoboken, New Jersey, USA.

Couvillion, B.R., Barras, J.A., Steyer, G.D., William, W.S., Fisher, H., Beck, H., Trahan, N., Griffin, B. & Hekcman, D. 2011. Land Area Change is Coastal Louisiana from 1932 to 2010. U.S. Geological Survey Scientific Investigation Map 3164 (scale 1:265,000), pp. 12. Available at: http://pubs.usgs.gov/sim/3164/downloads/SIM3164_Pamphlet.pdf (last accessed 23 June 2018).

Cowardin, L.M., Carter, V., Golet, F.C. & LaRoe, E.T. 1979. Classification of wetlands and deep-water habitats of the United States. U.S. Department of the Interior, Fish & Wildlife Service, Washington D.C., USA.

Dahl, T.E. & Stedman, S.M. 2013. Status and trends of wetlands in the coastal watersheds of the Conterminous United States 2004 to 2009. U.S. Department of the Interior, Fish & Wildlife Service and National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington D.C., USA.

Durham, R.S. & Afton, A.D. 2003. Nest-site selection and success of Mottled Ducks on agricultural lands in southwest Louisiana. *Wildlife Society Bulletin* 31: 433–442.

Durham, R.S. & Afton, A.D. 2006. Breeding biology of Mottled Ducks on agricultural lands in southwestern Louisiana. *Southeastern Naturalist* 5: 311–316.

Dzus, E.H. & Clark, R.G. 1997. Overland travel, food abundance, and wetland use by Mallards: relationships with offspring survival. *Wilson Bulletin* 109: 504–515.

ESRI. 2011. *ArcGIS Desktop: Release 10*. Environmental Systems Research Institute, Redlands, USA.

Esslinger, C.G. & Wilson, B.C. 2001. North American waterfowl management plan, Gulf Coast Joint Venture: Chenier Plain Initiative. North American Waterfowl Management Plan, Albuquerque, USA.

Finger, R. S., Ballard, B.M., Merendino, M.T., Hurst, J.P., Lobpries, D.S. & Fedynich, A.M. 2003. Habitat use, movements, and survival of female mottled ducks and ducklings during brood rearing. Texas Parks & Wildlife Department, Austin, USA.

Fitzsimmons, O.N., Ballard, B.M., Merendino, M.T., Baldassarre, G.A. & Hartke, K.M. 2012. Implications of coastal wetland management to nonbreeding waterbirds in Texas. *Wetlands* 32: 1057–1066.

Fulbright, T.E. & Bryant, F.C. 2004. The last great habitat. Caesar Kleberg Wildlife Research Institute, Texas A & M University-Kingsville, Kingsville, USA.

Gollop, J.B. & Marshall, W.H. 1954. A guide for aging duck broods in the field. Mississippi Flyway Council Technical Section Report. Northern Prairie Wildlife Research Center, Jamestown, USA.

Grand, J.B. 1988. Habitat use and social structure of Mottled Ducks in a Texas coastal marsh. Ph.D. thesis, Texas A & M University, College Station, USA.

Haukos, D.A., Martinez, S. & Heltzel, J. 2010. Characteristics of ponds used by breeding mottled ducks on the Chenier Plain of the Texas Gulf Coast. *Journal of Fish and Wildlife Management* 1: 93–101.

Hickey, T.E. & Titman, R.D. 1983. Diurnal activity budgets of Black Ducks during their annual cycle in Prince Edward Island. *Canadian Journal of Zoology* 61: 743–749.

Holbrook, R.S., Rohwer, F.C. & Johnson, W.P. 2000. Habitat use and productivity of Mottled Ducks in the Atchafalaya River Delta, Louisiana. *Proceedings of the Annual Conference Southeast Association of Fish and Wildlife Agencies* 54: 292–303.

Johnson, F. A., Montalbano, F., Truitt, J. & Eggeman, D. 1991. Distribution, abundance, and habitat preferences of Mottled Ducks in Florida. *Journal of Wildlife Management* 55: 476–487.

Kaminski, R.M. & Prince, H.H. 1981. Dabbling duck activity and foraging responses to aquatic macroinvertebrates. *Auk* 98: 115–126.

Kennish, M.J. 2001. Coastal marsh systems in the U.S.: a review of anthropogenic impacts. *Journal of Coastal Research* 17: 731–748.

Korschgen, C.E., Kenow, K.P., Gendron-Fitzpatrick, A., Green, W.L. & Dein, F.J. 1996. Implanting intra-abdominal radio-transmitters with external whip antennas is ducks. *Journal of Wildlife Management* 60: 132–137.

Krainyk, A. & Ballard, B.M. 2014. Decision support tool: Prioritization of Mottled Duck (*Anas fulvigula*) habitat for conservation and management in the western Gulf Coast. Texas A & M University-Kingsville report to Gulf Coast Joint Venture, Texas A & M University-Kingsville, Kingsville, USA. Available at: http://gcjv.org/docs/Mottled%20Duck%20Decision%20Support%20Tool_Final%20Report.pdf (last accessed 23 June 2018).

Krapu, G.L. & Reinecke, K.J. 1992. Foraging ecology and nutrition. *In* B.D.J. Batt, A.D. Afton, M.G. Anderson, C.D. Ankney, D.H. Johnson, J.A. Kadlec & G.L. Krapu (eds.), *Ecology and Management of Breeding Waterfowl*, pp. 1–29. University of Minnesota Press, Minneapolis, USA.

Longcore, J.R., McAuley, D.G., Pendelton, G.W., Bennatti, C.R., Mingo, T.M. & Stromborg, K.L. 2006. Macroinvertebrate abundance, water chemistry, and wetland characteristics affect use of wetlands by avian species in Maine. *Hydrobiologia* 567: 143–167.

McCracken, K.G., Johnson, W.P. & Sheldon, F.H. 2001. Molecular population genetics, phylogeny, and conservation biology of the Mottled Duck (*Anas fulvigula*). *Conservation Genetics* 2: 87–102.

McFeeters, S.K. 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing* 17: 1425–1432.

Mitsch W.J. & Gosselink, J.G. 2007. *Wetlands, 4th edition*. John Wiley & Sons, Hoboken, New Jersey, USA.

Moon, J.A. 2014. Mottled Duck (*Anas fulvigula*) ecology in the Texas Chenier Plain Region.

Ph.D. thesis, Stephen F. Austin State University, Nacogdoches, Texas, USA.

Moon, J.A., Haukos, D.A. & Conway, W.C. 2017. Seasonal survival of adult female Mottled Ducks. *Journal of Wildlife Management* 81: 461–469.

Moon, J.A., Haukos, D.A. & Conway, W.C. 2015. Mottled duck (*Anas fulvigula*) movements in the Texas Chenier Plain region. *Journal of Southeastern Association of Fish and Wildlife Agencies* 2: 255–261.

Moorman, A.M., Moorman, T.E., Baldassarre, G.A. & Richard, D.M. 1991. Effects of saline water on growth and survival of Mottled Duck ducklings in Louisiana. *The Journal of Wildlife Management* 55: 471–476.

Moorman, T.E. & Gray, P.N. 1994. Mottled Duck (*Anas fulvigula*). *In* A. Poole & F. Gill (eds.), *The Birds of North America*. Number 81. Academy of Natural Sciences, Philadelphia and American Ornithologists' Union, Washington, D.C., USA.

Morton, R.A., Miller, T.L. & Moore, L.J. 2004. National assessment of shoreline change: Part 1: Historical shoreline changes and associated coastal land loss along the U.S. Gulf of Mexico. Open-file Report No. 2004-1043, U.S. Department of the Interior, Geological Survey, Washington D.C. USA.

Moulton, D.W., Dahl, T.E. & Dahl, D.M. 1997. Texas coastal wetlands; status and trends, mid 1950s to early 1990s. U.S. Department of the Interior, Fish & Wildlife Service, Albuquerque, USA.

Muehl, G.M. 1994. Distribution and abundance of waterbirds in coastal Texas. M.Sc. thesis, Texas A & M University, Kingsville, Texas, USA.

Murkin, H.R., Kadlec, J.A. & Murkin, E.J. 1991. Effects of prolonged flooding on nektonic invertebrates in small diked marshes. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2355–2364.

Murkin, H.R., Murkin, E.J. & Ball, J.P. 1997. Avian habitat selection and prairie wetland dynamics: a 10-year experiment. *Ecological Applications* 7: 1144–1159.

Murkin, H.R. & Ross, L.C.M. 2000. Invertebrates in prairie wetlands. *In* H.R. Murkin, A.G. van der Valk & W.R. Clark (eds.), *Prairie Wetland Ecology*, pp. 201–248. Iowa State University Press, Ames, USA.

National Oceanic and Atmospheric Administration (NOAA). 2011 *U.S. Climate Atlas*. Available at: http://www.ncdc.noaa.gov/climateatlas (last accessed 23 June 2018).

Neu, C.W., Byers, C.R. & Peek, J.M. 1974. A technique for analysis of utilization-availability data. *Journal of Wildlife Management* 38: 541–545.

Paulus, S.L. 1984. Behavioral ecology of Mottled Ducks in Louisiana. Ph.D. thesis, Auburn University, Auburn, Alabama, USA.

Poiani, K.A., Johnson, W.C. & Kittel, T.G.F. 1995. Sensitivity of prairie wetlands to increased temperature and precipitation changes. *Water Resources Bulletin* 31: 283 – 294.

Poysa, H. 1983. Morphology-mediated niche organization in a guild of dabbling ducks. *Ornis Scandinavica* 14: 317–326.

Poysa, H. 1989. Foraging patch dynamics in the teal (*Anas crecca*): effects of sociality and search method switching. *Behavior* 110: 306–318.

Raven, G.H., Armstrong, L.M., Howerter, D.W. & Arnold, T.W. 2007. Wetland selection by Mallard broods in Canada's Prairie-Parklands. *Journal of Wildlife Management* 71: 2527–2531.

Ricketts, T.H., Dinerstein, E., Olson, D.M., Loucks, C.J., Eichbaum, W., DellaSala, D., Kavanagh, K., Hedao, P., Hurley, P.T., Carney, K.M., Abell, R. & Walters, S. 1999. *Terrestrial Ecoregions of North America: A Conservation Assessment*. World Wildlife Fundation Island Press, Washington D.C., USA.

Rigby, E.A. 2008. Recruitment of Mottled Ducks (*Anas fulvigula*) on the upper Texas Gulf Coast. M.Sc. thesis, Texas Tech University, Lubbock, Texas, USA.

Rigby, E.A. & Haukos, D.A. 2012. Breeding season survival and breeding incidence of female mottled ducks on the upper Texas Gulf Coast. *Waterbirds* 35: 260–269.

Rigby, E.A. & Haukos, D.A. 2015. Duckling survival, fecundity, and habitat selection of Mottled Duck broods on the upper Texas Gulf Coast. *Journal of the Southeastern Association of Fish and Wildlife Agencies* 2: 156–163.

Rigby, E.A. & Haukos, D.A. 2014. A matrix population model for mottled ducks (*Anas fulvigula*) of the western Gulf Coast. *Southeastern Naturalist* 13 (Special Issue 5): 26–40.

Ringelman, J.K. & Flake, L.D. 1980. Diurnal visibility and activity of Blue-winged Teal and Mallard broods. *Journal of Wildlife Management* 44: 822–829.

Ringelman, J.K., Longcore, J.R. & Owen, R.B. 1982. Nest and brood attentiveness in female Black Ducks. *The Condor* 84: 110–116.

Ringelman, J.K. & Longcore, J.R. 1982. Movements and wetland selection by brood-rearing Black Ducks. *Journal of Wildlife Management* 46: 615–621.

Rotella, J.J. & Ratti, J.T. 1992a. Mallard brood survival and wetland habitat conditions in southwestern Manitoba. *Journal of Wildlife Management* 56: 499–507.

Rotella, J.J. & Ratti, J.T. 1992b. Mallard brood movements and wetland selection in southwestern Manitoba. *Journal of Wildlife Management* 56: 508–515.

Samuel, M.D. & Fuller, M.R. 1994. Wildlife radio-telemetry. *In* T.A. Bookhout (ed.), *Research and Management Techniques for Wildlife and Habitats*, pp. 370–418. The Wildlife Society, Inc., Bethesda, USA.

Stutzenbaker, C.D. 1988. *The Mottled Duck: Its Life History, Ecology and Management.* Texas Parks and Wildlife Department, Austin, USA.

Swanson, G.A. & Bartonek, J.C. 1970. Bias associated with food analysis in gizzards of blue-winged teal. *Journal of Wildlife Management* 34: 739–746.

Tacha, T.C., Holzem, A.M. & Bauer, D.W. 1993. Changes in freshwater wetlands and waterfowl distribution in the Chenier Plain of Texas, 1970–1991. *Texas Journal of Agriculture and Natural Resources* 6: 31–40.

Talent, L.G., Jarvis, R.L. & Krapu, G.L. 1983. Survival of Mallard broods in south-central North Dakota. *The Condor* 85: 74–78.

Texas A. & M. Natural Resources Institute. 2016. *Texas Land Trends*. Texas A & M Natural Resources Institute, Kingsville, Texas. Available at: www.txlandtrends.org (last accessed 5 June 2016).

U.S. Fish and Wildlife Service. 2015. *National Wetland Inventory*. U.S. Department of the Interior, Fish and Wildlife Service, Washington D.C., USA. Available at: http://www.fws.gov/wetlands/ (last accessed 4 July 2018).

U.S. Department of Agriculture. 2016. National Agricultural Statistics Service. Available at: www.nass.usda.gov/Statistics_by_State/Texas/index.php (last accessed 25 July 2015).

U.S. Geological Survey. 2016. Science for a changing world. Available at: www.earthexplorer.usgs.gov (last accessed 14 January 2016).

Voigts, K. 1976. Aquatic invertebrate abundance in relation to changing marsh vegetation. *The American Midland Naturalist* 95: 313–322.

Walters, N.F., Rohwer, F.C. & Harris, J.O. 2001. Nest success and nesting habitats of Mottled Ducks on the Mississippi River Delta in Louisiana. *Proceedings of the Annual Conference of the Southeast Association of Fish and Wildlife Agencies* 55: 498–505.

Wehland, E.M. 2012. Survival and post-breeding habitat use by mottled ducks in the western Gulf Coast. Ph.D. thesis, Texas A & M University-Kingsville, USA.

Williams, C.H., Fedynich, A.M., Pence, D.B. & Rhodes, O.E. 2005. Evaluation of allozyme and microsatellite variation in Texas and Florida Mottled Ducks. *The Condor* 107: 155–161.

Wilson, B.C. 2007. North American waterfowl management plan, Gulf Coast Joint Venture: Mottled Duck Conservation Plan. North American Waterfowl Management Plan, Albuquerque, USA.

Zwank, P.J., McKenzie, P.M. & Moser, E.B. 1989. Mottled Duck habitat use and density indices in agricultural lands. *Journal of Wildlife Management* 53: 110–114.

Photograph: Mottled Duck male, by Ron Bielefeld/Minden Pictures/FLPA.

