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Research Article

Seasonal Survival of Adult Female Mottled Ducks

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ABSTRACT The mottled duck (*Anas fulgivula*) is a non-migratory duck dependent on coastal habitats to meet all of its life cycle requirements in the Western Gulf Coast (WGC) of Texas and Louisiana, USA. This population of mottled ducks has experienced a moderate decline during the past 2 decades. Adult survival has been identified as an important factor influencing population demography. Previous work based on band-recovery data has provided only annual estimates of survival. We assessed seasonal patterns of female mottled duck survival from 2009 to 2012 using individuals marked with satellite platform transmitter terminals (PTTs). We used temperature and movement sensors within each PTT to indicate potential mortality events. We estimated cumulative weekly survival and ranked factors influential in patterns of mortality using known-fate modeling in Program MARK. Models included 4 predictors: week; hunting and non-hunting periods; biological periods defined as breeding, brooding, molt, and pairing; and mass at time of capture. Models containing hunt periods, during and outside the mottled duck season, comprised essentially 100% of model weights where both legal and illegal harvest had a negative influence on mottled duck survival. Survival rates were low during 2009–2011 (12–38% annual rate of survival), when compared with the long-term banding average of 53% annual survival. During 2011, survival of female mottled ducks was the lowest annual rate (12%) ever documented and coincided with extreme drought. Management actions maximizing the availability of wetlands and associated upland habitats during hunting seasons and drought conditions may increase adult female mottled duck survival. © 2017 The Authors. *Journal of Wildlife Management* Published by Wiley Periodicals, Inc. on behalf of The Wildlife Society.

KEY WORDS *Anas fulgivula*, Chenier Plain, mortality, mottled duck, Program MARK, survival, Texas.

The mottled duck (*Anas fulvigula*) is a non-migratory duck that resides along the coast of the Gulf of Mexico from Veracruz, Mexico, to Florida, USA. Across this range, mottled duck populations are considered an indicator for coastal marsh quality and a species of concern for the United States Fish and Wildlife Service (Wilson 2007; U.S. Fish and Wildlife Service [USFWS] 2008, 2011). Two distinct populations of mottled ducks exist in North America, a Florida population and a Western Gulf Coast (WGC) population, which are separated genetically and geographically (McCracken et al. 2001, Bielefeld et al. 2010). The WGC population inhabits a narrow band of available habitat along the gulf coast from Alabama, USA, west and south into Mexico. The Chenier Plain Region of Texas and Louisiana, USA, roughly spans 322 km of this region, and consists of coastal areas between Galveston Bay, Texas, and Vermilion Bay, Louisiana (Esslinger and Wilson 2001). The Chenier Plain Region is an area rich in natural resources and traditionally supports the greatest proportion and density of mottled ducks in the WGC (Haukos 2015, Moon et al. 2015). The Chenier Plain Region, although historically characterized by high-quality coastal habitats for mottled ducks, has sustained natural and anthropogenic changes that have led to declines in habitat structure and function (White and Tremblay 1995, Allain et al. 1999, Couvillion et al. 2011). Cumulative and synergistic effects of hydrologic alterations have caused mottled duck habitat to be considered one of the most critically endangered habitats in the United States (U.S. Geological Survey [USGS] 1997, Gough and Grace 1998).

Population surveys and banding data suggest that the WGC mottled duck population has declined since the mid-1990s (Wilkins 2008, Johnson 2009, Rigby and Haukos 2015). All population indices indicate a decline from the mid-1990s to early 2000s in Texas with annual fluctuations of several thousand birds (Wilson 2007; Haukos 2015; Texas Parks and Wildlife Department, unpublished data). The mean estimate of the annual January Midwinter Waterfowl Survey 2000–2016 is 48% less than the Gulf Coast Joint Venture goal of 35,322 individuals in Texas (Wilson 2007).

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Factors potentially contributing to mottled duck declines in Texas, in addition to habitat loss and degradation, include predation (McNease and Joanen 1977, Stutzenbaker 1988, Elsey et al. 2004, Carethers 2011, Rigby and Haukos 2012), hybridization (Stutzenbaker 1988), and inter-annual variation in precipitation and landscape habitat changes (Stutzenbaker 1988, Moulton et al. 1997, Wilson 2007, Bielefeld et al. 2010). Contemporary lead exposure and anthropogenic disturbance may also be contributing to mottled duck population declines (Stutzenbaker 1988, Merchant et al. 1991, Merendino et al. 2005, McDowell et al. 2015). These factors may also lead to declining body condition on local and regional scales (Stutzenbaker 1988, Haukos et al. 2001, Bielefeld et al. 2010). It is currently unknown whether factors contributing to population decline affect vital rates independently or interactively. Periods of extended drought and extreme weather are likely to exacerbate factors affecting vital rates because of the mottled duck's sedentary life history, which limits dispersal from affected habitats (Stutzenbaker 1988). Additionally, global climate change poses substantial long-term threats to coastal marsh habitats because the 2 most direct effects are land submergence through sea-level rise and decreases in water quality (Day and Templet 2008, Moon 2014).

Although mottled duck harvest has declined over the past 20 years in Texas and Louisiana, harvest in Texas can be high with historical estimates of >50% of the population legally harvested annually (Rorabaugh and Zwank 1983). More recent estimates show that harvest has been relatively steady for the past decade (Haukos 2012*b*; Fig. 1). Mottled ducks continue to be a popular game bird on the Gulf Coast comprising >3% of the legal waterfowl harvest (Raftovich et al. 2011). During our study period, Central Flyway harvest was estimated to be >10,000 birds/year (Raftovich et al. 2011, Haukos 2012*b*, Raftovich et al. 2012). The effect of hunting and disturbance and potential influences on the population trajectory of mottled ducks are unknown and warrant investigation.

Mottled ducks have been banded regionally by the USFWS, Texas Parks and Wildlife Department, and the Louisiana Department of Wildlife and Fisheries since the mid-late 1990s (Haukos 2015). Banding analyses suggest that annual adult female survival rates are 50–56% in the WGC (Haukos 2015). Breeding season survival rates (Mar–Jul) as estimated by very high frequency (VHF) telemetry are 63–87%, but few other seasonal estimates of survival exist (Wehland 2012; Rigby and Haukos 2014, 2015). Variation in adult female annual survival accounted for 32–60% of the variation in the annual growth rate (λ) of mottled duck populations in matrix models (Johnson 2009, Rigby and Haukos 2014). Thus, annual adult female survival is one of the most important factors affecting mottled duck population demography, stability, and possibly persistence.

The mottled duck's limited geographic range, persistent habitat loss and degradation, and declining population establish a clear need for continued priority-based research on this species in the Chenier Plain Region (USFWS 2011; Haukos 2012*a*,*b*). Few data are currently available to estimate seasonal survival rates or cause-specific mortality of adult females for the Texas Chenier Plain Region. Factors hypothesized to cause variation in survival include phenological period in the annual cycle (pairing, molting, breeding, and brooding), periods of hunting, body condition, and inter-annual variation in precipitation, which can be captured within a year effect (Stutzenbaker 1988, Wilson 2007, Moon 2014). To improve our understanding of mottled duck survival, our objectives were to quantify survival across multiple periods based on the species biology and evaluate the relative influence of temporal variation and periods of disturbance on seasonal mottled duck survival rates. We then assessed periods with lowest survival to elucidate temporal patterns of mottled duck survival.

STUDY AREA

We conducted the study in the Chenier Plain Region, Texas, USA within the Gulf Prairie and Marsh ecological region (Gould et al. 1960, Gossenlink et al. 1979; Fig. 2). This area is characterized by large expanses of coastal marsh, with coastal prairie and rice fields, cattle pasture, and other agricultural lands nearby (Stutzenbaker 1988). Gulf Coast marshes are considered high-disturbance habitats affected by hurricanes, fire, flood, drought, grazing, and vegetation eat-outs by muskrats (*Ondatra zibethicus*) and large (>100,000) flocks of wintering geese (Bhattacharjee et al. 2007, USFWS 2008). The area had a subtropical climate with a strong maritime influence. Annual average precipitation was 137 cm and mean air temperature was 20°C with daily temperatures ranging from 0°C to 39°C (National Oceanic and Atmospheric Administration, National Climatic Data Center [NOAA, NCDC] Texas 1971–2000). The average growing season was 250 days, with infrequent freezes (USFWS 2008). Wetland types across the area included coastal marshes, forested wetlands, natural and man-made reservoirs, livestock ponds, open water bays, rivers, bayous, and other drainages (Moulton et al. 1997, Haukos et al. 2010).

We characterized coastal marsh type by vegetation and salinity. These wetlands included saline (>18 parts per thousand [ppt]), brackish (5–18 ppt), intermediate (0.5–5 ppt), and fresh (0–0.5 ppt) conditions (USFWS 2008). The majority

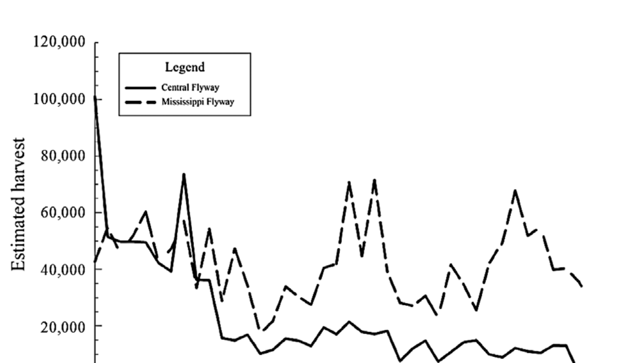

Figure 1. Estimated harvest of mottled ducks in the Central (Texas, USA) and Mississippi (Louisiana, USA) Flyways (Raftovich et al. 2014).

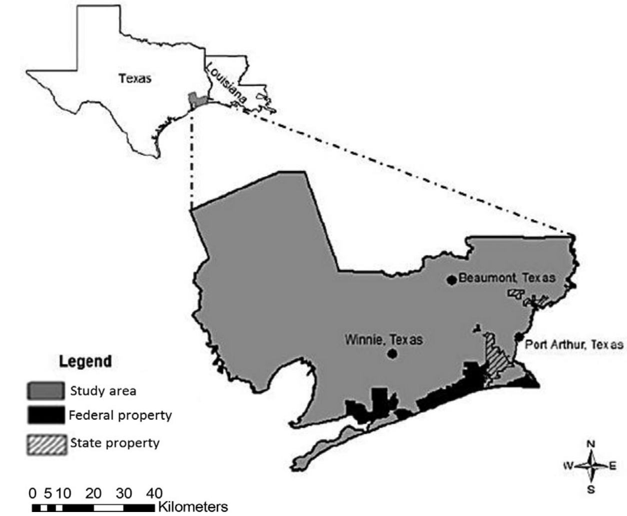

Figure 2. Study area for mottled ducks marked with satellite transmitters during 2009–2012 including United States Fish and Wildlife Service (USFWS) and Texas Parks and Wildlife (TPWD) property boundaries within the Texas Chenier Plain Region, USA.

of marshes within the study area were intermediate or brackish (Haukos et al. 2010). Common vegetation in intermediate marsh included Olney bulrush (*Schoenoplectus americanus*), California bulrush (*S. californicus*), banana waterlily (*Nymphaea mexicana*), and seashore paspalum (*Paspalum vaginatum*; Stutzenbaker 1999, USFWS 2008). Common vegetation in brackish marsh included saltmarsh bulrush (*Bolboschoenus rosbustus*), widgeon grass (*Ruppia maritima*), dwarf spikerush (*Eleocharis parvula*), and marshhay cordgrass (*Spartina patens*; Stutzenbaker 1999, USFWS 2008).

During 2009–2010, temperatures in the Chenier Plain Region of Texas were within normal regional ranges (2–38°C) and annual rainfall averaged 124.3 cm in 2009 and 122.4 cm in 2010, which was approximately 10% below the long-term average of 137 cm (stations FADT2 and TR474; Texas Remote Automated Weather Station 2012*a*,*b*). During 2011, Texas Chenier Plain Region was in severe drought conditions and Texas experienced the most significant 1-year drought event ever recorded (Neilson-Gammon 2012). Temperatures remained within normal ranges; average monthly temperatures ranged from 6°C to 33°C (FADT2 and TR474; Texas Remote Automated Weather Station 2012*a*,*b*), but average rainfall for the year was 76.2 cm, 44% below the long-term average (FADT2 and TR474; Texas Remote Automated Weather Station 2012*a*,*b*).

Wetland salinities during our study varied by year and often exceeded target levels of 3–6 ppt for most marsh management units. In 2009, salinity ranged 15–22 ppt for much of the year following Hurricane Ike, which made landfall roughly 150 km south of our study area on 12 September 2008. Precipitation returned salinities to <10 ppt during the fall of 2009. Coastal marsh salinities were 6–22 ppt in 2010 and 7–36 ppt in 2011.

METHODS

The Texas Chenier Plain National Wildlife Refuge Complex banding crew captured mottled ducks via night lighting from airboats during summer 2009, 2010, and 2011 under USGS Bird Banding Lab permit 09072 and all birds were handled in accordance with the North American Bird Banding Manual (Gustafson et al. 1997). In addition, crews followed guidelines for capture and marking by the North American Ornithological Council (2010). Capture dates ranged from early May to mid-August. To ensure that a representative sample of mottled ducks inhabiting the Texas Chenier Plain Region were marked, crews captured birds during brooding and molt periods relative to their distribution among management units within Anahuac, McFaddin, and Texas Point National Wildlife Refuges (NWRs).

Upon capture, we determined the sex and age of mottled ducks and measured body mass using a spring scale (±5 g; Stutzenbaker 1988, Carney 1992). We attached a USGS numbered aluminum leg band to each mottled duck. We fitted adult female mottled ducks weighing >740 g with a model 100 18-g solar, satellite platform transmitter terminal (PTT; Microwave Telemetry, Columbia, MD, USA) dorsally as a backpack with a custom fashioned 0.476-cm Teflon® ribbon harness (Bally Ribbon Mills, Bally, PA, USA; Miller et al. 2005). Radios comprised ≤2.5% of mass for all marked birds. We handled all mottled ducks for <1 hour; if they had a brood, we placed the brood in a separate mesh bag for holding while we attached the PTT to the female. We released broods with females following PTT placement to reduce potential brood displacement or abandonment.

During 2009 and 2010, we deployed PTTs with a duty cycle of 10 hours active and 72 hours inactive on a rotating window. The duty cycle for 2011 was 10 hours active and 24 hours inactive. Each PTT was equipped with sensors to transmit information on unit temperature, battery voltage, and bird motion to determine mortality of marked mottled ducks. Data were sent to the lead author by electronic mail approximately every 72 hours. We right-censored each duck for 72 hours following their release (Dabbert and Powell 1993, Miller et al. 2005, Haukos et al. 2006) because of capture myopathy and to allow for adjustment to the radio-package.

The encounter interval used for survival analyses was 1 week and the experimental unit for survival was each radio-tagged individual. We estimated cumulative weekly survival (Kaplan and Meier 1958) to identify temporal periods of varying mortality and compare survival estimates to previous studies. We used the known-fate survival modeling approach in Program MARK to assess the influence of potential mortality factors affecting female mottled duck survival (White and Burnham 1999). The model set included 30 survival models with *a priori* combinations of 4 predictors: year, which provided a proxy for average rainfall; hunting and non-hunting periods; biological time period; and body mass at capture (Table 1). We defined biological time periods as breeding (1 Jan–15 May), brooding (16 May–31 Jul), remigial molt (1 Aug–15 Sep), and pairing (16 Sep–31 Dec; Stutzenbaker 1988, Bielefeld et al. 2010, Rigby and Haukos 2012). We censored birds upon the last date of location or known emigration from the study area; therefore, we did not

Table 1. Number of parameters (*K*), corrected Akaike's Information Criterion (AIC_c), ΔAIC_c weights (w_i), and ΔAIC_c values used to rank models containing factors or individual covariates hypothesized to affect the probability of seasonal survival of adult female mottled ducks in the Chenier Plain Region of Texas, USA, 1 June–31 May 2009–2011. Models may contain general waterfowl season (GW), general waterfowl early split (GWES), general waterfowl late split (GWLS), special teal season (ST), non-hunted periods (NH), and biological seasons (BS).

Model[a]	*K*	AIC_c	w_i	ΔAIC_c
(GW + NH) × year	6	698.87	0.42	0.00
((GW + NH) × year) + mass[b]	7	700.18	0.21	1.31
(ST + GW + NH) × year	9	700.64	0.17	1.77
((ST + GWES + GWLS + NH) × year) + mass	12	703.10	0.05	4.23
BS + GW + NH[c]	5	704.34	0.03	5.47
(BS + GW + NH) × year	15	704.57	0.02	5.70
BS + ST + GW + NH	6	707.12	0.01	8.25
(BS + ST + GW + NH) × year	18	707.45	0.01	8.58
BS	4	709.19	0.00	10.32
BS × year	12	710.53	0.00	11.65
(BS × year) + mass	13	711.05	0.00	12.19
BS + mass	5	711.11	0.00	12.24
GW + NH	2	711.73	0.00	12.86
(ST + NH) × year	6	711.81	0.00	12.94
ST + GWES + GWLS + NH	4	713.48	0.00	14.61
ST + GW + NH	3	713.61	0.00	14.74
(ST + GW + NH) + mass	3	707.64	0.00	14.78
Year	3	710.89	0.00	18.03
Time constant	3	716.90	0.00	18.03
ST + NH	2	720.32	0.00	21.45
Constant survival	1	722.16	0.00	23.29
Full time dependence	156	893.17	0.00	194.30

[a] Special teal, goose, and special conservation goose seasons were treated as NH. Dates for ST included 12 Sep–27 Sep 2009, 11 Sep–26 Sep 2010, and 10 Sep–25 Sep 2011. Dates for the GWES were 31 Oct–29 Nov 2009, 30 Oct–28 Nov 2010, and 5 Nov–27 Nov 2011. Dates for GWLS were 12 Dec 2009–24 Jan 2010, 11 Dec 2010–23 Dec 2011, and 10 Dec 2011–29 Dec 2012.
[b] We considered mass at time of capture to be constant with respect to time.
[c] Biological periods were breeding (1 Jan–15 May), brooding (16 May–31 Jul), molt (1 Aug–15 Sep), and pairing (16 Sep–31 Dec).

include transmittered birds with known fates after leaving the study area in analysis of survival rates.

The hunting season in Texas was closed for mottled ducks for the first 5 days of the general waterfowl hunting season for all years of the study. Other than the 5-day closure, mottled ducks were included in the aggregate bag within the normal split hunt season framework (74 days) with a daily bag limit of 1 mottled duck (either-sex). Specific season dates remained relatively constant across the study; however, sample sizes varied by year and season (Table 2). We used adjusted Akaike's Information Criterion (AIC_c) to rank and select the most parsimonious model(s) (Burnham and Anderson 2002). Although conservative with respect to AIC model selection, we present results with 95% confidence intervals to make them directly comparable to previously published survival estimates (Arnold 2010).

RESULTS

During 18 June–8 July 2009, 11 May–2 August 2010, and 1 June–4 August 2011, we captured and marked 15, 30, and 46 after-hatch-year (AHY) female mottled ducks, respectively. The majority of PTTs lasted ≤1 year with average length of satellite transmission being 198 ± 96 days (SD). One female was censored because of transmitter malfunction. Capture mass of adult females ranged 740–1,050 g before transmitter attachment, with an average of 819 g ($n = 91 \pm 60.1$).

We verified the harvest of 6 transmittered mottled ducks (6.7%) during the study. Hunters legally harvested 4 mottled ducks: 3 were within the confines of the study area (5.6 km southeast of Winnie, TX; 21.4 km west of Sabine Pass, TX on McFaddin NWR; and 27.8 km southwest of Winnie, TX on Anahuac NWR), the other was reported approximately 6.1 km northeast of Pecan Island, Louisiana. We confirmed 1 mottled duck shot (pellets were detected via X-ray) during the special teal season and retrieved by a Texas Parks and Wildlife Department game warden in Chambers County, Texas. We retrieved another from a residence near Anahuac, Texas, during the special teal season. Of the 80 mortalities, 6.8% occurred during the breeding season, 9.4% during the brooding season, 23.0% during molt, and 60.8% during pairing. Mortalities were also partitioned by hunt season with 46.1% during the general waterfowl season (either early or late splits), 5.1% during the 5-day mottled duck season closure preceding the general waterfowl season, 20.5% during the waterfowl split, and 28.2% during the special teal season in Texas. These periods of hunting overlapped with portions of the molt and pairing biological time periods (Table 2).

Three models were competitive ($\Delta AIC_c \leq 2.0$; Table 1). The most parsimonious model (AIC_c weight $[w_i] = 0.42$) suggested weekly survival probability varied between hunt and non-hunt periods and among years (Tables 1 and 3; Fig. 3). This model did not distinguish between special teal season, general waterfowl season, and the 5-day closure. This model estimated annual survival as 21.3% (95% CI = 8.1–45.2) for 2009–2010, 38.3% (95% CI = 23.9–55.1) for 2010, and 12.3% (95% CI = 6.7–21.7%) for 2011–2012 (Fig. 4). Our second ranked model ($w_i = 0.22$) was similar to the first

Table 2. Phenological time periods, hunt periods and dates used to estimate seasonal survival of radio-marked adult female mottled ducks in the Texas Chenier Plain Region, USA, 2009−2011. Sample sizes per period are in parentheses following dates.

	2009–2010		2010–2011		2011–2012	
Period	**Start**	**End**	**Start**	**End**	**Start**	**End**
Breeding			01 Jan (6)	15 May (10)	01 Jan (17)	15 May (14)
Brooding	16 May (0)	31 Jul (15)	16 May (23)	31 Jul (30)	16 May (14)	31 Jul (40)
Molt	01 Aug (15)	15 Sep (13)	01 Aug (30)	15 Sep (28)	01 Aug (40)	15 Sep (30)
Pairing	16 Sep (13)	31 Dec (6)	16 Sep (28)	31 Dec (17)	16 Sep (30)	31 Dec (12)
Special teal season[a]	12 Sep (13)	27 Sep (10)	11 Sep (28)	26 Sep (24)	10 Sep (30)	25 Sep (25)
Mottled duck closure[b]	05 Nov (9)	09 Nov (9)	30 Oct (23)	04 Nov (21)	31 Oct (20)	05 Nov (20)
General waterfowl[a]						
Early split	31 Oct (9)	29 Nov (8)	30 Oct (23)	28 Nov (20)	05 Nov (20)	27 Nov (19)
Late split	12 Dec (7)	24 Jan (6)	11 Dec (18)	23 Jan (15)	10 Dec (17)	29 Jan (9)

[a] If any portion of a week was hunted it was designated as hunted for analysis purposes.
[b] Dates indicate the 5-day mottled duck closure at the beginning of the general waterfowl season in Texas.

except it included body mass at capture. The addition of body mass at capture did not further improve model fit and the effect was small ($\beta = 0.002$, 95% CI = 0–0.006, $P = 0.413$), indicating a likely spurious effect (Andersen et al. 2001, Arnold 2010). Our third ranked model ($w_i = 0.17$) indicated weekly survival probability varied among the special teal season, general season, and non-hunt periods and among years (Tables 1 and 3; Fig. 3). Models that contained a hunt season component comprised approximately 100% of model weights (Table 1), indicating that periods of harvest are the primary factors influencing temporal variation in mottled duck survival in the Chenier Plain Region of Texas. In contrast, models that contained biological periods were not supported (Table 1).

We assessed Kaplan–Meier survival distributions for cumulative annual survival by year for comparative purposes. In 2009–2010, estimated annual survival was 33.3% (95% CI = 26.7–39.8%), whereas cumulative weekly survival rates in 2010–2011 were 43.3% (95% CI = 38.9–47.6) and 4.7% in 2011–2012 (95% CI = 0–10.0; Fig. 4). Other than year, harvest was a primary factor influencing temporal variation in female mottled duck survival, and effects were not consistent among years. The impact of harvest on mottled duck mortality appeared greatest in 2010 (Fig. 3).

DISCUSSION

Annual survival rates for mottled ducks in the Texas Chenier Plain from 2009 to 2012 are among the lowest reported (Wilson 2007, Wehland 2012, Haukos 2015), and varied with respect to harvest period and annual variation. Further, harvest models outperformed concurrent biological season models, suggesting harvest may be additive rather than a

Table 3. Estimated weekly survival of adult female mottled ducks on the Texas Chenier Plain, USA, Western Gulf Coast population, during 2009−2012, including coefficient estimates and upper and lower 95% confidence intervals for the top 2 ranked models and biological seasons.

Model	Yr	Season	Weekly estimate	Lower Cl	Upper Cl	β	Lower Cl	Upper Cl
(GW + NH) × year[a]								
	2009–2010	NH	0.973	0.948	0.9S6	1.24	1.13	1.35
	2009–2010	GW	0.964	0.919	0.9S6	1.19	1.01	1.37
	2010–2011	NH	0.995	0.9S7	0.99S	1.44	1.3S	1.51
	2010–2011	GW	0.953	0.926	0.976	1.14	1.03	1.24
	2011–2012	NH	0.964	0.949	0.976	1.19	1.12	1.26
	2011–2012	GW	0.953	0.931	0.96S	1.13	1.05	1.22
(ST + GW + NH) × year[a]								
	2009–2010	NH	0.973	0.961	0.982	1.24	1.12	1.35
	2009–2010	ST	0.964	0.949	0.976	1.57	1.15	1.98
	2009–2010	GW	0.949	0.873	0.9S0	1.12	0.90	1.33
	2010–2011	NH	0.995	0.987	0.998	1.44	1.37	1.51
	2010–2011	ST	0.939	0.878	0.970	1.07	0.89	1.25
	2010–2011	GW	0.960	0.927	0.978	1.17	1.04	1.29
	2011–2012	NH	0.964	0.948	0.975	1.19	1.12	1.27
	2011–2012	ST	0.949	0.902	0.974	1.12	0.96	1.27
	2011–2012	GW	0.953	0.926	0.972	1.14	1.03	1.24
BS[b]								
		Breed	0.991	0.981	0.996	1.38	1.31	1.46
		Brood	0.974	0.958	0.983	1.25	1.17	1.32
		Molt	0.957	0.941	0.968	1.15	1.07	1.21
		Pair	0.964	0.945	0.976	1.19	1.11	1.27

[a] General waterfowl season (GW), special teal season (ST), non-hunted periods (NH).
[b] Biological season (BS) is reported for thoroughness; biological season estimates were not supported by modeling efforts, thus seasonal estimates are reported across years.

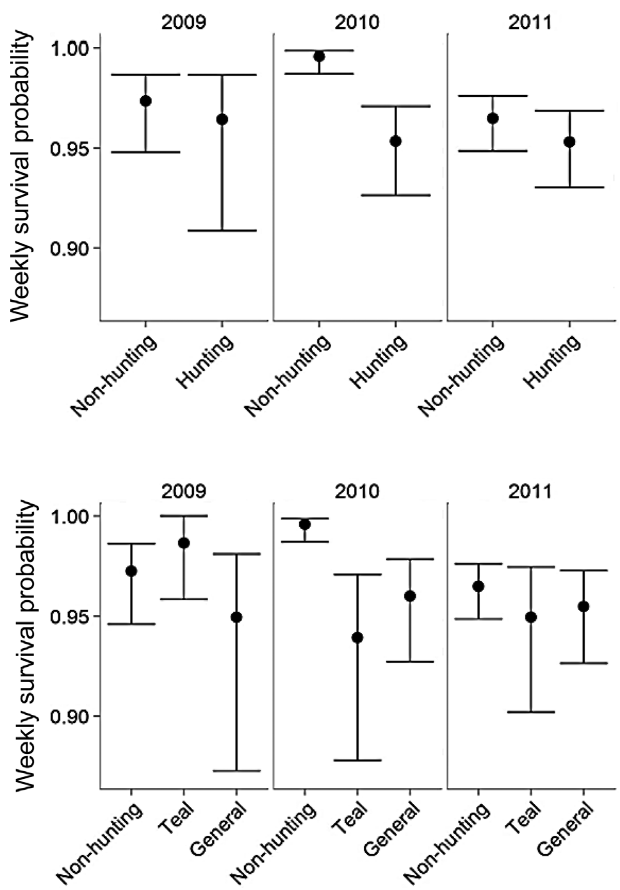

Figure 3. Average weekly survival of the most parsimonious model, which included hunting season by year effects, and the second most supported model, which further parsed the hunting season into the special teal season and general waterfowl season by year for adult female mottled ducks radio-tagged in the Chenier Plain Region of Texas, USA, and monitored 1 June 2009–31 May 2012. Error bars denote 95% confidence intervals surrounding survival estimates.

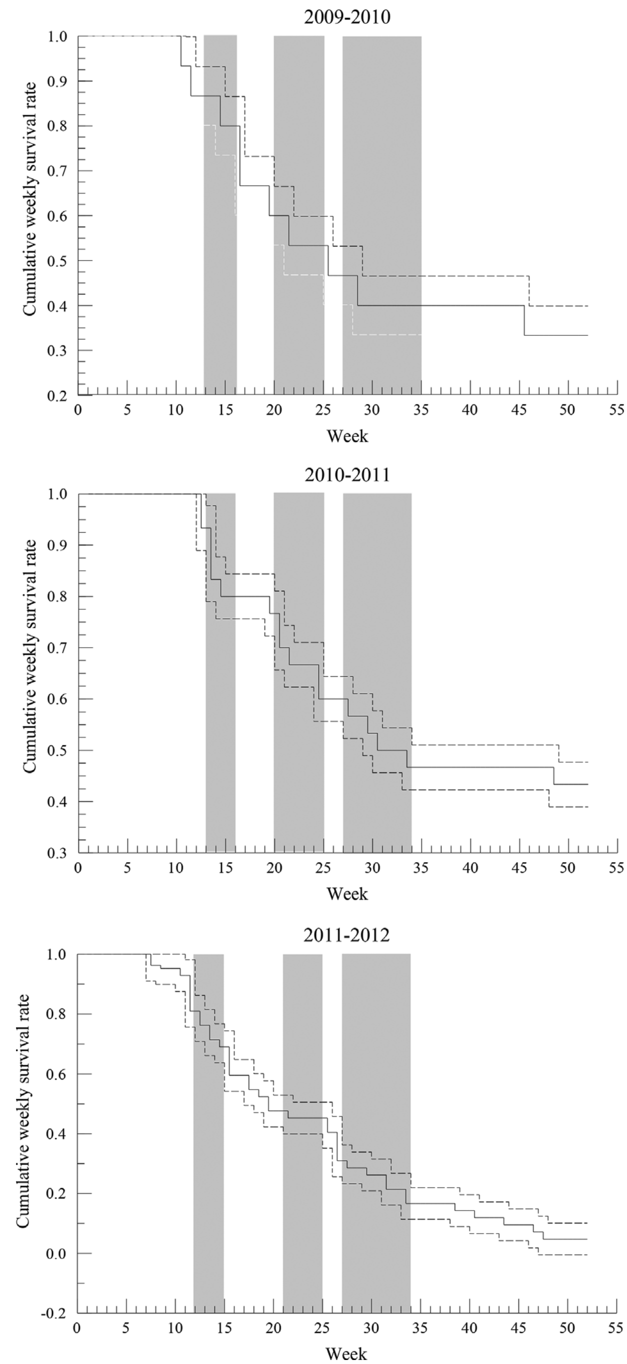

Figure 4. Weekly Kaplan–Meier survival distributions during for adult female mottled ducks radio-tagged in the Chenier Plain Region of Texas and monitored yearly 1 July (week 0)–30 June during 2009, 2010, and 2011. Dashed lines indicate upper and lower 95% confidence intervals. Weeks within hunt seasons are shaded in gray.

compensatory factor in mottled duck survival. The most supported model included periods of harvest, with lowest seasonal survival during the general waterfowl season. Similarly, several studies have reported elevated mortality rates 1 August–30 December (Bielefeld and Cox 2006, Wehland 2012). These dates coincide with molt, the general waterfowl season, and special seasons for other waterfowl (i.e., teal and wood duck [*Aix sponsa*]) that occur within the mottled duck range. Bielefeld and Cox (2006) reported the post-breeding and hunting season to be the most hazardous periods for mottled duck survival in east-central Florida. Similarly, a conventional telemetry study in the WGC population from 2006–2010 documented that most mortalities occurred during periods of hunting (52%) and post-breeding (25%; Wehland 2012), and reported lower rates of mortality for the breeding season (18%) and late winter (5%) periods (Wehland 2012). Further, hunting was an important mortality factor for wintering female northern pintails (*A. acuta*; Cox et al. 1998) and mallards (*A. platyrhynchos*; Link 2007) in parts of southwestern Louisiana.

Many previous studies link declines in waterfowl survival during periods of harvest, but none of the aforementioned studies documented declines in survival during which their focal species were not legal targets (Cox et al. 1998, Bielefeld and Cox 2006, Péron et al. 2012, Wehland 2012). Seasonal survival was lower during the special teal season than during non-hunted periods. An average of 14% of the annual mortality of mottled ducks in this study occurred during the special teal season (15 days) each year. Although our estimates have wide confidence intervals, we did observe what appears to be a meaningful decrease in survival rates during the special teal season in 2010 (6%) and a similar pattern in 2011 (2%). We documented a reduced effect in 2009, which was likely the result a smaller sample size (i.e., fewer radios deployed) in 2009 than 2010 and 2011. Harvest may be confounded with other factors influencing survival during this time period. The typical remigial molt for mottled ducks immediately precedes the special teal season, and periods of molt may negatively affect overall body condition and subsequent survival of mottled ducks (Stutzenbaker 1988). The potential effects of illegal harvest and potential influences on the population trajectory of mottled ducks are unknown and warrant investigation.

We speculate our results may underestimate susceptibility to harvest because of documented survival patterns among age and sex cohorts for mottled ducks (Haukos 2015). Individuals with greater body mass at time of capture have been linked to high overwinter survival rates when compared to individuals in average or poor condition for many migratory waterfowl species (Haramis et al. 1986, Bergan and Smith 1993, Schmutz and Ely 1999, Hill et al. 2003, Moon and Haukos 2006). A review by Péron et al. (2012) suggested waterfowl hunting and associated high disturbance periods likely decrease survival by requiring additional expenditures of energy for evasion and associated behaviors, which may have a more pronounced effect on birds in poor condition. Although body mass did not improve model fit for these data, it should be noted that transmitters were placed only on females with a minimum mass of 740 g, such that females were arguably in comparatively good body condition when compared to a population average during the study (687 g; USFWS, unpublished data). It is possible that hatch-year mottled ducks, or adults in poorer body condition may be more susceptible to mortality (regardless of age or sex).

Overall, our annual survival estimates are lower than any other previously estimated in Texas (Stutzenbaker 1988; Haukos 2012*a*,*b*; Rigby and Haukos 2012) or in Florida (Bielefeld and Cox 2006, Varner et al. 2014). However, estimated annual survival rates had 95% confidence intervals that overlapped estimates calculated using band-recovery data (50.9%, 95% CI = 48.6–53.3; Haukos 2015). No studies are currently available assessing the impact of radio transmitters on mottled ducks; however, we feel that a radio effect was unlikely in our data set because of prior research finding no effect of backpack transmitters on overall survival for other waterfowl species common to the Gulf Coast (Gammonley and Kelley 1994, Fleskes 2003), and because radio transmitters were such a low proportion of the radio-marked females overall weight (i.e., <2% of body weight on average). If estimated survival rates during this study were not biased by an outside source (e.g., radio effect) survival rates of other age and sex cohorts could be lower than estimates documented for adult females during this study and warrants investigation (i.e., lower survival for male and female juveniles; Haukos 2015).

Survival rates varied among years and were lowest during a below-average rainfall year (2011) when compared with average rainfall years (2009, 2010). Because of drought and lack of swift restorative actions following Hurricane Ike, habitat conditions during 2011 were the most extreme and deleterious that the Texas Coast had experienced in the past 100 years (Neilson-Gammon 2012). Salinities in coastal marsh systems within the Chenier Plain area ranged from sea-strength (36 ppt) to hypersaline (>50 ppt) in many areas within the region during 2011–2012 (USFWS, unpublished data), far greater than the 9 ppt threshold documented to negatively affect mottled duck brood survival (Moorman et al. 1991). Below-average annual precipitation in 2011 and elevated wetland salinity likely negatively affected mottled duck survival rates in the Texas Chenier Plain Region, with an almost 60% reduction in annual survivorship that year compared to 2009−2010 estimates. Past work has suggested that above-average rainfall decreases salinities in coastal marshes and increases ephemeral prairie wetland availability for mottled ducks, together these effects have often yielded greater breeding season survival rates and increased recruitment (Stutzenbaker 1988, Moorman et al. 1991, Rigby and Haukos 2012). It is unclear how carry-over effects of hurricane and drought affect breeding mottled ducks and long-term survival rates. Because of reduced sample sizes during the breeding season because of high mortality during the previous hunting season, we were unable to fully investigate these trends. However, one would assume given similar habitat conditions on the Texas Gulf Coast that annual survival rates would remain low until environmental conditions (e.g., salinity) return to historical levels following periods of average or greater precipitation.

MANAGEMENT IMPLICATIONS

In our study, the primary period of mortality for mottled ducks occurred in conjunction with fall and winter general waterfowl season, thus regulatory entities should continue to work toward solutions to minimize hunting impacts on mottled ducks (e.g., establishment of sanctuaries, flooding programs, increased law enforcement). Flooding programs targeted on National Wildlife Refuges, State Wildlife Management Areas, and private property may be used in combination with sanctuary areas to meet mottled duck needs during suboptimal environmental conditions and periods of hunting. Whether harvest constitutes additive mortality to the population remains unknown and an Adaptive Harvest Management model specific to mottled ducks could assist in future regulatory decisions. Threats to the WGC population of mottled ducks are pervasive (e.g., climate change, urbanization, habitat fragmentation), such that management actions providing low salinity habitats during periods with documented high mortality rates (hunting season, drought) could be key to improving survival rates (Stutzenbaker 1988, Bielefeld and Cox 2006). Further research is needed to elucidate the impacts of legal and illegal harvest and unravel the relationship between environmental conditions and mottled duck survival. Future research should seek to measure the effect of harvest and habitat management on population demography of mottled ducks.

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