Duck Non-Breeding Body Condition Differs by Sex, Age, and Year on the Texas Mid-Coast

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Abstract: Waterfowl are of significant cultural, economic, and conservation importance along the Texas Gulf Coast. Millions of ducks utilize this region as they move along the Central Flyway each winter. Understanding body condition patterns for these birds has important implications for overwinter survival, breeding success, and population regulation. This is especially true for females, which are typically the limiting sex in ducks. Herein, we analyze sex- and age-specific differences in body condition of non-breeding dabbling ducks over the winter hunting season in coastal Texas. We collaborated with hunters over two winters to salvage, weigh, and measure 1255 dabbling ducks, including blue-winged teal (*Spatula discors*), green-winged teal (*Anas crecca*), northern shoveler (*Spatula clypeata*), gadwall (*Mareca strepera*), and northern pintail (*Anas acuta*). Using a modern body condition index calculation, we found that females were in better body condition than males for four of the five species studied (i.e., blue-winged teal, northern shoveler, gadwall, and green-winged teal), although this effect depended on year for green-winged teal. Body condition differed between immatures and adults, although the direction of that difference varied between the two winters. Ducks generally declined in body condition across the winter hunting season and body condition was typically higher in 2017–2018 than 2018–2019. Yearly differences in body condition may be due to major differences in precipitation, with our results suggesting differential responses by sex, age class, and species to increased availability of temporary habitats when precipitation was greater.

Key words: hunting, waterfowl, scaled mass index, Texas, winter

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During the 20th century, most waterfowl biology research focused on breeding season ecology (Batt et al. 1992). This trend was sustained by the belief that factors that control population sizes occur during the breeding period (Weller and Batt 1988). Although availability of breeding habitat and nesting and fledging success are critical for population growth (e.g., Hoekman et al. 2002), activities and conditions in wintering areas also can affect population dynamics (Heitmeyer and Fredrickson 1981, Kaminski and Gluesing 1987, Raveling and Heitmeyer 1989, Guillemain et al. 2008, Davis et al. 2014, Osnas et al. 2016). For dabbling ducks (Anatini), these activities include replenishing reserves following fall migration, courtship and pair formation, and preparation for spring migration and breeding (Tamisier et al. 1995). Conditions during these non-breeding activities correlate with waterfowl recruitment and reproductive success (e.g., Sedinger and Alisauskas 2014, Osnas et al. 2016). Even for small-bodied ducks, such as teal (e.g., *Anas crecca*, *Spatula discors*), which are expected to obtain most of their nutrient resources for reproduction on the breeding grounds (Janke et al. 2015), winter body condition is correlated with later reproductive success, probably due to carry-over effects (Guillemain et al. 2008). Moreover, body condition at the start of winter can influence condition at the end of winter, which is critical for migratory success (Loesch et. al. 1992, Tamisier et al. 1995). Thus, wintering body condition patterns have important implications for breeding success, winter survival, and population growth for dabbling ducks (Hepp et al. 1986, Tamisier et al. 1995, Robb 2002). This phenomenon is especially true for females, which are typically the limiting sex in ducks (Bellrose et al. 1961).

Body condition is typically estimated by the size of nutrient stores (Brown 1996), such as body mass, lipid deposits, and protein (Owen and Cook 1977, Ringelman and Szymczak 1985). Body condition of migratory ducks generally increases after arrival in wintering areas, then decreases toward the end of winter when energy is expended to find mates, molt, and cope with poor weather and limited and unpredictable food resources (e.g., Baldassarre et al. 1986, Tamisier et al. 1995). Mid-winter body condition decline may also be under endogenous control because the constant availability of resources may reduce the need to store energy as costly extra mass (Haukos et al. 2001) or a reduction in lean mass may lower daily energy requirements (Reinecke et al. 1982, Loesch et al.

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1992). Mass tends to increase prior to spring migration (Haukos et al. 2001). However, these patterns are not universal and can depend on collection technique (e.g., hunter harvested vs. scientific collection; Collins 2012).

In this study, we focused on blue-winged teal (*S. discors*), northern shoveler (*S. clypeata*), green-winged teal (*A. crecca*), northern pintail (*A. acuta*), and gadwall (*Mareca strepera*). Northern pintail is of special concern in North America because its population sizes remain below population goals (U.S. Department of the Interior et al. 2012). Results of previous studies suggest that body condition of northern pintail is not increasing throughout the winter (Mora et al. 1987, Ballard et al. 2006, Moon and Haukos 2009) and that protection and better management of winter wetland habitats are needed to support healthy pintail populations (Raveling and Heitmeyer 1989, Ballard et al. 2006). However, body condition during winter can be sex- and age-specific because of different energetic requirements of males and females (e.g., females must recover energy following breeding; Johnson et al. 1999), and immature ducks have lower endogenous fat storage (Reinecke et al. 1982). Further understanding of sex- and age-specific winter body condition patterns would aid in winter management decisions by allowing managers to focus their efforts on subpopulations of species important to recruitment (i.e., females and immatures).

Herein, we investigated sex and age differences in the body condition of dabbling ducks across the winter season on the Texas Gulf Coast with the objective of establishing baseline data for future studies. Our target species are all popularly hunted species that coexist in the same locations but have a diversity of vegetation and water depth foraging preferences (White and James 1978). We predicted that: 1) the body condition of all ducks would decline from November to January, consistent with previous literature (e.g., Tamisier et al. 1995), 2) adult females would be in lower body condition than males in early winter because females that successfully bred must recover from higher energetic costs of breeding (Johnson et al. 1999) and this difference will diminish across winter, and 3) immature ducks would be in lower body condition than adults throughout the winter because of lower fat storage and skeletal size (Reinecke et al. 1982). Our second hypothesis assumes that most adult females attempted to breed in the previous season.

Study Area

Specimens were collected from three private hunting clubs (Run-and-Gun Adventures, Thunderbird Hunting Club, and Pierce Ranch) and one public wildlife management area (Mad Island Wildlife Management Area) on the central Texas Gulf coast in Matagorda (28.896736, –95.992273) and Wharton (29.304244, –96.213699) counties in the 2017–2018 and 2018–2019 hunting seasons. These sites included marsh, pond, and flooded agricultural fields that were physically separated on the landscape and were located ~63 km inland from the coast. Total precipitation during the period of this study (10 November–27 January) was 33.15 cm in 2017–2018 and 15.98 cm in 2018–2019 (averaged from weather stations in Matagorda and Wharton counties).

Methods

Field Methods

We collected hunter-donated specimens of green-winged teal, northern pintail, blue-winged teal, northern shoveler, and gadwall. Samples were collected between 0800 and 1500 hours December 2017–January 2018 (9 and 16 December; and 13, 20, and 27 January) and November 2018–January 2019 (10 and 17 November; 8 and 15 December; 12 and 19 January), although collections were not made at every site on every date. Collection dates were set in collaboration with hunting site managers, resulting in a slightly later start in 2017 than 2018 and in neither case did collection dates include the early teal hunting season (September). Each duck was identified to species, weighed (electronic balance, ±1 g), and labeled with a unique identifier. Ducks were predominantly hunted in the morning, with later collection times reflecting longer distances from the hunting site to the collection site. Because these species were typically hunted as they left roosts to forage, we did not remove ingesta prior to weighing. We then removed the breast meat with one wing attached (required for legal transport) and returned these to the hunters. The remainder of the body was transported to the laboratory for storage between –20 and –80 ^{o}C. All samples were collected under the U.S. Fish and Wildlife Service (USFSW) Scientific Collecting Permit (MB66499C) and Texas Parks and Wildlife Scientific Permit (SPR-0317-079).

Laboratory Methods

We thawed specimens and re-identified them to species, sex, and age (i.e., immature, adult) using the USFWS Wing Guide (Carney 1992), head and body plumage, internal anatomy (i.e., presence of ovary or testes for sexing), and tertial/tail molts (aging). Next, we measured each bird for tarsus length (caliper ±1 mm), bill length (from anterior side of the nostril to the tip of the bill; caliper ±1 mm), and flattened wing chord (ruler, ±1 mm). We also scored visceral fat around the gizzard as high (fat covering 11% or more of the ventral side of the gizzard) or marginal (fat covering 10% or less of the ventral side) (McCabe 1943). Birds first deposit adipose tissue under the skin along feather tracts and last throughout the abdominal cavity (Blem 1976), which is the first to be metabolized when energy stores are used. Thus, birds with high gizzard fat are 'excessively/very fat' whereas birds with marginal gizzard fat can be 'fat,' 'moderately fat,' or 'not fat' (McCabe 1943). The gizzard was used as an indicator of visceral fat because it was the most intact, highly accessible organ in the abdominal cavity, is one of the larger fat pads in birds (Scanes 2015), and because of gunshot damage to other specimen fat deposits. One researcher conducted all measurements and identification to ensure consistency of data collection.

Data Analysis

Body Condition Calculation.—We used scaled mass index (SMI) as our body condition index (Peig and Green 2009) because waterfowl body condition is better approximated by condition indices that scale body mass for structural size (Brown 1996) rather than body mass alone (Schamber et al. 2009). We chose to use SMI because it uses a multiplicative error function instead of an additive one (as in ordinary least squares regression), which better accounts for the scaling between mass and length (Peig and Green 2009). We calculated SMI for each species using the equation: $M_i(L_0/L_i)^b$, where M_i is individual mass of each sample bird, L_0 is the mean length of the linear measure that most highly correlates with mass (wing chord instead of tarsus or bill length measures because it had the strongest relationship with mass for all species; green-winged teal $r^2 = 0.2$, blue-winged teal and northern shoveler $r^2 = 0.3$, gadwall and northern pintail $r^2 = 0.5$), L_i is the individual length of this linear measure, and b is the slope of a Standardized Major Axis (SMA) regression of the natural log of mass on the natural log of the linear measure (Peig and Green 2009). For our five study species, L_0 was 193.5 mm for blue-winged teal ($n = 431$), 189.4 mm for green-winged teal ($n = 390$), 273.7 mm for northern pintail ($n = 94$), 274.3 mm for gadwall ($n = 165$), and 246.9 mm for northern shoveler ($n = 175$) (see Table 1 for species-specific measurement statistics). A single scaling component was calculated for each species because no significant interactions between linear measurements and sex or age were found for any of the five focal species (ANOVA, $P > 0.05$).

Model Selection.—Linear models were evaluated within a multimodel inference framework, which has the benefit of evaluating the relative strength of evidence for multiple alternative hypotheses (Anderson 2008). For each analysis set, models were derived from subsets of a global model and ranked using Akaike's Information Criterion corrected for small sample size (AICc) via the package MuMIn in R (Barton 2018). We defined our top model as that with the lowest AICc value without uninformative predictors (Anderson 2008). To identify uninformative predictors, we examined the 95% confidence intervals (CI) of predictor beta coefficients and the log-likelihood of each model within 2 AICc units of the model with the lowest AICc (Arnold 2010, Leroux 2019). More complex models that increased the log-likelihood very little and for which the CI of the beta coefficient of predictors overlapped zero were excluded and we moved to the next model in the set.

Table 1. Mean (standard deviation) values of mass, tarsus length, wing length, and bill length for each species, sex, and age class of hunter harvested dabbling ducks on the Texas mid-coast in winters 2017–2018 and 2018–2019.

	Immature female	Immature male	Adult female	Adult male
Blue-winged teal				
Mass (g)	363.27 (37.98)	402.20 (34.5)	368.99 (41.77)	401.55 (38.45)
Tarsus (mm)	31.50 (1.09)	32.60 (1.03)	31.80 (1.16)	32.60 (1.08)
Wing (mm)	187.85 (4.05)	196.76 (4.38)	188.97 (4.33)	197.7 (4.53)
Bill (mm)	30.16 (1.28)	31.66 (1.13)	30.22 (1.42)	31.88 (1.20)
Green-winged teal				
Mass (g)	302.27 (39.36)	332.91 (42.17)	313.89 (35.92)	348.93 (43.74)
Tarsus (mm)	30.29 (0.85)	31.42 (1.26)	30.55 (1.12)	31.31 (1.04)
Wing (mm)	183.63 (3.96)	190.42 (4.44)	185.47 (4.68)	193.57 (4.58)
Bill (mm)	27.94 (1.03)	29.45 (1.39)	27.89 (0.93)	29.40 (1.10)
Northern pintail				
Mass (g)	755.00 (75.02)	871.73 (109.44)	794.90 (82.04)	951.90 (106.43)
Tarsus (mm)	41.79 (1.37)	44.71 (1.48)	42.08 (1.45)	44.52 (1.36)
Wing (mm)	259.54 (9.92)	274.30 (6.24)	264.37 (9.87)	282.88 (8.29)
Bill (mm)	37.02 (1.27)	39.57 (1.42)	36.31 (1.19)	40.20 (1.95)
Northern shoveler				
Mass (g)	520.46 (50.41)	580.50 (74.91)	533.58 (62.63)	600.6 (61.09)
Tarsus (mm)	37.15 (1.62)	38.71 (1.43)	37.13 (1.29)	39.05 (1.56)
Wing (mm)	236.85 (6.38)	249.82 (6.45)	240.79 (5.93)	256.13 (5.25)
Bill (mm)	45.80 (1.60)	49.50 (2.02)	45.70 (2.27)	49.94 (1.81)
Gadwall				
Mass (g)	767.24 (75.27)	843.7 (66.94)	777.93 (69.35)	889.61 (91.51)
Tarsus (mm)	41.11 (1.40)	42.44 (1.22)	41.14 (1.67)	43.01 (1.35)
Wing (mm)	263.38 (8.05)	279.75 (6.31)	265.16 (6.26)	285.28 (5.89)
Bill (mm)	33.21 (1.36)	35.74 (1.26)	33.42 (1.45)	36.00 (1.41)

Effects of Date, Sex, and Age.—For each species, effects of collection day and year, sex, and age class on SMI and fat score were evaluated using general linear models (GLM function, identity link for SMI, logit link for fat score) where the global model consisted of the main effects of sex, age, day, and year, and two-way interactions between sex and age, sex and day, sex and year, age and day, age and year, and day and year. Q-Q plots of residuals for each model were visually examined for outliers. Outliers were inaccurate measurements or recording errors that produced measurements beyond established size limits for each species and were removed (three each for blue-winged teal, green-winged teal, northern pintail, and gadwall, and four for northern shoveler). Linear models were run twice, first with all data and then excluding date ranges that were not represented in both years (2017–2018 lacked November sampling, and 2018–2019 did not continue into late January). There were no differences in the direction of most effects between this subset of data and the full data set, thus we only report results using the full data set. For fat models, pseudo r^2 values were calculated according to Veall and Zimmerman (1994) using the package DescTools (Signorell 2020) in R. All statistical analyses were conducted in R statistical software (R Core Team 2017).

Results

Sample Sizes

A total of 1255 samples over both winters was analyzed after the removal of outliers. We analyzed SMI for 431 blue-winged teal (157 adult males, 110 adult females, 84 immature males, 80 immature females), 390 green-winged teal (188 adult males, 160 adult females, 17 immature males, 25 immature females), 165 gadwall (52 adult males, 36 adult females, 36 immature males, 41 immature females), 175 northern shovelers (60 adult males, 18 adult females, 41 immature males, 56 immature females), and 94 northern pintails (49 adult males, 25 adult females, 11 immature males, 9 immature females). Descriptive statistics for mass, tarsus length, wing chord length, and bill length for each species, sex and age classification were recorded (Table 1; fuller summary information is available from the corresponding author on request), as they are important baselines for future studies and calculations (Labocha et al. 2012).

Top Models and Relative Variable Importance for Predicting SMI

For teal, gadwall, and northern shoveler, sex had the greatest relative importance, closely followed by year for gadwall and blue-winged teal, and day for green-winged teal and northern shoveler (Table 2). For northern pintail, year and day were most important, closely followed by age (Table 2). Top models for predicting SMI had r^2 values ranging from 0.08 for green-winged teal to 0.23 for northern pintail (see Table 3 for model selection results).

Table 2. Relative variable importance by species for each predictor (sex, year, day of harvest, and age) of dabbling duck scaled mass index, calculated from a saturated model set for each species. Higher values indicate stronger relative importance. Day is the day of harvest within each year. A colon indicates an interaction between two variables. Scaled mass index was calculated from wing chord and mass of dabbling ducks during hunter harvest along the central Texas coast in winters 2017–2018 and 2018–2019.

Predictor	Blue-winged teal	Green-winged teal	Northern shoveler	Northern pintail	Gadwall
Sex	1	1	1	0.66	1
Year	0.99	0.94	0.88	1	0.99
Day	0.92	0.97	0.99	1	0.72
Age	0.84	0.56	0.87	0.98	0.86
Day:Sex	0.55	0.28	0.5	0.17	0.18
Day:Year	0.49	0.62	0.47	0.25	0.49
Day:Age	0.22	0.14	0.43	0.3	0.22
Year:Age	0.28	0.14	0.56	0.96	0.76
Year:Sex	0.31	0.68	0.38	0.18	0.31
Age:Sex	0.35	0.17	0.35	0.19	0.21

Table 3. Model evaluation parameters for models within two AICc units of the top model for each species predicting scaled mass index (SMI) using demographic variables. "Day" is the day of harvest within each year, "Year" is 2017–2018 or 2018–2019, "Age" is immature or adult, and a colon indicates an interaction term. Bold models are those that were used in further analysis (i.e., determined to be the "top" model by our model selection criteria). All models are derived from the global model: SMI ~ Age + Day + Sex + Year + Sex:Age + Sex:Day + Sex:Year + Age:Day + Age:Year + Day:Year.

Model	df	Log-likelihood	ΔAICc[a]
Blue-winged teal			
Age + Day + Sex + Year + Age:Sex + Day:Sex + Day:Year	9	−2112.009	0
Age + Day + Sex + Year + Day:Sex + Day:Year	8	−2113.125	0.14
Age + Day + Sex + Year + Day:Sex	7	−2114.200	0.22
Age + Day + Sex + Year + Age:Sex + Day:Sex	8	−2113.242	0.38
Age + Day + Sex + Year	6	−2115.448	0.65
Age + Day + Sex + Year + Day:Year	7	−2114.467	0.75
Day + Sex + Year	**5**	**−2116.588**	**0.87**
Day + Sex + Year + Day : Sex	6	−2115.589	0.93
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Sex + Day:Year	10	−2111.495	1.07
Day + Sex + Year + Day:Sex + Day:Year	7	−2114.631	1.08
Age + Day + Sex + Year + Age:Year + Day:Sex + Day:Year	9	−2112.580	1.14
Day + Sex + Year + Day:Year	6	−2115.701	1.15
Age + Sex + Year	5	−2116.859	1.41
Age + Day + Sex + Year + Day:Year + Sex:Year	8	−2113.876	1.65
Age + Day + Sex + Year + Age:Year + Day:Year	8	−2113.982	1.86
Age + Day + Sex + Year + Age:Sex + Day:Sex + Day:Year + Sex:Year	10	−2111.892	1.86
Age + Day + Sex + Year + Sex:Year	7	−2115.034	1.89

(table continues)

Table 3. *(continued)*

Model	df	Log-likelihood	ΔAICc[a]
Blue-winged teal (continued)			
Age + Day + Sex + Year + Age:Day + Age:Sex + Day:Sex + Day:Year	10	−2111.908	1.89
Age + Day + Sex + Year + Day:Sex + Day:Year + Sex:Year	9	−2112.962	1.9
Age + Day + Sex + Year + Age:Year + Day:Sex	8	−2114.052	2
Green-winged teal			
Day + Sex + Year + Day:Year + Sex:Year	7	−1938.535	0
Age + Day + Sex + Year + Day:Year + Sex:Year	8	−1938.193	1.4
Day + Sex + Year + Sex:Year	**6**	**−1940.281**	**1.42**
Day + Sex + Year + Day:Year	6	−1940.468	1.79
Northern shoveler			
Age + Day + Sex + Year+ Age:Day + Age:Year + Day:Year + Sex:Year	10	−912.305	0
Age + Day + Sex + Year + Age:Year + Day:Sex	8	−914.711	0.34
Age + Day + Sex + Year+ Age:Day + Age:Year + Day:Year	9	−913.605	0.35
Age + Day + Sex + Year+ Age:Day + Age:Sex + Age:Year + Day:Year + Sex:Year	11	−911.385	0.44
Age + Day + Sex + Year + Age:Year + Day:Sex + Day:Year	9	−913.68	0.5
Age + Day + Sex + Year + Age:Day + Age:Year + Sex:Year	9	−913.749	0.64
Age + Day + Sex + Day:Sex	6	−917.131	0.81
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year + Sex:Year	10	−912.725	0.84
Age + Day + Sex + Year + Age:Day + Age:Year	8	−915.005	0.93
Age + Day + Sex + Year + Age:Day + Age:Year + Day:Sex + Day:Year	10	−912.776	0.94
Day + Sex + Year + Day:Sex + Day:Year	7	−916.112	0.94
Age + Day + Sex + Year + Age:Day + Age:Year + Day:Sex	9	−913.936	1.01
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year + Day:Year	10	−912.846	1.08
Day + Sex + Year + Day:Year	6	−917.274	1.1
Day + Sex + Day:Sex	**5**	**−918.350**	**1.1**
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Sex	9	−913.994	1.13
Age + Day + Sex + Year + Age:Year + Day:Sex	9	−914.012	1.16
Age + Day + Sex + Year + Age:Year + Day:Year + Sex:Year	9	−914.022	1.18
Age + Day + Sex + Year + Age:Year + Day:Sex + Day:Year + Sex:Year	10	−912.907	1.2
Age + Day + Sex + Year + Day:Sex + Day:Year	8	−915.147	1.21
Age + Day + Sex + Year + Day:Sex	7	−916.302	1.32
Day + Sex + Year + Day:Sex	6	−917.399	1.35
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year	9	−914.150	1.44
Age + Day + Sex + Year + Age:Day + Age:Year + Day:Sex + Day:Year + Sex:Year	11	−911.902	1.47
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Sex + Day:Year	10	−913.046	1.48
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year + Day:Sex	10	−913.095	1.58
Age + Day + Sex + Year + Age:Year + Sex:Year	8	−915.372	1.66
Age + Day + Sex + Year + Day:Year	7	−916.473	1.66
Age + Day + Sex + Year + Age:Day + Age:Year + Day:Sex + Sex:Year	10	−913.155	1.7
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year + Day:Sex + Day:Year	11	−912.021	1.71
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Sex + Sex:Year	10	−913.180	1.75
Age + Day + Sex + Age:Sex + Day:Sex	7	−916.517	1.75
Age + Day + Sex + Year + Age:Day + Day:Year	8	−915.436	1.79
Age + Day + Sex + Year + Age:Year + Day:Year	8	−915.446	1.81
Day + Sex + Year	5	−918.777	1.96
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Year + Sex:Year	10	−913.285	1.96
Age + Day + Sex + Year + Age:Sex + Age:Year + Day:Sex + Day:Year + Sex:Year	11	−912.161	1.99
Age + Day + Sex + Year + Age:Day + Age:Sex + Age:Year + Day:Sex + Day:Year + Sex:Year	12	−911.010	2

(table continues)

Table 3. *(continued)*

Model	df	Log-likelihood	ΔAICc[a]
Northern pintail			
Age + Day + Year + Age:Year	**6**	**−536.905**	**0**
Age + Day + Sex + Year + Age:Year	7	−536.100	0.73
Gadwall			
Age + Sex + Year + Age:Year	**6**	**−920.273**	**0**
Age + Day + Sex + Year + Age:Year + Day:Year	8	−918.203	0.25
Age + Day + Sex + Year + Age:Day + Age:Year + Day:Year	9	−917.643	1.37
Age + Sex + Year + Age:Year + Sex:Year	7	−919.970	1.57
Age + Day + Sex + Year + Age:Year	7	−919.997	1.63
Age + Day + Sex + Year + Age:Year + Day:Year + Sex:Year	9	−917.932	1.95

a. Lowest AICc values by species: blue-winged teal = 4242.4, green-winged teal = 3891.4, northern shoveler = 1846.0, northern pintail = 1086.8, and gadwall = 1853.1.

Sex, Age, and Date Effects on Body Condition

Birds that had high gizzard fat had greater SMI scores than those with marginal fat (two-sided Welch's t-test, blue-winged teal: $t = 4.6$, df = 159, $P < 0.001$; green-winged teal: $t = 7.8$, df = 220, $P < 0.001$; northern pintail: $t = 3.9$, df = 27, $P = 0.002$; gadwall: $t = 4.4$, df = 48, $P < 0.001$; northern shoveler: $t = 2.1$, df = 44, $P < 0.001$). Thus, SMI appears to reflect fat stores for birds in this study.

Males had lower SMI values than females for blue-winged teal ($\beta = -20.27$ [SE = 3.20], $n = 431$), green-winged teal (−23.89 [5.24], $n = 390$), northern shoveler (−61.77 [18.47], $n = 175$), and gadwall (−41.68 [10.23], $n = 165$) (Figure 1). For green-winged teal, the effect of sex on SMI was moderated by year (sex × year: $\beta = 15.10$ [7.17]), such that the difference in SMI by sex in 2018–2019 was less than in 2017–2018 (Figure 2). The interaction between sex and day was in the top model for northern shoveler; however, the 95% confidence interval of the beta coefficient for this interaction overlapped zero, indicating that this was not an important effect (sex × day: $\beta = 0.52$ [0.30], confidence limits: [−0.07, 1.11]). There was no difference in SMI by sex for northern pintail.

Age was in the top model predicting SMI (Table 2) for northern pintail ($\beta = 42.79$ [27.87], $n = 94$) and gadwall (−59.98 [23.02], $n = 165$), but that effect was moderated by year (northern pintail age × year: $\beta = -126.73$ [38.01], gadwall age × year: 65.67 [25.65]). SMI was greater for immature than adult northern pintail in 2017–2018 but was lower for immature than adult pintail and gadwall in 2018–2019 and 2017–2018, respectively (Figure 2). These results appear to be driven primarily by high SMI values for immature northern pintail and adult gadwall in 2017–2018. There was no effect of age on SMI for northern shoveler or teal species.

SMI was higher in 2018–2019 than 2017–2018 for blue-winged teal ($\beta = 10.35$ [3.81]). SMI was lower in 2018–2019 than 2017–2018 for green-winged teal (−13.76 [5.40]), but yearly differences by sex were found only for females (Figure 2). SMI decreased across day

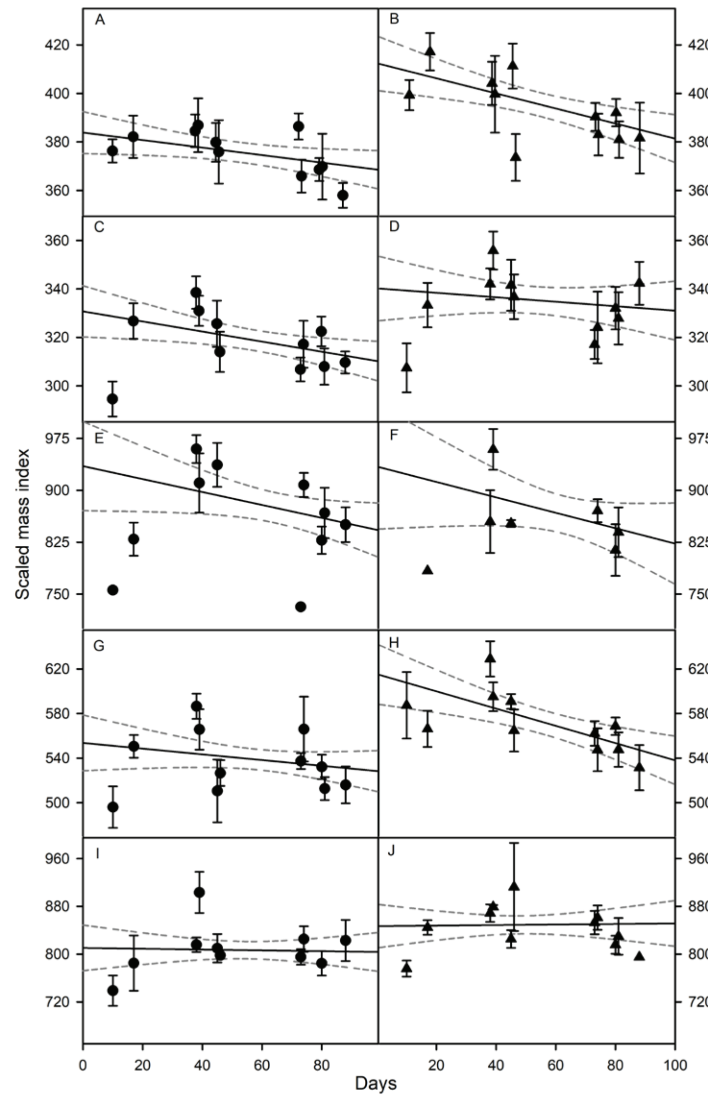

Figure 1. Effect of sex and collection day (Days, 1 = Nov to 92 = Jan 31) on scaled mass index for blue-winged teal males (A) and females (B), green-wing teal males (C) and females (D), northern pintail males (E) and females (F), northern shoveler males (G) and females (H), and gadwall males (I) and females (J). Circles represent means for males (first column), triangles represent means for females (second column), bars represent standard error, solid lines are regression lines, and dashed lines are confidence intervals of the regression line. Note different y-axis scales between rows.

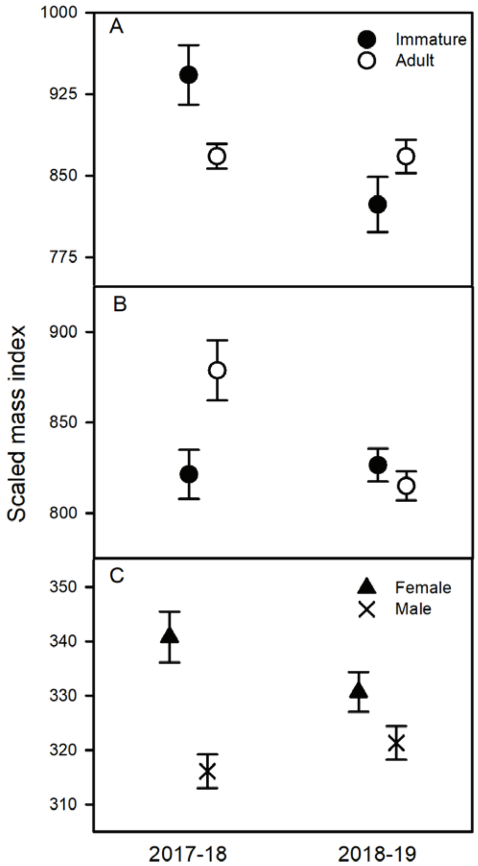

Figure 2. Mean (SE) scaled mass index by age (A, B) and sex (C) in the two winters of the study for northern pintail (A), gadwall (B), and green-winged teal (C).

of collection for blue-winged teal (β = –0.16 [0.06], *n* = 431), green-winged teal (–0.20 [0.08], *n* = 390), northern shoveler (–0.78 [0.22], *n* = 175), and northern pintail (–1.54 [0.41], *n* = 94) (Figure 1). Although female gadwall appeared to increase in SMI across collection day, this effect was not in the top model (Figure 1J). There were no important interactions between collection day and age or sex for any species, indicating a consistent effect of day for all age and sex classes. There was no effect of collection day on SMI for gadwall.

Sex, Age, and Date effects on Fat Score

Immature ducks were less fat than adults for green-winged teal (β = –0.93 [0.34], pseudo r^2 = 0.06, *n* = 390), and northern shoveler (β = –0.92 [0.43], pseudo r^2 = 0.06, *n* = 175) (Table 4). Fat scores were lower in 2018–2019 than 2017–2018 for green-winged teal (β = –0.62 [0.24], *n* = 390). Although age, year, and the interaction between age and year was in the top model for northern pintail (pseudo r^2 = 0.24, Table 5), the 95% CIs for each of these beta coefficients overlapped zero, indicating that they were not important effects. The null model was the top model for gadwall and blue-winged teal (Table 5). Sex and day of collection did not influence gizzard fat score for any species.

Table 4. Percentage of harvested dabbling ducks by species, sex, and age group, for which gizzard fat was high. Sample size is given in parentheses. Ducks were harvested by hunters on the Texas mid-coast between November and January of 2017–2018 and 2018–2019 to evaluate overwintering body condition.

Species	Adult females	Adult males	Immature females	Immature males
Blue-winged teal	79.1 (110)	89.9 (157)	72.5 (80)	72.6 (84)
Green-winged teal	71.9 (160)	77.1 (188)	56.0 (25)	52.9 (17)
Northern shoveler	94.4 (18)	86.7 (60)	75.0 (56)	75.6 (41)
Northern pintail	84.0 (25)	87.8 (49)	72.7 (11)	55.6 (9)
Gadwall	72.2 (36)	86.5 (52)	78.0 (41)	77.8 (36)

Table 5. Model evaluation parameters for models that are within two AICc units of the top model, for each species, predicting gizzard fat score using demographic variables. "Day" is the day of harvest within each year, "Year" is 2017–2018 or 2018–2019, "Age" is immature or adult, and a colon indicates an interaction term. Bold models are those that were used in further analysis (i.e., determined to be the "top" model by our model selection criteria). All models are derived from the global model: Fat score ~ Age + Day + Sex + Year + Sex:Age + Sex:Day + Sex:Year + Age:Day + Age:Year + Day:Year.

Model	df	Log-likelihood	ΔAICc[a]
Blue-winged teal			
Age	2	−229.414	0
Day	2	−229.519	0.21
Age + Day	3	−228.838	0.88
Null	1	−231.054	1.26
Age + Year	3	−229.067	1.34
Age + Year + Age:Year	4	−228.246	1.73
Age + Sex	3	−229.374	1.95
Green-winged teal			
Age + Year	3	−222.195	0
Age + Sex + Year + Sex:Year	5	−220.564	0.83
Age + Sex + Year	4	−221.774	1.20
Age + Day + Year	4	−221.977	1.61
Northern shoveler			
Age	2	−82.165	0
Age + Day	3	−81.589	0.92
Age + Sex	3	−82.090	1.92
Northern pintail			
Day + Sex + Year + Day:Sex + Day:Year + Sex:Year	7	−29.941	0
Age + Sex + Year + Age:Year + Sex:Year	6	−31.200	0.18
Age + Day + Sex + Day:Sex + Year + Day:Year + Sex:Year	8	−28.839	0.19
Age + Sex + Year + Sex:Year	5	−32.738	0.97
Age + Year + Age:Year	4	−33.894	1.05
Age + Day + Sex + Year + Age:Year + Day:Sex + Sex:Year	8	−29.502	1.51
Age + Day + Sex + Year + Age:Year + Day:Sex + Day:Year + Sex:Year	9	−28.480	1.92
Gadwall			
Null	1	−83.934	0
Sex	2	−83.204	0.59
Day	2	−83.315	0.81
Year	2	−83.617	1.42
Day + Sex	3	−82.733	1.72
Age	2	−83.838	1.86
Sex + Year	3	−82.853	1.96

a. Lowest AICc values by species: blue-winged teal = 462.9, green-winged teal = 450.5, northern shoveler = 168.4, northern pintail = 75.2, and gadwall = 169.9.

Discussion

Sex Differences in Body Condition

We predicted that female ducks would be in lesser body condition than males early in winter (Baldassarre 2014) but found no support for this hypothesis. Instead, females were in better body condition than males for four of the five species studied (i.e., blue-winged teal, northern shoveler, gadwall, and green-winged teal) across winter. Pair formation occurs around January for all our study species except gadwall (Hepp and Hair 1983); thus, females are unlikely to have benefited from mate guarding (associated with an increase in female body condition in mallards, *Anas platyrhynchos*; Heitmeyer 1988). Courtship and pair formation activities, however, may have influenced sex-specific body condition. Male ducks typically invest more time in courting and mate competition than female ducks, and this may reduce time spent feeding while increasing energetic costs (Miller 1986). Female ducks of some species also increase foraging time and fat reserves prior to migration so that they arrive on nesting grounds with the energetic reserves required for an initial clutch (Miller 1986, Guillemain et al. 2008).

Our sex-specific results are supported by findings with American black ducks (*Anas rubripes*) wintering in Atlantic Canada and scientifically collected green-winged teal and northern shoveler wintering on the Texas coast, where adult females were in higher body condition (or exhibited higher percent fat) than adult males (English et al. 2018, Collins 2012). However, our findings contrast with those for Eurasian teal (*Anas crecca crecca*) (Fox et al. 1992) and hunter-collected green-winged teal and northern shoveler (Collins 2012), where wintering body condition was higher in males than females, and for blue-winged teal where there was no difference between the sexes (Collins 2012). We also found no effect of sex on body condition or fat in northern pintail in contrast with previous studies in this species that have found higher percent fat in wintering female northern pintail (Smith and Shelley 1993) or fluctuating relationships between sex and fat depending on winter month (Miller 1986). These discrepancies between our results and those of other studies regarding sex-specific body condition may be due to annual or regional variation in sex-specific body condition, other endogenous or exogenous factors unknown to us, or differences in the body condition index calculation. For example, in two studies whose results differ from ours, body condition was calculated either by using a scaling component based on the wing/mass relationship or by dividing mass by length (Fox et al. 1992, Collins 2012), whereas English et al. (2018), whose results agree with ours, estimated body condition with SMI as we did. All species studied exhibit sexual size dimorphism with males being larger than females in size and mass. Thus, differences in body condition index calculations that scale size to mass could lead to differences in sex-specific results.

Age and Year Differences in Body Condition and Fat

We found some support for our hypothesis that immature ducks would be in lower body condition than adults. Immature green-winged teal and northern shoveler were less fat than adults, and immatures exhibited lower scaled mass indices than that of adults for gadwall in 2017–2018 and northern pintail in 2018–2019. These results provide some support for our hypothesis and are consistent with findings for other duck species (Fox et al. 1992, Hohman and Weller 1994). However, immature northern pintail also had much higher body condition than adult northern pintail in 2017–2018, and only a moderately lower body condition than adults in 2018–2019. We found no effect of age on SMI or fat score for blue-winged teal, perhaps due to the early migration of this species (Rohwer et al. 2002) which may have allowed immature blue-winged teal to catch up to adults in body condition. Thus, our results suggest no consistent trend toward lower body condition in immature dabbling ducks and highlight the need for additional multi-year studies of these effects in ducks.

Conditions on the wintering grounds, alone or in conjunction with breeding/migratory conditions, could have produced our observed sex- and age-specific effects of year on body condition. For example, catastrophic weather events are known to impact waterfowl body condition (Miller 1986, Nichols et al. 1995). Total precipitation in Matagorda County over the period of our study was over twice as high in 2017–2018 compared to 2018–2019 (2017–2018 mean of weather stations = 33.15 cm, 2018–2019 = 15.98 cm, from 10 November–27 January both winters). Thus, our high SMI averages for adult gadwall, immature northern pintail, and female green-winged teal and higher fat scores for green-winged teal in 2017–2018 are consistent with previous studies that found higher duck body condition in wet winters than dry winters (Delnicki and Reinecke 1986, Miller 1986, Smith and Sheeley 1993). These differences are probably due to the associated increase in wetlands with abundant native vegetation (Haukos and Smith 1993, Smith and Sheeley 1993) and flooding of rice fields. This is an important avenue of future studies of northern pintail, especially, because populations remain 42% below the long-term average and Texas hosts 78% of the wintering Central Flyway population (Pintail Action Group 2015). Age-specific impacts of winter water availability or climatic conditions on body condition could affect overwinter survival of immature northern pintail and thus breeding population size.

Precipitation is predicted to increase in volume and regularity in the future (Fowler and Hennessy 1995) for the Gulf Coast but in the form of more frequent powerful clustered storms (Mulholland et al. 2002) such as hurricanes. Thus, understanding the responses of vital cohorts, such as females and immatures, to tropical cyclones and precipitation is of importance for predictive population modeling and management. Although our attribution of yearly body condition changes to winter rainfall patterns and/or late summer storms is speculative, our results suggest that females and immatures are not in consistently poorer body condition than adult males while wintering on the Texas coast and that immature northern pintail may benefit from increased precipitation perhaps due to an increase in the availability of freshwater wetlands that provide high quality food for northern pintail (Ballard et al. 2004, Huck 2014). Longer-term research on the Gulf coast is needed to determine if these observed yearly fluctuations are due to precipitation patterns, or other factors.

Collection Day and Body Condition

We found support for our prediction that body condition would decline from November through January. Except for gadwall, the body condition of all duck species declined across the winter hunting season, consistent with the results of previous studies of dabbling ducks in general (Miller 1986, Fox et al. 1992, Loesch et al. 1992, Haukos et al. 2001) and of northern pintail, specifically, on the Texas mid-coast (Garrick 2016). Our observed decline in winter body condition could be due to the energetic demands of mate pairing activities in late winter, endogenous control of energetic reserves (Loesch et al. 1992), and/or differential migratory patterns for birds in high or low body condition. Fat stores, which increase body condition, are essential to survive periods of unpredictable fasting and to insulate against cold weather. Waterfowl wintering on the Texas coast benefit from mild, predictable winters and probably experience few periods of unpredictable fasting due to poor weather (Ballard et al. 2004), and thus may not need to store large amounts of excess energy (Loesch et al. 1992, Garrick 2016). There was no change in body condition across the winter season for gadwall, probably due to low sample sizes for this species at the beginning of the season. The effect of day was not sex-specific or age-specific for any species. Thus, neither immatures nor females exhibit a greater or lesser decline in body condition over winter than adult males.

Limitations and Constraints

For all our top models, our r^2 values were low ($r^2 \leq 0.24$) suggesting that much variation in body condition remains un-explained by our predictors. This was not unexpected, given that body condition is probably controlled by a variety of past and current variables that we did not evaluate, such as local habitat conditions (Mason et al. 2007, Palm et al. 2013) and variability (Barboza and Jorde 2002) and availability of food resources (Bond and Esler 2006) at current and past locations. However, the strong performance of our top models over null models indicates that these models provided important information regarding dabbling duck body condition.

In both the 2017–2018 and 2018–2019 hunting seasons, our collection dates did not include the early teal hunting season. Teal, especially blue-winged teal (Rohwer et al. 2002), typically begin migration earlier than gadwall, northern pintail, and northern shoveler. Thus, we may have missed short-term differences in body condition between males and females or immatures and adults that occurred early in the non-breeding season. Future work should evaluate this possibility. Additionally, our study relied on hunter collection, which imposed potential restraints on our sampling. The results of previous studies suggest that body condition of hunter-shot mallard, ring-necked duck (*Aythya collaris*), green-winged teal, blue-winged teal, and northern shoveler differ from that of scientifically collected birds (Dufour et al. 1993, Greenwood et al. 1986, Heitmeyer et al. 1993, McCraken et al. 2000, Collins 2012), that hunting pressure prevents gadwall from lipid establishment (Gaston 1991), and that these effects may be stronger for males than females (in mallards and American black ducks; Hepp et al. 1986, Robb 2002). In that case, our inferences about sex-specific body condition may be impacted by hunter collection. However, effects of hunter collection on body condition are dependent on age, sex, species, region, hunting method, and body condition analysis (Sheeley and Smith 1989, Heitmeyer et al. 1993, Collins 2012). Moreover, in at least one study, collection technique did not influence demographic effects on body condition (Collins 2012). Thus, although differences between collection methods may exist, they do not outweigh the importance of hunter shot sampling as a research collection method which has utility in producing large sample sizes without additional population impact as well as the power to engage hunters in conservation research.

Conclusions and Management Implications

This study used a modern body condition index calculation and detailed demographic comparisons to contribute to the body of knowledge on wintering migratory dabbling duck species. We verified that the scaled mass index positively correlates with gizzard fat presence, suggesting it is a meaningful measurement of energetic stores. The scaled mass index may be a useful measure of body condition for future studies of species of concern because it does not require lethal sampling unlike most traditional body composition analyses. Our results suggest females and immatures of both sexes have similar body condition to males and adults, respectively, during the non-breeding season. We also confirmed that dabbling duck body condition decreases over the wintering period (November–January) on the Texas coast. We found that yearly differences in body condition may be due to major differences in water availability and differed by sex, age class, and species, suggesting differential responses to increased availability of temporary wetlands and flooded fields when precipitation was greater. Ensuring sufficient availability of such habitats in dry years may be important to increase body condition of some species and age groups, including immature northern pintail. Interestingly, our body condition index revealed trends in species that our fat score measure did not, and vice versa, suggesting that more than one index of body condition should be applied by researchers of dabbling ducks.

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