Daily Weather Affects Body Condition, Sex, and Age Ratios of Harvested Dabbling Ducks in Texas

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Abstract: Duck activity patterns have anecdotally been associated with weather for thousands of years. However, these relationships have rarely been tested scientifically. We hypothesized that characteristics of wintering ducks harvested by hunters would be associated with daily weather conditions (precipitation, temperature, and wind speed), and specifically, that smaller-bodied ducks and those with poor body condition would be harvested less frequently in adverse weather conditions relative to 30-year daily normals. We evaluated these hypotheses using beta regression modeling and general linear models for five species of dabbling ducks: blue-winged teal (*Spatula discors*; $n = 608$), green-winged teal (*Anas crecca*; $n = 518$), northern shoveler (*Spatula clypeata*; $n = 175$), northern pintail (*Anas acuta*; $n = 94$), and gadwall (*Mareca strepera*; $n = 206$) harvested by hunters on the coastal Texas wintering grounds (December 2017–January 2018 and November 2018–January 2019). We found that temperature did not affect age and species composition of harvested ducks, but wind and precipitation did, with fewer small-bodied duck species generally being harvested in higher-than-average wind and precipitation and immature ducks harvested in significantly lower proportions at higher-than-average wind speed. Body condition of harvested ducks for all species was significantly related to temperature but was related to wind and precipitation for larger-bodied species only. Overall, our results provide strong support for our hypothesis that hunter harvest patterns are associated with daily weather but only mixed support for our prediction that weather predicts body size and condition of harvested ducks. These results can inform managers on hunter placement based on forecasted weather. In addition, as weather patterns are expected to become less predictable due to global climate change, understanding responses of duck hunter harvest to daily weather fluctuations becomes more important for informing management.

Key words: body condition, climate change, scaled mass index, thermoregulatory constraints, waterfowl hunting, wintering grounds

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Historically, popular culture has often associated waterfowl (i.e., ducks, geese, and swans) activity with weather patterns. As far back as the 1st century AD, Roman writings state that observation of preening ducks foretold wind (Minard 2010). These beliefs have continued to contemporary times, with western folklore and colloquial speech suggesting that changes in duck behavior, including increased preening, huddling, flocking, and flight direction, indicate coming rain and/or storms (Minard 2010). Research has confirmed that waterfowl migration in North America occurs in association with large seasonal fluctuations in temperature (Xiao et al. 2007). However, relationships between smaller scale, short-term weather patterns and duck movement or behavior, and their resultant possible effects on harvest rates, have rarely been tested in a scientific manner (but see Paulus 1984, Hepp 1985, Cox and Afton 2000). As weather patterns are expected to become less predictable due to global climate change (Peterson et al. 2008), understanding responses of hunter harvest to daily weather fluctuations becomes more important to inform game management.

Current evidence suggests that duck foraging and activity patterns during winter reflect thermoregulatory constraints, which are influenced by daily and seasonal weather patterns (Nilsson 1970, Bennett and Bolen 1978, Hepp 1985, Jorde and Owen 1988). For example, wintering gadwall (*Mareca strepera*) increase foraging rates in cooler temperatures and during light precipitation to maximize food intake while minimizing time in adverse conditions (i.e., low temperatures, high winds, and high precipitation) (Paulus 1984). Similarly, wintering bufflehead (*Bucephala albeola*) increase foraging activity as winter progresses and weather conditions presumably become harsher (Bergan et al. 1989). Comparing between bird species of similar life-histories, smaller-bodied species are often more susceptible to thermoregulatory stress due to cold temperatures because of their proportionately greater surface area to volume ratio and higher metabolic rate in cold temperatures (Kendeigh 1970, Goudie and Ankney 1986), and these can lead to differences in activity patterns (Nilsson 1970).

Intraspecific differences in thermoregulatory constraints can also correspond with differences between sexes and age groups in activity patterns and presence on foraging grounds. Female and

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immature ducks are not only typically smaller than males and adults of both sexes, respectively, but are in a more vulnerable energetic state post-breeding due to higher costs during the breeding season for females (Johnson 1999) and lower fat storage among immatures (Reinecke et al. 1982). Thus, females and immature ducks are more susceptible to thermoregulatory stress than adult males during migration and on the wintering grounds, and this can be reflected in activity patterns. For example, proportions of female and immature mallards (*Anas platyrhynchos*) on wintering grounds increase significantly during warm weather conditions (Jorde et al. 1984), and female goldeneyes (*Bucephala clangula*) show higher feeding intensities than males during cold periods (Nilsson 1970). Over-winter survival of females and immatures is critical for determining annual waterfowl population growth rates which heavily influence management decisions. Thus, understanding the effects of weather on age- and sex-specific harvest throughout winter has wide-ranging implications for conservationists, hunters, managers, and policymakers.

Texas is a major migratory stopover and wintering location for up to 90% of Central Flyway migratory ducks (Ferro et al. 2010) and, as such, hosted more than 68,000 hunters during the 2019–2020 duck hunting season who accounted for nearly 40% of the annual Central Flyway duck harvest (Dubovsky 2020). The composition of Texas duck hunter harvests, on average between 1999 and 2019, is approximately 20% blue-winged teal, 18% green-winged teal, 5% northern pintail, 7% northern shoveler, and 22% gadwall (Dubovsky 2020), with these being the five most commonly harvested dabbling ducks in the state. These proportions, however, are measured at a broad temporal scale, and short-term harvest trends are understudied, particularly during winter. Therefore, we evaluated the relationship between daily weather and winter hunter harvest for five species of dabbling ducks: blue-winged teal (*Spatula discors*), green-winged teal (*Anas crecca*), northern pintail (*Anas acuta*), northern shoveler (*Spatula clypeata*), and gadwall (*Mareca strepera*), collected on the Texas coast. Our goal was to analyze the composition of hunter harvests across varying short-term weather conditions, with a secondary objective to analyze the relationship between hunter harvests and potential weather-induced thermoregulatory constraints. This study provides baseline data for future analyses of hunter harvests within an easily repeatable framework, to elucidate effects of weather on hunter harvest, and to inform how ducks may be adjusting activity patterns accordingly.

We hypothesized that hunter harvests of wintering ducks would be affected by daily weather conditions (i.e., precipitation, temperature, and wind speed). We predicted that ducks with small bodies (both between and within species) and poor body condition (within species) would limit their exposure to conditions promoting thermoregulatory stress and thus would be harvested less often in colder than average temperatures, higher than average precipitation, and higher than average wind speeds (compared to 30-year normals for each harvest date). We also predicted that relatively lower proportions of females and immatures would be harvested during these conditions because of their smaller body size and possibly more vulnerable energetic state post-breeding (most northern hemisphere ducks exhibit female-only incubation and parental care; Johnson et al. 1999) and post-fledging. We conducted this study under the assumption that duck foraging activity and relative abundance patterns influence hunter harvests. Several factors supported this assumption: (1) ducks at our study locations are typically shot while flying, (2) baiting, luring with live birds, concentrating, rallying, driving, and stirring of ducks is illegal in Texas, and (3) the ducks harvested for this study were shot only in the morning hours, when ducks are typically leaving roosting sites. Additionally, hunter harvests of ducks have been used to study duck populations in previous studies (Heath 1969, Prouty and Bunck 1986, Levengood 2003), allowing for large sample sizes without additional lethal take.

Study Area

We collected hunter donated ducks from three sites in Matagorda County, Texas, and one site in Wharton County, Texas, on 11 dates between December 2017–January 2018 and November 2018–January 2019 within the Central Flyway. All sites contained coastal wetland, forested ponds, managed (i.e., planted and flooded) agricultural fields, or a combination of these three habitats. The site located in Wharton County was a private hunting club (Pierce Ranch [29.233404°N, –96.184319°W] managed by Karankawa Plains Outfitting Company) and consisting of a combination of agricultural fields, managed ponds, and marshes; it was only sampled during the 2018–2019 winter duck hunting season. Two sites in Matagorda County were private hunting clubs (Thunderbird Hunting Club [29.019275°N, –96.098746°W] and Run-N-Gun Adventures [28.925600°N, –95.980611°W]) and were similarly managed for duck hunting with agriculture, managed ponds, and marshes. Thunderbird Hunting Club was only sampled for the 2017–2018 season. Mad Island Wildlife Management Area (WMA; 28.680496°N, –96.046210°W) in Matagorda County was the only public site sampled in this study, and hunting primarily occurred over natural ponds and marshes.

Methods

Field Sampling

We collected 608 blue-winged teal, 518 green-winged teal, 175 northern shoveler, 94 northern pintail, and 206 gadwall harvested by hunters on the coastal Texas wintering grounds. Hunters were required to properly follow all state and federal regulations, including species-specific bag limits. We were therefore limited to collecting a maximum of six duck carcasses per hunter. We measured the mass (electronic balance, ±1 g) of each duck in the field, identified each specimen to species, and returned the breast meat with one wing attached to the hunters for legal transport. The remainder of each specimen was transported to our laboratory and frozen. All specimens were obtained under scientific collecting and research permits from the U.S. Fish and Wildlife Service (MB66499C) and Texas Parks and Wildlife Department (SPR-0317-079). Because all carcasses in this study were donated postmortem, no Institutional Animal Care and Use approval was required.

Laboratory Sampling

Each specimen was thawed and re-identified to species, sexed, and aged (i.e., immature or adult). We used the USFWS Wing Guide (Carney 1992) to determine sex and age by head and body plumage, presence of ovary or testes, and tertial/retrice molts. Additionally, we measured flattened wing chord (ruler, ±1 mm), tarsus (calipers, ±0.1 mm), bill length (calipers, ±0.1 mm), and classified gizzard fat as ≤10% ("Low") ventral surface coverage or >10% ("High") ventral surface coverage. Adipose tissue in the abdominal cavity is deposited after other locations (i.e., under the skin) and is the first deposit to be lost if a bird experiences energetic stress (Blem 1976). Therefore, a gizzard fat rating of 'High' indicates ducks are 'excessively/very fat' and a score of 'Low' indicates ducks are 'moderately fat' or 'not fat' (McCabe 1943). We used visceral fat around the gizzard as the diagnostic fat deposit due to the accessibility of the gizzard and the relatively large size of the surrounding fat pad (Scanes 2015).

Statistical Analyses

Weather categorization.—For weather categorizations, we used the National Oceanic and Atmospheric Administration's weather database [National Climatic Data Center (NCDC)] to determine total precipitation (converted to cm), average temperature (converted to °C after binning, below), and average wind speed (converted to km/hr) for the harvest area and date (NCDC 2019a). We then calculated the standard deviation of these data from the 30-year daily climatic normals for the harvest area on each sampling date (NCDC 2019b) and binned weather data accordingly. We used 30-year normals for each specific sampling date to account for changes in weather as the season progresses (i.e., 9 December 2017 was compared to the 30-year normal for 9 December). We classified daily precipitation and temperature as "Average" if they fell within one standard deviation, "High" if they were greater than one standard deviation above, and "Low" if they were greater than one standard deviation below the 30-year normal for that date (Table 1). Thirty-year wind speed normals and standard deviation of daily precipitation were unavailable for the harvest area; therefore, we used the daily average wind speed and standard deviation of precipitation for each date between 1 January 2017 and 31 January 2019 as reference instead of 30-year normals. The weather station located at Palacios Municipal Airport in Matagorda County (28.72472°N, –96.25361°W) was used to collect daily weather conditions and 30-year climatic normals, as this is the closest NCDC weather station to our sites in both Matagorda and Wharton counties. These counties share a border and Wharton County is approximately 40 km from this weather station.

Interspecific analyses of weather on species, sex, and age ratios, fat, body size and body condition.—Only ducks with known ages and sexes were used in this study. For species, sex, and age analyses, we evaluated the proportions of adults vs. immatures, males vs. females, and of each species harvested for each day. We did not evaluate total harvest numbers of species, sexes, or age groups because these vary by hunter effort, which we could not control. We calculated the proportions of males and females harvested each day. We analyzed effects of weather on species, sex, and age ratios, and the proportion of ducks with high fat on each harvest day using beta regression modeling (maximum likelihood estimation, logit mean model link, identity dispersion). We performed beta regression because response variables were continuous and limited to the interval (0,1) (Ferrari and Cribari-Neto 2004). Due to our limited number of sampling dates (11), for all analyses we used categorical weather variables as described above and did not test interactions between weather categories to avoid over-specification of our data. Predictors in each model included precipitation (high, low;

Table 1. Weather classifications (values on the day of harvest; 30-year normals) for each harvest date in this study. Weather data were provided by the National Climatic Data Center weather station at Palacios Municipal Airport in Matagorda County, Texas. Units were converted from Customary to SI. The conversion between Fahrenheit and Celsius temperature values is not proportional, thus, the bins for temperature classifications reflect the data measured in Fahrenheit values, but exact values are reported in Celsius.

Date	Precipitation (mm)	Temperature (°C)	Wind speed (kph) (Norm 16.58)
9 Dec 2017	Low (0.00; 4.83)	Average (9.44; 13.33)	Low (9.37)
16 Dec 2017	High (25.15; 5.08)	Average (11.94; 12.56)	Average (18.36)
13 Jan 2018	Low (0.00; 6.35)	Low (6.11; 11.39)	Average (14.76)
20 Jan 2018	Low (0.254; 6.10)	High (16.67; 11.39)	Low (9.37)
27 Jan 2018	High (15.49; 5.59)	High (18.33; 11.56)	Low (10.44)
10 Nov 2018	Low (0.00; 8.13)	Low (11.94; 18.22)	Average (18.71)
17 Nov 2018	Low (0.00; 7.11)	Average (18.33; 16.89)	Low (12.25)
8 Dec 2018	High (25.40; 4.83)	Average (10.00; 13.50)	High (30.24)
15 Dec 2018	Low (0.00; 4.83)	Average (13.06; 12.67)	Average (16.21)
12 Jan 2019	High (17.02; 6.35)	High (15.83; 11.22)	Average (18.72)
19 Jan 2019	Low (1.02; 6.10)	Average (13.61; 11.39)	High (32.04)

no study dates were in the "average" category), temperature (high, average, low), and wind speed (high, average, low). For these analyses, sample sizes were the number of harvest dates across the study period because proportions were calculated for each date.

We estimated body condition using scaled mass index (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 body length (Peig and Green 2009). We calculated SMI using the equation: $Mi(L_0/L_i)^b$, where Mi is individual mass, L_0 is mean wing chord, L_i is individual wing chord, and b is the slope of a Standardized Major Axis (SMA) regression of the natural log of mass on the natural log of wing chord (Peig and Green 2009). We analyzed effects of weather on individual SMI (z-scored within species) and body size (estimated by flattened wing chord length, z-scored within species and sex) using general linear models (GLM, Gaussian family, identity link). For each of these general linear models, we examined and accepted standard assumptions that residuals were independent and normally distributed with a mean of approximately zero and constant or equal variance. For these analyses, sample size was number of ducks collected.

Intraspecific analyses of weather on body condition.—SMI values and body size were also analyzed in separate GLMs for each species to evaluate whether relationships between weather and body condition/size were species-specific (e.g., SMI may be related to weather for smaller-bodied species but not larger-bodied species due to differences in thermal mass). The directions of effects for all models were determined by the *β*-coefficients of predictors. All statistics were performed using JMP Pro statistical software (SAS Institute 2020).

Results

Interspecific Effects of Weather on Species, Sex, and Age Ratios, Fat, Body Size, and Body Condition

We predicted that smaller-bodied species would be harvested more often in on days that were warmer, had lower precipitation, and were less windy than average. In support of that prediction, a significantly higher proportion of blue-winged teal and a significantly lower proportion of gadwall (a large bodied species) were harvested on days of lower-than-average precipitation (Table 2, Figure 1), and at both high and average wind speeds, proportionately fewer green-winged teal were harvested and proportionally more gadwall were harvested (Table 2, Figure 2). However, contrary to our prediction, green-winged teal were also harvested at significantly lower proportions on days of lower-than-average precipitation (Table 2, Figure 1). Temperature did not affect proportions of species harvested ($P > 0.05$), and there were no significant effects of weather on the proportions of northern shoveler ($P > 0.05$) or northern pintail harvested ($P > 0.05$), which may be explained in part by these species having the lowest sample sizes.

We also predicted that females and immatures would be harvested less often in colder than average temperatures, higher than average precipitation, and higher than average wind speeds. In

Table 2. Significant effects of weather on the proportions of each species, proportion of adults, and the scaled mass index (SMI) of all species for hunter-harvested ducks obtained in coastal Texas, 2017–2019. Values include sample size (*n*), regression beta coefficient (*ß*), and its standard error (SE) and 95% confidence limits. "Low", "Average", or "High" indicate associations with daily values that were below, within, or greater than, respectively, one standard deviation from the 30-year normal for each harvest date (or average for the sampling period in the case of wind speed). BWTE: proportion of blue-winged teal; GWTE: green-winged teal; GADW: proportion of gadwall.

Effect	*n*	*ß*	*SE*	Lower C.L.	Upper C.L.	*P*-value
Precipitation						
High: BWTE	11	0.75	0.69	0.06	1.44	0.030
Low: GWTE	11	−0.59	0.40	−0.99	−0.19	0.002
Low: GADW	11	−0.52	0.37	−0.89	−0.15	0.006
Low: All species SMI	1255	−0.10	0.07	−0.17	−0.03	0.007
Wind Speed						
High: GWTE	11	−0.92	0.49	−1.41	−0.43	0.002
Average: GWTE	11	−0.93	0.41	−1.34	−0.52	<0.0001
High: GADW	11	1.30	0.52	0.78	1.82	<0.0001
High: Adults	11	0.80	0.50	0.30	1.30	0.002
High: All species SMI	1255	−0.11	0.10	−0.21	−0.01	0.03
Temperature						
High: Adults	11	0.84	0.70	0.06	1.54	0.020
Average: All species SMI	1255	0.27	0.09	0.18	0.36	<0.001
High: All species SMI	1255	−0.29	0.12	−0.41	−0.17	<0.0001

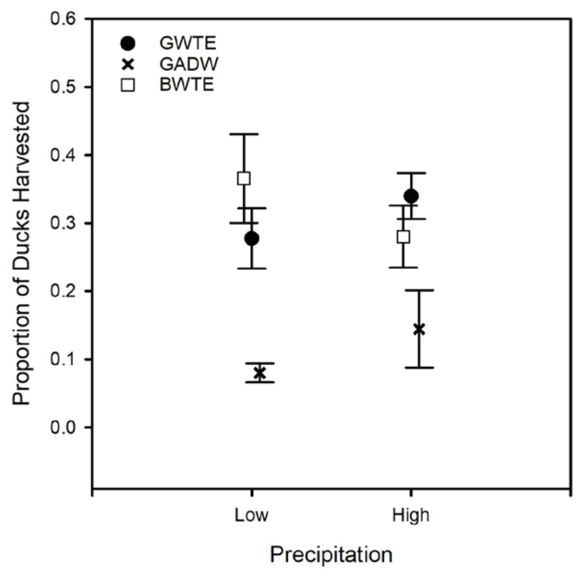

Figure 1. Relationship between precipitation and mean (SE) proportion of ducks harvested that were green-winged teal (GWTE), gadwall (GADW), and blue-winged teal (BWTE) for hunter- harvested ducks obtained in coastal Texas, 2017–2019. Daily precipitation was categorized as below ("Low"), within, or greater than ("High") one standard deviation from the 30-year normal for precipitation for each harvest date.

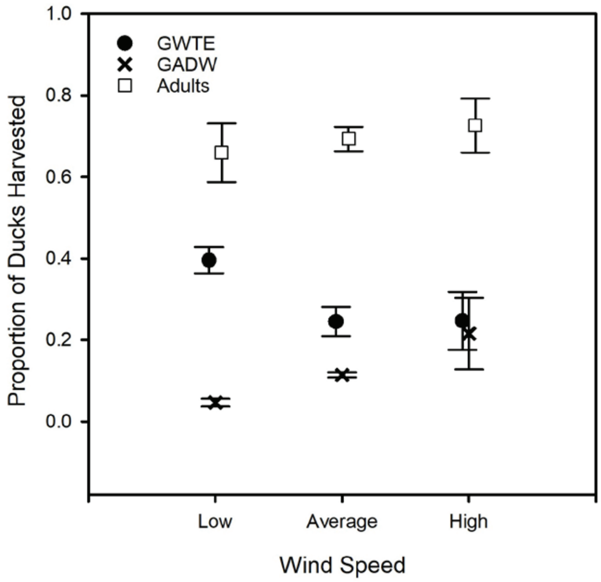

Figure 2. Relationship between wind speed and mean (SE) proportion of ducks harvested that were green-winged teal (GWTE), gadwall (GADW), and adults (vs. immatures) for hunter- harvested ducks obtained in coastal Texas, 2017–2019. Daily wind speed was categorized as below ("Low"), within ("Average"), or greater than ("High") one standard deviation of daily averages over the sampling period.

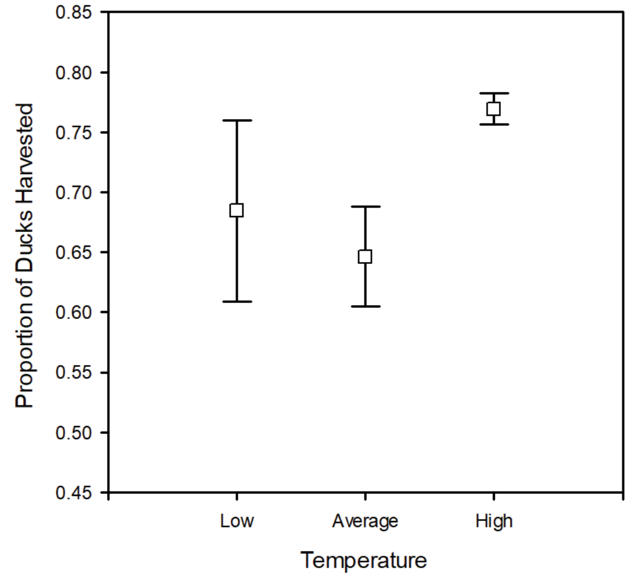

Figure 3. Relationship between temperature and mean (SE) proportion of ducks harvested that were adults (vs. immatures) for hunter- harvested ducks obtained in coastal Texas, 2017–2019. Daily temperature was categorized as below ("Low"), within ("Average"), or greater than ("High") one standard deviation of 30-year daily temperature normals for each harvest date.

support of this prediction, the proportion of adult ducks (vs. immatures) harvested was highest at higher-than-average wind speed (Table 2, Figure 3). Contrary to our predictions proportionally more adults were also harvested at higher-than-average temperatures (Table 2, Figure 3) and there were no significant effects of weather on sex ratio ($P > 0.05$).

Regarding body condition, we found mixed support for our prediction that average SMI of all species would be greater under conditions that were colder, wetter, and windier than average. The SMI of all harvested ducks was predicted by all three weather variables (Table 2). In support of our prediction, SMI was lowest on days of higher-than-average temperature and lower than average precipitation, but counter to our prediction SMI was highest during average temperature, and lowest at higher-than-average wind speeds (Table 2, Figure 4). There were no significant effects of weather on gizzard fat ($P > 0.05$) or body size ($P > 0.05$).

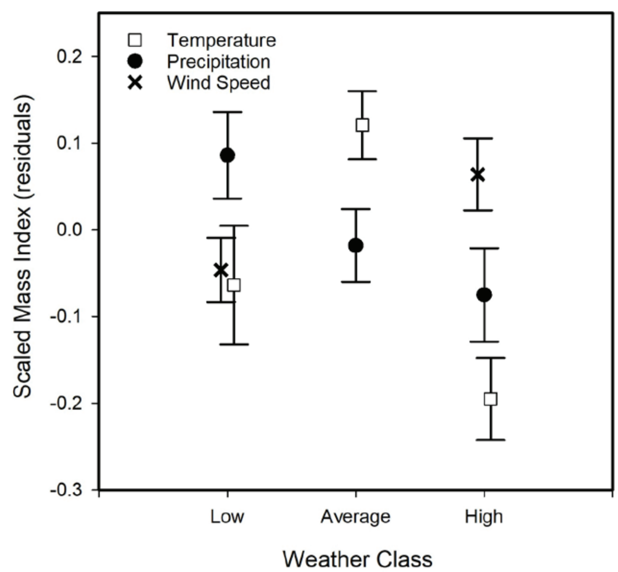

Figure 4. Relationship between Scaled Mass Index (*z*-scored) and temperature, precipitation, and wind speed for all species of hunter- harvested ducks obtained in coastal Texas, 2017–2019. Symbols are means and error bars are standard error. Scaled Mass Index values are the residuals of a regression with the two other weather variables because all three weather variables were significant predictors in the original model. Daily weather values were categorized as below ("Low"), within ("Average"), or greater than ("High") one standard deviation of 30-year daily temperature normals for each harvest date (or average for the sampling period in the case of wind speed).

Intraspecific Effects of Weather on Body Condition and Size

When species were analyzed separately, temperature was the only weather variable that was related to SMI for blue-winged teal and green-winged teal, with average body condition being highest during average temperatures (Table 3, Figure 5). This finding is consistent with our interspecific results and counter to our predictions. In contrast, all three weather variables were related to SMI for larger-bodied species (i.e., northern shoveler, northern pintail, and gadwall). In support of our thermoregulatory predictions, body condition of all three large-bodied species was lowest at higher-than-average temperatures, and lower than average precipitation. But counter to our prediction, SMI was highest at average

Table 3. Significant effects of weather on intraspecific scaled mass index (SMI) for hunter- harvested ducks obtained in coastal Texas, 2017–2019. Values include sample size (*n*), regression beta coefficient (*ß*), and its standard error (SE) and 95% confidence limits. "Low", "Average", or "High" indicate associations with daily values that were below, within, or greater than, respectively, one standard deviation from the 30-year normal for each harvest date (or average for the sampling period in the case of wind speed). BWTE: blue-winged teal; GWTE: green-winged teal; NSHO: northern shoveler; NOPI: northern pintail; GADW: gadwall.

Effect	*n*	*ß*	*SE*	Lower C.L.	Upper C.L.	*P*-value
Precipitation						
Low: GADW SMI	206	−0.31	0.20	−0.51	−0.11	0.004
Low: NSHO SMI	175	−0.23	0.19	−0.42	−0.04	0.020
Low: NOPI SMI	94	−0.34	0.28	−0.62	−0.06	0.020
Wind Speed						
High: GADW SMI	206	−0.37	0.30	−0.67	−0.07	0.020
Average: NSHO SMI	175	−0.31	0.26	−0.57	−0.05	0.010
High: NOPI SMI	94	−0.43	0.39	−0.82	−0.04	0.030
Temperature						
Average: BWTE SMI	608	0.27	0.17	0.10	0.45	0.001
Average: GWTE SMI	518	0.31	0.17	0.14	0.48	< 0.001
High: GADW SMI	206	−0.41	0.36	−0.77	−0.05	0.030
High: NSHO SMI	175	−0.45	0.29	−0.74	−0.16	0.002
High: NOPI SMI	94	−0.87	0.54	−1.41	−0.33	0.002
Average: NOPI SMI	94	0.43	0.38	0.05	0.81	0.030

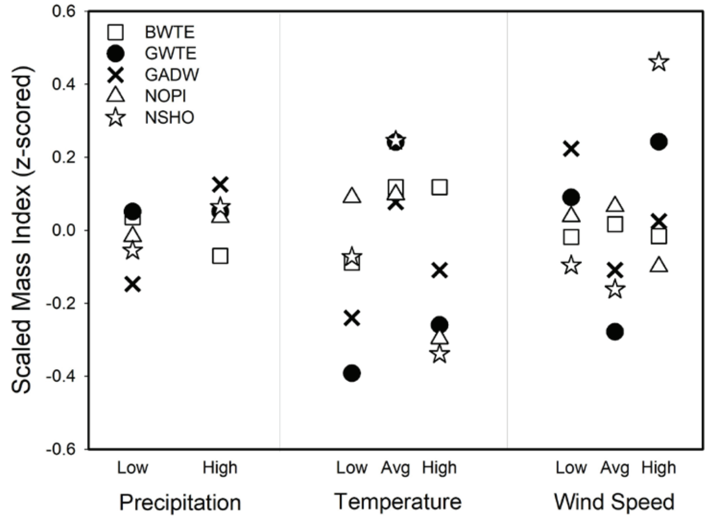

Figure 5. Relationship between Scaled Mass Index (*z*-scored) and temperature, precipitation, and wind speed within blue-winged teal (BWTE), green-winged teal (GWTE), gadwall (GADW), northern pintail (NOPI), and northern shoveler (NSHO) for hunter- harvested ducks obtained in coastal Texas, 2017–2019. Symbols are means. Daily weather values were categorized as below ("Low"), within ("Average"), or greater than ("High") one standard deviation of 30-year daily temperature normals for each harvest date (or average for the sampling period in the case of wind speed).

temperatures for northern pintail, lower at higher-than-average wind speed for northern pintail and gadwall, and at average wind speed for northern shoveler (Table 3, Figure 5).

Discussion

Our results support the hypothesis that daily weather conditions influence hunter harvest of dabbling ducks with respect to species, age, and body condition (i.e., scaled mass index, SMI). At the interspecific level, we found mixed support for our hypothesis that ducks of smaller body sizes would be harvested less often in thermoregulatory adverse conditions. In support of our hypothesis, teal species tended to be harvested relatively less often than larger-bodied species in average wind speeds and high precipitation, while gadwall were harvested relatively more often in high wind speeds. This latter result, combined with results of Hepp (1985), who found that foraging rates typically increase in this species under such condition, supports our assumptions that foraging activity and hunter harvest are directly related within the context of daily weather. However, counter to our hypothesis, green-winged teal were also harvested in high proportions during higher-than-average precipitation and temperature did not affect species harvested, unlike the results of previous studies conducted at higher latitudes (e.g., Hepp 1985 in coastal North Carolina).

We also found mixed support for our prediction that lower proportions of females and immatures would be harvested in adverse conditions (i.e., lower than average temperatures, higher wind speeds, and higher precipitation). Our lack of sex-specific patterns is supported by the conclusions of Hepp (1985), who found that speed and rate of foraging does not differ between the sexes in wintering ducks. However, pre-breeding or breeding dabbling duck females typically forage for longer periods than males (Hepp 1985, Arzel and Elmberg 2015), and sex-specific foraging and activity patterns are well known in other sexually dimorphic species such as downy woodpeckers (*Picoides pubescens*) (Peters and Grubb 1983), northern harrier (*Circus hudsonius*) (Temeles 1986), white-breasted nuthatch (*Sitta carolinensis*) (Grubb 1982), and multiple species of boobies (Lewis et al. 2005, Weimerskirch et al. 2006); however, these patterns may not be related to thermoregulatory constraints.

We found limited support for our prediction that the average body condition of harvested ducks would be higher in adverse conditions because ducks in poor body condition would avoid activity at these times. Our results suggest that ducks in poor body condition were more active during low precipitation and high temperatures. However, average body condition was lowest on days with higher-than-average wind speed, which we predicted individuals in poor body condition would avoid. These interspecific results for body condition may have provided mixed support for our hypotheses because larger-bodied duck species may be less affected by weather than smaller-bodied duck species. When analyzed by species, we found that the body condition of larger-bodied species was affected by all of our weather variables, indicating that differences in body condition may determine the susceptibility of larger-bodied species to harvest, within the context of daily weather.

Our study was limited in several ways. First, we analyzed relative values (i.e., proportions) rather than absolute harvest numbers and therefore could not differentiate among different combinations of preference, indifference, or avoidance that could produce the patterns we observed. For example, at high wind speeds, all ducks may reduce flight and foraging activity, but those that do fly tend to be gadwall. Alternatively, gadwall may preferentially fly in high wind speeds. Additionally, NCDC weather stations with 30-year weather data are limited in our study region, confining the accuracy of our weather trends to a regional scale. Specifically, the weather station data we used was from Matagorda County, approximately 40 km from three of our sites. We therefore had to limit our conclusions to regional daily weather as opposed to instantaneous weather conditions at the time and location of harvest, conditions known to affect duck behavior and foraging activity (Jorde et al. 1984). Our study also relied on hunter harvest, which restricted our sample sizes for each species in accordance with bag limits and may have influenced our results through hunter detection and selection patterns or differences in hunting strategies that vary with weather. Weather is known to affect hunter detection rates for other bird species (Robbins 1981) and evidence from mallards and ring-necked ducks (*Aythya collaris*) suggests that hunter-shot birds weigh less compared to the relevant local population (Greenwood et al. 1986, Heitmeyer et al. 1993, McCraken et al. 2000) although no hunter bias in body condition was found for northern pintails in Texas (Sheeley and Smith 1989). Hunter bias has not been previously investigated for our other focal species within our study area. Thus, we limit our conclusions to the effects of weather on hunter harvest, not on the general dabbling duck population. We do not believe hunters differentially harvested males vs. females in our study because sex biases in hunter harvest typically occur when ducks are in alternate (breeding) plumage (Metz and Ankney 1991) and most ducks harvested in this study were in winter (non-breeding) plumage.

Overall, our findings provided mixed support for the hypothesis that duck thermoregulatory constraints influence hunter harvest with respect to weather at both the interspecific and intraspecific levels, but strongly support the hypothesis that hunter harvest patterns are associated with weather conditions. Regarding the former, thermoregulatory costs may be so minimal during the Texas winter that the requirement to adjust activity by energetic condition and/or body size is reduced compared to previous studies in more northern locations (e.g., Goudie and Ankney 1986) and had little effect on hunter harvest in our study. Regarding the latter hypothesis, our results from the southern U.S. Central Flyway wintering grounds are supported by research at higher latitudes in the Mississippi and Atlantic flyways which found that weather conditions including temperature, snowfall, humidity, and air pressure affect waterbird migratory density and duck abundance (Nisbet and Drury 1968, Schummer et al. 2010, Van den Elsen 2016). Schummer et al. (2010) suggested that this effect occurred indirectly through changes in food availability, energy expenditures, and snow and ice cover. Our results in a warmer, southern climate suggest that snow and ice are not necessary to induce activity changes in dabbling ducks in response to weather, but those activity changes cannot be fully predicted by thermoregulatory constraints. These changes in dabbling duck activity directly influence the hunter harvest measured in this study. Future studies on species-, sex-, and age-specific behavior during specific weather conditions may provide more insight into the mechanisms underlying our results and further inform trends in hunter harvest.

Management Implications

Our results have implications for harvest management by informing managers on hunter placement based on forecasted weather to maximize duck harvest. Informed wildlife management is key to the North American model of conservation (Organ et al. 2012), and we believe that making hunters, managers, and scientists aware of historical trends and future changes is vital to continued sustainable management. Additionally, our study provides a baseline for typical weather-related patterns in dabbling duck species on coastal Texas wintering grounds. These data can be used by future studies examining dabbling duck activity and behavior, often an animal's first mechanism for responding to environmental change (Mench 1998). The Texas coast hosts up to 90% of the Central Flyway ducks (Ferro et al. 2010) and is undergoing rapid anthropogenic and climatic environmental change (Fowler and Hennessy 1995, Mullholland et al. 2002), heightening the need to establish baseline data to monitor health of ducks and the broader environment.

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