Factors Affecting Fat Content in Mottled Ducks on the Upper Texas Gulf Coast

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Abstract: Body condition, or an individual's ability to address metabolic needs, is an important measure of organism health. For waterfowl, body condition, usually some measure of fat, provides a useful proxy for assessing energy budgets during different life history periods and potentially is a measure of response to ecosystem changes. The mottled duck (*Anas fulvigula*) is relatively poorly studied in respect to these dynamics and presents a unique case because its non-migratory life-history strategy releases it from metabolic costs experienced by many related migratory waterfowl species. Additionally, as a species in decline and of conservation concern in many parts of its range, traditional methods of fat content estimation that involve destructive sampling are less viable. The goal of this study was to produce an equation for estimating fat content in mottled ducks using birds (n = 24) donated at hunter-check stations or collected by law enforcement efforts on the Texas Chenier Plain National Wildlife Refuge Complex from 2005–2007. Morphometric measurements were taken, and ether extraction and fat removal was used to estimate percent body fat content and abdominal fat mass, respectively. A hierarchical simple linear regression modeling approach was used to determine external morphometrics that best predicted abdominal fat content. A ratio model based on body mass and a length metric (keel and wing chord length possessed equal model support) provided the best relationship with abdominal fat in sampled individuals. We then applied the regression equation to historical check station data to examine fluctuations in fat content over time; fat content or condition varied relatively little with the exception of years characterized by major disturbances. The mottled duck condition model created here can be used to better monitor population status and health without destructively sampling individuals.

Key words: avian health, body condition, mottled duck, Texas, waterfowl

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Body condition, or an individual's ability to address present and future metabolic needs and stresses, is an important measure of organism health in avian species (Owen and Cook 1977). In many waterfowl species, knowledge of relative body condition is needed to give managers an understanding of potential responses to increasing anthropogenic changes in local habitats and the environment at large (Austin et al. 2000). For species in decline, it is especially important that estimates of body condition can be made easily and quickly so that negative impacts of these changes can be detected *in situ*. For migratory species, body condition can also have wide-reaching implications on breeding success. For instance, a primary hypothesis for significant population declines of lesser scaup (*Aythya affinis*) is that females are arriving on breeding grounds in poor condition after the substantial energetic cost of migration and relative lack of available forage at stop-over sites; thus, birds are unable to allocate necessary resources to produce successful clutches (Afton and Anderson 2001, Anteau and Afton 2004).

Much debate continues to occur in the literature regarding appropriate methods to represent body condition in avian species. For many waterfowl species, it is commonly considered that estimates of body fat content provide a suitable proxy for organism health (Whyte et al. 1986). Although other measures exist, such as observing metabolic products in the blood (Brown 1996), collection of usable data for these analyses frequently proves costly and labor intensive. Fat content, however, is often directly related to mass adjusted for body size, although the appropriate way to characterize this relationship and the efficacy with which morphometric indices predict condition varies greatly (Green 2001, Labocha and Hayes 2012). For wildlife managers operating hunter-check stations or engaged in other field operations, the ability to estimate the condition of a bird from morphometric measurements alone can prove invaluable in assessing long-term effects of factors such as environmental disturbance, changes in trophic factors such as competition, or availability of food resources.

We examined condition variables in the mottled duck (*Anas fulvigula*), a non-migratory waterfowl species native to the coastal marshes of the Gulf of Mexico. The mottled duck resides year-round chiefly in the coastal marshes of Texas and Louisiana as well as peninsular Florida (Bielefeld et al. 2010). Trends in body condition of mottled ducks are of particular interest in their management because their life-history and energetic demands differ substantially from their migratory phylogenetic relatives. Because mottled ducks have lower breeding propensity than many other species and move only short distances within their year-round habitat, they face different ecophysiological challenges than many other species (Stutzenbaker 1988, Rigby and Haukos 2012). The mottled duck has been designated as a focal species by the U.S. Fish and Wildlife Service, making conservation issues related to this species priorities in management of regional wetland habitats (Haukos 2012).

The Texas Chenier Plain National Wildlife Refuge (NWR) Complex and Texas Midcoast NWR Complex have historically accounted for >80% of mottled ducks that reside on federal lands in Texas due to the central location of these sites in its range and abundance of suitable waterfowl habitats (Ballard et al. 2001, Finger et al. 2003). Mottled ducks have been declining on Texas NWRs since the mid 1990s, with the only continuous breeding survey effort indicating a 95% reduction in breeding pair densities in the Chenier Plain of Texas (GCJV 2007, Haukos 2012). Factors potentially contributing to mottled duck decline may be numerous, and include increasing predator populations (Elsey et al. 2004), loss of coastal prairie and marsh habitats (Varner et al. 2013), conversion of native habitat to agriculture (Durham and Afton 2003), saltwater intrusion (Moorman et al. 1991), and ingestion of lead shot pellets from historical hunting activities or ongoing hunting for mourning doves (*Zenaida macroura*) (Merendino et al. 2005).

Our primary goal was to create a nonbreeding season (~October – January) body condition index for mottled ducks that would predict fat content in mottled ducks without the need for destructive sampling. Our equation should provide managers on the upper Texas Coast with the ability to conduct field estimation of abdominal fat content, which represents the most variable body fat depot and correlates with total fat content (Thomas et al. 1983). Availability of a representative index to body fat may provide critical management insights in the context of increasing threats from environmental contaminants, habitat degradation, and other factors. Condition estimates for mottled ducks can also be used comparatively with those collected via similar means for other waterfowl species to assess energetic differences inferred by variation in life-history strategies. Such analysis has not yet been conducted for this species, although similar equations are available for mallard (Owen and Cook 1977), northern pintail (*Anas acuta*) (Smith et al. 1992), and American wigeon (*A. americana*) (DeVault et al. 2003). Additionally, we applied the developed model to check-station data from the upper Texas Coast to evaluate variations in predicted fat content in mottled ducks relative to precipitation and potential resulting annual variation in habitat quality.

Study Site

Data were collected on Anahuac and McFaddin NWRs, which comprise part of the Texas Chenier Plain NWR complex on the Upper Texas Gulf Coast. Other refuges in this complex include Texas Point and Moody NWRs. This complex had a cumulative area of ~42,762 ha, and included a mix of coastal wetland habitats including intermediate, brackish, saline, and freshwater marshes (USFWS 2007, Haukos et al. 2010). Much of the surrounding land was used for agriculture, specifically rice (*Oryza sativa*), which is an important food source for mottled ducks (Stutzenbaker 1988). Approximately 40% of the complex was open to waterfowl hunting activities, and so provided a suitable location for collecting morphometric data from hunter-bag birds.

Methods

Condition Data Collection

Mottled ducks were collected between 1 October and 31 January at hunter-check stations and from confiscations from law enforcement efforts during 2005–2007. We froze and transported these birds to a laboratory at Stephen F. Austin State University for compositional analysis. In the lab, body mass (g) was measured using an electronic scale, and we used rulers or calipers to measure flattened wing chord (mm), culmen (mm), keel (mm), tarsus (mm), and total body length (mm). Abdominal fat mass (g) (omental, mesentery, and visceral fat) was determined by removing and weighing these fat depots. Total percent fat content was determined through ether extraction (Schemnitz 1980) for a subset of birds ($n = 11$) to provide a correlation with measured abdominal fat mass (W. Conway, Stephen F. Austin State University, unpublished data). Exploratory analysis using simple linear regression showed a suitable correlation between abdominal fat and total percent fat ($r = 0.69$, $P = 0.02$), suggesting that abdominal fat content provides a useful proxy to total percent fat in mottled ducks, similar to in other waterfowl species (Thomas et al. 1983).

Condition Model Development

We ranked regression models based on various combinations of field-measurable metrics as listed below for their utility in providing an *in-situ* measure of body condition such as mass (M), wing chord (WC), body length (L), and keel (K). In addition to primary morphometric variables, we tested ratio indices for body condition (i.e., adjusting body mass for body size) by dividing total body mass by various length metrics including wing chord, body, and keel length (Owen and Cook 1977, DeVault et al. 2003). Because the different morphometric measurements were related, we also reduced the morphometric measures using a Principal Components Analysis (PCA) with the resulting score from the first principal component as an additional independent variable in the regression model set (Alisaukas and Ankney 1990).

Because energetic requirements and behavioral demands were hypothesized to differ between age (adult and juvenile) and sex classes, interactive model terms were used to address potential differences in the relationship between external metrics and fat content due to sex and age. We assessed model fit using Akaike's Information Criterion corrected for small sample size (AIC_c) (Akaike 1974). Models with $\Delta AIC_c \leq 2$ were considered to have adequate support (Burnham and Anderson 2002). In addition to AIC_c, the correlation coefficient (r) and coefficient of determination (r^2 or R^2) were used to assess the strength of the relationship between external metrics and abdominal fat content provided by each model. All statistical analyses were conducted using JMP 11 (SAS 2014).

Model Application

After development of an equation to predict fat content based on morphometric measurements, historical check station data of mottled duck morphometrics were used to assess annual variation in population-level fat content since 1986. Check station data (total field M (g) and WC length (mm) by age and sex) were available from years 1986–1999, 2004, 2006, 2007, 2010, and 2011. Birds were aged and sexed in the field using tail and wing feather characteristics (Carney 1992). Hurricane Rita precluded check-station operations in 2005, and Hurricane Ike precluded check-station operation in 2008 and destroyed data from 2000–2003. Data from 2009 and 2012–2013 were excluded due to poor identification by check-station personnel.

Estimated abdominal fat mass was compared among years using a factorial analysis of variance including an age by year interaction using JMP 11 ($\alpha = 0.05$). Average annual estimated abdominal fat mass was compared against measures of growing season precipitation of the associated year to determine whether this variable would impact food availability (Bhattacharjee et al. 2009) and consequently a change in observed fat stores. Precipitation data for years addressed in this study were sourced from the Texas Water Development Board Precipitation and Lake Evaporation Database (TWDB 2014), which provided monthly average precipitation values. These were grouped into six-month (April – September) and twelve-month (October – September) periods to capture variation in precipitation leading up to the start of the hunting season. Pearson's correlation was used to determine the relationship between measures of precipitation and annual variation in percent fat.

Results

Abdominal fat content was compared against body metrics for 24 mottled ducks: three adult females, seven adult males, five juvenile females, and nine juvenile males (Table 1). Predicted fat content values were generated from historical data for 690 adult birds and 472 juvenile birds (Table 2).

Three models showed nearly equal support using AIC values, all of which were based around ratio models of mass and an external body length metric (Table 3). The condition model based around PC1 also showed a high level of support from its AIC_c value, but

Table 1. Summary morphometric statistics for 24 mottled ducks collected for body condition analyses from the Texas Chenier Plain National Wildlife Refuge Complex during 2005–2007.

	AF[a] (n = 3)		AM[a] (n = 7)		JF[a] (n = 5)		JM[a] (n = 9)	
	x̄	SE	x̄	SE	x̄	SE	x̄	SE
Mass (g)	810.6	19.32	974.0	17.30	871.6	8.56	951.6	10.68
Wing chord (mm)	240	0.84	251	1.66	242	2.46	247	0.85
Tarsus (mm)	51	0.88	51	0.67	51	0.55	52	0.28
Keel (mm)	94	1.90	99	1.06	95	0.75	98	0.56
Body length (mm)	505	5.49	535	3.58	523	3.28	538	1.83
Abdominal fat (g)	4.58	0.97	11.62	0.97	7.80	0.79	10.68	0.63

a. AF = adult female, AM = adult male, JF = juvenile female, JM = juvenile male

Table 2. Measures of average mass, wing chord, and estimated abnominal fat for 1,162 mottled ducks from historic check-station data (1986–2011) on Anahuac National Wildlife Refuge on the Texas Chenier Plain National Wildlife Complex.

	Adult (n = 690)		Juvenile (n = 472)	
	x̄	SE	x̄	SE
Mass (g)	1034.6	3.7	925.6	4.77
Wing chord (mm)	253	0.37	246	0.46
Estimated abnominal fat (g)	14.27	0.22	10.36	0.15

Table 3. Top ranked models describing the relationship between external morphometric data and abdominal fat content in nonbreeding mottled ducks sampled from the Texas Chenier Plain National Wildlife Refuge Complex during 2005–2007.

Model	R^2	Adj. R^2	AIC_c[a]	ΔAIC_c	K
M/K[b]	0.3008	–	145.5275	0.0000	2
M/WC	0.2980	–	145.6202	0.0927	2
PC1	0.2942	–	145.7435	0.2160	2
M	0.2554	–	146.9710	1.4435	2
M/L	0.2202	–	148.0351	2.5076	2
M/WC, M/WC∗Age, Age	0.3594	0.2583	149.7795	4.2520	4
L	0.1206	–	150.7996	5.2721	2
Null	–	–	151.0935	5.5660	1
M/WC, M/WC∗Sex, Sex	0.3076	0.1982	151.5698	6.0423	4
PC1, PC1∗Age, Age	0.2726	0.1578	152.7014	7.1739	4

a. AICc = Akaike's Information Criterion, correction for small sample size
b. M = mass, WC = wing chord, K = keel, PC1 = 1st principal component, L = body length

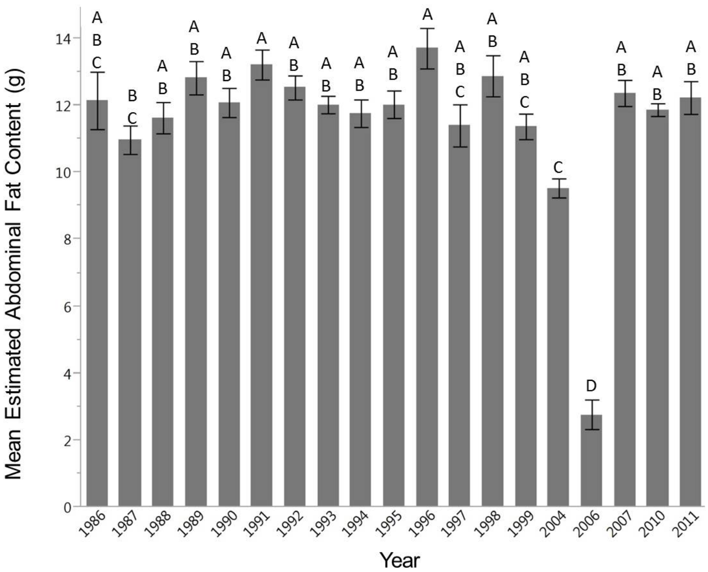

Figure 1. Mean estimated abdominal fat (± SE) by year from morphometric measurements of mottled ducks presented at hunter-check stations at the Texas Chenier Plain National Wildlife Refuge Complex during 1986–2011. Years with the same letter are not different ($P < 0.05$).

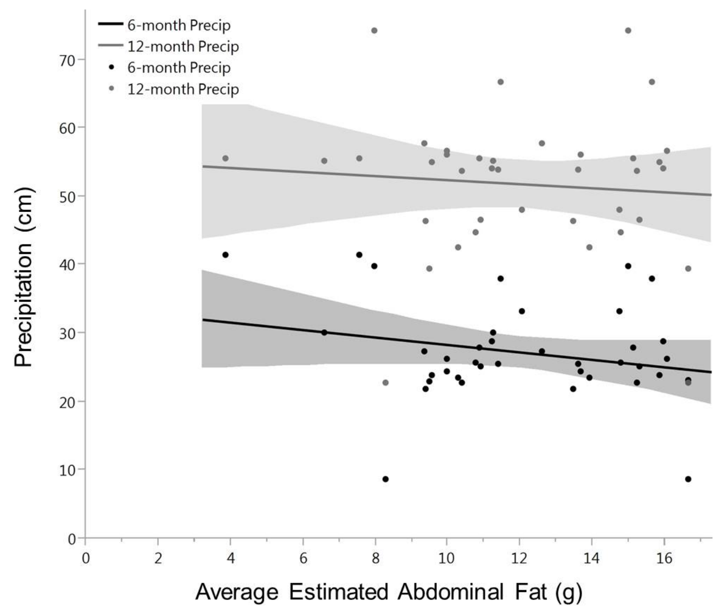

Figure 2. Relationships between annual average estimated abdominal fat content and cumulative 6-month and 12-month precipitation values from 1 April – 30 September and 1 October – 30 September, respectively, for mottled ducks presented at hunter-check stations stations at the Texas Chenier Plain National Wildlife Refuge Complex during 1986–2011.

did not demonstrate any improvement in model fit for its added complexity. Although age class showed some potential importance in determining fat content in sampled birds, the top model with an age interaction was not well supported ($\Delta \text{AIC}_c > 2$). Sex was not an important factor in determining fat content in the non-breeding season. Based on the ratio model of M/WC, which showed nearly identical support to the top model and has been commonly used in the field of waterfowl biology as a condition index, abdominal fat can be predicted for mottled ducks using the following equation:

$$\text{AbFat} = (-24.3276) + 9.0497(\text{M/WC})$$

Predicted fat values from historical check station data differed among years ($F_{18,1143} = 26.40$, $P < 0.0001$; Figure 1). Essentially, there was little variation among years with the exception of 2004 and 2006. Measures of precipitation did not have an effect on predicted abdominal fat content. Linear model fits were poor for both 6-month ($r = 0.22$, $F_{1,36} = 2.08$, $P = 0.16$) and 12-month ($r = 0.08$, $F_{1,36} = 0.28$, $P = 0.60$; Figure 2). This suggests that precipitation during the previous growing season or entire year did not directly affect fat content in mottled ducks at this study site.

Discussion

This analysis has yielded a model that has utility in predicting changes in fat content using abdominal fat deposits for mottled ducks using morphometric field measurements. Mottled ducks appear to follow the trend of other waterfowl species in that their fat content appears to be reasonably well-represented by a ratio model adjusting body mass for structural size. Mallards (Whyte and Bolen 1984) showed a similar relationship between total fat stores and a ratio index of M/WC ($r^2 = 0.73$), and age and sex also provided no additional information in this relationship for this species. The comparatively low r^2 values for top-ranked ratio models in this study ($r^2 = 0.29$) are likely attributable to small sample size requiring merging of available data and resulting sampling variation. Northern pintails in California demonstrated a difference in predicting fat content based on sex, but their condition predictions were also based on a ratio model (Miller 1989). Sample sizes in our study for individual sexes and age classes were too small to establish meaningful model interactions for the different groups, so we are unable to predict variation in fat content between groups for mottled ducks from these data. This was confirmed by the low level of support for these models in our model set. Additionally, although we believe that examination of hunter-collected mottled ducks provides a reasonable proxy to the overall population in this area, there is some concern that there may be a condition bias in hunter-shot birds (McCracken et al. 2000). Additional analyses would be necessary to substantiate a difference between these two categories.

The top-ranked model in our set, however, confirms that a ratio model based on m and WC is a reasonably good approximation of condition for this species on this study site and provides at least an initial insight for managers into organism health. Although it has been acknowledged in the literature that there are some potential factors in ratio models that may generate spurious statistical results (Green 2001, Peig and Green 2010, Labocha and Hayes 2012), the model developed herein uses correlation with collected fat data to show a reasonable estimate of condition. The lowest observed mass value for a mottled duck in this study was measured at 544 g with 1.1 g abdominal fat. As such, we warn that this model will be ineffective at predicting fat content for birds below these mass values. Additionally, fat store usage would likely vary during different life history periods (e.g., egg laying, molt) when energetic needs differ, so this model should be used only to track nonbreeding season condition over time.

Overall, when the regression model was applied to historic check station data, fat content remained relatively constant for mottled ducks across years with the exception of 2004 and 2006. Although standard error values were relatively large for mean values, our predictive equation allowed us to track major fluctuations in predicted fat content over time. The decreased condition for both age classes in 2004 and 2006 can likely be explained by the occurrence of large-scale landscape environmental disturbances. Surveys in 2004 took place following a substantial drought in 2003; conditions similar to this drought were not experienced again until 2011, at which time precipitation levels still remained higher (TWDB 2014). This would likely reduce food availability and, consequently, fat content (Bhattacharjee et al. 2009). The drop in estimated fat in 2006 can likely be attributed to the occurrence of Hurricane Rita, which passed over the Chenier Plain of Texas in 2005. Hurricanes, as a major ecological disturbance (Michener et al. 1997), have several impacts that could influence the condition of animals living in affected habitats. Firstly, mottled ducks, because of their non-migratory life history strategy, do not relocate to distant habitats to escape immediate and resultant hurricane impacts (Stutzenbaker 1988); this was corroborated by similar population counts of year-round resident waterbirds in wetlands before and after Hurricane Rita (O'Connell and Nyman 2011). Additionally, hurricanes have major effects at a landscape level and many environmental ramifications such as greatly increased sedimentation (Turner et al. 2006), rapid erosion of coastal land forms such as barrier islands (Stone et al. 1997), and drastic changes in salinity due to oceanic storm surges and sedimentation (Blood et al. 1991). One of the results of these changes is also physical destruction of plant communities. On a smaller scale, plant communities in a coastal marsh took up to 10 years to recover from removal by muskrats (*Ondatra zibethicus*) (Bhattacharjee et al. 2007); a hurricane would have similar effects on a landscape scale, significantly limiting food resources and potentially causing reductions in condition on a short-term basis. Although these disturbances would have an intuitive impact on organism success in an affected habitat, this dataset is admittedly small and correlation values generated from regression analyses are relatively weak even for the top ranked models ($r = 0.54$). Concrete scientific support for these concepts would require further body composition analysis of mottled ducks to determine fat content in relation to measured environmental conditions, which was not feasible as part of the current study.

Trends in precipitation effects on fat content, although correlations were not present given the current dataset, provide an interesting initial result. Intuitively, a relationship might be expected between precipitation and mottled duck fat reserve levels. Fat content would be expected to increase with increasing precipitation, as this would translate in many ecosystems to an increase in plant biomass and food availability. In mottled ducks, however, increased precipitation and resource availability is typically associated with increased breeding effort, because the species is a voluntary clutch layer (Stutzenbaker 1988, Rigby and Haukos 2012). As such, an increase in adult breeding effort during years of increased precipitation might manifest as a reduction in fat reserves because of greater energetic input into reproduction. Sex partitioning of analyses would be required to determine whether this effect is sex-specific; if not, factors such as molt may also play a role in reduced condition. This is a potentially complex issue for this species and warrants further investigation.

In conclusion, this study provides a first effort to describe body condition in mottled ducks and an equation to estimate condition in the field. As landscape changes continue to become more frequent and drastic, managers may desire to track changes in relevant metrics of focal species, such as mottled ducks. Especially in the context of lead exposure, recent surveys have shown that despite the national ban on the use of lead shot for waterfowl hunting, individual mottled ducks continue to experience lead exposure at occasionally toxic levels (McDowell 2014). Body condition measures in the field may provide rough insights on this issue given the numerous documented negative physiological effects of lead on waterfowl (Franson and Pain 2011) and results indicating that heavy metal concentrations may be directly and inversely related to body condition measures in at-risk species (Takekawa et al. 2002). Although destructive sampling of this species is not advisable because of its current population status, having a condition index that effectively and easily predicts fat content from normal check station or banding operation during the non-breeding season may allow managers to track responses to habitat and macro-climate change, observe the effects of anthropogenic impacts in this heavily impacted region, and inform conservation efforts on a regional scale that will aid in providing directed management efforts.

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