Diet and Body Mass of Wintering Ducks in Adjacent Brackish and Freshwater Habitats

Authors: Miller, Michael R., Burns, Edward G., Wickland, Bruce E., and Eadie, John M.

Source: Waterbirds, 32(3) : 374-387

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.032.0302

Diet and Body Mass of Wintering Ducks in Adjacent Brackish and Freshwater Habitats

MICHAEL R. MILLER[1*], EDWARD G. BURNS[2,4], BRUCE E. WICKLAND[3] AND JOHN M. EADIE[2]

[1]U.S. Geological Survey, Western Ecological Research Center, Dixon Field Station, 6924 Tremont Road, Dixon, CA, 95620, USA

[2]Wildlife, Fish and Conservation Biology, University of California, Davis, CA, 95616, USA

[3]Suisun Resource Conservation District, 2544 Grizzly Island Road, Suisun, CA, 94585, USA

[4]Current address: Natural Resources Conservation Service, U.S. Department of Agriculture, 1170 N Lincoln, Dixon, CA, 95620, USA

*Corresponding author; E-mail: michael_r_miller@usgs.gov

Abstract.—Field-collected and hunter-donated ducks obtained during September-January of 1997-98 and 1998-99 were used to determine if food habits and body mass of Northern Pintails (*Anas acuta*) and Mallards (*A. platyrhynchos*) wintering in Suisun Marsh (Suisun), California, a managed estuarine brackish marsh, differed from values in the adjacent Sacramento-San Joaquin River Delta (the Delta), a freshwater region of grain fields flooded after harvest. Ducks in Suisun fed primarily on seeds of Sea Purslane (*Sesuvium verrucosum*), followed by Alkali Bulrush (*Schoenoplectus maritimus*) and Wild Millet (*Echinochloa crusgalli*), together forming 73-90% (aggregate % dry mass) of the diets. Ducks in the Delta fed primarily on seeds of Smartweed (*Polygonum* spp.), followed by corn (*Zea mays*) and tomato seeds (*Lycopersicon esculentum*), together forming 62-88% of the diets. Pintails and Mallards collected in Suisun each had similar (5 of 11 seasonal comparisons) or greater (6 of the 11 comparisons) body mass compared to their conspecifics collected from the Delta (90% confidence interval analyses), despite a composite diet in the Delta having about 39% greater metabolizable energy content (ME) and 24% greater protein content than in Suisun. Therefore, diet quality alone was not a predictor of body mass in these two areas. Other factors must have been involved, such as greater food abundance and density, lower waterfowl abundance and density, or lower daily energy costs in Suisun. Direct measurement of these factors should explain the apparent inconsistencies in body mass relative to food quality in these brackish and freshwater habitats. *Received 28 June 2008, accepted 23 February 2009.*

Key words.—*Anas acuta, Anas platyrhynchos*, body mass, brackish water, California, diet, food habits, freshwater, Mallard, Northern Pintail.

Waterbirds 32(3): 374-387, 2009

The diets of wintering waterfowl using coastal brackish or marine habitats differ from those feeding in nearby freshwater habitats (Beter 1957; Tietje and Teer 1996; Ballard *et al.* 2004). The respective foods are often not of the same nutritional quality and may not allow accumulation of comparable winter fat and protein reserves (body condition) critical for subsequent breeding success (Krapu 1981; Mann and Sedinger 1993; Esler and Grand 1994), or support survival (Raveling 1979), recovery from food deprivation (Jorde *et al.* 1995), and migration (Alerstam and Lindström 1990). For example, foods consumed by Northern Shovelers (*Anas clypeata*) in saline wetlands along the Texas Gulf Coast differed from those in inland freshwater wetlands (Tietje and Teer 1996), and body condition (body mass, omental-fat, muscle mass) in freshwater generally exceeded that in the saline area (Tietje and Teer 1988). The diets of Northern Pintails (*A. acuta*) in Gulf Coast saline habitats contained less protein and fat and more ash than Pintails feeding inland in flooded rice (*Oryza sativa*) (Ballard *et al.* 2004), and the Pintails in the saline environment had lower body mass. Whether this is a consistent feature of other wintering regions is not known.

In California, the brackish Suisun Marsh (hereafter, Suisun) and the adjacent freshwater Sacramento-San Joaquin River Delta (hereafter, Delta) (Fig. 1) have traditionally supported relatively large wintering populations of waterfowl. However, Pintails, the most abundant duck wintering in Suisun, declined from the 1960s through the 1970s because increased commercial corn (*Zea mays*) produc-

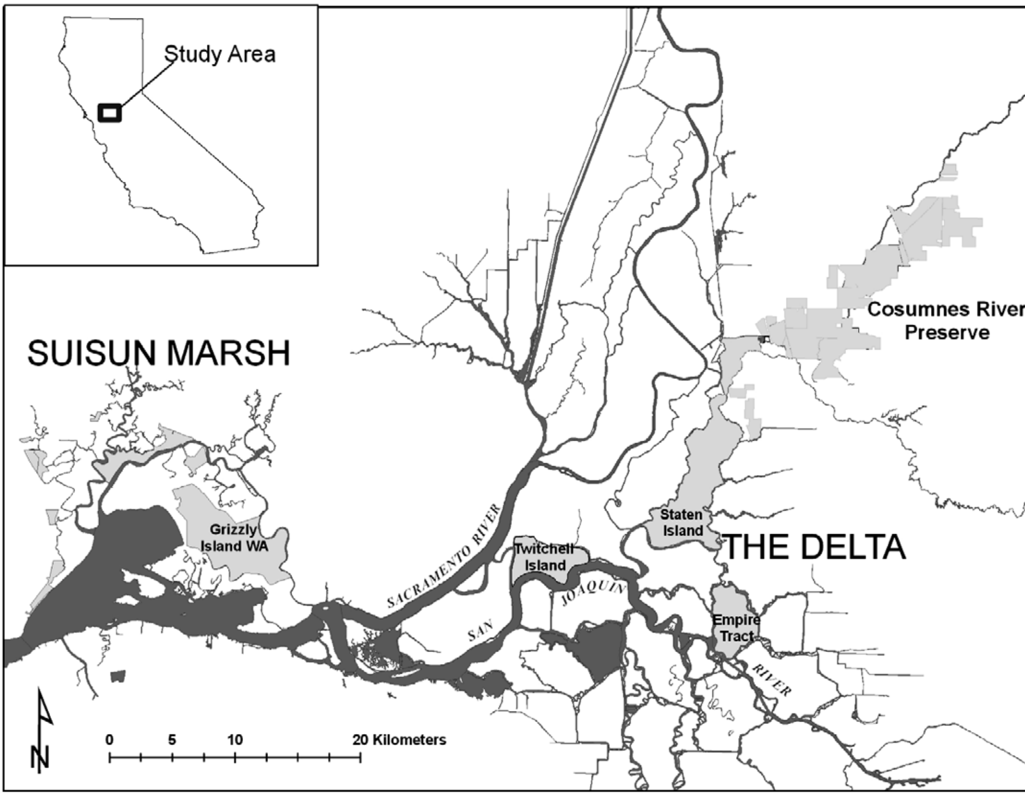

Figure 1. The Suisun Marsh and Sacramento-San Joaquin River Delta, California, study areas, 1997-99.

tion in the adjacent Delta provided easily obtained waste corn in harvested fields (Michny, F. J., unpublished report). Corn, wheat (*Triticum aestivum*), and rice grains remaining in fields after harvest are important foods for dabbling ducks because of their high metabolizable energy (ME) content (Baldassarre *et al.* 1983; Jorde *et al.* 1983; Joyner *et al.* 1987; Clark and Sugden 1990), and Pintails and Mallards will use agricultural grains even when marsh foods are available (Sugden 1980; Miller 1987). In contrast, Alkali Bulrush (*Schoenoplectus maritimus*) and many other marsh seeds eaten in Suisun (George *et al.* 1965; Burns 2003) have limited metabolizable energy (ME) content (Pederson and Pederson 1983; Petrie *et al.* 1998; Mueller and van der Valk 2002; Dugger *et al.* 2007).

The contrast in food resources available in Suisun and the Delta led us to suspect that food habits and body mass of these ducks could be different. If true, the results would suggest lower food quality and improved habitat management needs for the area with the lower average body mass. George *et al.* (1965) and Burns (2003) documented food use for Suisun, but no comparable data were available for the Delta. Therefore, we examined diets and body mass of Mallards and Pintails in the Delta during the fall and winters of 1997-98 and 1998-99, and herein compare our results with those from the Burns (2003) study, which was conducted simultaneously. Based on literature reports of greater quality diets in freshwater habitats, we predicted that body mass of collected ducks in the Delta would be greater than in Suisun.

METHODS

Study Area

Suisun Marsh—Suisun is a brackish estuarine wetland within a tidal zone consisting of 23,000 ha of wetlands managed to control daily tidal influence, reduce salt accumulation in the soil, and promote food production (Rollins 1981). During September to February, when pond water circulates and originates from adjacent delivery canals, the salinity of pond water can be

2.5-14.0 parts per thousand total dissolved solids (ppt TDS), and in marsh soils salinity reaches 6-44 ppt TDS (Mall 1969; Rollins 1973). Suisun supported a complex array of plants during our study, each with different ranges of salt tolerance, such as Alkali Bulrush, Fat-hen (*Atriplex triangularis*), Brass Buttons (*Cotula coronopifolia*), Sea Purslane (*Sesuvium verrucosum*), and Pickleweed (*Salicornia virginica*), as well as Wild Millet (*Echinochloa crusgalli*) in the fresher areas (< 3 ppt TDS) (Miller et al. 1975; Rollins 1981).

Wintering duck populations in Suisun had declined before the late 1990s as measured by annual midwinter surveys (M. Wolder, U.S. Fish and Wildlife Service, unpublished midwinter survey data). For example, we compared counts during 1973-1977, when large continental waterfowl populations prevailed in North America (North American Waterfowl Management Plan 2004), with those of 1997-1998, one of our study years. We found that total dabbling ducks (tribe Anatini) declined from 72,000 to 64,000, and Pintails declined from 47,000 to 16,000; however, Mallards increased from 6,000 to 10,000.

The Delta—The Delta is a freshwater system (generally 0 ppt TDS), but water of ≤1 ppt TDS can intrude into the narrow westernmost part of the Delta during drought years (California Department of Water Resources 1987: Fig. 30). High levees separate the Delta into a network of farmed islands isolated by navigable streams, and the primary crops grown included corn, wheat, and tomatoes. Landowners flooded harvested fields to control Johnsongrass (*Sorghum vulgare*) and leach salts from the soil, and these fields provided habitat used by wintering waterfowl. Isolated managed marsh occurred on some of the islands (e.g., Mandeville, Bract Tract) and on Cosumnes River Preserve (CRP) (Fig. 1).

Duck populations had generally been greater in the Delta than Suisun leading up to our study, but the disparity narrowed after the 1970s. Comparing average midwinter numbers during 1973-1977 with 1997-1998, we found that total dabbling ducks declined from 389,000 to 84,000 because Northern Pintails had declined from 371,000 to 47,000, following a continental trend (Miller and Duncan 1999); Mallards, however, increased from 11,000 to 22,000.

Minimal interchange of ducks occurs between Suisun and the Delta. Food habits studies have documented only small amounts of corn in ducks from Suisun where none is grown (George et al. 1965; Burns 2003). Also, telemetry data for Pintails radio-tagged in Suisun show that frequent and large-scale back-and-forth movements closely linking Suisun and the Delta apparently do not occur (Casazza 1995). Comparable data are not available for Mallards wintering in Suisun or for either species in the Delta.

Location of Duck Collections

The largely private ownership of the Delta and Suisun, wherein most lands served as duck clubs, precluded our collection of feeding ducks randomly during the duck hunting seasons. For example, in Suisun, Burns (2003) collected ducks on private lands only prior to the hunting seasons and on state-owned wildlife areas once the hunting seasons began. In the Delta, which contained few public hunting areas, we limited our work to Staten and Twitchell Islands, Empire Tract, and the CRP (Fig. 1). Further, during October 1998, the land manager at Staten Island denied further access to collect feeding ducks, and instead required that we obtain food samples only from hunter-donated ducks.

Duck Collections

General—Similar field procedures were followed in Suisun and the Delta to obtain samples. Investigators collected ducks by shotgun during autumn and winter 1997-98 (Year 1) and 1998-99 (Year 2). During the hunting seasons, they collected ducks only on non-shoot days (Monday, Tuesday, Thursday, Friday) or in afternoons (late October-January). Both studies used esophageal samples from actively feeding and non-feeding ducks to eliminate bias of hard foods common with gizzard analyses (Swanson and Bartonek 1970). Esophageal samples were obtained from actively feeding Mallards and Pintails (Swanson and Bartonek 1970; Miller 1987), those pass-shot as they transited the areas (Miller 1987; Ely and Raveling 1989), and those donated by private hunting clubs (Delnicki and Reinecke 1986). Body mass was obtained for each collected duck (not hunter-donated ones), and in the Delta we aged them as hatch-year (HY) or after hatch-year (AHY) (Carney 1992). Because hunter-donations and pass-shooting essentially sampled ducks under the same set of circumstances from blinds as the ducks returned to roosting ponds, and because sample sizes of pass-shot birds proved to be inadequate in the Delta (2 Pintails, 5 Mallards) compared to Suisun (35 Pintails, 48 Mallards), we pooled these two sources of ducks and categorized them as non-feeding.

Actively feeding ducks—Burns (2003) first collected actively feeding ducks in Suisun during September and October of both years, when all potential seeds would be present at maximum quantity and variety, and continued through December. In the Delta, we collected actively feeding ducks during December-February (Year 1) or September-February (Year 2). Although Burns (2003) collected benthic samples at feeding sites in Suisun, we obtained these only sporadically in the Delta. As a result, and because it would not be relevant to the point of our study, we do not consider food preference (Johnson 1980).

Non-feeding ducks—Burns (2003) pass-shot ducks in Suisun as they returned to diurnal roosts at dawn during October-December both years, and in the Delta we pass-shot ducks as opportunities arose and only during Year 1. Suisun duck club managers retained intact esophagi (with proventriculi) from ducks shot by members throughout the hunting season (October-January), preserving them in jars of 70% ethanol until retrieved (Burns 2003). In the Delta, during October-December of Year 2, we obtained esophageal contents of ducks directly from hunters on Staten Island and Empire Tract.

Processing Esophageal Contents

Processing of samples followed Miller (1987) in both regions. Esophageal contents (including proventriculus) from feeding and non-feeding ducks were removed after collection, placed in 70% ethanol in plastic bags, stored on ice in coolers, and later frozen for subsequent analyses. Food samples were thawed, washed through 500 µm mesh sieves, then each item was identified and dried to constant dry mass (DM) at 65º C (Reinecke and Owen 1980; Miller 1987). Existing reference samples, known seeds collected from the two study areas, and published sources (Miller 1987) were used to identify seeds. Additionally, the California Department of Food and Agriculture's seed laboratory in Sacramento identified many unknown seeds. Invertebrates were identified using Pennak (1978), Merritt and Cummins (1996), and assistance of the Bohart Museum of Entomology at UC Davis.

Data are presented for each food item as frequency of occurrence (% occc) and aggregate percent dry mass (agg% DM) (Swanson *et al.* 1974; Miller 1987):

(1) % occ = number of ducks in which the food item occurs ÷ total ducks;
(2) agg% DM = $\sum$(percentage DM of the food item in each duck) ÷ total ducks.

Nutritional Value of Foods

We used literature sources to obtain values of ME (apparent or true) content, as determined directly from feeding trials, of foods (>10.0 agg% DM) consumed in Suisun and the Delta. We also obtained percentages of crude protein (CP), fat (FAT), nitrogen free extract (NFE) (estimates carbohydrate), crude fiber (CF), and ash (ASH) of these foods from the literature. Where we could find no published ME data (one food item), we calculated a predicted value using an equation based on published digestibility and gross energy content of CP (91%, 4.1 kcal/g), NFE (96%, 4.2 kcal/g), and FAT (96%, 9.11 kcal/g), where ME of CF is assumed to be zero (Harris 1966:15; Vohra 1972). However, the method can bias ME high relative to direct feeding trial measures if hard seed coats resist digestion (Pederson and Pederson 1983; Dugger *et al.* 2007). For example, 50-72% of Alkali Bulrush seeds and 25-50% of Smartweed seeds fed to Mallards and Pintails passed intact in their excreta (Pederson and Pederson 1983; Hoffman and Bookhout 1985; Mueller and van der Valk 2002; Dugger *et al.* 2007). Therefore, we used published direct values of ME obtained from feeding trials for Alkali Bulrush (Ballard *et al.* 2004; Dugger *et al.* 2007), Smartweeds (Hoffman and Bookhout 1985, Petrie *et al.* 1998, Sherfy *et al.* 2001, Checkett *et al.* 2002), and Flatsedges (Sherfy 1999) to compare with predicted values calculated from the equations (Miller 1987: Table 7) (Alkali Bulrush: 3.24 vs. 1.3 kcal/g; Smartweeds: 3.16 vs. 1.4 kcal/g; Flatsedges: 3.08 vs. 2.0 kcal/g). This provided an average correction factor of 0.502 (SE = 0.08), which is the average percentage lower that a direct ME measure is versus the predicted value. Thus, the corrected ME for predicted values is 0.502 x predicted value.

We combined Pintail and Mallard food habits data to construct hypothetical composite diets and their ME (kcal/g) and CP content, each for Suisun and the Delta following Miller and Newton (1999) for ME. To do this, we multiplied aggregate percent dry mass of important food items (>5.0 agg% DM) by the average ME and CP of each, which yielded ME and CP for each food. We then summed these values from all foods to derive total ME and CP of the composite diet. We did not weight the ME or CP of each food by the number of ducks collected by region because we assumed ducks used one or the other region (little or no interchange). Finally, we compared total ME and CP of the composite diets in each region.

Statistical Analysis

Body mass—We combined all body mass estimates of collected ducks by sex to compare body mass of each species by period between the Delta and Suisun Marsh. We used confidence interval (CI) analyses (Johnson 1999; Anderson *et al.* 2001; Johnson 2002) for small sample sizes (Zar 1999) to determine if mean body mass could differ between Suisun and the Delta for each species. In the absence of controlled experiments and limited sample sizes resulting from limited areas to work, we adopted 90% CI (Tacha *et al.* 1982). Overlap of CIs on the means of body mass (CI on the means) and CIs on the difference between the means that include zero (CI on the difference) imply a strong probability of similar body mass between Suisun and Delta ducks. Zero or marginal overlaps are suggestive of different mean body masses. We could not compare body mass by age, because age was not assigned to Suisun ducks. We examined possible biases associated with this limitation by using 90% CI analyses to compare body mass of Delta Mallards and Pintails by age.

Dietary differences.—We did not use hypothesis-testing to detect differences in the diet of ducks between the Delta and Suisun, because differences in foods consumed between the two regions proved to be obvious and distinctive, precluding the necessity of statistical tests (Cherry 1998). Also, sample size was small in some instances in the Delta compared to the number of foods consumed (Miller 1987).

RESULTS

Collections of Ducks

Suisun Marsh—In Year 1, Burns (2003) collected 166 Mallards and 95 Pintails in Suisun from September to January, not all of which contained food items. These included 26 Mallards and 24 Pintails collected as they fed and, respectively, 140 and 71 non-feeding. During Year 2, Burns (2003) collected 159 Mallards and 130 Pintails, and these included 19 Mallards and 19 Pintails collected as they fed and, respectively, 140 and 111 non-feeding.

The Delta—During Year 1 in the Delta, we collected 33 Mallards and 26 Pintails from December to February, not all of which contained food items. These included 27 Mallards and 22 Pintails collected as they fed and, respectively, six and four non-feeding. During Year 2, we collected 46 Mallards and 17 Pintails from September to February, and these included 26 Mallards and ten Pintails taken as they fed and, respectively, 20 and seven non-feeding.

Body Mass in Suisun Marsh versus the Delta

Our data allowed eight direct body mass comparisons between Suisun and Delta Mallards and six comparisons for Pintails (Table 1). Mean body mass of Suisun Mal-

Table 1. Average body mass (g) ± SE, 90% confidence interval (CI) for small samples (Zar 1999), and period sample size (N), and average difference in body mass (g) ± SE and 90% CI on the difference for small samples (Zar 1999) of Mallards and Northern Pintails collected (actively feeding or passing) in Suisun Marsh and the Sacramento-San Joaquin River Delta, California, during September-October-November combined and December-January combined, 1997-98 and 1998-99.

	Mallard		Northern Pintail	
	Male	Female	Male	Female
1997-98 collections (Year 1)[a]				
December-January				
Suisun	1390 ± 40 (1315, 1465) (7) (df = 6, t = 1.943)	1210 ± 25 (1160, 1260) (7) (df = 6, t = 1.943)	1055 ± 25 (1010, 1100) (12) (df = 11, t = 1.796)	*1000 ± 25 (950, 1050) (6) (df = 5, t = 2.015)
Delta	1370 ± 35 (1305, 1435) (11) (df = 10, t = 1.812)	1180 ± 55 (1075, 1285) (8) (df = 7, t = 1.895)	1020 ± 35 (985, 1055) (15) (df = 14, t = 1.761)	890 ± 25 (845, 935) (9) (df = 8, t = 1.860)
Difference	20 ± 50 (-70, 110) (df = 13, t = 1.771)	30 ± 60 (-90, 150) (df = 5, t = 2.015)	35 ± 35 (-25, 95) (df = 22, t = 1.717)	110 ± 35 (50, 170) (df = 12, t = 1.782)
1998-99 collections (Year 2)				
September-October-November				
Suisun	*1380 ± 25 (1335, 1425) (21) (df = 20, t = 1.725)	1160 ± 25 (1115, 1205) (10) (df = 9, t = 1.833)	*1115 ± 20 (1080, 1150) (18) (df = 17, t = 1.740)	*985 ± 35 (920, 1050) (9) (df = 8, t = 1.860)
Delta	1285 ± 25 (1240, 1330) (18) (df = 17, t = 1.740)	1190 ± 25 (1090, 1290) (6) (df = 5, t = 2.015)	1010 ± 35 (945, 1075) (8) (df = 7, t = 1.895)	825 ± 40 (740, 910) (5) (df = 4, t = 2.132
Difference	95 ± 35 (60, 130) (df = 35, t = 1.645)	30 ± 55 (-75, 135) (df = 7, t = 1.895)	105 ± 45 (25, 185) (df = 11, t = 1.796)	160 ± 55 (60, 260) (df = 8, t = 1.860)
December-January				
Suisun	*1440 ± 25 (1395, 1485) (19) (df = 18, t = 1.734)	1235 ± 55 (890, 1580) (2) (df = 1, t = 6.314)	*1140 ± 25 (1095, 1185) (9) (df = 8, t = 1.860)	No comparative data
Delta	1330 ± 55 (1225, 1435) (7) (df = 6, t = 1.943)	1120 ± 35 (1020, 1220) (3) (df = 2, t = 2.920)	1055 ± 15 (1010, 1100) (3) (df = 2, t = 2.920)	No comparative data
Difference	110 ± 60 (0, 220) (df = 8, t = 1.860)	115 ± 80 (-120, 350) (df = 2, t = 2.920)	85 ± 30 (30, 140) (df = 9, t = 1.833)	—

*Indicates the larger body mass between Suisun and the Delta during each seasonal period as determined with 90% CI analysis.
[a]No data obtained in the Delta until December in Year 1, so no comparisons with Suisun are possible prior to this period.

lards and Pintails exceeded those of Delta Mallards and Pintails, respectively, in 13 of the 14 comparisons. However, not all of these differences were equally probable. For example, 90% CI analyses suggest that body mass of female Pintails was greater in Suisun than the Delta in December-January of Year 1, the only period available, but no other differences occurred for Pintails or Mallards in Year 1. However, during Year 2, body mass in Suisun likely exceeded that in the Delta for male Mallards in October and November, and male and female mallards in December-January, as well as female Pintails in September, and male Pintails in October, November, and December-January (Table 1). The exception occurred in Year 2, in which body mass of male Mallards in the Delta clearly exceeded mass in Suisun during September.

Body Mass Differences by Age in the Delta to Assess Potential Bias

We found mixed results for differences in body mass (years combined) by age for Delta ducks (90% CI on the means). Adult Mallards had larger body mass than HY Mallards, but we found no differences in mass by age for Pintails. Mallard males: AHY mean = 1410g, SE = 20g [N = 26, df = 25, t = 1.708, CI = 1375-1445g] vs. HY mean = 1270g, SE = 30g [N = 25, df = 24, t = 1.711, CI = 1240-1300g]; Mallard females AHY mean = 1240g, SE = 45g [N = 15, df = 14, t = 1.753, CI = 1195-1285g] vs. HY mean = 1150g, SE = 40g [N = 13, df = 12, t = 1.782, CI = 1100-1190g]. Pintail males: Male AHY mean = 1060g, SE = 35g [N = 9, df = 8, t = 1.860, CI = 1025-1095g] vs. HY mean = 1000g, SE = 30g [N = 19, df = 18, t = 1.734, CI = 970-1030g]; Pintail females: AHY mean = 920g, SE = 50g [N = 6, df = 5, t = 2.015, CI = 870-970g] vs. HY mean = 845g, SE = 35g [N = 8, df = 7, t = 1.895, CI = 785-905g].

General Patterns of Food Use

In Suisun, seeds from ten species of plants accounted for >90% of foods consumed for both duck species, and seeds of Sea Purslane, Alkali Bulrush, and Wild Millet each made up >10% of the diets of Pintails, Mallards, or both, regardless of collection method. Only small numbers of invertebrates occurred in the Suisun diet. In the Delta, seeds from seven species of plants accounted for >90% of foods consumed by Pintails and 14 accounted for >90% for Mallards. Agricultural grains formed a relatively large proportion of the Mallard and Pintail diets in the Delta, consisting of corn and tomato seeds, with some wheat, as well as large amounts of Smartweed seeds. Only Smartweeds (*Polygonum* spp.), corn, tomatoes, Flatsedge (*Cyperus* sp.), Wild Millet, and Rabbitsfoot Grass (*Polypogon monspeliensis*) each made up >10% of the diets of feeding and non-feeding Pintails, Mallards, or both. Ducks consumed measurable amounts of invertebrates in the Delta.

Actively Feeding Ducks

Suisun Marsh—Four food items each accounted for ≥5 agg% DM in feeding ducks (Table 2). Actively feeding Pintails consumed Sea Purslane in the largest quantity and, together with Alkali Bulrush and Wild Millet, most frequently. Actively feeding Mallards consumed these same foods most frequently, and they dominated the diet. Actively feeding ducks consumed few invertebrates, primarily midge larvae and diving beetle larvae. We found no agricultural grain in esophagi of feeding ducks.

The Delta—Seeds of six species of plants and one invertebrate each accounted for ≥5 agg% DM in feeding ducks (Table 3). In combined crop fields and freshwater marsh, actively feeding Pintails consumed Smartweed seeds most frequently, and they dominated Pintail diets, followed distantly by Rabbitsfoot Grass and tomato seeds. Wheat was consumed by only two feeding pintails, in Year 2, forming 9.4 and 17.8 agg% DM of their diets. Segmented worms (Naididae) and midge larvae together formed <1.0 agg% DM of the Pintail diet. Actively feeding Mallards in the Delta consumed Smartweeds most frequently, and this seed predominated in the diet, followed by corn, Flatsedge, and invertebrates (>8.0 agg% DM) (Naididae, Lumbricidae, Chironomidae).

Table 2. Foods of 38 Northern Pintails and 39 Mallards, all of which had ≥1 food items, collected while actively feeding in Suisun Marsh, California, during 1997-98 and 1998-99 (only foods ≥5.0 aggregate percent dry mass [agg% DM] in ≥1 duck species included in table).

	% occurrence		agg% DM	
Foods	Pintails	Mallards	Pintails	Mallards
Marsh and grass seeds				
Alkali Bulrush (*Schoenoplectus maritimus*)	82.9	69.6	8.8	34.1
Italian Ryegrass (*Lolium* spp.)	0	10.9	0	10.0
Sea Purslane (*Sesuvium verrucosum*)	85.4	63.0	71.2	27.0
Wild Millet (*Echinochloa crusgalli*)	29.3	39.1	9.6	23.4
Others[a]	29.3	13.1	9.4	3.8

[a]Items with <5 agg% DM, Pintail and Mallard data respectively: Fat hen (*Atriplex triangularis*) agg% DM = 2.5 and 0.3; Pickleweed (*Salicornia virginica*) agg% DM = 1.9 and 0.1; Smartweed (*Polygonum* spp.) agg% DM = <0.1 and 1.4; Swamp Timothy (*Crypsis schoenoides*) agg% DM = 4.9 and 2.0; midge larvae (Chironomidae) % occ. = 24.4 and 32.6; diving beetles (Dytiscidae) % occ. = 4.9 and 13.0; water boatman (Corixidae) % occ. = 0 and 13.0.

Table 3. Foods of 25 Northern Pintails and 39 Mallards, all of which had ≥1 food item, collected while actively feeding in the Sacramento-San Joaquin River Delta, California, during combined 1997-98 and 1998-99 (only foods >5.0 agg% dry mass [agg% DM] in at least 1 duck species included in main table).

	% occurrence		agg% DM	
Foods	Pintails	Mallards	Pintails	Mallards
Commercial grains				
Corn (*Zea mays*)	4.0	17.9	2.4	17.9
Tomato (*Lycopersicon esculentum*)	8.0	2.6	8.0	2.6
Marsh and grass seeds				
Flatsedge (*Cyperus* spp.)	12.0	17.9	0.1	11.0
Rabbitsfoot Grass (*Polypogon monspeliensis*)	32.0	0	11.8	0
Smartweeds (*Polygonum* spp.)	76.0	66.7	58.5	41.5
Wild Millet (*Echinochloa crusgalli*)	12.0	23.1	3.9	6.0
Other seeds[a]	22.0	7.1	13.7	14.1
Invertebrates[a]	36.5	12.8	0.8	8.5
Segmented worms (Naididae)	25.0	17.9	0.4	5.6

[a]Items with <5 agg% DM, Pintail and Mallard data respectively: Wheat (*Triticum aestivum*) agg% DM = 1.1 and 3.6; Ammannia (*Ammannia coccinea*) agg% DM = <0.1 and 1.7; Arrowhead (*Sagitaria* spp.) agg% DM = 0 and 2.2; Johnsongrass (*Sorghum halepense*) agg% DM = 3.7 and 0.2; Lambsquarters (*Chenopodium album*) agg% DM = 0.1 and 1.8; Pickleweed (*Salicornia virginica*) agg% DM = 4.0 and <0.1; Ryegrass (*Lolium* spp.) agg% DM = 0.2 and 1.6; Swamp Timothy (*Crypsis schoenoides*) agg% DM = 4.0 and 0; midge larvae (Chironomidae) agg% DM = 0.4 and 2.9.

Only three mallards consumed wheat in Year 2 (32.9, 43.5, and 64.7 agg% DM of their diets, respectively). One Mallard and one Pintail actively feeding at the CRP obtained some rice seed, probably from nearby fields (<0.3 agg% DM).

Non-feeding Ducks

Suisun Marsh—Non-feeding Pintails and Mallards collected from Suisun consumed Alkali Bulrush, Sea Purslane, and Wild Millet most frequently, and these items dominated the diets (Table 4). Only about 5% of non-feeding Pintails and 3% of non-feeding Mallards contained midge larvae in Suisun, the most-frequently used invertebrate, and none of these ducks had consumed agricultural grains.

The Delta—Non-feeding Pintails in the Delta consumed Smartweed seeds most frequently (75% of all birds), which formed half of the diet, followed by tomato seeds, which formed one-quarter of the diet (Table 5). A small amount of wheat had been consumed by one non-feeding Pintail (4.3 agg% DM).

Table 4. Foods of 178 non-feeding Northern Pintails (35 pass-shot; 143 hunter-donated) and 270 Mallards (48 pass-shot; 222 hunter-donated) in Suisun Marsh, California, during combined 1997-98 and 1998-99 (only foods >5.0 agg% dry mass [agg% DM] in at least 1 duck species included in table).

	% occurrence		agg% DM	
Foods	Pintails	Mallards	Pintails	Mallards
Marsh seeds				
Alkali Bulrush (*Schoenoplectus maritimus*)	58.5	67.1	37.1	33.0
Sea Purslane (*Sesuvium verrucosum*)	50.5	51.1	23.6	17.5
Swamp Timothy (*Crypsis schoenoides*)	22.0	20.0	8.4	6.3
Wild Millet (*Echinochloa crusgalli*)	24.9	47.1	12.6	22.7
Others[a]	9.1	13.0	15.7	17.1

[a]Items with <5.0 agg% DM (Pintail and Mallard data, respectively): Fat-hen (*Atriplex triangularis*) agg% DM = 3.1 and 4.5; Dock (*Rumex* spp.) agg% DM = 1.2 and 0.3; Pickleweed (*Salicornia virginica*) agg% DM = 4.7 and 2.2; Rabbitsfoot Grass (*Polypogon monspeliensis*) agg% DM = 1.1 and 1.9; Ryegrass (*Lolium* spp.) agg% DM = 0.1 and 1.1; Smartweed (*Polygonum* spp.) agg% DM = 2.3 and 3.8; corn (*Zea mays*) agg% DM = 1.8 and 0.3; Asters (*Aster* spp.) agg% DM = 1.0 and 0.5; Pondweed (*Potamogeton* spp.) agg% DM = 0.4 and 0.2; all other seeds <1.0 agg% DM in both species: agg% DM = 2.0 and 2.1; midge larvae (Chironomidae) % occ. = 4.9 and 3.0.

Table 5. Foods of 8 non-feeding Northern Pintails (2 pass-shot; 6 hunter-donated) and 19 Mallards (5 pass-shot; 14 hunter-donated) collected in the Sacramento-San Joaquin River Delta, California, during 1998-99 (only foods >5.0 agg% dry mass [agg% DM] in at least 1 duck species listed in table).

	% occurrence		agg% DM	
Foods	Pintails	Mallards	Pintails	Mallards
Commercial grains				
Corn (*Zea mays*)	12.5	42.1	12.5	35.4
Tomato (*Lycopersicon esculentum*)	25.0	21.1	24.9	11.9
Marsh and weed seeds				
Wild Millet (*Echinochloa crusgalli*)	0	15.8	0	11.8
Chickweed (*Stellaria media*)	12.5	5.2	<0.1	5.2
Rabbitsfoot Grass (*Polypogon monspeliensis*)	12.5	10.5	11.7	<0.1
Smartweeds (*Polygonum* spp.)	75.0	64.7	50.6	29.6
Others[a]				

[a]Items <5 agg% DM, Pintail and Mallard data respectively: Flatsedges (*Cyperus* spp.) agg% DM = 0 and 2.6; midge larvae (Chironomidae) agg% DM = 0.2 and 0.1; segmented worms (Naiaidae, Lumbriculidae) agg% DM = 0 and <0.1; diving beetle larvae (Dytiscidae) agg% DM = <0.1 and 0.1.

Pintails consumed midge and diving beetle larvae, which formed <0.5% of the diet. Likewise, non-feeding Mallards in the Delta consumed Smartweeds most frequently, followed by corn, tomato seeds, and Wild Millet. Corn formed about 35 agg% DM of Mallard diets, followed by Smartweeds (about 30%), tomato seeds and Wild Millet (12% each). Less than 0.5% of the diet of non-feeding Mallards was formed of invertebrates.

Nutritional Value of Duck Foods

Nutritional content varied among the most-used foods in Suisun and the Delta (Table 6). The heavily used Smartweeds in the Delta and Sea Purslane and Alkali Bulrush in Suisun had relatively the lowest ME values of the other foods. The commercial grains and tomato seeds all contained the highest ME values. Tomato seeds also had the highest CP and FAT content of any food consumed in both regions, followed by Sea Purslane. Wild Millet, which was important primarily in Suisun, but used in the Delta, had modest to high levels of ME.

The composite diet in Suisun consisted of 0.36 kcal/g and 0.043 g of CP from Sea Purslane, 0.43 kcal/g and 0.022 g of CP from Alkali Bulrush, 0.53 kcal/g and 0.021 g of CP from Wild Millet, and 0.15 kcal/g and 0.008

Table 6. Metabolizable Energy (ME), and percent Crude Protein (CP), Fat, Nitrogen-free Extract (NFE), and Crude Fiber (Fiber) content of important seeds consumed by Mallards and Northern Pintails in Suisun Marsh and the Sacramento-San Joaquin River Delta, California, during 1997-98 and 1998-99.

Food item	ME (kcal/g)	%CP	%Fat	%NFE	%Fiber
Suisun Marsh					
Sea Purslane (*Sesuvium verrucosum*)	1.5[q]	17.9[k]	8.2[k]	38.2[k]	31.9[k]
Alkali Bulrush (*Schoenoplectus maritimus*)	0.7-1.9[o, n]	8.3[j]	3.2[j]	65.8[j]	16.2[j]
Wild Millet (*Echinochloa crusgalli*)	2.6-3.3[c, d, m, s]	9.5-12.9[d, f, m]	2.2-5.1[d, f, m]	67.1-69.1[d, f, m]	9.5-14.6[d, f, m]
The Delta					
Smartweeds (*Polygonum* spp.)	1.1-1.6[c, d, s, t]	9.3-9.9[d, j]	2.2-2.4[d, j]	66.5-72.1[d, j]	14.3-18.5[d, j]
Flatsedges (*Cyperus* spp.)	2.0[r]	8.9-9.0[f, r]	4.0-4.8[r, f]	59.4[f]	19.5[f]
Corn (*Zea mays*)	3.6-4.0[a, b, d, e]	7.8-8.8[a, d, l]	3.3-4.5[d, l]	70.1-84.8[d, l]	2.1-3.6[d, l]
Tomato seed (*Lycopersicon esculentum*)	3.2[i, p]	25.0-32.4[h, i]	20.0-26.3[h, i]	16.0-16.8[h, i]	21.4-35.1[h, i]
Wheat (*Triticum aestivum*)	3.3-3.9[a, b, e, g]	14.3-23.3[a, d]	7.8[d]	53.9[d]	11.9[d]

[a]Joyner *et al.* 1987, [b]Reinecke *et al.* 1989, [c]Checkett *et al.* 2002, [d]Petrie *et al.* 1998, [e]Miller and Reinecke 1984, [f]Miller 1987, [g]Sugden 1971, [h]Yaseen *et al.* 1991, [i]Persia *et al.* 2003, [j]Bardwell *et al.* 1962, [k]Swiderek *et al.* 1988, [l]Loesch and Kaminski 1989, [m]Miller 1984, [n]Dugger *et al.* 2007, [o]Ballard *et al.* 2004, [p]nitrogen-corrected, [q]predicted from equations in Harris (1966) and Vohra (1972) = 2.9 kcal/g, then corrected for over-prediction of equations: 2.9 × 0.502, which is average percentage lower that predicted values are from actual ME estimated from feeding trials, [r]Sherfy 1999, [s]Sherfy *et al.* 2001, [t] = Hoffman and Bookhout 1985.

g of CP from Swamp Timothy, for a total of 1.47 kcal/g of ME and 0.99 g of protein. In the Delta, the composite diet consisted of 0.62 kcal/g and 0.043 g of CP from Smartweeds, 0.63 kcal/g and 0.014 g of CP from corn, 0.29 kcal/g and 0.026 g of CP from tomato seeds, 0.19 kcal/g and 0.007 g of CP from Wild Millet, 0.15 kcal/g and 0.022 g of CP from invertebrates, 0.10 kcal/g and 0.004 g of CP from Flatsedges, and 0.09 kcal/g and 0.004 g of CP from Rabbitsfoot Grass (no specific data available, so we used the Flatsedge value), for a total of 2.07 kcal/g ME and 0.123 g of CP in the composite diet. The Delta composite diet had 38.8% more ME and 24.2% more CP than the Suisun Diet.

DISCUSSION

Dietary Differences between Suisun Marsh and the Delta

Mallard and Pintail diets varied markedly between Suisun and the Delta, reflecting the patterns detected elsewhere between saline/brackish and freshwater habitats (Beter 1957; Tietje and Teer 1996; Ballard *et al.* 2004). In both California areas, seeds formed nearly the entire diets, a common feature in California wintering ducks (Miller 1987; Euliss and Harris 1987). Alkali Bulrush, Sea Purslane, and Wild Millet seeds dominated in Suisun, as shown by actively feeding and non-feeding ducks. In contrast, Smartweeds, corn, and tomato seeds predominated in the Delta, and invertebrates were relatively important compared to Suisun.

Routine foraging flights between Suisun and the Delta would affect the interpretation of our results if individual ducks obtained important quantities of foods in both areas. However, corn, wheat, and rice were found in only one Mallard and three Pintails donated by hunters in Suisun (Burns 2003), similar to findings of George *et al.* (1965), and no actively-feeding or pass-shot ducks in Suisun contained these grains. Likewise we detected no important quantity of dietary items from Delta ducks characteristic only of Suisun. For example, ducks consumed Wild Millet in Suisun, but it formed >10 agg% DM (11%) in the Delta only for non-feeding Mallards. Also, ducks consumed large amounts of Smartweed seeds in the Delta, but this food always formed <4 agg% DM of the diet in Suisun. Alkali Bulrush and Pickleweed seeds, characteristic of Suisun, occurred only in trace amounts, and Sea Purslane not at all, in esophagi of Delta ducks. Finally, *a posteriori* analysis of direct band recoveries from ducks banded preseason during 1995-2004, showed that only 10.9% of recoveries of Mallards banded in Suisun were recovered in the Delta, and only 11.1% of recoveries of Mallards banded in the Delta were recovered in Suisun (R. Eddings, California Waterfowl Association, Sacramento, unpublished data). Overall, these data suggest the absence of routine inter-area movements, and body mass should reflect intra-regional dietary effects.

Diet and Body Mass in Suisun Marsh versus the Delta

Adequacy of body mass data—Contrary to expectations, Mallards and Pintails from the brackish habitats of Suisun tended to have larger or similar body mass compared to ducks from the freshwater environments of the Delta. We caution that our mixed-age samples, which we had to use because Suisun ducks had not been aged, could have biased body mass comparisons because AHY ducks usually have greater mass than HY ducks (Bellrose 1980; Haukos *et al.* 2001). However, body mass comparisons for our Delta Pintails showed no mass differences by age, and at baited sites in Suisun Marsh live-trapped HY Pintails had similar or greater mass than AHY females (M. R. Miller, unpublished data referenced in Austin and Miller 1995). Since Delta AHY Mallards tended to have greater mass than HY Mallard, any bias caused by unknown proportions of HY and AHY ducks from Suisun and Delta samples would be more important for Mallards than Pintails.

Diets and body mass—In Texas, greater body mass of ducks was associated with freshwater rather than coastal marine habitats because the former provided higher quality diets (explicit: Tietje and Teer 1988; implied:

Ballard *et al.* 2004). However, the larger body masses of ducks in Suisun, suggest that the brackish habitats of Suisun provided foods of greater nutritional quality compared to the freshwater Delta. Suisun ducks did consume seeds from a larger variety of plant species than did Delta ducks (30 species [Burns 2003] vs. 23 species), which is advantageous in achieving a balanced diet (Kaminski *et al.* 2003) and favorable to larger body mass. However, our composite diets consisting of the most important foods, clearly show that the Delta diet had markedly higher ME and CP contents than the Suisun diet, and corn, tomato seeds, and invertebrates in the Delta diet all had relatively higher ME, CP, or FAT, or all three, than all foods in Suisun. Unfortunately, direct ME and nutrient digestibility assays from feeding trials are unavailable for the majority of foods consumed in Suisun and the Delta, a pervasive problem generally for marsh seeds and other waterfowl foods (Dugger *et al.* 2007).

Consumption of corn by wintering waterfowl, although providing a good source of ME, results in poor condition of wintering ducks because of deficiencies in certain amino acids (Baldassarre *et al.* 1983; Jorde *et al.* 1983; Loesch and Kaminski 1989). However, protein contributed by even small amounts of protein-rich invertebrates (e.g., midge larvae 66% CP) (Krapu and Swanson 1975) or seeds improves high carbohydrate diets (Jorde *et al.* 1983). Invertebrates formed a measurable portion of the diet in the Delta, and even the low numbers consumed in Suisun might have been sufficient to help balance the diet in concert with Sea Purslane, which had a relatively high CP value. Dabbert *et al.* (1996) showed that corn and rice with protein levels well within the range or less than Suisun and Delta foods did not induce protein deficiency in HY game farm Mallards. Consumption of tomato seeds (28-32.5% CP) (Canella *et al.* 1979; Carlson *et al.* 1981; Yaseen *et al.* 1991) would have raised dietary protein of ducks feeding in the Delta.

We probably underestimated the consumption rates of wheat, tomatoes, and corn in ducks from the Delta, a critical consideration, because these foods had high ME content and would have contributed additional energy (kcal) to the composite diet. Landowners flooded harvested wheat fields in August and September, which was followed by intensive feeding by Pintails (Miller *et al.* 1993). As a result, these ducks likely removed most of the grain prior to our collections of actively-feeding ducks and prior to hunting season collections from hunt clubs. For example, four of six feeding ducks collected in wheat fields in September had wheat but none of six did so in October. A late start to field work in Year 1 (December) precluded collection of ducks in harvested grain fields immediately after landowners flooded the fields when seeds would have been most abundant. Also, the access limitation imposed on Staten Island in early October in Year 2 precluded collections in corn shortly after harvest. These circumstances likely reduced the quantity of grains in our samples of ducks.

The diet-body mass contradiction suggests that factors other than diet quality likely controlled comparative body mass between Suisun and the Delta. First, any nutritional advantage in Delta foods, as shown by the composite diet, could have been overwhelmed by regional differences in food abundance. Estimated waste corn density is 119-286 kg/ha in the Delta (Jones and Stokes Associates 1991), which is similar to or lower than estimates elsewhere (Baldassarre *et al.* 1983; Warner *et al.* 1985; Krapu *et al.* 2004). However, we did not find similar data for Smartweeds, wheat, tomatoes, or other seeds in the Delta, or for Sea Purslane, Wild Millet, Alkali Bulrush, or other marsh seeds in Suisun. Invertebrate density has been estimated in Suisun (Batzer and Resh 1992), where use by Mallards and Pintails was apparently low (Burns 2003; but see Batzer *et al.* 1993), but not in the Delta, where use was somewhat more important. Secondly, seasonal energy costs of ducks (Miller and Newton 1999) could be higher in the Delta. For instance, the average length of flights between diurnal roosts and nocturnal foraging areas in the Delta (5.1 ± 0.3 km) were double that in Suisun (2.5 ± 0.1 km) (Fleskes *et al.* 2005). Thirdly, Pintails are known to move to the Delta in December from the San Joaquin (Fleskes *et al.* 2002) and Sacramento Valleys (M. R. Miller, unpublished telemetry data). The Sacramento Valley ducks had lower body mass at that time (Miller 1986) and could have reduced the average body mass we detected in the Delta compared to Suisun. Finally, the larger numbers of Mallards and Pintails, and other grain-consuming waterfowl and birds present in the Delta but not Suisun, such as Tundra Swans (*Cygna columbianus*), Sandhill Cranes (*Grus canadensis*), and Snow (*Chen caerulescens*), Ross' (*C. rossii*), and Greater White-fronted Geese (*Anser albifrons*) (Small 1994), could have increased competition and reduced food densities more rapidly in the Delta compared to Suisun.

Our working assumption that ME and CP content of composite diets is most important in controlling comparative duck body condition during winter in the two regions may need re-assessment. This will require estimates of duck population density (birds/km^2) and the density of their foods (kg/ha) in the managed wetlands of Suisun, and in the harvested grain and tomato fields in the Delta. Also needed are direct determinations of ME and nutrient composition of all critical foods from both regions. This research could directly document how waterfowl population size and density interact with food abundance, density, and nutritional quality to affect body mass of Mallards and Pintails in brackish and freshwater habitats.

ACKNOWLEDGMENTS

We thank P. Finfrock and B. J. Grewell (California Department of Water Resources) and W. Keck (U.S. Bureau of Reclamation) for assistance with project development and funding. We thank L. C. Lehman (Suisun Resource Conservation District) and D. R. Becker (California Department of Fish and Game, Grizzly Island Wildlife Area) for facilitating collections in Suisun Marsh. We thank D. G. Paullin (Central Valley Joint Venture) and M. A. Bias (Ducks Unlimited, Inc.) for assisting with study development and funding for the Delta studies. J. Shanks and S. Shanks provided access to Staten Island for collecting ducks, M. L. Quartaroli provided access to Empire Tract, R. Boeck (California Department of Water Resources) provided access to Twitchell Island, and R. Cooper (Bureau of Land Management) granted access to CRP. K. L. Petrik (Ducks Unlimited, Inc.) provided GIS data for CRP. We thank R. Eddings (California Waterfowl Association) for Suisun Mallard band recovery data. M. L. Casazza, B. M. Ballard, T. Suchanek and two anonymous referees provided reviews of the manuscript.

LITERATURE CITED

Alerstam, T. and Å. Lindström. 1990. Optimal bird migration: the relative importance of time, energy, and safety. Pages 331-351 *in* Bird Migration (E. Gwinner, Ed.). Springer-Verlag, Berlin, Germany.

Anderson, D. R., W. A. Link, D. H. Johnson and K. P. Burnham. 2001. Suggestions for presenting the results of data analysis. Journal of Wildlife Management 65: 373-378.

Austin, J. E. and M. R. Miller. 1995. Northern Pintail (*Anas acuta*). *In* The Birds of North America, No. 163 (A. Poole and F. Gill, Eds.). The Academy of Natural Sciences, Philadelphia; The American Ornithologists' Union, Washington, D.C.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlan and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11: 25-31.

Ballard, B. M., J. E. Thompson, J. J. Petrie, M. Chekett and D. G. Hewitt. 2004. Diet and nutrition of Northern Pintails wintering along the southern coast of Texas. Journal of Wildlife Management 68: 371-382.

Bardwell, J. L., L. L. Glasgow and E. A. Epps, Jr. 1962. Nutritional analysis of foods eaten by Pintail and teal in south Louisiana. Proceedings of the Annual Conference of the Southeast Association of Game and Fish Commissioners 16: 209-217.

Batzer, D. P. and V. H. Resh. 1992. Macroinvertebrates of a California seasonal wetland and responses to experimental habitat manipulation. Wetlands 12: 1-7.

Batzer, D. P., M. McGee, V. H. Resh and R. R. Smith. 1993. Characteristics of invertebrates consumed by mallards and prey response to wetland flooding schedules. Wetlands 13: 41-49.

Bellrose, F. C., Jr. 1980. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, Pennsylvania.

Beter, R. A. 1957. A comparative winter food habit study of dabbling ducks from the brackish Lake Borgne marsh of St. Bernard Parish and the fresh marsh of Pass A Loutre (Miss. Delta) Plaquemines Parish, Louisiana. Unpublished M.S. Thesis, Louisiana State University, Baton Rouge, Louisiana.

Burns, E. G. 2003. An analysis of food habits of Green-winged Teal, Northern Pintails, and Mallards wintering in the Suisun Marsh to develop guidelines for food plant management. Unpublished M.S. Thesis, University of California, Davis, California.

California Department of Water Resources. 1995. Sacramento-San Joaquin Delta Atlas. The California Resources Agency, Department of Water Resources, Sacramento, California (also available at: http://baydeltaoffice.water.ca.gov/DeltaAtlas/index.cfm, accessed 14 February 2009).

Canella, M., F. Cardinali, G. Castriotta and R. Nappucci. 1979. Chemical properties of the seeds of different tomato varieties. Rivista Italiana Sostanze Grasse 56: 8-11.

Carlson, B. L., D. Knorr and T. R. Watkins. 1981. Influence of tomato seed addition on the quality of wheat flour breads. Journal of Food Science 46: 1029-1031.

Carney, S. M. 1992. Species, age and sex identification using wing plumage. U.S. Department of Interior, Washington, D.C. (also available at: http://www.npwrc.usgs.gov/resource/birds/duckplum/index.htm, accessed 12 February 2009).

Casazza, M. L. 1995. Habitat use and movements of Northern Pintails wintering in the Suisun Marsh, California. Unpublished M.S. Thesis, California State University, Sacramento, California.

Checkett, J. M., R. D. Drobney, M. J. Petrie and D. A. Graber. 2002. True metabolizable energy of moist-soil seeds. Wildlife Society Bulletin 30: 1113-1119.

Cherry, S. 1998. Statistical tests in publications of The Wildlife Society. Wildlife Society Bulletin 26: 947-953.

Clark, R. G. and L. G. Sugden. 1990. The importance of agricultural foods in the annual diet of Mallard (*Anas platyrhynchos*) and Sandhill Crane (*Grus canadensis*). Pages 317-331 *in* Granivorous birds in the agricultural landscape (J. Pinowski and J. D. Summers-Smith, Eds.). Proceedings of General Meetings of the Working Group on Granivorous Birds, Institute of Ecology, Polish Academy of Sciences, Warszawa, Poland.

Dabbert, C. B., K. C. Powell and T. E. Martin. 1996. Effects of monotypic diets of soybean, rice, and corn on Mallard (*Anas platyrhynchos*) physiological status. Journal of Zoo and Wildlife Medicine 27: 248-254.

Delnicki, D. and K. J. Reinecke. 1986. Mid-winter food use and body weights of Mallards and Wood Ducks in Mississippi. Journal of Wildlife Management 50: 43-51.

Dugger, B. D., M. L. Moore, R. S. Finger and M. J. Petrie. 2007. True metabolizable energy for seeds of common moist-soil plant species. Journal of Wildlife Management 71: 1964-1967.

Ely, C. R. and D. G. Raveling. 1989. Body composition and weight dynamics of wintering Greater White-fronted Geese. Journal of Wildlife Management 53: 80-87.

Esler, D. and J. B. Grand. 1994. The role of nutrient reserves for clutch formation by Northern Pintails in Alaska. Condor 96: 422-432.

Euliss, N. H. and S. W. Harris. 1987. Feeding ecology of Northern Pintails and Green-winged Teal wintering in California. Journal of Wildlife Management 51: 724-732.

Fleskes, J. P., R. L. Jarvis and D. S. Gilmer. 2002. Distribution and movements of female Northern Pintails radiotagged in San Joaquin Valley, California. Journal of Wildlife Management 66: 138-152.

Fleskes, J. P., J. L. Yee, M. L. Casazza, M. R. Miller, J. Y. Takekawa and D. L. Orthmeyer. 2005. Waterfowl distribution, movements, and habitat use relative to recent habitat changes in the Central Valley of California: a cooperative project to investigate impacts of the Central Valley Joint Venture and changing agricultural practices on the ecology of wintering waterfowl. Final Report, U.S. Geological Survey, Western Ecological Research Center, Dixon Field Station, Dixon, California. (available at http://www.werc.usgs.gov/dixon/pdfs/AllCombinedFinalRptOCT05-allpgnuB.pdf, accessed 12 February 2009).

George, H. A., W. Anderson and H. McKinnie. 1965. An evaluation of the Suisun Marsh as a waterfowl area. California Department of Fish and Game, Administrative Report 20, Sacramento, California.

Harris, L. E. 1966. Biological energy interrelationships and glossary of energy terms. National Academy of Sciences, National Research Council Publication 1411. Washington, D.C.

Haukos, D. A., J. E. Neaville and J. E. Myers. 2001. Body condition of waterfowl harvested on the Upper Gulf Coast of Texas, 1986-2000. U.S. Fish and Wildlife Service, Region 2, Department of Range, Wildlife, and Fisheries Management, Texas Tech University, Lubbock, Texas.

Hoffman, R. D. and T. A. Bookhout. 1985. Metabolizable energy of seeds consumed by ducks in Lake Eire marshes. Transactions of the North American Wildlife and Natural Resources Conference 50: 557-565.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61: 65-71.

Johnson, D. H. 1999. The insignificance of statistical significance testing. Journal of Wildlife Management 63: 763-772.

Johnson, D. H. 2002. The role of hypothesis testing in wildlife science. Journal of Wildlife Management 66: 272-276.

Jones and Stokes Associates, Inc. 1991. Habitat evaluation procedures (HEP) report for the Delta Wetlands Project, Draft (JSA 87-119), January 1991. Prepared for the California State Water Resources Control Board, Division of Water Rights, and the U.S. Army Corps of Engineers, Sacramento, District. Sacramento, California.

Jorde, D. G., G. M. Haramis, C. M. Bunck and G. W. Pendleton. 1995. Effects of diet on rate of body mass gain by wintering Canvasbacks. Journal of Wildlife Management 59: 31-39.

Jorde, D. G., G. L. Krapu and R. D. Crawford. 1983. Feeding ecology of Mallards wintering in Nebraska. Journal of Wildlife Management 47: 1044-1053.

Joyner, D. E., B. N. Jacobson and R. D. Arthur. 1987. Nutritional characteristics of grains fed to Canada Geese. Wildfowl 38: 89-93.

Kaminski, R. M., J. B. Davis, H. W. Essig, P. D. Gerard and K. J. Reinecke. 2003. True metabolizable energy for Wood Ducks from acorns compared to other waterfowl foods. Journal of Wildlife Management 67: 542-550.

Krapu, G. L. 1981. The role of nutrient reserves in Mallard reproduction. Auk 98: 29-38.

Krapu, G. L., D. A. Brandt and R. R. Cox, Jr. 2004. Less waste corn, more land in soybeans, and the switch to genetically modified crops: trends with important implications for wildlife management. Wildlife Society Bulletin 32: 127-136.

Krapu, G. L. and G. A. Swanson. 1975. Some nutritional aspects of reproduction in prairie nesting Pintails. Journal of Wildlife Management 39: 156-162.

Loesch, C. R. and R. M. Kaminski. 1989. Winter body-weight patterns of female Mallards fed agricultural seeds. Journal of Wildlife Management 53: 1081-1087.

Mann, F. E., and J. S. Sedinger. 1993. Nutrient reserve dynamics and control of clutch size in Northern Pintails breeding in Alaska. Auk 110: 264-278.

Mall, R. E. 1969. Soil-water-salt relationships of waterfowl food plants in the Suisun Marsh of California. California Department of Fish and Game, Wildlife Bulletin No. 1. Sacramento, California.

Merritt, R. W. and K. W. Cummins. 1996. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing, Dubuque, Iowa.

Miller, A. W., R. S. Miller, H. C. Cohen, and R. F. Schultze. 1975. Suisun Marsh study. U.S. Department of Agriculture, Soil Conservation Service, Davis, California.

Miller, M. R. 1984. Comparative ability of Northern Pintails, Gadwalls, and Northern Shovelers to metabolize foods. Journal of Wildlife Management 48: 362-370.

Miller, M. R. 1986. Northern Pintail body condition during wet and dry winters in the Sacramento Valley, California. Journal of Wildlife Management 50: 189-198.

Miller, M. R. 1987. Fall and winter foods of Northern Pintails in the Sacramento Valley, California. Journal of Wildlife Management 51: 405-414.

Miller, M. R., and D. C. Duncan. 1999. The Northern Pintail in North America: status and conservation needs of a struggling population. Wildlife Society Bulletin 27: 788-800.

Miller, M. R. and W. E. Newton. 1999. Population energetics of Northern Pintails wintering in the Sacramento Valley, California. Journal of Wildlife Management 63: 1222-1238.

Miller, M. R. and K. J. Reinecke. 1984. Proper expression of metabolizable energy in avian energetics. Condor 86: 396-400.

Miller, M. R., D. L. Orthmeyer, M. L. Casazza, M. R. McLandress and D. P. Connelly. 1993. Survival, habitat use, and movements of female Northern Pintails radio-marked in the Suisun Marsh, California. Final Report, June 1993. National Fish and Wildlife Foundation and California Waterfowl Association, Sacramento, California.

Mueller, M. H. and A. G. van der Valk. 2002. The potential role of ducks in wetland seed dispersal. Wetlands 22: 170-178.

North American Waterfowl Management Plan. 2004. Plan Update, December 2004, Strategic Guidance: Strengthening the Biological Foundation. Canadian Wildlife Service, U.S. Fish and Wildlife Service, Secretaria de Medio Ambiente y Recursos Naturales. (also available at: http://www.fws.gov/birdhabitat/NAWMP/files/NAWMP2004.pdf, accessed 14 February 2009).

Pederson, G. B. and R. L. Pederson. 1983. Feeding ecology of Pintails and Mallards in Lower Klamath marshes. U.S. Fish and Wildlife Service, final report 14-16-0001-79106. Humboldt State University, Arcata, California.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States. John Wiley and Sons, New York, New York.

Persia, M. E., C. M. Parsons, M. Schang and J. Azcona. 2003. Nutritional evaluation of dried tomato seeds. Poultry Science 82: 141-146.

Petrie, M. J., R. D. Drobney and D. A. Graber. 1998. True metabolizable energy estimates of Canada Goose foods. Journal of Wildlife Management 62: 1147-1152.

Raveling, D. G. 1979. The annual cycle of body composition of Canada Geese with special reference to control of reproduction. Auk 96: 234-252.

Reinecke, K. J., R. M. Kaminski, D. J. Moorhead, J. D. Hodges and J. R. Nassar. 1989. Mississippi Alluvial Valley. Pages 203-247 *in* Habitat management for migrating and wintering waterfowl in North America (L. M. Smith, R. L. Pederson, and R. M. Kaminski, Eds.). Texas Tech. University Press, Lubbock, Texas.

Reinecke, K. J. and R. B. Owen, Jr. 1980. Food use and nutrition of Black Ducks nesting in Maine. Journal of Wildlife Management 44: 549-558.

Rollins, G. L. 1973. Relationships between soil salinity and the salinity of applied water in the Suisun Marsh of California. California Fish and Game 59: 5-35.

Rollins, G. L. 1981. A guide to waterfowl habitat management in Suisun Marsh. The Resources Agency, California Department of Fish and Game, Sacramento, California. (also available at: http://www.calwaterfowl.org/web2/leftcolumnmenu/habitatservices/habitatservicespdfs/mgmtguide_suisun.pdf, accessed 14 February 2009).

Sherfy, M. H. 1999. Nutritional value and management of waterfowl and shorebird foods in Atlantic Coastal moist-soil impoundments. Unpublished Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Sherfy, M. H., R. L. Kirkpatrick and K. E. Webb, Jr. 2001. Nutritional consequences of gastrolith ingestion in Blue-winged Teal: a test of the hard-seed-for-grit hypothesis. Journal of Wildlife Management 65: 406-414.

Small, A. 1994. California birds: Their status and distribution. Ibis Publishing Company, Vista, California.

Sugden, L. G. 1971. Metabolizable energy of small grains for Mallards. Journal of Wildlife Management 35: 781-785.

Sugden, L. G. 1980. Natural foods of Mallards in Saskatchewan parklands during late summer and fall. Journal of Wildlife Management 44: 705-709.

Swanson, G. A. and J. C. Bartonek. 1970. Bias associated with food analysis in gizzards of Blue-winged Teal. Journal of Wildlife Management 34: 739-746.

Swanson, G. A., and G. L. Krapu, J. C. Bartonek, J. R. Serie and D. H. Johnson. 1974. Advantages in mathematically weighting waterfowl food habits data. Journal of Wildlife Management 38: 302-307.

Swiderek, P. K., A. S. Johnson, P. E. Hale and R. L. Joyner. 1988. Production, management, and waterfowl use of Sea Purslane, Gulf Coast Muskgrass, and Widgeongrass in Brackish Impoundments. Pages 441-457 *in* Waterfowl in Winter (M. W. Weller, Ed.). University of Minnesota Press, Minneapolis, Minnesota.

Tacha, T. C., W. D. Warde and K. P. Burnham. 1982. Use and interpretation of statistics in wildlife journals. Wildlife Society Bulletin 10: 355-362.

Tietje, W. D. and J. G. Teer. 1988. Winter body condition of Northern Shovelers on freshwater and saline habitats. Pages 353-376 *in* Waterfowl in Winter (M. W. Weller, Ed.). University of Minnesota Press, Minneapolis, Minnesota.

Tietje, W. D. and J. G. Teer. 1996. Winter feeding ecology of Northern Shovelers on freshwater and saline wetlands in south Texas. Journal of Wildlife Management 60: 843-855.

Vohra, P. 1972. Evaluation of metabolizable energy for poultry. World's Poultry Science Journal 29: 204-214.

Warner, R. E., S. P. Havera and L. M. David. 1985. Effects of autumn tillage systems on corn and soybean harvest residues in Illinois. Journal of Wildlife Management 49: 185-190.

Yaseen, A. A. E., M. H. A. S. El Din and A. R. A. El Latif. 1991. Fortification of Balady bread with tomato seed meal. Cereal Chemistry 68: 159-161.

Zar, J. H. 1999. Biostatistical analysis, 4th ed. Prentice-Hall, Upper Saddle River, New Jersey.