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Research Article

Increased Body Mass of Ducks Wintering in California's Central Valley

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ABSTRACT Waterfowl managers lack the information needed to fully evaluate the biological effects of their habitat conservation programs. We studied body condition of dabbling ducks shot by hunters at public hunting areas throughout the Central Valley of California during 2006–2008 compared with condition of ducks from 1979 to 1993. These time periods coincide with habitat increases due to Central Valley Joint Venture conservation programs and changing agricultural practices; we modeled to ascertain whether body condition differed among waterfowl during these periods. Three dataset comparisons indicate that dabbling duck body mass was greater in 2006–2008 than earlier years and the increase was greater in the Sacramento Valley and Suisun Marsh than in the San Joaquin Valley, differed among species (mallard [*Anas platyrhynchos*], northern pintail [*Anas acuta*], America wigeon [*Anas americana*], green-winged teal [*Anas crecca*], and northern shoveler [*Anas clypeata*]), and was greater in ducks harvested late in the season. Change in body mass also varied by age–sex cohort and month for all 5 species and by September–January rainfall for all except green-winged teal. The random effect of year nested in period, and sometimes interacting with other factors, improved models in many cases. Results indicate that improved habitat conditions in the Central Valley have resulted in increased winter body mass of dabbling ducks, especially those that feed primarily on seeds, and this increase was greater in regions where area of post-harvest flooding of rice and other crops, and wetland area, has increased. Conservation programs that continue to promote post-harvest flooding and other agricultural practices that benefit wintering waterfowl and continue to restore and conserve wetlands would likely help maintain body condition of wintering dabbling ducks in the Central Valley of California. Published 2016. This article is a U.S. Government work and is in the public domain in the USA.

KEY WORDS American wigeon, *Anas* spp, body condition, California, ducks, green-winged teal, mallard, northern pintail, northern shoveler, wintering waterfowl.

For waterfowl, the dynamics of physical condition (e.g., primarily carcass fat and protein) during winter are related to food supply (Ryan 1972, Owen and Cook 1977, Peterson and Ellarson 1979, Miller 1986, Heitmeyer 2006), which can be a function of habitat management (Chabreck 1979) or flooding induced by precipitation (Chabreck 1979, Fredrickson 1980, Heitmeyer and Fredrickson 1981, Heitmeyer 2006). Body condition of wintering waterfowl can also vary by month, region, age, and sex (Miller 1986, Hine et al. 1996, Haukos et al. 2001, Moon et al. 2007). Understanding how these factors influence waterfowl body condition is necessary before the effectiveness of habitat programs on waterfowl condition can be fully determined.

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Changes in body condition of waterfowl during winter might greatly affect waterfowl populations. Winter survival (Conroy et al. 1989, Hohman et al. 1995, Fleskes et al. 2002), timing of pairing (Hepp 1986), propensity to nest (Warren et al. 2014), and productivity (Arnold et al. 2010) have all been related to body condition of individual ducks. Body condition depends upon food quality, abundance and density of food, competition with other waterfowl, and daily energy costs (Ballard et al. 2004, 2006; Miller et al. 2009). Habitat programs that improve the body condition of wintering waterfowl might increase waterfowl populations by improving survival and recruitment (Raveling and Heitmeyer 1989). Ideally, winter habitat provides enough food to ensure that ducks leave wintering grounds in good condition to facilitate successful spring migration and reproduction.

In 1986, the newly formed North American Waterfowl Management Plan (NAWMP) identified the Central Valley of California (CVCA) as a waterfowl habitat area of major concern (U.S. Fish and Wildlife Service and Canadian Wildlife Service 1986). In 1988, the Central Valley Joint

Venture (CVJV) was formed as part of NAWMP, to restore and enhance habitats necessary to support abundance and distribution of waterfowl in the CVCA similar to the 1970s (CVJV Implementation Board 1990). One of the basic tenets of CVJV's conservation planning in 1988, based on evidence of late-winter declines in body mass of ducks in the Central Valley, especially during dry winters (Miller 1986, Miller et al. 1988), was that food energy available in wetland and agricultural habitats was inadequate to support wintering waterfowl populations. Central Valley Joint Venture conservation programs were then designed to increase the extent of habitat and the density of food available to waterfowl in wetland and agricultural habitats with one expected outcome: body condition of waterfowl wintering in the CVCA would improve.

Wintering waterfowl habitat increased throughout the CVCA since the CVJV started work in the late 1980s, but the amount of change in area of wetlands and agricultural habitats has differed among the northern (Sacramento Valley), central (Suisun Marsh-Sacramento and San Joaquin River Delta [Suisun-Delta]), and southern (San Joaquin Valley) regions of the CVCA. Central Valley Joint Venture and other conservation programs increased area of managed wetlands 62% in the Sacramento Valley, 10% in the Suisun-Delta region, and 27% in the San Joaquin Valley between 1988 and 2000 (Fleskes et al. 2005*b*). Increased planting of rice and mandated phase-out of rice straw burning (Hill et al. 1999) have increased area of rice fields flooded after harvest in the Sacramento Valley (e.g., 47% from 1989 to 1999; Fleskes et al. 2005*a*). Conservation programs and changing agricultural practices also increased post-harvest flooding of fields (mostly corn and wheat) in the Suisun-Delta region (Fleskes et al. 2005*b*). However, higher priced and more restricted water supplies (Department of Water Resources 2005) reduced post-harvest field flooding in the San Joaquin Valley (Fleskes et al. 2013). As a result, area of winter-flooded agriculture increased 58% in the Sacramento Valley and 35% in the Suisun-Delta but declined 34% in the San Joaquin Valley between 1988 and 2000 (Fleskes et al. 2005*b*). Overall, area of flooded waterfowl habitat (i.e., managed wetland and flooded agriculture combined) in the CVCA increased 39% between 1988 and 2000, but the increase was greater in the Sacramento Valley (58%) than in the Suisun-Delta region (19%) and San Joaquin Valley (14%; Fleskes et al. 2005*b*).

Abundance and species composition of waterfowl wintering in the CVCA has also changed since the 1980s, resulting in increased wintering waterfowl biomass and food energy needs. For instance, mean total biomass of waterfowl at the time of the January midwinter survey (calculated by multiplying abundance of each species [U.S. Fish and Wildlife Service, unpublished data] by the approximate mean body mass of each species [Bellrose 1980, assuming equal age and sex ratios]) during 2007–2008 averaged 13%, 35%, and 96% greater than during 1980–1982, 1983–1984, and 1986–1993, respectively. Distribution of wintering waterfowl within the Central Valley tracked the northern shift in habitat, increasing the proportion of the total Central Valley waterfowl use occurring in the Sacramento Valley (Fleskes et al. 2005*b*).

The NAWMP has directed its Joint Ventures to develop biological measures of success (NAWMP 2004). A cooperative research project used aerial surveys and radio-telemetry to compare abundance, distribution, movement patterns, habitat use, and survival of waterfowl from before or during the first few years of the CVJV versus 1998–2000 (Fleskes et al. 2005*a*,*b*). However, response of waterfowl body condition to habitat changes was not evaluated. To fulfill the NAWMP directive and help guide conservation programs, we studied body condition of 5 dabbling duck species in the CVCA during 2 time periods (2006–2008 [late period] and 1979–1993 [early period]) separated by more than a decade, over which time significant habitat changes occurred, to determine if duck body condition has improved along with habitat improvements.

STUDY AREA

The CVCA includes 52,000 km^2 and spans 640 km from Red Bluff in the north to the Tehachapi Mountains in the south, and is 48–112 km wide between the foothills of the Sierra Nevada and Pacific Coastal Ranges, California, USA (Gilmer et al. 1982). The CVCA is composed of 3 regions: the Sacramento Valley in the north, the San Joaquin Valley in the south, and the Suisun Marsh-Sacramento and San Joaquin River Delta (Suisun-Delta) region (Fig. 1). Central Valley of California wetlands, once estimated at 1.6–2 million hectares, were reduced by over 90% by the early 1900s (U.S. Fish and Wildlife Service 1978). However, conservation programs and changing agricultural practices increased area of waterfowl habitat in the CVCA during our study, although the magnitude of change and types of habitat varied among regions. In the Sacramento Valley, managed wetlands on private lands, National Wildlife Refuges (NWRs; e.g., Sacramento and Delevan NWRs), and State Wildlife Areas (WAs; e.g., Gray Lodge WA) increased from about 162 km^2 in 1987 to 256 km^2 in 2000 and agricultural fields (mostly rice) flooded after harvest increased from 537 km^2 to 847 km^2 during the same interval (Fleskes et al. 2005*a*,*b*). In the Suisun-Delta region, Suisun Marsh provided about 70 km^2 of unmanaged brackish wetlands and 153 km^2 of managed brackish wetlands on private and public (e.g., Grizzly Island WA) areas throughout our study (Heitmeyer et al. 1989, Fleskes et al. 2005*b*). However, in the Sacramento and San Joaquin River Delta, managed wetlands increased from 13 km^2 to 26 km^2 and grain and other fields flooded after harvest increased from 95 km^2 to 128 km^2; 17 km^2 of riverine wetlands also were available as habitat (Heitmeyer et al. 1989, Fleskes et al. 2005*b*). In the San Joaquin Valley, seasonally flooded managed wetlands (about 80% in the Grassland Ecological Area and 10% each in Mendota WA and the Tulare Lake Basin; Fleskes 1999) increased from 257 km^2 in 1987 to 315 km^2 in 2000; however, area of post-harvest flooded fields, mostly in the Tulare Lake Basin, declined from 47 km^2 to 31 km^2 during the same interval.

Climate in CVCA is Mediterranean, with dry, warm summers and wet, mild winters. September–January rainfall

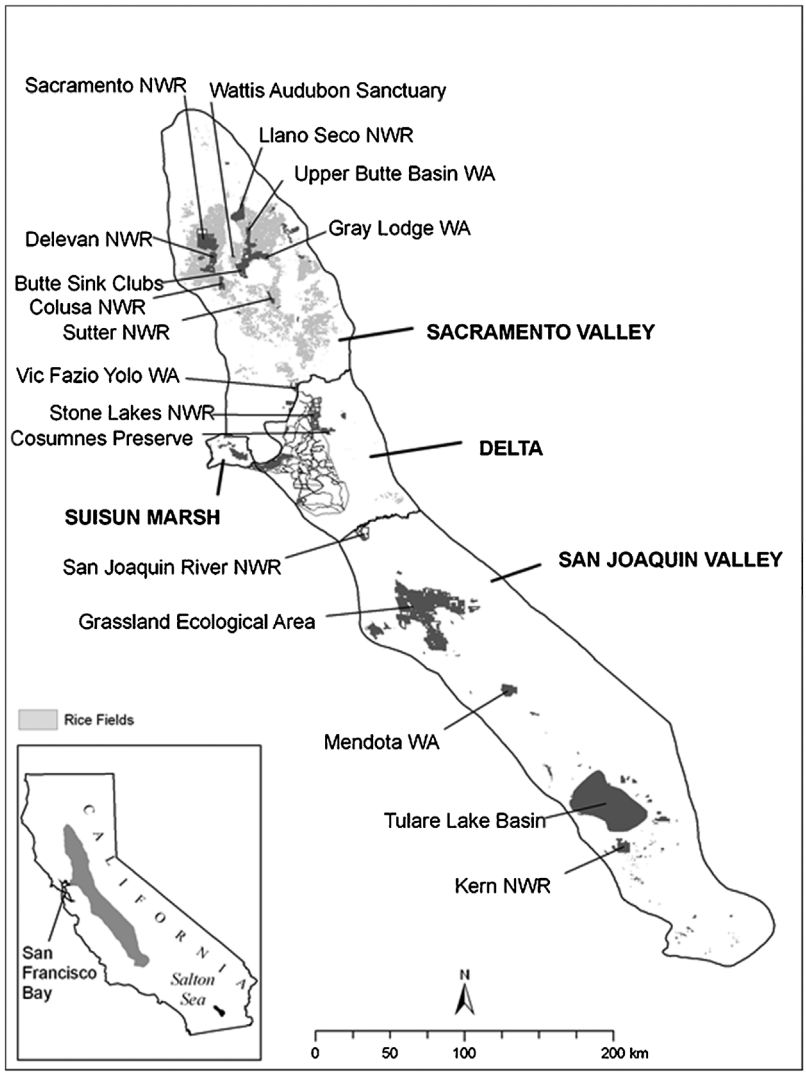

Figure 1. Central Valley of California, USA showing regions, rice field extent, and other major waterfowl habitat areas. Dabbling duck body mass data were collected at Public Hunting Area check stations on Sacramento National Wildlife Refuge (NWR), Delevan NWR, and Gray Lodge State Wildlife Area (WA) in the Sacramento Valley region, Grizzly Island WA in Suisun Marsh in the Suisun-Delta region, and Mendota WA in the San Joaquin Valley region.

at Sacramento, California averaged 23.83 cm during 1941–2008 but varied during our study (Western Regional Climate Center 2013). Sacramento September–January rainfall was only 46% of average in 2006–2007 but 128% of average during 2007–2008. Two earlier studies of body condition of wintering ducks in CVCA also included both dry and wet years. September–January rainfall during a 3-year 1979–1982 northern pintail (*Anas acuta*) study (M. R. Miller, U.S. Geological Survey, unpublished data) was 70–189% of normal and during an 8-year 1985–1993 mallard (*Anas platyrhynchos*) study (California Waterfowl Association, unpublished data) was 42–162% of average. However, both years of a 1982–1984 dabbling duck study (Miller et al. 1988) were wet (Sep–Jan rainfall 195% and 122% of normal).

METHODS

Field Methods

We weighed (±1 g) ducks shot by hunters at NWR and WA hunter check stations throughout the Central Valley of California (Fig. 1) during 2006–2008 (i.e., late period) to compare with body mass data collected from ducks shot by hunters during 3 prior studies (Miller et al. 1988; California Waterfowl Association, unpublished data; and M. R. Miller, unpublished data) conducted during 1979–1993 (i.e., early period). We replicated sample collections across species, dates, and hunter check stations previously sampled during the earlier studies to facilitate 3 comparisons (A–C). For comparison A of ducks at Mendota WA in the San Joaquin Valley and Sacramento NWR in the Sacramento Valley, we weighed 2,085 northern pintails, 2,036 mallards, 1,604 American wigeon (*Anas americana*), 2,186 green-winged teal (*Anas crecca*), and 2,072 northern shovelers (*Anas clypeata*) during 2006–2008 to compare with 1,259 northern pintails, 668 mallards, 176 American wigeon, 1,151 green-winged teal, and 698 northern shovelers weighed during 1982–1984 (Miller et al. 1988). For comparison B of mallards throughout the Central Valley, we weighed 2,388 mallards during 2006–2008 to compare with 10,988 mallards weighed at Gray Lodge WA in the Sacramento Valley during

1986–1993, Mendota WA in the San Joaquin Valley during 1988–1993, or Grizzly Island WA in the Suisun-Delta region during 1985–1993 (but only opening weekend in 1985; California Waterfowl Association, unpublished data). For comparison C of northern pintails at Sacramento and Delevan NWRs in the Sacramento Valley, we weighed 1,196 pintails during 2006–2008 to compare with 864 pintails weighed during 1979–1982 (M. R. Miller, unpublished data). After we weighed each duck, we removed a wing from most and placed the wing in a labeled clear plastic bag. We refrigerated the wings and within a few days identified sex and age class (hatch-year [immature] or after-hatch-year [adult]; Larson and Taber 1980, Duncan 1985, Carney 1992) for each bird. For the few ducks where the hunter did not want the wing removed, we aged and sexed the duck in the field. Procedures were part of a study plan approved by U.S. Geological Survey. An Animal Care and Use Committee reviewed and approved our methods to ensure that they were in compliance with the Animal Welfare Act and United States Government Principals for the Utilization and Care of Vertebrate Animals Used in Testing, Research, and Training policies.

Data Analysis

We used body mass as a condition index because body mass is highly correlated with body lipids (Miller 1989, Thomas 2009) and it was universally available from birds collected from both periods, unlike other structural measurements that might improve the correlation (e.g., flat wing cord) but were available for only certain datasets included in this study. We grouped samples into 4 sample months (Oct–early Nov [20 Oct–5 Nov], mid Nov [9–20 Nov], mid Dec [7–18 Dec], and mid–late Jan [14–27 Jan]) for the 2006–2008 versus 1982–1984 (Miller et al. 1988) comparison of 5 duck species from Sacramento NWR and Mendota WA (i.e., comparison A) and the 2006–2008 versus 1979–1982 (M. R. Miller, unpublished data) comparison of Sacramento Valley pintails (i.e., comparison C). We grouped samples into 3 sample months (Oct–early Nov [20 Oct–1 Nov], Nov–Dec [22 Nov–13 Dec], and early–mid Jan [4–12 Jan]) for the 2006–2008 versus 1985–1993 (California Waterfowl Association, unpublished data) comparison of mallards from Grizzly Island, Gray Lodge, and Mendota WAs (i.e., comparison B).

For each comparison (and by species for comparison A), we analyzed mixed effects analysis of variance (ANOVA) models of body mass (natural log-transformed for normality) explained by combinations of the fixed effects of period (early, late), September–January rain (above average = wet, below average = dry), age–sex cohort (adult F, adult M, immature F, immature M), sample region (comparison A: Sacramento Valley and San Joaquin Valley; comparison B: Sacramento Valley, Suisun-Delta, and San Joaquin Valley; comparison C: not applicable), and sample month (comparisons A and C: Oct–early Nov, mid Nov, mid Dec, and mid–late Jan; comparison B: Oct–early Nov, Nov–Dec, early–mid Jan), and the random effect of year nested within period. Both 1982–1983 and 1983–1984 were wet, so the rain × period interaction effect could not be analyzed in comparison A.

We performed model selection by first using the restricted maximum likelihood (REML) method to fit and compare saturated models, which included all fixed effects and their interactions, containing different variance structures based on combinations of the random year effect and its interactions with other effects (Littell et al. 1996, Zuur et al. 2009). We included a model without any year effects (the null variance structure). We used Akaike's Information Criterion corrected for small sample sizes (AIC_c) to select the model with the best variance structure (Burnham and Anderson 2002).

Using the selected variance structure, we completed our model selection by using AIC_c to compare models, fitted by the maximum likelihood method, containing different combinations of fixed effects. Because our primary objective was to evaluate the importance of period, we implemented a tiered modeling strategy (Fleskes et al. 2007, 2010) that began by finding the best model explaining body mass variation based on all covariates except period to account for factors that varied between periods and that are already demonstrated to influence body mass (Miller 1986, Hine et al. 1996, Haukos et al. 2001, Moon et al. 2007). We fit and compared models with all combinations and interactions (2-way and any higher order) of rain, age–sex cohort, sampling region, and sampling month effects. The top models ($\Delta AIC_c \leq 2$) from this initial tier represent the best models to use for body mass when there are no differences between periods, which make them appropriate null models for our objective. Next, we included period and refit the resulting models to determine whether there was an overall period effect. For any models supporting a period effect ($\Delta AIC_c \leq 2$), we compared further variations of these models for evidence of complex patterns in the period effect by including 2-way interactions with period. When there was support for any model with 2-way interaction effects involving period, we compared further models with 3-way interaction effects containing those 2-way interactions, and so on, until there was no support for further interactions. We also eliminated models from consideration when their solutions lacked a positive-definite Hessian matrix, which can result from various issues such as the model being too complex for the data (Kiernan et al. 2012).

We refit the final best model (lowest AIC_c) using the REML method to compute the effect of period, if any, as the percent change in body mass from the early to late period. We did not model-average our estimates because the most competitive models contained many of the same predictors and would have resulted in similar predictions. Competitive models ($\Delta AIC_c < 2$) usually differed by 1 or 2 extra terms that could be uninformative parameters (Arnold 2010). Model averaging would have accounted for but not eliminated model selection uncertainty, and the sequential process we used to develop our list of candidate models could have biased model averages in unclear ways (Burnham and Anderson 2002). Model averaging would have either involved larger models containing period effects and interactions (i.e., less parsimonious models with higher estimation variances) or assumed zero effect in models where

these effects were absent; both approaches requiring cautious interpretations. Our single best models are simple to interpret and we believe unlikely to vary substantially from a model-averaging approach. We estimated percent change by taking the antilog of the period coefficient and subtracting 100%, and similarly for the 95% confidence limits. We estimated the standard error of the percent change using the delta method (Williams et al. 2002). When other factors were found to interact with the period effect, we also computed the effect of period separately for the different levels of those factors. We conducted all statistical analyses using SAS software (SAS Institute 2011).

RESULTS

Model selection results for the 3 comparisons indicated that body mass of harvested dabbling ducks differed among periods; results also indicated that the change in dabbling duck body mass among periods varied among regions, months, species, and age–sex cohorts (Tables 1–3). Duck body mass was consistently greater in 2006–2008 than earlier years with the increase generally less in the San Joaquin Valley than other regions, less during October–November than December–January, and less for northern shovelers and green-winged teal than for mallards, northern pintails, and America wigeon. When period effects differed among age–sex cohorts, body mass increase across periods was greater for immature than adult ducks.

Comparison A: Dabbling Ducks in Sacramento and San Joaquin Valleys

Model selection of factors related to body mass of 5 dabbling duck species (northern pintail, mallard, American wigeon, green-winged teal, northern shoveler) in Sacramento and San Joaquin Valleys during 2006–2008 and 1982–1984 indicated that body mass differed among the late and early year periods with the magnitude of the period effect varying among species and month (Table 1; Figs. 2–6). Some evidence indicated that the period effect also varied by region for all species except green-winged teal and by age–sex cohort for mallard, American wigeon, and possibly green-winged teal (Table 1). Random effects did not improve models for pintails, mallards, or wigeon, but random year effects and the random interaction of month × year did improve the teal and northern shoveler models. Two

Table 1. Comparison A mixed effects model selection results for ln-transformed body mass of northern pintails, mallards, American wigeon, green-winged teal, and northern shovelers wintering in the Central Valley of California, USA based on various combinations of fixed factors for period (late [2006–2008], early [1982–1984]), region (Sacramento Valley, San Joaquin Valley), sample month (Oct–early Nov [20 Oct–5 Nov], mid Nov [9–20 Nov], mid Dec [7–18 Dec], and mid–late Jan [14–27 Jan]), age and sex cohort (cohort: adult M, adult F, immature M, immature F), and rain (Sep–Jan rain above or below average). Interactions (×) indicate lower interactions and main effects are also included. We compared random main and interaction effects for year nested within period for all species, but they were supported only in models for green-winged teal (year, year × region, year × month, and year × region × month) and northern shoveler (year and year × month), except where indicated for some models when 1 or 2 random effects parameter were 0 and excluded for being non-informative. Fit statistics include number of parameters (K), −2 log likelihood (−2LogLik), Akaike's Information Criterion corrected for small sample size (AIC_c), difference in AIC_c relative to the lowest AIC_c (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown except the best model lacking period effects is shown for comparison.

Model						
Period effects	**Base model**	K	−2LogLik	AIC_c	ΔAIC_c	w_i
Northern pintail						
Period × region × month	Cohort × month + month × rain + region × rain	34	−5,380.0	−5,311.3	0.00	1.00
None	Cohort × month + month × rain + region × month	25	−5,167.5	−5,117.1	194.10	0.00
Mallard						
Period × region × month + period × cohort	Region × month × rain + cohort × month	40	−4,940.1	−4,858.9	0.00	0.64
Period × region × month + period × cohort × month	Region × month × rain	49	−4,957.4	−4,857.5	1.33	0.33
None	Region × month × rain + cohort × month	29	−4,654.1	−4,595.5	263.40	0.00
American wigeon						
Period × region + period × month + period × cohort	Cohort × month + month × rain + region × month + region × rain	34	−2,728.3	−2,659.1	0.00	0.30
Period × region + period × month + period × cohort	Cohort × month + month × rain + region × month	33	−2,724.9	−2,657.7	1.36	0.15
None	Cohort × month + month × rain + region × month	25	−2,542.7	−2,492.0	167.10	0.00
Green-winged teal						
Period × month	Cohort × region	18[a]	−6,394.7	−6,358.5	0.00	0.21
Period × month	Cohort × region + cohort × month	27[a]	−6,412.9	−6,358.4	0.05	0.21
Period × month + period × cohort	Cohort × region + cohort × month	30[a]	−6,417.7	−6,357.2	1.32	0.11
None	Cohort × region + cohort × month	25	−6,398.7	−6,348.3	10.19	0.00
Northern shoveler						
Period × region × month	Cohort × month + region × month × rain	39	−4,928.4	−4,849.3	0.00	0.99
None	Cohort × month + region × month × rain	30[a]	−4,897.3	−4,836.6	12.70	0.00

[a] One or 2 random effects parameters were zero and, therefore, non-informative and excluded.

Table 2. Comparison B mixed effects model selection results for ln-transformed body mass of mallards wintering in the Central Valley of California, USA based on various combinations of fixed factors for period (late [2006–2008], early [1985–1993]), region (Sacramento Valley, Suisun-Delta, San Joaquin Valley), sample month (Oct–early Nov [20 Oct–1 Nov], Nov–Dec [22 Nov–13 Dec], early–mid Jan [4–12 Jan]), age and sex cohort (cohort: adult M, adult F, immature M, immature F), and rain (Sep–Jan rain above or below average). Two-way interactions (×) indicate main effects are also included. All models include random effects for year nested within period, and random interaction effects year × region, year × month, and year × region × month, except where indicated for some models with a random effects parameter of zero that was excluded for being non-informative. Fit statistics include number of parameters (K), −2 log likelihood (–2LogLik), Akaike's Information Criterion corrected for small sample size (AIC_c), difference in AIC_c relative to the lowest AIC_c (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown except the best model lacking period effects is shown for comparison.

Model						
Period effects	Base model	K	−2LogLik	AIC_c	ΔAIC_c	w_i
Period × region + period × month	Cohort × region + cohort × month	29[a]	−2,4423.9	−2,4365.7	0.00	0.52
Period × region + period × month	Cohort × region × month	45[a]	−2,4454.1	−2,4363.8	1.93	0.20
None	Cohort × region + cohort × month	25	−2,4399.1	−2,4349.0	16.76	0.00

[a] One random effects parameter was zero and, therefore, non-informative and excluded.

additional random interaction effects (region × year, and region × month × year) also improved and were included in green-winged teal models.

Northern pintail.—Pintail body mass (±SE) was 4.3 ± 0.7% (CI = 3.0–5.6%) greater in 2006–2008 than in 1982–1984, averaged across all other factors (Fig. 2). The change in body mass across periods varied by region, with a 9.2 ± 0.9% (CI = 7.5–10.9%) increase in the Sacramento Valley but little change (−0.3 ± 1.0%, CI = −2.1–1.6%) in the San Joaquin Valley. Overall, the period effect was greatest in late winter (−2.2 ± 0.8% in Oct–early Nov, 2.0 ± 1.7% in mid Nov, 9.3 ± 1.0% in mid Dec, 8.6 ± 1.5% in mid–late Jan). However, there was an interaction between region and month, with pintail body mass greater in the late period in all 4 sampling months in the Sacramento Valley (2.5 ± 0.9% in Oct–early Nov, 10.4 ± 2.3% in mid Nov, 11.0 ± 1.3% in mid Dec, 13.0 ± 2.2% in mid–late Jan) but only in late winter in the San Joaquin Valley (−6.6 ± 1.1% in Oct–early Nov, −5.8% ± 2.2% in mid Nov, 7.7% ± 1.4% in mid Dec, 4.3% ± 1.9% in mid–late Jan).

Mallard.—Mallard body mass was 6.1 ± 0.6% (95% CI = 4.9–7.4%) greater in 2006–2008 than in 1982–1984, averaged across all other factors (Fig. 3). Mallard body mass increased more in the Sacramento Valley (9.9 ± 0.9%, CI = 8.2–11.7%) than in the San Joaquin Valley (2.5 ± 0.8%, CI = 0.8–4.1%). A 3-way interaction between region, month, and period effects showed that the greatest increase among periods occurred later during winter in the San Joaquin Valley (−2.5 ± 1.2% in Oct–early Nov, −2.6 ± 1.7% in mid Nov, 7.2 ± 1.3% in mid Dec, 8.2 ± 2.0% in mid–late Jan) than in the Sacramento Valley (8.4 ± 1.3% in Oct–early Nov, 12.9 ± 1.9% in mid Nov, 12.5 ± 1.6% in mid Dec, 6.0 ± 1.8% in mid–late Jan). The greatest increases were observed for immature males (9.0 ± 0.9%, CI = 7.3–10.7%), followed by immature females (6.5 ± 0.9%, CI = 4.8–8.2%), adult males (6.3 ± 1.2%, CI = 3.9–8.7%), and adult females (2.9 ± 1.5%, CI = −0.1–5.9%).

American wigeon.—American wigeon body mass was 7.4 ± 1.4% greater (CI = 4.6–10.2%) in 2006–2008 than in 1982–1984, averaged across all other factors (Fig. 4). The increase in wigeon body mass across periods was greater in the Sacramento Valley (12.7 ± 1.1%, CI = 10.7–14.9%) than in the San Joaquin Valley (2.2 ± 2.5%, CI = −2.5–7.3%) and was generally greater in November–January than in October. The increase in body mass across years was greater for immature (10.9 ± 2.3% for F, 9.1 ± 1.9% for M) than adult (4.0 ± 2.4% for F, 5.6 ± 1.7% for M) wigeon.

Table 3. Comparison C mixed effects model selection results for ln-transformed body mass of northern pintails wintering in the Sacramento Valley of California based on various combinations of fixed factors for period (late [2006–2008], early [1979–1982]), sample month (Oct–early Nov [20 Oct–5 Nov], mid Nov [9–20 Nov], mid Dec [7–18 Dec], and mid–late Jan [14–27 Jan]), age and sex cohort (cohort: adult M, adult F, immature M, immature F), and rain (Sep–Jan rain above or below average). Two-way interactions (×) indicate main effects were also included. All models include random effects for year nested within period (year), and random interaction effects year × month, except where indicated for some models with a random effects parameter of zero that was excluded for being non-informative. Fit statistics include number of parameters (K), −2 log likelihood (–2LogLik), Akaike's Information Criterion corrected for small sample size (AIC_c), difference in AIC_c relative to the lowest AIC_c (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c \leq 2$ are shown except the best model lacking period effects is shown for comparison.

Model						
Period effects	Base model	K	−2LogLik	AIC_c	ΔAIC_c	w_i
Period	Cohort × month	19[a]	−2,779.4	−2,741.1	0.00	0.20
Period × month	Cohort × month	22	−2,785.1	−2,740.6	0.49	0.15
Period	Cohort + month	10[a]	−2,759.6	−2,739.5	1.59	0.09
Period × month + period × cohort	Cohort × month	25	−2,790.1	−2,739.5	1.61	0.09
Period × cohort	Cohort × month	22[a]	−2,783.7	−2,739.2	1.88	0.08
Period	Cohort × month + rain	20[a]	−2,779.6	−2,739.1	1.94	0.07
None	Cohort × month	19	−2,766.9	−2,728.5	12.56	0.00

[a] One random effects parameter was zero and, therefore, non-informative and excluded.

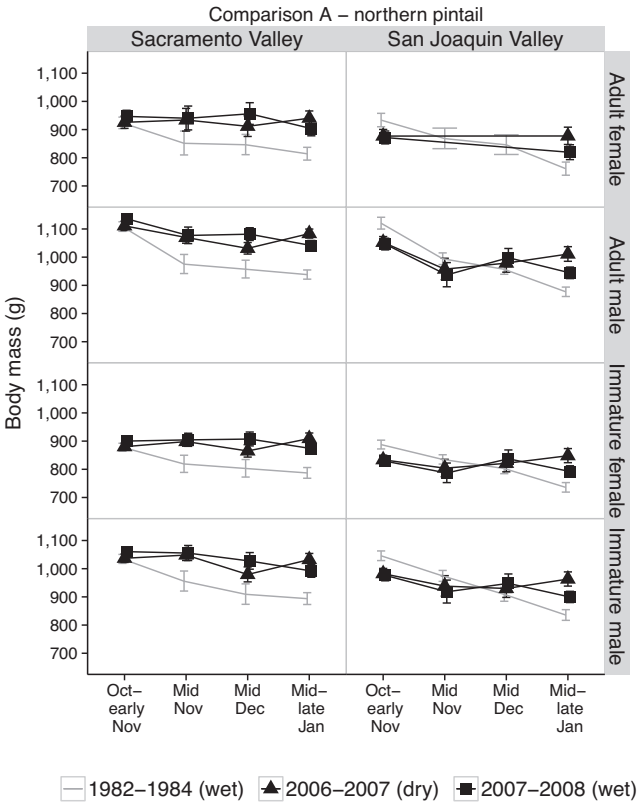

Figure 2. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male northern pintails in the Sacramento Valley (left column) and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1982–1984 (Miller et al. 1988).

Green-winged teal.—Green-winged teal body mass was $3.3 \pm 1.7\%$ greater (CI = −4.2–11.4%) in 2006–2008 than in 1982–1984, averaged across all other factors (Fig. 5). The period effect varied among months but not regions (Table 1). The increase in body mass across periods was greatest in the last sample month ($-2.3 \pm 2.6\%$ in Oct–early Nov, $5.4 \pm 2.8\%$ in mid Nov, $3.6 \pm 2.7\%$ in mid Dec, $6.7 \pm 2.8\%$ in mid–late Jan).

Northern shoveler.—Northern shoveler body mass was $0.8 \pm 2.3\%$ greater (CI = −24.5–34.6%) in 2006–2008 than in 1982–1984, averaged across all other factors (Fig. 6). However, the period effect varied among regions and months. In the Sacramento Valley, northern shoveler body mass in 2006–2008 was much lower than in 1982–1984 at the start of winter ($-8.2 \pm 3.8\%$ in Oct–early Nov) but thereafter averaged greater in 2006–2008 than in 1982–1984 ($5.2 \pm 4.2\%$ in mid Nov, $4.7 \pm 4.2\%$ in mid Dec, $3.3 \pm 4.2\%$ in mid–late Jan). In the San Joaquin Valley, shoveler body mass in 2006–2008 was slightly lower than in 1982–1984 at the start of winter ($-1.8 \pm 4.1\%$ in Oct–early Nov) and showed only slight improvement as winter progressed ($-1.4 \pm 4.1\%$ in mid Nov, $1.8\% \pm 4.1\%$ in mid Dec, $3.2 \pm 4.1\%$ in mid–late Jan). The small sample of shovelers resulted in wide confidence intervals, so there is less certainty in results for shovelers than for the other species.

Comparison B: Mallards in Sacramento Valley, Suisun Marsh, and San Joaquin Valley

Model selection of factors related to mallard body mass in Sacramento Valley, Suisun Marsh, and San Joaquin Valley during 2006–2008 and 1985–1993 provided support for an overall period effect (Table 2), with mallard body mass $3.2 \pm 1.4\%$ (CI = 0.0–6.5%) greater on average in 2006–2008 than in 1985–1993 (Fig. 7). Models in which mallard body mass varied among years nested within periods and where these random year effects interacted with region and month effects were also supported. The period effect varied by region, with the largest increases in Suisun Marsh ($6.0 \pm 1.7\%$, CI = 2.5–9.7%) and the Sacramento Valley ($3.0 \pm 1.6\%$, CI = −0.4–6.4%); the increase in the San Joaquin Valley was negligible ($0.7 \pm 1.6\%$). The period effect also varied by month, with the period difference increasing from $0.2 \pm 1.8\%$ in October–early November, to $2.7 \pm 1.9\%$ in November–December, and $6.8 \pm 2.0\%$ in early–mid January.

Comparison C: Pintails in Sacramento Valley

Model selection indicated that body mass of northern pintails from the Sacramento Valley differed among the late (2006–2008) and early (1979–1982) periods (Table 3). Models in which pintail body mass varied among years nested

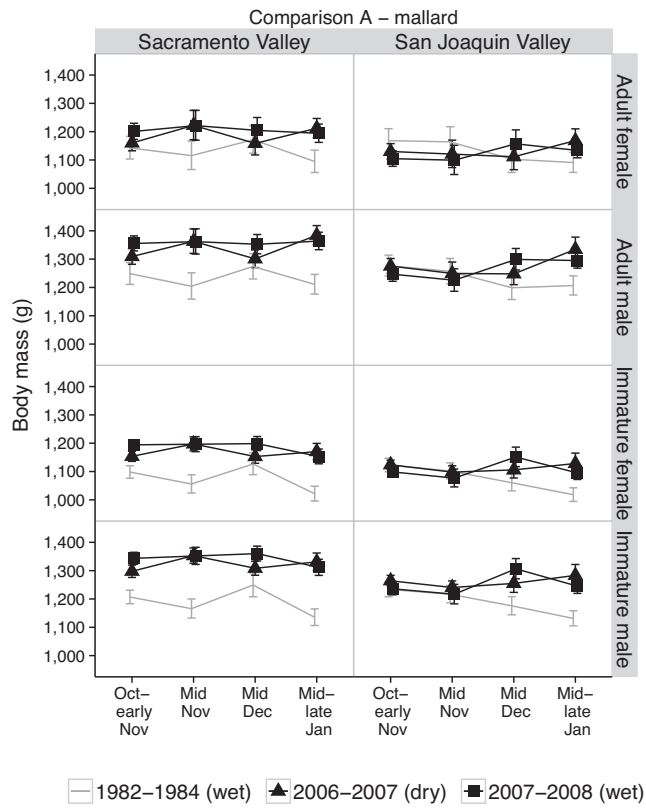

Figure 3. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male mallards in the Sacramento Valley (left column) and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1982–1984 (Miller et al. 1988).

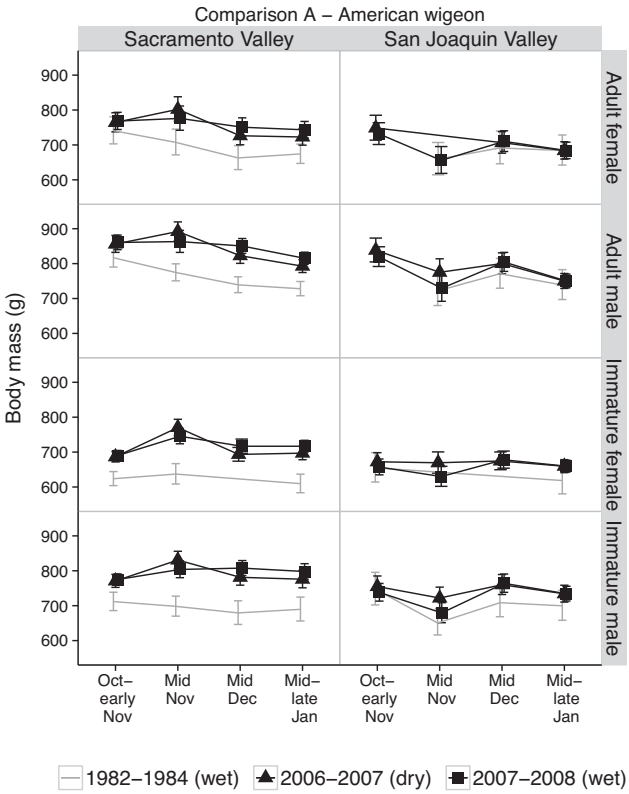

Figure 4. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male American wigeon in the Sacramento Valley (left column) and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1982–1984 (Miller et al. 1988).

within periods and where these random year effects interacted with month effects were also supported. Based on the best model, pintail body mass in the Sacramento Valley was $9.4 \pm 2.2\%$ (CI = 4.8–14.3%) greater on average in 2006–2008 than in 1979–1982 with the period difference consistent across months (Fig. 8). However, model selection did provide weak support, in the form of higher likelihoods (lower −2 log likelihoods) sufficient to result in similar AIC_c, for models that included the period effect interacting with month and age–sex cohort. Based on the best of these models, the increase in pintail body mass across periods increased as winter progressed (Oct–early Nov: $4.9 \pm 4.2\%$, CI = −3.9–14.5%; mid Nov: $8.9 \pm 4.3\%$, CI = −0.2–18.8%; mid Dec: $7.9 \pm 4.2\%$, CI = −1.1–17.7%; mid–late Jan: $16.6 \pm 4.7\%$, CI = 6.8–27.4%) and was $11.1 \pm 2.5\%$ (CI = 5.9–16.5%) for immature females, $10.8 \pm 2.6\%$ (CI = 5.5–16.2%) for immature males, $10.7 \pm 2.9\%$ (CI = 5.0–16.8%) for adult females, and $8.0 \pm 2.3\%$ (CI = 3.1–13.0%) for adult males.

DISCUSSION

During dry winters, natural flooding is minimal and habitat available to waterfowl in the Central Valley is mostly managed habitats (Gilmer et al. 1982, Fleskes 2012). Thus, the increase in duck body mass that we observed across study periods, even after accounting for rain and random year effects, is strong evidence of a habitat management impact and indicates that CVJV habitat conservation programs and increased post-harvest flooding of rice fields have made the Central Valley landscape more favorable for wintering dabbling ducks. The increased body condition we observed in comparison A provides additional evidence that duck body mass increases were due to changes in area and productivity of managed wetland and agricultural habitats rather than changes in natural flooding due to annual variation in precipitation. The increased body condition we observed occurred even though one late-period winter (2006–2007) was very dry, with January precipitation one of the lowest ever recorded in that month, whereas both early-period winters (1982–1983, 1983–1984) were wet (Western Regional Climate Center 2013).

The greater increase in body mass of ducks in Sacramento Valley and Suisun-Delta than in San Joaquin Valley indicate that food supplies are currently abundant in large part because availability of waste rice and other crop seeds have increased for dabbling ducks. Both wetland and flooded agricultural field area increased in the Sacramento Valley and Suisun-Delta region, whereas wetlands increased but flooded croplands decreased in the San Joaquin Valley (Fleskes et al. 2005*b*, 2013). In addition, the increase in body mass of ducks across periods was greater in the Sacramento Valley and

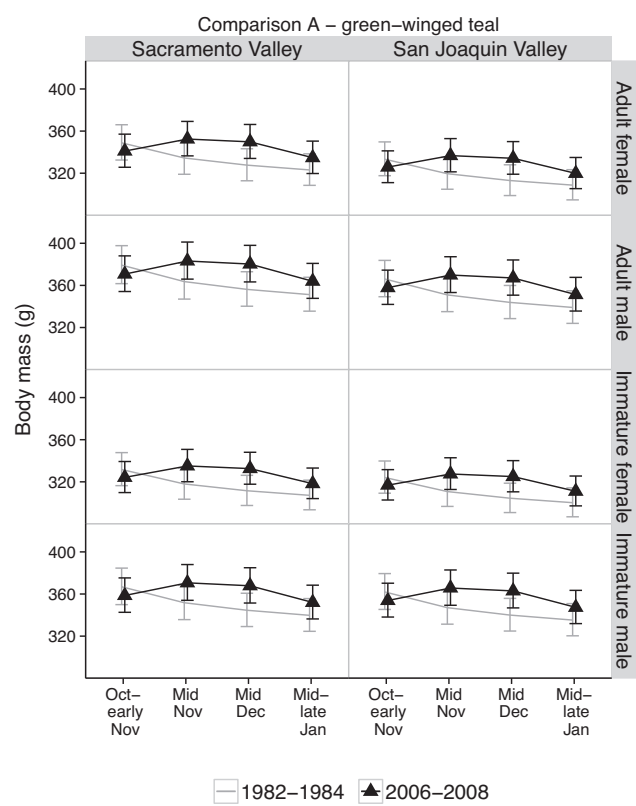

Figure 5. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male green-winged teal in the Sacramento Valley (left column) and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1982–1984 (Miller et al. 1988).

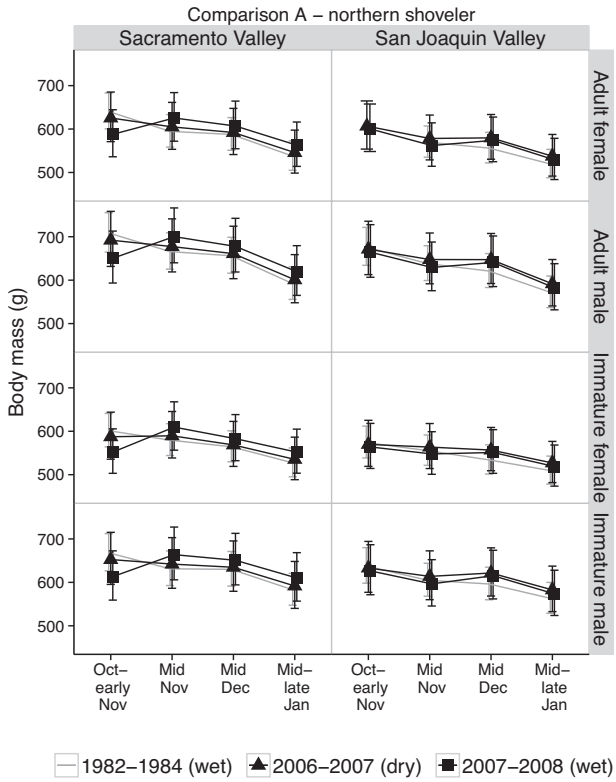

Figure 6. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male northern shovelers in the Sacramento Valley (left column) and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1982–1984 (Miller et al. 1988).

Suisun-Delta for species relying most heavily on rice and other crop seeds (i.e., northern pintails, mallards, American wigeon) than species primarily feeding on wetland moist soil foods (i.e., green-winged teal, northern shovelers; Bellrose 1980, Miller 1987). However, there was some evidence that even northern shovelers, which filter feed on microorganisms and eat wetland seeds (Bellrose 1980), had greater November–January body mass during 2006–2008 than 1982–1984 in the Sacramento Valley (Fig. 6). This mid-to-late winter increase across periods in body mass by northern shovelers in the Sacramento Valley indicates that the large increase in post-harvest flooding of rice fields might have increased availability of seeds and biomass of aquatic invertebrates (Manley et al. 2004, Lawler and Dritz 2005) on which shovelers mainly forage.

The increase in body mass of ducks across periods generally increased as winter progressed. This result indicates that period differences were not due to waterfowl arriving on the wintering grounds heavier during 2006–2008 than in 1979–1993 but rather an impact of improved Central Valley habitat conditions that compounded as winter progressed. Body mass of ducks increased across periods even though total abundance (and total biomass) of waterfowl wintering in the Central Valley also increased (U.S. Fish and Wildlife Service, unpublished data). Thus, the 2006–2008 Central Valley landscape supported 13–96% more waterfowl and those waterfowl were better maintained and in some cases increased their body mass as winter progressed, ending winter in better condition than in 1979–1993.

The increase in body mass across periods was greater for immature than adult mallard, American wigeon, and green-winged teal. This suggests that at least for these species, immatures were less adept at or spent more energy acquiring food than adults, and when conditions were less favorable had more difficulty maintaining or improving their body condition during winter. Thus, immature ducks benefited the most from improved habitat conditions. There is evidence of older ducks arriving on breeding grounds in better condition than juveniles but the rate of body condition gain as it relates to age is poorly understood (Warren et al. 2013). Our result of an age-related body condition response to habitat conditions is, as best as we can determine, unique in the literature.

Habitat conservation programs of CVJV partners and changing agricultural practices have improved the Central Valley landscape for wintering dabbling ducks in several ways. Wetland enhancement programs improved water and vegetation management and increased density of seeds and other waterbird foods in existing wetlands (Batzer and Resh 1992, Naylor 2002, Olson 2011). Wetland restoration programs and increased post-harvest flooding of crop fields

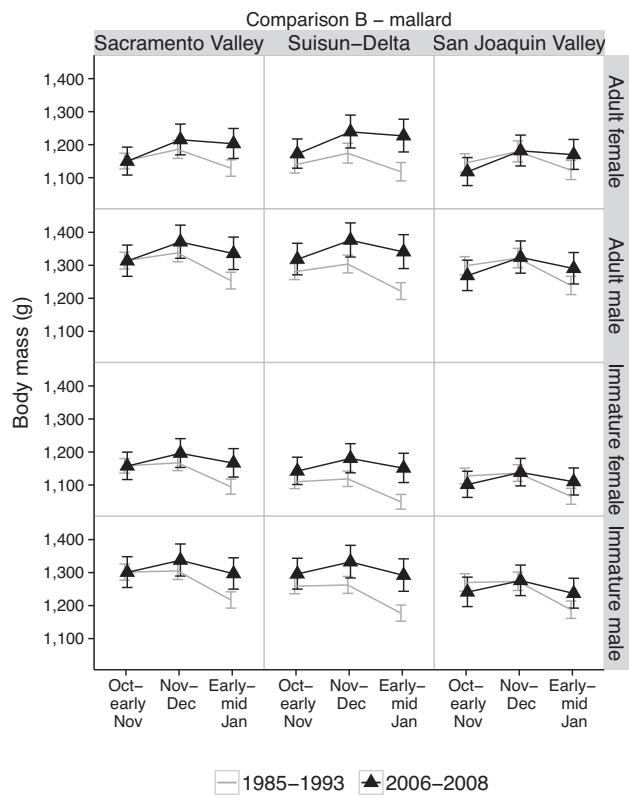

Figure 7. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male mallards in the Sacramento Valley (left column), Suisun-Delta (middle column), and San Joaquin Valley (right column), California, USA during Oct–early Nov (20 Oct–1 Nov), Nov–Dec (22 Nov–13 Dec), and early–mid Jan (4–12 Jan) in 2006–2008 versus 1985–1993 (M. R. McLandress, California Waterfowl Association, unpublished data).

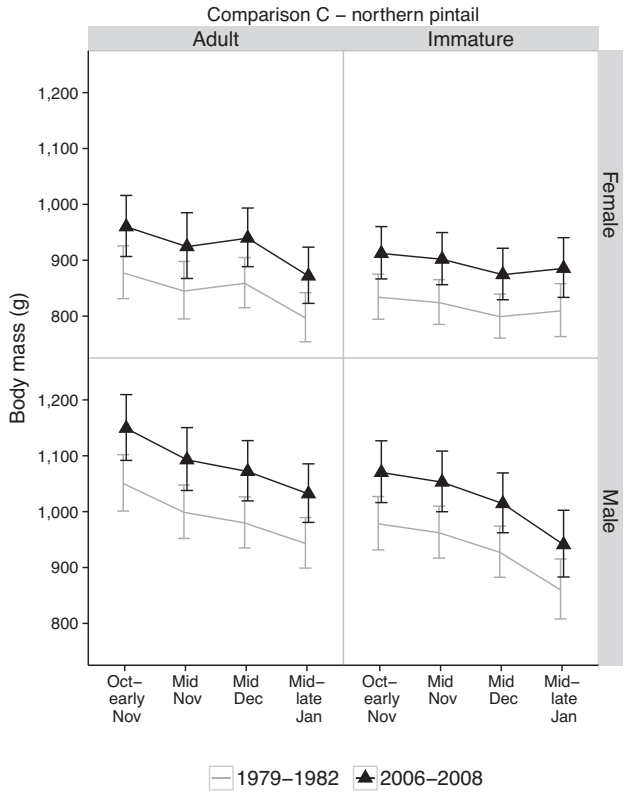

Figure 8. Body mass (mean, 95% CI) of adult female, adult male, immature female, and immature male northern pintails in the Sacramento Valley, California, USA during Oct–early Nov (20 Oct–5 Nov), mid Nov (9–20 Nov), mid Dec (7–18 Dec), and mid–late Jan (14–27 Jan) in 2006–2008 versus 1979–1982 (M. R. Miller, unpublished data).

increase not only overall food availability but also the density of foraging and roosting habitats on the landscape, which reduced distances (Fleskes et al. 2005*b*) and energy that ducks needed to fly between roosting and foraging habitats (Hamilton and Watt 1970, Baveco et al. 2011). Time required for dabbling ducks to meet energetic needs by acquiring waste seeds in flooded rice and other grain fields is low compared to other feeding options (Baldassarre and Bolen 2006). Thus, daily energetic costs are reduced and availability of foods to meet those demands is increased. The result was the increased body condition that we observed in this study as well as reduced natural mortality reported by Fleskes et al. (2007).

Hunter check stations provided opportunity to collect a large sample of body mass data from several ducks species in all 3 Central Valley regions. Although hunter-shot birds might be in poorer condition and might have different body condition dynamics than the general population (Greenwood et al. 1986, Heitmeyer et al. 1993), and samples were only available during hunting season, our results agree with Thomas (2009) who also reported increased body mass and condition of northern pintail, American wigeon, and (to a lesser degree) northern shovelers that he collected in the Sacramento Valley. Like others, we found that body condition of wintering waterfowl varied by month, age, sex, and rainfall (Miller 1986, Hine et al. 1996, Haukos et al. 2001, Moon et al. 2007). However, average body mass of most duck species we studied in the Central Valley was greater in the late than early period, and seasonal declines, and declines due to dry winters were reduced. Accounting for the effects of all these factors was necessary for understanding the impact of habitat programs and increased post-harvest flooding of crop fields on waterfowl condition.

We suggest that in addition to measuring body mass, future monitoring include other structural measurements (e.g., flat wing cord) that might improve the body condition correlation and enable detection of any changes in body size that could confound interpretation of body mass changes (Guillemain et al. 2010). To clearly distinguish impact on body condition of habitat conservation programs from impacts of climate change and other factors (Guillemain et al. 2010), we suggest that area of each important habitat type and climate variables be measured during the same time period and in the same locations that body condition data are collected. An experimental or adaptive management approach, where landscape variables are manipulated and body condition is tracked would be difficult to accomplish at a large enough scale, but would yield more definitive results than our observational study. Finally, although changes in body condition of waterfowl during winter are known or theorized to affect survival (Conroy et al. 1989, Hohman et al. 1995, Fleskes et al. 2002) and productivity of individual waterfowl (Hepp 1986, Arnold et al. 2010, Warren et al. 2014), additional research could be done to determine actual mechanisms and better define the relationship between magnitude of winter body condition change and population impact.

MANAGEMENT IMPLICATIONS

This study demonstrates that management programs that expand or improve wintering habitat can improve body condition of wintering waterfowl. During our study, dabbling duck body condition improved most in Central Valley regions where both wetlands and post-harvest flooding of crop fields increased. Seasonal wetlands provide about 50% more true metabolizable food energy per hectare to ducks than post-harvest flooded rice fields (CVJV 2006). However, bioenergetics modeling indicates that waterfowl food resources are abundant in CVCA largely because of the large area of post-harvest flooded rice fields, and current wetlands alone could not support desired waterfowl populations (CVJV 2006). Therefore, to ensure adequate waterfowl food resources and habitat into the future, we suggest that conservationists continue to promote agricultural practices that benefit wintering waterfowl (e.g., post-harvest flooding of rice and other grain fields) and continue to restore and conserve wetlands with secure water supplies in the event that changes to agricultural policy, cropping patterns, water supplies, harvester efficiency (Fleskes et al. 2012), or other factors that are largely out of their control significantly reduces waterfowl value of agricultural lands (Fleskes 2012).

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Cover image: Wintering northern pintails (and a few Ross' geese) roosting on a levee in a managed wetland at Sacramento National Wildlife Refuge in the northern Central Valley of California. Safe, undisturbed sites such as these allow pintails and other waterfowl to conserve energy, which is one reason why body condition of pintails and other waterfowl wintering in the Central Valley has improved. Photo by Robert McLandress.