Assessment of spatial changes in the duck harvest within the Central Flyway, 1997–2011

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Abstract

Knowledge of the factors which influence the spatial distribution of duck harvest would be useful to managers when setting dates for the duck hunting seasons. Here we used changes in mean latitude of harvest to represent changes in distribution of duck harvest during the hunting season within the Central Flyway from 1997–2011, derived from harvest data from the U.S. Fish and Wildlife Service Parts Collection Survey. A candidate set of models was developed to represent competing hypotheses of corn availability, weather, water on the landscape, competition via population density, hunting pressure, and regulatory change to explain the variation in harvest distribution of Mallard *Anas platyrhynchos*, dabbling ducks *Anas* sp., and diving ducks *Aythya* sp. The model selection process revealed that hunting pressure, the amount of water on the landscape, and Mallard density best explained the distribution of Mallard harvest. Mallard harvest distributions tended to be further north during wet years of high Mallard densities and low hunting pressure, relative to dry years with high Mallard densities and low hunting pressure. High hunting pressure shifted the spatial distribution of Mallard harvest further south. Regulations had the largest influence on both dabbling (non-Mallard) and diving duck harvest distribution. Dabbling duck harvest distribution was further north under the 2002–2011 frameworks, relative to the 1997–2001 frameworks. During the 2002–2011 frameworks, diving ducks were more likely to be harvested further south early in the season and further north later in the season, relative to 1997–2001 frameworks. Trends in the distribution of harvest should be informative for future harvest management decisions.

Key words harvest distribution, hunting pressure, Parts Collection Survey, regulations, waterfowl.

Waterfowl managers try to coincide hunting seasons with duck availability to maximise hunting opportunities (Bellrose 1980; Vrtiska 2012). However, annual variation makes it difficult for waterfowl managers to predict duck availability, both spatially and temporally. Although precise knowledge of duck migration chronology prior to setting season dates is improbable, managers still need to set reasonable hunting seasons. Setting hunting seasons too early or too late may result in hunter dissatisfaction, which in turn may influence hunter recruitment and retention rates (Stankey *et al.* 1973; Case 2004). Subsequently, funding for habitat conservation or management activities may be affected (Vrtiska *et al.* 2013). As such, setting appropriate hunting seasons could extend to waterfowl conservation.

Many factors may influence the annual variation in duck distribution, movement, and migration. For example, weather has been found to influence duck migration and movement (Richardson 1978; Nichols *et al.* 1983; Pearse 2007; Schummer *et al.* 2010). The distribution of water in the landscape (*i.e.* wetlands) in terms of availability and diversity may also affect duck distribution (Kaminski & Prince 1981; Kaminski & Prince 1984; Webb *et al.* 2010; Pearse *et al.* 2012). Studies also suggest changes in hunter regulation and activity can affect wildlife movement and habitat selection (Root *et al.* 1988; Conner *et al.* 2001; Cox & Afton 1997; Casazza *et al.* 2012). Finally, food availability and competition may affect duck behaviour (Jorde *et al.* 1983; Baldassarre & Bolen 1984), which in turn may affect duck distribution. All these factors which determine duck distribution, movement and migration may consequently influence the distribution of the duck harvest. However, few studies have attempted to offer explanations as to whether or why harvest distribution patterns change over time (Delta Waterfowl 2012).

Understanding changes in harvest distribution may allow managers to predict duck availability during hunting seasons more accurately. Thus, we used the U.S. Fish and Wildlife Service's (USFWS) Parts Collection Survey (PCS) database to examine what factors influence recent patterns of duck harvest distribution (Fig. 1). Our objective was to use a candidate set of competitive models to explain the variation in duck harvest distribution.

Methods

Parts Collection Survey data were obtained from the USFWS Branch of Harvest Surveys and only Central Flyway records from the 1997–2011 regular duck seasons were selected. Ducks were classified as one of three groups: Mallard *Anas platyrhynchos*, dabbling ducks *Anas* sp. (excluding Mallard), and diving ducks *Aythya* sp., to account for differences in management concern and life history strategies. The dabbling duck group included American Green-winged Teal *A. crecca*, Blue-winged Teal *A. discors*, Gadwall *A. strepera*, Northern Pintail *A. acuta*, American Wigeon *A. americana* and Northern Shoveler *A. clypeata*. The diving duck group included Redhead *Aythya americana*, Canvasback *A. valisineria*, Greater Scaup *A. marila* and Lesser Scaup *A. affinis*.

Principle hypotheses

Six principle hypotheses were tested to assess variation in harvest distribution for

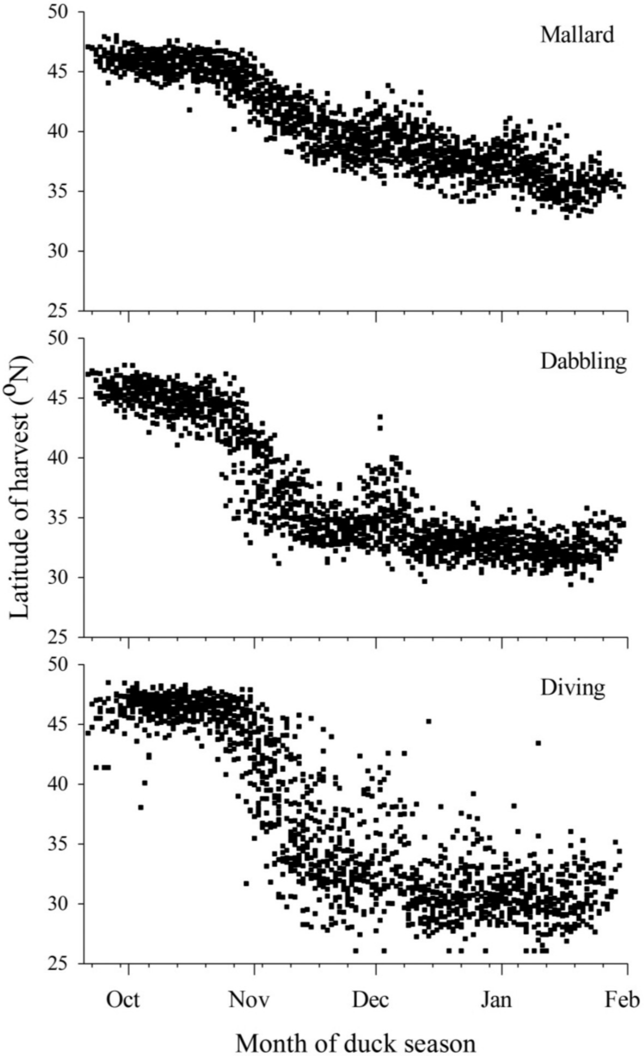

Figure 1. Variation in harvest distribution for Mallard, dabbling ducks *Anas* sp., and diving ducks *Aythya* sp. Figures represent mean annual (1997–2011) latitudes of duck harvest (weighted county centroids) on a given day during the autumn hunting season. Derived from U.S. Fish and Wildlife Service Parts Collection Survey data from the Central Flyway, 1997–2011.

Mallard, dabbling, and diving ducks (Fig. 1): corn availability, weather, relative wetness of the landscape at varying latitudes, competition via population density, hunting pressure and regulatory influences. These factors were assessed by calculating an average estimate across years for each factor. We then categorised each annual estimate either as above or below average, unless otherwise noted. Treating principle hypotheses as factors created a threshold effect around the average. However, thresholds should allow managers to anticipate changes in the distribution of harvest, depending on whether a variable is above or below a certain threshold on a given year. All factors were constant for a given year, so we used the variation inherent in the causal variables to precisely account for annual variation in distribution; we did not include "year" as a random effect.

Corn acres planted annually in North and South Dakota ($\text{CORN}_{\text{DAKOTAS}}$), as well as total corn acres planted annually in Nebraska (CORN_{NE}) from 1997–2011 were used to examine if corn availability influenced duck harvest distribution at different latitudes (U.S. Dept. of Agriculture 2013). Total corn acres planted were used because it is a food source readily used by most dabbling ducks (Moore 1980) and, if residual corn is sufficiently abundant, ducks may delay migration, which could influence harvest distribution. Estimates of total corn acres planted were categorised into high and low corn years (Fig. 2).

A daily cumulative weather severity index (hereafter WSI; Schummer *et al.* 2010) was used to examine weather's influence on the distribution of duck harvest. The WSI index includes factors of daily snowfall, consecutive days with snow depths ≥ 2.54 cm, temperature, and consecutive days with temperatures at or below 0°C (Schummer *et al.* 2010). Only weather data from North and South Dakota in October and November (WEATHER) were used in the analyses. Weather in these two months would better indicate when ducks migrate to southern latitudes as the breeding grounds are located in these states. Thus, a majority of ducks may be influenced by the same weather patterns. U.S. Historical Climatology Network data were used from eight weather stations (Menne *et al.* 2013), four each in North and South Dakota, to calculate a daily WSI. These were the Crosby, Grand Forks (Univ Nws), Jamestown (State Hosp), and New England weather stations in North Dakota and Alexandria, Clark, Cottonwood, and Dupree in South Dakota (Menne *et al.* 2013). To obtain an annual WSI across all stations, the average of the maximum daily WSI estimates was calculated for each station sampled. Annual estimates above average were classified as severe and below average estimates were classified as mild (Fig. 2). A model that incorporated both weather and corn factors was also created, because abundant corn on the landscape may delay migration even in the face of inclement weather.

High densities of ducks were expected to cause competition for limited resources, which may influence duck movements. To test for competition via population density (DENSITY) effects on harvest distribution, we first created an autumn population size index for a given species. Corrected age ratios of harvested birds were calculated in relation to the proportion of a species harvested in the Central and Mississippi Flyways, because breeding population estimates are for ducks from both the Mississippi and Central Flyways. Breeding population estimates were obtained from the U.S. Fish and Wildlife Service (USFWS 2013), and females were assumed to

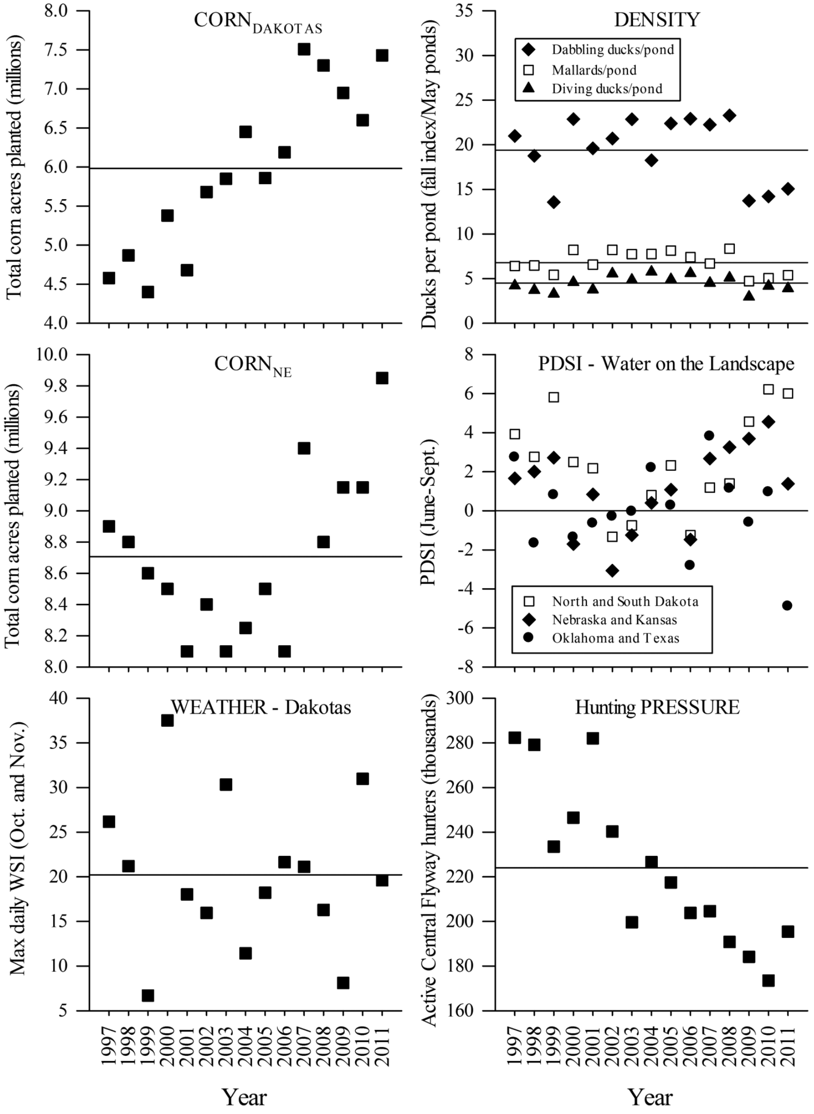

Figure 2. Annual estimates (1997–2011) for potential corn availability in North and South Dakota and Nebraska (U.S. Dept. of Agriculture 2013), weather severity indices (WSI) in North and South Dakota from October and November (U.S. Historical Climatology Network, Menne *et al.* 2013), density (autumn population index/U.S. May ponds), water on the landscape (mean Palmer Drought Severity Index; National Climate Data Center 1994), and hunting pressure (Central Flyway Harvest and Population Survey Data; Kruse *et al.* 2002; Kruse 2013). Annual estimates were treated as factors. Values above the line were categorised as high, whereas values below the line were categorised as low. Values for weather were categorised as severe or mild. Water on the landscape was categorised as wet or dry.

represent half the breeding population. The estimated female population size was then multiplied by the corrected age ratio to obtain an estimate of young produced. Finally, we added the estimated number of young to the breeding population, which resulted in our autumn population size index for a given species. Species estimates of production were summed within their respective duck groups (*e.g.* Redhead, Canvasback and Scaup estimates were summed to provide the total autumn diving duck population index). Population estimates were then divided by the abundance of ponds in the north-central U.S. (approximating to the U.S. prairie pothole region) during the annual waterfowl breeding population and habitat survey (U.S. "May ponds"; USFWS 2013), which resulted in our estimate of density (*i.e.* ducks per pond). DENSITY was categorised into high or low categories for each group of ducks (Fig. 2). A model that incorporated DENSITY and $\text{CORN}_{\text{DAKOTAS}}$ was constructed, because high competition for food with other ducks may cause some ducks to move to areas with less competition, and thereby influence the distribution of harvest.

The mean Palmer drought severity index (PDSI) from June–September for 1997–2011 was used to examine the effect of water on the landscape on the distribution of the duck harvest (National Climate Data Center 1994). An average PDSI was calculated for northern (North Dakota and South Dakota; $\text{PDSI}_{\text{NORTH}}$), mid (Nebraska and Kansas; PDSI_{MID}), and southern (Oklahoma and Texas; $\text{PDSI}_{\text{SOUTH}}$) latitudes for each year in the sampling frame. Interactions between the annual PDSI estimates at north, mid and south latitudes were used to examine where water on the landscape was most influential to harvest distribution. Annual PDSI estimates were categorised into wet or dry years, depending on whether they were > 0.0, or ≤ 0.0 for a given year, respectively (Fig. 2). Additional models were tested that included water on the landscape and either WEATHER, $\text{CORN}_{\text{DAKOTAS}}$, or DENSITY factors. Inclement weather may generally cause ducks to migrate, but ducks that encounter suitable water or food resources may delay migratory movements.

Estimates of the number of active hunters were used as an indicator of hunting pressure (PRESSURE). Active hunter estimates were summed annually for all Central Flyway states from both the Mail Questionnaire Survey (1997–1998; Kruse *et al.* 2002) and the Harvest Information Program (1999–2011; Kruse 2013). The distribution of active hunter estimates across states in the Central Flyway did not change during the sampling period (M. Haugen, unpubl. data). Thus, active hunters were assumed to have changed uniformly across the Central Flyway. Annual estimates were categorised into high or low hunting pressure years (Fig. 2). A model that incorporated hunting pressure and water on the landscape was also included, because hunting pressure may affect duck distribution differentially depending on water availability (Webb *et al.* 2010).

Finally, the sampling frame was divided into two periods, 1997–2001 and 2002–2011, to test the influence of hunting regulation on duck harvest distribution (FRAMEWORKS). From 2002–2011, hunting seasons were allowed to start earlier and end later compared to 1997–2001, but still retained the same season lengths and daily limits each year (Kruse *et al.* 2002; Kruse 2013). Thus, more ducks may be harvested or exposed to hunting pressure prior to or after the initiation of migration in 2002–2011. As such, more harvest may occur in the north and vulnerability may decrease in the south (Eadie *et al.* 2002; Szymanski & Afton 2005), which may influence harvest distribution.

Multi-model inference

Mean latitude of harvest was used to represent duck distribution across time during the autumn migration. We used SAS® software (SAS Institute 2009) to calculate mean latitudes of harvest for each group of ducks for each day (*i.e.* an ordinal day that starts on 21 September and ends on 31 January) during each hunting season from 1997–2011. Because the county is the smallest geographical unit in the PCS, mean latitudes of harvest were weighted averages of county centroids where ducks were reported to be harvested. Data that did not contain county information were removed, as it was not possible to determine reliably where the duck had been harvested.

Initial sets of generalised linear models were constructed and evaluated to determine whether the principle hypotheses were best represented as an additive or interactive model for each duck group. Mean latitude of harvest was used as the response variable, and a corrected Akaike Information Criterion (AIC_c) was used to select among the alternatives. Ordinal day (DAY) was included in all models, and AIC_c was used to determine if a quadratic or linear ordinal day best explained the variation in harvest distribution. From the initial model fitting, a candidate model set (Table 1) was developed for each group of ducks separately. A null model (*i.e.* the DAY-only model) was included in all candidate models sets, and AIC_c was again used to select among the alternative hypotheses. The distance between the AIC_c scores of our top model and the null model, relative to penalties inherent to an increase in model complexity, were used to assess the fit of our model (Maydeu-Olivares & García-Forero 2010). A Pearson's correlation test ($\alpha = 0.05$) tested for associations between explanatory variables, with a view to modifying or eliminating correlating variables prior to analysis.

Results

A quadratic description of harvest distribution by ordinal day provided a better fit than a linear model (linear model: Mallard $\Delta AIC_c = 149.1$; dabbling duck $\Delta AIC_c = 981.8$; and diving duck $\Delta AIC_c = 355.9$), so a quadratic function of day (*i.e.* DAY + DAY^2) was used in all models (Fig. 3).

Several variables were correlated, and so were omitted from the candidate models. For instance, as the landscapes in North and South Dakota ($PDSI_{NORTH}$) and Nebraska and Kansas ($PDSI_{MID}$) became wetter, DENSITY of Mallard and dabbling and diving ducks declined ($P < 0.05$). Thus, $PDSI_{NORTH}$ and $PDSI_{MID}$ were removed from the analyses; Mallard, dabbling, and diving duck DENSITY represents $PDSI_{NORTH}$ and $PDSI_{MID}$ in our models. Total corn acres planted in North and South

Table 1. Candidate models set (with number of parameters; k) used (x) for three groups of duck species to assess variation in harvest distribution in the Central Flyway, 1997–2011.

Candidate models	**Mallard**	**Dabbling duck**[a]	**Diving duck**[b]	**k**
DAY[c]	×	×	×	3
DAY + $\text{CORN}_{\text{DAKOTAS}}$[d]	×	×	×	5
DAY + WEATHER[e]	×	×	×	5
DAY + DENSITY[f]	×	×	×	5
DAY + PRESSURE[g]	×	×	×	5
DAY + FRAMEWORKS[h]	×	×		5
DAY × FRAMEWORKS			×	9
DAY + WEATHER + $\text{CORN}_{\text{DAKOTAS}}$	×	×	×	7
DAY + DENSITY + $\text{CORN}_{\text{DAKOTAS}}$	×	×	×	7
DAY + WEATHER + DENSITY		×		7
DAY + PRESSURE + DENSITY		×		7
DAY + DENSITY × $\text{PDSI}_{\text{SOUTH}}$[i]	×		×	11
DAY + $\text{CORN}_{\text{DAKOTAS}}$ + DENSITY × $\text{PDSI}_{\text{SOUTH}}$	×		×	13
DAY + WEATHER + DENSITY × $\text{PDSI}_{\text{SOUTH}}$	×		×	13
DAY + PRESSURE + DENSITY × $\text{PDSI}_{\text{SOUTH}}$	×		×	13

[a] Dabbling duck: American Green-winged Teal, Blue-winged Teal, Gadwall, Northern Pintail, American Wigeon and Northern Shoveler; [b] Diving duck: Canvasback, Redhead and Scaup; [c] Quadratic function for ordinal day from 21 Sept to 31 Jan in all models; [d] Factor of total corn acres planted in North and South Dakota; [e] Factor of a weather severity index for North and South Dakota in Oct and Nov; [f] Factor of an autumn population index/May ponds in the U.S.; [g] Factor of Central Flyway active hunter estimates; [h] Year factor, for 1997–2001 and 2002–2011, representing changes in the federal framework for allowable season dates; [i] Factor of Palmer Drought Severity Indices for Oklahoma and Texas (south).

Dakota ($\text{CORN}_{\text{DAKOTAS}}$) and Nebraska ($\text{CORN}_{\text{NE}}$) were positively correlated ($P < 0.05$), so CORN_{NE} was removed from the analyses because $\text{CORN}_{\text{DAKOTAS}}$ may have a stronger influence on the distribution of duck harvest as it is on the breeding grounds (*i.e.* corn in North and South Dakota may affect more ducks and ducks prior to migration). PRESSURE and $\text{CORN}_{\text{DAKOTAS}}$ were negatively correlated, but we retained both parameters in the candidate model sets as corn and hunting

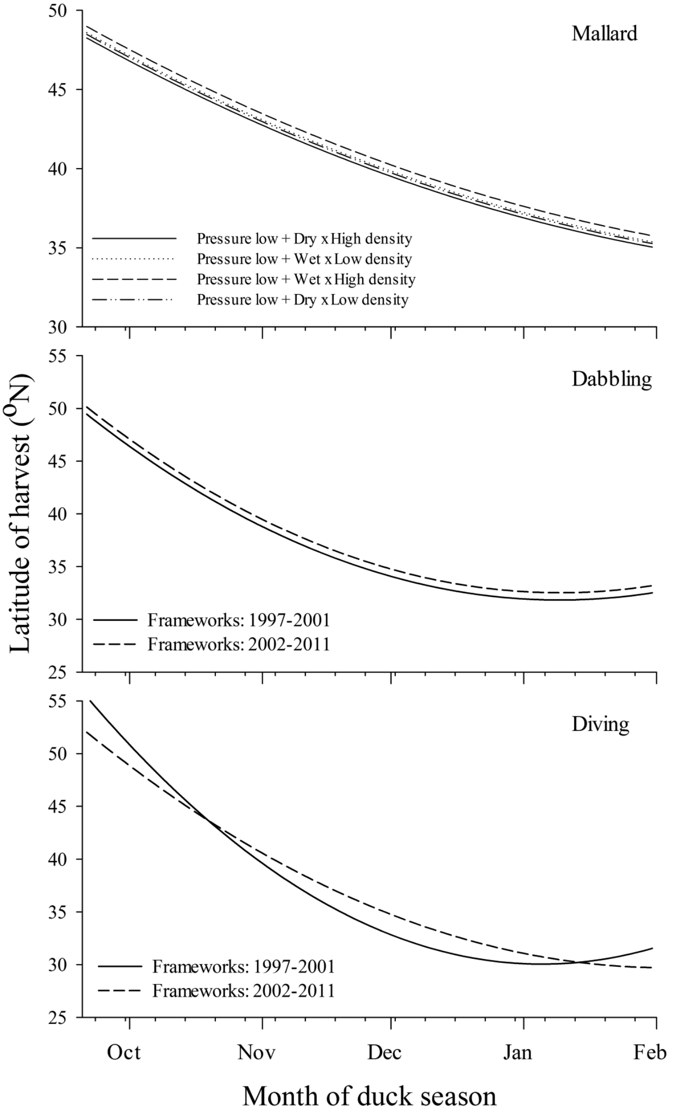

Figure 3. Plots of best models to explain variation in duck harvest distribution in the Central Flyway from 1997–2011 for Mallard, dabbling ducks *Anas* sp., and diving ducks *Aythya* sp. The variation in distribution of Mallard harvest was best explained by hunting pressure (factor of active Central Flyway duck hunters: low < 224,000 < high), water on the landscape (mean annual Palmer Drought Severity Indices from June–September for Oklahoma and Texas: dry ≤ 0.0 < wet), and density (Mallard autumn flight index/U.S. May ponds: low < 6,800 < high). The variation in the distribution of dabbling and diving duck harvest were best explained by framework changes in 2002 which allowed duck seasons to be set earlier and end later. Derived from U.S. Fish and Wildlife Service Parts Collection Survey data.

pressure may not be mechanistically correlated. For example, acres of corn may have increased due to increases in corn prices (U.S. Dept. of Agriculture 2013) and hunting pressure may have decreased because of increased urbanisation and other societal factors (Heberlein 1987). Thus, both parameters were included, and we were prepared to make *a posteriori* decisions to eliminate a model if it appeared the correlation was affecting model results.

Mallard

The variation in Mallard harvest distribution was best explained with a model that incorporated DAY, PRESSURE, and an interaction between $\text{PDSI}_{\text{SOUTH}}$ and Mallard DENSITY (Table 2; $\text{AIC}_c = 6472.3$, weight (w_i) = 0.996, parameters (k) = 13). The runner-up model contained DAY, $\text{CORN}_{\text{DAKOTAS}}$, and an interaction between $\text{PDSI}_{\text{SOUTH}}$ and Mallard DENSITY ($\Delta\text{AIC}_c = 11.1$, $w_i = 0.004$, $k = 13$). Only the top model was considered as it contained > 99% of the weight. The relative improvement of the value of the AIC_c for our top model, relative to the null model containing only the effect of DAY ($\Delta\text{AIC}_c = 124.7$, $w_i = 0.000$, $k = 3$) suggested that model fit improved considerably beyond the penalties inherent (+ 20 AIC_c) on adding 10 additional model parameters to the null model.

If hunting pressure was held constant at low pressure, wet landscapes (*i.e.* water at southern latitudes) and high Mallard density resulted in the most northerly harvest relative to other landscape and Mallard density scenarios (Fig. 3). Day-specific mean latitude during wet years and high densities was 0.39 (95% CI: 0.19–0.58 degrees) degrees latitude (43 km) farther north than mean latitude during wet years with low densities of Mallard. Also relative to wet, low density years, the distribution of Mallard harvest during dry years with low Mallard densities was 0.12 degrees further south (56 km; 95% CI: 0.30 degrees south to 0.07 degrees north). Finally, dry landscapes and high Mallard densities shifted the distribution of Mallard to their most southerly distribution: 0.34 degrees latitude to the south (81 km; 95% CI: 0.97 degrees south to 0.29 degrees north) of distributions during wet years with high Mallard densities (Fig. 3). High hunting PRESSURE shifted any of these distributions of Mallard harvest 0.57 (95% CI: 0.43–0.70) degrees latitude (63 km) southward on any given day relative to distribution estimates from low hunting PRESSURE (Table 2, Fig. 3).

Dabbling duck

Annual variation in dabbling duck harvest distribution was best explained by DAY and FRAMEWORKS (Table 2; $w_i = 1.00$, $k = 5$). The relative improvement of the value of the AIC_c for our top model, relative to the null model containing only the effect of DAY ($\Delta\text{AIC}_c = 43.8$, $w_i = 0.000$, $k = 3$) suggested that model fit improved considerably beyond the penalties inherent (+ 4 AIC_c) when adding two additional model parameters to the null model.

Dabbling ducks were harvested at a latitude 0.69 degrees higher (95% CI: 0.49–0.88), equating to a distance of 77 km, under the 2002–2011 frameworks which allowed seasons to be set one week earlier and end one week later relative to 1997–2001 frameworks (Fig. 3). Actual PCS

Table 2. Parameter estimates from the best model explaining the variation in harvest distribution across the hunting season in the Central Flyway for each duck group (Mallard, dabbling duck *Anas* sp. (excluding Mallard), and diving duck *Aythya* sp.), as determined by Akaike's Information Criterion correct for small sample sizes (s.e. = standard error) from U.S. Fish and Wildlife Service Parts Collection Survey data, 1997–2011.

Duck group	**Effect**	**Estimate**	**s.e.**	***P* > |t|**
Mallard[a]	Intercept	48.7513	0.1351	<0.001
	DAY	–0.1508	0.0041	<0.001
	DAY^2	0.0004	0.0000	<0.001
	DENSITY			
	High	0.3859	0.0980	<0.001
	$PDSI_{SOUTH}$[f]			
	Dry	–0.1150	0.0919	0.211
	DENSITY × $PDSI_{SOUTH}$			
	High × Dry	–0.6110	0.1340	<0.001
	PRESSURE[g]			
	High	–0.5667	0.0675	<0.001
Dabbling duck[b,d]	Intercept	49.7686	0.1821	<0.001
	DAY	–0.3221	0.0055	<0.001
	DAY^2	0.0014	0.0000	<0.001
	FRAMEWORKS[h]			
	2002–2011	0.6850	0.0984	<0.001
Diving duck[c,e]	Intercept	55.8622	0.5290	<0.001
	DAY	–0.4816	0.0179	<0.001
	DAY^2	0.0022	0.0001	<0.001
	FRAMEWORKS[h]			
	2002–2011	–3.5110	0.5997	<0.001
	DAY × FRAMEWORKS			
	2002–2011	0.1496	0.0203	<0.001
	DAY^2 × FRAMEWORKS			
	2002–2011	–0.0010	0.0001	<0.001

[a]Model: Mean latitude of harvest = Intercept + DAY + Hunting PRESSURE + DENSITY × $PDSI_{SOUTH}$; [b]Model: Mean latitude of harvest = Intercept + DAY + FRAMEWORKS; [c]Model: Mean latitude of harvest = Intercept + DAY × FRAMEWORKS; [d]Dabbling duck: American Green-winged Teal, Blue-winged Teal, Gadwall, Northern Pintail, American Wigeon and Northern Shoveler; [e]Diving duck: Canvasback, Redhead and Scaup; [f]Factor of Palmer Drought Severity Indices for Oklahoma and Texas (south); [g]Factor of Central Flyway active hunter estimates; [h]Year factor, for 1997–2001 and 2002–2011, representing changes in the federal framework for allowable season dates.

harvest indicated similar temporal trends in the average daily harvest recorded for dabbling ducks between frameworks (Fig. 4).

Diving duck

Variation in the harvest distribution of diving ducks was also best explained by an interaction between DAY and FRAMEWORKS (Table 2; $w_i = 1.00$, $k = 9$). The relative improvement of the value of the AIC_c for our top model, relative to the null model containing only the effect of DAY ($\Delta AIC_c = 34.4$, $w_i = 0.000$, $k = 3$) suggested that model fit improved considerably beyond the penalties inherent (+ 12 AIC_c) when adding six additional model parameters to the null model.

Under the 2002–2011 frameworks, diving ducks were harvested further south at the beginning of the hunting season, but harvest distributions in mid- to late October shifted northward relative to 1997–2001 (Fig. 3). Harvest distribution between frameworks converged upon similar latitudes towards the end of the hunting seasons (*e.g.* 31 January, Fig. 3). The maximum degrees to which harvest distribution shifted southward on any day between frameworks was 3.36 degrees (373 km, on 21 September) and the maximum northward shift on any day between frameworks was 1.92 degrees (213 km, on 2 December). Actual PCS harvest indicates that differences existed in the temporal trends of average daily harvest between regulation sets (Fig. 4). Frameworks for 2002–2011 resulted in more diving duck being harvested during the first half of the hunting season relative to the 1997–2001 frameworks; however, harvest was similar between frameworks later in the hunting season (Fig. 4).

Discussion

Hunting pressure, wetland conditions in Oklahoma and Texas, and Mallard density best explained the variation in the distribution of Mallard harvest. Duck movements may be influenced by hunting pressure (Cox & Afton 1997; Casazza *et al.* 2012), as well as water availability (Kaminski & Prince 1984; Webb *et al.* 2010; Pearse *et al.* 2012), and competition (Jorde *et al.* 1983; Baldassarre & Bolen 1984). Thus it seems plausible that all three factors may affect the distribution of Mallard harvest, singly or in combination.

High Mallard DENSITY resulted in a northward shift in harvest distribution relative to low Mallard DENSITY. By definition, high Mallard densities can indicate either higher production or lower water availability. In either scenario, more ducks may be harvested on the breeding grounds prior to southward movements resulting in northward shifts in the distribution of Mallard harvest. For example, dry wetland conditions may concentrate ducks onto more finite resources, but it may also concentrate hunting pressure, which could hypothetically increase harvest. Increases in hunting PRESSURE resulted in a southward shift in harvest distribution. Because ducks react to hunter activity (Cox & Afton 1997; Casazza *et al.* 2012), increased hunting pressure, specifically on the breeding grounds, may cause ducks to initiate migration sooner, thereby causing a southward shift in harvest distribution. Dry conditions in the south resulted in a

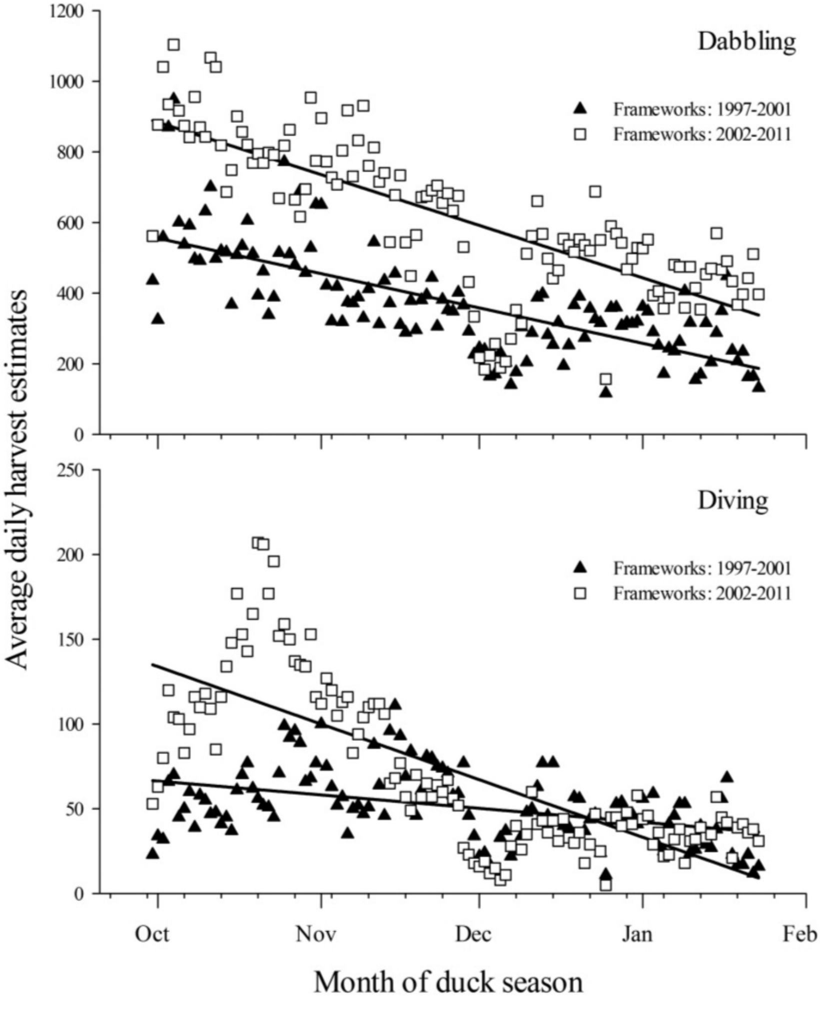

Figure 4. Average daily harvest estimates both for dabbling ducks *Anas* sp. (excluding Mallard) and for diving ducks *Aythya* sp. over each regulatory period, 1997–2001 and 2002–2011 (*i.e.* when changes in frameworks allowed states to set seasons earlier and end seasons later relative to 1997–2001; season length and daily bag limits were comparable). Derived from U.S. Fish and Wildlife Service Parts Collection Survey data.

southward shift in the distribution of harvest, and the interaction between dry conditions in the south and high densities of Mallards resulted in an even larger southward shift in harvest distribution. Similar to the previous example, Mallards may become concentrated in southern states, resulting in a southward shift in harvest distribution under dry conditions and high densities of Mallards. Managers should focus on Mallard densities, water conditions, and local hunting regimes when they consider the distribution of Mallard harvest and regulation setting.

Framework changes provided the greatest explanation for the variation in harvest distribution for both dabbling and diving ducks. Northward shifts in the distribution of dabbling duck harvest may have occurred because earlier seasons allowed more dabbling ducks to be exposed to hunting pressure closer to the breeding grounds prior to migration. Specifically, there may be fewer ducks available at southern latitudes in addition to a higher proportion of ducks at southern latitudes that have been exposed to hunting pressures, which may reduce their vulnerability (Eadie *et al.* 2002; Szymanski & Afton 2005; Ackerman *et al.* 2006). Diving ducks were also influenced by framework changes; however, contrary to the situation with dabbling ducks, an interaction between FRAMEWORKS and DAY provided the best fit. Similar to dabbling ducks, decreased vulnerability at southern latitudes may account for at least the northward shifts in harvest of diving duck, but that alone may not completely explain the interaction between FRAMEWORKS and DAY. Scaup daily bag limits were reduced in 1999 from six to three (Kruse *et al.* 2002), which may account for the interaction between FRAMEWORKS and DAY. Although daily limits on other diving duck species remained comparable among framework sets (Kruse 2013), it appears that actual diving duck harvest increased earlier in the hunting season during 2002–2011 (Fig. 4), which may have also triggered the interaction between FRAMEWORKS and DAY. Dabbling ducks did not exhibit the same noticeable changes in actual harvest between the framework sets.

Although our model predicted small spatial shifts in harvest, it is important to consider the scale at which these shifts occurred. Specifically, a change of 1° latitude may be very small when focusing on a county inference. However, when considering our explanatory variable affected the spatial distribution of harvest at the flyway level our results become much more significant. Future management actions should consider the temporal and spatial changes in duck harvest. That is, changes in allowable start and end dates for hunting seasons can affect the harvest distribution of dabbling and diving duck species. Additionally, anthropogenic and environmental stimuli appeared to influence harvest distribution for Mallard. Hunters appreciate opportunities to harvest waterfowl (Stankey *et al.* 1973; Brunke & Hunt 2007), and an appropriate hunting season is critical for hunter satisfaction. Increased hunter satisfaction may lead to increased hunter retention (Case 2004), which is important as hunters provide support to wildlife and habitat conservation efforts (Vrtiska *et al.* 2013). Our results should help mangers in setting appropriate hunting seasons. The distributions we provide also may help managers inform their hunters as to the reasons for temporal and spatial changes in harvest.

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