Wildl. Biol. 16: 113-122 (2010)
DOI: 10.2981/09-071

www.wildlifebiology.com

Original article

Factors associated with hunter success for ducks on state-owned lands in Illinois, USA

Joshua D. Stafford, Aaron T. Pearse, Christopher S. Hine, Aaron P. Yetter & Michelle M. Horath

Factors that influence hunter success for waterfowl are subject to varying levels of control by managers. The relative influence of these factors is poorly understood, but such information may be valuable to guide management actions intended to promote successful hunting and communicate management decisions to constituents. We used bag-check data to investigate factors influencing hunter success for mallards *Anas platyrhynchos* and other dabbling ducks (tribe Anatini) during the period 1981-2000 and 2002 at Illinois public waterfowl areas. Competing models of hunter success for mallards and other dabbling ducks included a negative association with average low temperature during the duck season (uncontrollable by managers) and positive associations with estimates of local and continental duck abundance, factors which we considered partially controllable by managers. Although a certain proportion of variation in hunter success for ducks cannot be directly influenced by managers, we suggest that programs and management efforts, which promote larger continental duck populations (e.g. Conservation Reserve Program) and local duck abundance (e.g. provide quality wetland foraging habitats), may positively influence hunter success.

Key words: Anas platyrhynchos, Anatidae, habitat conservation, harvest, hunter success, Illinois, public lands

Joshua D. Stafford, Christopher S. Hine, Aaron P. Yetter & Michelle M. Horath, Frank C. Bellrose Waterfowl Research Center, Illinois Natural History Survey, Institute of Natural Resource Sustainability, University of Illinois, P.O. Box 590, Havana, Illinois 62644, USA - e-mail addresses: jdstaff@illinois.edu (Joshua D. Stafford); chine@inhs.uiuc.edu (Christopher S. Hine); ayetter@illinois.edu (Aaron P. Yetter); mgeorgi@inhs.uiuc.edu (Michelle M. Horath)
Aaron T. Pearse, U.S. Geological Survey, Northern Prairie Wildlife Research Center, 8711 37th Street SE, Jamestown, North Dakota 58401, USA - e-mail: apearse@usgs.gov

Corresponding author: Joshua D. Stafford

Received 7 August 2009, accepted 13 January 2010

Associate Editor: Jesper Madsen

Previous research on waterfowl harvest in North America has focused on estimating parameters (e.g. population size and harvest rate) that may be used to optimize harvest regulations (e.g. Johnson et al. 1997). However, relationships between hunter success for waterfowl and factors influencing success are complex and remain poorly understood. Many state- and federally-owned lands in the United States are managed to provide opportunities for waterfowl hunting, and an improved understanding of factors influencing hunter success may provide information for guiding management actions and communicating decisions to constituents. Additionally, the successful harvesting of waterfowl is of primary importance to hunters; thus, investigation of factors associated with success may increase the understanding of human dimensions (e.g. Ringelman 1997, Case 2004).

The ability to control factors that potentially influence waterfowl harvest varies considerably. Factors controlled by government agencies include season lengths, dates and bag limits as defined by regulations under Adaptive Harvest Management (AHM; Johnson et al. 1997). Large-scale investigations of the relationship between duck harvest and regulations have been conducted (e.g. Afton & Anderson 2001), but few local-scale studies exist. Furthermore, effects of some regulations on harvest may be modest or difficult to predict (Martin & Carney 1977). For example, Nagel & Low (1971) reported that variation in bag limits had negligible effects on waterfowl harvest on public lands in Utah, USA. Waterfowl managers commonly attempt to encourage successful hunting by providing foraging and rest areas for migrating birds. These efforts likely influence distribution of waterfowl and harvest (Gilmer et al. 1989) but may not improve hunter success (Walters et al. 1973), thereby resulting in only partial control. Similarly, harvest may be influenced by breeding population sizes, which may be partially controlled via management actions (Trost et al. 1987, Runge et al. 2006). Finally, uncontrollable factors contribute to the success of waterfowl hunters and, of these, weather influences waterfowl distributions and hunter success at local and potentially regional scales (Schummer et al. 2010). Gilmer et al. (1989) speculated that precipitation influenced hunter success on public lands in California, USA, whereas wind was identified as positively influencing duck hunter success in Canada (Boyd 1971, Walters et al. 1973) and California (Miller et al. 1988).

Our understanding of factors that influence hunter success for waterfowl is limited, especially with respect to controllability. Such an investigation would provide empirical information useful to the planning and implementation of habitat, harvest and human-dimension strategies for waterfowl management (Martin & Carney 1977). Therefore, we assembled duck-harvest data from the Illinois Department of Natural Resources (IDNR) waterfowl hunting area check stations during 1981-2000 and 2002 to investigate proximate factors influencing hunter success. Our objective was to model annual variation in hunter success (i.e. harvest/hunter/day) for two groups, mallard *Anas platyrhynchos* and other dabbling ducks (tribe Anatini), at IDNR sites as functions of controllable, partially controllable and uncontrollable factors.

Methods

Study area

The IDNR operates 72 properties which are intended to provide habitat for resident and migratory waterfowl (Havera 1999). As of 1983, public waterfowl hunting was permitted on 77% (N = 51,351 ha) of the area managed for waterfowl at these sites. These lands comprised only 12% of the natural wetland area in the state of Illinois (Havera 1999:74), and yet Miller et al. (2002) estimated that 49% of waterfowl were harvested on public lands in Illinois. In this article, we focus on data collected during 1981-2000 and 2002 at the following 11 locations along the Illinois and Mississippi Rivers: 1) Lake DePue FWA, 2) Donnelley WMA, 3) Woodford County FWA, 4) Rice Lake FWA, 5) Anderson Lake State Fish and Wildlife Area (FWA), 6) Sanganois FWA, 7) Godar-Diamond-Hurricane Island FWA, 8) Glades 12-Mile Island FWA, 9) Stump Lake FWA, 10) Calhoun Point FWA, and 11) Batchtown FWA (Fig. 1). Many U.S. states are divided into geographic zones to accommodate different opening and closing dates of the duck hunting season. All sites in our analysis were in the same regulatory zone (i.e. central) and, therefore, were subject to the same season dates within a given year.

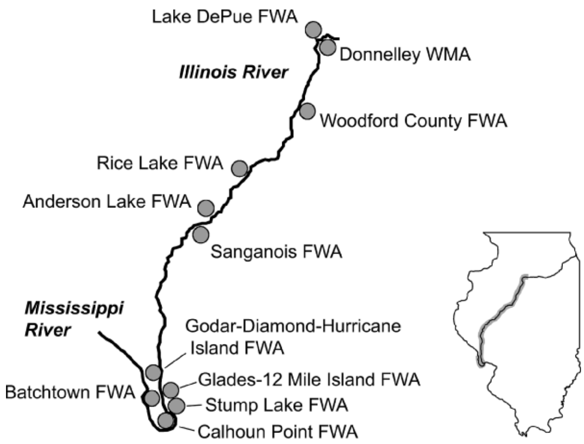

Figure 1. Locations of the 11 IDNR sites in central Illinois, USA, from which we obtained duck-harvest data for the period 1981-2000 and 2002.

Data collection and analyses

Duck harvest is commonly estimated using mail questionnaires (e.g. Padding et al. 2006, Lischka et al. 2008), but this approach may overestimate hunter success compared to estimates derived from bag-check data (Wright 1978). Many IDNR sites recorded waterfowl harvest via check stations or individual bag checks; thus, we obtained available data on site-specific waterfowl harvest from IDNR personnel. Harvest data were collected daily, but biologists combined these records into summaries that included the total number of harvest records (i.e. hunter-days) and total number of ducks harvested during each season, after which the daily records were discarded or unavailable. Thus, we compiled our data set from annual hunter-use and harvest summaries for analyses of hunter success.

We modeled hunter success for two groups of waterfowl: mallards and 'other dabbling ducks' (i.e. northern pintail *Anas acuta*, American wigeon *A. americana*, gadwall *A. strepera*, American green-winged teal *A. crecca*, blue-winged teal *A. discors*, northern shoveler *A. clypeata* and American black duck *A. rubripes*). We excluded diving ducks (tribe Aythini) because few were harvested during the study period. We also excluded wood duck *Aix sponsa* harvest from models of hunter success because we believed that most habitat covariates (e.g. abundance of prairie wetlands) would not predict wood duck harvest potential and because information on abundances of breeding and migrating wood ducks was lacking. Harvest data were missing for some years and sites, particularly during 1993 and 1995, when flooding prevented hunting or operation of check stations. Furthermore, we excluded harvest data from 2001 because results of aerial inventories of waterfowl were unavailable, precluding computation of a covariate of interest. To compute the dependent variables for each analysis (i.e. harvest/hunter/day), we summarized yearly harvest data for mallards and other dabbling ducks and divided these values, for each site and year combination, by the number of hunter-days recorded during that hunting season (i.e. reported in IDNR harvest summaries).

We used an information-theoretic approach (Anderson et al. 2000, Burnham & Anderson 2002) to identify factors potentially influencing variation in hunter success for mallards and other dabbling ducks among years and sites in relation to covariates classified as controllable, partially controllable or uncontrollable by agencies or managers. We identified season length (SEASON; categorical (30, 40, 50 or 60 days)) and season closing date (CLOSE; days from earliest closing date in our data set; $\bar{x} = 13.9$, range: 0-32; $\bar{x}$ date of close = 9 December, range: 25 November - 27 December) as controllable variables of interest (Havera 1999). We hypothesized that longer seasons and later closing dates would have positive relationships with hunter success (e.g. Afton & Anderson 2001).

The North American Waterfowl Management Plan assumes that habitat conservation efforts will positively influence populations of breeding waterfowl and recruitment (e.g. Canadian Wildlife Service, U.S. Fish and Wildlife Service & Mexico National Institute of Ecology 1998). Therefore, we included the following variables which we considered to be under partial control by waterfowl managers: estimated breeding population size of mid-continent mallards (BMPOP; millions; $\bar{x} = 6.5$, range: 4.7-10.1) and other dabbling ducks (BOPOP; millions; $\bar{x} = 13.6$, range: 9.7-20.7), indices of local abundance of mallards (MALLAB; 10,000s; $\bar{x} = 3.7$, range: 0.1-25.1) and other dabbling ducks (ODABBAB; 10,000s; $\bar{x} = 1.0$, range: < 0.1-4.7) and estimated age ratios of mallards for the Mississippi Flyway (MSRATIO; juvenile:adult; $\bar{x} = 1.0$, range: 0.7-1.4).

We compiled BMPOP and BOPOP using U.S. Fish & Wildlife Service Waterfowl Breeding Population and Habitat Survey data for strata 13-18, 20-50 and 75-77 (i.e. the mid-continent; U.S. Fish & Wildlife Service 2008), obtained through the Migratory Bird Data Center website (available at: http://mbdcapps.fws.gov/). We used data from aerial counts of waterfowl, conducted approximately weekly from a fixed-wing, single-engine aircraft at altitudes of 61-137 m and speeds of 161-241 km/hour (Havera 1999:186), to compute MALLAB and ODABBAB. To compute these variables, we first calculated use-days for mallards and other dabbling ducks during the legal hunting season for all wetlands surveyed within 8 km of each IDNR site, following the methods outlined in Stafford et al. (2007:95-396). Use-days are estimates of total waterbird use for a specified location and time period; for example, 100 ducks using a wetland for 10 days would equal 1,000 use-days. Finally, because duck seasons varied in length (e.g. 30 vs 40 days), we divided these use-day values by the number of days in each duck season. We hypothesized positive associations between hunter success and continental and local waterfowl abundance (Bellrose 1944, Green 1963, Hochbaum & Walters 1984, Trost et al. 1987, Raveling & Heitmeyer 1989). We obtained MSRATIO from waterfowl parts collection survey data (Martin & Carney 1977, Baldassarre & Bolen 2006:307) and did not correct these data for differential vulnerability, because unadjusted ratios may be better indicators of annual productivity than corrected age ratios (Heitmeyer & Fredrickson 1981). We hypothesized that more juveniles in the year of harvest would positively associate with hunter success (Raveling & Heitmeyer 1989, Christensen 2005).

We considered variables related to weather patterns as uncontrollable by waterfowl managers, including an estimate of wetlands present in the primary breeding grounds during May (PONDS; 100,000s; $\bar{x}$ = 30.5, range: 14.4-50.6) and average daily low temperature during the duck season (LOWTEMP; °C; $\bar{x}$ = 0.1, range: -7.6-3.6). Furthermore, we included cumulative elevation of the Illinois River above flood stage during fall (FDEPTH; m; $\bar{x}$ = 7.7, range: 0.0-143.3) and summer (SUMFDEPTH; m; $\bar{x}$ = 26.4, range: 0.0-318.6), and the number of days that river gage readings were above flood stage during the fall (FDAYS; $\bar{x}$ = 2.0, range: 0.0-17.0) and summer (SUMFDAYS; $\bar{x}$ = 6.8, range: 0.0-56.0). We obtained yearly estimates of PONDS from surveys conducted by the U.S. Fish & Wildlife Service and hypothesized that hunter success would increase with increasing PONDS (Wilkins et al. 2005). We obtained annual temperature data from the weather station nearest each IDNR site, via the Midwest Regional Climate Center, and used these data to compute the average low temperature during each duck season. We hypothesized a negative relationship between LOWTEMP and hunter success. We obtained river elevation data for the gage nearest each IDNR site and estimated extent of flooding by summing river elevations above flood stage for each gage during the fall (1 October - 31 December; FDEPTH) and summer (1 July - 30 September; SUMFDEPTH). Similarly, we estimated duration of flooding by summing the number of days that river gage readings were above flood stage during the fall (FDAYS) and summer (SUMFDAYS). We hypothesized that summer flooding would negatively influence fall forage abundance for waterfowl, thereby decreasing hunter success indirectly. Conversely, we predicted fall flooding would positively influence forage availability and increase hunter success, indirectly.

We fit candidate models using the MIXED procedure, SAS version 9.1 (SAS Institute 2004). We evaluated various autoregressive and spatial covariance structures using the TYPE option in the RANDOM and REPEATED statements and selected the appropriate combination based on the least second-order Akaike's Information Criterion value (AIC_c), for the full model. We evaluated best and competing models using AIC_c and calculated a maximum likelihood coefficient of determination (r^2) as a measure of fit of the best and competing models (Nagelkerke 1991). When covariates appeared in multiple competing models ($\Delta AIC_c \leq 2.0$), we derived model-averaged parameter estimates and standard errors across all models where parameter estimates were assumed to be 0 when covariates did not appear in models within the candidate set (Burnham & Anderson 2002:152). Finally, we computed 95% confidence intervals about parameter estimates to interpret the importance of covariates.

Results

Our analyses included 21 years of hunter success data from the 11 IDNR sites (see Fig. 1). Data were not available for 10 site-year combinations; thus, we included 221 observations in the analyses. Mean annual hunter success among all sites during 1981-2000 and 2002 was 0.53 ± 0.27 (SD) mallards/hunter/day (range: 0.09-1.93) and 0.18 ± 0.10 (SD) ducks/hunter/day for other dabbling ducks (range: 0.0-0.49). Annual hunter success for all dabbling ducks during the period averaged 0.71 ± 0.31 (SD) ducks/hunter/day (range: 0.15-2.17).

Of the 21 candidate models developed to explain variation in hunter success for mallards, four were competitive, cumulatively accounting for 72.3% of the model weight (r^2 = 0.14-0.18; Table 1). Competing models included covariates from all categories, including the controllable (CLOSE, Σw_i = 0.457), partially controllable (BMPOP, Σw_i=0.393; MALLAB, Σw_i=0.355) and uncontrollable (LOWTEMP, Σw_i = 0.908) by managers. Models including only a single category of covariates ranked lower than models with multiple categories (see Table 1). All competing models included the uncontrollable effect of LOWTEMP, and the model-averaged estimate indicated that hunter success increased by 0.03 mallards/hunter/day for each 1°C decrease in average low temperature ($\hat{\bar{\beta}}_{LOWTEMP}$=-0.030; 95% CI: -0.049, -0.011). We detected positive relationships between hunter success and BMPOP ($\hat{\bar{\beta}}_{BMPOP}$ = 0.015; 95% CI: < 0.001, 0.030), MALLAB ($\hat{\bar{\beta}}_{MALLAB}$ = 0.004; 95% CI: 0.000, 0.008) and CLOSE ($\hat{\bar{\beta}}_{CLOSE}$ = 0.003; 95% CI: -0.001, 0.006); however, the lower confidence limits for these estimates approached or included 0.

Of the models of hunter success for other dabbling ducks, four had ΔAIC_c values of $\leq$ 2.0 units and cumulatively accounted for 59.0% of the model weight (r^2 = 0.05-0.08; Table 2). Similar to models of hunter success for mallards, covariates from all categories were included in the competing models. The partially controllable variable BOPOP was present in three competing models and had the greatest cumulative variable weight ($\Sigma w_i = 0.652$). The uncontrollable variable LOWTEMP was included in one competing model ($\Sigma w_i = 0.474$), as were the controllable variables CLOSE ($\Sigma w_i = 0.248$) and SEASON ($\Sigma w_i = 0.112$). Of covariates from competing models, only BOPOP had a model-averaged parameter estimate with a confidence interval that did not include 0 and suggested a small, positive relationship with hunter success for other dabbling ducks ($\hat{\bar{\beta}}_{BOPOP} = 0.006$; 95% CI: 0.001, 0.012).

Discussion

Lischka et al. 2008 reported that hunter success estimated using annual mail surveys of Illinois waterfowl hunters during 1981-2002 averaged 0.6 ducks/hunter/day (all species). Also during these years, 46,593 hunters/year spent 11.6 days/season in the field, thereby bagging an average of 7.0 ducks/season (Lischka et al. 2008). Thus, hunter success at IDNR sites during our study was similar to the statewide mail-survey estimates, although our estimates are not directly comparable because we did not include harvest of ducks other than dabbling ducks in our analyses.

Results of our modeling effort indicated that hunter success for mallards and other dabbling ducks was influenced by factors of varying levels of control by waterfowl managers. The best approximating model of both dependant variables included the partially controllable variable of breeding population size and the uncontrollable variable of average low temperature. Season closing date, a variable controllable by managers, was included in competing models, but associations with hunter success were small and variable, compared to effects

Table 1. Candidate models to explain variation in annual hunter success (mallards/hunter/day) at Illinois Department of Natural Resources public hunting areas during 1981-2000 and 2002, ranked by second order Akaike's information criterion (AIC_c). Also included are the number of estimable parameters (K), -2 log likelihood score (-2 Log(L($\hat{\theta}$))), and model weight (w_i). Competing models ($\Delta AIC_c \leq 2.0$) appear in italics.

Model	K	-2Log(L($\hat{\theta}$))	AIC_c	ΔAIC_c	w_i
All categories					
LOWTEMP+MALLAB+CLOSE	*8*	*-124.1*	*-107.4*	*0.1*	*0.241*
LOWTEMP+BMPOP+CLOSE	8	-122.1	-105.4	2.1	0.089
Controllable and partially controllable					
BMPOP+SEASON	9	-114.1	-95.3	12.3	0.001
Controllable and uncontrollable					
LOWTEMP+CLOSE	*7*	*-120.4*	*-105.9*	*1.7*	*0.111*
LOWTEMP+SEASON	9	-122.2	-103.4	4.2	0.032
LOWTEMP+SEASON+LOWTEMP*SEASON	12	-123.6	-98.2	9.4	0.002
Partially controllable and uncontrollable					
LOWTEMP+BMPOP	*7*	*-122.1*	*-107.6*	*0.0*	*0.260*
LOWTEMP+MALLAB	*7*	*-120.4*	*-105.9*	*1.7*	*0.111*
BMPOP+MSRATIO	7	-118.0	-103.5	4.1	0.033
BMPOP+PONDS	7	-113.7	-99.2	8.4	0.004
Controllable					
CLOSE	6	-114.4	-102.0	5.6	0.016
SEASON	8	-112.7	-96.0	11.5	0.001
Partially controllable					
MSRATIO	6	-114.9	-102.5	5.1	0.021
BMPOP	6	-112.8	-100.4	7.2	0.007
MALLAB	6	-111.3	-98.9	8.7	0.003
Uncontrollable					
LOWTEMP	6	-117.1	-104.7	2.9	0.062
SUMFDAYS	6	-110.0	-97.6	10.0	0.002
FDEPTH	6	-108.7	-96.3	11.3	0.001
SUMFDEPTH	6	-109.4	-97.0	10.6	0.001
FDAYS	6	-108.7	-96.0	11.6	0.001
PONDS	6	-107.9	-95.5	12.1	0.001

Table 2. Candidate models to explain variation in annual hunter success (other dabbling ducks/hunter/day) at Illinois Department of Natural Resources public hunting areas during the 1981-2000 and 2002, ranked by 2nd order Akaike's information criterion (AIC_c). Also included are the number of estimable parameters (K), -2 log likelihood score (-2 Log(L($\hat{\theta}$))) and model weight (w_i). Competing models ($\Delta AIC_c \leq 2.0$) appear in italics.

Model	K	-2 Log(L($\hat{\theta}$))	AIC_c	ΔAIC_c	w_i
All categories					
LOWTEMP+BOPOP+CLOSE	8	-503.4	-486.7	2.1	0.080
LOWTEMP+ODABBAB+CLOSE	8	-500.7	-484.0	4.8	0.021
Controllable and partially controllable					
BOPOP+SEASON	*9*	*-505.9*	*-487.1*	*1.8*	0.095
Controllable and uncontrollable					
LOWTEMP+CLOSE	7	-500.5	-486.0	2.9	0.055
LOWTEMP+SEASON	9	-500.6	-481.8	7.1	0.007
LOWTEMP+SEASON+LOWTEMP*SEASON	12	-504.4	-479.0	9.9	0.002
Partially controllable and uncontrollable					
LOWTEMP+BOPOP	*7*	*-503.4*	*-488.9*	*0.0*	*0.235*
BOPOP+PONDS	7	-501.1	-486.6	2.3	0.074
LOWTEMP+ODABBAB	7	-498.6	-484.1	4.8	0.021
Controllable					
CLOSE	*6*	*-499.4*	*-487.0*	*1.9*	*0.092*
SEASON	8	-499.1	-482.4	6.4	0.009
Partially controllable					
BOPOP	*6*	*-500.6*	*-488.2*	*0.7*	*0.168*
ODABBAB	6	-495.0	-482.6	6.3	0.010
Uncontrollable					
LOWTEMP	6	-498.3	-485.9	3.0	0.053
FDAYS	6	-496.4	-484.0	4.9	0.021
SUMFDEPTH	6	-496.2	-483.8	5.1	0.019
FDEPTH	6	-495.6	-483.2	5.7	0.014
PONDS	6	-495.4	-483.0	5.9	0.012
SUMFDAYS	6	-495.3	-482.9	6.0	0.012

of covariates in other categories. Johnson & Case (2000) reviewed adaptive regulation of waterfowl harvest in North America and noted that variation in uncontrollable factors can result in regulation-specific harvest rates that vary by up to 50% of the mean. Therefore, it may be valuable to understand the influence of unmanageable factors on hunter success, to improve understanding of effects of regulations on harvest (Johnson & Case 2000).

The uncontrollable covariate, accounting for average low temperature during the duck season, was an important predictor of hunter success for mallards and other dabbling ducks, where success improved as the average low temperature during the hunting season decreased. In their investigation of hunter success, Trost et al. (1987) did not document a relationship with temperature, but other studies have speculated that weather may exert considerable influence on hunter take (Boyd 1971, Walters et al. 1973, Miller et al. 1988). The estimated effect of average low temperature on hunter success was 10 times greater for mallards ($\hat{\bar{\beta}}$ = -0.030) than for other dabbling ducks ($\hat{\bar{\beta}}$ = -0.003). We speculate that this disparity may be related to differences in migration chronology. For example, during 1948-1996 the average peak abundances of northern pintail, American wigeon and gadwall in the Illinois River valley (IRV) occurred during 27 October - 2 November, whereas mallard abundance peaked during 17-23 November (Havera 1999). Thus, it is possible that mallards were more abundant later in the season, and colder temperatures may have increased their vulnerability if the birds were unfamiliar with the area (e.g. recent migrants) or sought forage as lipid stores were depleted (McIlhenny 1940, Miller et al. 1988, Newton 1998:297).

Of factors subject to partial control via management, size of breeding populations and indices of local abundance were included in some competing models. Estimates of breeding populations appeared in competing models of both candidate sets and indicated positive associations with hunter success. Trost et al. (1987) and Raveling & Heitmeyer (1989) also suggested that breeding duck abundances positively influenced hunter harvest. Therefore, programs or management efforts that increase breeding populations of ducks (e.g. habitat management) may have a modest influence on hunter success for dabbling ducks. Two competing models of hunter success for mallards included an index of local duck abundance during the hunting season. However, the model-averaged parameter estimate was small, indicating that success increased by 0.02 mallards/hunter/day for each increase of 50,000 mallards/day within 8 km of IDNR sites during the hunting season. Based on the aforementioned average days afield of 11.6/hunter/season during 1981-2002 (Lischka et al. 2008), this hypothetical increase in mallard abundance would translate to 0.23 more mallards harvested per hunter each season. Nonetheless, this result is of interest because abundance of ducks on or near IDNR sites may be partially controllable through management activities, including those aimed at increasing the foraging carrying capacity or creating refugia (Bellrose et al. 1979, Madsen 1998, Havera 1999, Stephens et al. 2003).

Afton & Anderson (2001) reported that the controllable factors of season length and bag limit explained considerable variation (53-64%) in harvest of lesser scaup *Aythya affinis* in the Mississippi Flyway. In contrast, our analyses did not reveal strong relationships between controllable factors and hunter success. However, we acknowledge that our results may not be directly comparable to those of Afton & Anderson (2001), unless hunter numbers, and thus hunter success, were similar to those of our study. Season closing date appeared in competing models of hunter success for both candidate sets, but confidence intervals about both estimates included 0, providing equivocal results. Furthermore, a model containing only closing date was not competitive in our candidate set for mallards, possibly indicating that later seasons only resulted in appreciable increases in harvest success, when other factors were favourable, e.g. weather or waterfowl abundance.

It is intuitive that bag limit, defined as the number of ducks a hunter may legally harvest in one day, has potential to influence hunter success by imposing a maximum daily harvest. However, we were unable to include a simple measure of daily bag limit in our analyses, because harvest management in Illinois was based on a 'points system' during the period 1970-1987, wherein a duck of a certain species or sex was assigned a point value that contributed to a total of 100 points (Ringelman 1991, Havera 1999). This management program resulted in varying species specific and total bag limits within a hunting season, thereby making it impossible to assign a specific value to the years during which this system was applied and was, hence, inappropriate for our modeling effort. Nonetheless, we do not believe that the exclusion of bag limits from our analyses was problematic because: 1) evidence suggests that bag limits explain little variation in hunter take on public lands in the U.S., because in a given day, few individual hunters shoot as many ducks as the bag limit allows (Nagel & Low 1971), and 2) average hunter success was so low (0.71 ducks/day) that we did not suspect that bag limit constrained harvest significantly.

We included season closing date in some candidate models because recent human dimension surveys of Illinois waterfowl hunters suggested that some interest exists for seasons to open, and therefore close, later (e.g. Lischka et al. 2008). It is possible that such an effort could improve hunter success, because mallards or other large-bodied dabbling ducks are among the latest fall migrants (Bellrose 1980:235). However, some commonly harvested species at IDNR sites migrate early in autumn (Bellrose 1980). For example, Illinois waterfowl hunters, who responded to a mail survey which indicated that the wood duck (i.e. a species that breeds locally and migrates early) was their second-most preferred species (Hubert et al. 2005), and wood duck harvest accounted for 14% of all duck harvest at the IDNR sites that were included in our analyses. Thus, efforts intended to improve hunter success by delaying the closing date of duck seasons, after some species have left the region, could possibly reduce the opportunity to harvest early-migrating species. Because parameter estimates for season closing date were variable, we suggest that more detailed research is required to understand the role of season timing in hunter success for multiple species of ducks.

Our efforts to model hunter success at IDNR sites yielded some insight into factors that are proximately associated with harvest, but models explained only modest amounts of variation in success. Hunter success for ducks undoubtedly varies within seasons and specific events, particularly weather, may result in periods of greater or reduced harvest (e.g. Walters et al. 1973, Fleskes et al. 2007). Therefore, it may be valuable for future studies to obtain daily harvest data from public and private lands (e.g. from check-station, mandatory harvest records or direct observation; *sensu* Walters et al. 1973) and to model daily hunter take in relation to regulatory, time-dependant (e.g. daily temperature) and hunter-specific covariates (e.g. use of spinning-wing decoys; Ackerman et al. 2006). Such an investigation would allow for improved inference regarding the influence of intraseasonal variation in proximate factors that may be important determinants of hunter success.

Management implications

Hunter success at IDNR sites was mostly influenced by factors which managers cannot control. We suggest that this insight may be valuable to waterfowl managers, by providing empirical evidence that can be used to communicate to constituents, what role unmanageable events play in hunter success. However, variables in competing models of both candidate sets also indicated that hunter success was positively related to indices of duck abundance at local and continental scales, which may be partially controllable through habitat management. Within breeding areas, efforts to improve nesting habitat and recruitment of mallards and other dabbling ducks, such as the Conservation Reserve Program (Reynolds et al. 2001), may translate into increased hunter success. Local-scale management actions may also increase hunter success. Bellrose et al. (1979) identified significant and positive relationships between fall duck use and abundance of moist-soil and submersed aquatic plants in IRV wetlands. We suggest that efforts to increase foraging carrying capacity of wetlands for waterfowl, particularly active moist-soil management (Brasher et al. 2007, Kross et al. 2008), may be practical, effective and ecologically sound techniques to increase local waterfowl abundance. Additionally, wetlands in the contemporary landscape of the IRV are largely devoid of submersed aquatic vegetation, the presence of which may be particularly attractive to some dabbling ducks (e.g. American wigeon; Bellrose et al. 1979, Horath & Havera 2007). Thus, restoration and management efforts to improve abundance of these plant communities in IRV wetlands may be critically important to increasing waterfowl abundance and thereby improving hunter success.

Acknowledgements - we are especially grateful for all the IDNR employees who willingly gathered and shared their hunter harvest data with us. We thank Steve Cordts, Matthieu Guillemain, Steve Havera, Ed Heske, Dave Sharp, Randy Smith, Josh Vest and an anonymous reviewer for critical reviews that improved our manuscript. Robert Crompton conducted aerial inventories during the study period and Dale Tunis was the pilot. Funding was provided by the Federal Aid in Wildlife Restoration Fund and administered through the IDNR project W-43-R. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Ackerman, J.T., Eadie, J.M., Szymanski, M.L., Caswell, J.H., Vrtiska, M.P., Raedeke, A.H., Checkett, J.M., Afton, A.D., Moore, T.G., Caswell, F.D., Walters, R.A., Humberg, D.D. & Yee, J.L. 2006: Effectiveness of spinning-wing decoys varies among dabbling duck species and locations. - Journal of Wildlife Management 70: 799-804.

Afton, A.D. & Anderson, M.G. 2001: Declining scaup populations: a retrospective analysis of long-term population and harvest survey data. - Journal of Wildlife Management 64: 781-796.

Anderson, D.R., Burnham, K.P. & Thompson, W.L. 2000: Null hypothesis testing: problems, prevalence, and an alternative. - Journal of Wildlife Management 64: 912-923.

Baldassarre, G.A. & Bolen, E.G. 2006: Waterfowl ecology and management. 2nd edition. - Krieger, Malabar, 567 pp.

Bellrose, F.C., Jr. 1944: Duck populations and kill: an evaluation of some waterfowl regulations in Illinois. - Illinois Natural History Survey Bulletin 23: 327-372.

Bellrose, F.C. 1980: Ducks, geese and swans of North America. - Stackpole, Harrisburg, 540 pp.

Bellrose, F.C., Paveglio, F.L., Jr. & Steffeck, D.W. 1979: Waterfowl populations and the changing environment of the Illinois River valley. - Illinois Natural History Survey Bulletin 32: 1-54.

Boyd, H. 1971: Observations on duck hunting in eastern Canada in 1968 and 1969. - Canadian Wildlife Service Occasional Paper 12, 23 pp.

Brasher, M.G., Steckel, J.D. & Gates, R.J. 2007: Energetic carrying capacity of actively and passively managed wetlands for migrating ducks in Ohio. - Journal of Wildlife Management 71: 2532-2541.

Burnham, K.P. & Anderson, D.R. 2002: Model selection and inference: a practical information-theoretic approach. 2nd edition. - Springer-Verlag, New York, USA, 488 pp.

Canadian Wildlife Service, U.S. Fish and Wildlife Service & Mexico National Institute of Ecology 1998. Expanding the vision: 1998 update to the North American waterfowl management plan. - Canadian Wildlife Service, U.S. Fish and Wildlife Service & Mexico Institute of Ecology, Washington, D.C., USA, 32 pp.

Case, D.J. 2004: Waterfowl hunter satisfaction think tank. - Final report to the Wildlife Management Institute for U.S. Fish and Wildlife Service Multistate Conservation Grant # DC M-15-P, 58 pp.

Christensen, T.K. 2005: Factors affecting the bag size of the common eider *Somateria mollissima* in Denmark, 1980-2000. - Wildlife Biology 11(1): 89-99.

Fleskes, J.P., Yee, J.L., Yarris, G.S., Miller, M.R. & Casazza, M.L. 2007: Pintail and mallard survival in California relative to habitat, abundance, and hunting. - Journal of Wildlife Management 71: 2238-2248.

Gilmer, D.S., Hicks, J.M., Fleskes, J.P. & Connelly, D.P. 1989: Duck harvest on public hunting areas in California. - California Fish and Game 75: 115-168.

Green, W.E. 1963: Waterfowl utilization and kill 1946 through 1960. - Special Scientific Report, Wildlife No. 71, U.S. Fish and Wildlife Service, Washington, D.C., USA, 62 pp.

Havera, S.P. 1999: Waterfowl of Illinois: status and management. - Illinois Natural History Survey Special Publication 21, 628 pp.

Heitmeyer, M.E. & Fredrickson, L.H. 1981: Do wetland conditions in the Mississippi delta hardwoods influence mallard recruitment? - Transactions of the North American Fish and Wildlife Conference 46: 44-57.

Hochbaum, G.S. & Walters, C.J. 1984: Components of hunting mortality in ducks. - Canadian Wildlife Service Occasional Paper 52, 29 pp.

Horath, M.M. & Havera, S.P. 2007: Waterfowl populations at Spunky Bottoms. - In: Heske, E.J., Herkert, J.R., Blodgett, K.D. & Lemke, A.M. (Eds.); Spunky Bottoms: restoration of a big-river floodplain. Proceedings of the Spunky Bottoms Restoration Symposium, Champaign, Illinois, USA. Illinois Natural History Survey Special Publication 29: 40-42.

Hubert, P.D., Anderson, W.L. & Campbell, L.K. 2005: Results of the 2004-2005 Illinois Waterfowl Hunter Survey. - Job Completion Report, Federal Aid in Wildlife Restoration W-112-R-14. Illinois Natural History Survey, Champaign, Illinois, USA, 55 pp.

Johnson, F.A. & Case, D.J. 2000: Adaptive regulation of waterfowl harvest: lessons learned and prospects for the future. - Transactions of the North American Wildlife and Natural Resources Conference 65: 94-108.

Johnson, F.A., Moore, C.T., Kendall, W.L., Dubovsky, J.A., Caithamer, D.F., Kelley, J.T., Jr. & Williams, B.K. 1997: Uncertainty and the management of mallard harvests. - Journal of Wildlife Management 61: 203-217.

Kross, J., Kaminski, R.M., Reinecke, K.J., Penny, E.J. & Pearse, A.T. 2008: Moist-soil seed abundance in managed wetlands in the Mississippi Alluvial Valley. - Journal of Wildlife Management 72: 707-714.

Lischka, S.A., Anderson, W.L. & Campbell, L.K. 2008: Results of the 2006-2007 Illinois Waterfowl Hunter Survey. - Job Completion Report, Federal Aid in Wildlife Restoration W-112-R-16. Wildlife harvest and Human Dimensions Program Report HR-07-03/INHS Technical Report (67). Illinois Natural History Survey, Champaign, Illinois, USA, 49 pp.

Madsen, J. 1998: Experimental refuges for migratory waterfowl in Danish wetlands II: Tests of hunting disturbance effects. - Journal of Applied Ecology 35: 398-417.

Martin, E.M. & Carney, S.M. 1977: Population ecology of the Mallard IV: A review of duck hunting regulations, activity, and success, with special reference to the mallard. - U.S. Fish and Wildlife Service Resource Publication 130, 137 pp.

McIlhenny, E.A. 1940: Effect of excessive cold on birds in southern Louisiana. - Auk 57: 408-410.

Miller, C.A., Anderson, W.L., Campbell, L.K. & Yeagle, J.A. 2002: Results of the 2000-2001 Illinois Waterfowl Hunter Survey. - Job Completion Report, Federal Aid in Wildlife Restoration W-112-R-10. Waterfowl Program Periodic Report 103. Human Dimensions Program Report HR-00-04. Illinois Natural History Survey, Champaign, Illinois, USA, 66 pp.

Miller, M.R., Beam, J. & Connelly, D.P. 1988: Dabbling duck harvest dynamics in the Central Valley of California - implications for recruitment. - In: Weller, M.W. (Ed.); Waterfowl in Winter: symposium and workshop, Galveston, Texas, USA, pp. 553-569.

Nagel, J.E. & Low, J.B. 1971: Effect of regulations of waterfowl kill in Utah. - Journal of Wildlife Management 35: 554-557.

Nagelkerke, N.J.D. 1991: A note on a general definition of the coefficient of determination. - Biometrika 78: 691-692.

Newton, I. 1998: Population Limitation in Birds. - Academic Press, San Diego, California, USA, 597 pp.

Padding, P.I., Gobeil, J.F. & Wentworth, C. 2006: Estimating waterfowl harvest in North America. - In: Boere, G.C., Galbraith, C.A. & Stroud, D.A. (Eds.); Waterbirds around the world. The Stationery Office, Edinburgh, Scotland, pp. 849-852.

Raveling, D.G. & Heitmeyer, M.E. 1989: Relationships of population size and recruitment of pintails to habitat conditions and harvest. - Journal of Wildlife Management 53: 1088-1103.

Reynolds, R.E., Shaffer, T.L., Renner, R.W., Newton, W.E. & Batt, B.J. 2001: Impact of the conservation reserve program on duck recruitment in the U.S. Prairie Pothole Region. - Journal of Wildlife Management 65: 765-780.

Ringelman, J.K. 1991: Differential harvest of male and female mallards under conventional and point system regulations. - Wildlife Society Bulletin 19: 258-267.

Ringelman, J.K. 1997: Effects of regulations and duck abundance on duck hunter participation and satisfaction. - Transactions of the North American Wildlife and Natural Resources Conference 62: 361-376.

Runge, M.C., Johnson, F.A., Anderson, M.G., Koneff, M.D., Reed, E.T. & Mott, S.E. 2006: The need for coherence between waterfowl harvest and habitat management. - Wildlife Society Bulletin 34: 1231-1237.

SAS Institute 2004: SAS/STAT Users' Guide, Version 9.1. - SAS Institute, Cary, North Carolina, USA, 5121 pp.

Schummer, M.L., Kaminski, R.M., Raedeke, A.H. & Graber, D.A. 2010: Weather-related indices of autumn-winter dabbling duck abundance in middle North America. - Journal of Wildlife Management 74: 94-101.

Stafford, J.D., Horath, M.M., Yetter, A.P., Hine, C.S. & Havera, S.P. 2007: Wetland use by mallards during spring and fall in the Illinois and Central Mississippi River valleys. - Waterbirds 30: 394-402.

Stephens, P.A., Freckleton, R.P., Watkinson, A.R. & Sutherland, W.J. 2003: Predicting the response of farmland bird populations to changing food supplies. - Journal of Applied Ecology 40: 970-983.

Trost, R.E., Sharp, D.E., Kelly, S.T. & Caswell, F.D. 1987: Duck harvest and proximate factors influencing hunting activity and success during the period of stabilized regulations. - Transactions of the North American Wildlife and Natural Resources Conference 52: 216-232.

U.S. Fish & Wildlife Service 2008: Adaptive Harvest Management: 2008 Hunting Season. - U.S. Department of the Interior, Washington, D.C., USA, 54 pp.

Walters, C.J., Reed, R. & Ward, J. 1973: Some factors determining success of duck hunters in southern British Columbia. - Canadian Wildlife Service Progress Note 36, 6 pp.

Wilkins, K.A., Otto, M.C. & Koneff, M.D. 2005: Trends in breeding duck populations, 1955-2005. - U.S. Fish and Wildlife Administrative Report, Laurel, Maryland, USA, 19 pp.

Wright, V.L. 1978: Causes and effects of biases on waterfowl harvest estimates. - Journal of Wildlife Management 42: 251-262.