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Research Papers

Linking Canadian Harvested Juvenile American Black Ducks to Their Natal Areas Using Stable Isotope (δD, δ13C, and δ15N) Methods

Établissement de liens entre les Canards noirs juvéniles pris au Canada et leurs régions natales à l’aide des méthodes fondées sur les isotopes stables (δD, δ13C et δ15N)

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ABSTRACT. Understanding source-sink dynamics of game birds is essential to harvest and habitat management but acquiring this information is often logistically and financially challenging using traditional methods of population surveys and banding studies. This is especially true for species such as the American Black Duck (*Anas rubripes*), which have low breeding densities and extensive breeding ranges that necessitate extensive surveys and banding programs across eastern North America. Despite this effort, the contribution of birds fledged from various landscapes and habitat types within specific breeding ranges to regional harvest is largely unknown but remains an important consideration in adaptive harvest management and targeted habitat conservation strategies. We investigated if stable isotope (δD, δ13C, δ15N) could augment our present understanding of connectivity between breeding and harvest areas and so provide information relevant to the two main management strategies for black ducks, harvest and habitat management. We obtained specimens from 200 hatch-year Black Duck wings submitted to the Canadian Wildlife Service Species Composition Survey. Samples were obtained from birds harvested in Western, Central, and Eastern breeding/harvest subregions to provide a sample representative of the range and harvest rate of birds harvested in Canada. We sampled only hatch-year birds to provide an unambiguous and direct link between production and harvest areas. Marine origins were assigned to 12%, 7%, and 5% of birds harvested in the Eastern, Central, and Western subregions, respectively. In contrast, 32%, 9%, and 5% of birds were assigned, respectively, to agricultural origins. All remaining birds were assigned to nonagricultural origins. We portrayed probability of origin using a combination of Bayesian statistical and GIS methods. Placement of most eastern birds was western Nova Scotia, eastern New Brunswick, Prince Edward Island, and southern Newfoundland. Agricultural birds from the Central region were consistent with the Saguenay region of Québec and the eastern claybelt with nonagricultural birds originating in the boreal. Western nonagricultural birds were associated with broad boreal origins from southern James Bay to Lake of the Woods and east to Cochrane, Ontario. Our work shows that the geographic origins, landscape, and habitat associations of hatch-year Black Ducks can be inferred using this technique and we recommend that a broad-scale isotopic study using a large sample of Canadian and US harvested birds be implemented to provide a continental perspective of source-sink population dynamics.

RÉSUMÉ. Une bonne compréhension de la dynamique sources-fuites des oiseaux gibiers est essentielle pour la gestion de la chasse et l’aménagement de l’habitat. Toutefois, l’acquisition de cette information à partir des méthodes traditionnelles de suivi des populations et de baguage est souvent difficile d’un point de vue logistique et financier. Ceci est particulièrement vrai pour des espèces comme le Canard noir (*Anas rubripes*), qui sont caractérisées par de faibles densités et une aire de nidification très étendue qui requièrent des dénombrements à grande échelle et des programmes de baguage dans tout l’est de l’Amérique du Nord.

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En dépit des efforts déployés, la contribution à la chasse régionale d'oiseaux nés dans différents paysages et types d'habitat situés dans des secteurs de nidification spécifiques est presque inconnue, même si cette information demeure très importante pour la gestion adaptative de la chasse et la conservation stratégique des habitats. Nous avons cherché à savoir si les isotopes stables (δD, δ13C, δ15N) pouvaient améliorer notre compréhension de la connectivité entre les zones de reproduction et les secteurs de chasse et à fournir ainsi des renseignements pertinents aux deux principales stratégies de gestion du Canard noir, soit la gestion de la chasse et l'aménagement de l'habitat. Nous avons obtenu les ailes de 200 jeunes canards noirs nés la même année, ayant fait l'objet de l'Enquête sur la composition des prises par espèces du Service canadien de la faune. Les échantillons provenaient d'oiseaux pris dans les sous-régions de reproduction et de chasse de l'Ouest, du Centre et de l'Est afin que les données soient représentatives de l'aire de répartition et du niveau de chasse à travers le Canada. Nous avons prélevé des échantillons seulement à partir d'oiseaux nés la même année afin d'obtenir un lien direct et sans ambiguïté entre les aires de reproduction et les secteurs de chasse. L'origine marine a été attribuée à 12 %, 7 % et 5 % des oiseaux pris dans l'Est, le Centre et l'Ouest, respectivement. En revanche, 32 %, 9 % et 5 % d'oiseaux provenant des régions respectives ont été attribués à des régions agricoles. L'origine de tous les autres oiseaux était considérée comme non agricole. Nous avons représenté la probabilité d'origine en utilisant une combinaison de statistiques bayésiennes et d'approches SIG. La plupart des oiseaux de l'Est provenaient de l'ouest de la Nouvelle-Écosse, de l'est du Nouveau-Brunswick, de l'Île-du-Prince-Édouard et du sud de Terre-Neuve. Les oiseaux d'origine agricole de la région centrale étaient analogues à ceux de la région du Saguenay (Québec), tandis que ceux de la ceinture d'argile étaient apparemment d'origine non agricole et boréale. Les oiseaux d'origine non agricoles de l'Ouest avaient une origine boréale, soit du sud de la baie de James à lac des Bois et à l'est jusqu'à Cochrane, Ontario. Nos travaux indiquent que, grâce à cette technique, l'on peut déduire des associations entre l'origine géographique, le type de paysage et le type d'habitat des Canards noirs nés la même année. Nous recommandons ainsi qu'une analyse isotopique à grande échelle portant sur un grand échantillon d'oiseaux pris au Canada et aux États-Unis soit entreprise afin de fournir une perspective continentale sur la dynamique sources-fuites des populations.

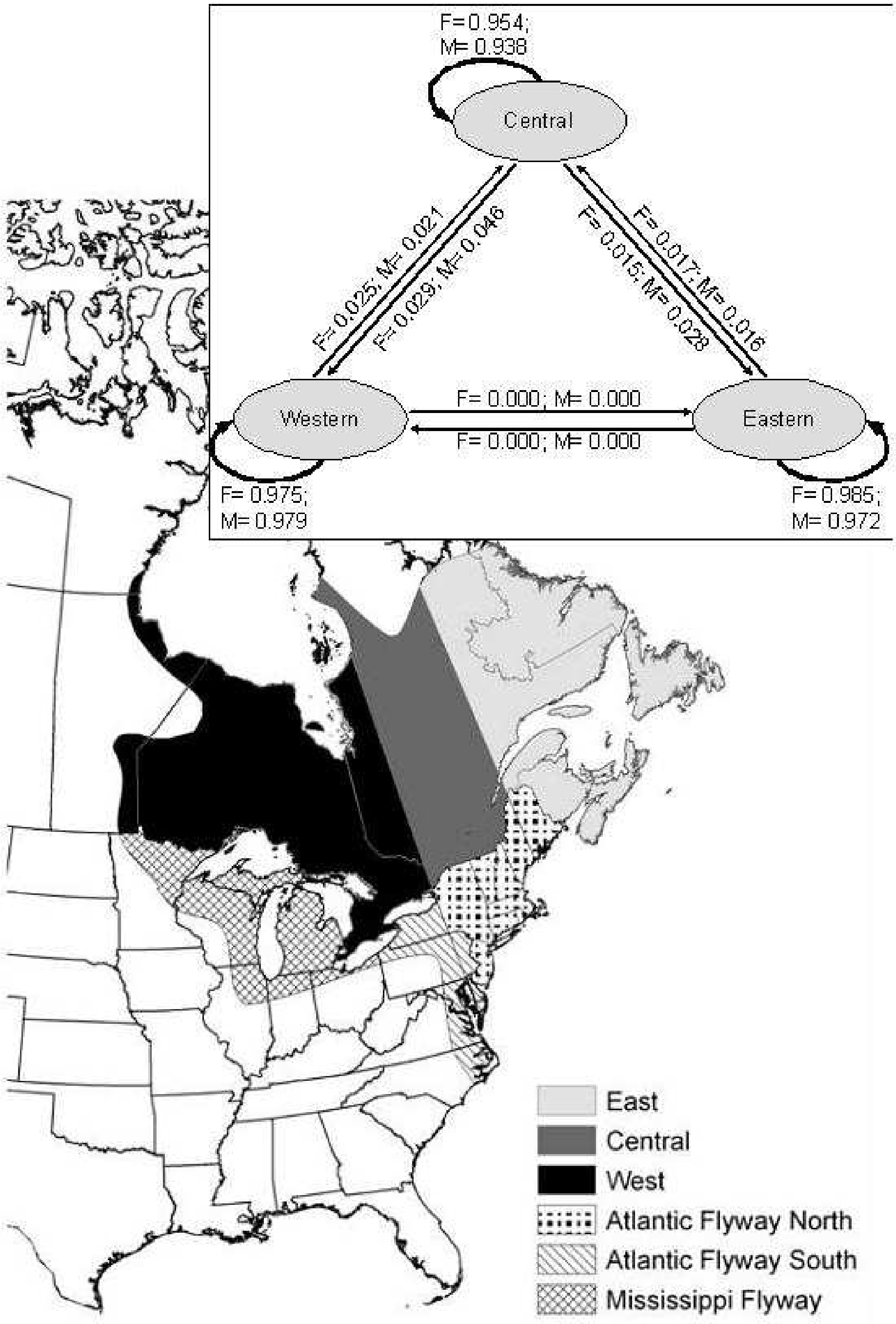
Key Words: *American Black Duck; Anas rubripes; harvest and habitat management; natal areas; stable isotopes*

INTRODUCTION

Effective harvest management of migratory game birds requires knowledge of the geospatial linkages between production and harvest areas as well as an understanding of how discrete breeding populations contribute to regional harvest (Hobson et al. 2006, Runge et al. 2006, Hobson et al. 2009). This understanding is particularly important for species such as the American Black Duck (*Anas rubripes*; hereafter Black Duck), which exhibits markedly different demographic characteristics among harvested populations (Conroy et al. 2002). Numerous Black Duck populations have been identified across eastern North America by the distribution and recovery of banded individuals (Lemieux and Moisan 1959, Geis et al. 1971, Pendleton and Sauer 1992) but adaptive harvest management (AHM) of individual breeding stocks is currently not possible. Consequently, the Black Duck Adaptive Management Working Group has tentatively amalgamated the populations along major migration corridors and geopolitical boundaries to create three breeding/harvest areas in Canada and another three harvest subregions in the US (Fig. 1; Zimpfer and Conroy 2006).

Agencies of both the Canadian and US governments conduct mark-recapture studies, large-scale breeding ground surveys, and harvest and species composition surveys to assist with AHM of the species. Acquiring such information is logistically and financially challenging, and despite this effort, the contribution to regional harvest made by birds fledged from various populations, landscapes, and habitat types within specific breeding ranges cannot be adequately deduced. We analyzed stable isotope markers of Canadian harvested juvenile Black Ducks to see if we could improve upon our understanding of connectivity between breeding

Fig. 1. Breeding and harvest area delineations for American Black Ducks (*Anas rubripes*). Arrows represent movements between populations and movement probabilities for males (M) and females (F). Curved arrows represent probabilities associated with birds remaining in the same area as their natal origin (modified from Zimpfer and Conroy 2006). Origins are constrained to the recognized North American range (Longcore et al. 2000).



and harvest areas at a scale relevant to Black Duck harvest and habitat management, currently the main approaches to managing this species (Runge et al. 2006).

Stable isotope measurements of the light elements in animal tissues (e.g., δD, $\delta^{18}O$, $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) can provide an intrinsic marker to determine the origins of migratory animals (Hobson 1999, Hobson and Wassenaar 2008) and can be used to predict natal regions of harvested birds (Hobson et al. 2006, 2009, Dunn et al. 2006). Origins on a broad geographic scale may be inferred because predictable continental-scale patterns of δD occur in precipitation across North America. For instance, amount-weighted mean growing season δD in precipitation exhibits a general decline with increased latitude from southeast to northwest, with some exceptions in coastal and montane areas, and this pattern is passed on to higher trophic levels (Hobson and Wassenaar 1997). The use of the δD approach in cases where birds may have access to marine or estuarine foodwebs during tissue growth or synthesis is much more complex and potentially confounding (Larson and Hobson 2009). In some cases, alternate isotope measurements can assist in sorting out some of this complexity. For example, use of freshwater vs. marine habitat prior to fledging may be inferred using other isotopes (e.g. $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$), which typically differ substantially between marine habitats and those with terrestrial C3 freshwater, i.e., a metabolic pathway where CO_2 is converted to 3-phophoglycerate, a stable intermediate organic compound . Birds fledged from agricultural or nonagricultural landscapes might also be inferred using $\delta^{15}N$ measurements because of enrichment in ^{15}N in agricultural landscapes (Hebert and Wassenaar 2001, Yerkes et al. 2008, Pardo and Nadelhoffer 2010).

Here, we report the results of a preliminary isotopic (δD, $\delta^{13}C$, and $\delta^{15}N$) analysis of Black Duck feathers to link natal and Canadian harvest areas of hatch-year birds (HY), i.e., birds in their first calendar year of life and usually ≤ 7 months old, for each of the three Canadian breeding and harvest subregions and infer prefledging habitat associations.

METHODS

Collection of specimen wings

To provide a sample representative of the range and proportion of harvest of birds taken in Canada, we obtained feather samples from 200 HY Black Duck wings submitted to the Canadian Wildlife Service (CWS) Species Composition Survey (SCS) from birds harvested in Western (n=21), Central (n=58), and Eastern (n=121) subregions (Fig. 1). For each sample, we recorded date and location of harvest from the information supplied by the hunter. Age and sex were determined using methods developed by Carney (1992). We sampled only HY birds to provide an unambiguous and direct link between production and harvest areas. Primary feathers of HY birds were analyzed because they are grown prior to fledging and are fully developed 44 to 60 days posthatch (Palmer 1976). For each sample, we pulled the first primary, i.e., P1, adjacent to the first secondary, and stored it in a paper envelope for later analysis.

Stable isotope analysis

Prior to analysis, all feathers were cleaned of surface oils in a 2:1 chloroform:methanol solvent rinse and prepared for stable-hydrogen isotope analysis at the Stable Isotope Hydrology and Ecology Laboratory of Environment Canada in Saskatoon, Canada. The comparative equilibration method described by Wassenaar and Hobson (2003) was used for stable-hydrogen isotope analyses of feathers, through the use of calibrated keratin hydrogen-isotope reference materials. Stable-hydrogen isotope measurements were performed on H_2 derived from high-temperature (1400ºC) flash pyrolysis of 350±10 *ug* feather subsamples using continuous-flow isotope-ratio mass spectrometry. All results are for nonexchangeable δD expressed in the typical delta notation, in units of per mil (‰), and normalized on the Vienna Standard Mean Ocean Water – Standard Light Antarctic Precipitation (VSMOW-SLAP) standard scale. Measurement of three keratin laboratory reference materials (CFS, CHS, BWB), corrected for linear instrumental drift, were both accurate and precise with typical mean δD ± SD values of –147.4 ± 0.79‰ (n=5), -187 ± 0.56‰ (n=5) and -108 ± 0.33‰ (n=5) per autorun, respectively. A control keratin reference yielded a 6-month SD of ±3.3‰ (n=76). All results are for nonexchangeable δD expressed in the typical delta notation, in units of per mil (‰), and normalized on the Vienna Standard Mean Ocean Water – Standard Light Antarctic Precipitation (VSMOW-SLAP) standard scale.

Stable-carbon and nitrogen isotope analyses were performed by weighing out ~1 mg distal feather vane samples into tin cups. Sealed cups were then combusted in a Robo-Prep elemental analyzer interfaced with a Europa 20:20 continuous flow isotope ratio mass spectrometer. Two internal laboratory standards (egg albumen and Bowhead Whale Baleen) were placed between every 5 unknowns. Results were calibrated to the VPDB and AIR standards for $\delta^{13}C$ and $\delta^{15}N$ values, respectively. Based on within-run replicate measurements of standards, we estimated measurement precision to be ±0.1 °/oo for $\delta^{13}C$ and ±0.3°/oo for $\delta^{15}N$.

Statistical analysis

Establishing catchment areas for harvested American Black Ducks

Prior to assigning samples to a feather deuterium isoscape, we followed the approach of Yerkes et al. (2008), and classified samples into freshwater vs marine, on the basis of $\delta^{13}C$, and agricultural vs nonagricultural, on the basis of $\delta^{15}N$, sources. Samples having $\delta^{13}C$ values ≤ -20‰ were classified as freshwater and if > -20‰ were classified as marine (Fry and Sherr 1989; Hobson and Sealy 1991; Hobson 1999). Similarly, feathers with $\delta^{15}N$ ≥ 9‰ were considered as having come from an agricultural source, whereas all others were assumed to have come from nonagricultural sources (Hebert and Wassenaar 2001, 2005, Yerkes et al. 2008). To determine the sensitivity of assignment to freshwater and marine habitats and agricultural and nonagricultural landscapes, we compared assignments ± 1‰ to these thresholds. Where samples showed evidence of marine inputs, we made no further attempt to assign geographic origins based on δD of feathers (hereafter δD_f). Sixteen samples were subsequently excluded from the analysis because assigning geographic origins based on δD_f are unreliable when marine inputs are involved. We realize this approach is not favored by some (e.g., Rocque et al. 2009) but we believe it is the most parsimonious and valuable use of such multi-isotope datasets (Larson and Hobson 2009).

Geographic assignment of Black Duck natal origins based on δD_f is complicated by analytical error, interindividual differences in physiology between birds growing feathers at the same site, and errors associated with the surface to which the birds are being assigned (Wunder and Norris 2008). Therefore, measured δD_f values could not be directly mapped without considering possible sources of assignment error. We therefore used a likelihood-based assignment that incorporates estimates of uncertainty to place individuals to their geographic origins (Royle and Rubenstein 2004). To accomplish this, we first converted a GIS-based model of amount-weighted growing-season δD in precipitation (hereafter δD_p; Bowen et al. 2005), into a δD_f model. Eighty eight percent of the variance in δD_f from known-origin scaup and songbirds (Clark et al. 2006) was explained by δD_p, resulting in the equation ($\delta D_f = -30.44 + 0.93\ \delta D_p$) that was used to convert the GIS model of δD_p into a δD_f isoscape. All values within the resulting isoscape were then rounded into one per mil bands. For each individual sample, i.e., each bird, we subsequently assessed the likelihood that a given isotope band within the isoscape represented a potential origin for the individual using a Normal probability density function (Equation 1):

$$f(y^* \mid \mu_b, \sigma_b) = \left(\frac{1}{\sqrt{2\pi}\sigma_b}\right) \exp\left[-\frac{1}{2\pi\sigma_b^2}(y^* - \mu_b)^2\right] \quad (1)$$

Where $f(y^* \mid \mu_b, \sigma_b)$ represents the probability that a given band (b) represents a potential origin for an individual of unknown origin (y^*), given the expected mean δD_f for that band (μ_b), and the expected standard deviation (σ_b) of δD_f between individuals growing their feathers at the same locality. We estimated σ_b using the standard deviation of the residuals from the regression equation reported above (σ =12.8‰).

Band recovery data indicate that there is very little migration between breeding strata prior to hunting in Canada (Zimpfer and Conroy 2006). Therefore, we used movement probabilities between breeding/harvest regions (hereafter "population") identified by Zimpfer and Conroy (2006) as prior probabilities to further limit assignments to the most likely origins (see Fig. 1). Following Zimpfer and Conroy (2006), we assumed that movements of birds moving northward from the Atlantic Flyway North, Atlantic Flyway South, and Mississippi Flyways (see Fig. 1) would be minimal relative to continental migration, and thus assumed those prior probabilities to be approximately equal to zero. Thus, for each combination of isotope band, sex (see Fig. 1 for sex specific priors), and population, we calculated posterior probabilities as the product of Equation 1 and the prior probability that a bird shot within a breeding/harvest region originated from that region based on band recovery data. We then estimated the "probability of origin" by normalizing the posterior probabilities (Eq. 1) as follows (Equation 2):

$$\pi_b = \frac{f(y^* \mid \mu_b, \sigma_b)}{\sum_{b-1}^{B} f(y^* \mid \mu_b, \sigma_b)} \qquad (2)$$

For each population of interest, i.e., Eastern, Central, and Western, we assigned individual Black Ducks to the δD_f isoscape by first determining the odds that any given assigned origin, i.e., 1‰ isotopic band, was correct relative to the odds it was incorrect using an odds ratio. Based on 2:1 odds that a given assigned bird had truly originated from within that range, we identified the set of isotopic bands that defined the upper 67% of estimated "probabilities of origin" (from Equation 2) and coded those as 1 and all others as 0. For each isotopic band, we then summed the results for each of the individual assignments across all birds in the sample. For each individual sample, this resulted in a bird being assigned to multiple isotopic bands that represented probable origins for that sample, based on the odds ratio, given both measured δD_f and known error. We then mapped the summed results onto the δD_f isoscape using ArcGIS™ v. 9.2 and Spatial Analyst™ (ESRI, Redlands, CA) to reclassify the rounded δD_f isoscape based on the number of birds that were assigned to a given isotopic band. To further restrict depictions of the natal origins of HY American Black Ducks, we used an ArcGIS™ Spatial Analyst™ to clip the grid of assigned origins to the known breeding range.

RESULTS

Fourteen Black Ducks (12%) shot in the Eastern region had $\delta^{13}C$ values > -20‰ and were thus classified as marine in origin and not assigned to geographic origins using the δD_f isoscape. In comparison, four birds (7%) harvested in the Central region and one bird harvested in the Western region (5%) were isotopically consistent with our definition of "marine origins".

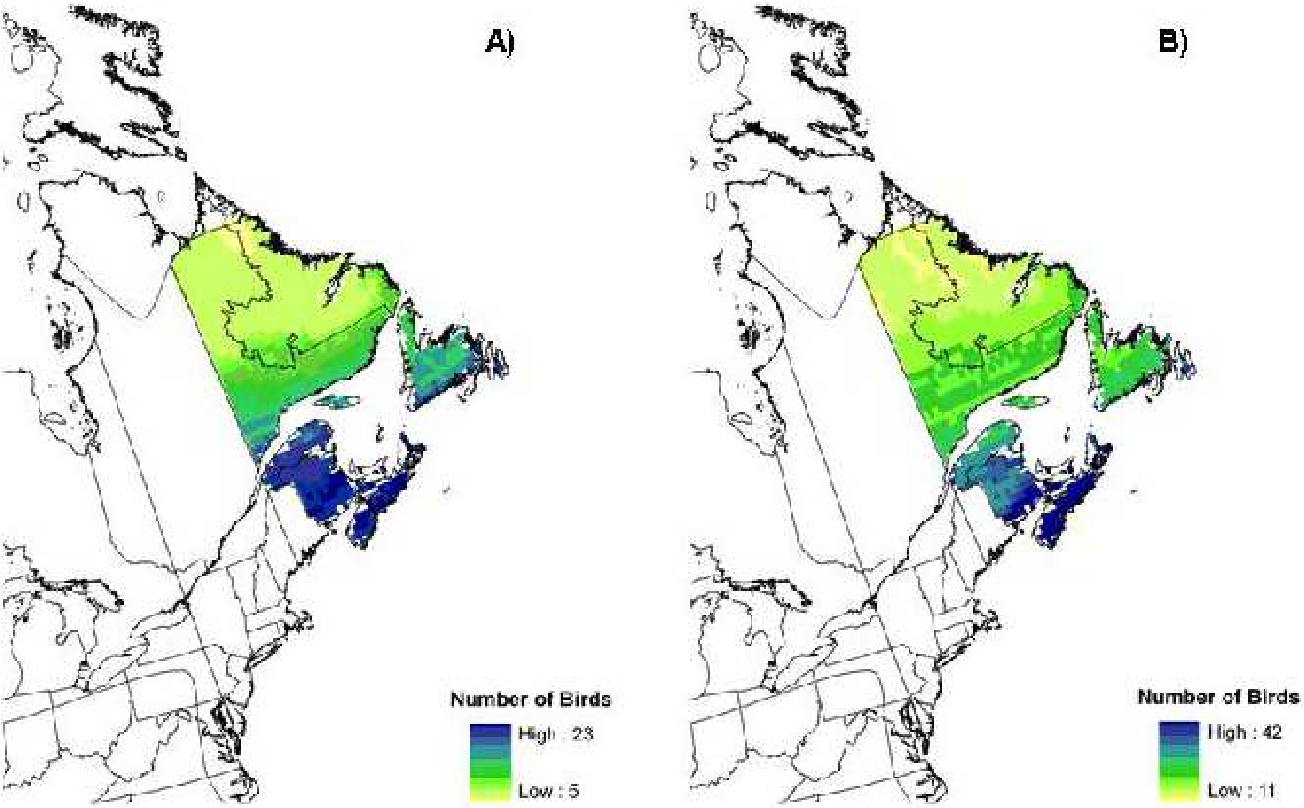
Thirty-nine (32%) birds shot in the Eastern subregion were assigned to agricultural sources (Fig. 2A). The remaining 68 birds harvested in the Eastern subregion (56%) were assigned to nonagricultural sources. The majority of both the agriculturally and nonagriculturally derived birds were assigned to origins that were consistent with Nova Scotia, eastern New Brunswick, Prince Edward Island, and the southern edge of Newfoundland (Fig. 2A and B, respectively).

Only five birds (9%) harvested in the Central subregion were assigned to agricultural sources. The remaining 49 birds (84%) were assigned to nonagricultural sources. The majority of agriculturally derived birds were assigned to origins consistent with central Québec, most likely in the Saguenay region or eastern edge of the claybelt area in Abitibi County (Fig. 3A). Nonagriculturally derived birds harvested in the Central subregion were assigned to a broad region of central Québec; with most birds assigned to a region extending between James Bay and the St. Lawrence Island and south toward Montréal (Fig. 3B).

Of the 21 birds harvested in the Western subregion, only one bird (5%) had a feather $\delta^{15}N$ value that suggested agricultural origins. This bird was assigned to origins consistent with parts of Ontario extending from the north shores of Lake Ontario, to north-west of Lake Superior (Fig. 4A). Although Figure 4A represents the origin for only one bird, this sample provides an illustration of the statistical methodology used to derive a solution space on an individual-by-individual basis. The figure depicts a large portion of Ontario as representing an origin for this sample; however, the region defined within Figure 4A represents a solution space from which this particular sample is likely to be derived, with a 67% chance of correct assignment. Nonagriculturally derived Black Ducks harvested in the Western subregion (n=19, 90%) were largely assigned to origins in the boreal forest of Ontario and western Québec (Fig. 4B). Within this region, the majority of the assignments were to areas extending from Lake of the Woods to southern James Bay and toward Cochrane, Ontario (Fig. 4B).

A ± 1‰ change in the $\delta^{13}C$ threshold we chose produced a maximum change of 5% in assignment from freshwater to marine habitats (Table 1). For

Fig. 2. Probable origins of American Black Ducks (*Anas rubripes*) harvested in the Eastern breeding/harvest region during the 2005 hunting season for birds fed in A) agricultural areas (*n*= 39) and B) in nonagricultural areas (*n*= 68). A likelihood based assignment was used to place individuals to geographic origins on the basis of stable hydrogen isotope values (see Methods). The results displayed represent the sum of assignments across the samples (see Methods).

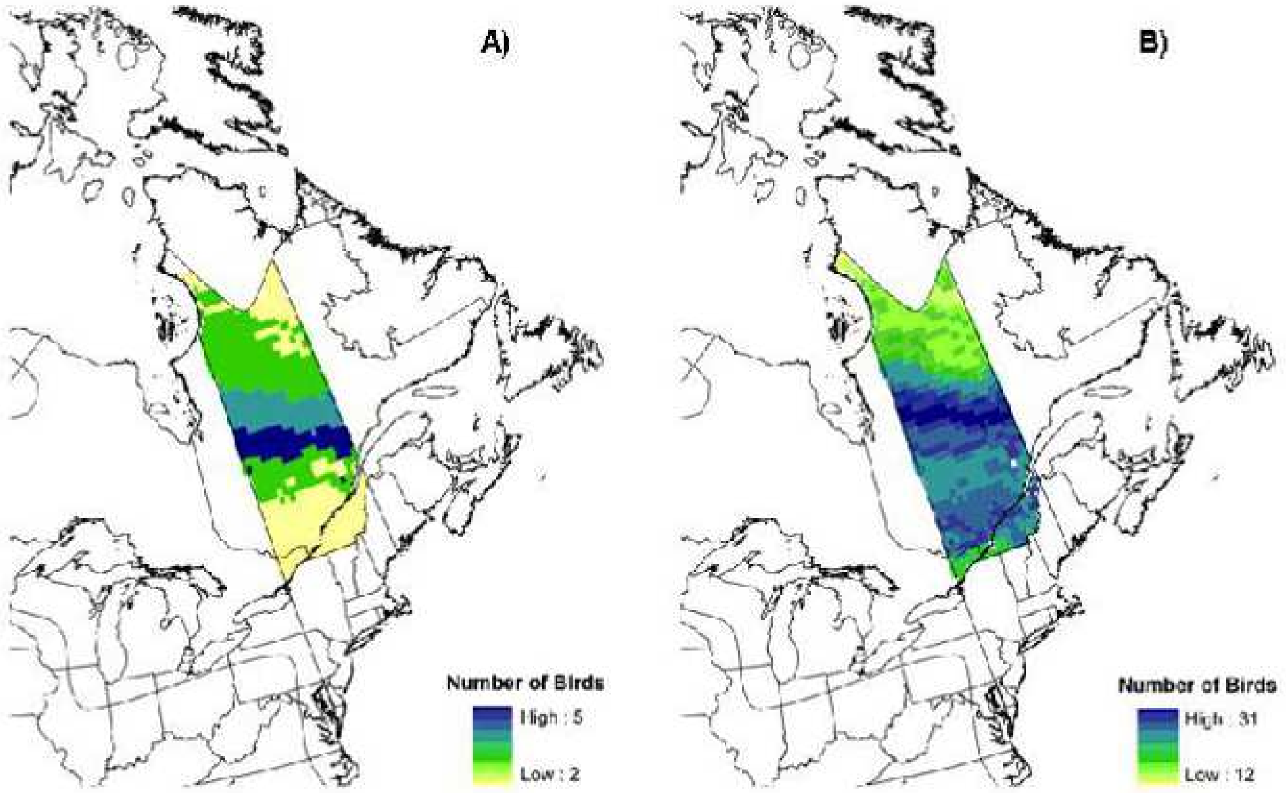


the designation of agricultural landscapes, a ± 1‰ change in $\delta^{15}N$ threshold produced a maximum change of 22%, with the cutoff threshold between 8 and 9‰ producing more than double the number of reassignments than the cutoff threshold between 9 and 10‰.

DISCUSSION

Our work shows that isotope analysis of hunter-harvested Black Ducks is useful for advancement of both habitat and harvest management. Using a multiple-isotope approach, we identified geographic regions, landscapes, and habitat associations of conservation importance to the maintenance of harvested stocks. Although most of these areas have been identified previously as important waterfowl production areas, our work provides additional quantitative estimates of their contribution to

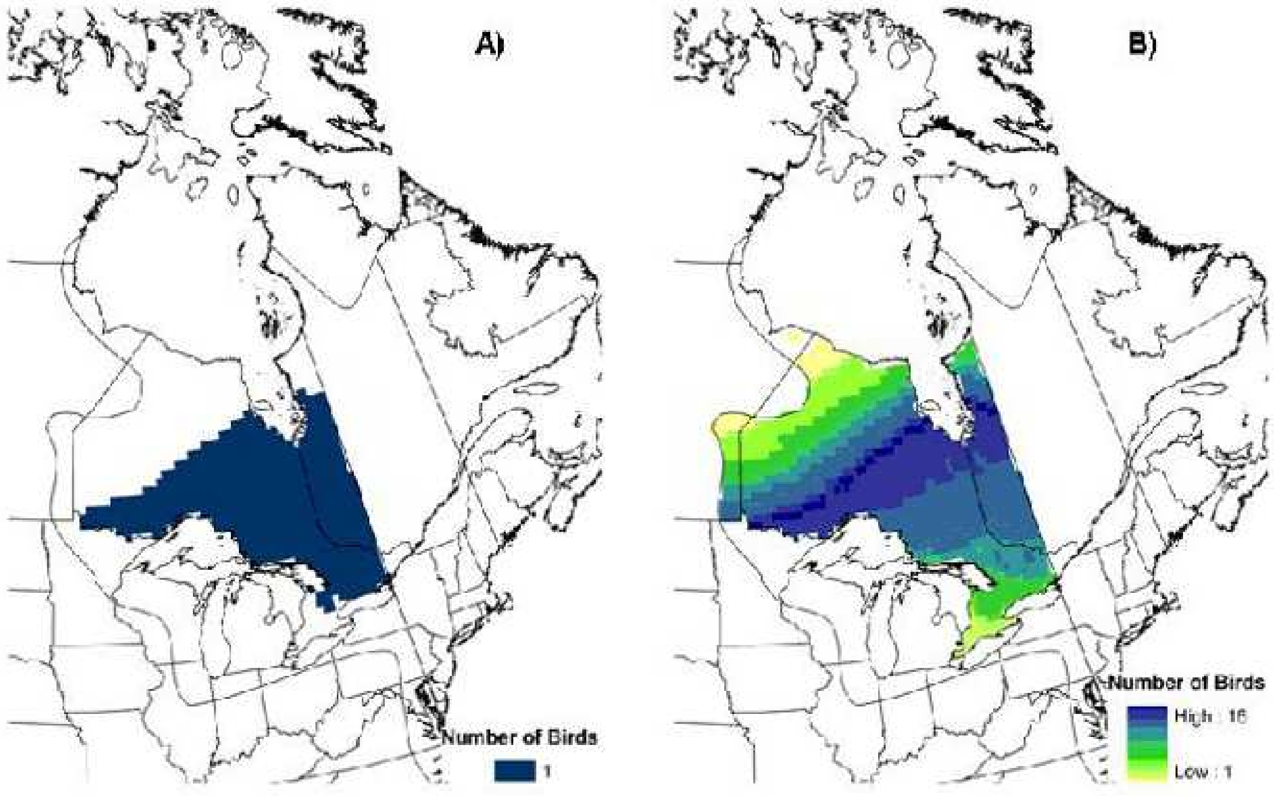
Fig. 3. Probable origins of American Black Ducks (*Anas rubripes*) harvested in the Central breeding/harvest region during the 2005 hunting season for birds fed in A) agricultural areas (*n*= 5) and B) in nonagricultural areas (*n*= 49). A likelihood based assignment was used to place individuals to geographic origins on the basis of stable hydrogen isotope values (see Methods). The results displayed represent the sum of assignments across the samples (see Methods).



regional harvest. This is a great step forward as it is extremely difficult using traditional methods to establish an unbiased cohort of marked individuals in any given year that represents all possible geographic origins and also obtain sufficient and timely recoveries from which to make management decisions (Hobson 2008, Hobson et al. 2009).

Our analysis of feather δ^{13}C values allowed us to approximate the proportion of the harvest originating from freshwater and marine/brackish habitats. Assignments based on our threshold value did not substantially change. Black Ducks nest and raise broods in a variety of predominantly freshwater habitats and are often associated with active and reflooded beaver ponds (Ringleman and Longcore 1982, Parker et al. 1992, Meredino et al. 1995). Saltwater and brackish marshes are also used extensively along the Atlantic coast (Stotts and Davis 1960, Krementz et al. 1992), St. Lawrence estuary (Reed and Moisan 1971), Hudson Bay and James Bay (Ross and Fillman 1990). Despite the abundance of this habitat type and its reportedly high use, only about 8% of birds in this study originated from marine-influenced habitats prior to fledging. The highest use of marine-influenced environments (about 12%) by prefledging birds was found in the Eastern subregion and associated Atlantic coastal marshes. A smaller percentage of the Central (7%) and Western (5%) subregion birds

Fig. 4. Probable origins of American Black Ducks (*Anas rubripes*) harvested in the Western breeding/harvest region during the 2005 hunting season for birds fed in A) agricultural areas (*n*= 1) and B) in nonagricultural areas (*n*= 20). A likelihood based assignment was used to place individuals to geographic origins on the basis of stable hydrogen isotope values (see Methods). The results displayed represent the sum of assignments across the samples (see Methods).



were classified as such and presumably derived from the coastal marshes of Hudson's Bay and James Bay.

The remaining nonmarine-influenced specimens were assigned to freshwater habitats and stratified into agricultural and nonagricultural landscapes. Reassignment of specimens to agricultural and nonagricultural landscapes based on ± 1‰ change in cutoff thresholds was more sensitive than those of $\delta^{13}C$. Until better estimates of feather $\delta^{15}N$ values and associated variance known to be associated with agricultural and nonagricultural lands are available, we suggest that estimates presented here be interpreted with caution. Future studies will attempt to refine these threshold estimates regionally and to also, when possible, test our predictions based on Black Ducks from known origins.

We were fortunate that Zimpfer and Conroy (2006) analyzed over 30 years of band recovery data to provide prior probabilities of movement between breeding and harvest areas which greatly reduced the area of probable origins to one of three Canadian breeding/harvest subregions. Most birds (136/181, 75%) were assigned to origins consistent with nonagricultural landscapes with highest agricultural associations in the east and lowest in the west. Only one bird harvested in the Western subregion showed evidence of association with an agricultural

Table 1. Sensitivity of American black duck feather samples to assignment to freshwater and marine habitats, and agricultural and non-agricultural landscapes based δ13C on and δ15N thresholds, respectively.

Breeding Sub-region	δ^{13}C threshold ‰	% Freshwater	% Marine	δ^{15}N threshold ‰	% Agriculture	% Non-Agriculture	% Marine
Western							
n = 22	*-19*	100	0	*8*	27	68	5
	-20	95	5	*9*	5	91	5
	-21	95	5	*10*	0	95	5
Central							
n = 58	*-19*	95	5	*8*	28	66	7
	-20	93	7	*9*	9	84	7
	-21	91	9	*10*	9	84	7
Eastern							
n = 118	*-19*	93	7	*8*	42	49	9
	-20	91	9	*9*	33	58	9
	-21	90	10	*10*	23	68	9

landscape prior to fledging. The agricultural area of the Western subregion, i.e., southern Ontario, historically provided important breeding habitats for Black Ducks (Collins 1974, Ankney et al. 1987) but they are now uncommon breeders in the region, being found mainly in the boreal region to the north (Merendino and Ankney 1994). The inferred origin of the one Western subregion bird is north of most agricultural lands but consistent with agricultural areas associated with the Great Claybelt, a relatively fertile region in the boreal forest. The Great Claybelt is characterized by clay soils that support limited agriculture and, in comparison with the surrounding muskeg and exposed bedrock of the Canadian shield, its wetlands support higher densities of nesting waterfowl.

In the Central subregion, 9% of birds originated from agricultural landscapes. Our analysis suggests that these birds originated from either the eastern edge of the claybelt region or the lowland agricultural areas of the Saguenay region. Black Duck use of Québec agricultural areas has decreased but is still higher than indicated breeding pair densities for southern Ontario before their decline (Maisonneuve et al. 2006). This apparent abundance is not reflected in the harvest of HY birds from the Central subregion, and birds produced in this area may be contributing more substantially to US harvest. Use of agricultural landscapes was highest in the eastern portions of the Central subregion with approximately one-third of all birds showing evidence of association with agriculture. Although we did not differentiate between different agricultural types, e.g., cereal grains vs. grasslands, we suspect that regional differences in agricultural activities influence Black Duck distribution and abundance. For instance, habitat models developed by Maisonneuve et al. (2006) identified an inverse relationship between cereal grain production and Black Duck nesting densities.

Cropland agriculture as a percentage of agricultural lands increases from east to west and therefore supports our hypothesis as well as the Maisonneuve et al. (2006) model. Most Western subregion birds in this study originated from nonagricultural lands from mid-latitudes of the subregion that includes the claybelt region and has been identified as a zone of medium breeding densities for the province (5-10 indicated pairs/km^2; Ross and Fillman 1990). The largest part of nonagriculturally assigned birds from the Central subregion originated from a band of similar latitude as those in the west and birds at the western edge of the subregion may be associated with the claybelt area. Most birds harvested in the Eastern subregion originated from the southern portion of their breeding range from the forests of Nova Scotia and New Brunswick. Northern populations were poorly represented in our sample and it is possible that these birds overfly southern Canadian harvest areas and are harvested in the US.

Our use of isotopic thresholds to categorize birds to marine vs C3-terrestrial/freshwater and to agricultural vs nonagricultural landscapes was not without error. However, without an exhaustive analysis of birds of known origins among each of these habitat types, it is currently not possible to estimate the error in our assignments. Nonetheless, the review by Yerkes et al. (2008), which formed the basis of our choice of thresholds and was indeed based on all available waterfowl and other avian taxa for North America, provides us with a reasonable basis for our approach. Again, future isotopic analyses of birds of known origin are encouraged so that we can refine these sorts of assignments and, more importantly, assign error or variance estimates that can be incorporated into probabilities of assignment.

The international harvest strategy for Black Ducks calls for an equal division of the total harvest between Canada and the US. Therefore, determining which populations are being harvested by each country and the capacity of those populations to sustain harvest is a necessary step in the management of the species. We recommend that a broad-scale isotopic study using a large sample of Canadian and US harvested Black Ducks be implemented to provide a continental picture of source-sink population dynamics. Because adult females molt primaries near their nest site (Longcore et al. 2000) they could also be used to provide a direct isotopic link to breeding areas. Such a study would provide the first comprehensive and unbiased study of source-sink dynamics of any North American game bird species.

Responses to this article can be read online at:
http://www.ace-eco.org/vol5/iss2/art7/responses/

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