Are Wintering Areas Shifting North? Learning from Lesser Snow Geese Banded in Southwest Louisiana

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Abstract - Several avian species have shifted their wintering or staging areas north in response to advancing onset of spring. Our objectives were to determine whether (1) the latitudinal distribution of recoveries changed for *Chen caerulescens caerulescens* (Lesser Snow Goose; hereafter Snow Goose) banded in southwest Louisiana, and (2) annual proportions of recoveries within Louisiana relative to other locations in the midcontinent flyways were related to local weather or Snow Goose population estimates for southwest Louisiana. We collated and analyzed population indices from the annual midwinter waterfowl survey for the period 2002–2013 with band recovery and local weather data. Latitudes of recovery shifted north during the period, and the increases were independent of season (fall, midwinter, and late winter/spring migration). Annual proportions of recoveries within Louisiana (all from southwest Louisiana), were lower during wet winters when the largest numbers of Snow Geese were counted in southwest Louisiana. We concluded that Snow Geese banded in our study area have shifted their wintering range northwards. Furthermore, the probability of recovery in Louisiana was somewhat dependent on Snow Goose numbers present, apparently because hunters shoot proportionally fewer banded birds during years with more Snow Geese, which in turn were related to high amounts of precipitation in the area.

Introduction

Several avian species, including some goose species, have advanced their migratory schedules and shifted their wintering or staging areas further north in response to an advance in the onset of spring (Fox and Walsh 2012, Gunnarsson and Tómasson 2010, Lehikoinen et al. 2008, Tombre et al. 2008). Historically, wintering geese were reported to be site-tenacious, but recent data have shown them to be more flexible and opportunistic, especially so for sub-adult geese, when selecting annual wintering sites (Kruckenberg and Borbach-Jaene 2004, Owen 1980, Prevett and MacInnes 1980, Raveling 1979). Hatch-year geese learn migratory paths from after-hatch-year geese, which generally return to previous staging, wintering, and breeding areas (Prevett and MacInnes 1980), whereas sub-adult geese are more mobile and exploratory in nature (Kruckenberg and Borbach-Jaene 2004).

Investigations of waterfowl band-recoveries have indicated northward shifts, although such changes may be largely explained by changes in hunting pressure rather than actual bird distribution (Lehikoinen et al. 2008). In North America, winter ranges of *Chen caerulescens caerulescens* L. (Lesser Snow Goose; hereafter

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Snow Goose) have shifted in response to changes in food availability (Alisauskas et al. 2011). Throughout each of 4 administrative waterfowl flyways, local Snow Goose numbers vary annually because of varying breeding success among colonies; food availability at breeding, staging, or wintering areas; hunting pressure; and weather (Mowbray et al. 2000).

Our first objective was to determine whether Snow Geese banded in Louisiana during winters of 2001–2004 shifted their wintering range northward between 2001 and 2013, perhaps because of the increasingly milder winters (US Environmental Protection Agency 2013). There are indications that waterfowl can winter further north during milder winters (Schummer et al. 2010).

Our second objective was to examine whether annual proportions of recoveries within Louisiana, relative to the sum of recoveries from other US states or Canadian provinces, were related to local weather or annual variations in Snow Goose numbers within southwest Louisiana. A higher proportion of recoveries in Louisiana would indicate that Snow Geese migrated all the way south, whereas a low proportion in Louisiana would indicate that either the birds stopped north of the state or there was low hunting pressure in Louisiana. Annual proportions of recoveries within Louisiana could be a function of vulnerability to hunting pressure—the primary source of recoveries. In turn, vulnerability to hunting may depend on hunter access and less so on hunter numbers, which can be restricted by environmental parameters. For example, local rainfall determines water levels in marshes, *Oryza sativa* L. (Rice) fields, and other wetlands (i.e., increased availability of standing water that may offer greater safety from hunters). Thus, temperature and precipitation in winter could affect whether Snow Geese move south to Louisiana earlier in the fall or back northwards from Louisiana within a given winter. Accordingly, we included local weather data in our analyses. Prior to conducting our analyses, we evaluated and were prepared to account for potential annual and spatial variation in hunting pressure, if needed.

Methods

We banded and neck-collared 1123 Snow Geese, (n = 993 after-hatch-year-plumage, n = 130 hatch-year-plumage) in southwest Louisiana in winters of 2001–2002, 2002–2003, and 2003–2004 (Jónsson 2005, Jónsson et al. 2014). We analyzed 12 winters (2002–2013) of recoveries of these banded Snow Geese. From November 2001 to March 2013, the US Geological Survey's Bird Banding Lab received 219 recoveries, of which 205 (93.6%) were reported as shot by hunters. Of the 14 recoveries not reported by hunters, 2 birds were reportedly found dead (one from southwest Louisiana on 20 December 2002 and the other from South Dakota on 27 November 2003); 1 bird was reported as band only from Colorado in 2006 with no date provided; 1 bird was caught and released at Anahuac National Wildlife Refuge, TX, on 20 January 2004; and 10 birds were reported as sight records by neck-collar observers. We included the 14 non-hunter recoveries in our analysis because most of them were comparable to other recoveries within the same states and range of dates. Among the sight recoveries were 2 exceptional recoveries from more distant regions, i.e., from Pennsylvania in March 2006 and Colorado in September 2006. A majority (60.7%) of the 219 recoveries were from the Gulf Coast or Upper South, although there were notable recoveries from the Midwest as well (Table 1).

Spring and fall migration routes are similar for midcontinent Snow Geese, which generally arrive in southwest Louisiana in November and December, and initiate spring migration north in January and February (Bateman et al. 1988, Jónsson 2005, Jónsson et al. 2014, Mowbray et al. 2000). Snow Geese stage and sometimes overwinter in Arkansas, Nebraska, Oklahoma, Kansas, Iowa, Illinois and Tennessee, in addition to southern Mississippi, Louisiana, and Texas (Davis et al. 1989, Mowbray et al. 2000). We grouped recoveries into 3 seasons, based on observed Snow Goose migration schedules and gaps within the range of recovery dates: (1) fall migration, which included all recoveries in September through 6 November; (2) midwinter, which spanned from 16 November (the date of the next recovery after 6 November) through 12 January; and 3) late winter/spring, from 15 January (the next recovery after 11 January, and around that date recoveries from

Table 1. Number of recoveries (%) of Lesser Snow Geese within the midcontinent region for winters 2002–2013, from Snow Geese banded in southwest Louisiana during winters 2002–2004.

Region	State	2002–2007	2008–2013	Total
Gulf Coast	Louisiana	65 (73.9)	23 (26.1)	88
	Texas	6 (100.0)	0 (0.0)	6
	Total	71 (75.5)	23 (24.5)	94
Upper South	Arkansas	24 (70.6)	10 (29.4)	34
	Mississippi	4 (100.0)	0 (0.0)	4
	Oklahoma	1 (100.0)	0 (0.0)	1
	Total	29 (74.4)	10 (25.6)	39
Lower Midwest	Missouri	7 (50.0)	7 (50.0)	14
	Kansas	1 (25.0)	3 (75.0)	4
	Kentucky	1 (100.0)	0 (0.0)	1
	Illinois	1 (50.0)	1 (50.0)	2
	Total	10 (47.6)	11 (52.4)	21
Upper Midwest	Nebraska	7 (63.6)	4 (36.4)	11
	Iowa	5 (83.3)	1 (16.7)	6
	South Dakota	7 (63.6)	4 (36.4)	11
	North Dakota	9 (100.0)	0 (0.0)	9
	Colorado	1 (50.0)	1 (50.0)	2
	Pennsylvania	1 (100.0)	0 (0.0)	1
	Total	30 (75.0)	10 (25.0)	40
Canada	Saskatchewan	11 (68.7)	5 (31.3)	16
	Manitoba	3 (50.0)	3 (50.0)	6
	Nunavut	1 (33.3)	2 (66.7)	3
	Total	15 (60.0)	10 (40.0)	25
Grand Total		155 (70.8)	64 (29.2)	219

north of Louisiana, especially Arkansas, were initially reported) through 21 April. During late winter/spring, most hunting occurred under liberalized hunting regulations during the Snow Goose Special Conservation Order (Kruse and Fronczak 2014), but dates varied by goose-hunting zones (within and among states). Used as a tool to limit increasing populations, this annual order sets harvest targets for light geese—*Chen caerulescens* L. (Greater Snow Geese), Lesser Snow Geese, and *C. rossii* Cassin (Ross's Geese).

The midwinter waterfowl survey is conducted annually by US Fish and Wildlife Service (USFWS) and Louisiana Department of Wildlife and Fisheries (LDWF) personnel during the first week of January and provides estimates of waterfowl numbers within major wintering areas throughout the US (Blohm et al. 2006, Eggeman and Johnson 1989, Sharp et al. 2002). This survey serves as an annual index of Snow Goose distribution, including its relative abundance within specific regions in each state and among administrative flyways. The midwinter survey is conducted from fixed-wing aircraft or helicopters and occasionally is supplemented by land counts. Instead of using specific transects, the midwinter survey relies on each counting crew knowing their area and how best to cover it for an assumed minimum count of all waterfowl within the predefined survey units and zones within units. We banded Snow Geese at 4 locations within Louisiana Zone 3 of the midwinter waterfowl survey, which corresponds to southwest Louisiana (for a map, see Jónsson et al. 2014:57). The midwinter survey is the only available estimate for Snow Goose abundance and relative use of the survey units in this area. Bateman et al. (1988), Jónsson (2005), and Jónsson et al. (2014) provide details regarding habitats used by Snow Geese in southwestern Louisiana.

Statistical analyses

Our objectives focused on ecological explanations for annual variation in our data. We used linear models to address the possible relationships with annual variation and weather data. Where appropriate, we looked into possible effects of hunter activity on our results.

(1) Did the distribution of recoveries shift northward in 2001-2013? To address our first objective, we used the latitude of individual recoveries as a continuous response variable and tested between additive and interactive models with 2 explanatory variables: season (fall migration, midwinter, and late winter/spring migration) as a categorical variable and winter as a continuous variable. We also considered single-effect models (e.g., season model, winter model, and null model). We included winter in all analyses to quantify annual changes across seasons. We considered it a fixed effect because the study spanned a fixed span of winters and it was thought to be the main exploratory variable. We included season to control for temporal variation within winters because migration schedules at different times of year affected recovery locations (i.e., caused intercepts to differ between seasons). We used generalized linear model analysis (PROC GENMOD; SAS Institute 1999). We designated each individual recovery as the sampling unit for which we obtained the recovery latitude. A model based on the normal distribution fit reasonably well

for this analysis (Pearson scaled-deviance for normal model was 213.0, whereas it was 242.5 for the comparable Poisson model).

The interactive model was the most parameterized model and included the latitude–season interaction because it was important to determine whether regression slopes differed among seasons; different slopes would indicate that Snow Geese exhibited different degrees of faithfulness to staging areas in either fall or spring, or to the wintering areas. The central and southern states comprise the largest geographical area of 3 main wintering areas for Snow Geese in North America (Mowbray et al. 2000), but for our sample of banded Snow Geese, the Gulf Coast represented the southernmost point of Snow Goose migration (the migratory terminus); the South represented both a wintering and staging area, whereas the remaining regions were primarily staging areas with potential for overwintering.

(2) Do local weather or Snow Goose numbers affect annual proportion of recoveries within Louisiana? We previously used weather data from Lake Charles Airport (93°13'24"N, 30°07'3"W) to index winter weather at our banding sites in southwest Louisiana from 2001 to 2013 (Jónsson and Afton 2006, 2009). Here, we used January averages for precipitation (in) and temperature (°C) from Lake Charles Airport as our indices of local weather (Louisiana Office of State Climatology 2014). We regressed 4 explanatory variables, i.e., winter, precipitation, temperature, and Snow Goose numbers on the response variable, annual proportion of recoveries from within Louisiana (PROC REG, SAS Institute 1999). The saturated least-square regression model that we originally considered was as follows:

Annual proportion of recoveries within Louisiana (Y) = $\beta 0$ + $\beta 1$(Snow Goose numbers in southwest Louisiana) + $\beta 2$(winter) + $\beta 3$(precipitation) + $\beta 4$(temperature)

We used Akaike's information criterion (Akaike 1973) adjusted for small sample size (AIC_c) to inform model selection in all analyses. We obtained deviance estimates (error sum of squares for each mode; SSE) from these analyses and then proceeded by calculating AIC_c from maximum-likelihood and log(L) values (Anderson 2008:66). For AIC_c calculations, we followed Burnham and Anderson (2002:63) when determining the number of parameters (K) and included the intercept and the error term (σ^2) in the parameter count with the regression coefficients (β). We included null models in all analysis and used cumulative weights to compare importance of explanatory variables. We stratified data by winter (September–May), with winter defined by January for the given calendar year for all data analyses.

Assessing time and space variation in hunting pressure

Temporal and spatial variation in hunting pressure could influence our results; thus, prior to conducting our model analyses, we evaluated and were prepared to control for varying hunting pressure in our analysis if needed. We first compared light goose harvest (i.e., hunter-activity data for all states that reported 9 or more recoveries during our study—Louisiana, Arkansas, Missouri, Nebraska, South

Dakota, and North Dakota; Table 1). These 6 states reported 167 of 219 recoveries (76%) in this study, whereas the remaining 52 recoveries (24%) came from 9 US states and 3 Canadian provinces (Table 1).

We first inspected annual survey data on total light goose harvest (regular season plus conservation order), number of active hunters, and estimates of days hunted by active hunters (Kruse and Fronczak 2014). Interrelationships of these 3 variables were investigated with principal components analysis (PCA), which indicated that the first principal score (with all 3 loadings meaningful) explained 63–84% of the overall variation within the 6 states. This result indicated that all 3 variables behaved similarly, and thus, we simplified our approach by choosing total light goose harvest as our index of hunting pressure. Number of active hunters and estimates of days hunted by active hunters generally declined in these 6 states during the period 2002–2013 (Kruse and Fronczak 2014).

Total light goose harvest increased or showed no annual trend in Arkansas, Missouri, Nebraska, South Dakota, and North Dakota during the period 2001–2013; thus, we concluded that there was little or no annual or spatial variation in hunting pressure in these 5 states because the number of recoveries declined in all the states throughout the period. Conversely, total Snow Goose harvest declined in Louisiana from 201,548 birds in 2002 to 64,193 birds in 2013 (Kruse and Fronczak 2014). Thus, hunter effort may have declined temporally in Louisiana, perhaps causing the recovery probability within the state to decline during 2001–2013, relative to the other 5 states (Appendix 1). We subsequently evaluated effects of hunting pressure within Louisiana on our findings.

Reduced light goose harvest in Louisiana could result in fewer recoveries there in the late years of our study. Thus, we conducted a second analysis of latitude of recovery to evaluate the possible effect of declining light goose harvest in Louisiana (relative to the other states) and created a data sub-set by excluding all recoveries from Louisiana and Texas, i.e., all recoveries south of 31°N latitude ($n = 128$ instead of $n = 219$). We present both analyses in our results. We hypothesized that if the results from the 2 analyses differed, we could infer an effect of declining light goose harvest in Louisiana; similar findings from the 2 regressions would indicate little or no effect of declining light goose harvest.

Our analysis of annual proportion of recoveries within Louisiana could be adjusted directly, if needed, by total light goose harvest in Louisiana for each year (2002–2013). We thus considered accounting for potential differences in hunting pressure in Louisiana by regressing total light goose harvest in Louisiana on annual proportion of recoveries within Louisiana, and then using the residuals from that regression as the response variable. However, we found no relationship between these 2 variables ($F = 0.01$, $P = 0.99$). Thus, we concluded that this adjustment was not necessary and subsequently conducted our analysis on unadjusted data, which are presented in the results.

Results

Of our 219 recoveries of Snow Geese banded in southwest Louisiana, 194 were from 4 regions within the US: the Gulf Coast, Upper South, Lower Midwest and

Upper Midwest (Table 1). The remaining 25 recoveries were from 3 Canadian provinces (Table 1). All recoveries within Louisiana were from the southwestern part of the state, which corresponds to Louisiana zone 3 of the annual midwinter waterfowl survey. As expected, annual numbers of recoveries declined throughout the study period as our sample population aged: 155 recoveries (70.8%) were from the first 6 years (2002–2007), whereas 64 (29.2%) were from the last 6 years (2008–2013) (Table 1).

Has latitude of recovery shifted northwards?

For the full data set (n = 219), our main effects model, season + winter, was the highest-ranked model (Table 2), with a model R^2 = 0.482 and model weight = 0.81. The competing model that included an interaction of winter and season was not supported (ΔAIC_c = 3.7); thus, regression slopes were similar among seasons. Latitude was positively related to winter for all 3 seasons (Fig. 1), indicating that mean latitudes of band recoveries had shifted northwards during 2002–2013. The null model was the lowest-ranked model (ΔAIC_c = 139.9; Table 1). As expected, recovery latitude was highest in fall and lowest in midwinter, and the latter overlapped somewhat with late winter/spring migration (see intercept and slope estimates in Fig. 1).

The data sub-set excluding all recoveries from Gulf Coast Louisiana and Texas, i.e., all recoveries south of 31° N latitude (n = 128) yielded results similar to those that employed the full data set. Our main effects model, season + winter, remained the highest-ranked model (Table 2), with a model R^2 = 0.393 and model weight (w_i) = 0.64. The closest competing model was the season model (ΔAIC_c = 1.7), indicating that the year trend was relatively weakly supported for recoveries north of 31°N latitude. As with the full dataset, the null model was the lowest-ranked model (ΔAIC_c = 59.5; Table 1).

Table 2. Summary of model selections for effects of winter and season on latitude of recovery from 2002–2013 for Snow Geese banded in southwest Louisiana during winters 2001–2004. The model used for interpretation of results is Season + Winter; + indicates an additive model with main effects only, whereas * indicates an interactive model including interaction and both main effects. K includes the intercept, error term (σ^2), and the regression coefficients (β) in the parameter count. Log(L) = Log-likelihood. Winter = 2002–2013, Season: fall, midwinter, and late winter/spring. See methods for details. An analysis of the full dataset is presented in the left-hand side of the table (n = 219). To evaluate possible effects of declining light goose harvest in Louisiana (relative to AR, MO, NE, SD and ND) on the results, a data sub-set was created by excluding all recoveries from Gulf Coast Louisiana and Texas, i.e., all recoveries south of 31°N latitude (n = 128 instead of n = 219). The analysis of the sub-dataset is shown in the right-hand side of the table.

	Full dataset (n = 219)					Sub-dataset (n = 128)				
Model	K	AIC_c	ΔAIC_c	w_i	Log(L)	K	AIC_c	ΔAIC_c	w_i	Log(L)
Season + winter	4	1395.7	0.0	0.81	-383.0	4	815.1	0.0	0.64	-379.0
Season * winter	5	1399.4	3.7	0.13	-382.7	5	819.2	4.1	0.08	-379.4
Season	3	1400.7	5.0	0.07	-386.5	3	816.7	1.7	0.28	-382.6
Winter	3	1532.0	136.3	0.00	-453.2	3	873.9	58.9	0.00	-433.4
Null model	2	1535.6	139.9	0.00	-455.0	2	874.6	59.5	0.00	-433.9

Do local weather or goose numbers influence proportion of recoveries in Louisiana?

Our top-ranked model that included only Snow Goose numbers in Louisiana zone 3 was the best-supported model for predicting the annual proportion of recoveries within Louisiana, with cumulative w_i = 0.92 and an R^2 = 0.59 (Table 3). Interestingly, the proportion of recoveries within Louisiana was inversely related to Snow Goose numbers each winter (Fig. 2A). The competing model that included Snow Goose numbers + precipitation (R^2 = 0.67) had less support (ΔAIC_c = 2.3) than did the Snow Goose numbers model (Table 3), and both models outperformed the null model (ΔAIC_c = 7.2). The proportion of recoveries within Louisiana was inversely related to precipitation (Fig. 2B), albeit with much less overall support with cumulative w_i = 0.26.

Discussion

Prior to conducting our analyses, we evaluated temporal and spatial variation in hunting pressure because such variation could affect our results. We found that total

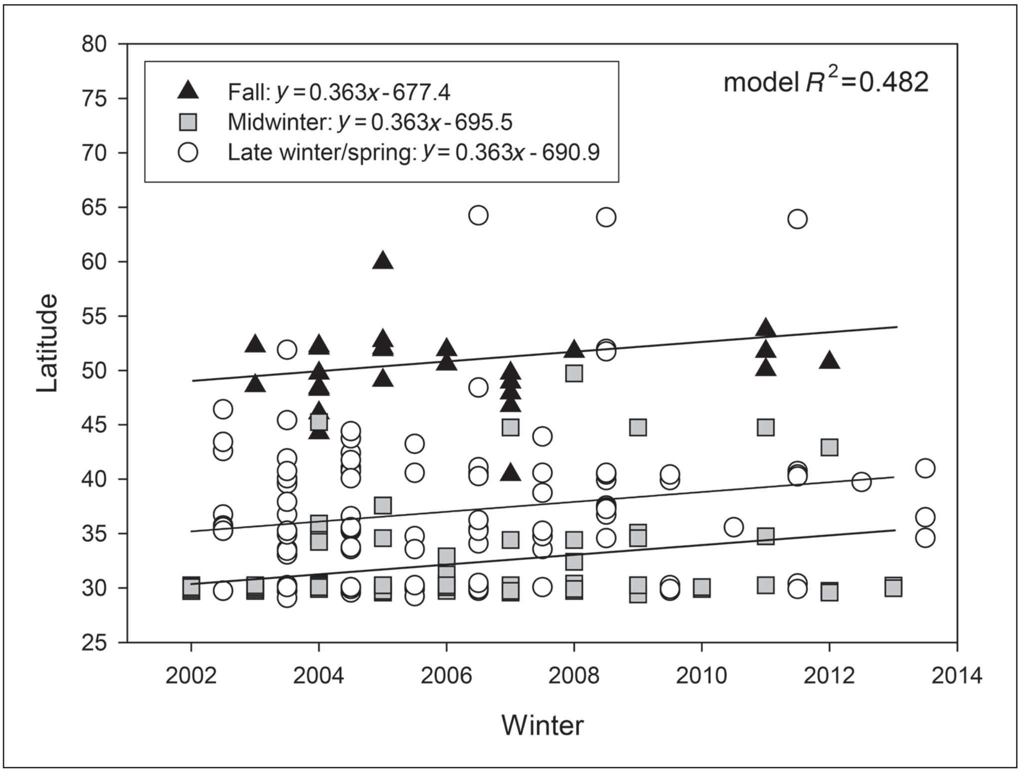

Figure 1. Relationships between winter of recovery (2002–2013) and latitude of recovery, for lesser Snow Geese banded in southwest Louisiana during winters 2002–2004. In the model selection, the best model was additive, i.e., had similar regression slopes for the 3 seasons; the R^2, slopes and intercepts shown are based on that model. To avoid overlap between data points, 0.5 were added to *x*-values for late winter/spring in the figure, but equations presented are unaltered from the model.

light goose harvest, our index of hunting pressure, showed similar trends in the 6 states with 10 or more recoveries, except for Louisiana where harvest was lower for 3 of the last 4 years of study. Nevertheless, annual differences in total Snow Goose harvest in Louisiana was not related to any variables we considered, nor did the apparent decrease in hunting pressure in Louisiana contribute to the positive relationship between latitude of recovery and year. Furthermore, an adjustment for varying hunter pressure in Louisiana was not needed in our analysis of factors influencing proportion of annual recoveries in Louisiana. Thus, we believe that spatial and temporal variation in hunting pressure had little effect on our results.

Have Snow Geese shifted their wintering range northward?

We found that the distribution of Snow Goose recoveries shifted, on average, 4º latitude northwards from 2002 to 2013. The linear trend in more northerly recoveries was independent of season, as indicated by the result that the main effects model outperformed the interactive model. The evidence favored equal slopes among seasons, which we interpret to indicate that Snow Geese were short-stopping (i.e., stopping short and staying north of their traditional wintering grounds) throughout the year in response to local environmental conditions and have shifted their distribution northward from fall to spring. Geese may adjust their movement to the next staging site based on conditions at the present site (Tombre et al. 2008); Snow Geese can delay fall migration and stay north longer in mild winters, or leave wintering areas earlier in midwinter and arrive early on the northern staging grounds in spring. Geese do not always respond to climate change (Tombre et al. 2008),

Table 3. Summary of model selection for effects of Snow Goose numbers, local weather, and winter on the annual proportion of recoveries from Snow Geese banded in southwest Louisiana during winters 2002–2004. Models used for interpretation of results are Survey and Survey Precip (first 2 lines of table). Legend: Winter = 2002–2013; Precip = precipitation average (January) for Lake Charles Airport; Temp: temperature average (January) for Lake Charles airport: Survey = Snow Goose numbers counted in midwinter survey in Louisiana zone 3; *K* includes the intercept, error term (σ^2), and the regression coefficients (β) in the parameter count. Log(L) = Log-likelihood.

Variables in model	K	AIC_c	ΔAIC_c	w_i	Log(L)
Survey	3	-48.5	0.0	0.57	28.7
Survey precip	4	-46.2	2.3	0.18	29.9
Survey winter	4	-44.6	3.8	0.08	29.2
Survey temp	4	-43.8	4.6	0.06	28.8
Precip	3	-43.5	4.9	0.05	26.3
None	2	-41.3	7.2	0.02	23.3
Survey precip temp	5	-40.8	7.6	0.01	30.4
Survey precip winter	5	-40.0	8.5	0.01	30.0
Precip temp	4	-39.5	8.9	0.01	26.6
Precip winter	4	-39.2	9.2	0.01	26.5
Survey winter temp	5	-38.6	9.9	0.00	29.3
Winter	3	-37.7	10.7	0.00	23.4
Temp	3	-37.6	10.8	0.00	23.3
Precip winter temp	5	-33.7	14.8	0.00	26.8
Winter temp	4	-33.0	15.4	0.00	23.4
Survey winter precip temp	6	-32.1	16.3	0.00	30.5

although some species clearly have advanced spring migration (Fox and Walsh 2012, Gunnarsson and Tómasson 2010, this study).

Our banded sample of after-hatch-year birds aged during the 12 years during our study, thus recoveries in the later years probably included many older geese. Older geese—birds at least 10–11 years old or older (Black et al. 2007) or pairs that have been together 9 years or longer (Black et al. 1996)—generally are less productive

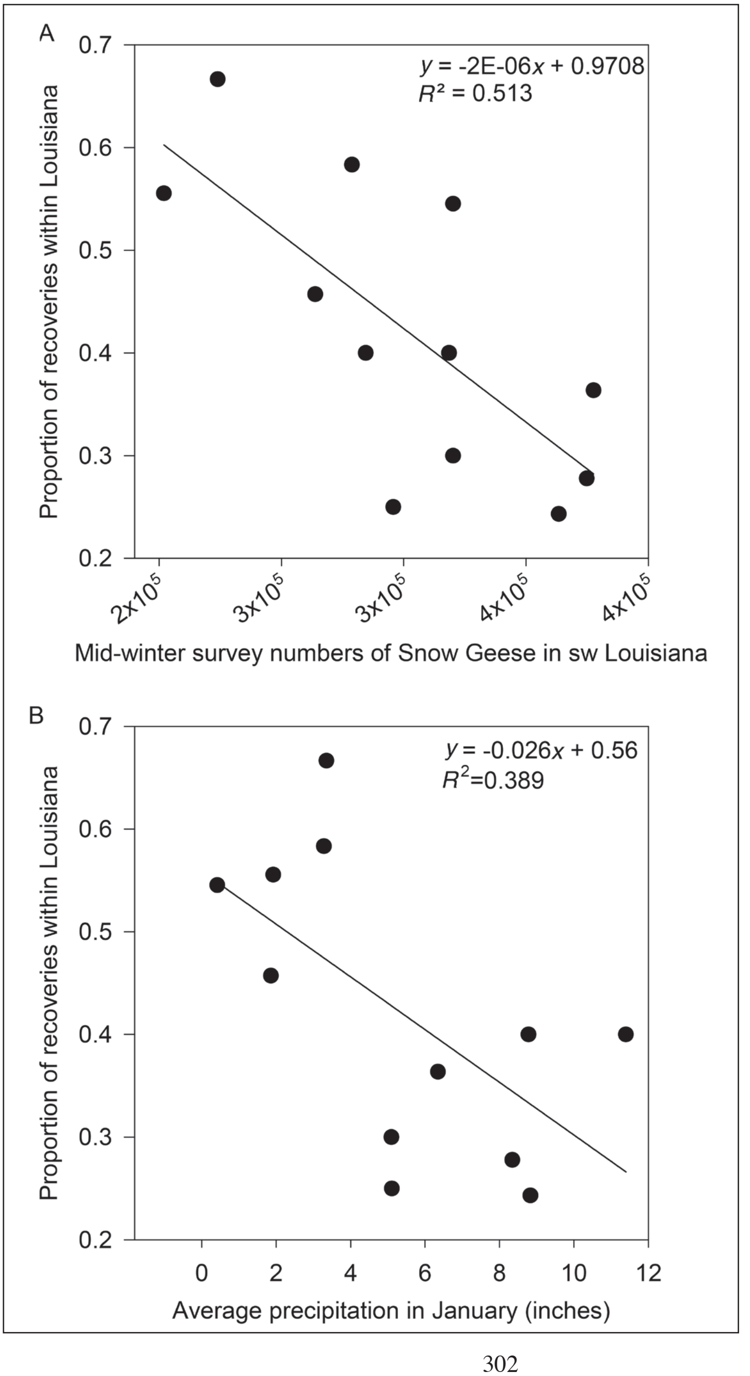

Figure 2. Annual proportion of recoveries within Louisiana for Snow Geese banded in southwest Louisiana during winters 2002–2004, relative to the other midcontinent states and Canadian provinces in winters 2002–2013, in relation to (A) total number of Snow Geese wintering in southwest Louisiana (estimated by midwinter waterfowl surveys), and (B) average January precipitation (in) at Lake Charles Airport, LA.

than younger breeders. Thus, our sample of recoveries could be somewhat biased towards conservatism because older birds are more reluctant to seek out new habitats or staging areas. Accordingly, we speculate that the northward winter range expansion of Snow Geese is driven by high recruitment during the population increase (Alisauskas et al. 2011) and subsequent exploratory nature of large numbers of younger Snow Geese.

Why were there fewer recoveries when larger numbers of Snow Geese were present?

Interestingly, the annual proportion of recoveries within Louisiana was inversely related to Snow Goose numbers surveyed in southwest Louisiana, suggesting there was a dilution effect, wherein hunters were less likely to shoot one of our banded birds when large numbers of Snow Geese were present. Moreover, Snow Geese were more likely to be recovered in southwest Louisiana in drier winters, which concomitantly were winters in which relatively fewer Snow Geese were counted in early January. We suggest that winters with greater precipitation, leading to more abundant standing water, may result in lower vulnerability of Snow Geese to hunters within southwest Louisiana, independent of hunter numbers or number of goose-hunting days.

In southwest Louisiana, dry winters can limit availability of wetland habitat, either in agricultural fields (Rice, *Lolium* sp. [ryegrass], or pasture), refuges, or wetlands. Dry conditions mean that fewer fields are attractive foraging sites, which in turn may make geese more willing to land in hunted foraging sites. Many hunted fields in southwest Louisiana are kept somewhat flooded by artificially pumping water from wells, so these sites are the ones that remain wet in the dry winters. Annual variation in hunting pressure also could cause Snow Geese to avoid certain locations and select others. We suggest that wet winters in Louisiana, with high standing water, provide optimal conditions for Snow Geese to choose locations based on hunting pressure.

Hunting pressure can cause stressful effects on surviving birds. Pearse et al. (2012) reported that the lipid content of Snow Geese in hunted areas was reduced by 25% (57 g) compared to those in non-hunted areas. In addition to responding to hunters, geese may alter their migration patterns to avoid certain areas because of stress from perceived danger from avian predators (Jonker et al. 2010) or active hazing by farmers (Klaassen et al. 2006). Snow Geese are commonly hazed from unharvested fields in southwestern Louisiana, either by approaching Snow Geese on foot or using bird-scare gas guns (J.E. Jónsson, pers. observ.).

The annual proportion of recoveries within Louisiana was lowest (<0.4) in the wettest winters, compared to drier winters (when annual proportion of recoveries within Louisiana was >0.4). During wet winters, there also were relatively more recoveries (13%, on average) from the fall period, relative to midwinter or late winter/spring. We speculate that the observed lower annual proportion of recoveries within Louisiana (more recoveries from the other states) in wetter winters may coincide with a relatively early fall migration in years when larger numbers of Snow Geese reached southwest Louisiana. Such "fast migration" may facilitate what hunters term a "new bird" effect while on migration, i.e., birds that have just arrived to an area are especially vulnerable to hunting. Such an effect could be more likely if migratory flocks are migrating southward relatively quickly.

Conclusion

The probability of recovery in Louisiana was somewhat dependent on Snow Goose numbers present, apparently because hunters shoot proportionally fewer banded birds during years of larger Snow Goose numbers, which in turn were related to high precipitation in the area. The midcontinent population increase of Snow Geese may have resulted in crowding and interference competition (see Jónsson and Afton 2009), which could have caused more Snow Goose flocks to explore for suitable winter areas in the northern staging areas or leave wintering areas earlier in the spring. Food resources have become abundant and more available in northern regions due to combined effects of improved conditions for agriculture and milder winter temperatures that have reduced snow cover. We found evidence that the latitudinal distribution of recoveries shifted northwards for Snow Geese during our study. Greater numbers of Snow Geese were counted in southwest Louisiana during wet winters, suggesting that local weather events affect the probability of early spring migration from this wintering area within a given winter.

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Appendix 1. Total light goose harvest in Louisiana and 5 other states, where 9 or more Snow Geese, banded in Louisiana, were recovered in winters 2002–2013. There was an inverse trend in Louisiana ($R^2 = 0.426$) but no linear trends were observed in the other 5 states. Note differing scales on the *y*-axis. Compiled after Kruse and Fronczak (2014).