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Research Paper

Predicting origins of passerines migrating through Canadian migration monitoring stations using stable-hydrogen isotope analyses of feathers: a new tool for bird conservation

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ABSTRACT. The Canadian Migration Monitoring Network (CMMN) consists of standardized observation and migration count stations located largely along Canada's southern border. A major purpose of CMMN is to detect population trends of migratory passerines that breed primarily in the boreal forest and are otherwise poorly monitored by the North American Breeding Bird Survey (BBS). A primary limitation of this approach to monitoring is that it is currently not clear which geographic regions of the boreal forest are represented by the trends generated for each bird species at each station or group of stations. Such information on "catchment areas" for CMMN will greatly enhance their value in contributing to understanding causes of population trends, as well as facilitating joint trend analysis for stations with similar catchments. It is now well established that naturally occurring concentrations of deuterium in feathers grown in North America can provide information on their approximate geographic origins, especially latitude. We used stable hydrogen isotope analyses of feathers (δ^2H_f) from 15 species intercepted at 22 CMMN stations to assign approximate origins to populations moving through stations or groups of stations. We further constrained the potential catchment areas using prior information on potential longitudinal origins based upon bird migration trajectories predicted from band recovery data and known breeding distributions. We detected several cases of differences in catchment area of species passing through sites, and between seasons within species. We discuss the importance of our findings, and future directions for using this approach to assist conservation of migratory birds at continental scales.

Prédiction de la provenance de passereaux détectés aux stations canadiennes de surveillance des migrations grâce à l'analyse d'isotopes stables d'hydrogène présents dans les plumes : un nouvel outil pour la conservation des oiseaux

RÉSUMÉ. Le Réseau canadien de surveillance des migrations (RCSM) est composé de stations de dénombrement d'oiseaux en migration dont les observations sont standardisées; ces stations sont surtout situées le long de la frontière sud du Canada. Un des objectifs principaux du RCSM est de détecter la tendance des populations de passereaux migrateurs qui nichent principalement dans la forêt boréale et qui sont moins bien suivis par le Relevé des oiseaux nicheurs (BBS) d'Amérique du Nord. Une des lacunes principales de cette approche de suivi est qu'on ne connait pas clairement de quelle région géographique de la forêt boréale est issue la tendance générée pour chaque espèce à chaque station ou groupe de stations. L'information relative à la provenance régionale des oiseaux va permettre d'améliorer considérablement la valeur des données récoltées par le RCSM parce qu'elles pourront alors contribuer à élucider les causes des tendances de population, de même que faciliter l'analyse conjointe de tendances issues de stations pour lesquelles les oiseaux auraient la même provenance. On sait maintenant que les concentrations naturelles de deutérium dans les plumes ayant poussé en Amérique du Nord peuvent fournir des renseignements à propos de l'origine géographique approximative des oiseaux, en particulier la latitude. Nous nous sommes servi d'analyses d'isotopes stables d'hydrogène (δ^2Hf) provenant de plumes appartenant à 15 espèces détectées à 22 stations du RCSM pour déterminer la provenance approximative des oiseaux se déplaçant par les stations ou des groupes de stations. Nous avons ensuite restreint les provenances potentielles des oiseaux au moyen d'information touchant l'origine latitudinale potentielle fondée sur des trajectoires de migration prédites à partir de données de récupération de bagues et d'aires de nidification connue. Nous avons détecté plusieurs cas de provenances régionales différentes d'espèces se déplaçant par les stations, et entre les saisons pour une même espèce. Nous discutons de l'importance de nos résultats et faisons des recommandations pour l'emploi futur de cette approche afin de contribuer à la conservation des oiseaux migrateurs aux échelles continentales.

Key Words: *catchment areas; CMMN; feathers; migration monitoring; population trends; stable isotopes*

INTRODUCTION

Canada's northern forests are increasingly influenced by human activities, leading to concern about bird populations breeding in boreal regions (Hobson et al. 2002, 2013, Bayne et al. 2005, Mahon et al. 2014). It has been estimated that up to five billion landbirds migrate through southern Canada each autumn (Blancher 2003), including warbler, thrush, and other species that

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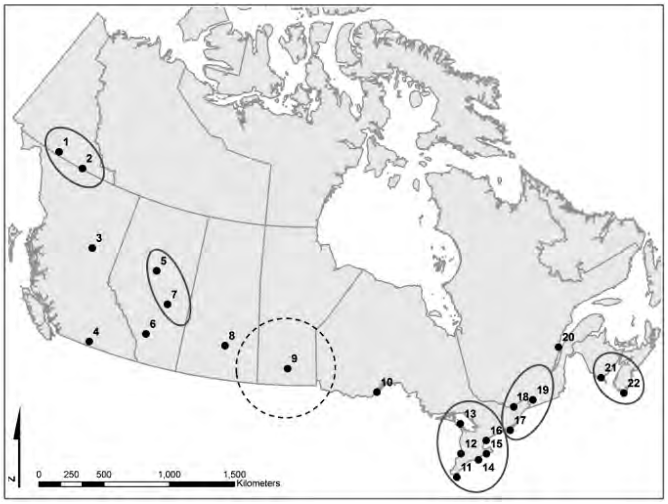
winter primarily in Mexico, Central and northern South America, and the Caribbean. Concern about decline in Neotropical migrants was one of the factors leading to formation of Partners in Flight and other major conservation initiatives (Faaborg et al. 2010).

Despite high interest in population trends of migratory passerines that breed in the North American boreal, most of these species are poorly monitored by breeding season surveys such as the North American Breeding Bird Survey (BBS) because of poor road access across most of the boreal forest. Similarly, winter surveys are uncommon in the regions to which many of these species migrate. For these reasons, boreal-nesting short-distance and Neotropical migrants have been targeted for priority monitoring by the Canadian Migration Monitoring Network (CMMN), a chain of stations that conduct standardized daily "counts" (sensu Dunn and Hussell 1995) of migrants across southern Canada (Fig. 1 includes most of the sites currently in the network). The strengths and limitations of such counts for population monitoring purposes are largely understood (Dunn 2005), and trend analysis procedures are under continual development (e.g., Francis and Hussell 1998, Farmer et al. 2007). Results of migration monitoring are increasingly being used to assess population status by conservation and government groups (e.g., Blancher et al. 2009).

Fig. 1. Canadian Migration Monitoring Network stations where samples were collected for this study. See Table 1 for key to station names. Ovals indicate stations that were combined into regions for certain analyses and maps (Table 1). The dashed circle shows a radius of about 900 km around station 9, to illustrate the size of the 7.5 degree radius zones used to define direction of migration (see Methods.)



One of the major limitations to using migration monitoring to direct conservation planning is that little is known about the geographic regions of the breeding grounds ("catchment areas") from which the migrants originate (Hussell 1981, Dunn and Hussell 1995, Dunn et al. 2006, Osenkowski et al. 2012). This information is important for identifying where conservation action may be needed. Moreover, the identification of catchment areas of birds migrating through monitoring stations should allow study of variation in annual population indices and trends that is related to variation in weather, climate, or habitat disturbance, from fire, insect outbreaks, forest harvesting, etc. (e.g., Savard et al. 2011).

Knowledge of catchment areas is also important for determining which monitoring stations are sampling different populations. Those sampling the same pool of migrants can have their results combined to provide more reliable and precise estimates of regional population trend. Defining the areas sampled by each station, or group of stations, would potentially allow regional trends to be combined into estimates of national or range-wide trends.

One approach to inferring geographic origin of birds and other wildlife is to analyze naturally occurring stable isotopes of elements in body tissues (Hobson and Wassenaar 2008, Voigt et al. 2012). Long-term data on amount-weighted stable-hydrogen isotope ratios in precipitation during the growing season (δ^2H_p) in North America show predictable patterns of δ^2H_p which are reflected in local foodwebs and are ultimately incorporated in bird feathers (Hobson and Wassenaar 1997, Hobson et al. 2012, Wunder 2012). Feather δ^2H values (δ^2H_f) can be assigned to the regions where those feathers could possibly have grown (Fig. 2). For feathers grown by nestlings and fledglings or by adults that molt during or immediately following breeding, including most boreal passerines (Pyle 1997), such assignments reflect the natal or breeding area, respectively.

Fig. 2. Predicted hydrogen isotope ratios of feathers (δ^2H_f) for North American passerines, calibrated from the amount-weighted mean growing season stable-hydrogen isotope ratio in precipitation (δ^2H_p) isoscape of Bowen et al. (2005). Known source feather samples (Clark et al. 2006, 2009) were used to derive the rescaling equation used to convert the δ^2H_p isoscape to a δ^2H_f isoscape based upon the equation $\delta^2H_f = -25.9 + 0.88\ \delta^2H_p$ (see Methods).

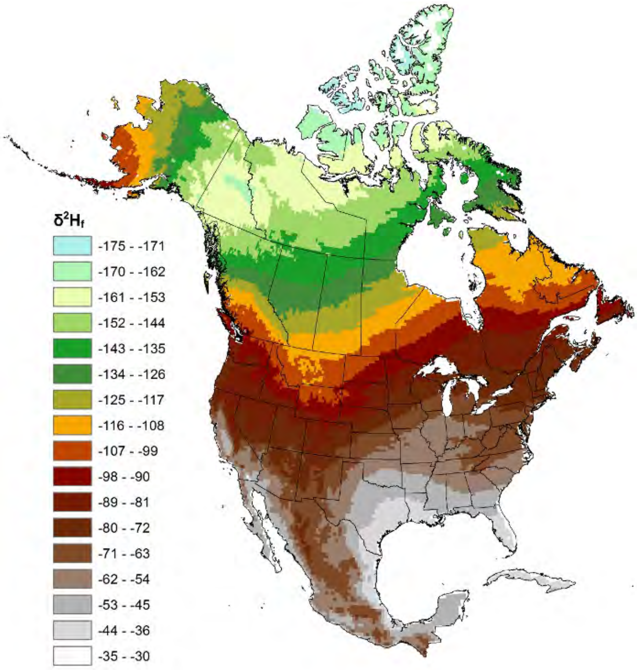


Table 1. Study species and classification of migration distance (Wong et al 2003).

Species		Code	Mig. Dist.	Sample size Fall	Sample size Spring
Alder Flycatcher	*Empidonax alnorum*	ALFL	Long	0	130
Swainson's Thrush	*Catharus ustulatus*	SWTH	Long	121	27
Hermit Thrush	*Catharus guttatus*	HETH	Short	17	130
Ruby-crowned Kinglet	*Regulus calendula*	RCKI	Short	87	200
Ovenbird	*Seiurus aurocapilla*	OVEN	Long	0	28
Northern Waterthrush	*Parkesia noveboracensis*	NOWA	Long	129	58
Orange-crowned Warbler	*Oreothlypis celata*	OCWA	Long	38	208
American Redstart	*Setophaga ruticilla*	AMRE	Long	82	0
Magnolia Warbler	*Setophaga magnolia*	MAWA	Long	78	159
Yellow Warbler	*Setophaga petechia*	YWAR	Long	100	321
Palm Warbler	*Setophaga palmarum*	PAWA	Long	53	75
Yellow-rumped Warbler	*Setophaga coronata*	YRWA	Short	98	101
Wilson's Warbler	*Cardellina pusilla*	WIWA	Long	108	0
Lincoln's Sparrow	*Melospiza lincolnii*	LISP	Short	55	170
White-throated Sparrow	*Zonotrichia albicollis*	WTSP	Short	0	30

Despite the short history of the δ^2H_f approach, the technique has already provided important information on migratory connectivity and has immense conservation potential (Hobson and Norris 2008). For example, Rubenstein et al. (2002) showed that stable northern breeding populations of Black-throated Blue Warblers (*Setophaga caerulescens*) wintered in Cuba, whereas declining southern breeding populations wintered primarily in the eastern Antilles. Similarly, Kelly et al. (2002) showed that northwestern populations of Wilson's Warbler (*Cardellina pusilla*) wintered in the southern portion of their wintering range whereas southwestern breeding populations wintered in the northern portion of their wintering range. Other studies have provided important information on migratory connectivity in Bicknell's Thrush (*Catharus bicknelli*; Hobson et al. 2004, Studds et al. 2012). Previous studies have also used δ^2H_f values to start identifying the breeding grounds of migrants captured at specific CMMN stations (Wassenaar and Hobson 2001, Dunn et al. 2006).

The isotope technique, however, has important limitations. First, the patterns of δ^2H_p in North America provide a strong latitudinal signal of origin but provide less resolution to delineating longitude of origin (Bowen et al. 2005, Van Wilgenburg and Hobson 2011; Fig. 2). This results in unavoidable ambiguity in assignment along east-west gradients. In addition, much of Alaska has isotopic patterns similar to those in parts of the southern boreal of Canada, often resulting in Alaska appearing as a potential region of origin when it may not represent a plausible origin for a migrant captured at a given migratory stopover site.

Here, we used two approaches to reduce ambiguity in assignment: restricting possible assignment regions to fall within the known species' breeding ranges, and migratory trajectories related to the most probable directions of movement through each study site (Van Wilgenburg and Hobson 2011). Our overall objective was to identify catchment areas as accurately as possible for a variety of species across the CMMN as a first step in interpreting population trend trajectories for boreal breeding birds.

METHODS

Data collection

In 2007, we asked all CMMN stations to collect the fourth rectrix on each side of the tail from selected migrants and store them in labeled paper envelopes. We provided a collection protocol that asked for samples from 21 species in spring and 14 species in fall, along with target numbers of birds of each species to be sampled, both for the whole season and for each 5-day period within the season, to ensure that samples were well-distributed across the season, because migrants from more northern latitudes pass through southern Canada later in the fall (Dunn et al. 2006). Nineteen stations took part in spring and collected feathers from 6549 birds, and 20 stations collected feathers from 11,534 birds in the fall. We selected species for sampling based on their relatively broad geographic breeding distribution in Canada, including substantial areas of the boreal forest, and that were captured in good numbers at several CMMN stations and represented a mix of long- and short-distance migrants. In addition we had available 674 fall samples collected in 2004 at Inglewood Bird Sanctuary (IBS) in Alberta. The latter included feathers from 6 species not targeted for the 2007 collections.

In several regions multiple stations are geographically close and likely sample birds from the same breeding grounds. Because of cost constraints, we were not able to use all samples, but we also wanted as many stations as possible to contribute. We therefore formed a priori groups of stations for the Yukon, northern Alberta, southwestern Ontario, southeastern Ontario, and southwestern Québec, and the Maritimes (Fig. 1, Table 1).

We targeted an upper limit of 25 individuals analyzed for any station or group of stations. When the number of feathers available exceeded 25, we designated the number of feathers to be selected for analysis from each 5-day period more or less in proportion to the seasonal pattern of abundance, and, for groups of stations, from as many stations as possible. Previously collected fall samples from IBS, which provided extra funds for analysis, often exceeded these limits, and included four additional species (Table 1, Appendix 1).

Table 2. Canadian Migration Monitoring Network stations participating in study (Fig. 1).

No. on Fig. 1	Name of CMMN station	Abbrev.	Region
1	Teslin Lake Bird Banding Station	TLBBS	Yukon
2	Albert Creek Bird Observatory	ACBO	Yukon
3	Mackenzie Nature Observatory	MNO	Northern BC
4	Vaseaux Lake Bird Observatory	VLBO	Southern BC
5	Lesser Slave Lake Bird Observatory	LSLBO	Northern AB
6	Inglewood Bird Sanctuary	IBS	Southern AB
7	Beaverhill Bird Observatory	BBO	Northern AB
8	Last Mountain Bird Observatory	LMBO	Saskatchewan
9	Delta Marsh Bird Observatory	DMBO	Manitoba
10	Thunder Cape Bird Observatory	TCBO	Northwestern ON
11	Pelee Island Bird Observatory	PIBO	Southwestern ON
12	AuSable Bird Observatory	AuBO	Southwestern ON
13	Bruce Peninsula Bird Observatory	BPBO	Southwestern ON
14	Long Point Bird Observatory	LPBO	Southwestern ON
15	Haldimand Bird Observatory	HBO	Southwestern ON
16	Tommy Thompson Park Bird Research Station	TTPBRS	Southwestern ON
17	Prince Edward Point Bird Observatory	PEPTBO	SE Ontario-SW Québec
18	Innis Point Bird Observatory	IPBO	SE Ontario-SW Québec
19	McGill Bird Observatory	MBO	SE Ontario-SW Québec
20	Observatoire d'oiseaux de Tadoussac	OOT	Eastern Québec
21	St. Andrew's Bird Banding Station	SABBS	Maritimes
22	Atlantic Bird Observatory	ABO	Maritimes

For this paper we selected 12 species for spring and 8 species for fall (Table 1, Appendix 1). The included samples were collected at 22 CMMN stations (Fig. 1, Table 2); 430 collected in 2004 and 2173 in 2007. Fall samples of Alder Flycatcher (*Empidonax alnorum*) were limited to hatch-year birds because breeding adults molt in winter after fall migration (Lowther 1999). Similarly, spring sampling for Swainson's Thrush (*Catharus ustulatus*) was limited to known second-year individuals, those with buffy-tipped coverts (Pyle 1997), because this species is known to be at least a partial molt migrant (Cherry 1985, Winker et al. 1992). Adult as well as hatch-year Swainson's Thrush were sampled in fall at IBS (southern Alberta), but results showed no separation of δ^2H_f values by age, so all samples are included here. In most other species, many individuals could not be reliably assigned to second-year vs. older age classes in spring, but because their adults molt close to the breeding site (Pyle 1997) our results should not vary because of different locations of feather growth according to age class. For these species, therefore, "catchment area" in this paper is used in a broad sense as referring to the portion of the breeding range sampled by a station, rather than natal area alone.

Stable isotope analysis

All feathers were cleaned of surface oils in a 2:1 chloroform: methanol solvent rinse and prepared for δ^2H analysis at the Stable Isotope Hydrology and Ecology Laboratory of Environment Canada in Saskatoon, Canada. Stable-hydrogen isotope analyses of feathers were conducted using the comparative equilibration method described by Wassenaar and Hobson (2003) through the use of three calibrated keratin hydrogen-isotope reference materials. Stable-hydrogen isotope measurements were performed on H_2 derived from high-temperature (1350°C) flash pyrolysis of 350 ± 10 µg feather subsamples using continuous-flow isotope-ratio mass spectrometry. All results are for nonexchangeable δ^2H 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 δ^2H ± 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).

Statistical analysis

We examined variation in δ^2H_f among species and stations for fall and spring, respectively. Variance components were estimated using linear mixed-effects modeling, with station treated as a random effect and a random effect for species nested within stations to estimate a separate intercept for each species/station combination. Finally, we inferred differences among stations within a priori groups of stations (Fig. 1) based upon 95% confidence intervals derived from random effects. Modeling was conducted using the "lme4" (Bates et al 2014) and "arm" packages (Gelman and Su 2014), and random effects were tested using the "lmerTest" package (Kuznetsova et al. 2014) in the R 3.1.1 statistical computing environment (R Core Team 2014).

Analysis and mapping of isotope values

Results were mapped only for stations or groups of stations with sample size of n ≥ 15. We assigned birds to their approximate geographic origins based on previously described spatially explicit likelihood-based assignment methods (Wunder 2007, 2010, Van Wilgenburg and Hobson 2011). In brief, we first converted a geographic information system (GIS)-based model of expected amount-weighted mean growing-season δ^2H in precipitation (hereafter δ^2H_p; Bowen et al. 2005), into a δ^2H_f model (hereafter isoscape). We derived the δ^2H_f isoscape using a rescaling function (Wunder 2010) created by regressing known-origin feather values from data reported in Clark et al.(2006, 2009) against predicted δ^2H_p from the precipitation isoscape of Bowen et al. (2005), resulting in an equation ($\delta^2H_f = -25.9 + 0.88\ \delta^2H_p$) that was used to convert the GIS model from δ^2H_p into a δ^2H_f isoscape. We subsequently used normal probability density functions to assess the likelihood that each cell (pixel) in the isoscape represented a potential origin for a given individual sample (bird) by comparing the observed δ^2H_f against the expected mean isoscape prediction of δ^2H_f for a given location (pixel) in the isoscape. We parameterized the normal probability density functions by treating the isoscape-predicted δ^2H_f value at each cell as the mean, and the standard deviation in the residuals from the calibration equation reported above (i.e., $\sigma = 12.6‰$), thereby accounting for assignment uncertainty.

To arrive at catchment basin maps for each CMMN station or group, we assigned individuals to the basemap by first determining the odds that any given assigned origin was correct relative to the odds that it was incorrect (Hobson et al. 2009, Wunder 2007, 2012). We identified the set of cells in the isoscape that defined the upper 67% of estimated “probabilities of origin” and coded those as 1, and all others as 0 following Hobson et al. (2009). This approach is consistent with 2:1 odds that a given assigned bird had truly originated from within those cells. We selected 2:1 odds because other odds ratios result in similar conclusions but with lower geographic precision (Chabot et al. 2012, Van Wilgenburg et al. 2012). Furthermore, previous use of 2:1 odds within North America in similar assignment models have resulted in rates of correct classification of known-provenance individuals that were greater than or equal to the rate expected by chance (Chabot et al. 2012, Hobson et al. 2012). Finally, the results of the individual assignments were then summed over all individuals and mapped on the δ^2H_f isoscape.

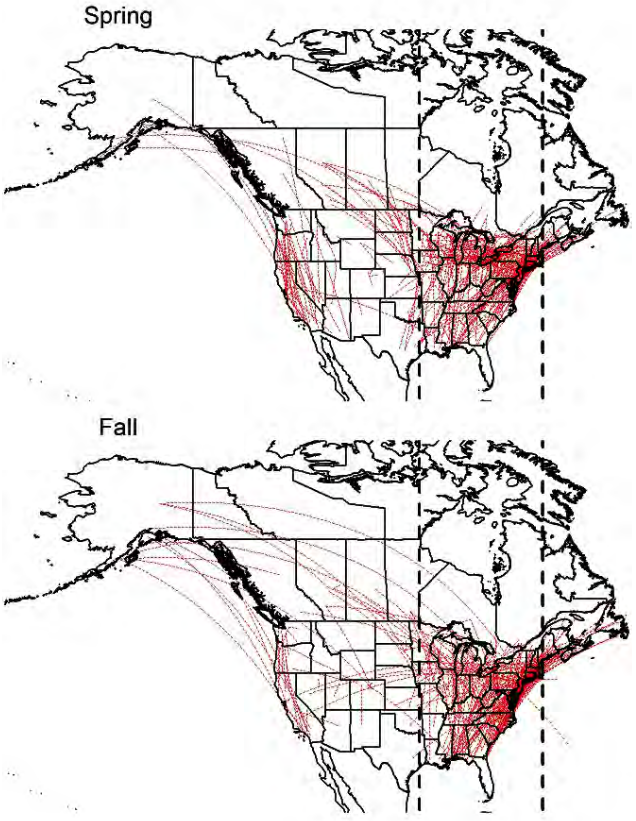
Our analyses were typically based on a single year of sampling, whereas the isotope assignments used the long-term International Atomic Energy Agency Global Network of Isotopes in Precipitation dataset. However, the transfer function we used to relate precipitation δ^2H with feather δ^2H incorporated some of the annual variance, and other studies have shown little evidence for year-effects (Hobson et al. 2010, but see Welker 2012). Recent work suggests assignments to isoscapes derived from the long-term data can produce similar accuracy as those to short-term or year-specific isoscapes (Vander Zanden et al. 2014).

Constraint of assigned origins

For each species, we clipped the isoscapes to more probable breeding ground potential catchment areas by extracting the portion of the δ^2H_f isoscape that fell within its georeferenced breeding range (BirdLife International and NatureServe 2014), using the “mask” and “crop” functions of the “raster” package in R (Hijmans 2014, R Core Team 2014).

To further constrain the assigned origin maps, we used a data set of band recoveries for all passerines banded or recovered in Canada or the U.S. between 1914 and 2004 (n = 2638). Banding and recovery dates were classified as spring (15 March-9 June), summer (10 June-31 July), fall (1 August-14 November), or winter (15 November-14 March). Records were dropped from the data set that did not involve a migration season, i.e., band and recovery dates both in summer or both in winter, or that had great circle distances between band and recovery location of < 100 km. Because our interest was in estimating the direction of travel while birds were passing through southern Canada, and because the Gulf of Mexico presents a significant potential migratory barrier that may cause individuals to alter their flight path from that used while passing through southern Canada, we also deleted band-recovery records for which the southern-most latitude was ≤ 30° N (Fig. 3). All recoveries for species with irregular or irruptive migration were excluded, as were the few recoveries for Blackpoll Warbler (*Setophaga striata*) and Northern Waterthrush (*Parkesia noveboracensis*), which are known to have a very strong eastern component to fall migration (DeLuca et al. 2013, Whitaker and Eaton 2014) that might skew the more typical direction of movement through CMMN stations. Finally, several very anomalous records were deleted, following the example of Brewer et al. (2000).

Fig. 3. Great circle migration routes of passerines during spring (n = 711) and fall (n = 550) migration from birds banded and subsequently recovered between 1914 and 2004 (restricted to records with termini north of 30 degrees latitude). Dashed lines indicate divisions used in subset data for circular ANOVA analyses (see Methods, Tables 3 and 4).



The edited data set included 1261 records (Fig. 3), for 68 species. Of these, only 10 were recoveries of the species covered in this paper. To maintain reasonable sample sizes for each station, we constrained origins of our focal species using trajectory data from all species combined.

Records were classified as "fall" if both banding and recovery date fell within the fall period defined above, or if one terminus was in fall and the other was either in summer or in winter. Those classified as "spring" had both termini in the spring period, or one in spring and the other in summer or in winter. "Other" records, those with one terminus in summer and the other in winter, were excluded from analyses testing for differences in direction between migration seasons. Species were further classified as long-distance (Neotropical) migrants, or as short-distance (temperate) migrants, as per Environment Canada's WILDSPACE database (Wong et al. 2003).

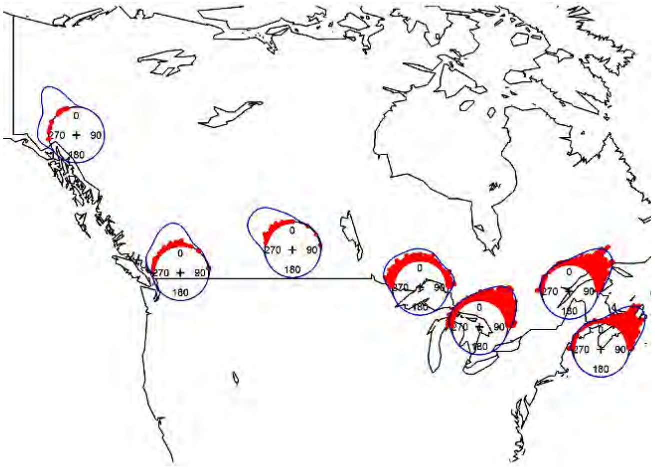
Because our assignments to origin are based on the assumption that feathers were grown on or near breeding grounds and north of CMMN stations, we calculated great circle back-bearings (addition of 180°; to bearings falling between 90° and 180° and subtraction of 180° from bearings between 180° and 270°), such that all bearings analyzed represent the presumed direction toward the breeding grounds.

We then tested for differences in great-circle migration direction using analysis of variance for circular data (Harrison and Kanji 1988). Using pooled species data, we tested for differences in migration direction between short- versus long-distance migrants within fall and spring migration separately, and the differences in spring versus fall migration directions within short-distance and long-distance migrants, respectively. Each of these analyses was conducted regionally within Canada by splitting the data based upon the longitude of the northern-most banding or recovery site. Specifically, we grouped data into eastern (Longitude < 70°), central (Longitude ≥ 70° and < 95°), and western (Longitude ≥ 95°), as shown in Fig. 3.

Statistical significance was assessed at $\alpha < 0.05$ and corrected for multiple comparisons using the false discovery rate control (Benjamini and Hochberg 1995). In addition, to guard against falsely rejecting a potentially biologically significant difference between migration directions in a given comparison, we also used circular histograms and/or scatterplots to graphically inspect the data between the factors in question, e.g., spring vs. fall.

Following Van Wilgenburg and Hobson (2011), we developed GIS surfaces based on band recoveries to further limit our assigned origin maps; however, unlike Van Wilgenburg and Hobson (2011), we created GIS "masks" to exclude areas of the breeding range that represented improbable origins from a given capture location. Using a GIS buffer analysis, we selected all great circle band-recovery vectors (see red lines in Fig. 3) that passed within a 7.5° (~900 km) radius of a given CMMN station; this distance was selected to ensure that all stations would have ≥ 30 band recoveries for analysis. We then used the "circular" package (Lund and Agostinelli 2011) within the R statistical computing environment (R Core Team 2014) to generate kernel density estimates using a von Mises smoothing function (see examples in Fig. 4). We then created a GIS buffer around each CMMN station and split these into 360 1° slices of pie-shaped wedges, and populated those with the appropriate kernel density estimates. Kernel densities were then normalized so that the sum of the densities for all 360 wedges summed to one (representing the estimated probability that a bird could have originated from the given compass bearing). We then selected the wedges associated with the upper (central) 85% of the probability distribution to represent the suite of directions we considered as most likely paths for a migrant passing through the station. All compass bearings associated with the lower 15% of probabilities were thus treated as unlikely, and were "masked" out of the assignment regions for the station in question. We used this approach as opposed to treating the migration direction kernel densities as spatially explicit prior probabilities, because we felt this would be more conservative for our application.

Fig. 4. Example circular histograms of migration directions calculated from great-circle bearings (°) between banding and recovery locations depicted in Figure 3. Data are as back-bearings used in subsequent analyses. Stacked points represent frequencies, and the blue lines represent kernel density estimates fit to the frequency data using a von Mises's probability density function (see Methods).



Resulting banding masks were of necessity a compromise related to small sample size. To meet our target sample size (≥ 30 records) for each sample location, we constructed wide buffers around each site (Fig. 1). Buffers therefore overlapped with those of other stations, and could have blurred any real differences in migratory directions through specific sites. Moreover, all recovery records were given equal weight, regardless of geographic variation in capture effort, time period between banding and recovery, or distance between banding and recovery locations, although all had to be > 100 km. Migration directions excluded by the masks may be more common in reality than are represented in the data set (e.g. recoveries within northern portions of the boreal forest are lacking), causing the banding masks to be too restrictive. Moreover, our methods likely excluded the less common but regularly used fall migration route of some far western birds moving through eastern Canada. On the other hand, combining recoveries for each site regardless of season, species or migration distance served to broaden the area of allowable directions. We feel the allowable directional "cones" are conservatively estimated, tending to be too broad for a given species rather than too narrow.

RESULTS

The only difference in migration directions between spring and fall was for long-distance migrants in western Canada (F_{1123} = 6.82, p = 0.01; Table 3), where spring migrants tended to head in a more northerly direction (mean = 339.3°, median = 340.4°, SD = 33.2°) relative to the origins of migrants in fall, which were shifted to the northwest (mean = 322.5°, median = 317.4°, SD = 37.8°). However, inspection of circular histograms suggested broad overlap in density kernels, so we did not differentiate seasons in further analyses. Similarly, the only difference in direction between short- and long-distance migrants was for fall migration in central Canada where the data were suggestive (F_{1418} = 3.74, $p > 0.05$; Table 4) that short-distance migrants tended to migrate more eastward (mean = 28.0°, median = 30.6°, SD = 36.0°) compared to long-distance migrants (mean = 20.3°, median = 27.4°, SD = 42.7°). Correction for multiple comparisons suggested that the result was not statistically significant, and inspection of circular histograms also showed broad overlap in kernel densities. We therefore pooled all band-recoveries, i.e., including both spring and fall migration regardless of migratory strategy, in further results. This led to more conservative interpretations by adding greater variance and thus a broader range of directions included in the upper 85% of direction probabilities, centered on the highest likelihood.

During fall migration, significantly (~7.4 times) more variance in δ^2H_f was associated with between-station variance (~65.7%) than that attributed to species within stations (~8.9%; Table 5). The large contribution of between station variance was driven by substantial regional variation in δ^2H_f, with birds captured at stations in the northwestern portion of the study area generally being far more depleted in ^2H than birds captured in the Maritimes (Tables A1.2). Within the a priori station groupings (Fig. 1) there was generally broad overlap in 95% confidence intervals among stations, although larger sample sizes might have exposed variation.

Consistent with the variance components, confidence intervals generally showed high overlap between species captured at the same location; but there were some differences. For example, Alder Flycatchers captured at ABO in the Maritimes were significantly more enriched in ^2H, suggesting more southerly breeding origins, than Magnolia (*Setophaga magnolia*) and Yellow Warblers (*Setophaga petechia*) captured there (Table A1.2). In contrast, Yellow Warbler tended to be more depleted in ^2H, suggesting more northerly breeding origins, than other species captured at the same locations, including Alder Flycatcher and Hermit Thrush (*Catharus guttatus*) at ABO, Alder Flycatcher at TCBO (northwestern Ontario), and numerous other species at IBS (southern Alberta): Northern Waterthrush, Lincoln's Sparrow (*Melospiza lincolnii*), Ovenbird (*Seiurus aurocapilla*), White-throated Sparrow (*Zonotrichia albicollis*), Swainson's Thrush, and Wilson's Warbler.

Catchment areas

All maps of probable catchment areas are shown in Appendix 2. Here we highlight selected examples and comparisons that illustrate the main findings of the study.

Data were most complete across the country for Yellow Warbler in the fall, so we use that species to illustrate the general pattern of results (Fig. 5-7). Catchment areas were similar for stations in Yukon (Fig. 5), northern British Columbia (Fig. 5), two of the Alberta sites (Fig. 5), and Saskatchewan (Fig. 6), suggesting origins in Yukon and western Northwest Territories. By contrast, assignment maps for southern British Columbia and one site in northern Alberta (BBO) showed Yukon as a less likely area of origin (Fig. 6). These two sites had probable origins generally south of 60° in northern British Columbia and environs, or possibly isotopically similar regions of Alaska that cannot be distinguished from other regions of the boreal based upon δ^2H alone (Fig. 3). Nonetheless, two band recoveries for Yellow Warbler in the band recovery database show links between Alaska and California, and much of the population that migrates through the western U.S. is likely to move though British Columbia. The southern British Columbia station, then, may well be capturing birds both from Alaska and northern BC. Figure 3 suggests that BBO in northern Alberta (Fig. 6) is also likely to intercept some Alaskan birds.

Fig. 5. Probable origins of Yellow Warblers (*Setophaga petechia*) during fall migration. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.

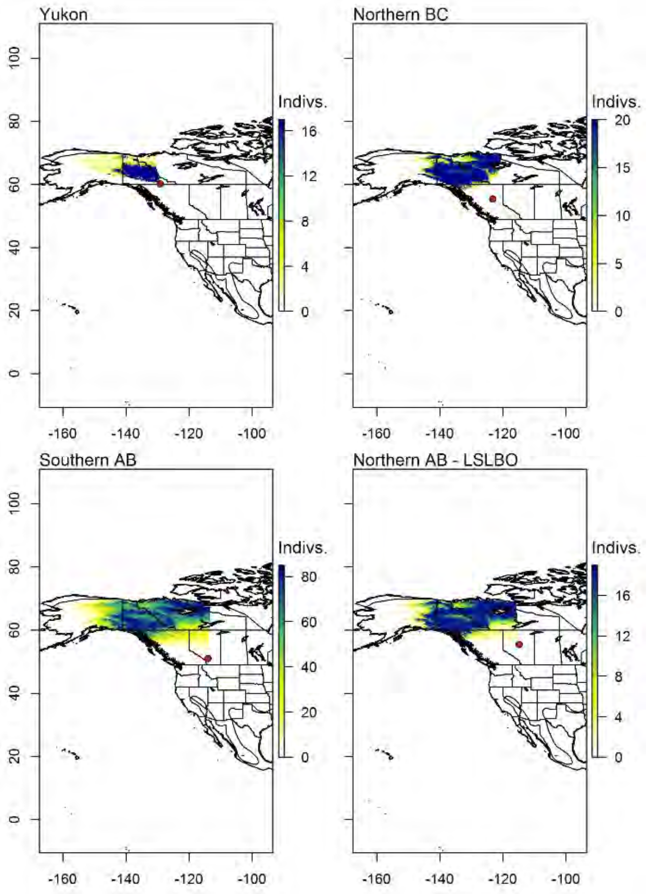


Table 3. Analysis of variance for circular data results comparing migration directions between spring and fall for short vs. long-distance migrants, respectively, based upon subsets of banding and recovery locations for 1261 passerines banded and recovered between 1914 and 2004.

	Short-distance Migrants					Long-distance Migrants				
	df	SS	MS	F	p	df	SS	MS	F	p
East										
Between	1	0.04	0.04	0.67	0.42	1	0.03	0.03	0.42	0.52
Within	32	1.94	0.06			75	6.26	0.08		
Total	33	1.98	0.06			76	6.30	0.08		
Central										
Between	1	0.33	0.33	1.69	0.19	1	0.61	0.61	2.69	0.10
Within	404	89.66	0.22			585	156.20	0.27		
Total	405	89.99	0.22			586	156.81	0.27		
West										
Between	1	0.02	0.02	0.21	0.65	1	1.06	1.06	6.82	0.01
Within	30	3.98	0.13			123	21.34	0.17		
Total	31	4.01	0.13			124	22.40	0.18		

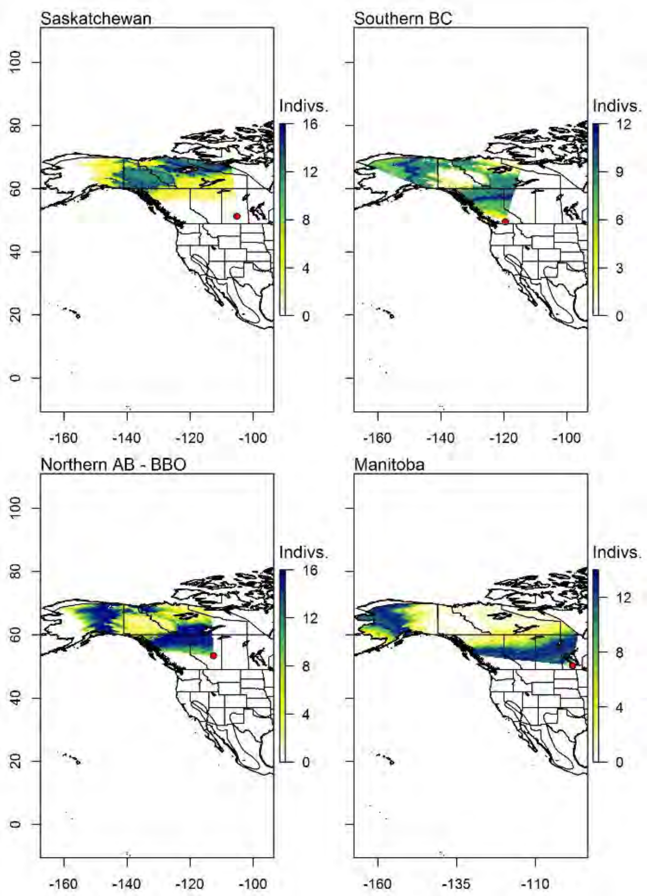
Table 4. Analysis of variance for circular data results comparing migration directions between short vs. long-distance migrant in spring and fall migration, respectively, based upon subsets of banding and recovery locations for 1261 passerines banded and recovered between 1914 and 2004.

	Spring					Fall				
	df	SS	MS	F	p	df	SS	MS	F	p
East										
Between	1	0.07	0.06	1.36	0.25	1	0.02	0.01	0.14	0.71
Within	41	2.07	0.05			66	6.14	0.09		
Total	42	2.13	0.05			67	26.14	0.09		
Central										
Between	1	0.22	0.22	0.95	0.33	1	0.72	0.72	3.74	0.05
Within	572	155.48	0.27			418	91.38	0.22		
Total	573	154.71	0.27			419	92.09	0.22		
West										
Between	1	0.11	0.11	0.88	0.35	1	0.01	0.02	0.14	0.71
Within	93	13.15	0.14			60	12.18	0.20		
Total	94	13.26	0.14			61	12.21	0.20		

Table 5. Random effects model results examining variation in δ^2H in bird feathers during spring migration (n = 966) versus fall migration (n = 1637) in relation to Canadian Migration Monitoring Network station and species nested within station (see Methods).

Fixed Effects						Random Effects				
Term	β	SE	df	t	p	Term	Variance	Chi-sq	df	p
Spring Migration										
Intercept	-108.8	4.8	14.1	-22.7	< 0.001	Species:Station	83.0	50.3	1	< 0.001
						Station	338.5	62.8	1	< 0.001
						Residual	485.6			
Fall Migration										
Intercept	-124.1	5.5	19.2	-22.8	< 0.001	Species:Station	76.9	259	1	< 0.001
						Station	570.5	138	1	< 0.001
						Residual	220.3			

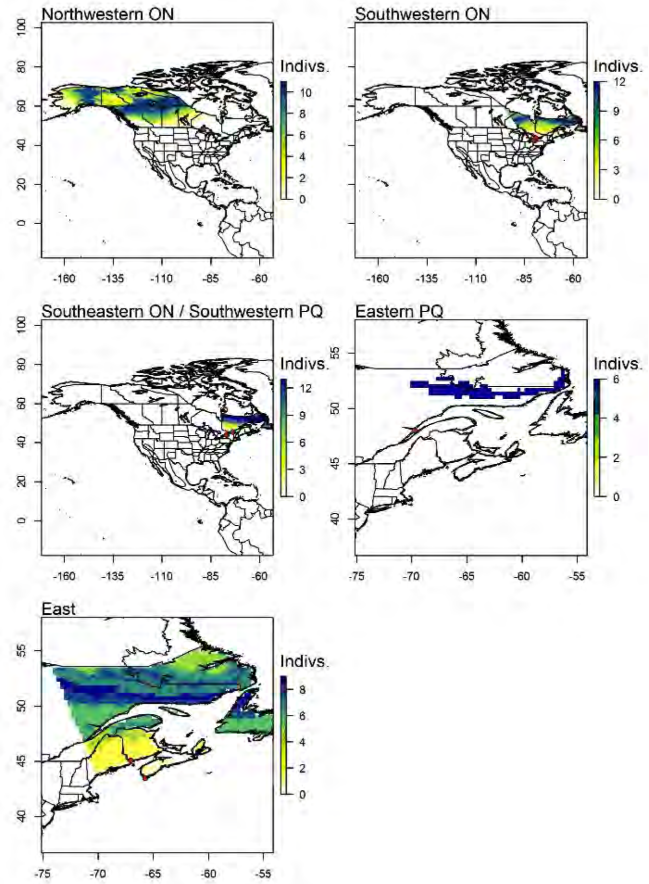
Fig. 6. Probable origins of Yellow Warblers (*Setophaga petechia*) during fall migration continued. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.



Comparison of Yellow Warbler assignment regions for the three stations in Alberta showed intriguing differences because one of the two in northern Alberta (BBO; Fig. 5) appeared to draw from different areas than the other northern site (LSLBO; Fig. 5) and the one in southern Alberta (IBS; Fig. 6). For most species, there were not enough samples to differentiate the two northern Alberta sites, and it is therefore possible that site differences are hidden in the results for other species and/or locations where stations have been grouped.

The band recovery analysis indicated directions of movement through the Manitoba site that include much of Alaska and the western portion of Canada (Fig. 3), making it difficult to narrow down most likely area of origin. Nonetheless, the map for Manitoba suggests high likelihood of origin primarily south of the 60th parallel from central BC and through the Prairie provinces (Fig. 6). Similarly, Yellow Warblers captured in northwestern Ontario also showed a very broad area of potential origin, for which band recoveries did not greatly improve precision beyond excluding central and eastern Canada.

Fig. 7. Probable origins of Yellow Warblers (*Setophaga petechia*) during fall migration continued. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.



Band recovery analysis indicated that southwestern Ontario stations (Fig. 7) sample very different regions than western stations. Yellow Warblers captured while moving through the southern Great Lakes most likely originated in northern Ontario and central Québec, while stations farther east (Fig. 7) sampled breeding grounds in eastern Québec and Newfoundland-Labrador. The slightly more northern origins of the eastern Québec samples are significantly different from the samples collected at Maritimes stations (Table A1.2).

Species differences within sites

Because we constrained results for all species to probable directions of migration using the same set of band recoveries, the general pattern described above for fall migration of Yellow Warbler is repeated across species. However, Table 5 and examination of results region by region indicate that there is also some variation among species within sites. For example, as noted for Yellow Warbler, the two northern Alberta stations showed different patterns in fall catchment area (Fig. 5). Of the nine species with fall data from the southern Alberta station, eight differed from the Yellow Warbler, which had most likely origins in the Yukon (Fig. 5), instead showing higher probability of origin from southwestern Northwest Territories, northern British Columbia and Alberta, and/or eastern Alaska (Swainson's Thrush, Fig. A2.3; Ruby-crowned Kinglet (*Regulus calendula*), Fig. A2.7d; Ovenbird, Fig A2.8; Northern Waterthrush, Fig. A2.10; Orange-crowned Warbler (*Oreothlypis celata*), Fig. A2.12d; Yellow-rumped Warbler (*Setophaga coronata*), Fig. A2.20; Lincoln's Sparrow, Fig. A2.23; and White-throated Sparrow, Fig A2.24). Band recoveries for Yellow-rumped Warbler link Alaska to Wisconsin (n = 2), Illinois (n = 1), Michigan (n = 1), Ohio (n = 1), and Maryland (n = 1), supporting the inclusion of Alaska in the catchment area sampled by Alberta stations.

There were similar mixes of fall origin among the six species sampled at the Saskatchewan site. For two species, areas of probable origin were primarily Yukon Territory and southern Northwest Territories (Ruby-crowned Kinglet, Fig. A2.7e; and Orange-crowned Warbler, Fig. A2.12f). In contrast, the other six species (Alder Flycatcher, Fig. A2.1c; Hermit Thrush, Fig. A2.5b; Magnolia Warbler, Fig. A2.15c; Yellow Warbler, Fig. 5-7 and A2.17; Palm Warbler (*Setophaga palmarum*), Fig. 2.19a; and Lincoln's Sparrow, Fig. A2.23d) were most likely to come from east and southeast of Yukon Territory, with strong affiliation to northern parts of British Columbia and Alberta.

Comparison of spring maps from the Manitoba site for Yellow Warbler (Fig. A2.16b) and Northern Waterthrush (Fig. A2.9c) indicated wide variation in the geographical extent of the most probable breeding area, with the latter species coming from a far broader area. Similarly, fall maps indicate that Yellow Warblers captured in Manitoba came from areas closer to the station (Fig. 5 and Fig. A2.17), while Ruby-crowned Kinglet (Fig. A2.7f) and Orange-crowned Warbler (Fig. A2.12g) most likely originated from further north and west.

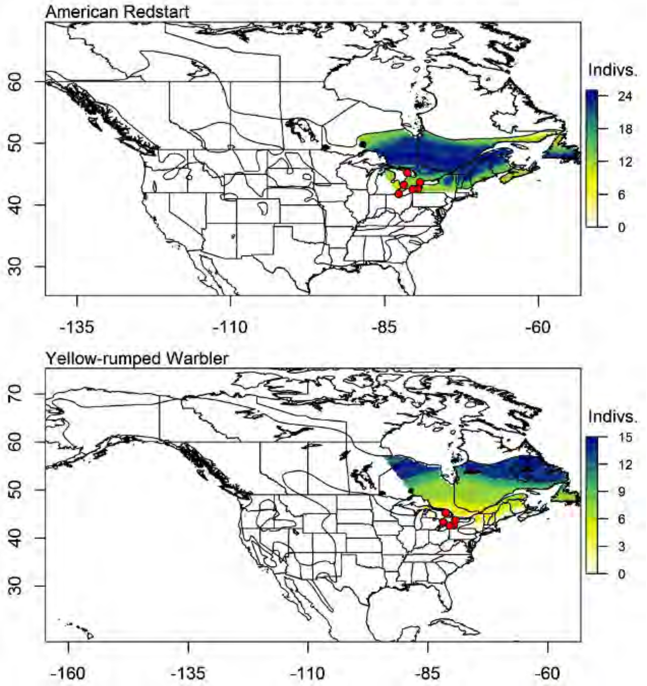
Catchment maps for southwestern Ontario show primarily northwestern Ontario origins for Northern Waterthrush (Fig. A2.9d), Orange-crowned Warbler (A2.12i), and Magnolia Warbler (Fig. A2.14b), while other species have potential origins both east and west of Hudson Bay (e.g., Yellow-rumped Warbler, Fig. A2.19c).

As was the case for Manitoba, the southwestern Ontario maps also show large differences among species in distance of the most probable breeding grounds from the sampling sites (e.g., Fig. 8). Most species captured in southwestern Ontario were more likely to come from an area far from the stations than nearby, regardless of season (Fig. A2) but spring Swainson's Thrush stand out as coming from close to stations, similar to the map for American Redstart (*Setophaga ruticilla*) in Figure 8.

Seasonal differences within species

In addition to species-specific variation in probable origins of birds captured at a particular station, there were also clear instances within species of seasonal variation at particular locations. For example, most Ruby-crowned Kinglet and Orange-crowned Warbler passing through southern Yukon in spring came from Alaska the previous year (Fig. 9), whereas fall samples were primarily of birds that had bred or been raised earlier that year in Yukon.

Fig. 8. Probable origins of American Redstart (*Setophaga ruticilla*) and Yellow-rumped Warbler (*Setophaga coronata*) captured in southwestern Ontario during spring migration. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.



Of four species captured in both seasons in northwestern Ontario, two show seasonal variation. Yellow Warbler and Ruby-crowned Kinglet had fall origins from areas farther to the north than shown by spring migrants (Fig. 10), suggesting spring movement more directly north toward breeding grounds. There were no seasonal differences in Palm (Fig A2.17a versus A2.18b) or Magnolia Warbler (Fig A2.14a versus A2.15d), but both these species have breeding ranges that do not extend as far west or into Alaska, such that their fall movements may have a weaker southeasterly component.

DISCUSSION

Our study demonstrates the considerable potential for using stable isotope methods to establish catchment areas for boreal songbirds moving through stations of the Canadian Migration Monitoring Network. Of particular note is the broad geographic scope and multispecies coverage of this study, which uncovered more species-specific and seasonal variations than found by earlier feather isotope studies (Wassenaar and Hobson 2001, Dunn et al. 2006, Boulet et al. 2006). Our use of direction of migration based on the long-term database of band recoveries provided greater resolution of probable breeding ground origins than earlier work based on δ^2H_f alone, despite caveats outlined in the Methods section. Together, this work provides a useful template for investigating hypotheses for potential causes of differences in population trends recorded among stations. For example (Fig. 9),

Fig. 9. Probable origins of Orange-crowned Warbler (*Oreothlypis celata*) and Ruby-crowned Kinglet (*Regulus calendula*) captured in Yukon Territory during spring and fall migration. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.

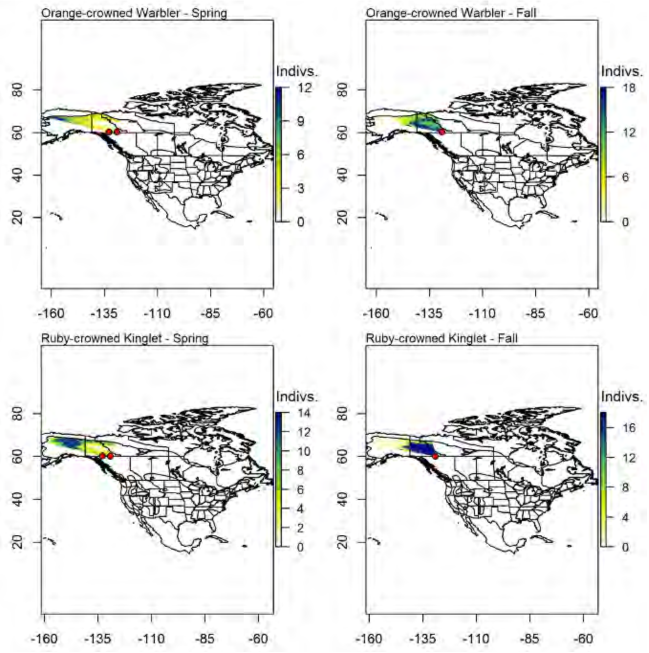
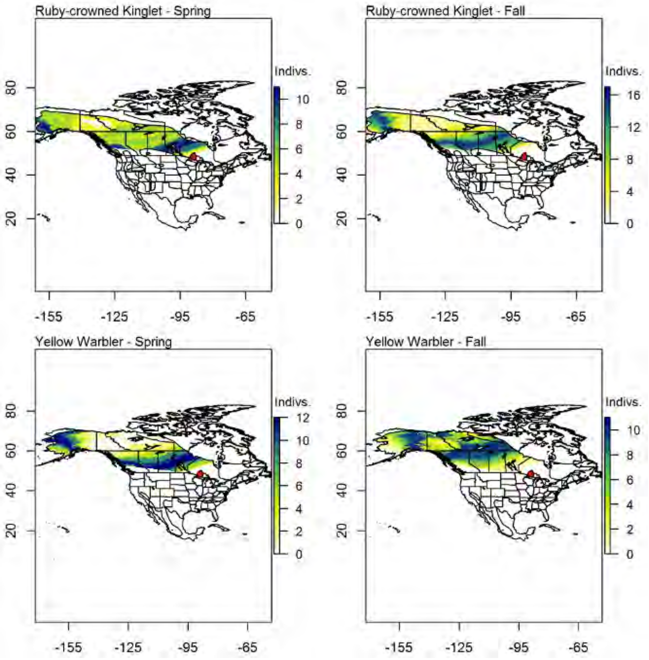


Fig. 10. Probable origins of Ruby-crowned Kinglet (*Regulus calendula*) and Yellow Warbler (*Setophaga petechia*) captured at Thunder Cape Bird Observatory in northwestern Ontario during spring and fall migration. Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given.

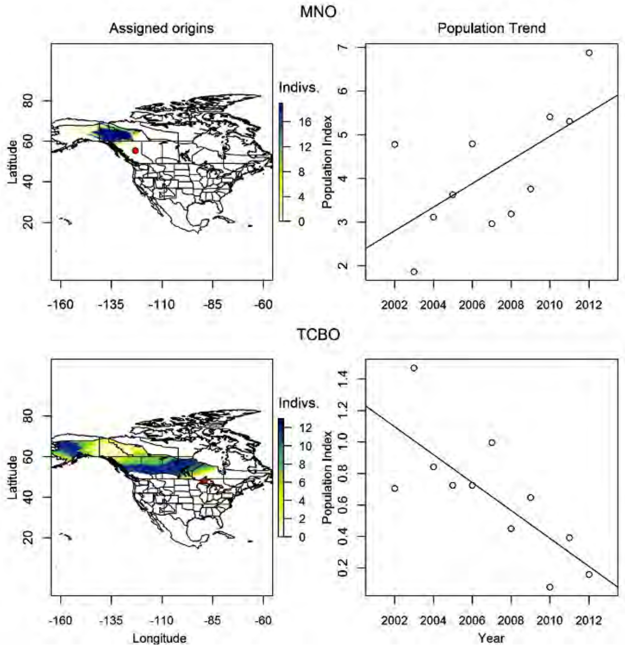


the station in northern British Columbia (MNO), which samples Orange-crowned Warblers in fall that originate primarily in the Yukon, recorded a steady increase in population of that species during 2002-2012 (6.69% year^{-1}, P = 0.038). In contrast, the population sampled in northwestern Ontario (at TCBO), which originates primarily from areas south and east of the Yukon (although western Alaska could not be ruled out based on the isotope data alone, Fig. 9) declined strongly over the same period (-13.12% year^{-1}, P = 0.004; Fig. 11; http://www.bsc-eoc.org/birdmon/cmmn/popindices.jsp).

Factors limiting populations of migratory birds can of course affect any stage of the annual cycle, and teasing out which factors may be operating on breeding, wintering, or stopover sites is a daunting task. Nonetheless, a useful next step would be to determine whether potential causal factors affecting specific portions of the breeding grounds are correlated with population trends recorded at the CMMN stations that sample those areas. In the above example of Orange-crowned Warblers, a useful starting point would be to compare conditions on the breeding grounds in northwest North America with those in northwestern Ontario. Other isotopic work has identified different wintering grounds associated with decreasing and stable or increasing populations of Black-throated Blue Warbler (Rubenstein et al. 2002). Hobson et al. (2015) established migratory connections between breeding and wintering populations of Golden-winged Warbler (*Vermivora chrysoptera*) that may assist in interpreting population trends and areas of future research on conservation of that species. No study to date, however, has examined correlation of population trends to potential causal factors across a set of catchment areas that vary in the magnitude of those factors. Our results provide an opportunity to conduct such an analysis.

Despite the many advantages of using stable isotope methods to help delineate catchment areas of CMMN stations, there are some obvious weaknesses. Chief among these is the inherent ambiguity associated with feather δ²H isoclines showing broad longitudinal distributions in North America. In addition, the similarity in isoscapes associated with parts of western Alaska and southern Canada often makes it difficult to confidently associate birds that are captured at southern migration monitoring stations with one or both of those two regions. Here, we attempted to constrain possible origins of populations using known breeding range and movement trajectories inferred from band recoveries. However, both of these constraints can be improved and incorporated into assignment models using a more probabilistic-based approach as true priors in a Bayesian framework. For example, Pekarsky et al. (2015) recently used probability of occurrence surfaces based on Maximum Entropy Modeling (MaxEnt version 3.3.3k; Phillips et al. 2006) combined with stable-oxygen isotopes to infer origins of Common Cranes (*Grus grus*). Van Wilgenburg and Hobson (2011) also demonstrated how migration vectors derived from

Fig. 11. Contrasting assigned origins (left-hand panels) and population trends (right-hand panels) of Orange-crowned Warbler (*Oreothlypis celata*) from migration monitoring during the fall at Mackenzie Nature Observatory (MNO) and Thunder Cape Bird Observatory (TCBO). Red dots indicate locations of Canadian Migration Monitoring Network stations used in the analysis. Scales indicate the number of individuals that were isotopically consistent with similarly colored pixels in the map given (left-hand panels). Population indices and trends are available from http://www.bsc-eoc.org/birdmon/cmmn/popindices.jsp.



band recoveries can be applied as a Bayesian prior in isotopic assignments of birds and other wildlife (see also Hobson et al. 2014). Here, we chose not to treat migration direction directly as a prior probability because of a lack of data on a species by species basis. Instead, we took a more conservative approach of using migration directions to simply constrain assignments. Future isotopic studies using samples from CMMN stations will benefit from applying these more advanced approaches and examining multiyear patterns of catchment delineation for several species.

The use of other tools in association with the isotope approach will undoubtedly help us to further refine catchment areas. For example, recent and future development of innovative tracking technologies may soon allow detection of much finer species and seasonal differences in direction of departure from capture stations, allowing more refined constraint of potential origins (e.g., Woodworth et al. 2014). Another avenue is the use of multiple isotopes, especially if they can be associated with a predictable isoscape surface such as those provided by plant physiology models (e.g., Hobson et al. 2012, García-Pérez and Hobson 2014, Hobson et al. 2014). Finally, there is much promise in combining isotopic results with patterns of genetic variation (Boulet et al. 2006, Chabot et al. 2012, Rundel et al. 2013, Ruegg et al. 2014). Such genetic analyses can often be conducted on the same feather samples as those used for stable isotope assays. Our broad geographic sampling is particularly suited for studies combining genetic variation with δ^2H_f patterns and we invite inquiries for cooperative study.

Yellow Warbler provides a good example of the improved resolution obtained by combining genetic with isotopic methods. Our assignment maps for Manitoba and northwestern Ontario (Fig. 5) include potential origins in Alaska, as well as isotopically similar regions of the northern Prairie Provinces and southern Northwest Territories (northwestern Ontario site only). However, the combined isotopic and genetic analysis of Boulet et al. (2006) found that more than 80% of fall migrant Yellow Warblers captured in Minnesota (just southeast of Manitoba) were likely to have come from the Yukon and western Northwest Territories, and not from Alaska. Isotope results indicate that Yukon birds are captured in fall in northern BC, Alberta, and Saskatchewan, but are largely absent from Manitoba and northwestern Ontario (Figs. 5-7), suggesting that fall migrants from Yukon move on a southeastern path toward Minnesota and pass to the south of Manitoba. Therefore, although we cannot statistically exclude portions of Alaska as probable origins for birds captured in Manitoba and northwestern Ontario, it is more likely that the birds passing through those sites originate from areas east of the Yukon, with the Manitoba site getting concentrations from the Prairie Provinces and the northwest Ontario site getting concentrations from Northwest Territories.

Future work using the isotopic approach alone is still well worth pursuing for our purposes. Analysis of additional CMMN samples would fill gaps to provide more seasonal comparisons, and more detailed work on selected species at nearby stations would show how much sampled populations are likely to overlap. Northern populations migrate through southern Canada later in the fall (Dunn et al. 2006), such that separate population trends could be calculated for early and late migrants, representing two different catchment areas. Close examination of δ^2H_f with date may help identify Alaskan migrants. Finally, more work on δ^2H_f of migrants captured at locations in the eastern U.S. and Gulf Coast states could be helpful in resolving routes of boreal forest passerines once they are farther from their breeding grounds.

Responses to this article can be read online at:
http://www.ace-eco.org/issues/responses.php/719

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Appendix 1. Summary of linear mixed model results examining variation in stable-isotope ratio (δ^2H) of feathers from birds captured during spring and fall migration at Canadian Migration Monitoring Network Stations.

Table A1.1. Predicted mean δ^2H_f and 95% Confidence Intervals from linear mixed effects models examining variation in δ^2H_f from 12 species of passerine captured at Canadian Migration Monitoring Network Stations during spring migration (n = 966 individuals).

				Predicted δ^2H_f (‰)			
Species	Station	Location	N	Lower CI	Mean	Upper CI	Difference
SWTH	ACBO	Yukon	16	-144.1	-133.0	-121.8	A
SWTH	TLBBS	Yukon	9	-155.2	-142.5	-129.9	A
SWTH	LSLBO	Northern AB	25	-137.2	-126.4	-115.7	A
SWTH	DMBO	Manitoba	13	-143.4	-131.3	-119.3	A
SWTH	TCBO	Northwestern ON	20	-104.0	-93.9	-83.9	B
SWTH	AuBO	Southwestern ON	3	-111.8	-96.6	-81.4	B
SWTH	BPBO	Southwestern ON	2	-121.8	-105.9	-90.0	AB
SWTH	HBO	Southwestern ON	3	-110.3	-95.1	-80.0	B
SWTH	LPBO	Southwestern ON	3	-106.5	-91.5	-76.5	B
SWTH	PIBO	Southwestern ON	3	-105.5	-90.1	-74.8	B
SWTH	TTPBRS	Southwestern ON	3	-106.0	-90.9	-75.8	B
SWTH	PEPTBO	SE Ontario/SW Quebec	21	-100.9	-90.6	-80.4	B
HETH	AuBO	Southwestern ON	1	-119.2	-102.3	-85.4	A
HETH	BPBO	Southwestern ON	3	-122.2	-107.1	-92.0	A
HETH	LPBO	Southwestern ON	8	-112.7	-100.1	-87.5	A
HETH	TTPBRS	Southwestern ON	5	-111.9	-98.1	-84.2	A
RCKI	ACBO	Yukon	14	-150.7	-139.3	-127.9	A
RCKI	TLBBS	Yukon	6	-151.9	-138.4	-124.8	A
RCKI	DMBO	Manitoba	12	-140.4	-128.2	-116.0	AB
RCKI	TCBO	Northwestern ON	17	-129.3	-118.8	-108.4	AB
RCKI	BPBO	Southwestern ON	5	-124.8	-110.9	-96.9	B
RCKI	HBO	Southwestern ON	2	-118.9	-103.0	-87.1	B
RCKI	LPBO	Southwestern ON	8	-120.2	-107.5	-94.9	B
RCKI	TTPBRS	Southwestern ON	5	-118.3	-104.4	-90.5	B
RCKI	IPBO	SE Ontario/SW Quebec	1	-122.6	-105.7	-88.8	B
RCKI	MBO	SE Ontario/SW Quebec	3	-122.4	-107.0	-91.7	B
RCKI	PEPTBO	SE Ontario/SW Quebec	14	-114.2	-103.1	-91.9	B
NOWA	ACBO	Yukon	9	-130.8	-118.3	-105.9	AB
NOWA	TLBBS	Yukon	6	-145.4	-131.9	-118.3	AB
NOWA	LSLBO	Northern AB	23	-149.7	-138.8	-127.9	A

NOWA	DMBO	Manitoba	25	-143.7	-132.7	-121.7	A
NOWA	TCBO	Northwestern ON	14	-119.5	-108.6	-97.6	B
NOWA	AuBO	Southwestern ON	5	-114.4	-100.2	-86.0	BC
NOWA	BPBO	Southwestern ON	2	-121.0	-105.1	-89.2	B
NOWA	HBO	Southwestern ON	5	-101.6	-87.5	-73.5	BC
NOWA	LPBO	Southwestern ON	5	-116.6	-102.7	-88.9	B
NOWA	PIBO	Southwestern ON	3	-106.5	-91.2	-75.8	BC
NOWA	TTPBRS	Southwestern ON	5	-112.8	-98.9	-85.1	BC
NOWA	IPBO	SE Ontario/SW Quebec	6	-114.1	-100.2	-86.3	BC
NOWA	MBO	SE Ontario/SW Quebec	8	-122.2	-108.6	-95.0	AB
NOWA	PEPTBO	SE Ontario/SW Quebec	11	-108.0	-96.2	-84.5	BC
NOWA	ABO	Maritimes	2	-88.0	-71.7	-55.5	C
OCWA	ACBO	Yukon	12	-136.4	-124.7	-112.9	A
OCWA	TLBBS	Yukon	7	-148.3	-135.1	-121.9	A
OCWA	AuBO	Southwestern ON	2	-124.7	-108.7	-92.8	AB
OCWA	BPBO	Southwestern ON	11	-126.0	-113.9	-101.8	AB
OCWA	LPBO	Southwestern ON	3	-111.7	-96.6	-81.6	B
OCWA	TTPBRS	Southwestern ON	1	-117.3	-100.4	-83.5	AB
OCWA	PEPTBO	SE Ontario/SW Quebec	2	-120.8	-104.9	-89.1	AB
AMRE	BBO	Northern AB	1	-146.1	-129.1	-112.0	A
AMRE	LSLBO	Northern AB	25	-146.4	-135.7	-124.9	A
AMRE	TCBO	Northwestern ON	10	-112.3	-100.5	-88.7	B
AMRE	AuBO	Southwestern ON	5	-98.8	-84.6	-70.4	B
AMRE	BPBO	Southwestern ON	5	-110.8	-96.8	-82.8	B
AMRE	HBO	Southwestern ON	5	-106.6	-92.5	-78.5	B
AMRE	LPBO	Southwestern ON	6	-97.6	-84.2	-70.8	B
AMRE	PIBO	Southwestern ON	3	-100.5	-85.2	-69.8	B
AMRE	TTPBRS	Southwestern ON	8	-103.5	-90.8	-78.1	B
AMRE	IPBO	SE Ontario/SW Quebec	5	-111.1	-96.9	-82.7	B
AMRE	PEPTBO	SE Ontario/SW Quebec	9	-101.2	-88.9	-76.6	B
MAWA	TCBO	Northwestern ON	20	-112.4	-102.4	-92.3	A
MAWA	AuBO	Southwestern ON	1	-120.0	-103.1	-86.2	A
MAWA	BPBO	Southwestern ON	3	-122.8	-107.7	-92.6	A
MAWA	HBO	Southwestern ON	1	-115.8	-98.9	-82.0	A
MAWA	LPBO	Southwestern ON	5	-109.9	-96.0	-82.2	A
MAWA	PIBO	Southwestern ON	3	-108.9	-93.5	-78.2	A
MAWA	TTPBRS	Southwestern ON	5	-114.5	-100.6	-86.8	A
MAWA	IPBO	SE Ontario/SW Quebec	2	-116.7	-100.7	-84.8	A
MAWA	MBO	SE Ontario/SW Quebec	2	-117.1	-101.1	-85.1	A
MAWA	PEPTBO	SE Ontario/SW Quebec	16	-108.7	-97.9	-87.0	A
MAWA	ABO	Maritimes	20	-93.0	-77.8	-62.6	A
YWAR	ACBO	Yukon	11	-152.4	-140.4	-128.4	A

YWAR	TLBBS	Yukon	10	-154.2	-141.8	-129.4	A
YWAR	BBO	Northern AB	8	-149.2	-133.2	-117.3	A
YWAR	DMBO	Manitoba	21	-138.4	-127.2	-116.0	A
YWAR	TCBO	Northwestern ON	17	-132.7	-122.2	-111.8	AB
YWAR	HBO	Southwestern ON	5	-113.9	-99.9	-85.8	B
YWAR	LPBO	Southwestern ON	9	-116.3	-104.0	-91.7	AB
YWAR	PIBO	Southwestern ON	3	-108.6	-93.3	-78.0	B
YWAR	TTPBRS	Southwestern ON	2	-113.5	-97.7	-81.8	B
YWAR	IPBO	SE Ontario/SW Quebec	7	-114.7	-101.2	-87.6	B
YWAR	MBO	SE Ontario/SW Quebec	7	-111.4	-97.6	-83.7	B
PAWA	TCBO	TCBO	20	-119.1	-109.0	-98.9	A
PAWA	BPBO	Southwestern ON	5	-120.8	-106.8	-92.9	A
PAWA	HBO	Southwestern ON	1	-116.2	-99.3	-82.4	A
PAWA	LPBO	Southwestern ON	3	-108.2	-93.2	-78.1	A
PAWA	TTPBRS	Southwestern ON	5	-114.5	-100.6	-86.7	A
PAWA	IPBO	SE Ontario/SW Quebec	3	-118.7	-103.5	-88.3	A
PAWA	PEPTBO	SE Ontario/SW Quebec	16	-107.9	-97.1	-86.2	A
YRWA	LSLBO	Northern AB	25	-158.3	-147.5	-136.8	A
YRWA	TCBO	Northwestern ON	23	-119.7	-109.9	-100.2	B
YRWA	AuBO	Southwestern ON	5	-120.3	-106.2	-92.0	B
YRWA	BPBO	Southwestern ON	5	-118.6	-104.6	-90.7	B
YRWA	HBO	Southwestern ON	5	-122.0	-108.0	-93.9	B
YRWA	LPBO	Southwestern ON	5	-112.3	-98.5	-84.7	B
YRWA	TTPBRS	Southwestern ON	5	-119.5	-105.7	-91.8	B
YRWA	PEPTBO	SE Ontario/SW Quebec	25	-113.8	-103.9	-94.0	B
WIWA	ACBO	Yukon	15	-135.1	-123.8	-112.5	AB
WIWA	TLBBS	Yukon	10	-147.5	-135.1	-122.7	A
WIWA	LSLBO	Northern AB	12	-142.5	-130.4	-118.4	AB
WIWA	TCBO	Northwestern ON	21	-120.3	-110.4	-100.4	B
WIWA	AuBO	Southwestern ON	4	-115.1	-100.5	-85.9	BC
WIWA	BPBO	Southwestern ON	4	-113.1	-98.6	-84.1	BC
WIWA	HBO	Southwestern ON	6	-100.4	-86.7	-73.1	C
WIWA	LPBO	Southwestern ON	3	-112.1	-97.0	-82.0	BC
WIWA	PIBO	Southwestern ON	4	-97.6	-82.8	-68.0	C
WIWA	TTPBRS	Southwestern ON	4	-106.6	-92.2	-77.8	BC
WIWA	IPBO	SE Ontario/SW Quebec	6	-117.4	-103.6	-89.7	BC
WIWA	MBO	SE Ontario/SW Quebec	5	-112.3	-97.9	-83.5	BC
WIWA	PEPTBO	SE Ontario/SW Quebec	14	-99.8	-88.6	-77.5	C
LISP	ACBO	Yukon	12	-159.1	-147.3	-135.5	A
LISP	TLBBS	Yukon	8	-139.6	-126.7	-113.8	AB
LISP	DMBO	Manitoba	9	-151.4	-138.7	-125.9	AB
LISP	TCBO	Northwestern ON	9	-126.8	-114.7	-102.6	B

LISP	AuBO	Southwestern ON	2	-119.4	-103.4	-87.5	B
LISP	BPBO	Southwestern ON	1	-123.1	-106.2	-89.3	B
LISP	HBO	Southwestern ON	3	-118.8	-103.6	-88.5	B
LISP	LPBO	Southwestern ON	5	-114.7	-100.9	-87.1	B
LISP	PIBO	Southwestern ON	1	-106.5	-89.6	-72.6	B
LISP	TTPBRS	Southwestern ON	5	-107.4	-93.5	-79.6	B

Table A1.2. Predicted mean δ^2H_f and 95% Confidence Intervals from linear mixed effects models examining variation in δ^2H_f from 14 species of passerine captured at Canadian Migration Monitoring Network Stations during fall migration (n = 1855 individuals). Stations arranged by numbers in Fig. 1. Identical letters in the Difference column indicate overlap of 95% Confidence Intervals with other CI's for the same species.

				Predicted δ^2H_f (‰)			
Species	Station	Location	N	Lower CI	Mean	Upper CI	Difference
ALFL	ACBO	Yukon	20	-167.7	-158.0	-148.4	A
ALFL	MNO	Northern BC	20	-164.4	-155.1	-145.8	A
ALFL	LMBO	Saskatchewan	20	-152.1	-143.1	-134.1	AB
ALFL	DMBO	Manitoba	10	-144.5	-132.8	-121.1	B
ALFL	AuBO	Southwestern Ontario	1	-119.3	-102.7	-86.1	BC
ALFL	BPBO	Southwestern Ontario	1	-127.0	-110.6	-94.3	BC
ALFL	LPBO	Southwestern Ontario	6	-119.0	-107.1	-95.2	BC
ALFL	HBO	Southwestern Ontario	7	-106.5	-94.6	-82.6	C
ALFL	TTPBRS	Southwestern Ontario	5	-118.3	-105.8	-93.4	C
ALFL	PEPTBO	SE Ontario/SW Quebec	12	-109.7	-99.2	-88.7	C
ALFL	MBO	SE Ontario/SW Quebec	8	-118.4	-107.4	-96.3	C
ALFL	ABO	Maritimes	20	-75.8	-65.5	-55.3	D
SWTH	IBS	Southern AB	27	-146.8	-138.9	-130.9	
HETH	MNO	Northern BC	17	-162.6	-153.0	-143.5	A
HETH	VLBO	Southern BC	3	-132.8	-119.1	-105.4	B
HETH	LSLBO	Northern AB	11	-157.3	-146.2	-135.1	A
HETH	LMBO	Saskatchewan	20	-158.2	-149.2	-140.2	A
HETH	TCBO	Northwestern Ontario	12	-138.2	-128.0	-117.9	AB
HETH	PIBO	Southwestern Ontario	2	-126.9	-111.2	-95.6	B
HETH	BPBO	Southwestern Ontario	5	-110.2	-96.9	-83.6	B
HETH	LPBO	Southwestern Ontario	4	-122.3	-109.3	-96.4	B
HETH	HBO	Southwestern Ontario	4	-118.0	-104.8	-91.7	B
HETH	TTPBRS	Southwestern Ontario	5	-124.7	-112.2	-99.8	B
HETH	PEPTBO	SE Ontario/SW Quebec	13	-106.0	-95.7	-85.4	B
HETH	MBO	SE Ontario/SW Quebec	7	-111.4	-100.0	-88.7	B
HETH	OOT	Eastern Quebec	7	-122.8	-110.3	-97.9	B

HETH	ABO	Maritimes	20	-69.2	-59.0	-48.8	C
RCKI	ACBO	Yukon	19	-179.5	-169.8	-160.1	A
RCKI	MNO	Northern BC	21	-169.3	-160.1	-150.8	A
RCKI	VLBO	Southern BC	32	-142.5	-133.2	-123.9	AB
RCKI	IBS	Southern AB	18	-158.4	-149.7	-141.1	B
RCKI	LMBO	Saskatchewan	20	-170.3	-161.3	-152.2	B
RCKI	DMBO	Manitoba	20	-158.6	-147.7	-136.7	AB
RCKI	TCBO	Northwestern Ontario	20	-138.1	-128.8	-119.5	BC
RCKI	LPBO	Southwestern Ontario	5	-120.8	-108.4	-96.0	C
RCKI	TTPBRS	Southwestern Ontario	5	-123.3	-110.8	-98.4	C
RCKI	PEPTBO	SE Ontario/SW Quebec	11	-122.0	-111.4	-100.8	C
RCKI	MBO	SE Ontario/SW Quebec	9	-117.5	-106.7	-96.0	C
RCKI	ABO	Maritimes	20	-95.6	-85.4	-75.1	D
OVEN	IBS	Southern AB	28	-152.7	-144.8	-136.8	
NOWA	IBS	Southern AB	58	-155.7	-148.6	-141.6	
OCWA	ACBO	Yukon	20	-168.2	-158.6	-148.9	A
OCWA	MNO	Northern BC	20	-176.3	-167.0	-157.7	A
OCWA	VLBO	Southern BC	20	-157.8	-148.0	-138.2	A
OCWA	LSLBO	Northern AB	15	-162.1	-151.4	-140.8	A
OCWA	IBS	Southern AB	36	-158.6	-151.0	-143.5	A
OCWA	BBO	Northern AB	12	-163.9	-150.0	-136.1	A
OCWA	LMBO	Saskatchewan	20	-163.2	-154.2	-145.2	A
OCWA	DMBO	Manitoba	16	-149.0	-137.8	-126.7	AB
OCWA	TCBO	Northwestern Ontario	20	-136.4	-127.1	-117.7	AB
OCWA	PIBO	Southwestern Ontario	2	-129.8	-114.2	-98.5	B
OCWA	AuBO	Southwestern Ontario	6	-127.5	-112.7	-97.9	B
OCWA	BPBO	Southwestern Ontario	4	-125.9	-112.3	-98.6	B
OCWA	LPBO	Southwestern Ontario	4	-128.0	-115.1	-102.2	B
OCWA	HBO	Southwestern Ontario	2	-127.3	-112.5	-97.7	B
OCWA	TTPBRS	Southwestern Ontario	2	-131.7	-117.0	-102.3	B
OCWA	PEPTBO	SE Ontario/SW Quebec	2	-128.5	-113.8	-99.1	B
OCWA	MBO	SE Ontario/SW Quebec	7	-133.5	-122.1	-110.7	B
MAWA	ACBO	Yukon	20	-186.1	-176.5	-166.8	A
MAWA	MNO	Northern BC	20	-168.4	-159.1	-149.8	AB
MAWA	LSLBO	Northern AB	11	-162.2	-151.1	-140.0	B
MAWA	LMBO	Saskatchewan	19	-157.2	-148.1	-139.1	B
MAWA	TCBO	Northwestern Ontario	19	-120.3	-110.9	-101.5	C
MAWA	PIBO	Southwestern Ontario	3	-122.1	-106.9	-91.7	CD
MAWA	BPBO	Southwestern Ontario	3	-106.8	-92.6	-78.4	CD
MAWA	LPBO	Southwestern Ontario	3	-124.5	-110.8	-97.1	CD
MAWA	HBO	Southwestern Ontario	5	-118.4	-105.8	-93.1	CD
MAWA	TTPBRS	Southwestern Ontario	5	-121.3	-108.9	-96.5	CD

MAWA	PEPTBO	SE Ontario/SW Quebec	12	-118.0	-107.5	-97.0	CD
MAWA	MBO	SE Ontario/SW Quebec	4	-125.8	-113.0	-100.2	C
MAWA	OOT	Eastern Quebec	12	-124.4	-112.7	-100.9	C
MAWA	SABBS	Maritimes	10	-109.9	-95.2	-80.5	CD
MAWA	ABO	Maritimes	13	-97.4	-86.7	-75.9	D
YWAR	ACBO	Yukon	19	-184.3	-174.6	-164.9	A
YWAR	MNO	Northern BC	20	-172.6	-163.3	-154.0	A
YWAR	VLBO	Southern BC	20	-141.3	-131.5	-121.7	B
YWAR	LSLBO	Northern AB	20	-170.1	-159.8	-149.5	A
YWAR	IBS	Southern AB	107	-170.3	-163.7	-157.0	A
YWAR	BBO	Northern AB	18	-158.6	-144.8	-131.0	AB
YWAR	LMBO	Saskatchewan	16	-172.4	-163.0	-153.6	A
YWAR	DMBO	Manitoba	20	-136.6	-125.6	-114.7	BC
YWAR	TCBO	Northwestern Ontario	15	-149.3	-139.6	-129.8	B
YWAR	LPBO	Southwestern Ontario	6	-132.1	-120.2	-108.3	BC
YWAR	HBO	Southwestern Ontario	8	-117.4	-105.7	-94.0	C
YWAR	TTPBRS	Southwestern Ontario	5	-126.0	-113.5	-101.1	BC
YWAR	PEPTBO	SE Ontario/SW Quebec	2	-120.4	-105.7	-91.0	C
YWAR	MBO	SE Ontario/SW Quebec	18	-118.9	-109.5	-100.0	C
YWAR	OOT	Eastern Quebec	11	-145.6	-133.7	-121.9	B
YWAR	SABBS	Maritimes	4	-116.6	-101.6	-86.6	C
YWAR	ABO	Maritimes	12	-104.8	-94.0	-83.1	C
PAWA	LMBO	Saskatchewan	17	-166.5	-157.2	-147.9	A
PAWA	TCBO	Northwestern Ontario	20	-123.1	-113.8	-104.5	B
PAWA	AuBO	Southwestern Ontario	2	-125.1	-109.4	-93.8	B
PAWA	LPBO	Southwestern Ontario	10	-121.9	-111.1	-100.2	B
PAWA	HBO	Southwestern Ontario	3	-124.4	-110.5	-96.7	B
PAWA	TTPBRS	Southwestern Ontario	5	-124.7	-112.2	-99.8	B
PAWA	PEPTBO	SE Ontario/SW Quebec	4	-121.3	-108.4	-95.5	B
PAWA	MBO	SE Ontario/SW Quebec	14	-120.7	-110.9	-101.0	B
YRWA	IBS	Southern AB	101	-159.3	-152.6	-145.9	
LISP	ACBO	Yukon	20	-169.7	-160.1	-150.4	A
LISP	MNO	Northern BC	14	-168.6	-158.7	-148.8	A
LISP	VLBO	Southern BC	20	-152.8	-143.0	-133.2	A
LISP	LSLBO	Northern AB	11	-161.6	-150.5	-139.4	A
LISP	IBS	Southern AB	25	-154.0	-145.9	-137.8	A
LISP	LMBO	Saskatchewan	15	-156.4	-146.9	-137.4	A
LISP	TCBO	Northwestern Ontario	20	-122.9	-113.6	-104.2	BC
LISP	BPBO	Southwestern Ontario	7	-108.2	-95.5	-82.7	C
LISP	LPBO	Southwestern Ontario	5	-124.5	-112.1	-99.8	BC
LISP	HBO	Southwestern Ontario	2	-122.9	-108.1	-93.3	BC
LISP	TTPBRS	Southwestern Ontario	5	-128.7	-116.2	-103.8	BC

LISP	PEPTBO	SE Ontario/SW Quebec	3	-118.2	-104.5	-90.8	BC
LISP	MBO	SE Ontario/SW Quebec	15	-128.1	-118.4	-108.6	B
LISP	OOT	Eastern Quebec	8	-123.6	-111.3	-99.0	BC
WTSP	IBS	Southern AB	30	-152.5	-144.7	-136.9	

Appendix 2. Geographic distribution of assigned origins for birds captured during spring and fall migration at Canadian Migration Monitoring Network Stations based upon stable-isotope (δ^2H) analysis of feathers.

Figure A2.1: Probable origins of hatching year (HY) Alder Flycatchers (*Empidonax alnorum*) captured during fall migration at CMMN stations in a) the Yukon (ACBO (n=20)); b) Northern British Columbia (MNO (n=20)); c) Saskatchewan (LMBO (n=20)); d) Southwest Ontario (AuBO (n=1), BPBO (n=1), HBO (n=7), LPBO (n=6), TTPBRS (n=5)); e) Southeast Ontario & Southwest Québec (MBO (n=8), PEPTBO (n=12)) and f) Eastern Canada (ABO (n=20)).

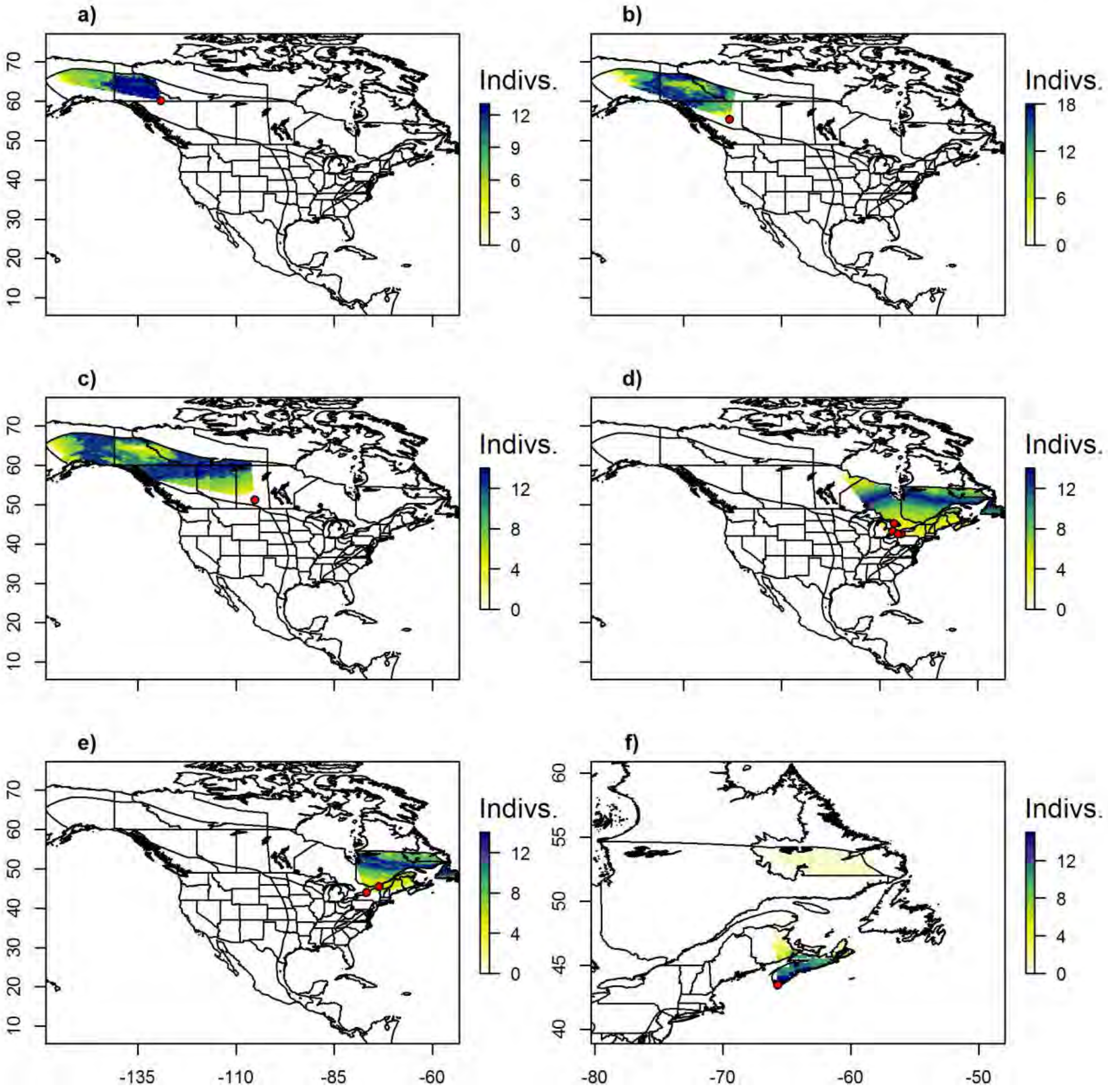


Figure A2.2: Probable origins of second year (SY) of Swainson's Thrushes (*Catharus ustulatus*) captured during spring migration at CMMN stations in a) the Yukon (ACBO (n=16), TLBBS (n=9)); b) Northern Alberta (LSLBO (n=25)); c) Western Ontario (TCBO (n=20)); d) Southwest Ontario (AuBO (n=3), BPBO (n=2), HBO (n=3), LPBO (n=3), PIBO (n=3), TTPBRS (n=3)); and e) Southeast Ontario & Southwest Québec (PEPTBO (n=21)).

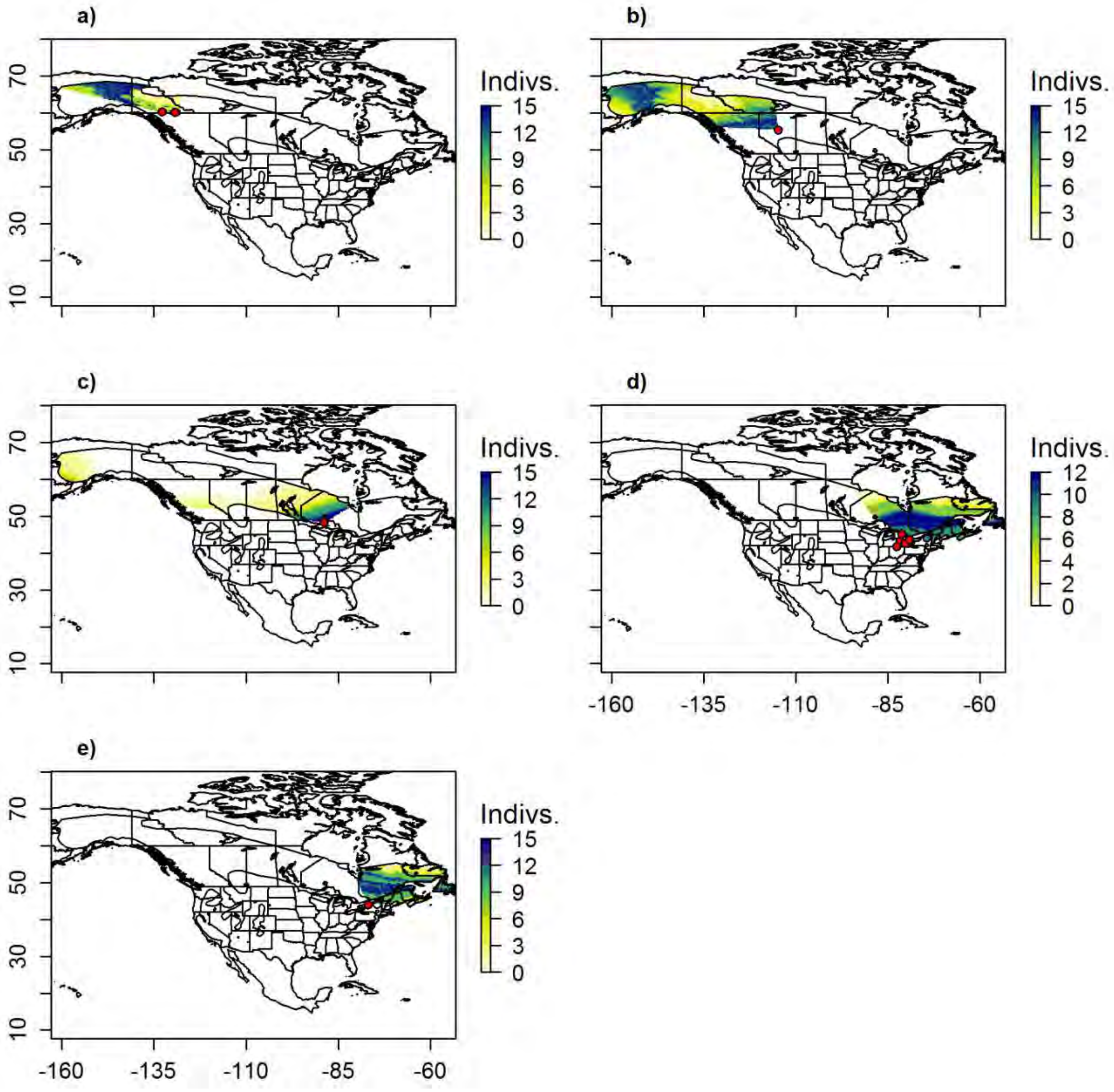


Figure A2.3: Probable origins of Swainson's Thrushes (*Catharus ustulatus*) captured during fall migration at the IBS CMMN station in Southern Alberta (n=27).

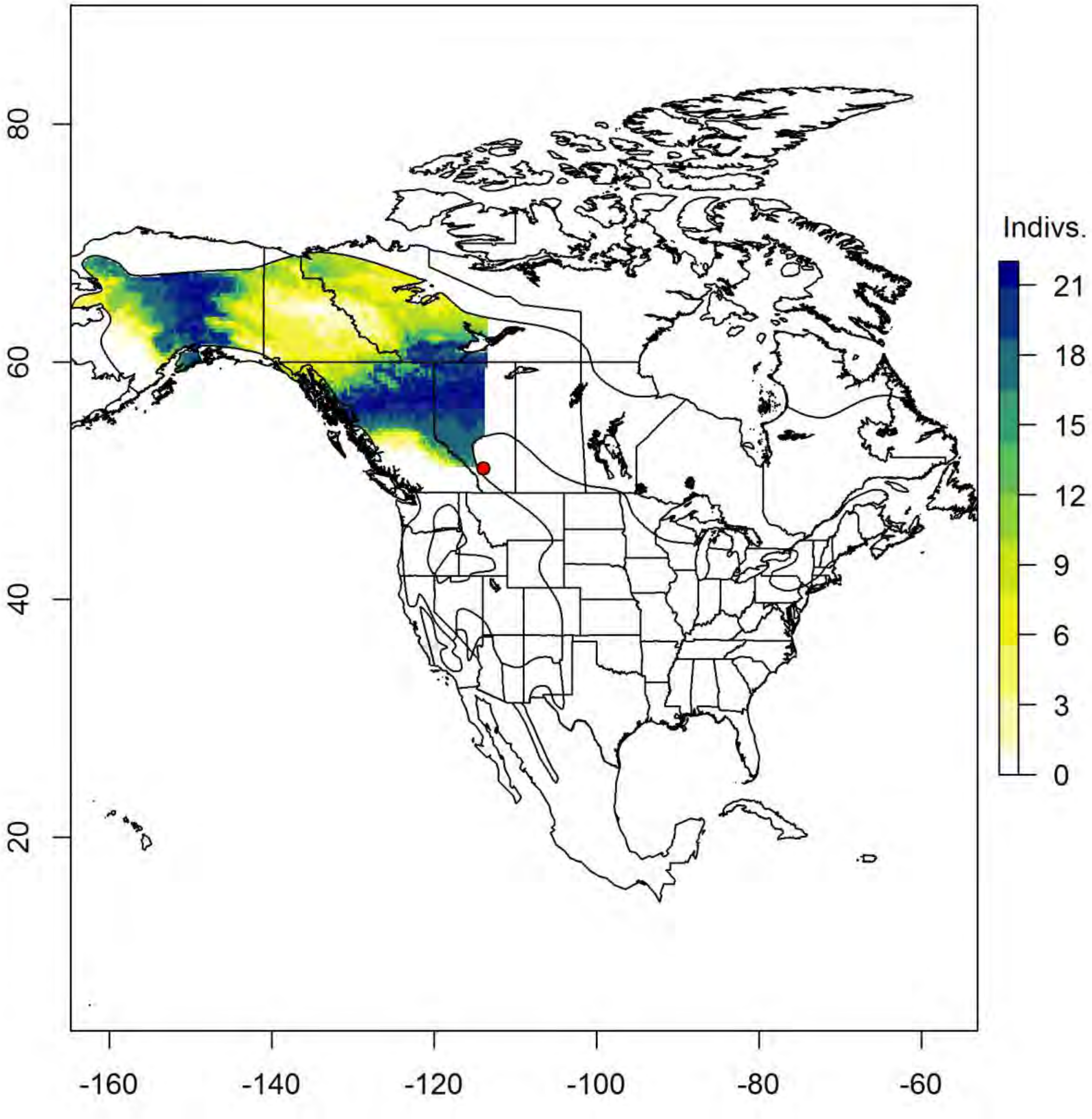


Figure A2.4: Probable origins of Hermit Thrushes (*Catharus guttatus*) captured during spring migration at CMMN stations in Southwest Ontario (AuBO (n=1), BPBO (n=3), LPBO (n=8), TTPBRS (n=5)).

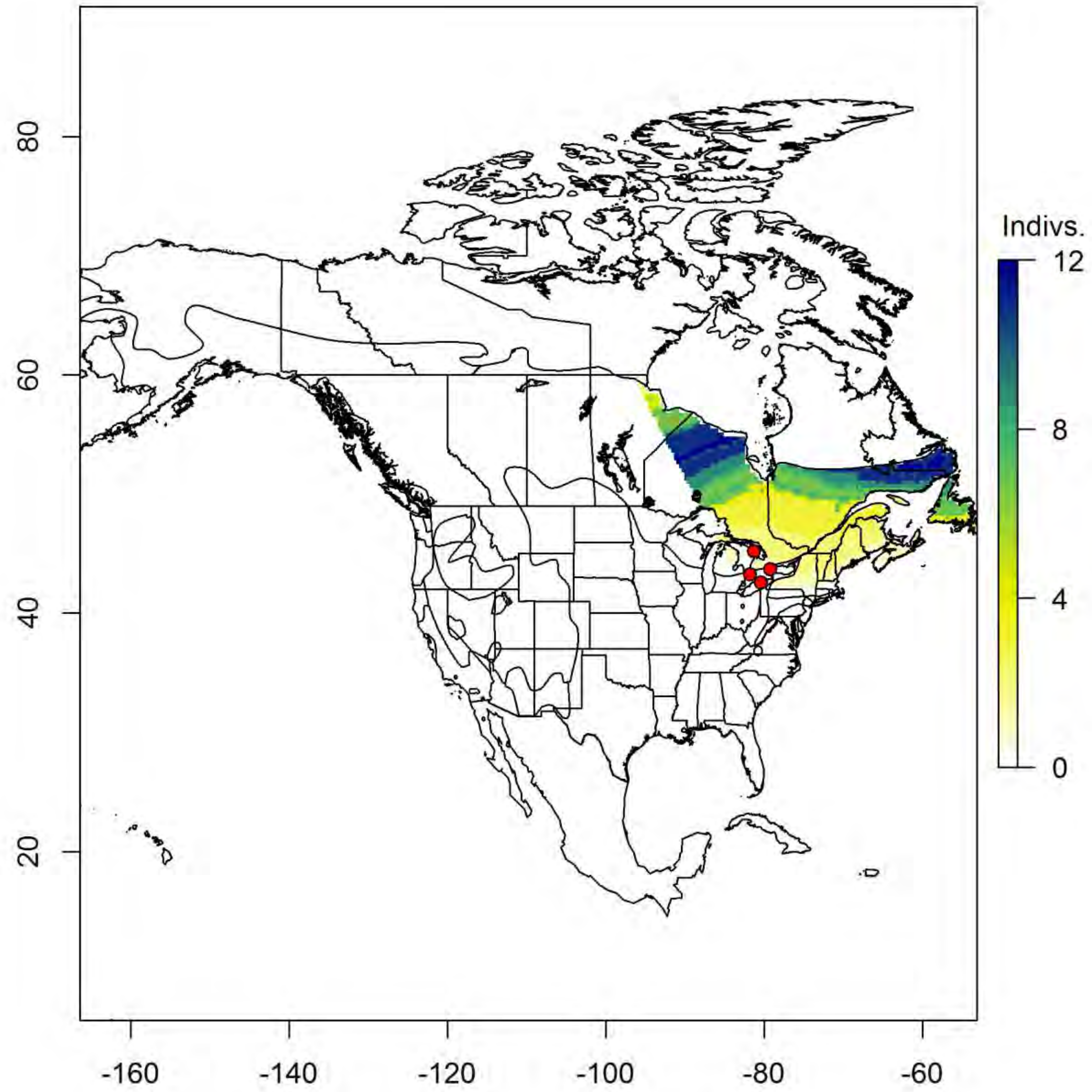


Figure A2.5: Probable origins of Hermit Thrushes (*Catharus guttatus*) captured during fall migration at Canadian Migration Monitoring Network (CMMN) stations in a) Northern British Columbia (MNO (n=17)); b) Saskatchewan (LMBO (n=20)); c) Southwest Ontario (BPBO (n=5), HBO (n=4), LPBO (n=4), PIBO (n=2), TTPBRS (n=5)); d) Southeast Ontario & Southwest Québec (MBO (n=7), PEPTBO (n=13)); and e) Eastern Canada (ABO (n=20)).

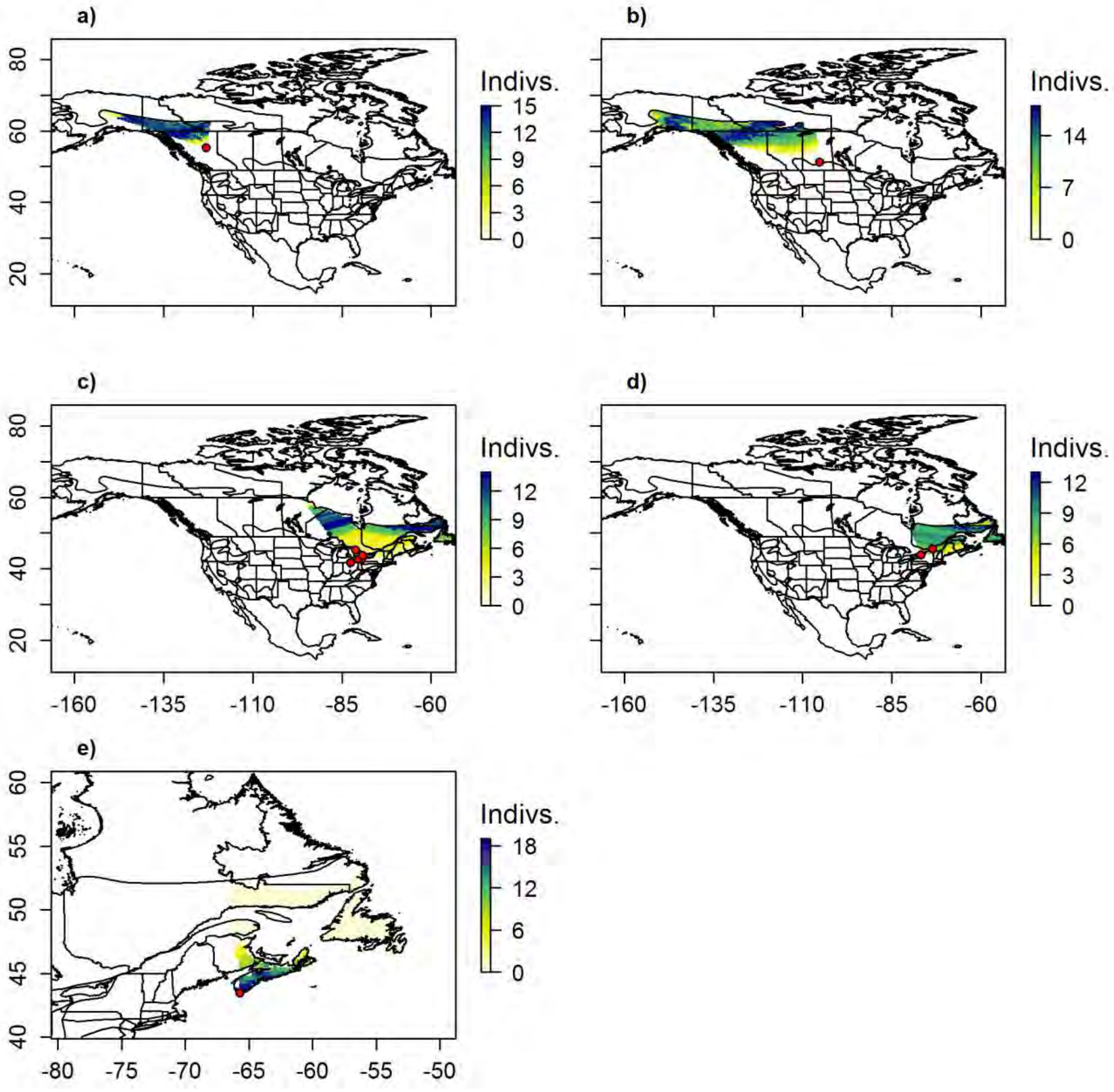


Figure A2.6: Probable origins of Ruby-crowned Kinglets (RCKI; *Regulus calendula*) captured during spring migration at CMMN stations in a) the Yukon (ACBO (n=14), TLBBS (n=6)); b) Western Ontario (TCBO (n=17)); c) Southwest Ontario (BPBO (n=5), HBO (n=2), LPBO (n=8), TTPBRS (n=5)); and d) Southeast Ontario & Southwest Québec (IPBO (n=1), MBO (n=3), PEPTBO (n=14)).

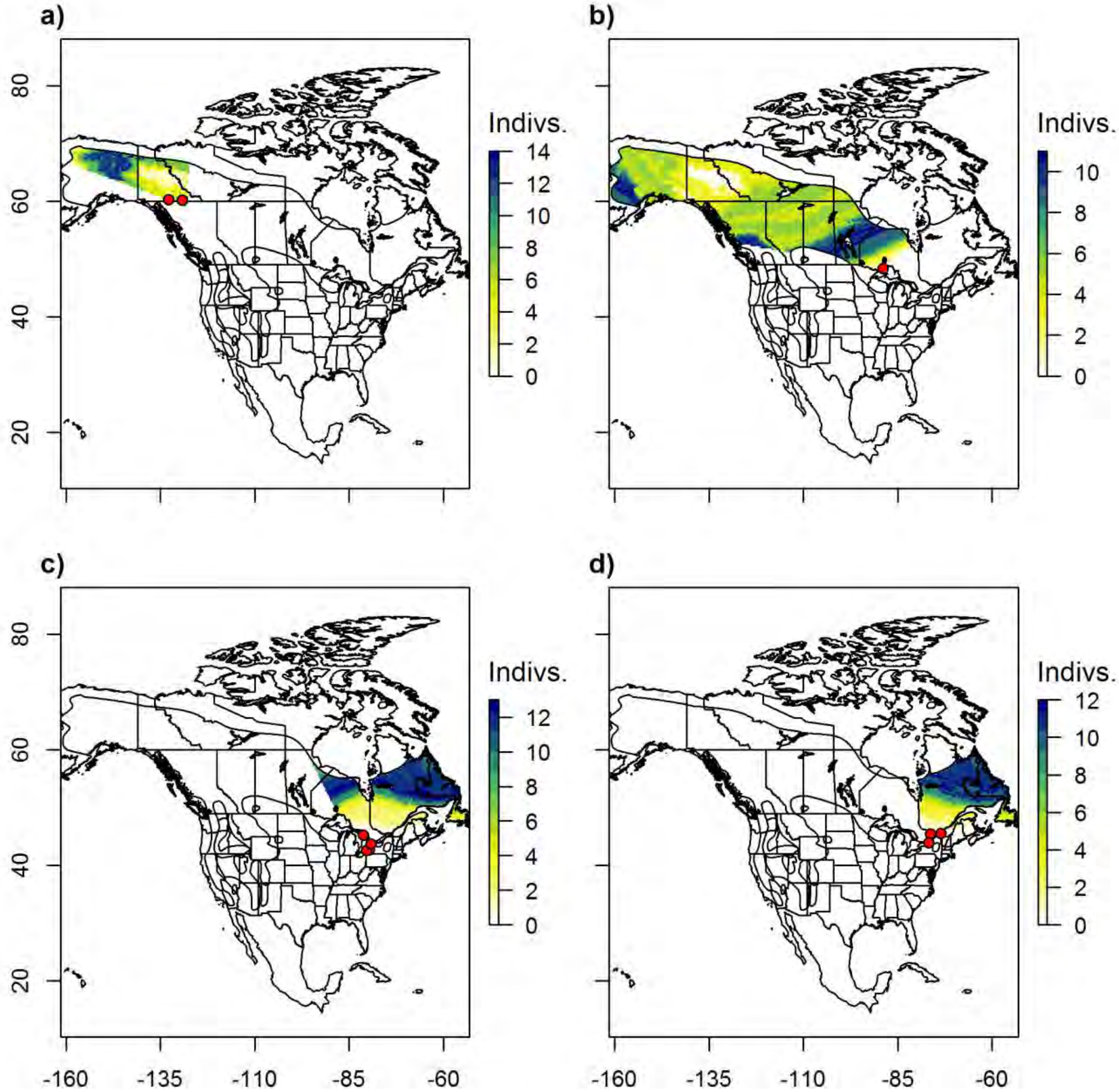


Figure A2.7: Probable origins of Ruby-crowned Kinglets (*Regulus calendula*) captured during fall migration at CMMN stations in a) the Yukon (ACBO (n=19)); b) Northern British Columbia (MNO (n=21)); c) Southern British Columbia (VLBO (n=32)); d) Southern Alberta (IBS (n=18)); e) Saskatchewan (LMBO (n=20)); f) Manitoba (DMBO (n=20)); g) Western Ontario (TCBO (n=20)); h) Southeast Ontario & Southwest Québec (MBO (n=9), PEPTBO (n=11)); and i) Eastern Canada (ABO (n=20)).

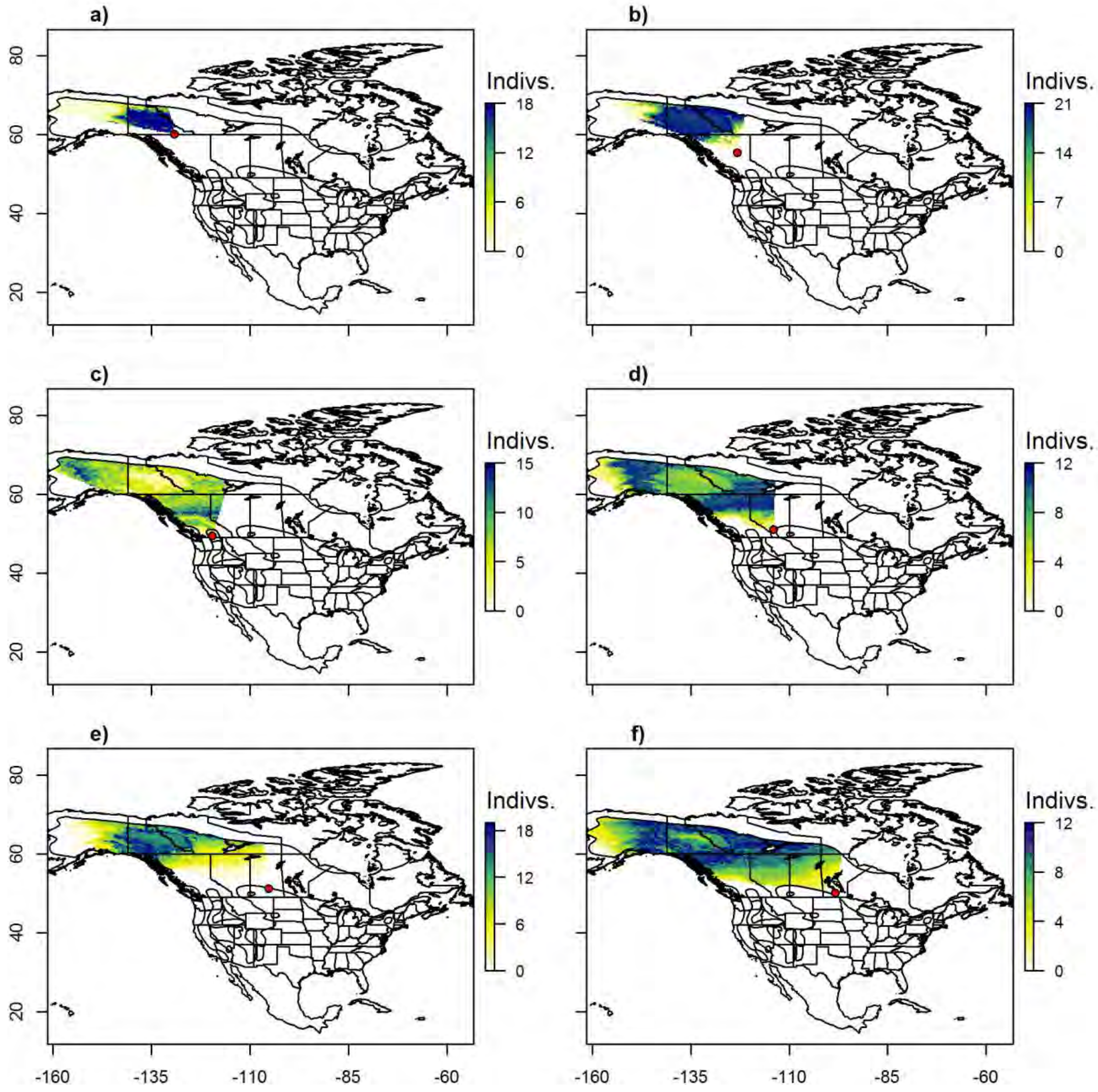


Figure A2.7 (con't):

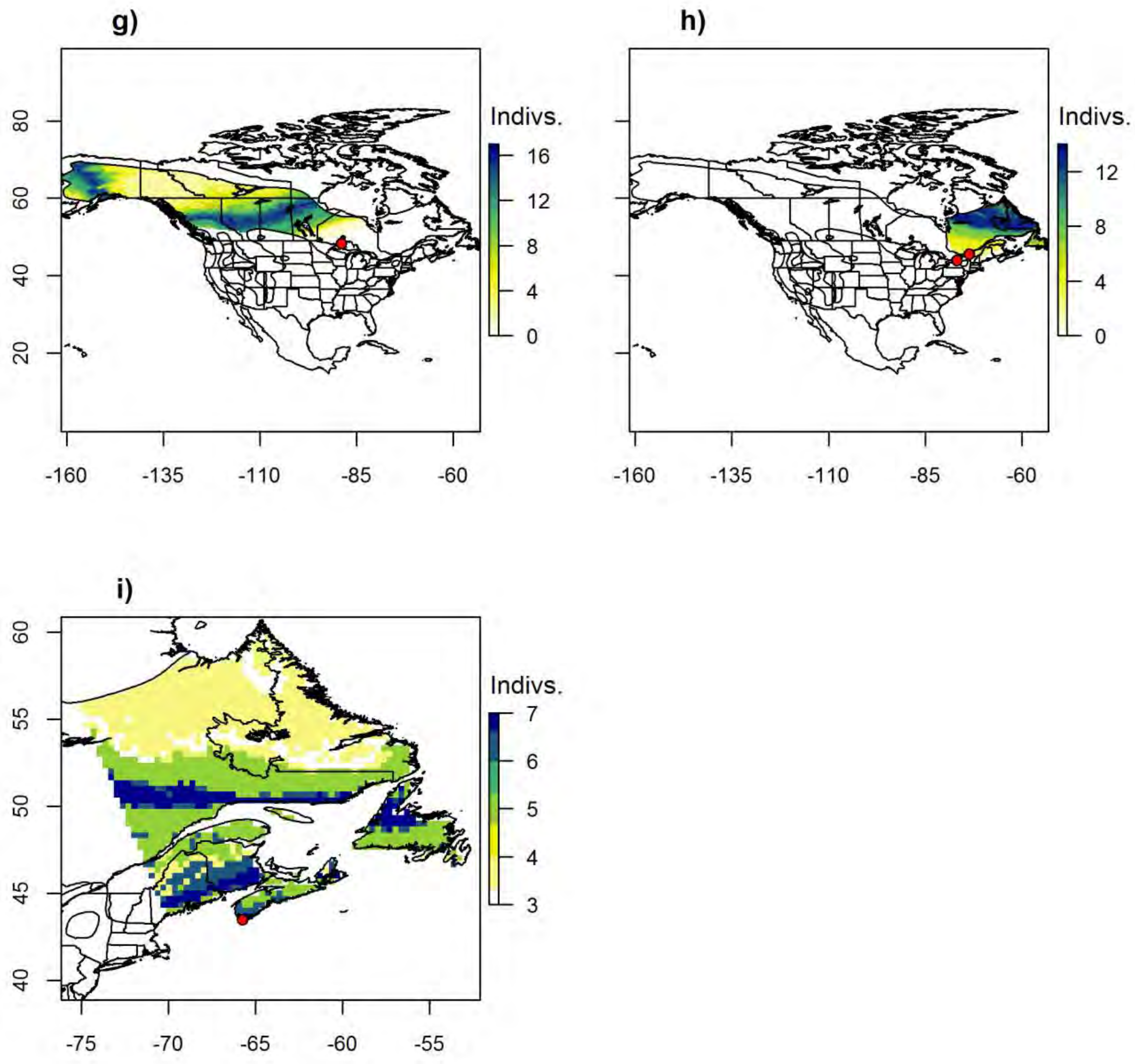


Figure A2.8: Probable origins of Ovenbirds (*Seiurus aurocapilla*) captured during fall migration at the IBS CMMN station in Southern Alberta (n=28).

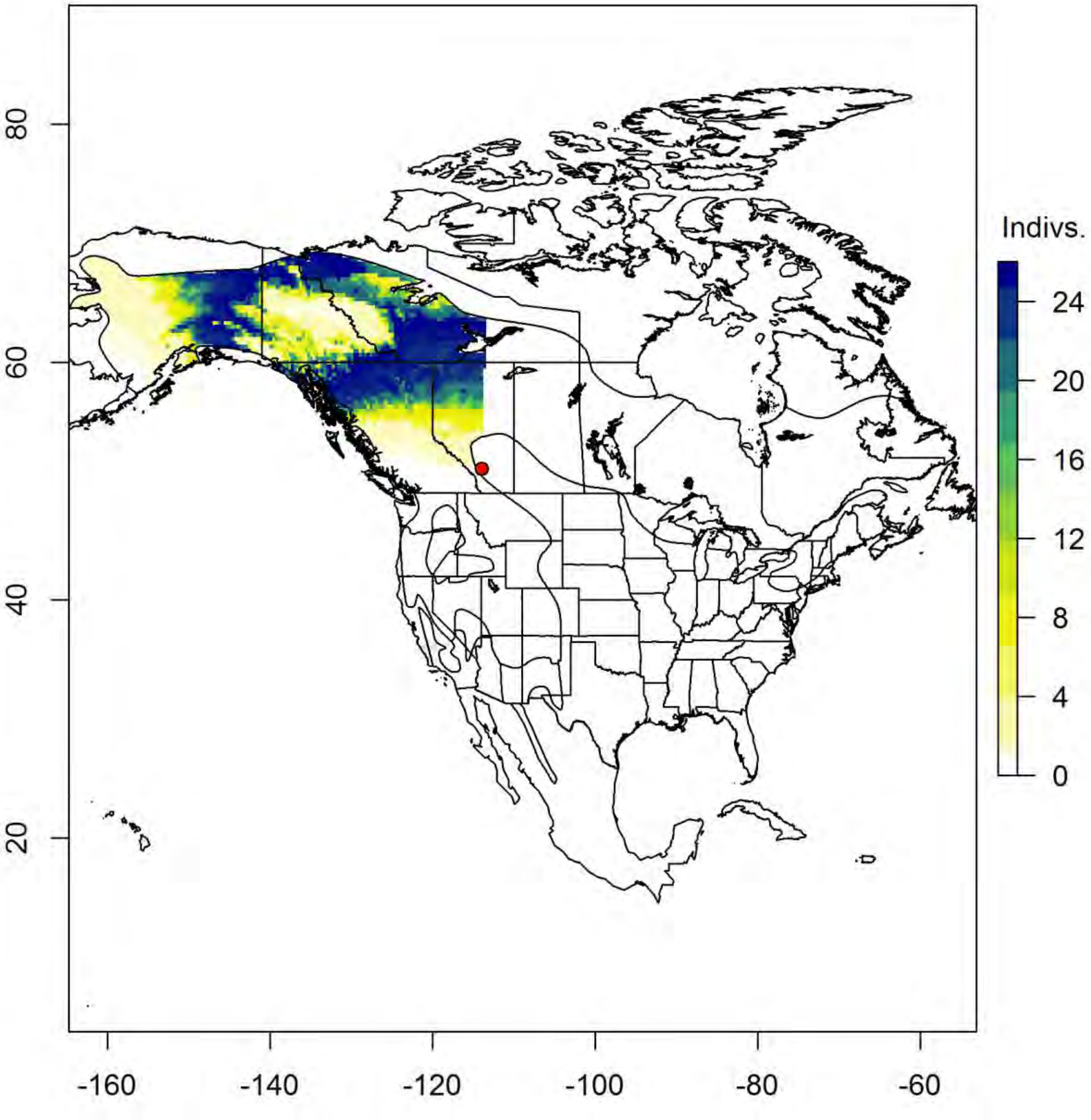


Figure A2.9: Probable origins of Northern Waterthrushes (*Parkesia noveboracensis*) captured during spring migration at CMMN stations in a) Yukon (ACBO (n=9) and TLBBS (n=6)), b) Northern Alberta (LSLBO (n= 23)) c) Manitoba (DMBO (n=25)); d) Southwest Ontario (AuBO (n=5), BPBO (n=2), HBO (n=5), LPBO (n=5), PIBO (n=3), TTPBRS (n=5)); and e) Southeast Ontario & Southwest Québec (IPBO (n=6), MBO (n=8), PEPTBO (n=11)).

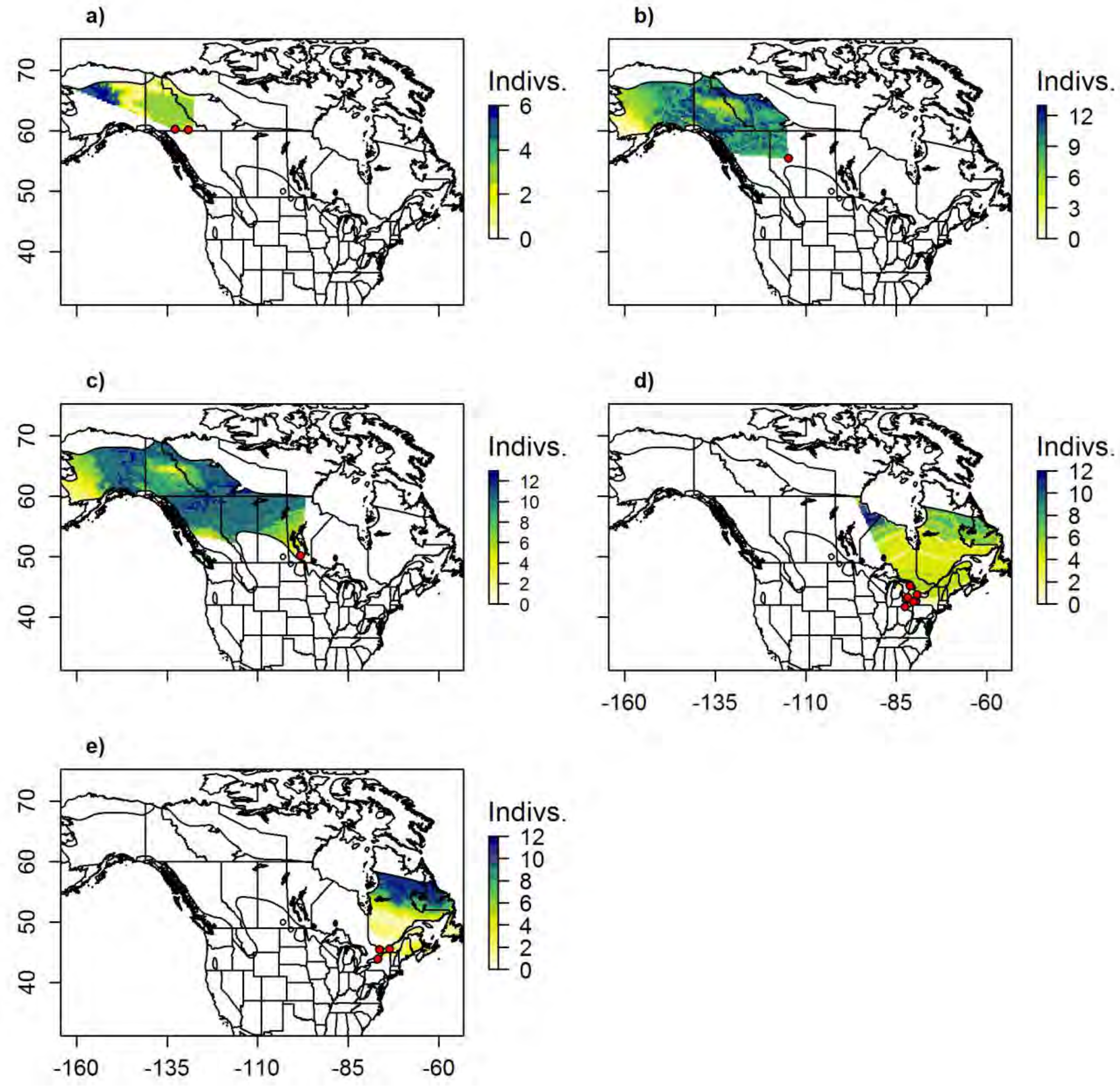


Figure A2.10: Probable origins of Northern Waterthrushes (*Parkesia noveboracensis*) during fall migration at the IBS CMMN station in Southern Alberta (n=58).

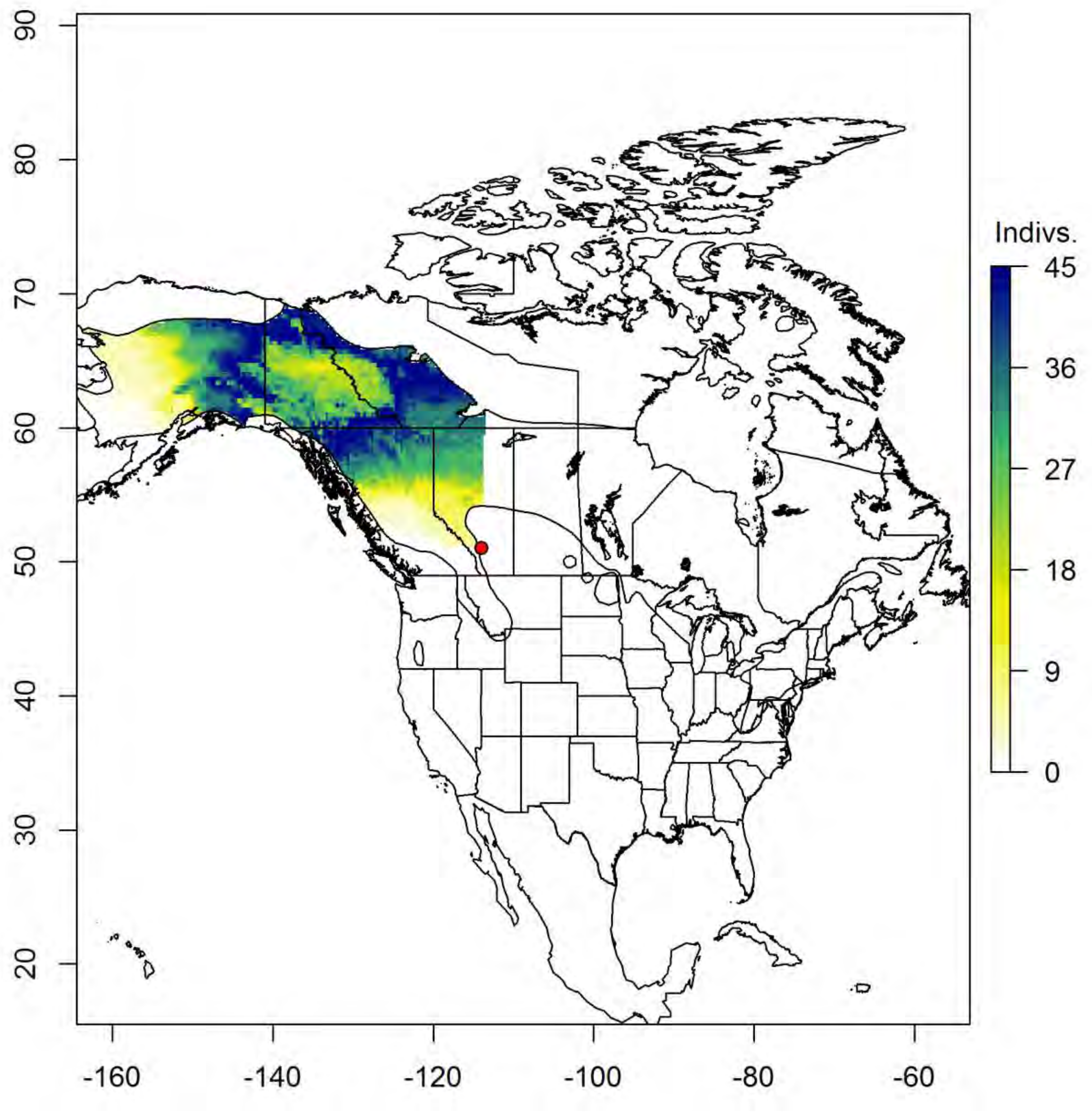


Figure A2.11: Probable origins of Orange-crowned Warblers (*Oreothlypis celata*) captured during spring migration at CMMN stations in a) the Yukon (ACBO (n=12), TLBBS (n=7)) and b) Southwest Ontario (AuBO (n=2), BPBO (n=11), LPBO (n=3), TTPBRS (n=1)).

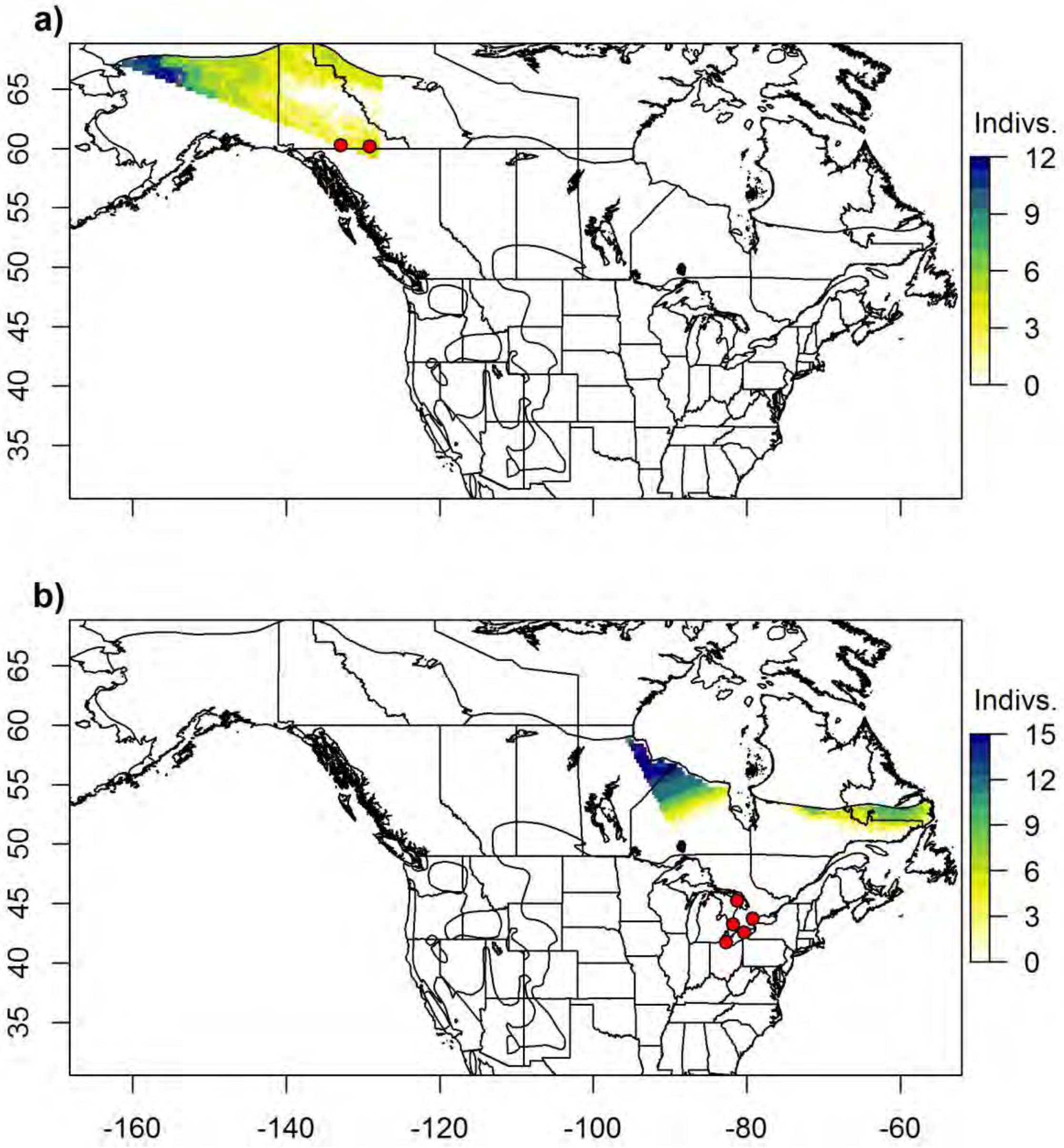


Figure A2.12: Probable origins of Orange-crowned Warblers (*Oreothlypis celata*) captured during fall migration at CMMN stations in a) the Yukon (ACBO (n=20)); b) Northern British Columbia (MNO (n=20)); c) Southern British Columbia (VLBO (n=20)); d) Southern Alberta (IBS (n=36)); e) Northern Alberta (BBO (n=12), LSLBO (n=15)); f) Saskatchewan (LMBO (n=20)); g) Manitoba (DMBO (n=16)); h) Western Ontario (TCBO (n=20)); and i) Southwest Ontario (AuBO (n=8), BPBO (n=15), HBO (n=2), LPBO (n=7), PIBO (n=2), TTPBRS (n=3)).

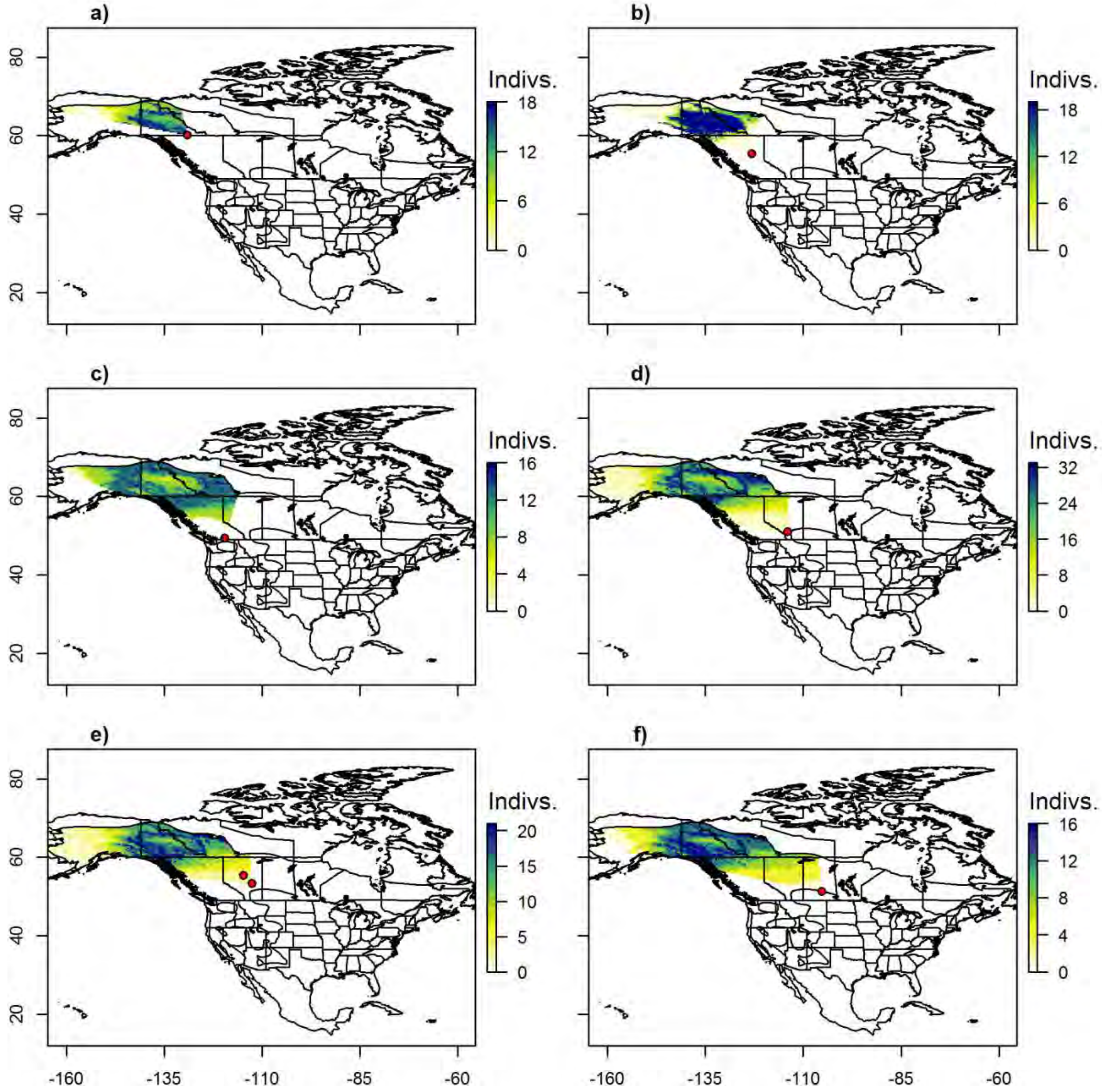


Figure A2.12 (con't):

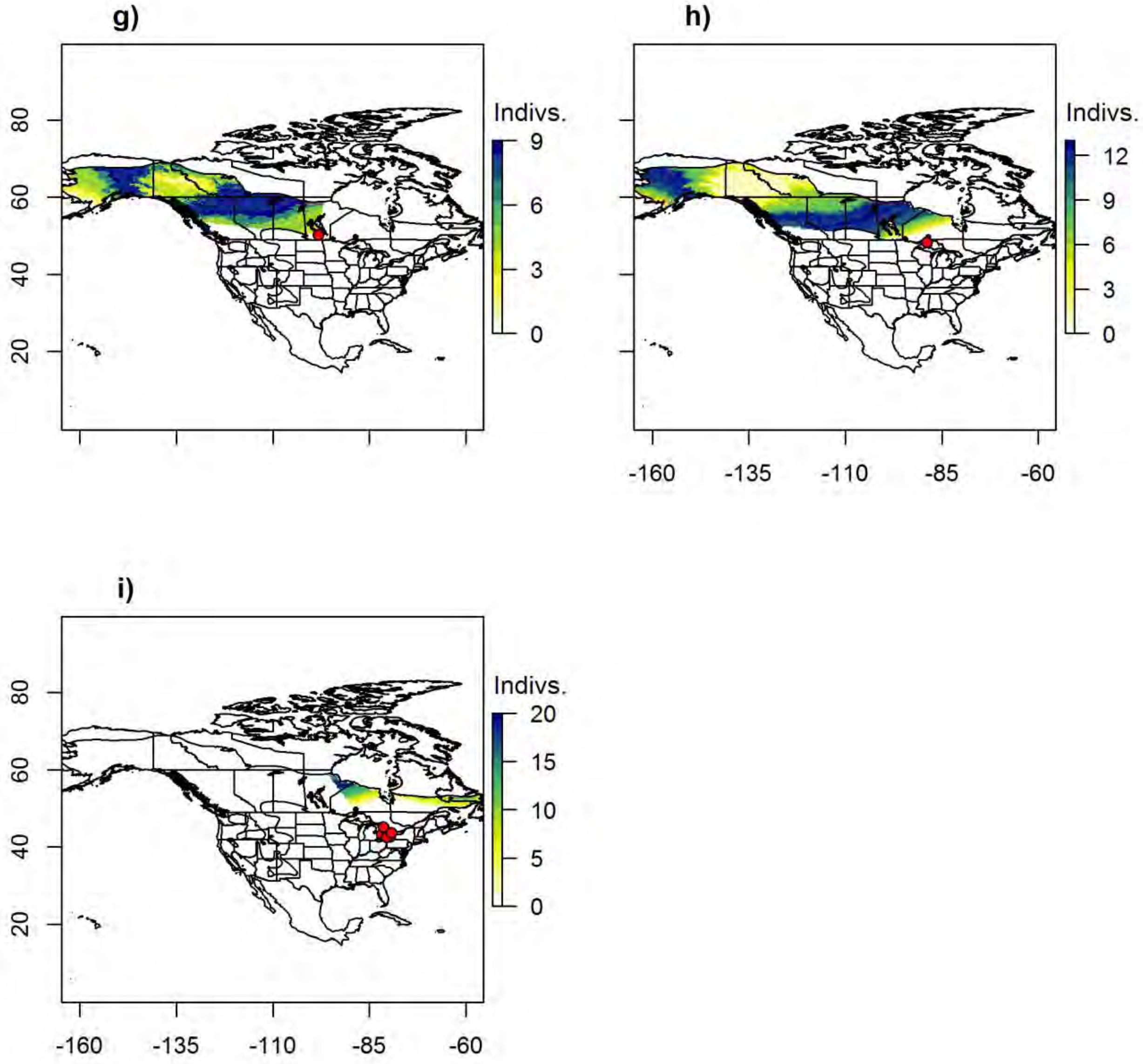


Figure A2.13: Probable origins of American Redstarts (*Setophaga ruticilla*) captured during spring migration at CMMN stations in a) Northern Alberta (BBO (n=1), LSLBO (n=25)); and b) Southwest Ontario (AuBO (n=5), BPBO (n=5), HBO (n=5), LPBO (n=6), PIBO (n=3), TTPBRS (n=8)).

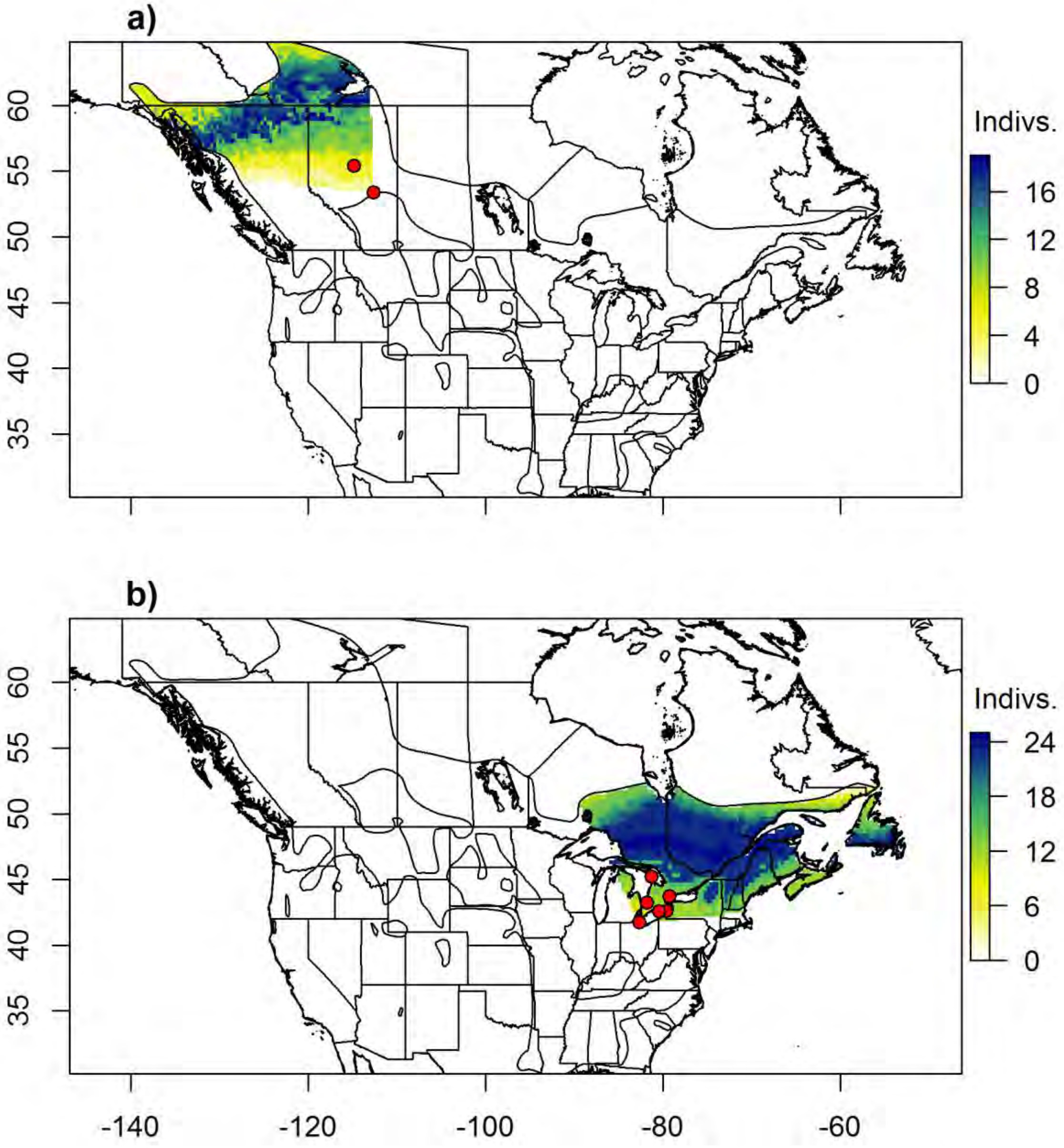


Figure A2.14: Probable origins of Magnolia Warblers (*Setophaga magnolia*) captured during spring migration at CMMN stations in a) Western Ontario (TCBO (n=20)); b) Southwest Ontario (AuBO (n=1), BPBO (n=3), HBO (n=1), LPBO (n=5), PIBO (n=3), TTPBRS (n=5)); c) Southeast Ontario & Southwest Québec (IPBO (n=2), MBO (n=2), PEPTBO (n=16)); and d) Eastern Canada (ABO (n=20)).

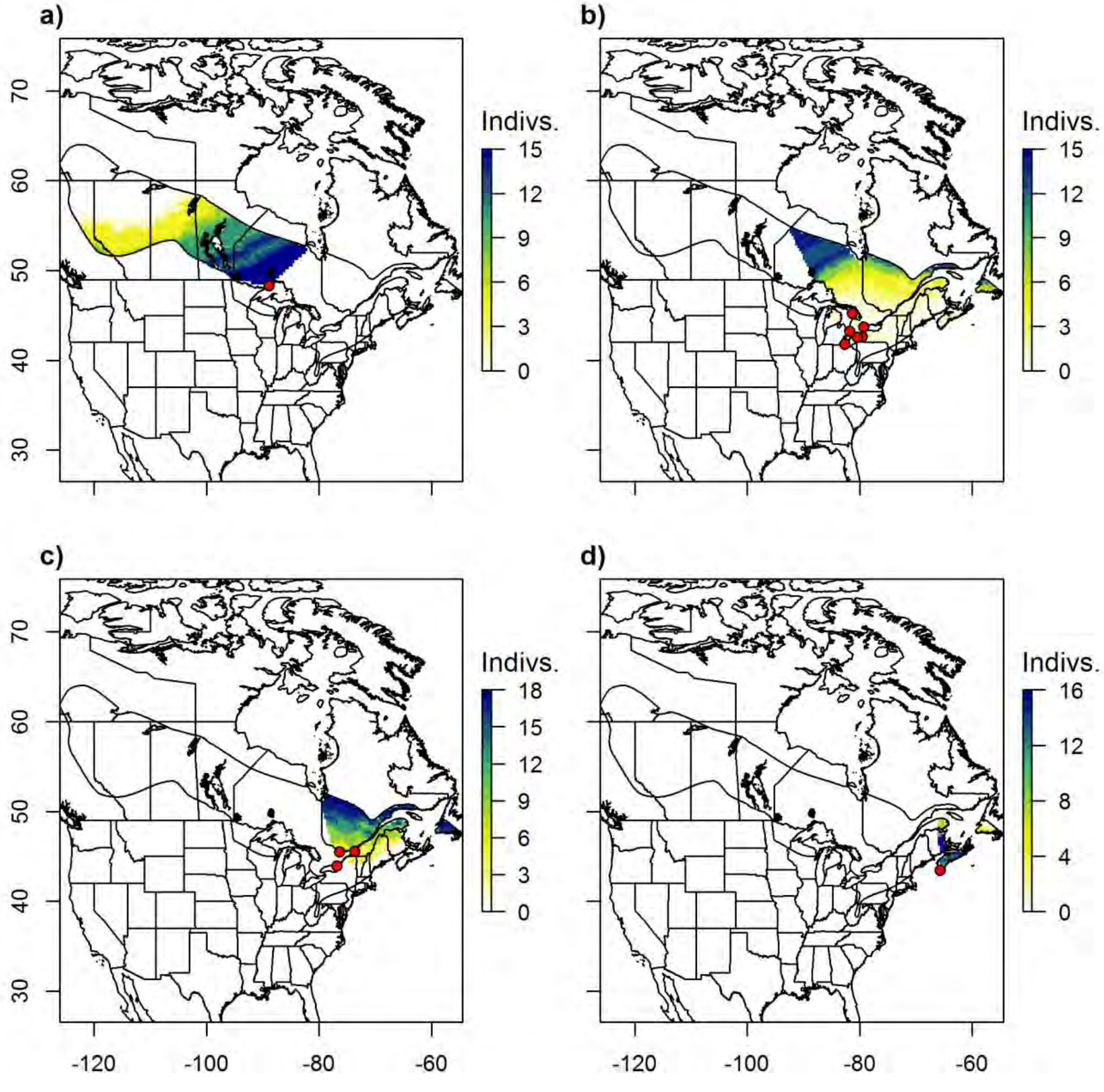
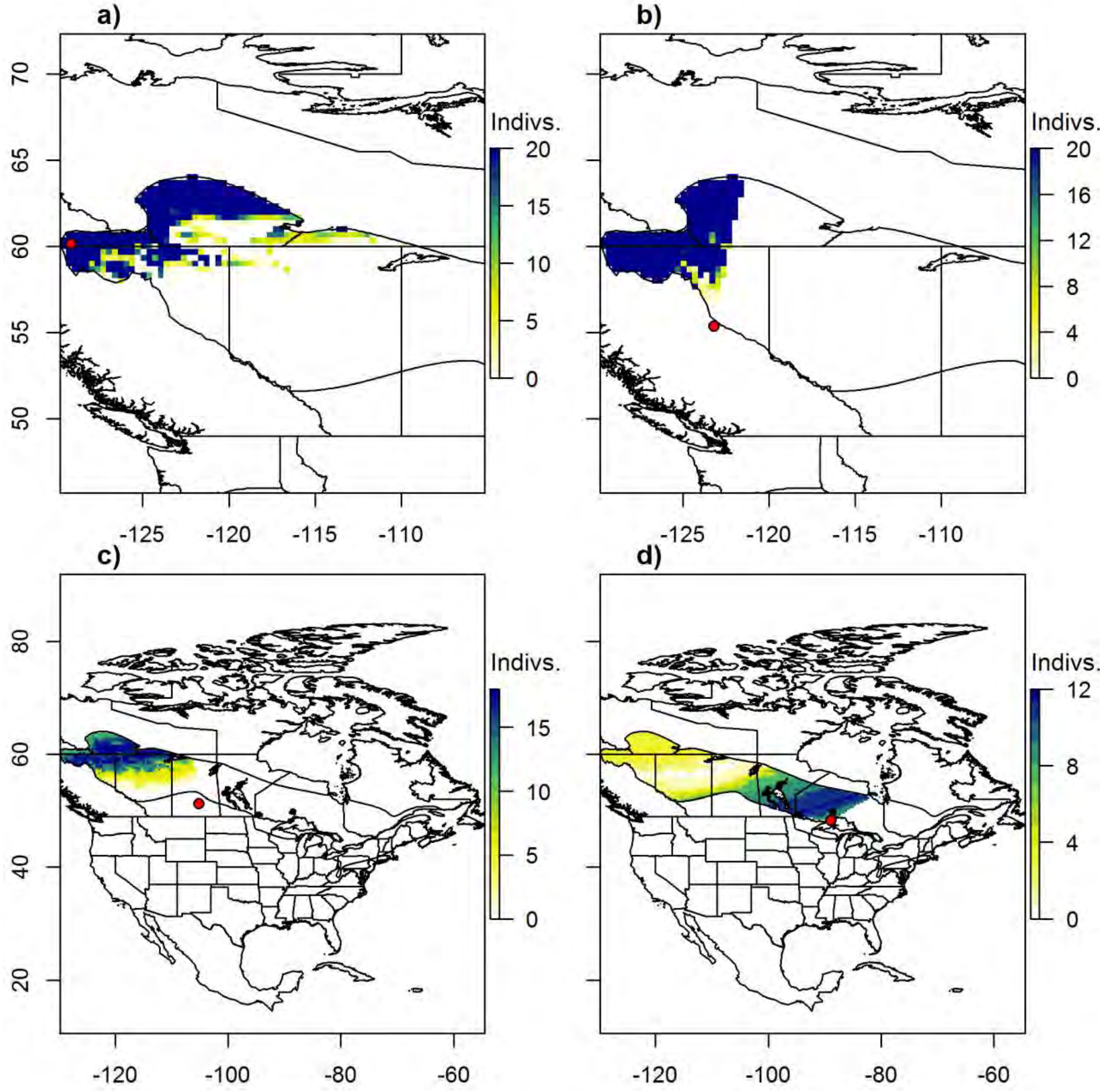


Figure A2.15: Probable origins of Magnolia Warblers (*Setophaga magnolia*) captured during fall migration at CMMN stations in a) the Yukon (ACBO (n=20)); b) Northern British Columbia (MNO (n=20)); c) Saskatchewan (LMBO (n=19)); d) Western Ontario (TCBO (n=19)); e) Southwest Ontario (BPBO (n=3), HBO (n=5), LPBO (n=3), PIBO (n=3), TTPBRS (n=5)); f) Southeast Ontario & Southwest Québec (MBO (n=4), PEPTBO (n=12)); and h) Eastern Canada (ABO (n=13), SABBS (n=10)).



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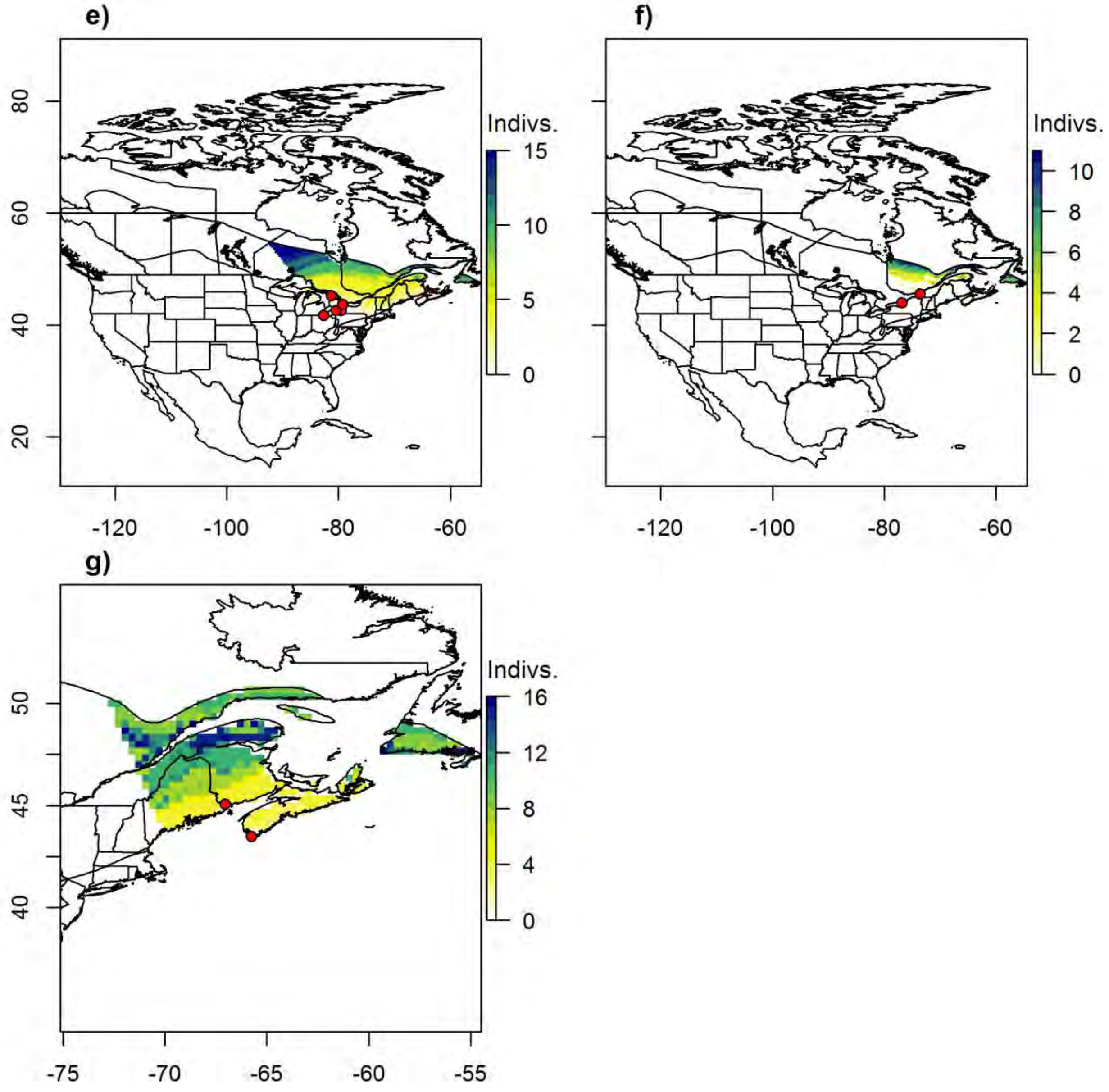

Figure A2.16: Probable origins of Yellow Warblers (*Setophaga petechia*) captured during spring migration at CMMN stations in a) the Yukon (ACBO (n=11), TLBBS (n=10)); b) Manitoba (DMBO (n=21)); c) Western Ontario (TCBO (n=17)); and d) Southwest Ontario (HBO (n=5), LPBO (n=9), PIBO (n=3), TTPBRS (n=2)).

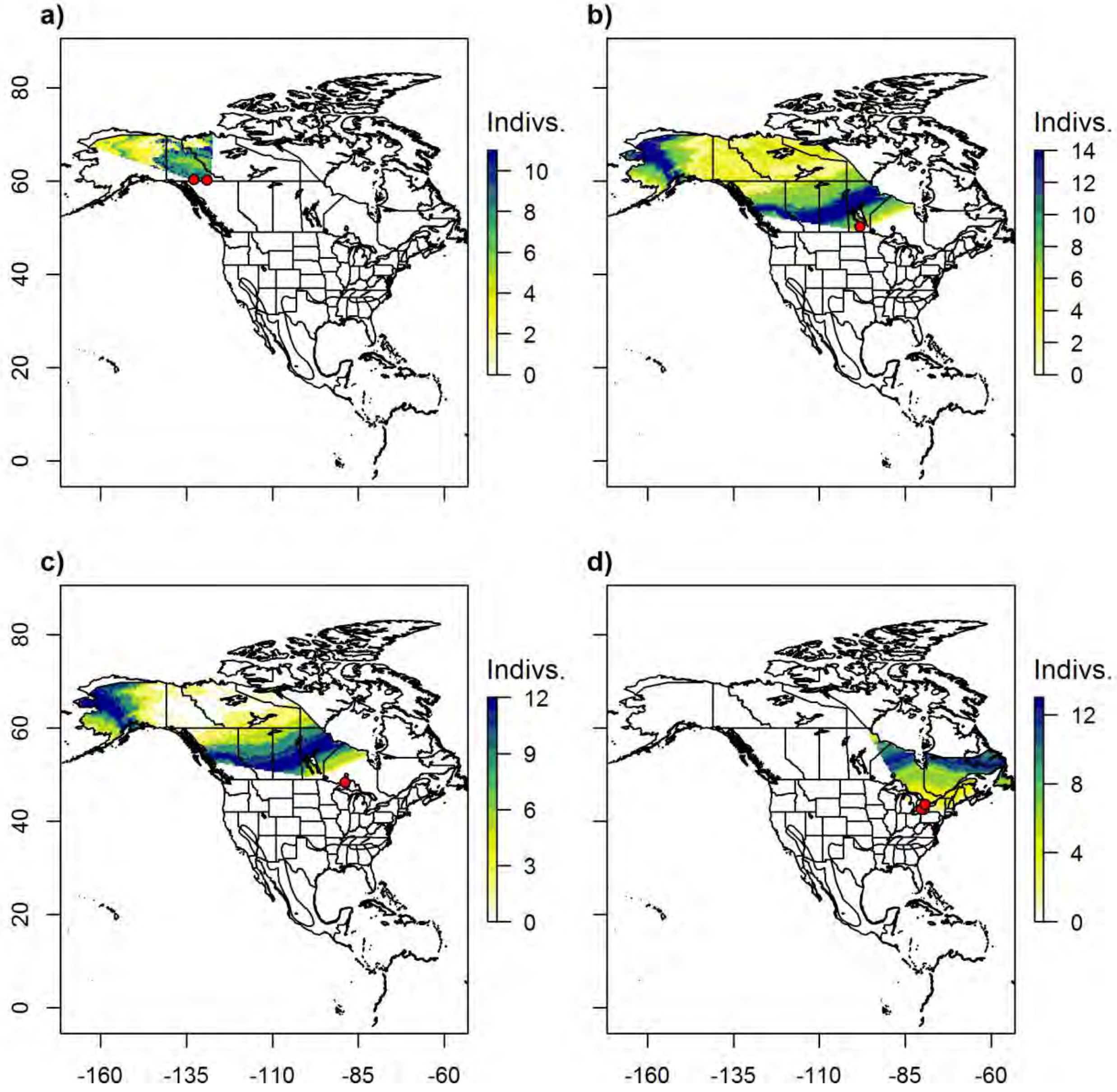

Figure A2.17: Probable origins of Palm Warblers (*Setophaga palmarum*) captured during spring migration at CMMN stations in a) Western Ontario (TCBO (n=20)) and b) Southeast Ontario & Southwest Québec (IPBO (n=3), PEPTBO (n=16)).

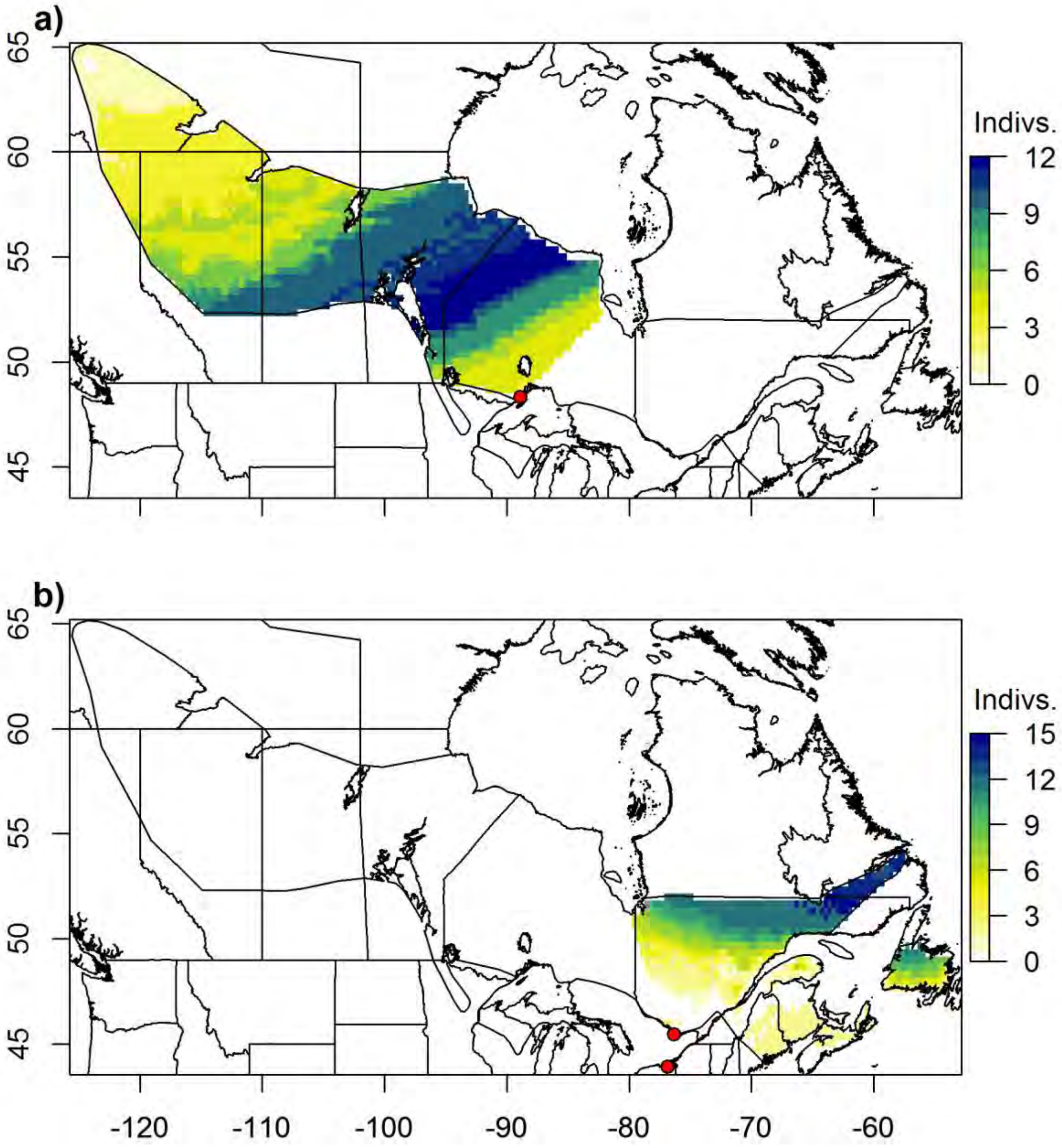

Figure A2.18: Probable origins of Palm Warblers (*Setophaga palmarum*) captured during fall migration at CMMN stations in a) Saskatchewan (LMBO (n=17)); b) Western Ontario (TCBO (n=20)); c) Southwest Ontario (AuBO (n=2), HBO (n=3), LPBO (n=10), TTPBRS (n=5)); and d) Southeast Ontario and Southwest Québec (MBO (n=14), PEPTBO (n=4)).

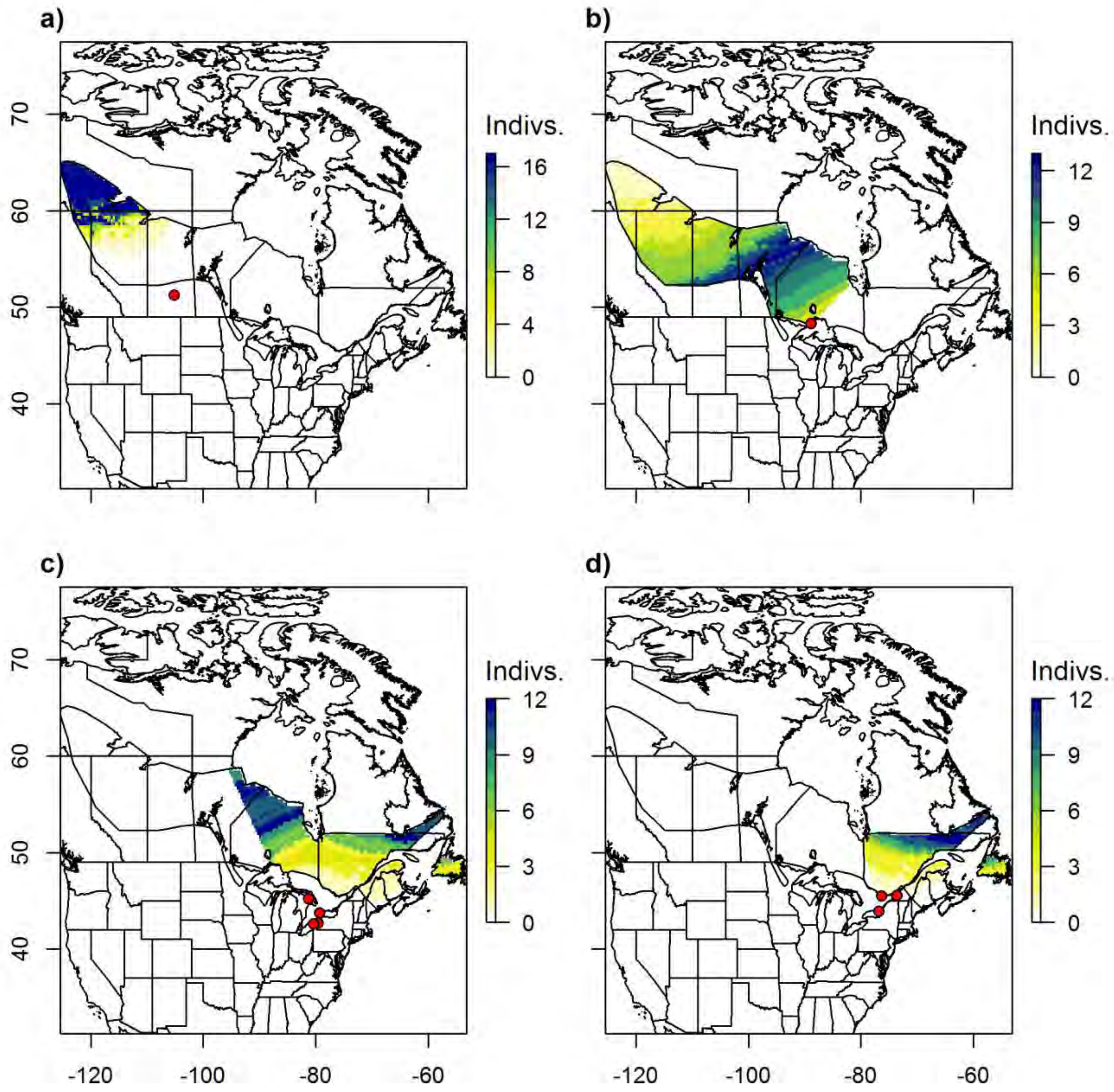

Figure A2.19: Probable origins of Yellow-rumped Warblers (*Setophaga coronata*) captured during spring migration at CMMN stations in a) Northern Alberta (LSLBO (n=25)); b) Western Ontario (TCBO (n=23)); c) Southwest Ontario (AuBO (n=5), BPBO (n=5), HBO (n=5), LPBO (n=5), TTPBRS (n=5)); and d) Southeast Ontario & Southwest Québec (PEPTBO (n=25)).

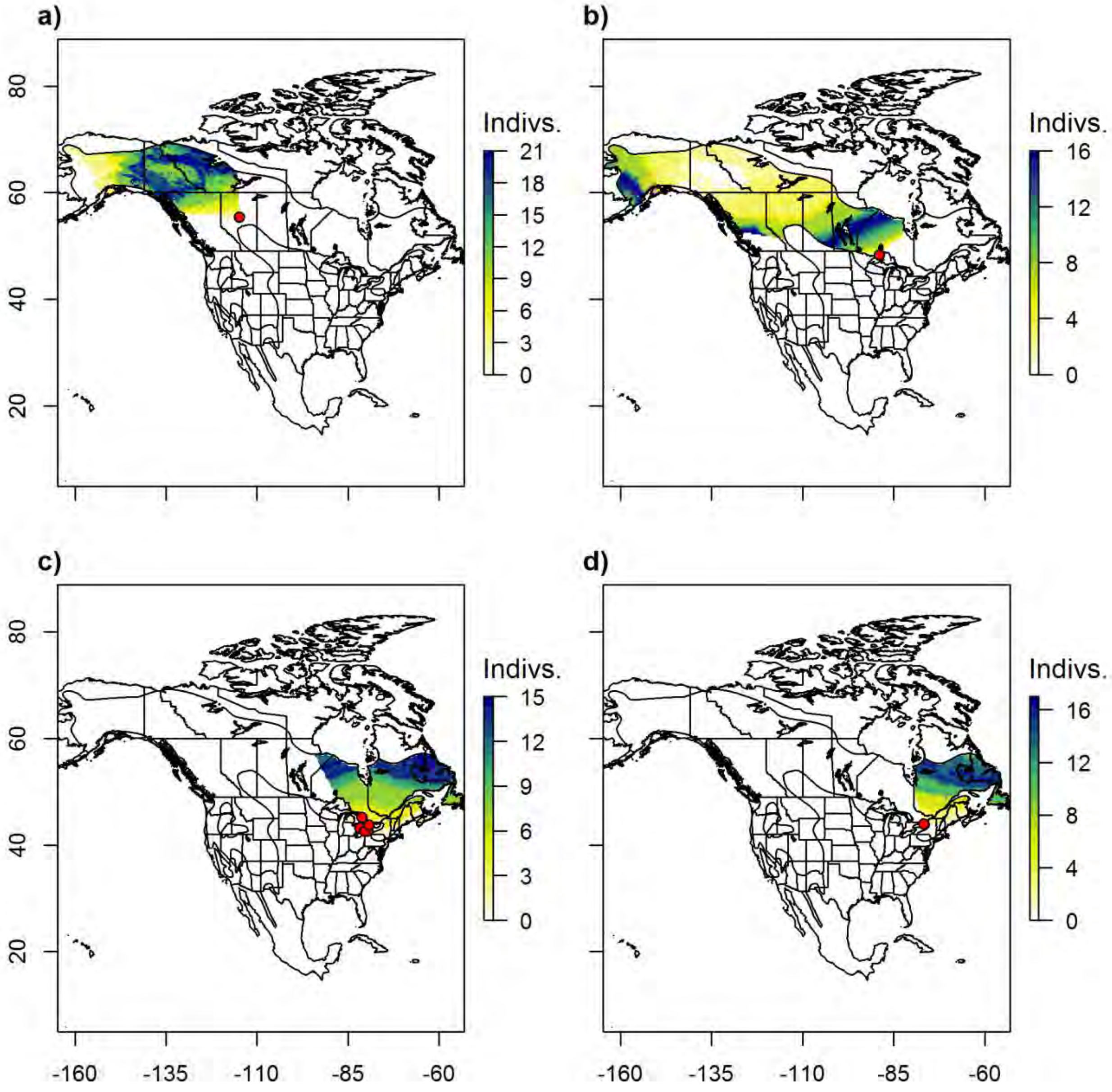

Figure A2.20: Probable origins of Yellow-rumped Warblers (*Setophaga coronata*) captured during fall migration at the IBS CMMN station in Southern Alberta (n=101).

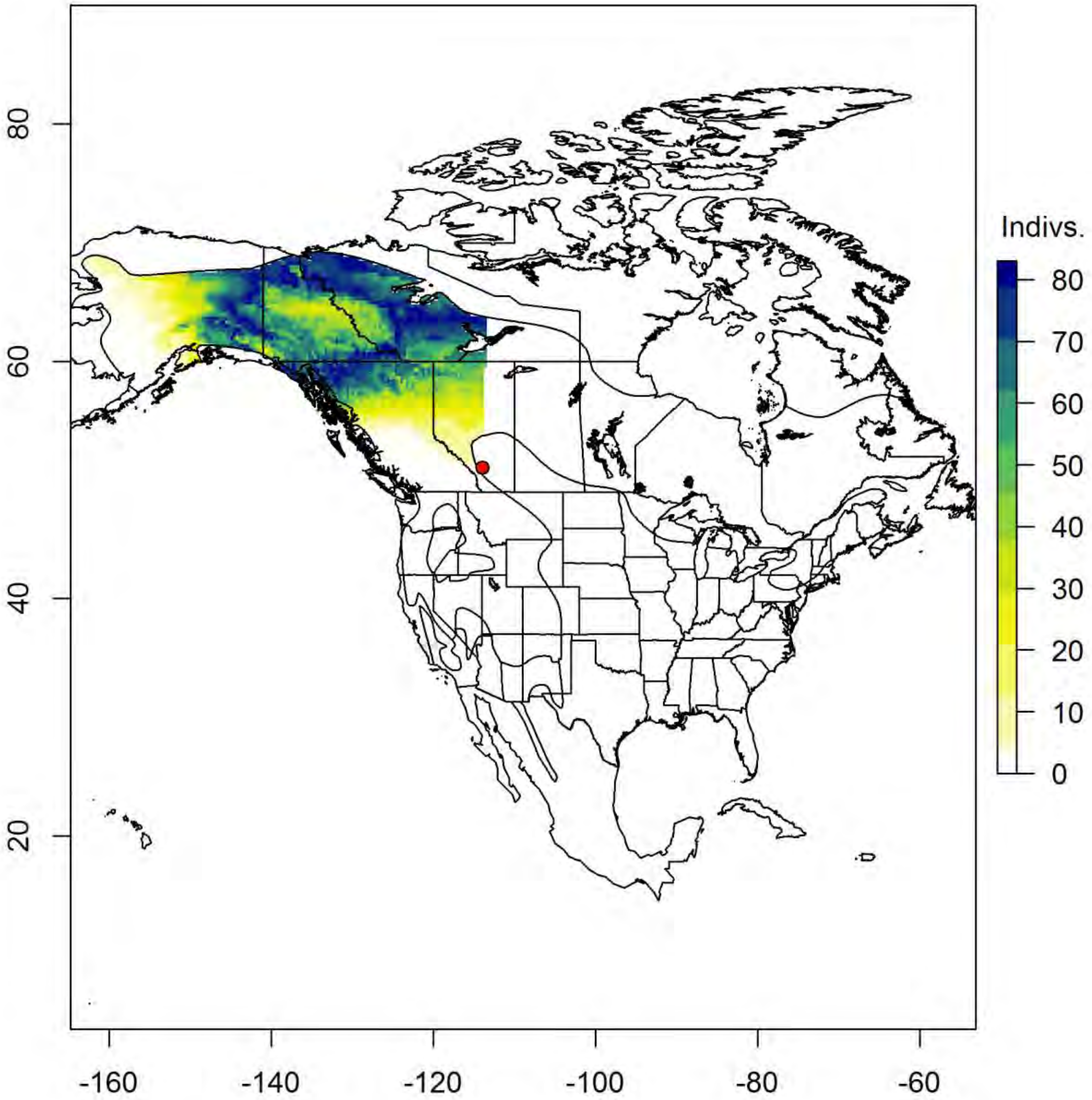

Figure A2.21: Probable origins of Wilson's Warblers (*Cardellina pusilla*) captured during spring migration at CMMN stations in a) the Yukon (ACBO (n=15), TLBBS (n=10)); b) Western Ontario (TCBO (n=21)); c) Southwest Ontario (AuBO (n=4), BPBO (n=4), HBO (n=6), LPBO (n=3), PIBO (n=4), TTPBRS (n=4)); and d) Southeast Ontario & Southwest Québec (IPBO (n=6), MBO (n=5), PEPTBO (n=14)).

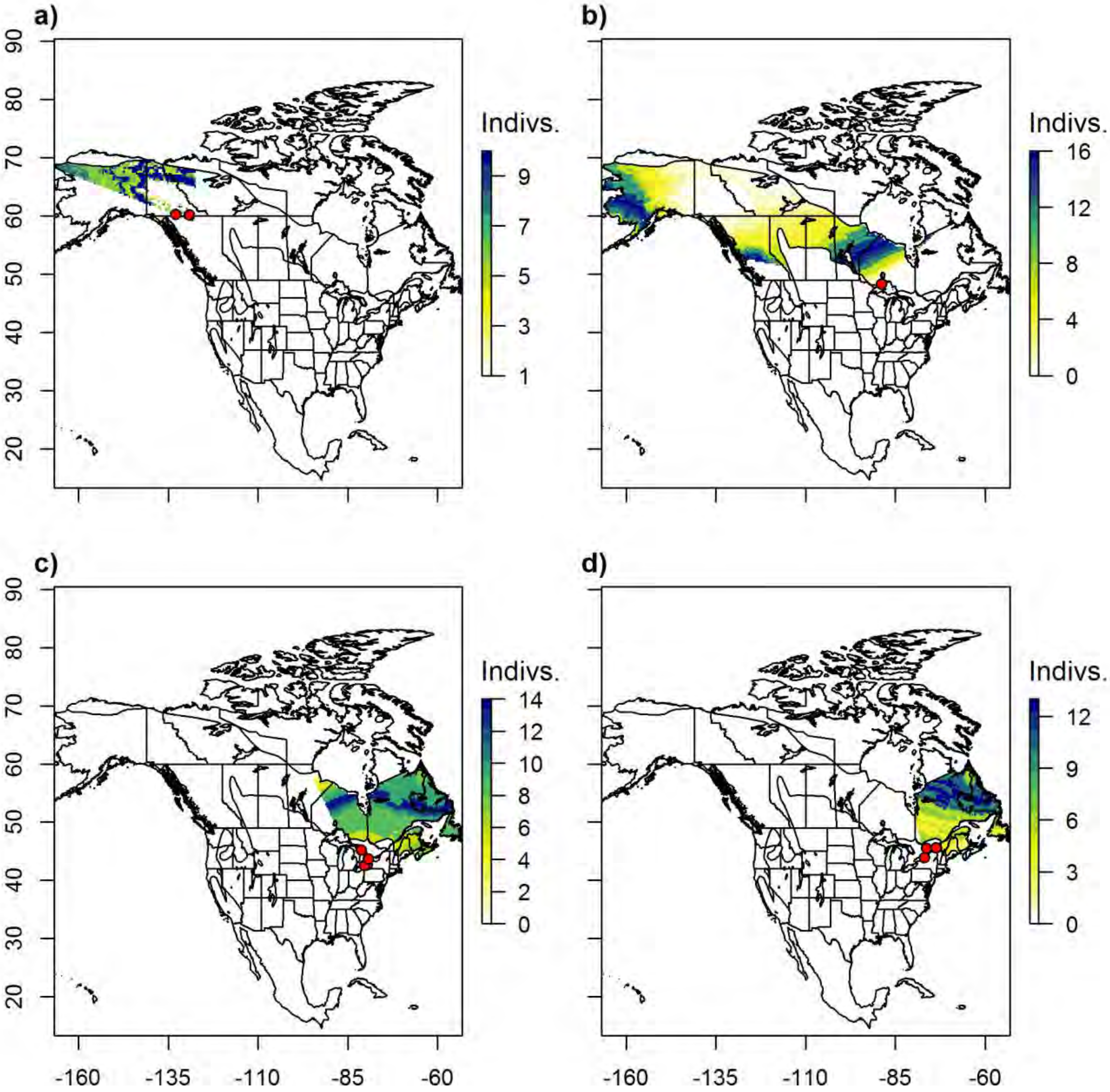

Figure A2.22: Probable origins of Lincoln's Sparrows (*Melospiza lincolnii*) captured during spring migration at CMMN stations in a) Yukon (ACBO (n=12), TLBBS (n=8)); b) Southwest Ontario (AuBO (n=2), BPBO (n=1), HBO (n=3), LPBO (n=5), PIBO (n=1), TTPBRS (n=5)).

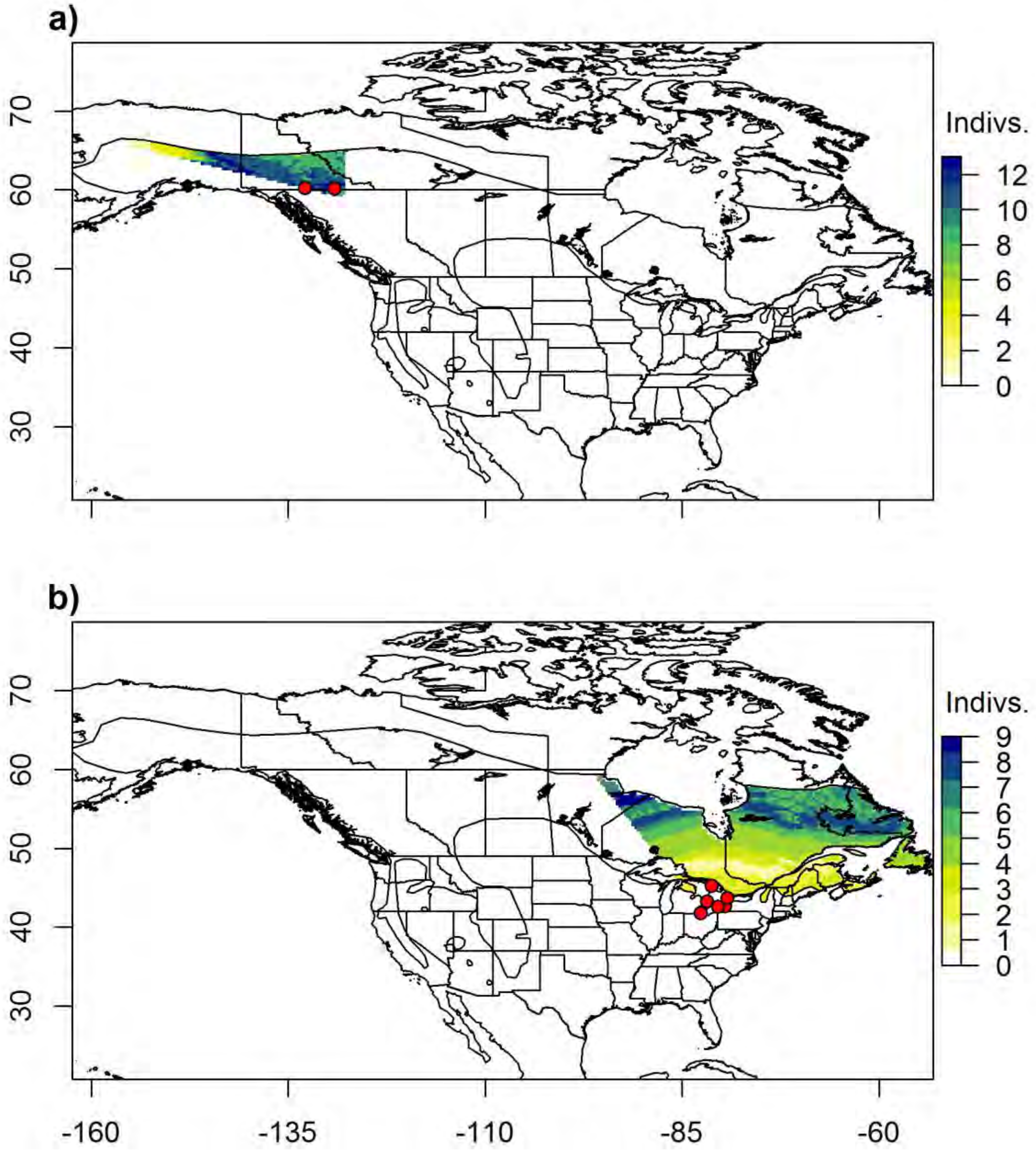

Figure A2.23: Probable origins of Lincoln's Sparrows (*Melospiza lincolnii*) captured during fall migration at CMMN stations in a) the Yukon (ACBO (n=20)); b) Southern British Columbia (VLBO (n=20)); c) Southern Alberta (IBS (n=25)); d) Saskatchewan (LMBO (n=15)); e) Western Ontario (TCBO (n=20)); f) Southwest Ontario (BPBO (n=7), HBO (n=2), LPBO (n=5), TTPBRS (n=5)); and g) Southeast Ontario & Southwest Québec (MBO (n=15), PEPTBO (n=3)).

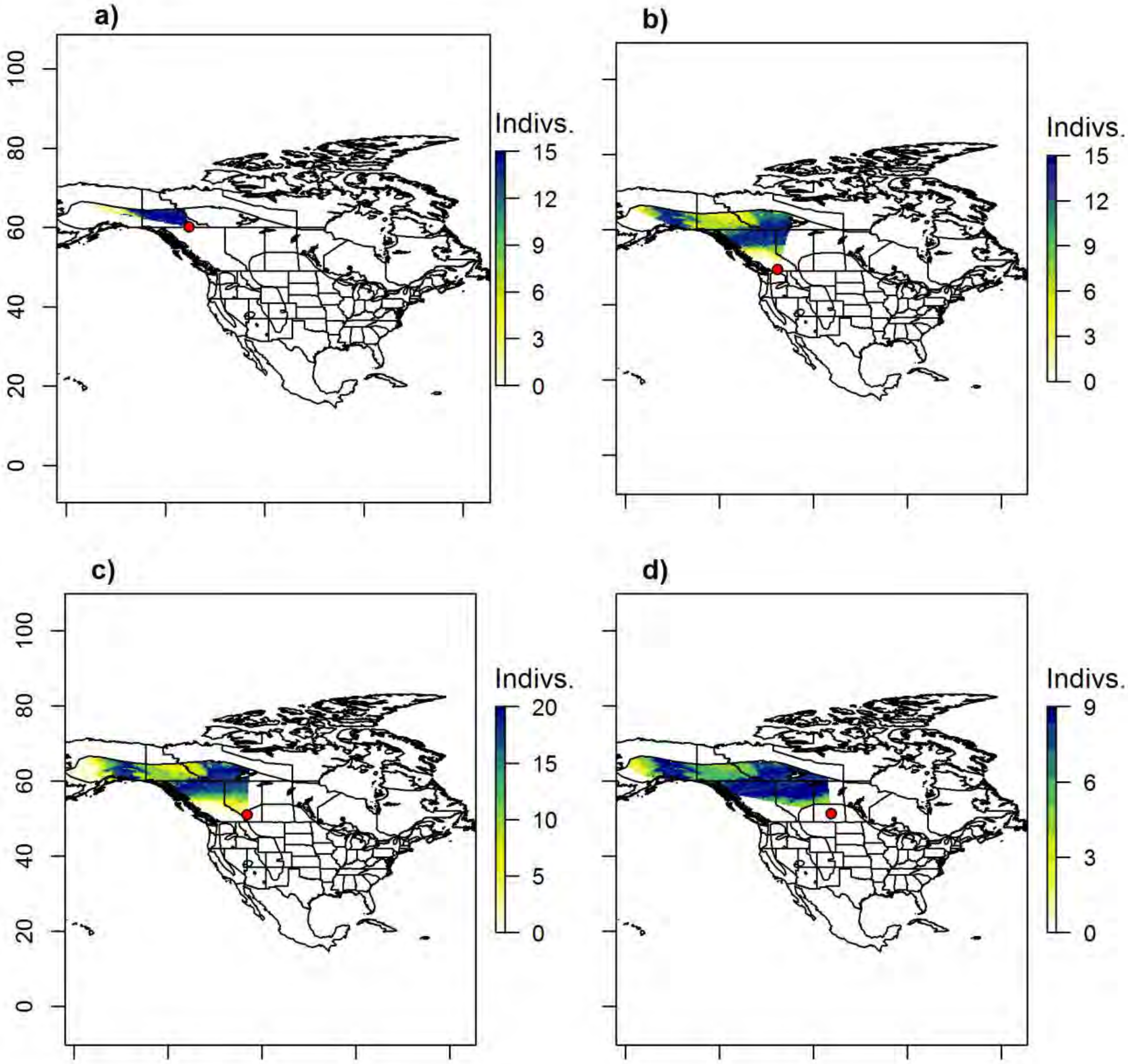

Figure A2.23 (con't)

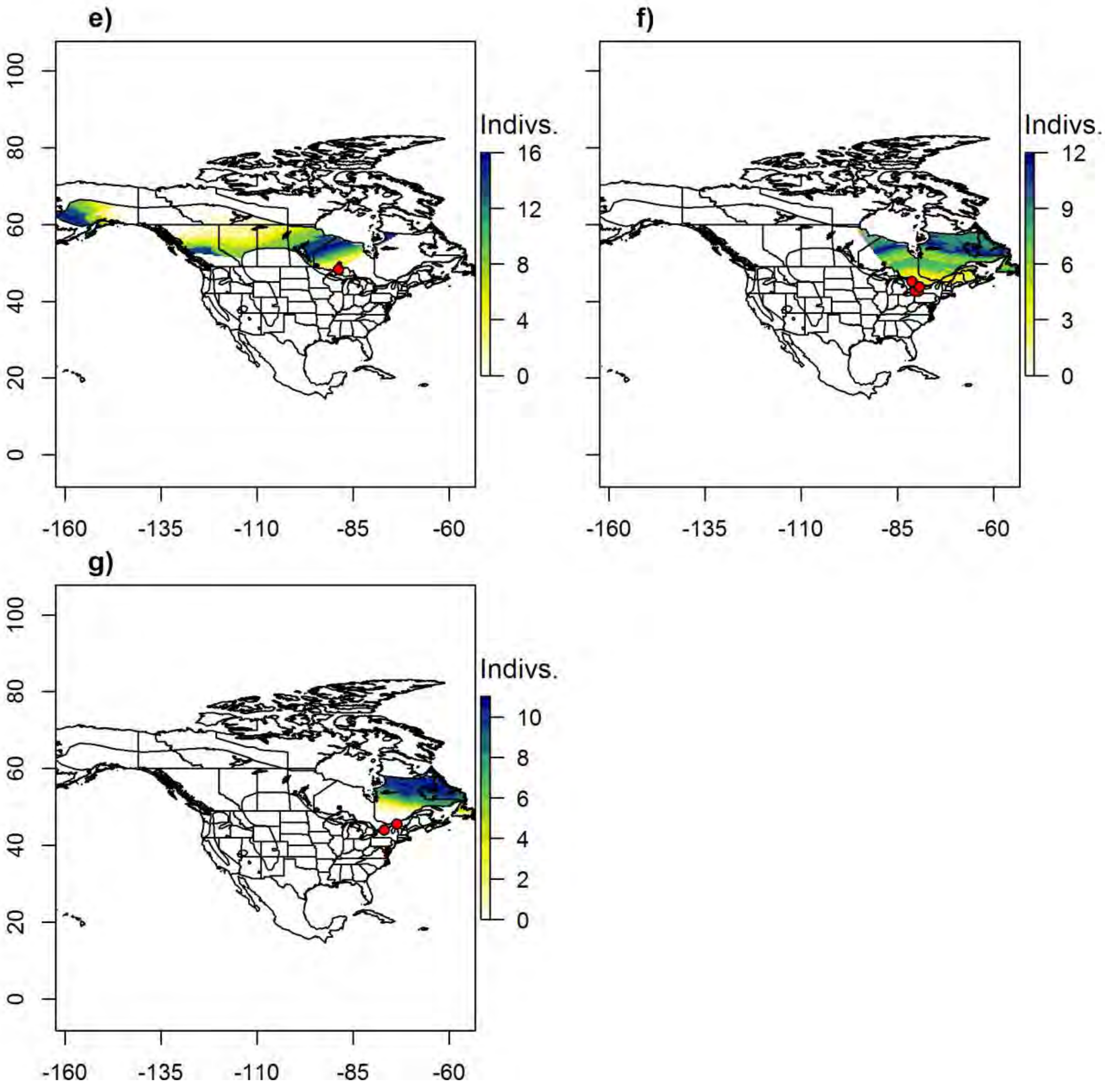

Figure A2.24: Probable origins of White-throated Sparrows (*Zonotrichia albicollis*) captured during fall migration at the IBS CMMN station in Southern Alberta (n=30).