Monitoring Avian Productivity and Survivorship in the Oil Sands Region of Northeastern Alberta

Boreal MAPS in the Oil Sands Region
2024 Annual Report

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Report to the

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Cover: Cape May Warbler, after second year, male. Photo by C. Godwin

SUMMARY

The Boreal Monitoring Avian Productivity and Survivorship (Boreal MAPS) program is part of the Oil Sands Monitoring (OSM) program's Terrestrial Biological Monitoring (TBM) theme. The Boreal MAPS program was designed to quantify the effects on landbird populations resulting from terrestrial disturbance in the Oil Sands Region (OSR) and has operated every year from 2011 to 2024. Boreal MAPS is a capture-mark-recapture program using bird banding procedures and operates as a surveillance monitoring program to identify landbird population changes and the underlying demographics (vital rates, including population trend or growth rate, productivity, first-year and adult survivorship, proportion of residents, and yearling and adult recruitment) that are responding to terrestrial disturbance in the OSR.

In 2024, monitoring effort comprised 16,871.5 net-hours, resulting in 2,700 birds being newly banded, 78 being released unbanded, and 1,051 recaptures of birds banded earlier in the same season or in previous years, for a total of 3,829 captures (of 59 species). Across all 14 years (comprising over 125,000 net-hours of effort), 54,816 captures of 91 species have been recorded, of which 40,658 were newly banded, 836 were unbanded, and 13,622 were recaptures of previously banded birds.

To date, population and productivity trends have been estimated using linear regression modeling, lambda (annual rate of population change) using Pradel modeling, and adult survivorship using Modified Cormack–Jolly–Seber (CJS) analyses. With the addition of the 2024 program data, population trends and demographic estimates for 35 landbird species have been derived. To compare population and vital-rate estimates derived from Boreal MAPS data with those for continental populations, we used a Bayesian modeling approach that can incorporate the many complicating factors that contribute to population change across a species' continental range. The outcomes of the regression/Pradel/CJS analyses and the Bayesian analyses were largely consistent across the 23 species for which data were available to meet the requirements of both analytical procedures. The overall consistency between the outcomes of the two approaches supports our choice to transition to the more powerful Bayesian modeling. In addition, the Bayesian approach can incorporate metrics of habitat and terrestrial disturbance, providing an integrated platform for analyses according to the TBM's before–after dose–response monitoring design. We present the population and demographic trends and estimates for 23 species comparing Boreal MAPS data to the continental MAPS data.

In 2023, we identified five species (Least Flycatcher, Hermit Thrush, Ovenbird, Northern Waterthrush, Canada Warbler) that were undergoing significant population decline and we presented an evaluation of the demographics and potential drivers of population change. For each of these species, we present here comparisons between the results of the regression and Bayesian modeling approaches. Declines in Least Flycatcher, Hermit Thrush, Ovenbird, and Northern Waterthrush continued through 2024. For Canada Warbler, the decline was not significant in 2024 based on the Bayesian modeling approach, although we have shown that populations of Canada Warbler and several other warbler species within our Boreal MAPS program exhibit cyclical trends. Bayesian estimates of lambda resulted in the identification of

five additional species declining regionally. Of the ten species, seven were responding better continentally, while three were experiencing similar declines continentally. Lower productivity may be influencing the declining regional populations of Yellow-bellied Sapsucker and Ovenbird, both of which appear to be doing better continentally. Yellow-bellied Sapsucker also appeared to be experiencing lower recruitment rates. Lower survival was found regionally for Hermit Thrush and Northern Waterthrush, whose populations were also doing better continentally. For the remaining six species, Least Flycatcher, Chipping Sparrow, Black-and-White Warbler, American Redstart, Yellow Warbler, and Myrtle Warbler, the underlying mechanisms leading to population declines are still to be identified.

Integrated population modeling (IPM) was used to evaluate the relative contributions of adult apparent survival probabilities, recruitment rate of 1-year-old individuals, and immigration rate of older adults to observed variation in population changes in four species. Alder Flycatcher is typically associated with deciduous shrub habitat, while Swainson’s Thrush, Ovenbird, and Canada Warbler are typically associated with older, closed canopy forests. Count data from automated recording units (ARUs) and point count data collected from field observers, from 3,220 locations across the region from 2011 to 2023, were used to derive regional annual abundance estimates for each species. Composite metrics of disturbance were also included, representing 1) fragmentation (soft linear features, roads, areal disturbance without noise or light impacts) and 2) activity (high human activity, light, noise, and atmospheric deposition impacts). Abundance estimates from this initial step were then incorporated into a regional IPM that included adult age–structure and capture–recapture data from 34 Boreal MAPS stations. Alder Flycatcher populations were positively related to fragmentation and industrial activity, while the other three species were negatively related to these disturbances. Alder Flycatcher population dynamics were strongly associated with immigration (i.e., breeding dispersal). Canada Warbler dynamics covaried strongly with recruitment. Ovenbird dynamics tracked both recruitment and immigration, and recruitment, immigration, and survival were important contributors to Swainson’s Thrush population dynamics. The importance of recruitment for most species suggests that management of breeding areas will be an important facet of migratory bird conservation in the region. However, when taken together, the combined contributions of adult apparent survival and immigration suggests that conservation efforts on nonbreeding areas must also be considered in efforts to protect these species.

Changes in male singing rates that occur from arrival of birds in the spring through to fledging of nestlings are indicators of active breeding. The song rate (change point) analyses initiated in 2022 were extended in 2024 to examine the potential for use of a deep learning auto-recognizer necessary to process large volumes of autonomous recording unit (ARU) audio recordings. Using Ovenbird data derived from ARU recordings collected at 35 locations including three Boreal MAPS stations, we showed that recognizer-derived song rates, even without manual validation, can likely differentiate locations with paired and unpaired males based on consistent patterns of song rate decline after pairing, aligning with established behavioral ecology and known paired status at MAPS stations. This classification provides insight into habitat quality, as paired males typically occupy higher-quality territories that support successful breeding, while a prevalence of unpaired males may indicate suboptimal habitat conditions. Finer-scale breeding stages aligned with breeding phenology at the MAPS stations were successfully identified;

however, those classifications require individual identification, a process which was not successfully automated using the deep learning recognizer. Although progress has been made towards creating a processing pipeline that uses automated recognition to determine the breeding status of landbirds (i.e., Ovenbird) from ARU data as a metric of breeding habitat quality, more work is needed before an automated approach can be implemented for evaluation of habitat disturbance effects within the OSM. Nevertheless, the use of deep learning recognizers to ascertain breeding status at the monitoring location level is positive and suggests that further development of the recognizers and change point modeling approaches holds promise for ARU-based breeding status determination as a monitoring endpoint.

The complicated relationships among bird species richness, habitat characteristics, and other environmental factors are being examined, including the contribution of terrestrial disturbance to landbird communities in the OSR. The community responses identified provide the important baseline information needed to address changes in sub-populations such as the composition of breeding birds as we anticipate incorporation of the data from the 25 recently established Boreal MAPS stations within the BADR design over the next three years. Four separate analyses were performed, the objective being to understand the patterns and underlying mechanisms driving changes in bird community composition using data collected from 2011 to 2024 across 34 MAPS stations. The mechanism driving changes in bird communities in the OSR was largely turnover (species replacement) and occurred at 32 of 34 MAPS stations. Nestedness, indicating that a species-poor community is a subset of a species-rich community, was the mechanism driving changes in composition at one station with early successional habitat. At this station, an increase in the number of species over time corresponded with vegetation growth, while the species captured originally remained, forming the original subset of the newer community composition. We used time lag analysis (TLA) to assess temporal dynamics in bird community composition. Stations with early successional vegetation (reclaimed or recently burned habitat) had significant positive and steeper TLA slopes, indicating strong directional divergence in community composition through time. A significant positive correlation between TLA slope and footprint at the 5 km scale suggests that bird communities in landscapes with greater cumulative human footprint show higher divergence over time. Six species (Cedar Waxwing, Least Flycatcher, Lincoln’s Sparrow, Chipping Sparrow, Black-capped Chickadee, Myrtle Warbler) commonly contributed to the high variation in community composition.

The Boreal MAPS program provides the population, demographic, and community composition data needed to assess landbird responses to terrestrial disturbance in the OSR. Of the 91 species captured and processed during MAPS banding operations since 2011, we identified 10 of 23 species, for which we have sufficient data to model population dynamics using Bayesian models, that show consistent population declines in the OSR. The 13 remaining species are potentially stable or increasing. Boreal MAPS is a surveillance monitoring program, and we have made advances in our analytical methods that will improve our ability to identify species that negatively respond to disturbance within the OSR. The Bayesian modeling approach provided the ability to incorporate a wider range of factors that may be contributing to population change within the Boreal MAPS program. The models that have been developed are still being refined to ensure that appropriate inputs are being incorporated. These models will become our primary analytical tools in the future.

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1.0 INTRODUCTION

1.1 Monitoring Avian Productivity and Survivorship (MAPS)

The Monitoring Avian Productivity and Survivorship (MAPS) program is a formal, scientific, and statistically robust mark-recapture (bird-banding) program, operated across Canada and the United States. It is designed to investigate the population ecology of resident and migrant breeding landbirds. MAPS data are used to derive vital rate estimates (including productivity, survivorship, and recruitment) that are critically needed to identify demographic causes for landbird population trends (DeSante et al. 1999, 2001, 2018; Roy et al. 2019; Saracco and Rubenstein 2020; Saracco et al. 2008, 2022). Such analyses have proven essential to developing management strategies attempting to reverse landbird population declines (DeSante et al. 1995; Roy et al. 2019; Saracco et al. 2010, 2012, 2022; Wilson et al. 2018). The MAPS protocol is an effective tool in monitoring landbird vital rates (see Appendix A for a glossary of terms) in the boreal forest (Foster et al. 2012, 2017; Kaschube et al. 2022; Pyle et al. 2020; Saracco et al. 2022) and has been adopted for the Boreal MAPS program.

1.2 Boreal MAPS

The Boreal MAPS program was initiated in 2011 with industrial support. In 2019, the Oil Sands Monitoring (OSM) Program joined as the primary sponsor through its Terrestrial Biological Monitoring (TBM) theme. From 2021 to present, OSM has been the sole sponsor of the Boreal MAPS program. Boreal MAPS is operated jointly by Owl Moon Environmental Inc. and The Institute for Bird Populations.

The objectives of the Boreal MAPS program are to determine if regional landbird populations have changed or are changing due to landscape alteration, to identify the underlying causes of change, to determine the degree that these changes are attributable to oil sands activities, and to assess the contribution of oil sands activities to cumulative effects on landbird populations in the Oil Sands Region (OSR).

In the context of landbird population dynamics monitoring, these objectives address the primary elements of the seven core OSM program outcomes:

1. identify, track, and report environmental impacts from oil sands development, including cumulative effects, in a risk-based framework;
2. provide quality data, information, and reporting of regional and sub-regional baseline environmental conditions, tracking environmental impacts, and the assessment of cumulative environmental effects from oil sands development to decision makers, rights-holders, and other stakeholders to inform management, policy, regulation, and other such measures and actions in pursuit of minimizing the effects of oil sands development and respecting potential impacts to Section 35 Rights in the oil sands region;
3. provide data, information, and reports in an accessible, open, transparent, and timely manner in accordance with a reporting plan and schedule;

4. meaningfully include and consider Indigenous community and stakeholder concerns in the assessment of environmental impacts, being inclusive of, and informed by, Indigenous knowledge and expertise;
5. involve and empower the Oversight Committee, including stakeholders, decision-makers, and Indigenous communities in the design, implementation, and governance of the OSM Program;
6. build the capacity of Indigenous communities in the oil sands region to participate in community-based monitoring (CBM); and
7. cost-effective use of resources is demonstrated through implementation of a risk-based monitoring approach.

Relationships among the Boreal MAPS program and Indigenous communities and CBM programs are managed through established OSM communication processes.

Boreal MAPS data alone and in combination with data acquired through other methods (e.g., autonomous recordings and human point counts) are used to quantify landbird population and demographic responses to terrestrial disturbances. These findings feed into TBM and broader OSM processes focusing on defining baseline levels, limits-of-change, and/or other management actions that may be taken to ameliorate oil sands development effects on individual landbird species and communities of species.

1.3 TBM Hierarchical Before–After Dose–Response Monitoring Design

From 2021 to 2024, the Boreal MAPS program transitioned into alignment with the TBM's hierarchical Before–After Dose–Response (BADR) monitoring design (Arciszewski et al. 2021; Bayne et al. 2021), with a substantive realignment of MAPS stations across the region. Data collected from 2011 to 2020 in natural, disturbed, and reclaimed habitats continue to be used to assess trends in landbird populations and vital rates.

The BADR design incorporates a spatial hierarchy that accounts for broad regional gradients and developmental pressures, including climactic (north–south and east–west gradients), terrain (upland, lowland), and industrial development (oil sands mining, *in situ*). Responses of landbirds are monitored (1) at locations experiencing different stages in oil sands industrial development (including before–after) and (2) along a gradient of current oil sands disturbances (dose–response). The gradient of terrestrial ecosystem disturbance was categorized according to five levels of intensity, which were re-grouped into three categories for the Boreal MAPS program:

1. reference: low energy sector-related disturbance;
2. fragmented disturbance:
    - soft linear: high density of seismic lines, pipelines;
    - road: energy sector roads;
    - low activity: energy sector disturbance without light or noise impacts (e.g., exploration well pads); and
3. high intensity: energy sector disturbance of high intensity (varying combinations of high human activity, light, noise, and atmospheric deposition).

The fragmented disturbance category reflects the reality of Boreal MAPS operations over a relatively large sampling area (10 to 20 ha) that typically encompasses more than one of the linear disturbance types (soft linear, road, low activity). The classification of disturbances in this way was used to guide the selection of monitoring locations across a gradient of disturbances, while actual disturbance types, magnitudes, and extents (e.g., using the ABMI human disturbance footprint, as in Saracco et al. 2022) are used in data analyses.

Boreal MAPS monitors landbird populations and demography in the deciduous/mixedwood forest (≥40 years of age) habitat type of the TBM program design. Although treed lowland (≥20 years of age) is also a target habitat type, it is not included in the Boreal MAPS program due to substantial constraints (e.g., access requiring helicopter or UTV use, operational and safety concerns). Furthermore, bird capture numbers in treed lowlands are typically too few to reliably support population trend and demographic estimation (based on Boreal MAPS data, 2011–2021). Landbird monitoring within treed lowlands is being conducted using other methods (e.g., autonomous recording units) within the broader TBM program.

1.4 Boreal MAPS Methods

The Boreal MAPS program operates in six landscape units (Figure 1), LUs 1 (In Situ), 2 (Reference), 3 (In Situ), 8 (Mining), 13 (Mining), and 16 (In Situ and Mining), and includes four legacy stations established in 2011–2012. In 2024, 40 stations were operated. Details on these stations and the historical stations that are no longer operated are presented in Appendix B.

Boreal MAPS station operations, including bird capture, banding, and breeding status observations follow the standardized MAPS procedures used across Canada and the United States (DeSante et al. 2024). These are summarized in Appendix C. Landbird species captured and detected during Boreal MAPS monitoring are listed in Appendix D.

2.0 POPULATION AND DEMOGRAPHIC TRENDS

2.1 Banding Program Summary

The number of net-hours of operation, new captures, captured birds released unbanded, recaptured birds, and species captured, both for the 40 stations operated in 2024 and the 66 stations operated over the duration of the program, are presented in Table 1. In 2024, effort comprised 16,871.5 net-hours, resulting in 2,700 birds being newly banded, 78 being released unbanded, and 1,051 recaptures of birds banded earlier in the same season or in previous seasons, for a total of 3,829 captures (of 59 species). Across all 63 stations and all 14 years (comprising over 125,000 net-hours of effort), 54,816 captures of 91 species have been recorded, of which 40,658 were newly banded, 836 were unbanded, and 13,622 were recaptures of previously banded birds. Capture rates vary among stations, generally reflecting variations in forest structure and disturbance levels across the program (Foster et al. 2017). Inter-annual variability at the station and program levels is also apparent, potentially reflecting the cyclical nature of natural populations, including those of landbirds.

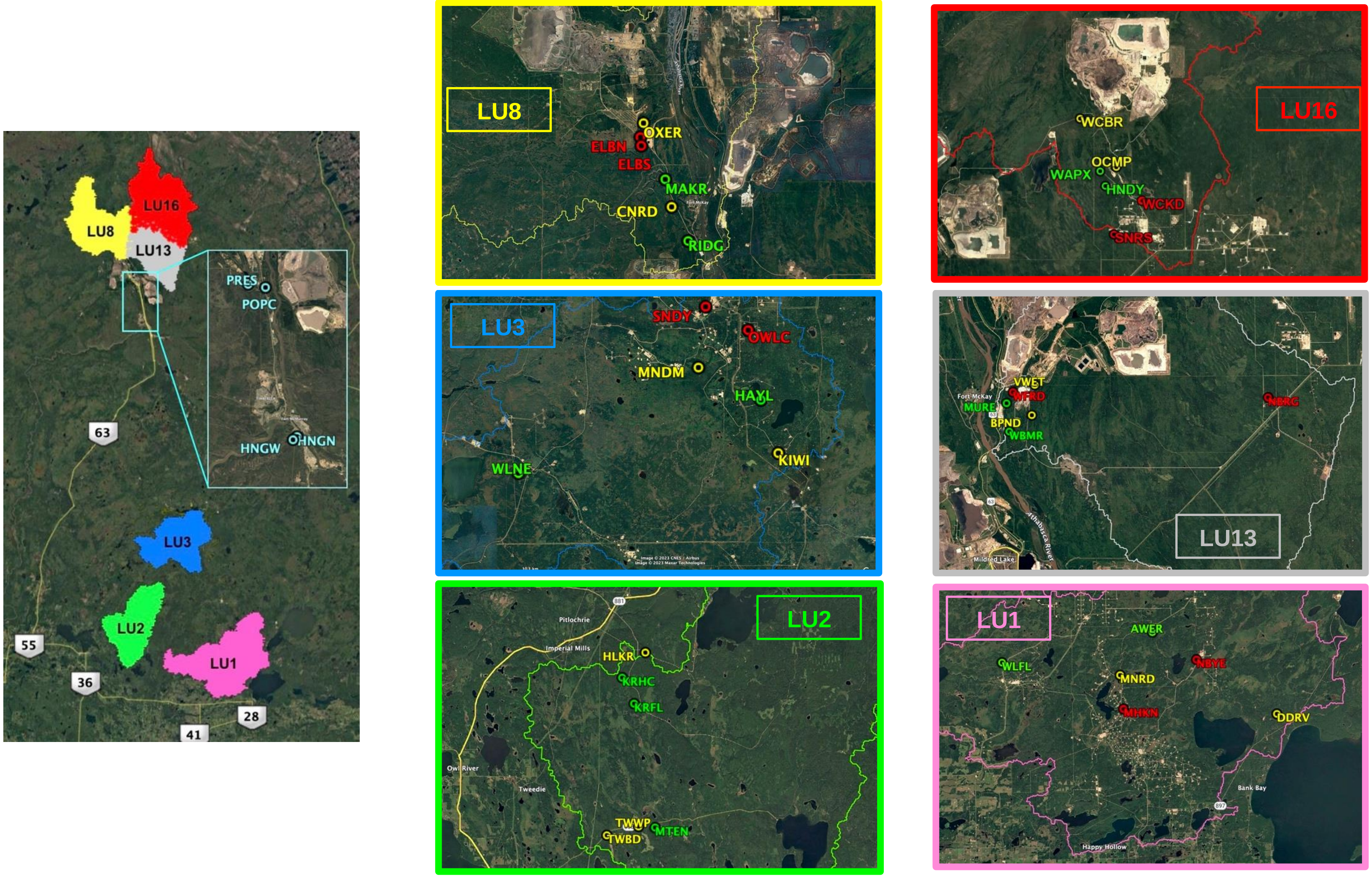


Figure 1: Boreal MAPS stations

Station Category (station label colours): Green = Reference; Yellow = Fragmented; Red = High Intensity Disturbance; Blue = Data Continuity.
Only stations in current operation are shown. See Appendix B for a listing of Boreal MAPS station names, coordinates and habitats (2011–2024)

Table 1: Bird Captures[1] at Boreal MAPS Stations (2011 to 2024)

Station	Years of Operation	2024[2]						Cumulative Over Period of Operation[2]					
		Net-hr	N	U	R	Total	Species	Net-hr	N	U	R	Total	Species
Landscape Unit 1 – *In Situ*													
AWER	2023–2024	411.00	30	0	5	35	12	771.00	80	0	15	95	18
DDRV	2023–2024	432.00	52	0	10	62	15	792.00	103	0	31	134	19
MHKN	2023–2024	430.50	17	0	10	27	10	790.50	43	0	18	61	15
MNRD	2023–2024	425.00	33	3	15	51	14	785.00	93	4	40	137	19
NBYE	2023–2024	408.00	36	0	20	56	14	768.00	97	3	38	138	23
WLFL	2023–2024	390.00	35	2	8	45	11	750.00	84	3	28	115	18
Landscape Unit 2 – Reference													
HLKR	2022–2024	407.00	25	0	6	31	9	1,195.50	73	3	17	93	19
KRFL	2022–2024	432.00	64	2	14	80	18	1,211.00	166	3	45	214	26
KRGY	2022	–	–	–	–	–	–	351.00	45	0	8	53	12
KRHC	2022–2024	432.00	36	1	22	59	12	1,220.50	115	3	57	175	15
MTEN	2023–2024	432.00	39	2	7	48	13	792.00	74	3	11	88	16
TWBD	2023–2024	429.50	51	2	19	72	16	788.17	104	4	36	144	26
TWWP	2023–2024	426.00	19	0	6	25	8	783.83	57	1	20	78	14
Landscape Unit 3 – *In Situ*													
HAYL	2022–2024	369.50	20	1	5	26	10	1,116.00	87	1	17	105	21
KIWI	2021–2024	343.00	27	0	4	31	12	1,397.50	242	1	51	294	25
MNDD	2021	–	–	–	–	–	–	332.50	29	1	13	43	10
MNDM	2021–2024	422.50	52	1	13	66	10	1,635.67	362	4	76	442	32
MNDY	2012–2019	–	–	–	–	–	–	2,753.50	523	9	139	671	39
OWLC	2021–2024	290.50	85	17	22	124	22	1,336.17	568	24	140	732	41
SNDY	2012–2019,2021–2024	316.50	76	0	17	93	12	3,845.83	817	14	242	1,073	48
WLNE	2021–2024	429.50	13	0	6	19	6	1,638.00	136	2	42	180	23

Table 1: Continued

Station	Years of Operation	2024[2]						Cumulative Over Period of Operation[2]					
		Net-hr	N	U	R	Total	Species	Net-hr	N	U	R	Total	Species
Landscape Unit 8 – Mining													
CNRD	2022–2024	432.00	83	1	22	106	20	1,218.67	241	11	57	309	31
CRBG	2021	–	–	–	–	–	–	360.00	53	3	12	68	21
CREB	2012–2019	–	–	–	–	–	–	3,203.00	944	23	372	1,339	47
ELBN	2012–2019, 2021–2024	360.00	50	0	38	88	14	3,682.00	1,083	29	481	1,593	43
ELBS	2012–2019, 2021–2024	350.50	91	2	43	136	14	3,703.83	1,365	38	572	1,975	42
HBVR	2012–2016	–	–	–	–	–	–	1,587.50	559	11	182	752	38
HFSH	2012–2016	–	–	–	–	–	–	1,685.33	951	26	243	1,220	47
HRAW	2015–2016	–	–	–	–	–	–	647.67	390	9	144	543	23
MAKR	2012–2024	350.00	67	3	58	128	14	4,564.50	1,360	28	692	2,080	37
OXER	2022–2024	720.00	72	0	22	94	16	1,415.17	350	17	88	455	33
RIDG	2021–2024	349.00	59	2	20	81	14	1,411.33	255	7	64	326	23
Landscape Unit 13 – Mining													
BPND	2011–2024	360.00	122	2	61	185	25	4,992.00	2,268	41	925	3,234	56
CSTU	2013–2019	–	–	–	–	–	–	2,398.33	1,616	27	551	2,194	47
KERL	2013–2016	–	–	–	–	–	–	993.00	211	6	46	263	30
MURE	2022–2024	864.00	103	3	31	137	20	1,631.67	296	8	96	400	28
MUSL	2013–2015	–	–	–	–	–	–	981.50	242	16	30	288	27
MUSR	2011–2021	–	–	–	–	–	–	3,079.33	1,260	17	292	1,569	42
NBRG	2022–2024	864.00	35	0	9	44	9	1,613.67	106	2	31	139	16
ODYS	2013–2019	–	–	–	–	–	–	2,388.17	715	20	277	1,012	39
RUSL	2013–2019	–	–	–	–	–	–	2,443.00	1,260	29	418	1,707	48
VWET	2011–2024	503.00	186	7	77	270	26	6,202.67	2,721	52	880	3,653	52
WBMR	2022–2024	429.33	62	0	16	78	19	1,211.67	185	4	59	248	27
WFRD	2022–2024	420.00	47	0	19	66	16	1,186.00	176	1	55	232	21

Table 1: Continued

Station	Years of Operation	2024[2]						Cumulative Over Period of Operation[2]					
		Net-hr	N	U	R	Total	Species	Net-hr	N	U	R	Total	Species
Landscape Unit 16 – Mining & *In Situ*													
HNDY	2023–2024	430.33	101	0	33	134	18	790.33	161	2	61	224	22
OCMP	2023–2024	357.50	69	7	33	109	16	717.50	177	9	73	259	22
SNRS[3]	2024	169.00	30	1	3	34	10	169.00	30	1	3	34	10
WAPX	2024	359.50	71	2	12	85	16	359.50	71	2	12	85	16
WCBR	2023–2024	358.33	56	3	29	88	10	717.33	128	5	53	186	22
WCKD[3]	2024	179.50	35	3	8	46	11	179.50	35	3	8	46	11
WPCK	2013–2015, 2017–2019	–	–	–	–	–	–	2,109.50	485	7	146	638	37
WPEX	2023	–	–	–	–	–	–	358.33	111	2	20	133	23
Data Continuity Stations													
HNGN	2012, 2014–2024	354.00	167	2	77	246	22	4,210.50	1,445	14	640	2,099	41
HNGW	2013–2015, 2017–2024	355.00	190	2	85	277	27	3,881.83	1,594	13	856	2,463	43
POPC	2012–2024	360.00	153	2	53	208	25	3,946.83	2,186	36	684	2,906	47
PRES	2012–2024	720.00	141	5	93	239	29	4,927.33	2,504	45	979	3,528	57

Table 1: Continued

Outside of Boreal MAPS Landscape Units													
BCDS	2011–2019	–	–	–	–	–	–	2,543.67	1,558	21	409	1,988	46
BRCH	2014, 2017–2019	–	–	–	–	–	–	1,402.67	532	4	148	684	45
CRLK	2012–2019	–	–	–	–	–	–	2,990.00	771	15	146	932	43
CRSL	2012–2019	–	–	–	–	–	–	2,891.67	355	10	109	474	37
ENGS	2012–2019	–	–	–	–	–	–	2,739.33	687	56	203	946	40
GRGR	2014–2020	–	–	–	–	–	–	2,323.83	535	8	148	689	40
HNGS	2012–2019	–	–	–	–	–	–	2,525.50	809	13	298	1,120	45
HSHO	2013–2019	–	–	–	–	–	–	2,412.67	2,080	30	532	2,642	52
SNDR	2012–2019	–	–	–	–	–	–	2,448.17	751	11	234	996	42
THEY	2012–2019	–	–	–	–	–	–	2,796.33	848	21	211	1,080	39
Totals		16,871.50	2,700	78	1,051	3,829	59	125,095.00	40,658	836	13,622	54,816	91

Notes:

[1] Capture totals are not directly comparable among stations, as they are not normalized for effort (net-hours).

[2] N = new bandings, U = released unbanded, R = recapture of a previously banded bird.

[3] SNRS and WCKD had truncated effort in 2024 due to a forest fire which did not allow access to the stations.

2.2 Landbird Populations and Demography

In each of our annual reports to date (e.g., Foster et al. 2024), we have presented updated analyses of population and productivity trends based on linear regression modeling that incorporates data from each year of operation. For adult survival, we have been using Cormack–Jolly–Seber modeling, and for lambda, a Pradel model (see Appendix E for details). To facilitate the ability to compare trends and vital rate estimates for landbird populations in the OSR to those for the continental populations, and to facilitate the integration of environmental and disturbance variables into our analyses, we are transitioning to a Bayesian modeling approach. This year, we present the population trends and vital rate estimates for 35 regionally breeding species derived from regression/CJS/Pradel modeling (Appendix E) and for 23 species for which there are currently sufficient data to support Bayesian reverse-symmetry (RS) modeling (Appendix F). Population trends and vital rate estimates for these 23 species were also derived using the continental dataset, allowing for comparisons between regional and continental population trends and vital rate estimates.

To minimize the effects of annual variability, trends and demographic estimates have been derived from data collected at stations which have operated for at least four years, a minimum period for the derivation of reasonable population and vital rate estimates (Kaschube et al. 2022). Over the next three years, 25 stations established within the BADR design will reach four years of operation and will begin contributing data to population trend and vital rate analyses. Assessing population responses to BADR-defined terrestrial disturbances will also become possible.

2.2.1 Trends and Estimates Based on Linear Regression Analysis, Modified Cormack–Jolly–Seber Modeling, and Pradel Modeling (Boreal MAPS)

We analyzed population trends and demographic variables using regression/CJS/Pradel analyses (Appendix E), with data from 29 Boreal MAPS stations operated for at least 4 of the 12 years from 2011 to 2024. The minimum data requirements for population and productivity trend analyses and survivorship estimation using linear regression modeling were met for 35 species. The population trend estimates (lambda and trends in adults captured) and vital rates (productivity trend and survival) for these 35 species are summarized in Table 2, with color coding to indicate significant positive and negative trends. Adult population size and productivity trend figures for each of the 35 species are presented in Appendix E.

Significant population declines according to either lambda (a measure of population growth rate in which significance is determined by 95% confidence intervals not crossing 0.000), or adult population trend according to linear regression, were recorded for 26 of the 35 species, with those for 19 species being significantly negative according to both measures. Significant population increases were recorded for seven species, with those of three species being significant according to both measures. Fourteen species showed negative productivity trends, and no species showed positive trends. Survival probabilities also are included in Table 2, and these values are used in the broader model calculations.

Table 2: Summary of Demographic and Population Trends for 35 Species based on Linear Regression, Cormack–Jolly–Seber (CJS), and Pradel Modeling (2011 to 2024)

Species[2]	Adult Population		Productivity[1]	Adult Survival
	Pradel Lambda ± SE	Lineal Regression Trend ± SE (p)[1]	Linear Regression Trend ± SE (p)	CJS Probability ± SE
Sharp-shinned Hawk	0.958 ± 0.040	-0.041 ± 0.033 (0.210)	-0.074 ± 0.310 (0.811)	0.505 ± 0.244
Yellow-bellied Sapsucker	0.858 ± 0.016	-0.165 ± 0.018 (<0.001)	-0.130 ± 0.034 (<0.001)	0.249 ± 0.051
Yellow-shafted Flicker	1.010 ± 0.034	+0.047 ± 0.032 (0.148)	-0.040 ± 0.046 (0.386)	0.405 ± 0.325
Alder Flycatcher	0.995 ± 0.008	+0.002 ± 0.007 (0.754)	-0.017 ± 0.020 (0.393)	0.451 ± 0.036
Least Flycatcher	0.913 ± 0.010	-0.102 ± 0.011 (<0.001)	-0.009 ± 0.015 (0.550)	0.316 ± 0.073
Philadelphia Vireo	n/a	+0.048 ± 0.022 (0.032)	+0.004 ± 0.035 (0.919)	n/a
Red-eyed Vireo	1.001 ± 0.010	+0.033 ± 0.010 (0.001)	-0.095 ± 0.024 (<0.001)	0.491 ± 0.044
Canada Jay	0.932 ± 0.026	-0.079 ± 0.026 (0.002)	+0.031 ± 0.025 (0.216)	0.570 ± 0.090
Black-capped Chickadee	0.993 ± 0.015	+0.039 ± 0.014 (0.006)	-0.026 ± 0.008 (0.002)	0.538 ± 0.051
Boreal Chickadee	0.949 ± 0.023	-0.062 ± 0.023 (0.006)	-0.046 ± 0.021 (0.027)	0.319 ± 0.081
Swainson's Thrush	1.019 ± 0.007	+0.037 ± 0.007 (<0.001)	-0.069 ± 0.009 (<0.001)	0.531 ± 0.030
Hermit Thrush	0.885 ± 0.026	-0.156 ± 0.027 (<0.001)	-0.017 ± 0.036 (0.632)	0.399 ± 0.093
American Robin	0.983 ± 0.010	+0.002 ± 0.010 (0.826)	-0.019 ± 0.018 (0.298)	0.443 ± 0.043
Purple Finch	0.935 ± 0.021	-0.049 ± 0.022 (0.029)	-0.076 ± 0.022 (<0.001)	0.299 ± 0.129
Chipping Sparrow	0.890 ± 0.009	-0.108 ± 0.010 (<0.001)	-0.073 ± 0.020 (<0.001)	0.362 ± 0.062
Clay-colored Sparrow	1.084 ± 0.019	+0.097 ± 0.018 (<0.001)	-0.143 ± 0.031 (<0.001)	0.166 ± 0.115
Slate-colored Junco	0.909 ± 0.025	-0.106 ± 0.024 (<0.001)	-0.055 ± 0.025 (0.028)	0.504 ± 0.094
White-throated Sparrow	0.993 ± 0.005	+0.025 ± 0.005 (<0.001)	-0.040 ± 0.006 (<0.001)	0.427 ± 0.018
Song Sparrow	n/a	+0.017 ± 0.026 (0.518)	-0.056 ± 0.029 (0.056)	n/a
Lincoln's Sparrow	0.956 ± 0.011	-0.046 ± 0.011 (<0.001)	+0.019 ± 0.011 (0.094)	0.327 ± 0.041
Swamp Sparrow	0.941 ± 0.016	-0.060 ± 0.015 (<0.001)	-0.033 ± 0.016 (0.038)	0.230 ± 0.064
Ovenbird	0.950 ± 0.010	-0.018 ± 0.009 (0.058)	-0.063 ± 0.012 (<0.001)	0.293 ± 0.051
Northern Waterthrush	0.856 ± 0.023	-0.189 ± 0.026 (<0.001)	-0.024 ± 0.030 (0.424)	0.588 ± 0.071
Black-and-white Warbler	0.928 ± 0.015	-0.079 ± 0.015 (<0.001)	-0.034 ± 0.021 (0.101)	0.402 ± 0.065
Tennessee Warbler	0.937 ± 0.005	-0.057 ± 0.005 (<0.001)	+0.003 ± 0.004 (0.540)	0.121 ± 0.073
Mourning Warbler	1.047 ± 0.012	+0.106 ± 0.011 (<0.001)	-0.060 ± 0.018 (0.001)	0.556 ± 0.034
Common Yellowthroat	0.936 ± 0.016	-0.098 ± 0.016 (<0.001)	-0.042 ± 0.030 (0.151)	0.376 ± 0.065
American Redstart	0.945 ± 0.015	-0.046 ± 0.016 (0.003)	-0.019 ± 0.022 (0.404)	0.504 ± 0.061
Magnolia Warbler	1.003 ± 0.011	+0.040 ± 0.011 (<0.001)	-0.055 ± 0.015 (<0.001)	0.467 ± 0.037
Yellow Warbler	0.919 ± 0.015	-0.096 ± 0.016 (<0.001)	-0.008 ± 0.018 (0.658)	0.490 ± 0.053
Myrtle Warbler	0.885 ± 0.015	-0.105 ± 0.015 (<0.001)	-0.002 ± 0.026 (0.993)	0.345 ± 0.056
Canada Warbler	0.965 ± 0.012	-0.004 ± 0.012 (0.726)	-0.010 ± 0.013 (0.432)	0.436 ± 0.048
Wilson's Warbler	0.900 ± 0.018	-0.114 ± 0.019 (<0.001)	+0.010 ± 0.022 (0.631)	0.332 ± 0.102
Western Tanager	0.944 ± 0.027	-0.047 ± 0.029 (0.107)	-0.066 ± 0.035 (0.061)	0.729 ± 0.203
Rose-breasted Grosbeak	0.924 ± 0.021	-0.069 ± 0.022 (0.002)	-0.035 ± 0.036 (0.331)	0.506 ± 0.113

Notes:

[1] For productivity and adult population trend estimates, orange indicates a significant decrease, and green indicates a significant increase (see Appendix E).

[2] Yellow shading indicates species listed in Alberta as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species also listed federally as Threatened or of Special Concern (Government of Canada 2023)

2.2.2 Trends and Estimates Based on Bayesian Modeling

We analyzed population trends and demographic variables using Bayesian modeling and the same data from the 29 Boreal MAPS stations operated for at least 4 years from 2011 to 2024. Minimum data requirements for seven parameters (lambda, adult trend, productivity, productivity trend, survival, survival trend, recruitment, and recruitment trend) were met for 23 species. We anticipate that the number of species for which valid estimates can be calculated will increase as more data are collected and as the 25 stations established in the last three years through the BADR transition reach four years of operation. Detailed analytical methods are presented in Appendix F.

A significance test for differences between the linear regression and Bayesian model estimates is not possible. However, a visual inspection indicates very few discrepancies in results. Only in 4 of the 69 significant trends derived did the outcomes of the two approaches differ, with the trends being in opposite directions. Some differences are to be expected, as the two approaches differ in their inputs, with the Bayesian approach having the ability to derive estimates that consider multiple factors that cannot be integrated into regression modeling. However, the overall consistency between the outcomes of the two approaches is remarkable and supports our choice to transition to Bayesian modeling.

2.2.3 Comparison Between Boreal MAPS and Continental MAPS Trends and Estimates

For the 23 species discussed above, we compared Bayesian-derived population and vital-rate estimates for the regional population (Boreal MAPS) from data collected from 2011 to 2024 with those for the continental population (Continental MAPS) from data collected from 2011 to 2023. This comparison is intended to determine if a regional population is changing in a direction and/or rate that is different from the continental population. The comparisons between populations are shown in Figure 2 (lambda), Figure 3 (productivity), Figure 4 (adult survival), and Figure 5 (recruitment). Detailed analytical methods and tabular summaries for these comparisons are presented in Appendix F.

Population growth rates (lambda) were opposite between Boreal MAPS and the Continental MAPS program for three species. For Least Flycatcher and American Redstart, the rates were significantly negative regionally but significantly positive continentally, whereas the opposite was the case for White-throated Sparrow, which appeared to be increasing regionally and decreasing continentally. Five other species appeared to be declining significantly regionally, but populations were apparently stable continentally: Yellow-bellied Sapsucker, Hermit Thrush, Ovenbird, Northern Waterthrush, and Black-and-White Warbler. Species that were decreasing significantly both regionally and continentally included Chipping Sparrow, Yellow Warbler, and Myrtle Warbler. The lambda estimate for the continental Canada Warbler population indicated a significant decline, while lambda was not significant regionally, although we have shown that populations of Canada Warbler and several other warbler species within our Boreal MAPS program exhibit cyclical trends (Appendix E). For the remaining species, lambda was either not significant or populations were experiencing significant positive population growth regionally.

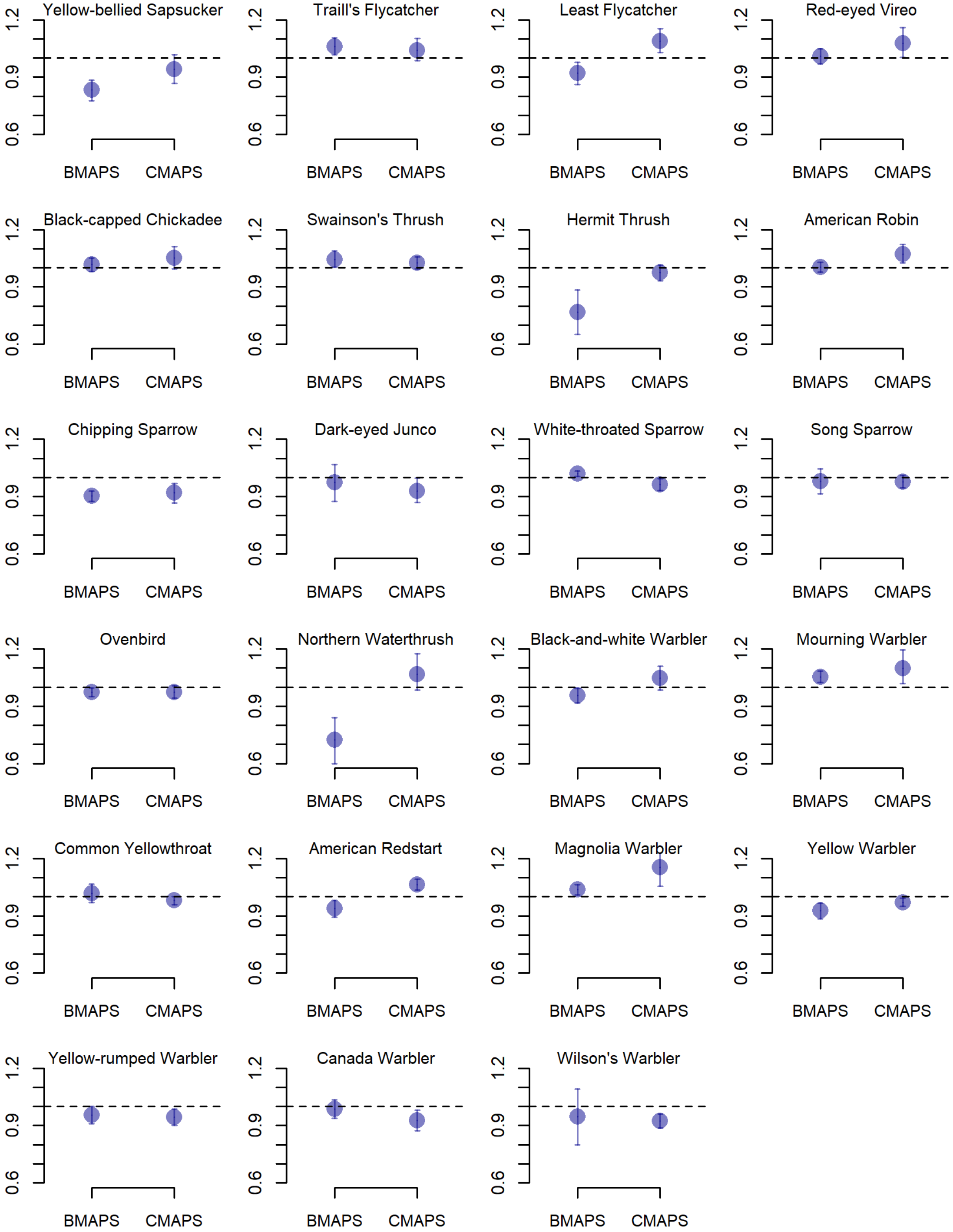


Figure 2: **Lambda estimates for regional (BMAPS) and continental (CMAPS) populations of 23 landbird species, derived using Bayesian modeling.**

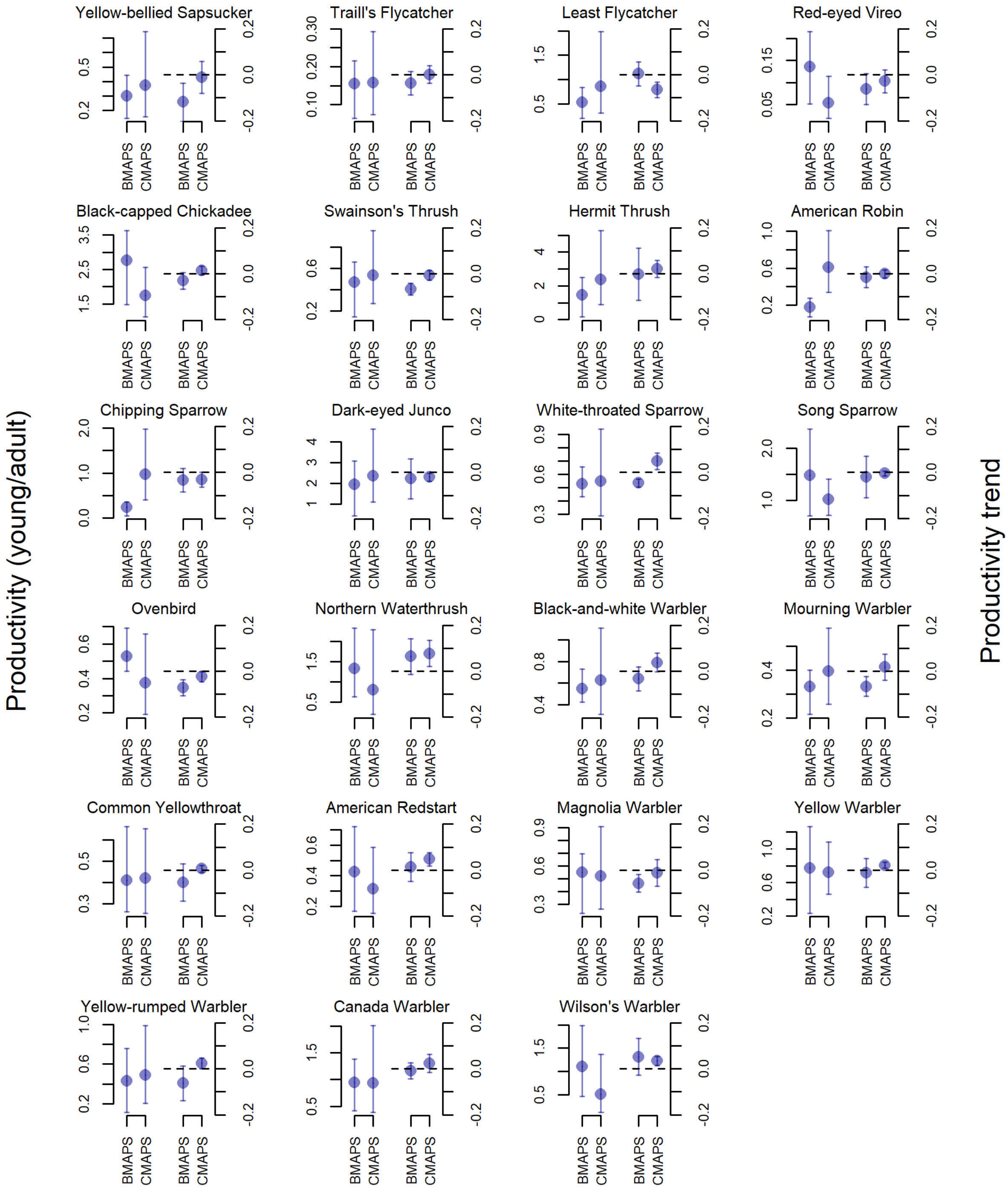


Figure 3: **Productivity estimates and trends for regional (BMAPS) and continental (CMAPS) populations of 23 landbird species, derived using Bayesian modeling.**

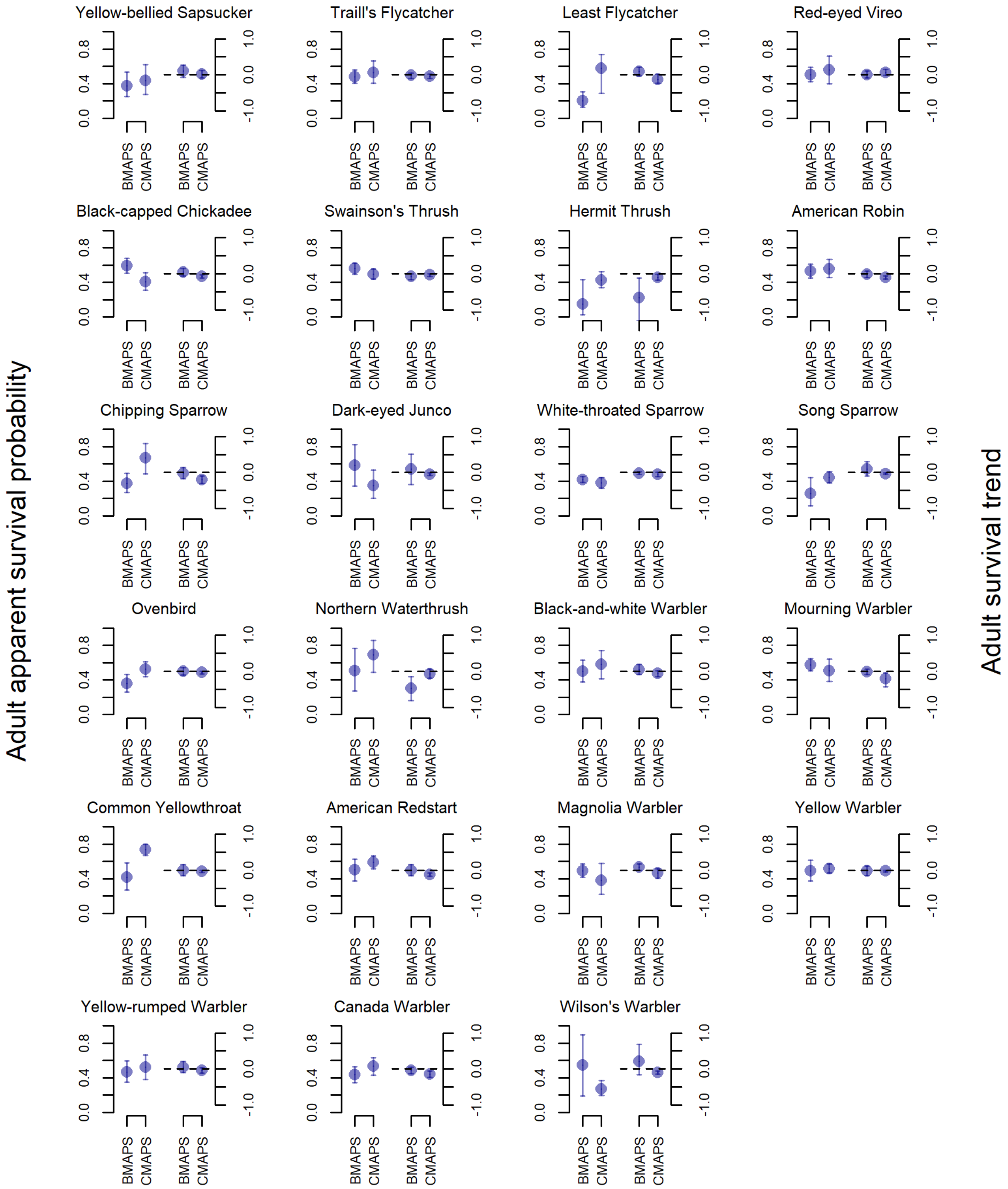


Figure 4: **Adult apparent survival probability (survivorship) estimates and trends for regional (BMAPS) and continental (CMAPS) populations of 23 landbird species, derived using Bayesian modeling.**

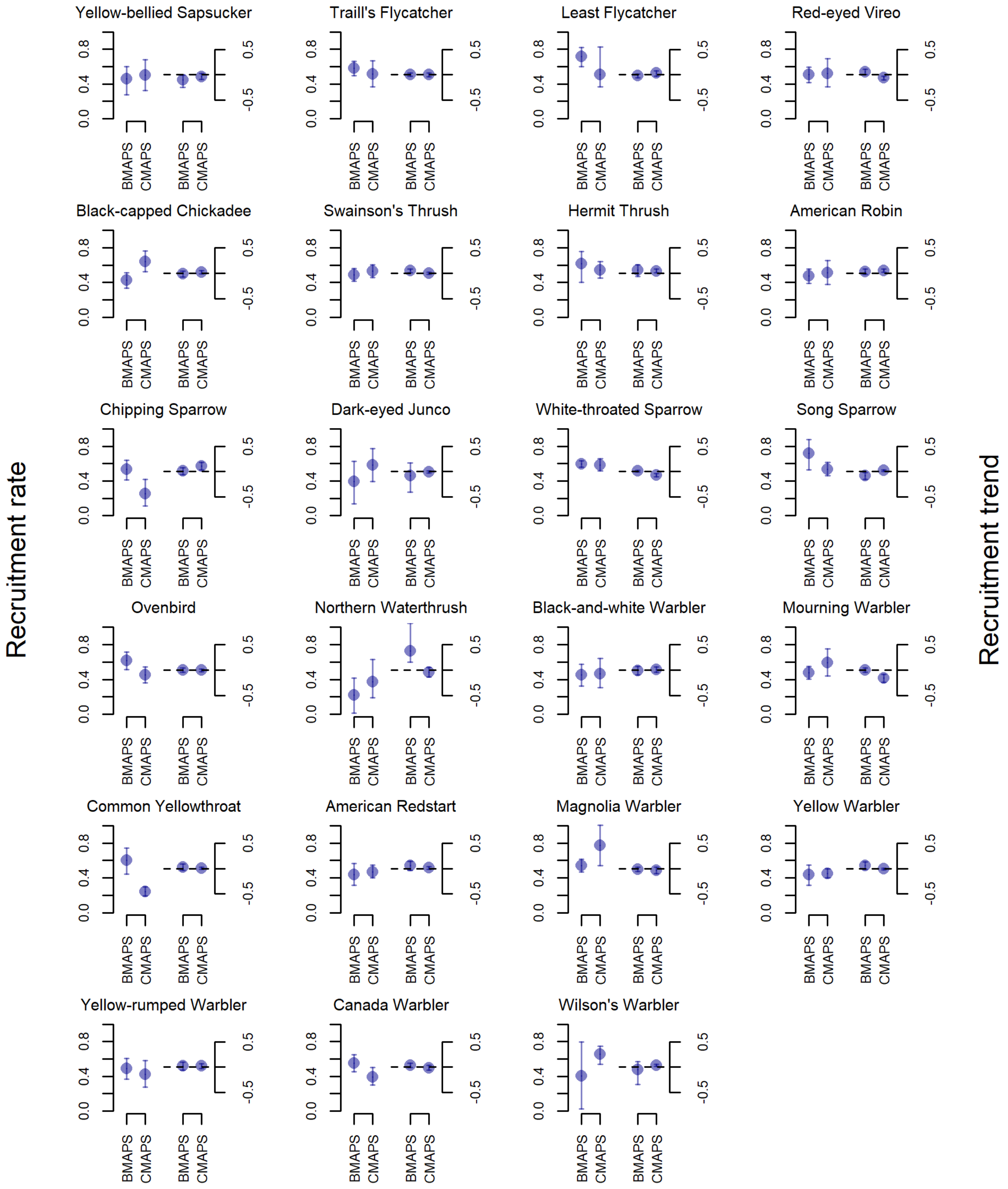


Figure 5: **Recruitment estimates and trends for regional (BMAPS) and continental (CMAPS) populations of 23 landbird species, derived using Bayesian modeling.**

Productivity (across the years of monitoring) and productivity trend (annual change over the period of monitoring) regionally were compared to those from the Continental MAPS program for the 23 species. There were no differences in productivity across years between regional and continental populations for any of the 23 species. However, the annual productivity trends were significantly negative for five species regionally, while continentally they were either stable or positive: Yellow-bellied Sapsucker, Swainson's Thrush, White-throated Sparrow, Mourning Warbler, and Magnolia Warbler. The productivity trend for Ovenbird was significantly negative both regionally and continentally, suggesting this species is experiencing breeding ground effects across its range. Of the ten species that exhibited signs of population decline based on lambda, a decrease in productivity may be a contributing factor for two species–Yellow-bellied Sapsucker and Ovenbird.

As with productivity, we examined both survival across the years of monitoring and the annual change in survival (survival trend) for each of the 23 species. Across years, survival was much lower regionally for Common Yellowthroat compared to continental populations. For all other species, confidence intervals overlapped between regional and continental populations, indicating no substantial difference. Even so, many species exhibited low mean survival (less than 0.400), including Yellow-bellied Sapsucker, Least Flycatcher, Hermit Thrush, Chipping Sparrow, Song Sparrow, and Ovenbird. The annual survival trend was also negative for Hermit Thrush both regionally and continentally, while the annual survival trend for Northern Waterthrush was negative regionally but apparently stable continentally. For the remaining species, the annual survival trend regionally appeared stable, while many of these same species were experiencing annual negative change in survival continentally. Of the ten species exhibiting signs of declining populations based on lambda, lower survival may be a contributing factor for six species: Yellow-bellied Sapsucker, Least Flycatcher, Hermit Thrush, Chipping Sparrow, Ovenbird, and Northern Waterthrush.

Recruitment across the years of monitoring was substantially different between regional and continental populations for two species: recruitment for Black-capped Chickadee was lower regionally compared to continental populations, while recruitment was higher regionally for Common Yellowthroat compared to continental populations. For all other species, confidence intervals overlapped between regional and continental populations, indicating no substantial difference in recruitment. The annual change in recruitment trend, however, was negative regionally for two species. The trend for Song Sparrow was significantly negative regionally while significantly positive continentally. The trend for Yellow-bellied Sapsucker was significantly negative regionally while stable continentally. Three species showed significant positive recruitment trends regionally: Red-eyed Vireo (significantly negative continentally) and Swainson's Thrush and Northern Waterthrush, which were both stable continentally. The overall population decrease found for Yellow-bellied Sapsucker may be influenced partially by lower recruitment. The population decline observed for Northern Waterthrush may be partially ameliorated by the positive regional recruitment trend. For the other eight species identified as experiencing population declines, low recruitment may not be the main contributing factor.

We identified 10 species regionally that were experiencing population decreases based on negative lambda values. Of these, seven species were responding better continentally, while three were experiencing similar continental declines. Lower productivity may be influencing the declining regional populations of Yellow-bellied Sapsucker and Ovenbird, both of which appear to be doing better continentally. Yellow-bellied Sapsucker also appeared to be experiencing lower recruitment rates. Lower survival was found regionally for Hermit Thrush and Northern Waterthrush, whose populations were also doing better continentally. For the remaining six species, Least Flycatcher, Chipping Sparrow, Black-and-White Warbler, American Redstart, Yellow Warbler, and Myrtle Warbler, the underlying mechanisms leading to population declines are still to be identified.

Due to the wide latitudinal differences in populations and the many complicating factors that can contribute to population change across a species' continental range, the Bayesian modeling approach was required to compare regional and continental trends. This approach provided the ability to incorporate a range of factors that may contribute to population change. The models that have been developed are still being refined to ensure that appropriate inputs are being incorporated. Once final, these models will become our primary analytical tool in the future.

3.0 SELECTION OF CANDIDATE LANDBIRD SPECIES FOR CONSIDERATION IN OSM'S ADAPTIVE MANAGEMENT PROCESSES

In our Boreal MAPS 2022 annual report (Foster et al. 2023), we presented a decision process designed to identify the species experiencing population declines linked to stresses being experienced on the regional breeding grounds. In the application of this process following the 2023 monitoring season (Foster et al. 2024), we identified five species experiencing population decline, four of which (Least Flycatcher, Hermit Thrush, Ovenbird, Canada Warbler) have been shown to be linked to habitat disturbances in the OSR (Saracco et al. 2022, Solymos et al. 2019). While population decline in the fifth species (Northern Waterthrush) was severe, no linkage to regional stresses has been identified. The decision process has been updated to anticipate the incorporation of Bayesian modeling (Figure 6). Updated summaries of population and vital rate trends and estimates, showing the outcomes of regression and Bayesian analyses, for these five species are presented in Figures 7 to 11.

We have not reassessed species selections, awaiting the stabilization of data flow following the large increase in regional data as the 25 recently established Boreal MAPS stations reach four years of operations over the next three years. However, it is clear from both the regression and Bayesian analyses that Least Flycatcher and Hermit Thrush continue to warrant consideration for management attention due to their regional population declines and links between these declines and regional terrestrial disturbance.

In future assessments of population decline we will apply the criteria developed by the International Union for Conservation of Nature (IUCN), specifically, the A2(b) criteria (IUCN Standards and Petitions Committee 2019), which are:

> A – population size reduction measured over the longer of 10 years or 3 generations;
> 2 – population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible; and

(b) – an index of abundance appropriate to the taxon.

Based on the magnitude of the population size reduction, a species is classified as being of *Least Concern* (reduction of <30%), *Vulnerable* (≥30% to <50% reduction), *Endangered* (≥50% to <80% reduction), or *Critically Endangered* (≥80% reduction).

The Government of Alberta (2024) has adopted the IUCN approach and criteria in the assessment of the status of populations of wild species in Alberta. This makes these criteria applicable in the assessment of regional population status.

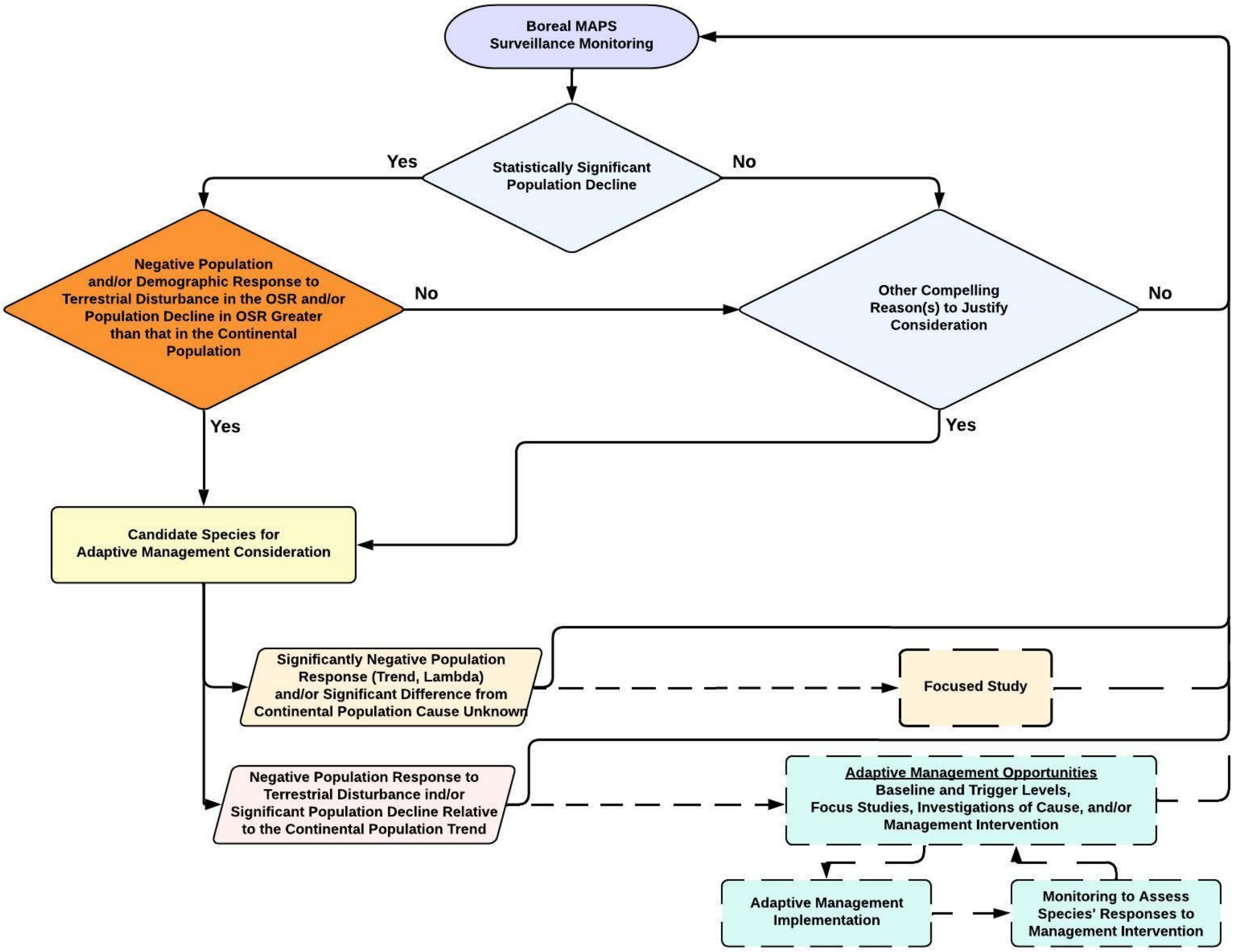


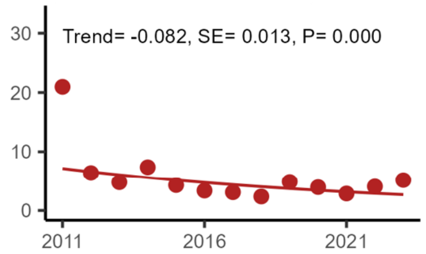
Figure 6: Generalized decision process for the selection of candidate landbird species for adaptive management process consideration

Hatched lines indicate processes that are within the mandate of OSM's TBM Technical Advisory Committee.

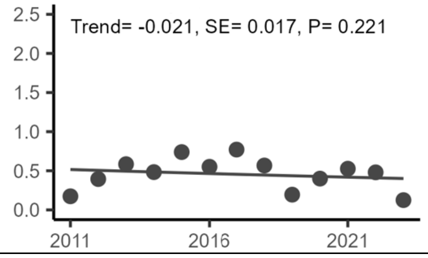
Least Flycatcher

Regression Analyses

Population Trend

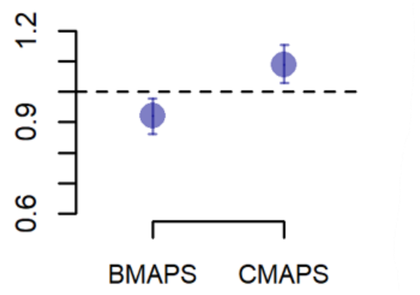


Productivity



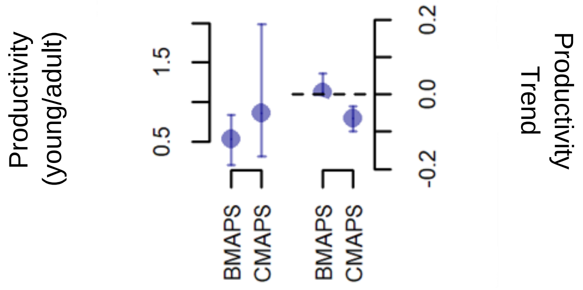
Bayesian Modeling

Lambda



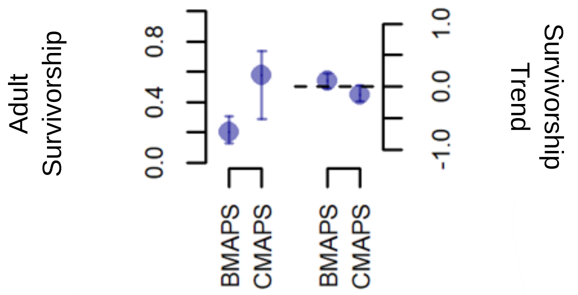
Boreal Population: 0.922 (0.862, 0.978)
Continental Population: 1.089 (1.029, 1.154)

Productivity and Productivity Trend



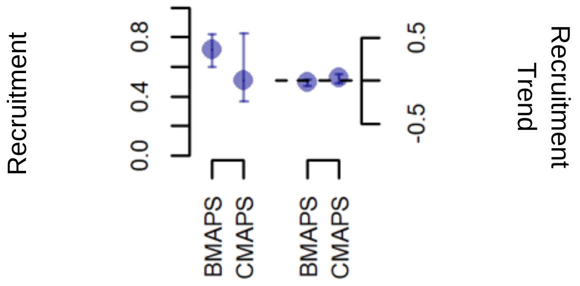
Productivity:	BMAPS= 0.534 (0.207, 0.842) CMAPS= 0.856 (0.309, 1.985)
Productivity Trend:	BMAPS= 0.005 (-0.047, 0.056) CMAPS= -0.065 (-0.099, -0.032)

Adult Survivorship and Survivorship Trend



Survivorship:	BMAPS= 0.202 (0.124, 0.304) CMAPS= 0.578 (0.287, 0.734)
Survivorship Trend:	BMAPS= 0.093 (-0.030, 0.212) CMAPS= -0.128 (-0.230, 0.016)

Recruitment and Recruitment Trend



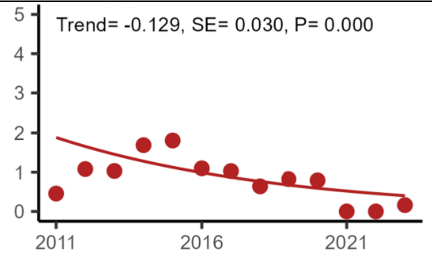
Recruitment:	BMAPS= 0.719 (0.602, 0.819) CMAPS= 0.511 (0.369, 0.829)
Recruitment Trend:	BMAPS= -0.020 (-0.060, 0.012) CMAPS= 0.032 (-0.027, 0.073)

Figure 7: Estimates of Least Flycatcher population change and vital rates using regression (top) and Bayesian (bottom) approaches, comparing populations monitored in the OSR (2011–2024) and continentally (2011–2023)

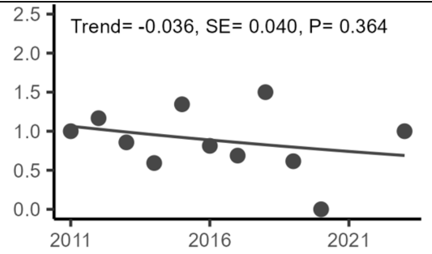
Hermit Thrush

Regression Analyses

Population Trend

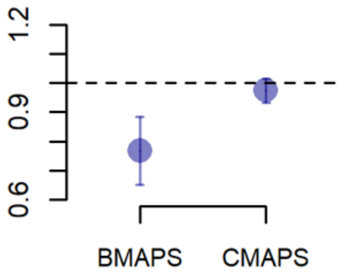


Productivity



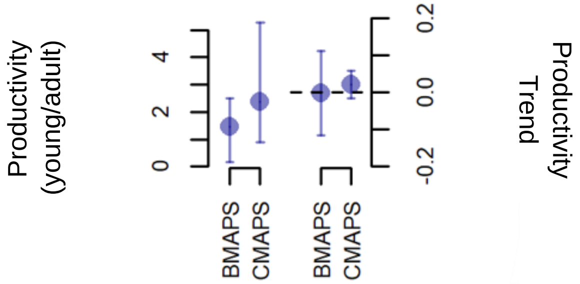
Bayesian Modeling

Lambda



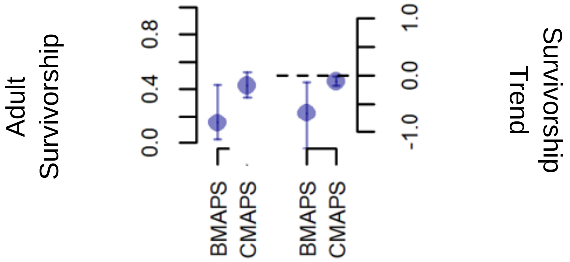
Boreal MAPS: 0.766 (0.651, 0.883)
Continental MAPS: 0.973 (0.932, 1.014)

Productivity and Productivity Trend



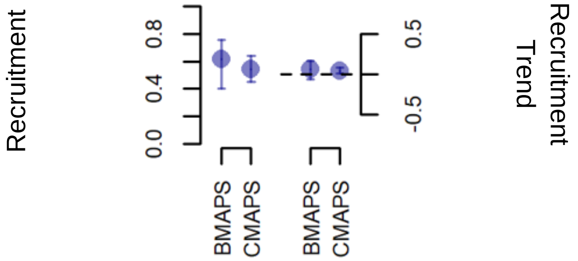
Productivity:	BMAPS= 1.466 (0.161, 2.509) CMAPS= 2.385 (0.903, 5.283)
Productivity Trend:	BMAPS= -0.003 (-0.116, 0.111) CMAPS= 0.021 (-0.016, 0.058)

Adult Survivorship and Survivorship Trend



Survivorship:	BMAPS= 0.150 (0.025, 0.430) CMAPS= 0.429 (0.338, 0.522)
Survivorship Trend:	BMAPS= -0.668 (-1.297, -0.125) CMAPS= -0.098 (-0.178, -0.020)

Recruitment and Recruitment Trend



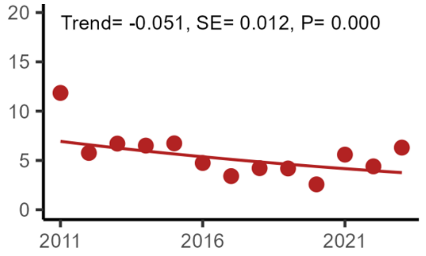
Recruitment:	BMAPS= 0.616 (0.400, 0.757) CMAPS= 0.545 (0.450, 0.639)
Recruitment Trend:	BMAPS= 0.061 (-0.06, 0.161) CMAPS= 0.045 (0.005, 0.087)

Figure 8: Estimates of Hermit Thrush population change and vital rates using regression (top) and Bayesian (bottom) approaches, comparing populations monitored in the OSR (2011–2024) and continentally (2011–2023)

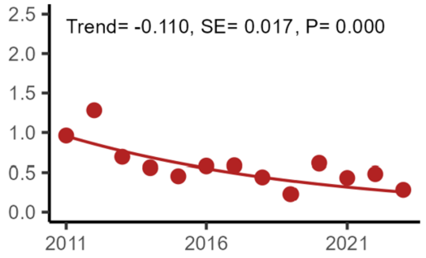
Ovenbird

Regression Analyses

Population Trend

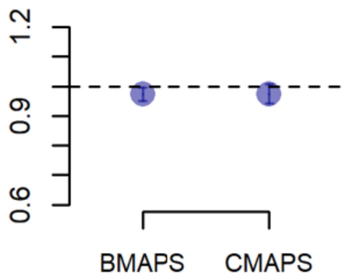


Productivity



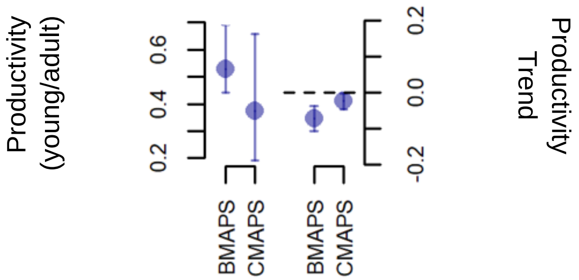
Bayesian Modeling

Lambda



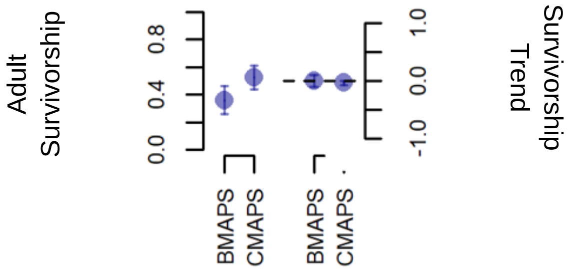
Boreal MAPS: 0.974 (0.951, 0.998)
Continental MAPS: 0.974 (0.941, 1.007)

Productivity and Productivity Trend



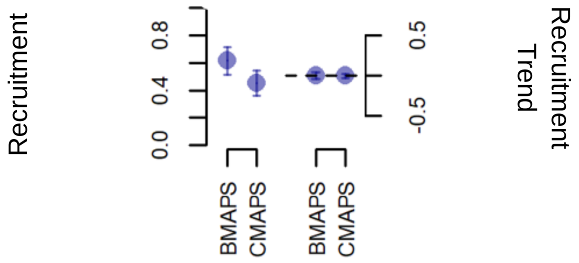
Productivity:	BMAPS= 0.528 (0.441, 0.693) CMAPS= 0.375 (0.191, 0.658)
Productivity Trend:	BMAPS= -0.072 (-0.107, -0.037) CMAPS= -0.023 (-0.045, -0.001)

Adult Survivorship and Survivorship Trend



Survivorship:	BMAPS= 0.356 (0.261, 0.461) CMAPS= 0.523 (0.439, 0.613)
Survivorship Trend:	BMAPS= -0.001 (-0.097, 0.101) CMAPS= -0.035 (-0.075, 0.005)

Recruitment and Recruitment Trend



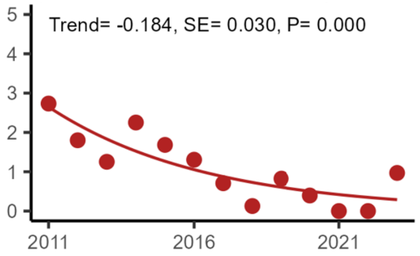
Recruitment:	BMAPS= 0.618 (0.513, 0.714) CMAPS= 0.451 (0.360, 0.542)
Recruitment Trend:	BMAPS= 0.004 (-0.038, 0.041) CMAPS= -0.003 (-0.031, 0.024)

Figure 9: Estimates of Ovenbird population change and vital rates using regression (top) and Bayesian (bottom) approaches, comparing populations monitored in the OSR (2011–2024) and continentally (2011–2023)

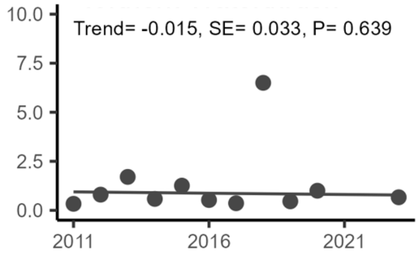
Northern Waterthrush

Regression Analyses

Population Trend

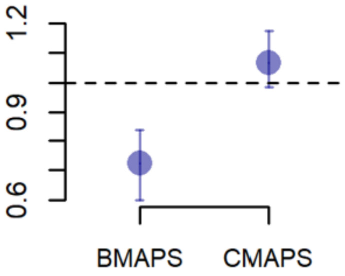


Productivity



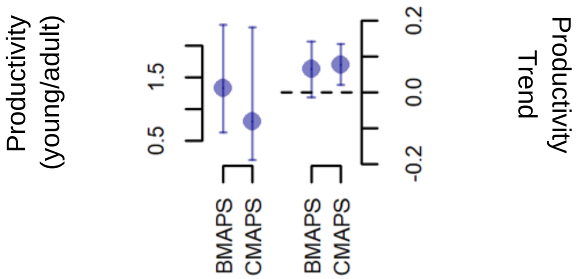
Bayesian Modeling

Lambda



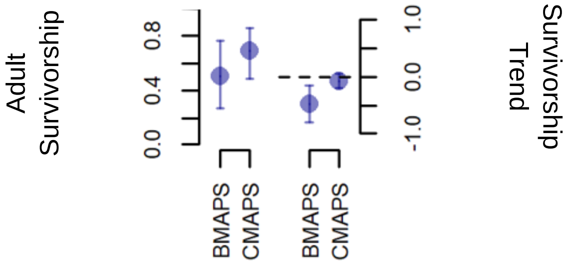
Boreal MAPS: 0.723 (0.599, 0.841)
Continental MAPS: 1.067 (0.984, 1.176)

Productivity and Productivity Trend



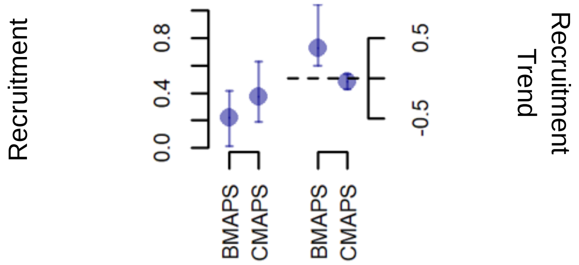
Productivity:	BMAPS= 1.333 (0.632, 2.322) CMAPS= 0.806 (0.201, 2.278)
Productivity Trend:	BMAPS= 0.064 (-0.013, 0.141) CMAPS= 0.078 (0.021, 0.136)

Adult Survivorship and Survivorship Trend



Survivorship:	BMAPS= 0.505 (0.271, 0.768) CMAPS= 0.692 (0.491, 0.855)
Survivorship Trend:	BMAPS= -0.467 (-0.818, -0.145) CMAPS= -0.065 (-0.197, 0.060)

Recruitment and Recruitment Trend



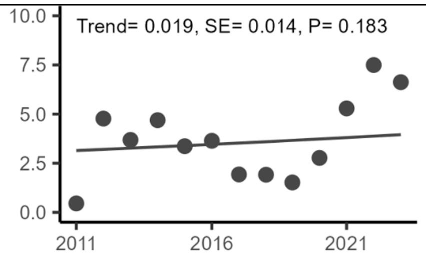
Recruitment:	BMAPS= 0.218 (0.009, 0.416) CMAPS= 0.375 (0.191, 0.632)
Recruitment Trend:	BMAPS= 0.382 (0.160, 0.920) CMAPS= -0.039 (-0.139, 0.058)

Figure 10: Estimates of Northern Waterthrush population change and vital rates using regression (top) and Bayesian (bottom) approaches, comparing populations monitored in the OSR (2011–2024) and continentally (2011–2023)

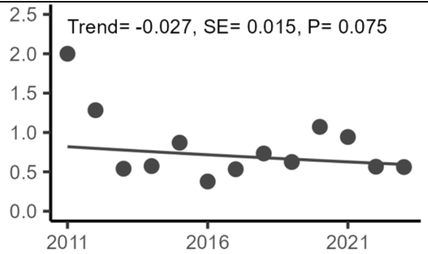
Canada Warbler

Regression Analyses

Population Trend

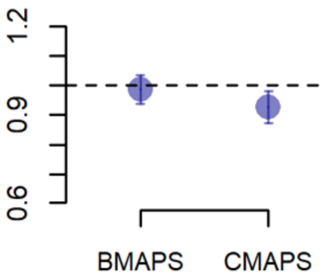


Productivity



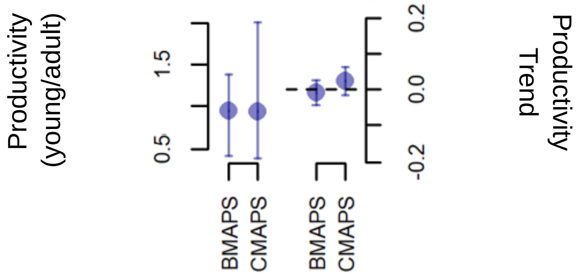
Bayesian Modeling

Lambda



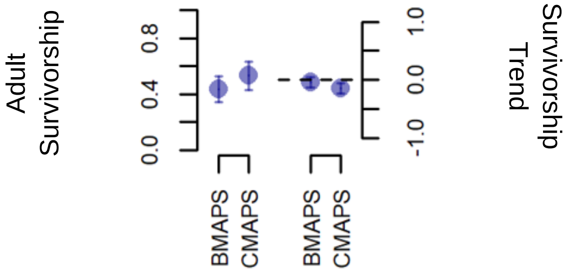
Boreal MAPS: 0.985 (0.939, 1.035)
Continental MAPS: 0.927 (0.873, 0.981)

Productivity and Productivity Trend



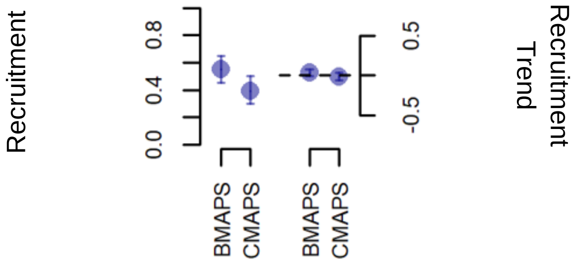
Productivity:	BMAPS= 0.947 (0.412, 1.383) CMAPS= 0.929 (0.391, 2.006)
Productivity Trend:	BMAPS= -0.010 (-0.044, 0.025) CMAPS= 0.024 (-0.016, 0.063)

Adult Survivorship and Survivorship Trend



Survivorship:	BMAPS= 0.434 (0.345, 0.529) CMAPS= 0.532 (0.428, 0.632)
Survivorship Trend:	BMAPS= -0.040 (-0.130, 0.051) CMAPS= -0.140 (-0.226, -0.062)

Recruitment and Recruitment Trend



Recruitment:	BMAPS= 0.552 (0.451, 0.650) CMAPS= 0.394 (0.299, 0.502)
Recruitment Trend:	BMAPS= 0.034 (-0.009, 0.079) CMAPS= -0.016 (-0.063, 0.030)

Figure 11: Estimates of Canada Warbler population change and vital rates using regression (top) and Bayesian (bottom) approaches, comparing populations monitored in the OSR (2011–2024) and continentally (2011–2023)

4.0 INTEGRATED POPULATION MODELING

4.1 IPM Background and Objectives

In the OSR, energy-sector development has altered the native boreal forest landscape with varied effects on wildlife species. Species that rely on open and younger deciduous forest habitats can benefit from regeneration of habitats following cessation of industrial activities, while other species that are dependent on older intact habitats can be negatively affected by loss of mature native forests. Migratory birds are among the most well-studied species in this system, and many rich datasets exist to inform the status of these species in the OSR, how they respond to disturbance, and what demographic rates are important in driving population changes. For the first time, we leveraged these varied datasets within an integrated population modeling (IPM) framework to better understand the relative contributions of adult apparent survival probabilities, recruitment rate of 1-year-old individuals, and immigration rate of older adults to observe variation in population changes of four target migratory bird species in the region. Our target species included Alder Flycatcher, a species typically associated with deciduous shrub habitat, and three species more associated with older forests, Swainson’s Thrush, Ovenbird, and Canada Warbler (Schieck and Song 2011).

Here, we develop a novel multi-site IPM that includes count, age–structure, and capture–recapture data from the four species. Our objectives were to 1) assess site-level population responses to habitat fragmentation and industrial activity related to energy-sector development, 2) estimate regional population dynamics and trends, and 3) assess the contributions of demographic parameters to population change.

4.2 IPM Methods

As an initial step to developing our IPM, we used count data, including passive acoustic monitoring data from automated recording units (ARUs) as well as point count data collected from field observers during the Boreal MAPS program, from 3,220 locations across the region from 2011 to 2023 to derive regional annual abundance estimates for each species using a model that accounted for variation in detectability among these datasets. A habitat suitability covariate was included in the abundance model to account for spatio-temporal variation in sampling across years, and two composite metrics of disturbance were also included, representing 1) fragmentation (soft linear features, roads, areal disturbance without noise or light impacts) and 2) activity (high human activity, light, noise, and atmospheric deposition impacts) to better understand responses of the four species to these disturbances and to better estimate abundances across years. Abundance estimates from this initial step were then incorporated into a regional IPM that included adult age–structure and capture–recapture data from 34 Boreal MAPS stations across the region.

We incorporated annual region-wide abundance estimates from our abundance model into an IPM that included sub-models for three time-specific demographic parameters informed by adult age–structure and capture–recapture data: adult survival probability, recruitment rate, and immigration rate. Adult age–structure data are commonly collected as part of bird capture–

recapture studies but seldom utilized to make inferences about populations (Pyle et al. 2020). Leveraging these data to inform recruitment is also attractive because it not only provides inferences about a more ecologically relevant recruitment parameter (number of 1-year-old recruits per adult in the previous time period) but it also opens the possibility of estimating a latent immigration parameter that can provide additional detail on population inputs represented by dispersing adults (Abadi et al. 2010, Schaub and Fletcher 2015).

We then estimated the relative contributions of each demographic parameter to the variation in population growth rate using a life table response experiment (Caswell 2001). Given the relatively ephemeral and patchy nature of Alder Flycatcher habitat and frequent industrial and fire disturbance in this region, we expected that recruitment and immigration might be especially important for explaining population growth in that species compared to the others (Travis and Dytham 1999). Comparison of the relative importance of recruitment vs. adult survival on population growth can provide some indication of the potential importance of breeding grounds (stronger recruitment signal) vs. nonbreeding season effects (stronger adult survival signal) on population change (Sillett and Holmes 2002, Saracco et al. 2008).

4.3 IPM Outcomes

We expected that the forest-associated species would respond negatively to fragmentation and activity (Leston et al. 2023), particularly Canada Warbler, for which we have found relatively strong negative responses to overall human footprint (Wilson et al. 2018, Saracco et al. 2022), while Alder Flycatcher might respond positively to fragmentation. Abundance responses to disturbance were largely as we expected. Alder Flycatcher, a species of earlier successional shrubby habitats, increased in abundance as a function of fragmentation and industrial activity, while the three species typical of older forests decreased as a function of these disturbance.

However, responses to each disturbance type were dependent on the presence of the other disturbance type. Alder Flycatcher and Canada Warbler represented the opposite extremes of these interactive responses, whereby increases in Alder Flycatcher abundance and decreases in Canada Warbler abundance were only evident when both fragmentation and industrial activity were high. Swainson’s Thrush and Ovenbird abundances were also negatively related to fragmentation and industrial activity, but here too these relationships were complicated by an interactive effect. The reason for this synergistic response to disturbance deserves additional study but generally aligns with earlier findings that showed a positive response in captures of adult Alder Flycatchers, a negative response in captures of adult Canada Warblers, and variable responses in adult captures of Ovenbird and Swainson’s Thrush to increasing overall human footprint in landscapes surrounding Boreal MAPS stations (Saracco et al. 2022).

Regionally, the results of our IPM suggested that Alder Flycatcher and Ovenbird populations remained stable over the 13-year study period, while Swainson’s Thrush populations significantly increased by about 4%/year. Canada Warbler populations declined over the same period.

We found immigration of adult birds to be an important contributor to population dynamics for Alder Flycatcher. For Alder Flycatcher, high rates of adult breeding dispersal could reflect the relatively dynamic nature of their habitats and their positive responses to disturbance. For Ovenbird, both immigration and recruitment were equally important. Adult apparent survival was especially low for Ovenbird, which also reflects high rates of adult breeding dispersal in this species and is consistent with low apparent survival and high breeding dispersal rates in other disturbed boreal forest landscapes (Bayne and Hobson 2002). Canada Warbler population dynamics were more strongly related to recruitment. All three vital rates, immigration, recruitment, and survival, were important contributors to changes in Swainson's Thrush populations, with recruitment being most important.

The importance of recruitment of 1-year-old adults for the three forest species suggests that management of breeding areas will be an important facet of migratory bird conservation in the region. The importance of recruitment for these three species could reflect local factors affecting breeding productivity or first-year survival, both of which might be expected to be more variable in disturbed landscapes. Factors determining reproductive success need further study; however, existing data support the protection of existing large tracts of older deciduous and mixed forests (Flockhart et al. 2016, Hunt et al. 2017), the minimization of potential negative effects of intensive industrial activities (e.g., Habib et al. 2007), and management of regenerating habitats on disturbed sites to support post-fledging birds (Saracco et al. 2022) as potentially important measures for supporting productivity of these species in the OSR.

Although we found a relatively minor signal of adult apparent survival in explaining variation in population growth rates, when combined with immigration of adult birds, which we presume is largely within-region dispersal, it suggests that factors outside of the breeding range are also likely important. This suggests that conservation of nonbreeding areas must also be considered in efforts to protect these species.

5.0 SONG RATES FROM ARU RECORDINGS AND CORRELATION WITH MAPS BREEDING STATUS

The ability to classify landbirds as breeders, with breeding use of habitat providing evidence of the quality of the habitat (Pyle et al. 2020), is a key value of the MAPS program. In addition to demographic variables (Saraco et al. 2022), changes in a species breeding status can be used in the assessment of habitat disturbance effects. An ability to assign species breeding status using data collected from autonomous recording units (ARUs) in habitats where MAPS is not conducted would enhance our ability to assess landbird disturbance effects with minimal incremental field effort across a wider area. Here, we extend the analyses that we conducted last year (Godwin et al., in Foster et al. 2024) using Common Yellowthroat (*Geothlypis trichas*) to evaluate the potential of using deep learning-based acoustic recognizers to classify the breeding status of songbirds recorded from ARUs by analyzing Ovenbird (*Seiurus aurocapilla*) song rate. A separate report has been prepared (Knight et al. 2025) that includes detailed descriptions of analytical methods, the application of a deep learning auto-recognizer, and modeling results and interpretations; a summary of this report follows.

Data collected from ARUs are used to model landbird abundances at the landscape scale. However, abundance alone may not always be reflective of habitat quality and can become decoupled from individual fitness and population viability (Rosenfeld & Hatfield, 2006). In extreme cases, this can be indicative of an ecological trap where animals select habitats where their fitness is reduced (Hale & Swearer 2016). Thus, attempts to understand the effects of habitat disturbances on landbird populations should consider integrated response metrics, such as demographic rates including abundance, distribution, and breeding phenology (pairing and mating success), which may be directly connected to habitat quality.

Our goal is to evaluate whether ARU recordings can be used to determine landbird breeding status. The co-location of MAPS and ARU recording data collection provides an opportunity to evaluate whether male territorial song rates, derived using a deep learning auto-recognizer, can be used to predict landbird breeding status at the scale of the OSR. Our approach was sequential:

1. use a deep learning auto-recognizer to identify singing Ovenbird males in ARU recordings;
2. derive song rates for singing males;
3. use a multi-step statistical analysis to classify sites with paired and unpaired males and identify change points in song rates, indicative of breeding status of the singing males; and
4. link recording-based defined breeding status assignments to verified breeding status and phenology based on MAPS capture data.

The manual analysis of ARU recordings is a labor-intensive process, made impractical as volumes of ARU recordings increase. Included in our work is the application of a new automated song recognizer built specifically for Canadian birds (Huus et al. *in review*). Previously, we showed that recognizers could be used to detect change points in Common Yellowthroat (*Geothlypis trichas*) song rates reflective of breeding phenology but with greater precision than human listeners (Godwin et al. 2024, in Foster et al. 2024). In that study, ARUs were deployed prior to the arrival of the birds, leading to a lack of understanding of whether the recorder locations represented common yellowthroat territory centers, which introduced uncertainty about the effects of movement of individuals into and out of the recording radius. Estimating breeding status from song rate requires an assumption of closure, or that the singing individual is within the survey area anytime that it is singing (Rota et al. 2009). Without closure, the song rate estimated from ARU recordings will not be accurately estimated and may also be potentially biased via confounds between singing location and breeding status.

We used the Ovenbird for this study because it is a recommended indicator species for monitoring in the OSR, is widespread across the region, and has previously been documented to show declines in song rate over the breeding season consistent with decreased habitat quality and possibly reduced pairing success (Grames et al. 2022). Furthermore, existing deep learning recognizers perform well for this species (Huus et al. *in review*).

In landbirds, three phases in breeding phenology are generally recognized: 1) unpaired males, 2) paired males and nest incubation, and 3) the nestling phase when young are being fed. Typically, male song rate is highest prior to arrival of females and declines during pairing and incubation, declining to very low rates during the post-hatch nestling phase (Wright 1997). In contrast, unpaired males can be classified as such because they consistently sing at high rates through the breeding season (Wright 1997). Song rates have therefore been used to discern breeding activity in Olive-sided Flycatcher (*Contopus cooperi*) during focused studies (Wright 1997), using point count data (Upham-Mills et al. 2020), and from ARU recordings (Brooks and Nocera 2021, Upham-Mills et al. *in press*). Song rate has also been correlated with breeding status in American Redstart (*Setophaga ruticilla*), and unpaired males sing more frequently than paired males (Staicer et al. 2006). Similar correlations have been observed in many avian species, and unpaired males tend to sing at higher rates, with the singing rate changing as their breeding status changes (Gottlander 1987, Gibbs and Wenny 1993, Hoi-Leitner et al. 1995, Hanski and Laurila 1993, Dussourd and Ritchison 2003, Liu et al. 2007), although there can be considerable variation, even among paired males (Robbins et al. 2009).

We collected acoustic recordings at the territory center of breeding ovenbirds at three MAPS stations where we could confirm that the species was breeding and the timing of breeding stages. We used a multi-step approach to predict the breeding status of Ovenbirds from the ARU recordings at those locations, including individual identification through automated classification, and estimation of vocal activity rates. We then applied the same approach to acoustic recordings collected from 32 locations monitored by ABMI where Ovenbirds were present based on manual verification of bird songs, where MAPS was not conducted. The ARU deployment at the ABMI locations was not targeted at the territory center of an Ovenbird. We also explored the ability to classify breeding status without manually validating the classifier results.

Based on MAPS data collected from 2022 and 2023, three MAPS stations (HNDY, NBRG, OCMP) where Ovenbirds were known to breed were selected to provide data on breeding phenology (Foster et al. 2024). At each of the three MAPS stations, a Song Meter SM4 ARU (Wildlife Acoustics Inc.) was deployed in 2024 near a mist-net location suspected to be at or close to the center of a male Ovenbird territory based on MAPS capture and banding data in the preceding two years. ARUs were programmed to record from May 15 to July 20 for 10 minutes each hour, beginning at one half-hour before sunrise and ending 6 hours after sunrise.

On each day of banding in 2024 at each of HNDY, NBRG, and OCMP, captured Ovenbird males and females were classified according to breeding status. For males, the presence of a cloacal protuberance indicated breeding condition. For females, brood patch condition was used to define breeding phenology: laying eggs (de-feathered brood patch), incubating (vascular brood patch), and feeding young (wrinkled and/or moulting brood patch).

The ABMI acoustic dataset was compiled from recordings collected throughout the breeding season at 32 locations monitored over 2015–2024. At each location, a Song Meter SM4 ARU (Wildlife Acoustics Inc.) was deployed following standardized ABMI protocols (Alberta Biodiversity Monitoring Institute 2021). Although ARUs were programmed to record from early March to late August, we limited our analyses to the period from May 10, the earliest detected Ovenbird arrival date, to July 20, during the fledging period near the end of the breeding season. This matched the period of recording at the MAPS stations.

Song rate metrics calculated across several individuals (at the station level) may be useful in detecting changes in breeding status if breeding is synchronous. We therefore calculated song rate metrics at both the station level and at the individual level to understand if the detected changes in song rate differed. Unfortunately, attempts to use the deep learning classifier to separate individuals suggested further work is needed; so, we used the expert labels of individual birds based on manual validation of recordings to calculate song rate at the individual level. Although expert annotation was conducted for each recording, individual Ovenbird labels were not consistent across the recordings, so we filtered the annotations to the loudest male in each recording, assuming that territorial dynamics during the breeding season resulted in consistent amplitudes across individuals.

We removed locations where Ovenbird was detected in recordings less than 70% of the days between the first and last detection, as this was interpreted to indicate a low overlap between an Ovenbird territory and the ARU recording radius. The reasons for this were twofold. First, locations with low ARU–Ovenbird territory overlap may result in sporadic patterns of song rate via bird movements in and out of the ARU recording radius, which can result in spurious conclusions about breeding status changes. Second, because low overlap is representative of low intensity of habitat use, removing locations with low detection rates is the first step towards identifying locations of high habitat quality. However, sporadic habitat use can be indicative of unpaired males who have larger territories and move around those territories more frequently than paired males, which is also representative of low habitat quality.

We compared our results calculated from the automated classifications to the known breeding status for Ovenbirds at the three MAPs stations. We also applied the same automated classification methods to our ARU dataset without the expert annotation of ovenbird songs to determine whether the classifier can be used to determine breeding status without manual verification of ARU recording results.

While there was a strong correlation between the number of individuals predicted by the deep learning embeddings (the numerical representations of the automated classification of Ovenbird) and the number of birds annotated in the recordings by expert listeners, many more individuals were predicted by the classifier than were annotated by listeners.

We removed 17 of the 35 ARU-monitored locations at which Ovenbirds were detected during less than 70% of the days between the first and last day of detection. Among the remaining 18 locations (15 ARU, 3 MAPS), we found no change in song rate across the season at three of the ABMI locations, and these were also removed from the analysis. The results for the remaining

15 locations suggested the presence of paired males at each. Although change points in song rates were identified, the majority of those change points had large confidence intervals (mean = 32.64 days, SD = 13.75 days), suggesting poor model fit. There were, however, four locations for which the modeled change points had 95% confidence intervals that were narrower than 2 weeks (i.e., a week of uncertainty on either side of the estimate) and that did not overlap the 95% confidence intervals of any of the other estimated change points. Two of those locations were the NBRG and OCMP MAPS stations, with the change points approximately corresponding to the known shift to feeding young in late June at those locations and to the predicted decline in song rate. In contrast, the two ABMI locations with more precise change point estimates corresponded to a decline in late May or early June, potentially corresponding to a decline in song rate associated with pairing success. The third MAPS station (HNDY) also had a change point estimated in mid-June; however, the 95% confidence interval was 43 days wide, and the change in song rate was contrary to our predictions.

The deep learning recognizer without manual verification was able to produce the same classification outcomes as the deep learning recognizer with manual verification for a range of score thresholds. Previous research suggests that paired males exhibit declines in singing activity after securing a mate and during incubation and nestling stages (Wright 1997; Staicer et al. 2006), and we saw this decline in song rate at most of our ARU study locations where ovenbirds were detected during at least 70% of the breeding season. This potential ability to differentiate paired from unpaired males has direct implications for assessing habitat quality because paired males typically occupy high-quality territories that provide the resources necessary to attract and retain mates and support reproductive success (Hoi-Leitner et al. 1995, Zanette et al. 2001, Johnson 2007) and as was previously shown from data acquired in the Boreal MAPS program (Pyle et al. 2020). In contrast, a higher prevalence of unpaired males may indicate suboptimal habitat, where individuals are present but unable to attract mates. The three MAPS locations with confirmed breeding status were accurately classified with our approach, both with and without manual verification of recognizer results. To scale this approach, success without manual verification of individual songs in recordings would be reliant on deep learning classification with high recall and precision and would be effective for other OSM indicator species with sufficiently high automated classification performance. Accurate classification of unpaired males relative to a dataset with known status will also be required prior to scaling this approach.

Breeding stage classification beyond pairing, however, likely requires individual identification and will require further development before it can be implemented rapidly and at scale. Our results suggest that shifts in breeding stages among individual Ovenbirds are not sufficiently synchronous within a given survey area. While our attempt to automate the classification of individuals here was unsuccessful, this approach continues to hold promise, and other researchers are finding success by building custom species-specific models from larger classifiers like BirdNET (Kahl et al. 2021). Our exploration of recordings for which individual birds were unreliably assigned to a breeding class suggested that high levels of sound masking (overlap of bird songs during busy dawn chorus recordings) were primarily responsible for misclassification. As differences in song rates between paired and unpaired males become more apparent outside of the immediate dawn period, inclusion of multiple, longer recordings per day in change point models would likely provide greater precision to the models, as shown in our previous report for common yellowthroat. Attempting automated individual identification using recordings from other times of day with less sound masking may be an avenue towards implementation of breeding stage classification for individual birds.

Breeding status classification beyond pairing status may also require targeted deployment of ARUs to territory centers to ensure the closure assumption is satisfied. We attempted to replicate this assumption here by limiting the locations included in our analyses; however, we failed to find precise change points in song rate at most of those locations, compared with the targeted deployment of ARUs at MAPS locations. For landbird species prioritized for research into investigation of cause by OSM, the deployment of arrays of time-synchronized ARUs could localize individual vocalizations (Rhinehart et al. 2020) and be used to disentangle the process between closure, individual movement, and estimates of song rate.

We showed that recognizer-derived song rates, even without manual validation, can likely differentiate locations with paired and unpaired males based on consistent patterns of song rate decline after pairing, aligning with established behavioral ecology and known paired status at MAPS stations. This classification provides insight into habitat quality, as paired males typically occupy higher-quality territories that support successful breeding, while a prevalence of unpaired males may indicate suboptimal habitat conditions. We also successfully identified finer-scale breeding stages that aligned with breeding phenology at the MAPS stations; however, those classifications require individual identification, a process which we were unsuccessful in automating from our deep learning recognizer. We recommend further development of individual identification methods, more extensive known breeding status datasets, and the inclusion of longer recording durations to enhance precision and scalability of breeding status classification across the OSM region. The following would be needed to continue development of this methodology:

- Larger and more comprehensive datasets of recordings of individuals with known breeding status that include data with paired and unpaired individuals.
- Larger datasets of breeding phenology, including individual-specific dates of hatching and fledging, to properly validate change point models and train different model types.
- Advances in individual identification are required for automated classification of breeding status beyond site-level pairing success.
- Inclusion of more and longer recordings per day, as recordings outside of the dawn period may provide more detail on breeding status.
- Deployment of ARU arrays to fully understand the effect of individual movement within territories on song rates estimated by a single ARU recording in order to understand how ARUs that are not deployed to target individual birds can be used to understand breeding status beyond site-level pairing status.

Although we showed progress here towards a processing pipeline that uses automated recognition to determine the breeding status of landbirds from ARU data for use at scale to determine pairing success as a metric of habitat quality, more work is needed before an automated approach could be implemented for evaluation of habitat disturbance effects within the OSM. Nevertheless, the progress made here towards the use of deep learning recognizers to ascertain breeding status at the monitoring location level is positive and suggests that further development of the recognizers and change point modeling approaches holds promise for ARU-based breeding status determination as a monitoring endpoint.

6.0 AVIAN COMMUNITY COMPOSITION

6.1 Breeding Status Observations Summary

Through 2024, 191 species across all bird families have been detected during MAPS station operations (Table 3), of which 138 have exhibited breeding behavior in at least one year at one or more MAPS stations. Of the 191 species detected (Appendix D), 42 are species of concern, and most of these (33 of 42) breed at least occasionally within station habitats.

For landbirds specifically, 108 species have been observed, of which 86 have exhibited breeding behavior in one or more years. A total of 21 of the 108 are species of concern, 18 of which were classified as breeding in one or more years. One provincially designated alien species (European Starling) has been recorded.

These breeding status data are fundamental in our analyses and assessments of landbird community composition and diversity and community responses to landscape disturbance. These data are also used to inform some of our analyses, in which only those species and/or individuals verified as breeders in at least some of the monitoring years are included.

Table 3: Species and Confirmed Breeding Species Observed across all Stations (2011 to 2024)[1]

Category	Number of Species	
All Species	Detected	191
	Breeding	138
	Species of Concern	42
	Breeding Species of Concern	33
Landbird Species	Detected	108
	Breeding	86
	Species of Concern	21
	Breeding Species of Concern	18
Alien Species	Detected	1

Notes:

[1] Species of concern include those listed as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020), and/or as Threatened or of Special Concern (Government of Canada 2023).

[2] Landbird Species = passerines and woodpeckers.

[3] As defined by Government of Alberta (2020).

6.2 Temporal Dynamics in Boreal Bird Communities

We are examining the complicated relationships among bird species richness, habitat characteristics, and other environmental factors in our progress towards understanding the contribution of terrestrial disturbance to landbird communities in the AOSR.

The Boreal MAPS program includes two measures to evaluate bird community composition at a monitoring station. The breeding status procedure is used to classify the behavior of individual birds as breeders or as transients through station habitats (DeSante et al. 2024). This binary classification provides a simple means of deriving breeding species richness, as well as overall community composition. Capture data, on the other hand, include assignment of male and female reproductive condition, providing both species abundance information and confirmation of breeding in a habitat, therefore providing a breeding species richness as a sub-component of the broader bird community. Our long-term MAPS dataset is being used to measure station-level landbird diversity to attempt to distinguish whether community composition changes are occurring and if the cause is anthropogenic, due to natural processes, or a combination of both and to what extent these factors influence the response of bird communities.

In these analyses, we looked at the community composition of all bird species. This is important in terms of understanding if changes are occurring in the broader bird community without diving directly into the specific demographic groups (e.g., breeding or non-breeding communities). Few studies in the AOSR have examined changes to bird community composition, and we could find none that talk about community-level dynamics from a temporal perspective. Therefore, our analyses create baseline knowledge on how bird community dynamics operate in the oil sands region, filling an important knowledge gap. This also gives us the direction needed to look at specific groups in the community like breeding birds (or habitat use for post-breeding moulting) as next steps.

The purpose of this analysis is to understand the patterns and underlying mechanisms driving changes in bird community composition using data collected prior to and including stations currently within the BADR design. Within the next three years, 25 recently established MAPS stations will reach four years of operation, the minimum number of years operated that are required (Kaschube et al. 2022) to directly apply the learnings gained here. This is the first step towards understanding what bird community changes are occurring in AOSR, and why. Our results are directly attributable to site-specific conditions, including habitat quality. The next steps in our analyses will be to connect our results with the local habitat structure data, including ground-truthed disturbance types and attributes (e.g., amount, activity), to examine the station-specific causes of bird community changes and then extrapolate the findings to the regional scale

An analysis of the bird community-level changes over time is presented in Appendix G. Here, we present a summary of four separate analyses that evaluate the beta-diversity (β-diversity) of bird communities using data collected from 2011 to 2024 across 34 MAPS stations. We specifically examined β-diversity, which refers to the variation in species composition between communities from a temporal perspective, focusing on how bird communities change over time and how both natural and anthropogenic disturbance may be influencing changes. Local species richness or alpha diversity (α-diversity), which is the diversity at an individual site, may not be a good indicator of habitat quality because some low-quality habitats can also have more species. β-diversity uses both presence–absence data and species relative abundances as indicators of habitat quality and changes happening in the surrounding habitat. Given the direct relationship between community composition, including breeders, and ecosystem health, the changes in community composition as measured by changes in β-diversity is a reliable measure of habitat quality as determined by changes in the surrounding environment.

Question 1: How do bird communities change in composition (β-diversity) over time and what is the relative importance of the underlying mechanisms driving the β-diversity over time?

We estimated total β-diversity (total dissimilarity) of bird communities across MAPS stations with at least five years of data. We compared strictly consecutive years (year t and t + 1) to quantify temporal changes in community composition. This approach avoids comparisons between non-adjacent years separated by different temporal gaps.

We used Sørensen and Jaccard dissimilarity, both are incidence-based (presence–absence) indices that evaluate compositional dissimilarity. The Sørensen index gives more weight to species shared among stations. The Jaccard index gives equal weight to shared and unique species. Where the two indices result in similar outcomes, we can have more confidence in the mechanisms of community change that are being identified.

We then assessed the relative contribution of two different mechanisms of β-diversity – species turnover, meaning species are being replaced, and nestedness indicating that species-poor communities are subsets of species-rich communities. The mechanism driving changes in bird communities in the AOSR was largely turnover (species replacement) and occurred at 32 of 34 MAPS stations. Nestedness was the mechanism driving changes in community composition at one station that was early successional at the start of monitoring, and an increase in the number of species over time corresponded with vegetation growth. At one other station, the results were unclear, and changes appeared to be driven equally by both turnover and nestedness.

This is an ecologically meaningful finding, as turnover implies that communities are not just losing or gaining species but undergoing reassembly. Our findings suggest that different years contribute distinct species to overall temporal diversity at our MAPS stations, creating dynamic bird assemblages. Land management strategies should therefore aim to guide turnover trajectories, requiring more flexible and adaptive approaches rather than plans based on single-year static assessments. From a spatial perspective, this mechanism of community change requires a regional approach that considers the species replacement between sites rather than species loss.

Question 2: What are the patterns of temporal dynamics in bird communities in the AOSR and do communities diverge, converge, or remain stable over time?

We used time lag analysis (TLA) to assess temporal dynamics in bird community composition. TLA compares dissimilarity at different time intervals (lags) rather than modeling continuous time. By analyzing fixed time lags (e.g., 1-year, 2-year, etc.), this method quantifies how and how fast dissimilarity accumulates over time and detects whether communities diverge, converge, or randomly fluctuate.

Significant positive TLA slopes indicate divergence, and species composition becomes increasingly different from its initial state as time progresses. Significant negative slopes indicate convergence, meaning the community is returning to a previous composition. Non-significant or near-zero slopes suggest either community stability or that species abundances fluctuate randomly without a clear temporal pattern. In this case, changes in species composition are short-term with no consistent trend over time.

Stations like SFEN, BMLN, HNGN, and HNGW have significant positive and steeper TLA slopes, indicating strong directional divergence in community composition through time. SFEN and BMLN were early successional reclaimed habitats at the start of monitoring, and species turnover can likely be attributed to the development of the shrub and forest vegetation over time. We have shown previously that the upper and mid-canopy forest exhibited positive correlations with habitat age at these stations (Foster et al. 2017). The forests at HNGN and HNGW were burned during the Horse River wildfire in 2016, and species turnover at these stations may be attributed to the removal of the forest canopy and the regeneration of the understory vegetation. The bird communities at these MAPS stations are becoming more dissimilar over time. In contrast, stations like MNDY and SNDY have slightly negative or near-zero slopes, suggesting either convergence or random fluctuations in species composition. The community composition is varying unpredictably from year to year without a clear directional trend. These two stations have not experienced any major habitat change since the start of monitoring.

At the station CRCL, directional change is occurring, but change is slow and stochastic variation between years is high. CRCL is an older reclaimed area adjacent to mature forest, and some disturbed vegetation is still undergoing successional change. A steeper slope and stronger signal of directional change was found at BISN, and this station was also a younger successional reclaimed habitat at the start of monitoring, and the habitat has changed with the vegetation growth over time.

Our results show consistent relationships between temporal changes in bird community composition and the cumulative human footprint at both 1 km and 5 km spatial scales. A significant positive correlation between TLA slope and footprint at the 5 km scale ($r = 0.375$, $P = 0.0289$), as well as a marginally significant correlation at the 1 km scale ($r = 0.334$, $P = 0.0536$), suggests that bird communities in landscapes with greater cumulative human footprint show higher divergence over time. In other words, the change in dissimilarity in community composition between years increases more consistently and substantially as time progresses in areas with more cumulative footprint.

Overall, the results show that bird communities at most MAPS stations undergo a clear directional change over time and mostly diverge, and each station appears to have its own magnitude of change, as indicated by varying TLA slopes. This suggests that station-specific environmental attributes may have substantial influence in determining temporal dynamics.

Question 3: How do individual species and specific time periods (years) contribute to the temporal dynamics (β-diversity) of bird communities in the Athabasca oil sands region?

We assessed the contribution of individual bird species to the total β-diversity at each site to understand the degree to which individual species drive variation in the community (SCBD, or species contribution to β-diversity). Species with higher SCBD values show greater variation in their abundances across years, thus contributing more substantially to temporal community turnover. These fluctuations can be species that appear and disappear across years or experience boom and bust cycles or are influenced by environmental filtering processes (e.g., effects of footprints or edge effects) that influence their numbers under certain environmental conditions. For each station, we identified the top 10 species with the highest SCBD values to determine which species contributed the most to the temporal beta diversity. There were six species that were common across most stations and frequently (appeared among the top 10 SCBD species 40% or more of the time) contributed to the high variation in community composition: Cedar Waxwing, Least Flycatcher, Lincoln’s Sparrow, Chipping Sparrow, Black-capped Chickadee, and Myrtle Warbler.

We also assessed year-specific variation at the site level to understand the uniqueness of the community in any given year (LCBD; local contribution to β-diversity) and how this may have contributed to changes over time. Higher LCBD values indicate years with more unique species relative to the average community structure at that station, while a lower LCBD value means that the community composition in that year was more similar to the average across all years. Each station appeared to exhibit unique LCBD patterns with varying high and low LCBD values across years. Common patterns across stations were difficult to discern, except for a signal related to the Horse River wildfire in 2016, which contributed to high community variation at burned stations in that year. Station-level conditions appear to contribute to the annual variation observed in the bird community composition. These factors will be examined as we begin to link our results to our habitat structure data and the specific disturbance types found at each station.

Question 4: How does wildfire influence the temporal changes in composition of boreal bird communities in the Athabasca oil sands region?

We used redundancy analysis (RDA) and distance-based redundancy analysis (dbRDA), both constrained ordination techniques that incorporate environmental variables to explore community dissimilarity. The RDA directly uses transformed abundance data from burned and unburned stations to perform the ordination, allowing for a direct comparison of species composition between treatments (e.g., fire status). In this method, the species are preserved, so we can show how species are affected in the ordination plot. The dbRDA is a derivative of RDA and first calculates a dissimilarity matrix (Bray–Curtis dissimilarity) based on abundance data, which is then used to perform the ordination. In both methods, dissimilarity is calculated between bird communities from consecutive years at the same station, separately for treatments (unburned/pre-fire and burned).

Overall, the species that were closely associated with unburned conditions were White-throated Sparrow, Yellow-bellied Sapsucker, Black-and-white Warbler, Hermit Thrush, Swainson's Thrush, Mourning Warbler, and Ovenbird. Species that were closely associated with post-fire conditions were Song Sparrow, Clay-colored Sparrow, Wilson's Warbler, Yellow Warbler, Common Yellowthroat, Red-eyed Vireo, Alder Flycatcher, Least Flycatcher, Lincoln's Sparrow, and Swamp Sparrow. Some of these species have been identified as experiencing population declines within our MAPS program, suggesting the importance of fire ecology in the conservation of these species that are more dependent on early successional habitats. The ordination results demonstrate that wildfire plays a significant role in shaping boreal bird community composition in the AOSR. Traditionally, bird community responses to post-fire conditions in the boreal forest have been attributed primarily to woodpeckers, but these results show that other species are associated with early seral habitats.

These findings are important as we begin to examine changes in species demographics and community composition in response to disturbance footprints within the BADR landscape units, as changes in some species may be attributed more to natural disturbance effects. As the data from the recently established, BADR-aligned MAPS stations become available for temporal analyses, we will be able to identify the mechanisms driving community change and quantify the contributions of various disturbances to those changes.

7.0 HABITAT STRUCTURE ASSESSMENT

Habitat structure assessments (HSAs) follow a standardized protocol (Nott et al. 2003) developed to support the MAPS banding program. HSAs have been completed at 5-year intervals since program inception, with the last assessments conducted in 2023. HSA data are used in analyses relating demographics (e.g., Foster et al. 2017) and community composition to habitat conditions and to evaluate landbird species and community-level responses to habitat disturbance. In addition, the characterization of disturbance, disturbance type (e.g., seismic, well pad, road) areal extent, age, and degree of habitat recovery is recorded, providing a ground-truthed dataset for use in understanding landbird responses to habitat disturbance. The next habitat structure assessments are scheduled for 2028.

8.0 LITERATURE CITED

Abadi F, Gimenez O, Ullrich B, Arlettaz R, Schaub M (2010) Estimation of immigration rate using integrated population models. Journal of Applied Ecology 47:393-400.

Alberta Biodiversity Monitoring Institute (2021) Terrestrial ABMI Autonomous Recording Unit (ARU) and Remote Camera Trap Protocols. https://ftp-public.abmi.ca/home/publications/documents/599_ABMI_2021_TerrestrialARUandRemoteCameraTrapProtocols_ABMI.pdf

Arciszewski TJ, Roberts DR, Munkittrick KR, Scrimgeour GJ (2021) Challenges and benefits of approaches used to integrate regional monitoring programs. Frontiers in Environmental Science Vol. 9 Article 666698.

Bayne EM, KA Hobson (2002) Apparent survival of male ovenbirds in fragmented and forested Boreal landscapes. Ecology 83:1307-1316.

Bayne E, Dennett J, Dooley J, Kohler M, Ball J, Bidwell M, Braid A, Chetelat J, Dillegeard E, Farr D, Fisher J, Freemark M, Foster K, Godwin C, Hebert C, Huggard D, McIssac D, Narwani T, Nielsen S, Pauli B, Prasad S, Roberts D, Slater S, Song S, Swanson S, Thomas P, Toms J, Twitchell C, White S, Wyatt F, Mundy L (2021) Oil Sands Monitoring Program: A Before-After Dose-Response Terrestrial Biological Monitoring Framework for the Oil Sands. (OSM Technical Report Series No. 7). https://open.alberta.ca/publications/9781460151341.

Brooks DR, Nocera JJ (2021) Using autonomous recording units and change-point analysis to determine reproductive activity in an aerial insectivore. Bioacoustics, DOI: 10.1080/09524622.2021.1921617.

Caswell H (2001) Matrix population models: construction, analysis, and interpretation. Sinauer Associates. Sunderland, Massachusetts, USA.

DeSante DF (1995) Suggestions for future directions for studies of marked migratory landbirds from the perspective of a practitioner in population management and conservation. Journal of Applied Statistics 22:949-965.

DeSante DF, O'Grady DR, Pyle P (1999) Measures of productivity and survival derived from standardized mist netting are consistent with observed population changes. Bird Study 46(suppl.): S178-188.

DeSante DF, Nott MP, O’Grady DR (2001) Identifying the proximate demographic cause(s) of population change by modeling spatial variation in productivity, survivorship, and population trends. Ardea 89 (special issue):185-207.

DeSante, DF, Saracco JF, Kaschube DR (2018) Population changes and their demographic drivers in landbirds of western North America: an assessment from the Monitoring Avian Productivity and Survivorship program. In: Shuford WD, Gill Jr. RE and Handel CM (Eds.) *Trends and Traditions: Avifaunal Change in Western North America. Studies of Western Birds 3*. Western Field Ornithologists, Camarillo, CA.

DeSante DF, Burton KM, Velez P, Froehlich D, Kaschube D, Albert S (2024) MAPS manual, 2024 protocol. The Institute for Bird Populations, Point Reyes Station, CA. 106 pp.

Dussourd N, Ritchison G (2003). Singing behaviour of male Yellow-breasted Chats: Repertoires, rates, reproductive success, and a comparison with other wood-warblers. The Wilson Bulletin, 115:52-57.

Flockhart DTT, Mitchell GW, Krikun RG, Bayne EM (2016) Factors driving territory size and breeding success in a threatened migratory songbird, the Canada Warbler. Avian Conservation and Ecology 11.

Foster KR, Godwin CM, Pyle P (2012) Monitoring avian productivity and survivorship in the oil sands region of northeastern Alberta. In: Fourie AB and Tibbett M (Eds.) *Mine Closure 2012, Proceedings of the Seventh International Conference on Mine Closure, Brisbane Australia.* Australian Centre for Geomechanics, Nedlands Australia. pp. 563-571.

Foster KR, Godwin CM, Pyle P, Saracco J (2017) Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada. Restoration Ecology 25:532-538.

Foster KR, Pyle P, Kaschube D, Godwin CM (2023) *Monitoring Avian Productivity and Survivorship in the Oil Sands Region of Northeastern Alberta – Boreal MAPS in the Oil Sands Region 2022*. A report to The Oil Sands Monitoring Program (Alberta Environment and Parks), Syncrude Canada Ltd., Hammerstone Infrastructure Materials Ltd., ConocoPhillips Canada Resources Corp., Cenovus Energy Inc., Suncor Energy Inc., Canadian Natural Resources Limited & CNOOC International. Fort McMurray AB.

Foster KR, Pyle P, Kaschube D, Godwin CM (2024) *Monitoring Avian Productivity and Survivorship in the Oil Sands Region of Northeastern Alberta – Boreal MAPS in the Oil Sands Region 2023*. A report to The Oil Sands Monitoring Program (Alberta Environment and Parks), Syncrude Canada Ltd., Hammerstone Infrastructure Materials Ltd., ConocoPhillips Canada Resources Corp., Cenovus Energy Inc., Suncor Energy Inc., Canadian Natural Resources Limited & CNOOC International. Fort McMurray AB.

Gibbs JP, Wenny DG (1993) Song output as a population estimator: effect of male pairing status. Journal of Field Ornithology, 64:316-322.

Gottlander K (1987) Variation in the song rate of the male pied flycatcher *Ficedula hypoleuca*; causes and consequences. Animal Behaviour, 35:1037-1043.

Government of Alberta (2020) Alberta wild species general status listing – 2020. https://www.alberta.ca/lookup/wild-species-status-search.aspx.

Government of Alberta (2024) Alberta species at risk strategies. https://www.alberta.ca/albertas-species-at-risk-strategies#jumplinks-1.

Government of Canada (2023) Birds protected by the *Migratory Birds Convention Act* and protected under SARA Schedule 1. https://species-registry.canada.ca/index-en.html -/migratory-birds.

Grames EM, Stepule PL, Herrick SZ, Ranelli BT, Elphick CS (2022) Separating acoustic signal into underlying behaviors with self-exciting point process models. Ecological Modelling, 468, 109965. https://doi.org/10.1016/j.ecolmodel.2022.109965.

Habib, L, Bayne EM, Boutin S (2007). Chronic industrial noise affects pairing success and age structure of ovenbirds *Seiurus aurocapilla*. Journal of Applied Ecology 44:176–184.

Hale R, Swearer SE (2016). Ecological traps: Current evidence and future directions. Proceedings of the Royal Society B: Biological Sciences, 283(1824), 20152647. https://doi.org/10.1098/rspb.2015.2647.

Hanski IK, Laurila A (1993) Variation in song rate during the breeding cycle of the chaffinch, *Fringilla coelebs*. Ethology, 93:161-169.

Hoi-Leitner M, Nechtelberger H, Hoi H (1995) Song rate as a signal for nest site quality in blackcaps (*Sylvia atricapilla*). Behavioral Ecology and Sociobiology, 37:399–405. https://doi.org/10.1007/bf00170587.

Hunt AR, Bayne EM, Haché S (2017) Forestry and conspecifics influence Canada Warbler (Car*dellina canadensis*) habitat use and reproductive activity in boreal Alberta, Canada. The Condor 119:832–847.

Huus J, Kelly K, Bayne EM, Knight EC (*in third review*) HawkEars: a regional, high-performance avian acoustic classifier. Submitted to Ecological Informatics.

IUCN Standards and Petitions Committee (2019) *Guidelines for Using the IUCN Red List Categories and Criteria*. Version 14. Prepared by the Standards and Petitions Committee. https://www.iucnredlist.org/resources/redlistguidelines.

Johnson MD (2007) Measuring habitat quality: a review. The Condor, 109:489–504. https://doi.org/10.1650/8347.1.

Kahl S, Wood CM, Eibl M, Klinck H. (2021) BirdNET: A deep learning solution for avian diversity monitoring. Ecological Informatics, 61, 101236. https://doi.org/10.1016/j.ecoinf.2021.101236.

Kaschube DR, Saracco JF, Ray C, Godwin CM, Foster KR, Pyle P (2022) Minimum MAPS capture-recapture rates and years of banding station operations to obtain reliable adult annual survival estimates. Journal of Field Ornithology 93:7. https://journal.afonet.org/vol93/iss1/art7/.

Knight E, Kelly K, Godwin C, Foster K, Bayne E, Roberts D (2025) Song Rates from ARU Recordings and Correlation with MAPS Breeding Status. A report submitted to the Oil Sands Monitoring Program, March 2025.

Leston L, Bayne E, Toms JD, Mahon CL, Crosby A, Sólymos P, Ball J, Song S, Schmiegelow FKA, Stralberg D, Docherty TDS (2023) Comparing alternative methods of modelling cumulative effects of oil and gas footprint on boreal bird abundance. Landscape Ecology 38:147-168.

Liu WC, Kroodsma DE (2007) Dawn and daytime singing behavior of chipping sparrows (*Spizella passerine*) The Auk, 124:44-52.

Nott MP, DeSante DF, Michel N (2003) *Monitoring avian productivity and survivorship (MAPS) habitat structure assessment protocol*. The Institute for Bird Populations, Point Reyes Station, CA. 48 pp. https://birdpop.org/docs/misc/MAPS-Materials-Complete-HSA-Manual-Through-Appendix-3.pdf.

Pyle P, Foster KR, Godwin CM, Kaschube DR, Saracco JF (2020) Correlations of landbird yearling proportion with demographic variables and habitat quality using a multi-species approach. PeerJ 8:e8898. https://doi.org/10.7717/peerj.8898.

Rhinehart TA, Chronister LM, Devlin T, Kitzes J (2020) Acoustic localization of terrestrial wildlife: Current practices and future opportunities. Ecology and Evolution, 10:6794-6818. https://doi.org/10.1002/ece3.6216.

Robbins MB, Nyari AS, Papers M, Benz BW (2009) Song rates, mating status, and territory size of Cerulean warblers in Missouri Ozark riparian forest. The Wilson Journal of Ornithology, 121:283-289.

Rosenfeld JS, Hatfield T (2006) Information needs for assessing critical habitat of freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences, 63: 683–698. https://doi.org/10.1139/f05-242.

Rota CT, Dorazio RM, Betts MG (2009) Occupancy estimation and the closure assumption. Journal of Applied Ecology, 46:1173-1181. https://doi.org/10.1111/j.1365-2664.2009.01734.x.

Roy C, Michel NL, Handel CM, Van Wilgenburg SL, Burkhalter JC, Gurney KEB, Messmer DJ, Princé K, Rushing CS, Saracco JF, Schuster R, Smith AC, Smith PA, Sólymos P, Venier LA, Zuckerberg B (2019) Monitoring boreal avian populations: how can we estimate trends and trajectories from noisy data? Avian Conservation and Ecology 14:8. https://doi.org/10.5751/ACE-01397-140208.

Saracco JF, DeSante DF, Kaschube DR (2008) Assessing landbird monitoring programs and demographic causes of population trends. Journal of Wildlife Management 72:1665-1673.

Saracco JF, Royle JA, DeSante DF, Gardner BA (2010) Modeling spatial variation in avian survival and residency probabilities. Ecology 91: 1885-1891.

Saracco, JF, Royle JA, DeSante DF, Gardner B (2012) Spatial modeling of survival and residency and application to the Monitoring Avian Productivity and Survivorship program. Journal of Ornithology 152:S469–S476.

Saracco JF, Rubenstein M (2020) Integrating broad-scale data to assess demographic and climatic contributions to population change in a declining songbird. Ecology and Evolution, 4:1804–1816. https://doi.org/10.1002/ece3.5975.

Saracco JF, Pyle P, Kaschube DR, Kohler M, Godwin CM, Foster, KR (2022) Demographic declines over time and variable responses of breeding bird populations to human footprint in the Athabasca Oil Sands Region, Alberta, Canada. Ornithological Applications 125:duac037. https://doi.org/10.1093/ornithapp/duac037.

Schaub M, Fletcher D (2015) Estimating immigration using a Bayesian integrated population model: choice of parametrization and priors. Environmental and Ecological Statistics 22:535-549.

Schieck J, Song SJ (2011) Changes in bird communities throughout succession following fire and harvest in boreal forests of western North America: Literature review and meta-analyses. Canadian Journal of Forest Research 36:1299-1318.

Sillett TS, Holmes RT (2002) Variation in survivorship of a migratory songbird throughout its annual cycle. Journal of Animal Ecology 71:296-308.

Solymos P, Becker M, Bayne E (2019) OSM Synthesis: Ovenbird. 47pp.

Staicer CA, Ingalls V, Sherry TW (2006) Singing behavior varies with breeding status of American redstarts (*Setophaga ruticilla*). The Wilson Journal of Ornithology, 118:439-451. doi.org/10.1676/05-056.1.

Travis JMJ, Dytham C (1999) Habitat persistence, habitat availability and the evolution of dispersal. Proceedings of the Royal Society of London. Series B: Biological Sciences 266:723-728.

Upham-Mills EJ, Reimer JR, Haché S, Lele SR, Bayne EM (2020) Can singing rate be used to predict male breeding status of forest songbirds? A comparison of three calibration models. Ecosphere, 11:e03005. 10.1002/ecs2.3005.

Upham-Mills EJ, Crosby AD, Reimer JR, Haché S, Stehelin T, Bayne EM (*in press*) Accurate prediction of olive-sided flycatcher breeding status using song rate measured with autonomous recording units. Submitted to Journal of Wildlife Management.

Wilson S, Saracco JF, Krikun R, Flockhart DTT, Godwin CM, Foster KR (2018) Drivers of demographic decline across the annual cycle of a threatened migratory bird. Scientific Reports 8:7316.

Wright JM (1997) Preliminary study of olive-sided flycatchers, July 1994–April 1997. Alaska Department of Fish and Game. Final research report. Endangered species conservation fund federal aid studies SE-3-3, 4 and 5. Juneau, Alaska. 34 pp.

Zanette L (2001) Indicators of habitat quality and the reproductive output of a forest songbird in small and large fragments. Journal of Avian Biology, 32:38–46. https://doi.org/10.1034/j.1600-048x.2001.320106.x.

Appendix A

Glossary of Terms

GLOSSARY

Adult Population Size	Standardized index, based on the number of individual adult birds captured per 600 net-hours, useful for comparisons (see 600 net-hours, below). An adult bird is defined as one of at least one year of age (AHY, SY, or ASY; see below). The index is more precise for species with a minimum of 2.5 adult birds captured per 600 net-hours per year, defining target species for which vital-rate indices can be calculated and statistical analyses can be conducted.
After Hatching Year (AHY)	The age assigned to a bird hatched in a previous calendar year. An adult bird that is at least one year old in summer is considered an AHY. See also ASY and SY.
After Second Year (ASY)	The age assigned to an adult bird hatched before the previous calendar year. An ASY bird is at least two years old. The ASY age category is a subset of the AHY age category.
ARU	Autonomous (or automated) recording unit
BADR	The hierarchical Before–After Dose–Response monitoring program design developed by the OSM program's TBM theme. The BADR design accounts for broad regional gradients and developmental pressures, including climactic, terrain, and industrial development (e.g., oil sands mining, *in situ*).
Banding Period	The breeding season is divided into ten 10-day periods: (1) May 1 to 10, (2) May 11 to 20, (3) May 21 to 30, (4) May 31 to June 9, (5) June 10 to 19, (6) June 20 to 29, (7), June 30 to July 9, (8) July 10 to 19, (9) July 20 to 29, and (10) July 30 to August 8. The initial MAPS banding period depends on latitude and is Period 5 in the boreal region.
Bayesian Modeling	Bayesian modeling is an approach where available knowledge about parameters in a statistical model is updated with the information in observed data. The background knowledge is expressed as a prior distribution and combined with observational data in the form of a likelihood function to determine the posterior distribution (analysis outcome).
Breeding-Status List	A complete list of the species observed at each station during the current breeding season along with an assessment of their breeding status from all years of operation of the station. Observations of nesting behaviour or territorial singing indicate species breeding in the habitats at the station, as do birds captured in reproductive condition; absence of these factors indicates species that are considered transient through the habitats.
Cormack–Jolly–Seber (CJS)	Modified Cormack–Jolly–Seber capture-mark-recapture models are used to obtain estimates of apparent adult survival, recruitment, and population growth rate. Meaningful mark-recapture models can be parameterized after a minimum of four consecutive years of data collection; however, more precise and biologically meaningful vital rate estimates require a minimum of six continuous years of station operation.
Demography	The structure of a population, based on the suite of vital (demographic) rates that interact to increase, decrease, or confer stability to a population.

GLOSSARY (cont'd)

First-Year Survival	The survival of birds from hatching until their first breeding attempt as yearlings. First-year survival is invariably much lower than adult survival due to lack of experience leading to increased mortality of first-year birds.
Hatch Year (HY)	The age assigned to a bird hatched in the current calendar year. A young bird that fledged during the summer of banding is considered an HY.
Integrated Population Model (IPM)	A mathematical model that integrates data from different but related monitoring programs to assess and predict population trends and estimate demographic parameters that cannot be derived using one dataset alone.
JEM Site	Joint environmental monitoring sites are locations within BADR-defined disturbance regimes where co-location of monitoring programs is intended.
Lambda	The population growth rate. A lambda estimate greater than 1.000 represents a growing population, while an estimate below 1.000 represents a declining population, providing that the standard error of the estimate does not include 1.000.
Landbird	Bird species including passerines and those of several other terrestrial non-passerine avian families. Target landbird species in the Boreal MAPS program include passerines and woodpeckers.
MAPS	Monitoring Avian Productivity and Survivorship, a continent-wide bird banding program that monitors breeding landbird populations. Constant-effort capture data and capture-recapture data from MAPS stations provide demographic information and indices or estimates of population vital rates.
Net-Hour	One net-hour is equal to one 12 m long, 2.6 m tall mist-net operated (open) for one hour. Number of net-hours is used as a measure of effort at MAPS stations.
600 Net-Hours	A standardized measure of effort used in the MAPS program to compare and analyze values among species, habitats, stations, regions, and other parameters. 600 net-hours approximates one day of banding during typical operation at most stations.
OSM	Oil Sands Monitoring Program (Alberta Environment and Protected Areas). OSM includes the Boreal MAPS program, which was initiated in 2011 and has operated every year through 2024, as reported on here.
Point Count	A standardized method for detecting landbirds by recording the number of birds identified visually or by vocalization from a single location and within a given time period and distance (for the Boreal MAPS program, within 10 minutes and unlimited radius).
Precision	The precision of a vital rate estimate derived using statistical models, expressed as the coefficient of variation (CV). A precise vital rate estimate is defined as having a CV <20%, while a CV between 20% and 30% is defined as being moderately precise. Six continuous years of station operation are usually required to obtain suitable precision of vital rate estimates for target species.

GLOSSARY (cont'd)

Productivity Index	A measure of reproductive success, the ratio of individual hatch-year (HY) birds to after hatch-year (AHY) birds captured during a given amount of effort. The index is usually meaningful for species with a minimum of 2.5 adult birds captured per 600 net-hours per year (see Adult Population Size).
Proportion of Residents	Proportion of residents excludes transient adults (dispersing and floater individuals that are only captured once in a season that are assumed not to be part of the breeding population).
Recruitment	An estimate of recruitment into the adult population is obtained from the number of young (HY) that survive and reproduce, as determined by the capture rate of second-year (SY) birds or through mark-recapture analyses. Recruitment may also include older birds that immigrate into the study area.
Regression Analysis	Regression is a statistical method used to determine the strength and character of the relationship between a dependent variable and one or more independent variables.
Second Year (SY)	The age assigned to a yearling adult bird that was hatched in the previous calendar year and is thus one year old. The SY age category is a subset of the AHY age category.
Species of Concern	Includes species listed in Alberta as Sensitive, At Risk, or May be at Risk (Government of Alberta 2020) and as Special Concern, Threatened, or Endangered in Schedule 1 of the *Species at Risk Act* (Government of Canada 2023).
Survivorship (Apparent Survival)	Survivorship is the probability of an adult bird surviving to the following year, estimated using modified Cormack–Jolly–Seber models. Apparent survival, derived from banding data, is the probability that a bird both survives and returns to the breeding grounds (i.e., does not emigrate from the population).
TBM	Terrestrial Biological Monitoring theme, one of several monitoring initiatives within the OSM Program. This initiative was developed to quantify the effects on landbird populations resulting from terrestrial disturbance in the Athabasca Oil Sands Region (AOSR).
Transient	Adult birds that are not on a breeding territory, including birds undergoing migration and failed or post-breeding birds dispersing from breeding territories to moulting or pre-migration staging areas. Transient individuals are not included in analyses of vital rates.
Vital Rates	The primary demographic parameters for a population, including productivity, first-year and adult survivorship, yearling proportion, and recruitment. Estimating vital rates is critical for understanding causes of population change.
Yearling	A one-year-old bird, or SY, in our dataset. Yearling birds are capable of breeding, although those that do typically suffer lower reproductive success due to inexperience and/or exclusion from optimal habitats by older birds (ASYs).

GLOSSARY (cont'd)

Yearling Proportion	The proportion of all breeding birds that are yearlings (one-year-old birds). Yearling proportion can be used as a measure of habitat quality for a given target species, because yearlings tend to be excluded from optimal habitats by older birds; this is generally referred to as despotic exclusion.

Appendix B

Boreal MAPS Stations (2011–2024)

Table B1: Boreal MAPS Stations

Station Code	Station Name	Latitude (N)	Longitude (W)	Elevation (m asl)	Years Operated	BADR Design	
						Habitat	**Disturbance Category**
Landscape Unit 1 – *In Situ*							
AWER	Air Weapons East Road	54° 45’ 19”	110° 26’ 30”	663	2023–2024	Deciduous/Mixedwood	Reference
DDRV	Dead River	54° 39’ 20”	110° 11’ 20”	586	2023–2024	Deciduous/Mixedwood	Fragmented
MHKN	Mahihkan	54° 39’ 53”	110° 30’ 15”	613	2023–2024	Deciduous/Mixedwood	High
MNRD	Mahihkan North Road	54° 42’ 19”	110° 30’ 36”	630	2023–2024	Deciduous/Mixedwood	Fragmented
NBYE	Nabiye	54° 43’ 19”	110° 21’ 08”	625	2023–2024	Deciduous/Mixedwood	High
WLFL	Wolf Lake	54° 43’ 18”	110° 45’ 13”	643	2023–2024	Deciduous/Mixedwood	Reference
Landscape Unit 2 – Reference							
HLKR	Heart Lake Road	54° 59’ 26”	111° 37’ 16”	652	2022–2024	Deciduous/Mixedwood	Fragmented
KRFL	K-Road Francis Lake	54° 57’ 18”	111° 38’ 14”	608	2022–2024	Deciduous/Mixedwood	Reference
KRGY	K-Road Gully	54° 58’ 03”	111° 38’ 31”	616	2022	Deciduous/Mixedwood	Fragmented
KRHC	K-Road Hidden Creek	54° 58’ 35”	111° 39’ 14”	648	2022–2024	Deciduous/Mixedwood	Reference
MTEN	Mile 10	54° 51’ 10”	111° 36’ 20”	625	2023–2024	Deciduous/Mixedwood	Reference
TWBD	Touchwood Beaver Dam	54° 50’ 46”	111° 40’ 29”	641	2023–2024	Deciduous/Mixedwood	Fragmented
TWWP	Touchwood Well Pad	54° 51’ 13”	111° 37’ 46”	622	2023–2024	Deciduous/Mixedwood	Fragmented
Landscape Unit 3 – *In Situ*							
HAYL	Hay Lake	55° 29’ 05”	110° 48’ 39”	625	2022–2024	Deciduous/Mixedwood	Reference
KIWI	Kirby/Winifred Intersection	55° 26’ 06”	110° 47’ 01”	673	2021–2024	Deciduous/Mixedwood	Fragmented
MNDD	Monday Creek Downstream	53° 35' 09"	110° 53' 22"	600	2021	Treed Lowland	High
MNDM	Monday Creek Midstream	55° 30' 55"	110° 54' 45"	635	2021–2024	Deciduous/Mixedwood	Fragmented
MNDY	Monday Creek	55° 32' 08"	110° 53' 19"	598	2012–2019	Treed Lowland	High
OWLC	Owl Moon Creek	55° 32’ 57”	110° 49’ 50”	601	2021–2024	Deciduous/Mixedwood	High
SNDY	Sunday Creek	55° 34' 15"	110° 54' 11"	570	2012–2019, 2021–2024	Deciduous/Mixedwood	High
WLNE	Wiau Lake Northeast	55° 25' 00"	111° 12' 29"	691	2021–2024	Deciduous/Mixedwood	Reference

Table B1: Boreal MAPS Stations (continued)

Landscape Unit 8 – Mining							
CNRD	Canadian Natural Road	57° 11’ 01”	111° 40’ 53”	304	2022–2024	Deciduous/Mixedwood	Fragmented
CRBG	Creeburn Bog	57° 14’ 59"	111° 35’ 38"	283	2021	Treed Lowland	High
CREB	Creeburn Archaeological Area	57° 14' 50"	111° 35' 43"	282	2012–2019	Deciduous/Mixedwood	High
ELBN	Ells River Bend North	57° 14' 54"	111° 44' 05"	286	2012–2019, 2021–2024	Deciduous/Mixedwood	High
ELBS	Ells River Bend South	57° 14' 24"	111° 44' 05"	290	2012–2019, 2021–2024	Deciduous/Mixedwood	High
HBVR	Horizon Beaver Pond	57° 22' 56"	111° 53' 05"	350	2012–2016	Deciduous/Mixedwood	High
HFSH	Horizon Fish Compensation Lake	57° 23' 34"	111° 58' 57"	419	2012–2016	Reclaimed[1]	Fragmented
HRAW	Horizon Reclamation Area West	57° 20’ 54”	111° 49’ 28”	322	2015–2016	Reclaimed[1]	n/a
MAKR	MacKay River	57° 12' 33"	111° 41' 30"	258	2012–2024	Deciduous/Mixedwood	Reference
OXER	Oxbows on the Ells River	57° 15’ 41”	111° 43’ 44”	302	2022–2024	Deciduous/Mixedwood	Fragmented
RIDG	Ridgeline	57° 09' 05"	111° 39' 09"	286	2021–2024	Deciduous/Mixedwood	Reference
Landscape Unit 13 – Mining							
BPND	Beaver Pond	57° 10' 08"	111° 32' 08"	298	2011–2024	Deciduous/Mixedwood	Fragmented
CSTU	Cousteau Pond	57° 10’ 08”	111° 02’ 16”	522	2013–2019	Treed Lowland	Fragmented
KERL	Kearl Lake	57° 18’ 04”	111° 13’ 02”	331	2013–2016	Deciduous/Mixedwood	Reference
MURE	Muskeg River East	57° 10’ 47”	111° 34’ 48”	273	2022–2024	Deciduous/Mixedwood	Reference
MUSL	Muskeg Lake	57° 18’ 45”	111° 12’ 42”	332	2013–2015	Deciduous/Mixedwood	High
MUSR	Muskeg River	57° 10' 52"	111° 35' 02"	272	2011–2021	Deciduous/Mixedwood	Reference
NBRG	Enbridge	57° 11’ 06”	111° 07’ 19”	440	2022–2024	Deciduous/Mixedwood	High
ODYS	Odysseus Pond	57° 11’ 50”	111° 02’ 46”	512	2013–2019	Treed Lowland	Fragmented
RUSL	Rusty Lake	57° 09’ 19”	111° 03’ 45”	513	2013–2019	Treed Lowland	Fragmented
VWET	V-Shaped Wetland	57° 11' 51"	111° 31' 50"	281	2011–2024	Deciduous/Mixedwood	Fragmented
WBMR	West Bank of Muskeg River	57° 09’ 12”	111° 34’ 30”	266	2022–2024	Deciduous/Mixedwood	Reference
WFRD	Will's Ford	57° 11’ 23”	111° 34’ 14”	278	2022–2024	Deciduous/Mixedwood	High

Table B1: Boreal MAPS Stations (continued)

Landscape Unit 16 – Mining & In Situ							
HNDY	Henday	57° 16’ 39”	111° 07’ 21”	397	2023–2024	Deciduous/Mixedwood	Reference
OCMP	Old Camp	57° 17’ 44”	111° 06’ 10”	392	2023–2024	Deciduous/Mixedwood	Fragmented
WPCK	Wapasu Creek	57° 15’ 26”	111° 02’ 29”	488	2013–2015, 2017–2019	Treed Lowland	Fragmented
SNRS	Sunrise	57° 13’ 51”	111° 06’ 26”	461	2024	Deciduous/Mixedwood	High
WAPX[2]	Wapasu Exit 2	57° 17’ 29”	111° 07’ 72”		2024	Deciduous/Mixedwood	Reference
WCBR	Wapasu Creek Bridge	57° 20’ 32”	111° 10’ 04”	324	2023–2024	Deciduous/Mixedwood	Fragmented
WCKD	Wapasu Creek Deciduous	57° 15’ 48”	111° 03’ 27”	475	2024	Deciduous/Mixedwood	High
WPEX[2]	Wapasu Exit	57° 17’ 49”	111° 08’ 01”	346	2023	Deciduous/Mixedwood	Reference
Data Continuity[3]							
HNGN[4]	Hangingstone North	56° 42' 08"	111° 22' 14"	258	2012, 2014–2024	Deciduous/Mixedwood	n/a
HNGW[4]	Hangingstone West	56° 41’ 50”	111° 23’ 53”	267	2013–2015, 2017–2024	Deciduous/Mixedwood	n/a
POPC	Poplar Creek	56° 54' 58"	111° 27' 28"	240	2012–2024	Deciduous/Mixedwood	n/a
PRES[4]	Poplar Creek Reservoir	56° 55' 26"	111° 30' 11"	310	2012–2024	Deciduous/Mixedwood	n/a
Outside of Boreal MAPS Landscape Units							
BCDS	Beaver Creek Diversion System	56° 58' 51"	111° 37' 07"	306	2011–2019	Deciduous/Mixedwood	n/a
BRCH[4]	Birch Lake	56° 23' 54"	110° 55' 19"	482	2014, 2017–2019	Deciduous/Mixedwood	n/a
CRLK	Crane Lake	56° 59' 24"	111° 32' 40"	324	2012–2019	Deciduous/Mixedwood	n/a
CRSL	Christina Lake	55° 36' 59"	111° 02' 27"	560	2012–2019	Deciduous/Mixedwood	n/a
ENGS	Engstrom Lake	56° 12' 03"	110° 53' 33"	559	2012–2019	Deciduous/Mixedwood	n/a
GRGR[4]	Gregoire River	56° 23' 22"	111° 02' 22"	486	2014–2020	Treed Lowland	n/a
HNGS	Hangingstone River South	56° 25' 10"	111° 22' 31"	498	2012–2019	Deciduous/Mixedwood	n/a
HSHO	Horseshoe Lake	57° 02’ 01”	111° 31’ 07”	236	2013–2019	Deciduous/Mixedwood	n/a
SNDR	Sand River	55° 23' 25"	110° 44' 37"	623	2012–2019	Deciduous/Mixedwood	n/a
THEY	The Y	56° 11' 23"	110° 58' 21"	666	2012–2019	Deciduous/Mixedwood	n/a

Notes:

[1] Stations in reclaimed habitats were a component of the Boreal MAPS program design, 2011–2019.

[2] In spring 2024, beaver activity at WAPX resulted in the complete flooding of the station. The WAPX station was established nearby and operated through the 2024 monitoring season.

[3] Data continuity stations are long-term legacy MAPS stations providing data that preserve the ongoing period of record sufficient to continue to derive vital rates and population trends through the period of transition into alignment with the BADR design.

[4] Affected by the Horse River Wildfire in 2016.

Appendix C

Boreal MAPS Monitoring Methods

C1.0 Bird Capture and Banding

MAPS stations were operated in accordance with standardized protocols (DeSante et al. 2023). At the latitudes of the boreal forest, station operation occurs over six 10-day periods beginning with MAPS Period 5 (June 10 to 19) and concluding with Period 10 (July 30 to August 8). On each typical day of operation, 8 to 14 mist-nets (12 m long, 2.6 m tall, 30 mm mesh, 4-tier nylon) were opened and continually monitored for six hours beginning at local sunrise. Operations avoided periods of inclement weather (e.g., rain, high wind), and nets were closed when conditions deteriorated during operation to the point of compromising bird safety. Operations occurred at each station once within each 10-day period, for a total of six days of operation per station per year. A biologist holding a Canadian Wildlife Service-issued bird banding permit led each crew, and all crew members were named in the Alberta Environment and Protected Areas general permit. The number and timing of net-hours on each day of operation were recorded in a standardized form, and population metrics calculated from MAPS data were normalized for effort.

For the great majority of captures, a uniquely numbered aluminum leg band, issued by the Canadian Wildlife Service, was applied to the bird's right leg. In rare instances, birds escaped prior to banding or the bird was released immediately near the net lane when capture appeared to compromise bird safety; such unbanded captures were recorded in the data. During periods of high capture, birds were banded and minimally processed to reduce or eliminate risks to bird health. Otherwise, on each fully processed banded bird, the following data were obtained:

- capture code (newly banded, recaptured, unbanded);
- band number;
- species;
- age and how aged (photographs taken for later confirmation if required);
- sex (if possible) and how sexed (if applicable);
- extent of skull pneumatization (if required to determine age);
- breeding condition of adults (i.e., extent of cloacal protuberance or brood patch);
- extent of juvenal plumage in young birds;
- extent of body and flight-feather moult;
- extent of primary feather wear;
- presence of moult limits and plumage characteristics;
- wing chord length;
- fat class and body mass;
- date and time of capture;
- station and net where captured;
- evidence of injury and/or disease; and
- other pertinent observations.

Age classes were assigned as HY (hatch year; a bird hatched during the year of capture) or AHY (after hatch year or adult; a bird hatched before the year of capture). To the extent possible, AHY-aged birds were separated into SY (second year; a yearling, one-year-old bird hatched the year prior to capture) or ASY (after second year; a bird hatched at least two years prior to capture). Age determination of AHY birds to SY and ASY can be difficult for some species, especially under challenging field conditions and during busy days. Time permitting, photographs of wing, tail, and body were taken of each AHY bird as well as individuals that were difficult to identify or sex. These photographs were later reviewed in detail to verify identification, age, and sex, and many birds were reclassified from AHY to either SY or ASY. Woodpeckers and raptors could also be aged to TY (third year) or ATY (after third year) due to less extensive moults and/or slower plumage maturation (Pyle et al. 2020). Criteria for aging (to HY, AHY, SY, ASY, or older) and sexing followed those presented by Pyle (1997, 2008).

The subtle characteristics among feathers of different ages and generations in flycatcher species makes aging of these species challenging. Based on analyses of photographs of captured flycatchers at our MAPS stations, we were able to characterize differences in moult patterns in Alder, Least, and Yellow-bellied flycatchers (Carnes et al. 2021; see also Pyle and Carnes 2022), improving our ability to properly age individuals of these species.

C2.0 Breeding Status Observations

From arrival to departure from a MAPS station, each bird seen, heard, or captured was identified to species, and its behavior was characterized according to the breeding status procedures in the MAPS protocol (DeSante et al. 2023). Nesting, feeding of young, territorial song, and display distractions indicate breeding in the station habitat, and any one of these behaviors was used to categorize a species as being a breeder within the area sampled by the mist-nets during that year. Species observed but not exhibiting these breeding behaviors were categorized as being either transients or migrants through the MAPS station habitats. Based on these observations and characterizations, each species was classified as a breeder, likely breeder, transient, or migrant at the station in the current year. These observations were then integrated across all years of station operation as follows:

- B = breeder, breeding in all years of station operation;
- U = usual breeder, breeding in 51% to 99% of years of station operation;
- O = occasional breeder, breeding in 1% to 50% of years of station operation;
- T = transient, no evidence of breeding at stations but breeds in general area; and
- M = migrant, observed in or over station habitats but does not breed in the general area.

C3.0 Point Count Observations

Prior to net opening on each day of banding, an unlimited-distance 10-minute point count (Ralph et al. 1993; Alberta Environment and Parks 2013) was conducted from a fixed location at each station. Each individual bird detected by sight and/or vocalizations within the station habitats was recorded. Birds flying over without entering station habitats were excluded.

C4.0 Habitat Structure Assessment

Habitat structure assessment (HSA) data describe the lateral and vertical structure of the habitat, allowing for a quantitative comparison of habitats among MAPS stations. HSAs follow the procedure established by Nott et al. (2003) and are typically conducted within a year or two of station establishment and are repeated every five years, more frequently if a substantial habitat change occurs (e.g., flooding, fire). HSAs have been completed in 2011–2013, 2018, and in 2023, with the next assessments scheduled for 2028.

C5.0 Data Verification

Computer entry, data proofing, and verification of banding and breeding status data were completed using specially designed data entry, verification, and editing programs, including:

- programs to check the validity of all codes and numerical data;
- comparisons of station, date, and net fields from the banding data with those from the effort and breeding status data;
- cross-checking age and sex codes with skull, plumage, moult, and other criteria to assess accuracy of these determinations;
- screening for incorrect, unusual, or duplicate band numbers;
- screening of banding and recapture data from all years of operation for inconsistent species, age, or sex determinations for each band number; and
- examination of photographs to confirm species, age, and/or sex classifications.

Any discrepancies or anomalous data identified by any of these programs were examined manually and corrected as necessary. Banding data have been submitted to the Canadian Wildlife Service's Bird Banding Office and to Alberta Environment and Protected Areas (per our bird-banding permit conditions), and these data are available upon request from these agencies.

C6.0 Literature Cited

Alberta Environment and Parks (2013) *Sensitive Species Inventory Guidelines*. https://open.alberta.ca/publications/sensitive-species-inventory-guidelines.

Carnes BH, Godwin CM, Foster KR, Pyle P (2021) Clarification of molt strategies in three Empidonax flycatchers. The Wilson Journal of Ornithology 133:34-42.

DeSante DF, Burton KM, Velez P, Froehlich D, Kaschube D, Albert S (2023) MAPS manual, 2023 protocol. The Institute for Bird Populations, Point Reyes Station, CA. 104 pp.

Nott MP, DeSante DF, Michel N (2003) *Monitoring avian productivity and survivorship (MAPS) habitat structure assessment protocol*. The Institute for Bird Populations, Point Reyes Station, CA. 48 pp. https://birdpop.org/docs/misc/MAPS-Materials-Complete-HSA-Manual-Through-Appendix-3.pdf.

Pyle, P (1997) Identification Guide to North American Birds, Part 1. Slate Creek Press, Bolinas, California.

Pyle, P (2008) Identification Guide to North American Birds. Part 2. Slate Creek Press, Point Reyes Station, CA.

Pyle, P, Carnes B (2022) Molt strategies by age and subspecies in the Willow Flycatcher. Western Birds 53:216-231.

Pyle P, Foster KR, Godwin CM, Kaschube DR, Saracco JF (2020) Correlations of landbird yearling proportion with demographic variables and habitat quality using a multi-species approach. PeerJ 8:e8898 https://doi.org/10.7717/peerj.8898.

Ralph CJ, Geupel GR, Pyle P, Martin TE, DeSante DF (1993) Handbook for Field Methods for Monitoring Landbirds. U.S. Department of Agriculture General Technical Report PSW-GTR-144, Albany, CA.

Appendix D

Species Encountered in the Boreal MAPS Program

Yellow shading indicates species listed as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020).

Pink shading indicates species listed as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020) and as Threatened or of Special Concern (Government of Canada 2023).

Orange shading indicates species listed as Threatened or of Special Concern (Government of Canada 2023).

Blue shading indicates species considered to be Alien in Alberta (Government of Alberta 2020).

Table D1: Species Codes, Common Names, and Scientific Names[1] of Birds Captured or Detected in the Boreal MAPS Program (2011 to 2024)

Species Code	Common Name	Scientific Name
SNGO	Snow Goose	*Anser caerulescens*
GWFG	Greater White-fronted Goose	*Anser albifrons*
CACG	Cackling Goose	*Branta hutchinsii*
CANG	Canada Goose	*Branta canadensis*
TRUS	Trumpeter Swan	*Cygnus buccinator*
BWTE	Blue-winged Teal	*Spatula discors*
NSHO	Northern Shoveler	*Spatula clypeata*
GADW	Gadwall	*Mareca strepera*
AMWI	American Wigeon	*Mareca americana*
MALL	Mallard	*Anas platyrhynchos*
NOPI	Northern Pintail	*Anas acuta*
GWTE	Green-winged Teal	*Anas crecca*
CANV	Canvasback	*Aythya valisineria*
REDH	Redhead	*Aythya americana*
RNDU	Ring-necked Duck	*Aythya collaris*
GRSC	Greater Scaup	*Aythya marila*
LESC	Lesser Scaup	*Aythya affinis*
BUFF	Bufflehead	*Bucephala albeola*
COGO	Common Goldeneye	*Bucephala clangula*
HOME	Hooded Merganser	*Lophodytes cucullatus*
COME	Common Merganser	*Mergus merganser*
RBME	Red-breasted Merganser	*Mergus serrator*
RUDU	Ruddy Duck	*Oxyura jamaicensis*
RUGR	Ruffed Grouse	*Bonasa umbellus*
SPGR	Spruce Grouse	*Falcipennis canadensis*
STGR	Sharp-tailed Grouse	*Tympanuchus phasianellus*
PBGR	Pied-billed Grebe	*Podilymbus podiceps*
HOGR	Horned Grebe	*Podiceps auritus*
RNGR	Red-necked Grebe	*Podiceps grisegena*
EAGR	Eared Grebe	*Podiceps nigricollis*
MODO	Mourning Dove	*Zenaida macroura*
CONI	Common Nighthawk	*Chordeiles minor*
VIRA	Virginia Rail	*Rallus limicola*
RTHU	Ruby-throated Hummingbird	*Archilochus colubris*
SORA	Sora	*Porzana carolina*
AMCO	American Coot	*Fulica americana*
YERA	Yellow Rail	*Coturnicops noveboracensis*
SACR	Sandhill Crane	*Antigone canadensis*
AMAV	American Avocet	*Recurvirostra americana*
KILL	Killdeer	*Charadrius vociferus*
SEPL	Semipalmated Plover	*Charadrius semipalmatus*
MAGO	Marbled Godwit	*Limosa fedoa*
LESA	Least Sandpiper	*Calidris minutilla*
PESA	Pectoral Sandpiper	*Calidris melanotos*
SBDO	Short-billed Dowitcher	*Limnodromus griseus*
LBDO	Long-billed Dowitcher	*Limnodromus scolopaceus*
WISN	Wilson's Snipe	*Gallinago delicata*

Species Code	Common Name	Scientific Name
SPSA	Spotted Sandpiper	*Actitis macularius*
SOSA	Solitary Sandpiper	*Tringa solitaria*
LEYE	Lesser Yellowlegs	*Tringa flavipes*
GRYE	Greater Yellowlegs	*Tringa melanoleuca*
BOGU	Bonaparte's Gull	*Chroicocephalus philadelphia*
FRGU	Franklin's Gull	*Leucophaeus pipixcan*
RBGU	Ring-billed Gull	*Larus delawarensis*
CAGU	California Gull	*Larus californicus*
HERG	Herring Gull	*Larus argentatus*
CATE	Caspian Tern	*Hydroprogne caspia*
BLTE	Black Tern	*Chlidonias niger*
COTE	Common Tern	*Sterna hirundo*
COLO	Common Loon	*Gavia immer*
DCCO	Double-crested Cormorant	*Phalacrocorax auritus*
AWPE	American White Pelican	*Pelecanus erythrorhynchos*
AMBI	American Bittern	*Botaurus lentiginosus*
GBHE	Great Blue Heron	*Ardea herodias*
TUVU	Turkey Vulture	*Cathartes aura*
OSPR	Osprey	*Pandion haliaetus*
GOEA	Golden Eagle	*Aquila chrysaetos*
NOHA	Northern Harrier	*Circus hudsonius*
SSHA	Sharp-shinned Hawk	*Accipiter striatus*
COHA	Cooper's Hawk	*Accipiter cooperii*
AGOS	American Goshawk	*Accipiter atricapillus*
BAEA	Bald Eagle	*Haliaeetus leucocephalus*
BWHA	Broad-winged Hawk	*Buteo platypterus*
RTHA	Red-tailed Hawk	*Buteo jamaicensis*
GHOW	Great Horned Owl	*Bubo virginianus*
NHOW	Northern Hawk Owl	*Surnia ulula*
BADO	Barred Owl	*Strix varia*
GGOW	Great Gray Owl	*Strix nebulosa*
LEOW	Long-eared Owl	*Asio otus*
SEOW	Short-eared Owl	*Asio flammeus*
BOOW	Boreal Owl	*Aegolius funereus*
NSWO	Northern Saw-whet Owl	*Aegolius acadicus*
BEKI	Belted Kingfisher	*Megaceryle alcyon*
YBSA	Yellow-bellied Sapsucker	*Sphyrapicus varius*
ATTW	American Three-toed Woodpecker	*Picoides dorsalis*
BBWO	Black-backed Woodpecker	*Picoides arcticus*
DOWO	Downy Woodpecker	*Dryobates pubescens*
HAWO	Hairy Woodpecker	*Dryobates villosus*
YSFL	Yellow-shafted Flicker	*Colaptes auratus auratus*
PIWO	Pileated Woodpecker	*Dryocopus pileatus*
AMKE	American Kestrel	*Falco sparverius*
MERL	Merlin	*Falco columbarius*
PEFA	Peregrine Falcon	*Falco peregrinus*
EAKI	Eastern Kingbird	*Tyrannus tyrannus*
OSFL	Olive-sided Flycatcher	*Contopus cooperi*
WEWP	Western Wood-Pewee	*Contopus sordidulus*
YBFL	Yellow-bellied Flycatcher	*Empidonax flaviventris*

Species Code	Common Name	Scientific Name
ALFL	Alder Flycatcher	*Empidonax alnorum*
LEFL	Least Flycatcher	*Empidonax minimus*
EAPH	Eastern Phoebe	*Sayornis phoebe*
SAPH	Say's Phoebe	*Sayornis saya*
BHVI	Blue-headed Vireo	*Vireo solitarius*
PHVI	Philadelphia Vireo	*Vireo philadelphicus*
WAVI	Warbling Vireo	*Vireo gilvus*
REVI	Red-eyed Vireo	*Vireo olivaceus*
NSHR	Northern Shrike	*Lanius borealis*
CAJA	Canada Jay	*Perisoreus canadensis*
BLJA	Blue Jay	*Cyanocitta cristata*
BBMA	Black-billed Magpie	*Pica hudsonia*
AMCR	American Crow	*Corvus brachyrhynchos*
CORA	Common Raven	*Corvus corax*
BCCH	Black-capped Chickadee	*Poecile atricapillus*
BOCH	Boreal Chickadee	*Poecile hudsonicus*
BANS	Bank Swallow	*Riparia riparia*
TRES	Tree Swallow	*Tachycineta bicolor*
NRWS	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
PUMA	Purple Martin	*Progne subis*
BARS	Barn Swallow	*Hirundo rustica*
CLSW	Cliff Swallow	*Petrochelidon pyrrhonota*
RCKI	Ruby-crowned Kinglet	*Regulus calendula*
GCKI	Golden-crowned Kinglet	*Regulus satrapa*
BOWA	Bohemian Waxwing	*Bombycilla garrulus*
CEDW	Cedar Waxwing	*Bombycilla cedrorum*
RBNU	Red-breasted Nuthatch	*Sitta canadensis*
WBNU	White-breasted Nuthatch	*Sitta carolinensis*
BRCR	Brown Creeper	*Certhia americana*
HOWR	House Wren	*Troglodytes aedon*
WIWR	Winter Wren	*Troglodytes hiemalis*
MAWR	Marsh Wren	*Cistothorus palustris*
GRCA	Gray Catbird	*Dumetella carolinensis*
EUST	European Starling	*Sturnus vulgaris*
EABL	Eastern Bluebird	*Sialia sialis*
MOBL	Mountain Bluebird	*Sialia currucoides*
GCTH	Gray-cheeked Thrush	*Catharus minimus*
SWTH	Swainson's Thrush	*Catharus ustulatus*
HETH	Hermit Thrush	*Catharus guttatus*
AMRO	American Robin	*Turdus migratorius*
VATH	Varied Thrush	*Ixoreus naevius*
AMPI	American Pipit	*Anthus rubescens*
EVGR	Evening Grosbeak	*Coccothraustes vespertinus*
PUFI	Purple Finch	*Haemorhous purpureus*
CORE	Common Redpoll	*Acanthis flammea*
RECR	Red Crossbill	*Loxia curvirostra*
WWCR	White-winged Crossbill	*Loxia leucoptera*
PISI	Pine Siskin	*Spinus pinus*
AGOL	American Goldfinch	*Spinus tristis*
CHSP	Chipping Sparrow	*Spizella passerina*

Species Code	Common Name	Scientific Name
CCSP	Clay-colored Sparrow	*Spizella pallida*
FOSP	Fox Sparrow	*Passerella iliaca*
SCJU	Slate-colored Junco	*Junco hyemalis hyemalis*
WCSP	White-crowned Sparrow	*Zonotrichia leucophrys*
WTSP	White-throated Sparrow	*Zonotrichia albicollis*
VESP	Vesper Sparrow	*Pooecetes gramineus*
LCSP	LeConte's Sparrow	*Ammospiza leconteii*
SAVS	Savannah Sparrow	*Passerculus sandwichensis*
SOSP	Song Sparrow	*Melospiza melodia*
LISP	Lincoln's Sparrow	*Melospiza lincolnii*
SWSP	Swamp Sparrow	*Melospiza georgiana*
YHBL	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
BAOR	Baltimore Oriole	*Icterus galbula*
RWBL	Red-winged Blackbird	*Agelaius phoeniceus*
BHCO	Brown-headed Cowbird	*Molothrus ater*
RUBL	Rusty Blackbird	*Euphagus carolinus*
BRBL	Brewer's Blackbird	*Euphagus cyanocephalus*
COGR	Common Grackle	*Quiscalus quiscula*
OVEN	Ovenbird	*Seiurus aurocapilla*
NOWA	Northern Waterthrush	*Parkesia noveboracensis*
BAWW	Black-and-white Warbler	*Mniotilta varia*
TEWA	Tennessee Warbler	*Leiothlypis peregrina*
OCWA	Orange-crowned Warbler	*Leiothlypis celata*
NAWA	Nashville Warbler	*Leiothlypis ruficapilla*
CONW	Connecticut Warbler	*Oporornis agilis*
MOWA	Mourning Warbler	*Geothlypis philadelphia*
COYE	Common Yellowthroat	*Geothlypis trichas*
AMRE	American Redstart	*Setophaga ruticilla*
CMWA	Cape May Warbler	*Setophaga tigrina*
MAWA	Magnolia Warbler	*Setophaga magnolia*
BBWA	Bay-breasted Warbler	*Setophaga castanea*
BLBW	Blackburnian Warbler	*Dendroica fusca*
YEWA	Yellow Warbler	*Setophaga petechia*
CSWA	Chestnut-sided Warbler	*Setophaga pensylvanica*
BLPW	Blackpoll Warbler	*Setophaga striata*
BTBW	Black-throated Blue Warbler	*Setophaga caerulescens*
WPWA	Western Palm Warbler	*Setophaga palmarum palmarum*
MYWA	Myrtle Warbler	*Setophaga coronata coronata*
BTNW	Black-throated Green Warbler	*Setophaga virens*
CAWA	Canada Warbler	*Cardellina canadensis*
WIWA	Wilson's Warbler	*Cardellina pusilla*
WETA	Western Tanager	*Piranga ludoviciana*
RBGR	Rose-breasted Grosbeak	*Pheucticus ludovicianus*

Appendix E

Population Trends and Vital Rate Estimates using Linear Regression Models (Population and Productivity Trends), Modified Cormack–Jolly–Seber (CJS) Mark-Recapture Analyses (Adult Survivorship) and Pradel Modeling (Lambda) on Data from 26 Boreal MAPS Stations Collected in 2011–2024

E1.0 Analytical Approaches

Capture rates were normalized to the number of captures per 600 net-hours of operation. This is a standard unit of effort across the continental MAPS program, allowing for comparison of data among Boreal MAPS stations and between these stations and those operated elsewhere in North America. The number of adult birds captured per 600 net-hours at each station was used as an index of adult population size. Post-fledging productivity was estimated by the ratio of individual young birds (HYs) captured to individual adult birds (AHYs, including SYs and ASYs) captured.

We examined 12-year trends in adult population size and productivity (a reproductive index; RI) using Generalized Linear Model (GLM) regression analyses, using data from the 29 stations operated for at least 4 of the 14 years from 2011 to 2024. Data for a given species from a given station were included in productivity analyses where the species was categorized as a breeder (B, U, or O) or transient (T), but not where the species was categorized as a migrant (M). Unbanded birds were excluded from these analyses.

A generalized linear ('log-linear') model appropriate for Poisson-distributed response variables was used to estimate adult population size and productivity trends. Poisson models allow for a trend in variance to match the trend in mean numbers. The number of adults per 600 net-hours is modeled with net-hours incorporated as an offset in a (Poisson-distributed) GLM of trend over time. Similarly, trend in productivity is modeled as the total number of young captured, with the number of breeding adults used as an offset in the (Poisson-distributed) GLM. Trends for the 33 species for which an average of ≥2.5 individual adults were captured per year were defined as being significant if $p \leq 0.050$ and steep if the absolute trend value is ≥0.100 or shallow if the absolute trend value is <0.100. Both the significance and degree of a trend (steep, shallow) are useful in characterizing its biological meaning.

Survival was estimated using modified Cormack–Jolly–Seber (CJS) mark-recapture analyses (Pollock et al. 1990; Lebreton et al. 1992; DeSante and Saracco 2009). Adult capture histories were from the 29 stations operated for at least 4 years with no more than 2 consecutive years of missed operation. Survival was estimated for species for which, on average, at least 2.5 individual adult captures per year and at least 2 between-year recaptures were recorded at stations where the species was categorized as a breeder (B, U, or O) but not as a transient (T) or migrant (M). We used the software program MARK (White and Burnham 1999) and the RMark package in R (Laake and Rexstad 2008; R Development Core Team 2013) to calculate maximum-likelihood estimates, standard errors, and coefficients of variation (CVs) for adult survival probability and estimates and standard errors for adult recapture probability and proportion of residents among newly captured adults using a time-constant, transient model (Pradel et al. 1997; Nott and DeSante 2002; Hines et al. 2003). Recapture probability is that of recapturing a bird in a subsequent year that was banded in a previous year, given that it survived and returned to the station where it was originally banded. Proportion of residents excludes transient adults (dispersing and floater individuals which are only captured once) that are assumed not to be part of the breeding population (Pradel et al. 1997). Controlling for capture probability and proportion of residents increases the precision of the survival estimates. We estimate lambda using Pradel reverse-time CMR models (Pradel 1996).

E2.0 Results

E2.1 Adult Population Size and Productivity

Data from the five stations established in 2021 (the initial year of transition into BADR alignment) are included in our analyses, with data from the remaining 25 new stations established since 2022 to be integrated into the analyses over the coming years. To preserve the continuity of the dataset since program inception in 2011 and to allow for ongoing demographic and population analyses through the transition period, a subset of legacy MAPS stations will continue operations through the 2027 field season. This continuity in the data record is essential in the ability to derive vital rates and evaluate population trends (Kaschube et al. 2022).

Significant ($p < 0.05$) declining population trends were evident for 15 species (Figure E1), 4 of which were steep (absolute trend ≥0.100) and 11 shallow (absolute trend <0.100). A significant and steep population increase occurred for two species, and significant shallow increases occurred for eight species. For all species pooled, adult population size showed a shallow decline (-0.004), but which was not significant ($p < 0.064$); however, we interpret the shallow decline being biologically meaningful based on high sample sizes and 14 years of capture data. Significantly declining productivity trends were indicated for 18 species (Figure E2), 3 of which were steep. The productivity trend for only one species was significantly positive, and it was shallow. Productivity for all species pooled showed a shallow (-0.040) and significant ($P = 0.003$) decline and is highly biologically meaningful.

Seven species showed significant declines in both population trend and productivity. One species (Yellow-bellied Sapsucker) showed steep declines for each, one species (Chipping Sparrow) showed a steep population decline and a shallow productivity decline, one species (Ovenbird) showed a shallow population decline and a steep productivity decline, and four species (Slate-colored Junco, Tennessee Warbler, Common Yellowthroat, and Myrtle Warbler) showed shallow declines for each. Only one species, Lincoln's Sparrow, showed as much as a shallow increase in productivity. Seven species (Red-eyed Vireo, Black-capped Chickadee, Swainson's Thrush, White-throated Sparrow, Song Sparrow, Mourning Warbler, and Clay-colored Sparrow) showed significant increases in population size and significant decreases in productivity, with Clay-colored Sparrow showing steep trends in both. This compares with only two species showing significant population increases but productivity declines following the 2022 season.

While otherwise similar to the population and productivity trends described after the 2022 monitoring year (Foster et al. 2023), changes in population and productivity estimates and trends over time demonstrate the importance of long-term datasets necessary for describing and separating long-period natural population cycles from long-term population trends. This is illustrated well by the Canada Warbler population trend, which through 2021 was trending significantly negative but which in 2022 and 2023 became non-significant. This pattern could reflect the effect of climate cycles, forest fire, insect outbreaks, or other time-varying processes.

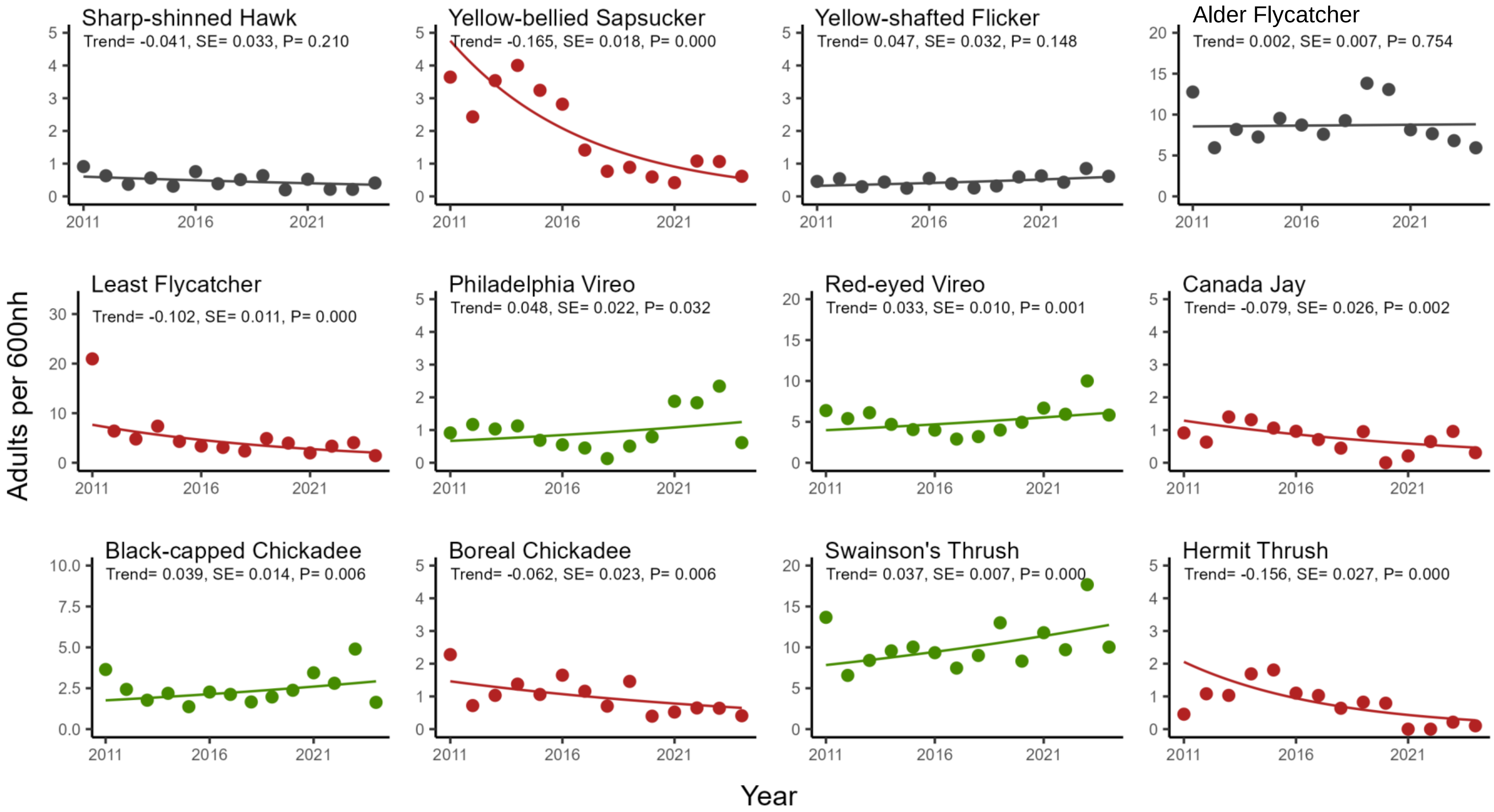


Figure E1: Population trends for 35 species at the 34 stations operated for at least 4 of 14 years (2011 to 2024)

The index of population size was determined as the number of adults captured per 600 net-hours, summed over all stations for 35 species that met our data requirements. The trend in population size was estimated using a Poisson regression of population size on year, green for significantly increasing and red for significantly decreasing trends. The population trend and its standard error and the significance of the trend (P) are presented on each graph.

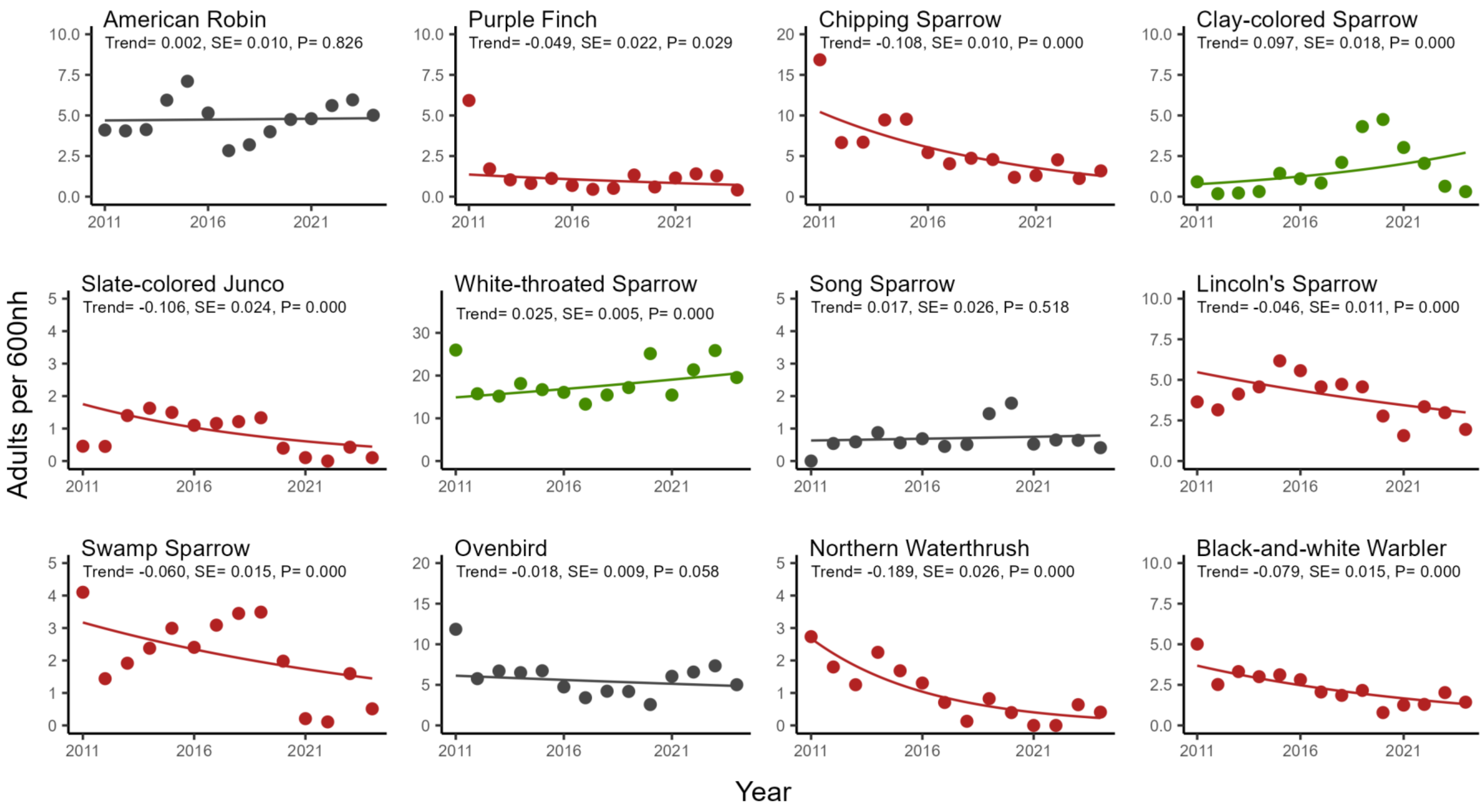


Figure E1: Continued

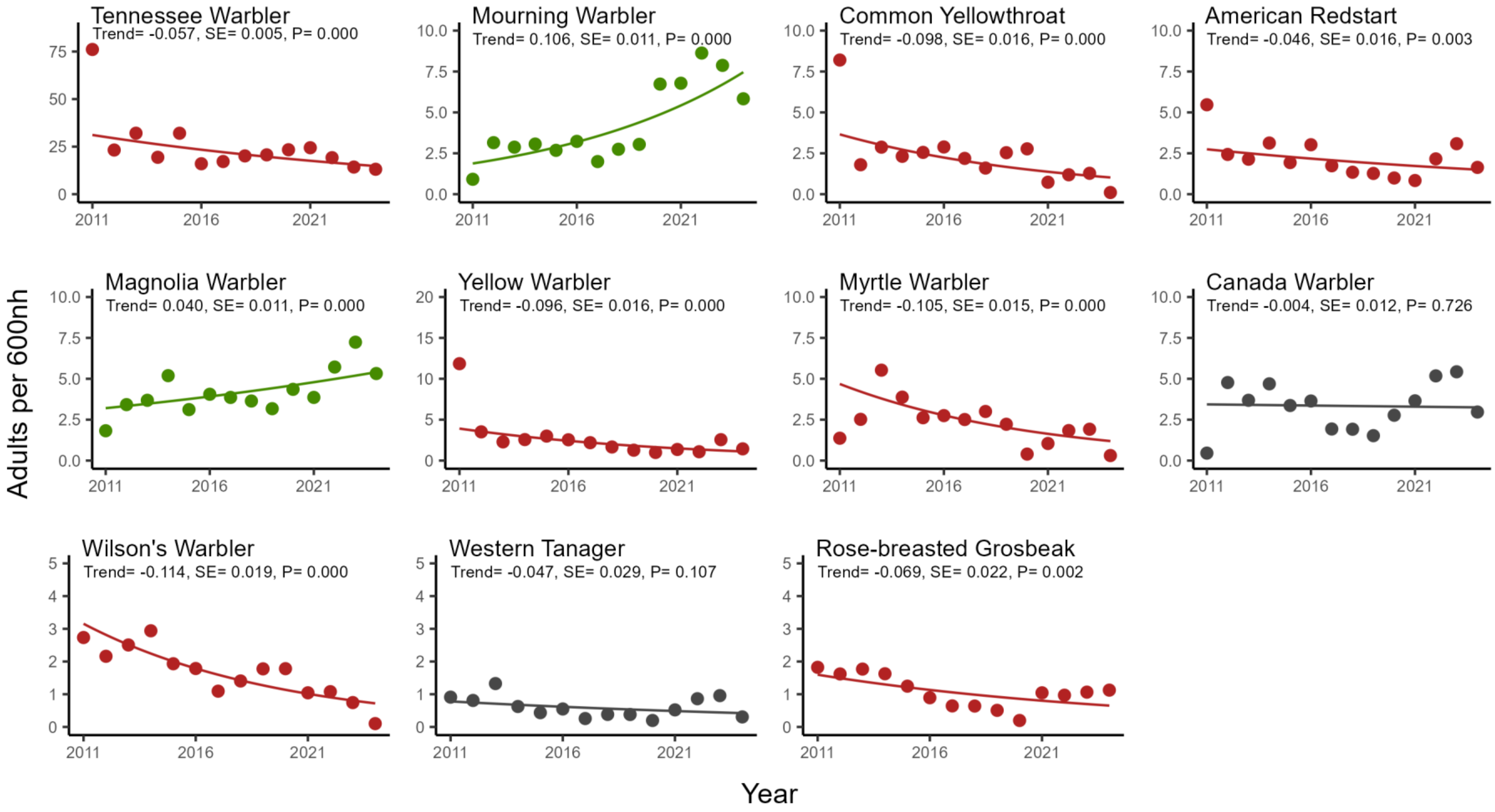


Figure E1: Concluded

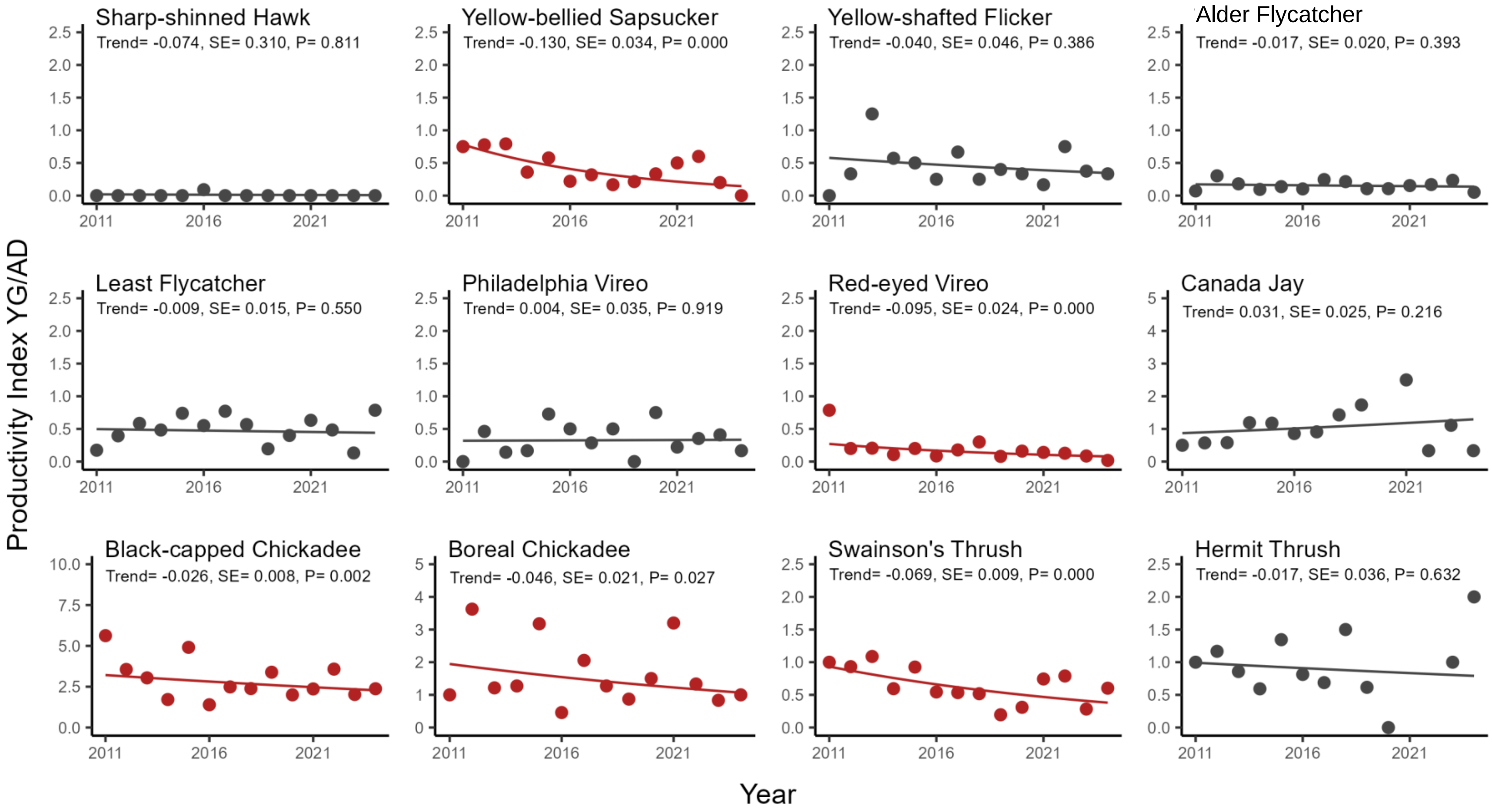


Figure E2: Trend in productivity for 35 species at the 34 stations operated for at least 4 of 14 years (2011 to 2024)

The productivity index was calculated as the productivity (HY per AHY) for each of 35 species that met our data requirements. The trend in productivity was estimated using a Poisson regression of productivity index on year, green for significantly increasing and red for significantly decreasing trends. The trend and its standard error and the significance of the trend (P) are presented on each graph.

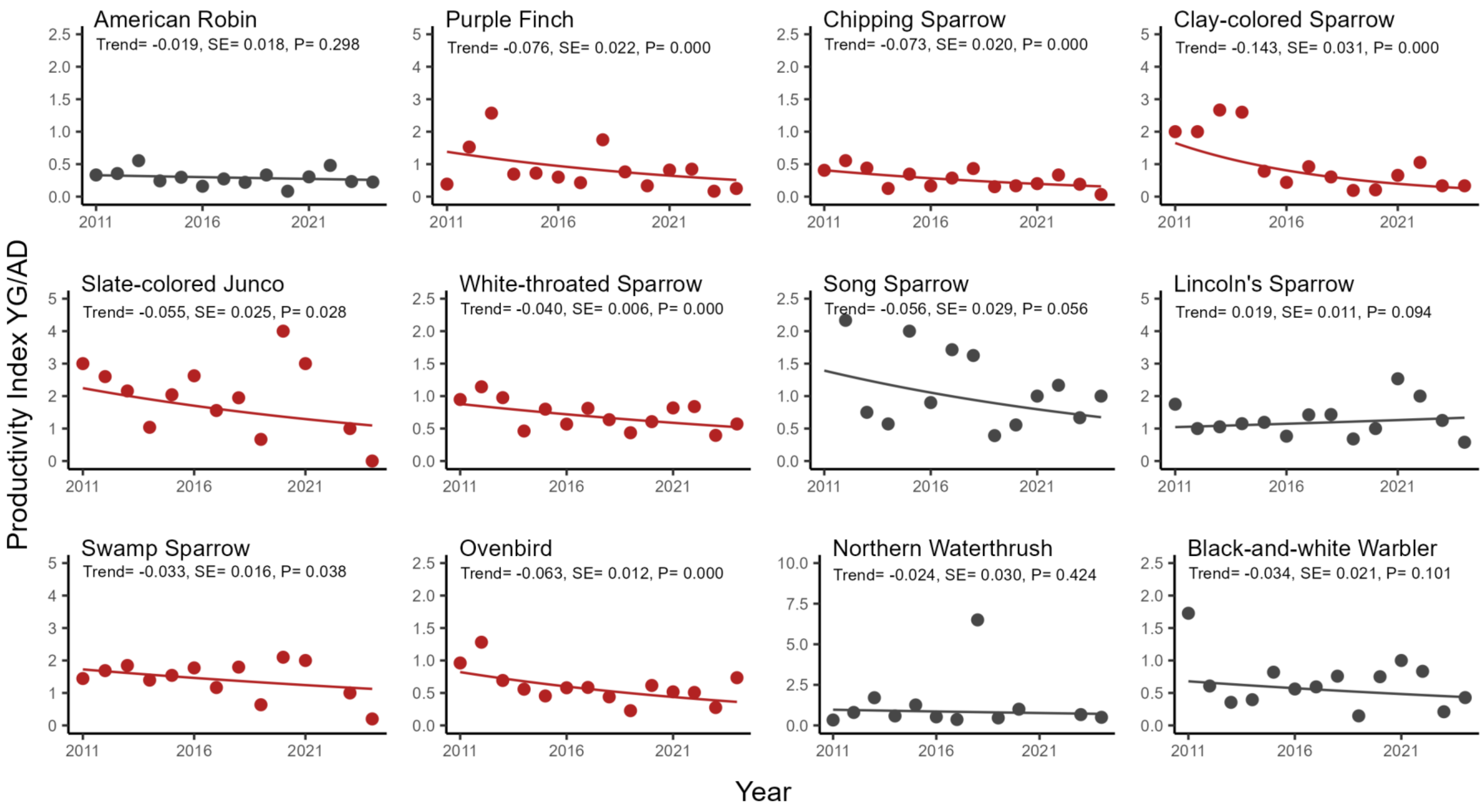


Figure E2: Continued

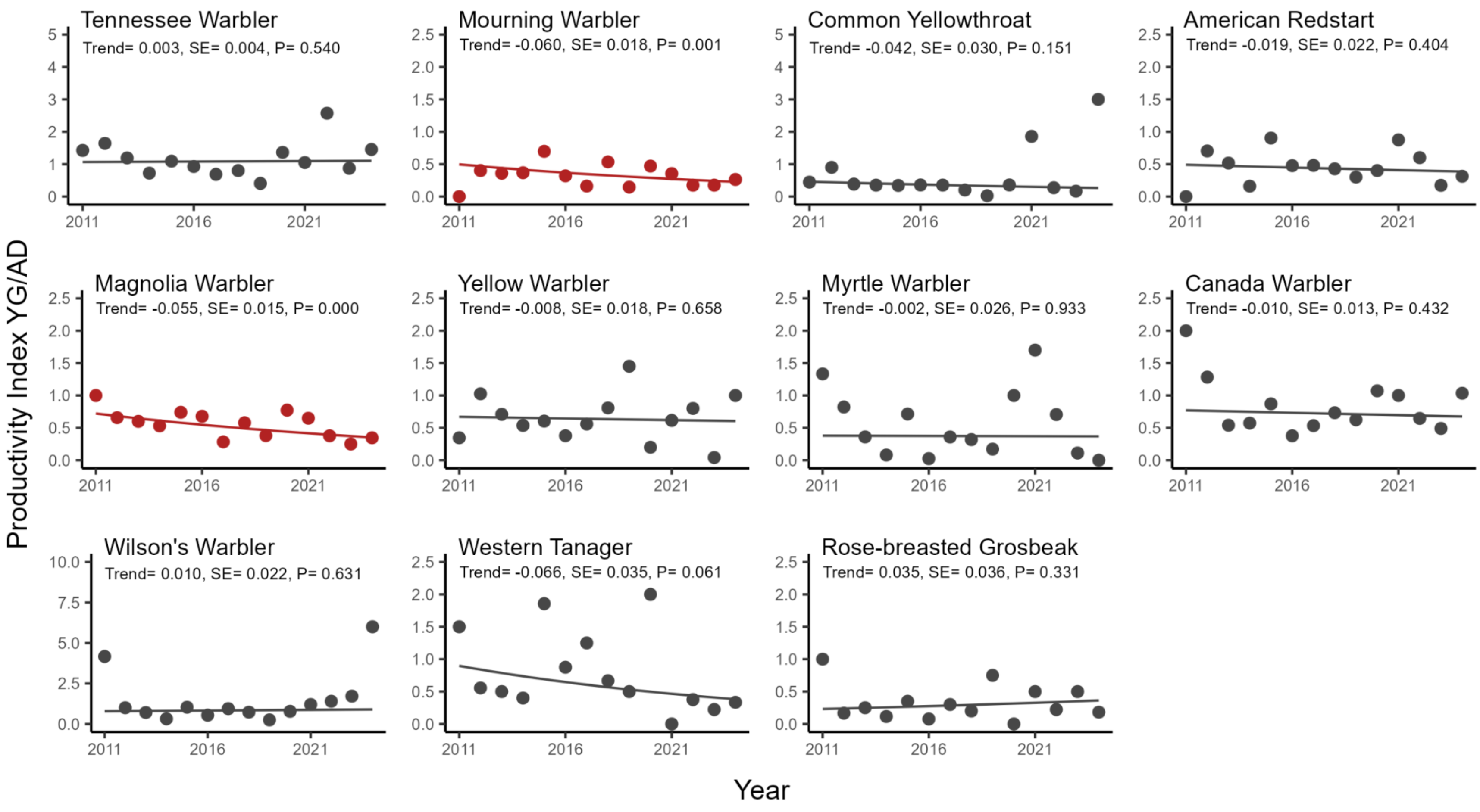


Figure E2: Concluded

E2.2 Adult Survivorship

Adult survivorship estimates were derived for 33 of the 35 species that met our data requirements (Table E1). Survival estimates for Philadelphia Vireo and Song Sparrow could not be derived because survival probability or recapture probability for each was estimated at 0.0 or 1.0, indicating insufficient or irregular data for realistic survivorship estimation. Sampling data have become sufficient to derive survival estimates for Yellow-shafted Flicker and Clay-colored Sparrow for the first time.

E2.3 Lambda (Population Growth Rate)

Lambda, the population growth rate, was estimated for 33 species (Table E1). An estimate greater than 1.000 represents a growing population, while an estimate below 1.000 represents a declining population, providing that the standard error does not include 1.000.

Integration of individual vital rates into the derivation of lambda represents a different approach to population change interpretation than does the adult population size regression analyses presented above (Figure E1). However, both are useful in visualizing and interpreting changes in populations.

Table E1: Estimates of Adult Survival and Lambda for the Period of 2011 to 2024

Species[1]	**Survival Probability ± SE (CJS)**	**Lambda ± SE (Pradel)**
Sharp-shinned Hawk*	0.505 ± 0.244	0.958 ± 0.040
Yellow-bellied Sapsucker	0.249 ± 0.051	0.858 ± 0.016
Yellow-shafted Flicker†*	0.405 ± 0.325	1.010 ± 0.034
Alder Flycatcher	0.451 ± 0.036	0.995 ± 0.008
Least Flycatcher	0.316 ± 0.073	0.913 ± 0.010
Philadelphia Vireo	n/a	n/a
Red-eyed Vireo	0.491 ± 0.044	1.001 ± 0.010
Canada Jay	0.570 ± 0.090	0.932 ± 0.026
Black-capped Chickadee	0.538 ± 0.051	0.993 ± 0.015
Boreal Chickadee	0.319 ± 0.081	0.949 ± 0.023
Swainson's Thrush	0.531 ± 0.030	1.019 ± 0.007
Hermit Thrush	0.399 ± 0.093	0.885 ± 0.026
American Robin	0.443 ± 0.043	0.983 ± 0.010
Purple Finch	0.299 ± 0.129	0.935 ± 0.021
Chipping Sparrow	0.362 ± 0.062	0.890 ± 0.009
Clay-colored Sparrow*	0.166 ± 0.115	1.084 ± 0.019
Slate-colored Junco	0.504 ± 0.094	0.909 ± 0.025
White-throated Sparrow	0.427 ± 0.018	0.993 ± 0.005
Song Sparrow	n/a	n/a
Lincoln's Sparrow	0.327 ± 0.041	0.956 ± 0.011
Swamp Sparrow	0.230 ± 0.064	0.941 ± 0.016
Ovenbird	0.293 ± 0.051	0.950 ± 0.010
Northern Waterthrush	0.588 ± 0.071	0.856 ± 0.023
Black-and-white Warbler	0.402 ± 0.065	0.928 ± 0.015
Tennessee Warbler*	0.121 ± 0.073	0.937 ± 0.005
Mourning Warbler	0.556 ± 0.034	1.047 ± 0.012
Common Yellowthroat	0.376 ± 0.065	0.936 ± 0.016
American Redstart	0.504 ± 0.061	0.945 ± 0.015
Magnolia Warbler	0.467 ± 0.037	1.003 ± 0.011
Yellow Warbler	0.490 ± 0.053	0.919 ± 0.015
Myrtle Warbler	0.345 ± 0.056	0.885 ± 0.015
Canada Warbler	0.436 ± 0.048	0.965 ± 0.012
Wilson's Warbler	0.332 ± 0.102	0.900 ± 0.018
Western Tanager*	0.729 ± 0.203	0.944 ± 0.027
Rose-breasted Grosbeak†	0.506 ± 0.113	0.924 ± 0.021

Note:

[1] Yellow shading indicates species listed as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species listed additionally as Threatened or of Special Concern (Government of Canada 2023).

E5.0 Literature Cited

DeSante DF, Saracco JF (2009) Power of the MAPS program to detect differences and trends in survival and a vision for program expansion. Bird Populations 9:42-75.

Foster KR, Pyle P, Kaschube D, Godwin CM (2023) *Monitoring Avian Productivity and Survivorship in the Oil Sands Region of Northeastern Alberta – Boreal MAPS in the Oil Sands Region 2022*. A report to The Oil Sands Monitoring Program (Alberta Environment and Parks), Syncrude Canada Ltd., Hammerstone Infrastructure Materials Ltd., ConocoPhillips Canada Resources Corp., Cenovus Energy Inc., Suncor Energy Inc., Canadian Natural Resources Limited & CNOOC International. Fort McMurray AB.

Hines JE, Kendall WL, Nichols JD (2003) On the use of the robust design with transient capture-recapture models. Auk 120:1151-1158.

Kaschube DR, Saracco JF, Ray C, Godwin CM, Foster KR, Pyle P (2022) Minimum MAPS capture-recapture rates and years of banding station operations to obtain reliable adult annual survival estimates. Journal of Field Ornithology 93:7. https://journal.afonet.org/vol93/iss1/art7/

Laake J and Rexstad E (2008) *RMark: an alternative approach to building linear models in MARK*. In: Cooch E and White G (Eds.) *Program MARK: A Gentle Introduction, 6th Ed.* pp. C1-C114. http://www.phidot.org/software/mark/docs/book/.

Lebreton J-D, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62:67-118.

Nott MP, DeSante DF (2002) Demographic monitoring and the identification of transients in mark-recapture models. In: Scott JM and Heglund P (Eds.) *Predicting Species Occurrences: Issues of Scale and Accuracy*. Island Press, NY. pp. 727-736.

Pollock KH, Nichols JD, Brownie C, Hines JE (1990) Statistical inference for capture-recapture experiments. Wildlife Monographs, No. 107. 95 pp.

Pradel R (1996) Utilization of Capture-Mark-Recapture for the study of recruitment and population growth rate. Biometrics 52:703-709.

Pradel R, Hines J, Lebreton J-D, Nichols JD (1997) Estimating survival probabilities and proportions of 'transients' using capture-recapture data. Biometrics 53:60-72.

R Development Core Team (2013) R: A Language and Environment for Statistical Computing, Version 3.4.1. R Foundation for Statistical Computing. Vienna, Austria. http://www.R-project.org/.

White GC, Burnham KP (1999) Program MARK: survival estimation for populations of marked animals. Bird Study 46 (Supplement):120-138.

Appendix F

Population Trends and Vital Rate Estimates for 23 Species Derived from Boreal MAPS Data (2011–2024) and Data Collected Across the Continental MAPS Program (2011–2023) Using Bayesian Models

F1.0 Populations Trends and Demographic Variables for Boreal MAPS Stations

We modeled adult apparent survival probability, recruitment rate, and residency probability based on a Bayesian reverse-symmetry (RS) model that accounts for transients in the dataset (Telenský et al. 2024, Neate-clegg et al. 2025). For each of the survival and recruitment parameters, we estimated intercept and trend parameters from logit- and log-linear models, respectively. The RS models also include a model for capture probability, for which we included a logit-linear model that included a random station effect and a station-specific effort covariate representing the annual effort (net-hours) relative to mean effort across all years for the station. In future analyses we will consider additional model structures, model comparisons, and assessment of model fits. We implemented analyses of MAPS capture data (numbers of adults and young captured) and productivity (probability of capturing a young bird) that were structurally comparable to the RS models. We assumed that annual numbers of young (hatching-year) and adult (after-hatching-year) birds were each distributed as Poisson random variables. The effort variable in these models was the number of net-hours completed in the year. For productivity, we assumed that the number of young captured was a binomial random variable with probability parameter equal to the probability of capturing a young bird (our productivity metric) and the number of trials equal to the total number of birds captured at each station × year. We then modeled the probability parameter as a function of effort, trend, and latitude, as was done for the models of adult and young captures. The effort variable used in the productivity models was the proportion of effort during the period of the season when young birds were primarily exposed to capture relative to the total seasonal effort. We present productivity results as exponentiated derived estimates from the logit-scale (i.e., in terms of odds ratios, young/adult rather than on the probability scale). Boreal MAPS data included 13,401 captures and 1,809 recaptures of these 23 species from 34 BMAPS stations operated in 2011–2024 (Table F1).

F2.0 Comparison of Results between Boreal and Continental MAPS Stations

We compared mean vital rates and vital rate trends from 2011 to 2024 between Boreal MAPS (BMAPS) stations and other MAPS stations operated across Continental North America (CMAPS) from 2011 to 2023. Given latitudinal gradients in survival across species (Scholer et al. 2020) and similar latitudinal patterns often observed within species (DeSante et al. 2015), we also included latitude effects in these models to account for latitudinal sampling variation and to derive estimates of vital rates that would be comparable for the same latitude of Boreal Maps vs. continental MAPS stations. Continental MAPS data included 64,702 captures and 11,599 recaptures of these 23 species from 484 CMAPS stations operated in 2011–2023 (Table F1).

Table F1: Counts for Boreal MAPS (BMAPS) and Continental MAPS (CMAPS) of the Number of Stations, Individuals, and Returns, and the Latitudinal Ranges (km) of Stations in Continental MAPS

Species[1]	Number of Stations[2]		Number of Individuals[3]		Number of Returns[4]		CMAPS Latitudes[5]		
	BMAPS	CMAPS	BMAPS	CMAPS	BMAPS	CMAPS	Minimum	Maximum	Range (km)
Yellow-bellied Sapsucker	28	42	274	374	40	61	41.771	57.393	1737.549
Alder Flycatcher[§]	32	103	1297	2591	122	252	31.542	57.393	2872.618
Least Flycatcher	28	47	668	1641	29	141	37.312	57.393	2232.545
Red-eyed Vireo	29	153	712	2992	95	377	29.802	57.393	3065.522
Black-capped Chickadee	29	116	302	2304	64	461	35.367	57.758	2488.993
Swainson's Thrush	34	72	1451	4573	187	1300	32.558	57.393	2759.973
Hermit Thrush	21	56	124	747	17	135	31.452	57.758	2923.248
American Robin	34	181	684	5473	92	661	31.452	57.393	2882.628
Chipping Sparrow	32	101	878	1938	43	197	33.099	57.393	2699.933
Slate-colored Junco^	15	54	138	2496	18	465	35.325	57.383	2451.945
White-throated Sparrow	34	24	2401	982	449	212	41.959	57.393	1716.631
Song Sparrow	13	155	102	8210	12	1911	31.542	57.209	2852.139
Ovenbird	34	105	838	2979	58	658	33.801	57.393	2622.170
Northern Waterthrush	17	27	134	421	28	124	40.413	57.393	1888.309
Black-and-white Warbler	26	55	335	748	43	99	30.267	57.393	3014.007
Mourning Warbler	20	21	501	382	142	90	42.019	57.393	1709.905
Common Yellowthroat	21	169	299	7232	35	1421	29.802	57.393	3065.522
American Redstart	21	90	292	2796	43	545	30.315	57.393	3008.648
Magnolia Warbler	27	19	564	390	111	74	41.087	57.393	1813.443
Yellow Warbler	17	129	312	8254	52	1553	31.542	57.758	2913.237
Myrtle Warbler[#]	27	70	370	2229	52	125	31.452	57.758	2923.248
Canada Warbler	18	15	476	491	65	142	35.367	57.393	2448.374
Wilson's Warbler	21	52	249	3829	12	595	35.324	57.758	2493.709
TOTAL of 23 Species	**34**	**247**	**13401**	**64072**	**1809**	**11599**	**29.802**	**57.758**	**3103.080**

Notes:

[1] Yellow shading indicates species listed as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species listed additionally as Threatened or of Special Concern (Government of Canada 2023).

[2] Number of stations where the species was a regular, usual, or occasional breeder at which adults of the species were captured.

[3] Number of adult individuals captured at stations where the species was a regular, usual, or occasional breeder.

[4] Total number of returns. A return is the first recapture in a given year of a bird originally banded at the same station in a previous year.

[5] Survival probability presented as the maximum likelihood estimate, plus/minus the standard error of the estimate.

[§] Continental counts are for Traill’s flycatcher, a grouping of Alder and Willow flycatcher species, due to the difficulty of differentiating between these species where their ranges overlap. Only Alder Flycatcher is present in northeastern Alberta.

^ Continental counts are for Dark-eyed Junco, which includes several subspecies. Only Slate-colored Junco is present in northeastern Alberta.

[#] Continental counts are for Yellow-rumped Warbler, which includes Myrtle and Audubon subspecies. Only Myrtle Warbler is present in northeastern Alberta.

We attempted to include trend and latitude effects in logit-linear models of residency probability as well; however, these models did not converge for many of our focal species. Means of Poisson random variables were modeled as log-linear functions of effort, latitude, and linear trend effects with model intercepts and trends varying between BMAPS stations and continental MAPS stations. The primary period of exposure of young captures was determined for each species by summing the numbers of captures across seasons at a regional scale (here Bird Conservation Regions; Bird Studies Canada and NABCI 2014) for each MAPS within-season subperiod (DeSante et al. 2020) and then summing effort for each station x year across regional subperiods accounting for > 97.5% of young captures (Saracco et al. 2019).

All models were implemented using JAGS (Plummer 2003) using the JagsUI package (Kellner 2021) in R (R Core Team 2023). We used standard vague priors for all parameters and hyperparameters. Posterior inferences were based on three independent Markov chain Monte Carlo (MCMC) simulations of at least 60,000 iterations after an adaptive phase of 10,000 iterations and burn-in of 20,000 iterations each and thinning by 5 to reduce chain autocorrelation (for a total of at least 24,000 posterior samples). Gelman–Rubin statistic values <1.1 for all model parameters suggested successful model convergence (Gilks et al. 1996). Results are presented in Tables F2A to F2D.

Table F2A: Comparison of Boreal MAPS (2011 to 2024) and Continental MAPS (2011 to 2023) Demographic and Population Estimates and Trends for 23 Species use Bayesian Modeling: Lambda and Trends in the Number of Adults

Species[2]	Lambda with 95%CI[1]		Adult Trends with 95%CI[1]	
	Boreal MAPS	Continental MAPS	Boreal MAPS	Continental MAPS
Yellow-bellied Sapsucker	0.832 (0.777, 0.883)	0.940 (0.868, 1.016)	-0.141 (-0.180, -0.103)	-0.024 (-0.055, 0.008)
Alder Flycatcher	1.061 (1.017, 1.105)	1.041 (0.987, 1.103)	0.056 (0.037, 0.075)	-0.042 (-0.055, -0.028)
Least Flycatcher	0.922 (0.862, 0.978)	1.089 (1.029, 1.154)	-0.067 (-0.091, -0.043)	-0.014 (-0.028, 0.001)
Red-eyed Vireo	1.010 (0.970, 1.049)	1.077 (1.002, 1.158)	0.034 (0.013, 0.056)	0.005 (-0.008, 0.019)
Black-capped Chickadee	1.016 (0.981, 1.052)	1.052 (0.994, 1.112)	0.020 (-0.011, 0.052)	-0.052 (-0.065, -0.039)
Swainson's Thrush	1.043 (1.003, 1.087)	1.025 (0.995, 1.056)	0.053 (0.037, 0.068)	0.020 (0.010, 0.029)
Hermit Thrush	0.766 (0.651, 0.883)	0.973 (0.932, 1.014)	-0.103 (-0.166, -0.041)	-0.029 (-0.051, -0.008)
American Robin	1.003 (0.977, 1.028)	1.070 (1.026, 1.123)	-0.005 (-0.027, 0.016)	-0.024 (-0.033, -0.016)
Chipping Sparrow	0.904 (0.876, 0.928)	0.920 (0.867, 0.968)	-0.099 (-0.121, -0.077)	-0.077 (-0.091, -0.062)
Slate-colored Junco	0.973 (0.876, 1.067)	0.929 (0.869, 0.998)	-0.028 (-0.092, 0.036)	-0.011 (-0.022, 0.001)
White-throated Sparrow	1.018 (1.004, 1.032)	0.963 (0.931, 0.995)	0.016 (0.004, 0.028)	0.007 (-0.012, 0.025)
Song Sparrow	0.979 (0.915, 1.044)	0.976 (0.945, 1.011)	-0.022 (-0.075, 0.031)	-0.004 (-0.011, 0.004)
Ovenbird	0.974 (0.951, 0.998)	0.974 (0.941, 1.007)	-0.031 (-0.053, -0.009)	0.004 (-0.007, 0.015)
Northern Waterthrush	0.723 (0.599, 0.841)	1.067 (0.984, 1.176)	-0.171 (-0.227, -0.116)	0.020 (-0.006, 0.046)
Black-and-white Warbler	0.955 (0.917, 0.993)	1.047 (0.986, 1.110)	-0.042 (-0.077, -0.008)	-0.015 (-0.039, 0.008)
Mourning Warbler	1.054 (1.024, 1.084)	1.099 (1.018, 1.195)	0.051 (0.027, 0.074)	0.000 (-0.025, 0.026)
Common Yellowthroat	1.018 (0.969, 1.065)	0.981 (0.958, 1.003)	0.002 (-0.039, 0.043)	-0.025 (-0.033, -0.017)
American Redstart	0.940 (0.892, 0.981)	1.064 (1.036, 1.093)	-0.053 (-0.086, -0.022)	0.005 (-0.006, 0.017)
Magnolia Warbler	1.037 (1.011, 1.063)	1.155 (1.055, 1.269)	0.032 (0.008, 0.055)	0.018 (-0.009, 0.045)
Yellow Warbler	0.928 (0.885, 0.967)	0.971 (0.951, 0.992)	-0.074 (-0.105, -0.044)	-0.032 (-0.039, -0.024)
Myrtle Warbler	0.954 (0.909, 0.999)	0.945 (0.901, 0.988)	-0.068 (-0.106, -0.031)	-0.068 (-0.080, -0.055)
Canada Warbler	0.985 (0.939, 1.035)	0.927 (0.873, 0.981)	-0.037 (-0.062, -0.012)	-0.006 (-0.028, 0.017)
Wilson's Warbler	0.947 (0.799, 1.090)	0.924 (0.886, 0.960)	-0.093 (-0.139, -0.048)	-0.024 (-0.035, -0.013)

Notes:

[1] For lambda and trend estimates, orange indicates a significant decline, and green indicates a significant increase (see Appendix C).

[2] Yellow shading indicates species listed in Alberta as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species also listed federally as Threatened or of Special Concern (Government of Canada 2023)

Table F2B: Comparison of Boreal MAPS (2011 to 2024) and Continental MAPS (2011 to 2023) Demographic and Population Estimates and Trends for 23 Species use Bayesian Modeling: Productivity and Productivity Trend

Species[2]	Productivity with 95%CI		Productivity Trends with 95%CI[1]	
	Boreal MAPS	Continental MAPS	Boreal MAPS	Continental MAPS
Yellow-bellied Sapsucker	0.298 (0.146, 0.443)	0.375 (0.154, 0.746)	-0.118 (-0.203, -0.037)	-0.010 (-0.080, 0.059)
Alder Flycatcher	0.155 (0.065, 0.216)	0.157 (0.074, 0.293)	-0.036 (-0.088, 0.015)	0.002 (-0.037, 0.039)
Least Flycatcher	0.534 (0.207, 0.842)	0.856 (0.309, 1.985)	0.005 (-0.047, 0.056)	-0.065 (-0.099, -0.032)
Red-eyed Vireo	0.136 (0.051, 0.216)	0.054 (0.020, 0.115)	-0.061 (-0.128, 0.005)	-0.028 (-0.078, 0.022)
Black-capped Chickadee	2.761 (1.473, 3.636)	1.735 (1.119, 2.567)	-0.031 (-0.067, 0.005)	0.014 (-0.005, 0.033)
Swainson's Thrush	0.468 (0.144, 0.659)	0.534 (0.268, 0.954)	-0.067 (-0.093, -0.041)	-0.007 (-0.028, 0.015)
Hermit Thrush	1.466 (0.161, 2.509)	2.385 (0.903, 5.283)	-0.003 (-0.116, 0.111)	0.021 (-0.016, 0.058)
American Robin	0.177 (0.072, 0.275)	0.607 (0.336, 1.010)	-0.016 (-0.061, 0.030)	-0.001 (-0.019, 0.016)
Chipping Sparrow	0.237 (0.049, 0.358)	0.974 (0.405, 1.974)	-0.033 (-0.084, 0.017)	-0.031 (-0.064, 0.001)
Slate-colored Junco	1.941 (0.442, 3.085)	2.353 (1.096, 4.617)	-0.027 (-0.114, 0.059)	-0.020 (-0.038, -0.003)
White-throated Sparrow	0.526 (0.43, 0.655)	0.547 (0.287, 0.937)	-0.046 (-0.063, -0.028)	0.049 (0.014, 0.085)
Song Sparrow	1.484 (0.700, 2.372)	1.012 (0.708, 1.409)	-0.019 (-0.109, 0.070)	-0.004 (-0.015, 0.006)
Ovenbird	0.528 (0.441, 0.693)	0.375 (0.191, 0.658)	-0.072 (-0.107, -0.037)	-0.023 (-0.045, -0.001)
Northern Waterthrush	1.333 (0.632, 2.322)	0.806 (0.201, 2.278)	0.064 (-0.013, 0.141)	0.078 (0.021, 0.136)
Black-and-white Warbler	0.545 (0.423, 0.728)	0.626 (0.307, 1.110)	-0.033 (-0.085, 0.019)	0.038 (-0.003, 0.079)
Mourning Warbler	0.33 (0.214, 0.402)	0.396 (0.258, 0.577)	-0.067 (-0.109, -0.024)	0.018 (-0.040, 0.075)
Common Yellowthroat	0.411 (0.265, 0.662)	0.421 (0.256, 0.655)	-0.053 (-0.136, 0.027)	0.006 (-0.010, 0.021)
American Redstart	0.425 (0.166, 0.721)	0.313 (0.153, 0.587)	0.013 (-0.048, 0.075)	0.047 (0.018, 0.077)
Magnolia Warbler	0.549 (0.228, 0.695)	0.522 (0.261, 0.908)	-0.058 (-0.095, -0.020)	-0.012 (-0.071, 0.046)
Yellow Warbler	0.774 (0.234, 1.264)	0.720 (0.460, 1.081)	-0.013 (-0.075, 0.050)	0.021 (0.008, 0.035)
Myrtle Warbler	0.432 (0.118, 0.757)	0.492 (0.207, 0.988)	-0.062 (-0.138, 0.012)	0.024 (0.001, 0.047)
Canada Warbler	0.947 (0.412, 1.383)	0.929 (0.391, 2.006)	-0.010 (-0.044, 0.025)	0.024 (-0.016, 0.063)
Wilson's Warbler	1.112 (0.465, 1.983)	0.509 (0.132, 1.373)	0.052 (-0.027, 0.132)	0.035 (0.015, 0.055)

Notes:

[1] For productivity trend estimates, orange indicates a significant decline, and green indicates a significant increase (see Appendix C).

[2] Yellow shading indicates species listed in Alberta as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species also listed federally as Threatened or of Special Concern (Government of Canada 2023)

Table F2C: Comparison of Boreal MAPS (2011 to 2024) and Continental MAPS (2011 to 2023) Demographic and Population Estimates and Trends for 23 Species use Bayesian Modeling: Survival and Survival Trend

Species[2]	Survival with 95%CI		Survival Trend with 95%CI[1]	
	Boreal MAPS	Continental MAPS	Boreal MAPS	Continental MAPS
Yellow-bellied Sapsucker	0.375 (0.247, 0.530)	0.436 (0.277, 0.619)	0.104 (-0.074, 0.271)	0.024 (-0.080, 0.127)
Alder Flycatcher	0.480 (0.406, 0.555)	0.529 (0.404, 0.659)	-0.018 (-0.093, 0.055)	-0.041 (-0.100, 0.017)
Least Flycatcher	0.202 (0.124, 0.304)	0.578 (0.287, 0.734)	0.093 (-0.030, 0.212)	-0.128 (-0.230, 0.016)
Red-eyed Vireo	0.502 (0.424, 0.586)	0.557 (0.4, 0.718)	0.012 (-0.090, 0.115)	0.063 (-0.010, 0.148)
Black-capped Chickadee	0.592 (0.504, 0.680)	0.408 (0.312, 0.509)	0.038 (-0.066, 0.150)	-0.070 (-0.116, -0.026)
Swainson's Thrush	0.558 (0.495, 0.622)	0.495 (0.436, 0.557)	-0.079 (-0.160, 0.001)	-0.036 (-0.068, -0.003)
Hermit Thrush	0.150 (0.025, 0.430)	0.429 (0.338, 0.522)	-0.668 (-1.297, -0.125)	-0.098 (-0.178, -0.020)
American Robin	0.527 (0.448, 0.608)	0.558 (0.455, 0.668)	-0.017 (-0.108, 0.078)	-0.106 (-0.147, -0.065)
Chipping Sparrow	0.372 (0.267, 0.491)	0.667 (0.486, 0.838)	-0.016 (-0.170, 0.138)	-0.197 (-0.304, -0.094)
Slate-colored Junco	0.580 (0.341, 0.822)	0.349 (0.2, 0.527)	0.100 (-0.335, 0.509)	-0.047 (-0.087, -0.005)
White-throated Sparrow	0.420 (0.384, 0.455)	0.379 (0.316, 0.444)	-0.015 (-0.051, 0.020)	-0.047 (-0.104, 0.009)
Song Sparrow	0.259 (0.117, 0.444)	0.441 (0.378, 0.507)	0.101 (-0.097, 0.307)	-0.037 (-0.058, -0.015)
Ovenbird	0.356 (0.261, 0.461)	0.523 (0.439, 0.613)	-0.001 (-0.097, 0.101)	-0.035 (-0.075, 0.005)
Northern Waterthrush	0.505 (0.271, 0.768)	0.692 (0.491, 0.855)	-0.467 (-0.818, -0.145)	-0.065 (-0.197, 0.060)
Black-and-white Warbler	0.503 (0.381, 0.629)	0.58 (0.414, 0.742)	0.045 (-0.090, 0.187)	-0.064 (-0.148, 0.018)
Mourning Warbler	0.576 (0.506, 0.646)	0.508 (0.384, 0.642)	-0.012 (-0.086, 0.062)	-0.207 (-0.423, -0.043)
Common Yellowthroat	0.415 (0.271, 0.586)	0.739 (0.672, 0.798)	-0.003 (-0.150, 0.161)	-0.031 (-0.059, -0.003)
American Redstart	0.501 (0.374, 0.629)	0.593 (0.518, 0.665)	0.000 (-0.154, 0.156)	-0.119 (-0.164, -0.074)
Magnolia Warbler	0.494 (0.420, 0.569)	0.379 (0.219, 0.578)	0.081 (-0.009, 0.175)	-0.085 (-0.227, 0.036)
Yellow Warbler	0.492 (0.374, 0.616)	0.519 (0.469, 0.57)	-0.026 (-0.152, 0.108)	-0.024 (-0.048, -0.001)
Myrtle Warbler	0.462 (0.346, 0.593)	0.522 (0.378, 0.664)	0.041 (-0.098, 0.205)	-0.038 (-0.117, 0.038)
Canada Warbler	0.434 (0.345, 0.529)	0.532 (0.428, 0.632)	-0.040 (-0.130, 0.051)	-0.140 (-0.226, -0.062)
Wilson's Warbler	0.544 (0.188, 0.895)	0.269 (0.196, 0.366)	0.215 (-0.152, 0.690)	-0.096 (-0.137, -0.054)

Notes:

1 For survival trend estimates, orange indicates a significant decline, and green indicates a significant increase (see Appendix C).

2 Yellow shading indicates species listed in Alberta as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species also listed federally as Threatened or of Special Concern (Government of Canada 2023)

Table F2D: Comparison of Boreal MAPS (2011 to 2024) and Continental MAPS (2011 to 2023) Demographic and Population Estimates and Trends for 23 Species use Bayesian Modeling: Recruitment and Recruitment Trend

Species[2]	**Recruitment with 95%CI**		**Recruitment Trend with 95%CI** [1]	
	Boreal MAPS	**Continental MAPS**	**Boreal MAPS**	**Continental MAPS**
Yellow-bellied Sapsucker	0.458 (0.277, 0.599)	0.505 (0.327, 0.678)	-0.106 (-0.243, -0.008)	-0.035 (-0.091, 0.021)
Alder Flycatcher	0.581 (0.498, 0.663)	0.512 (0.368, 0.666)	0.006 (-0.026, 0.039)	-0.001 (-0.036, 0.035)
Least Flycatcher	0.719 (0.602, 0.819)	0.511 (0.369, 0.829)	-0.020 (-0.060, 0.012)	0.032 (-0.027, 0.073)
Red-eyed Vireo	0.508 (0.416, 0.593)	0.521 (0.366, 0.692)	0.056 (0.006, 0.104)	-0.063 (-0.106, -0.026)
Black-capped Chickadee	0.424 (0.335, 0.514)	0.643 (0.523, 0.763)	-0.016 (-0.079, 0.045)	0.020 (-0.010, 0.049)
Swainson's Thrush	0.485 (0.414, 0.559)	0.530 (0.457, 0.605)	0.046 (0.005, 0.084)	0.001 (-0.021, 0.023)
Hermit Thrush	0.616 (0.400, 0.757)	0.545 (0.450, 0.639)	0.061 (-0.060, 0.161)	0.045 (0.005, 0.087)
American Robin	0.476 (0.392, 0.556)	0.513 (0.375, 0.652)	0.032 (-0.021, 0.084)	0.052 (0.023, 0.081)
Chipping Sparrow	0.532 (0.413, 0.638)	0.252 (0.115, 0.418)	0.013 (-0.062, 0.081)	0.110 (0.037, 0.188)
Slate-colored Junco	0.393 (0.136, 0.627)	0.580 (0.396, 0.774)	-0.074 (-0.401, 0.176)	-0.002 (-0.023, 0.020)
White-throated Sparrow	0.598 (0.561, 0.635)	0.584 (0.514, 0.655)	0.013 (-0.004, 0.029)	-0.068 (-0.097, -0.040)
Song Sparrow	0.721 (0.528, 0.875)	0.535 (0.459, 0.617)	-0.077 (-0.152, -0.012)	0.021 (0.008, 0.035)
Ovenbird	0.618 (0.513, 0.714)	0.451 (0.360, 0.542)	0.004 (-0.038, 0.041)	-0.003 (-0.031, 0.024)
Northern Waterthrush	0.218 (0.009, 0.416)	0.375 (0.191, 0.632)	0.382 (0.160, 0.920)	-0.039 (-0.139, 0.058)
Black-and-white Warbler	0.452 (0.325, 0.577)	0.467 (0.304, 0.644)	-0.008 (-0.094, 0.071)	0.013 (-0.036, 0.062)
Mourning Warbler	0.477 (0.404, 0.552)	0.591 (0.439, 0.755)	0.004 (-0.037, 0.045)	-0.160 (-0.240, -0.082)
Common Yellowthroat	0.602 (0.441, 0.745)	0.242 (0.192, 0.300)	0.033 (-0.032, 0.087)	0.004 (-0.016, 0.023)
American Redstart	0.439 (0.313, 0.565)	0.471 (0.399, 0.550)	0.057 (-0.031, 0.145)	0.015 (-0.010, 0.039)
Magnolia Warbler	0.543 (0.468, 0.616)	0.777 (0.539, 1.004)	-0.012 (-0.056, 0.033)	-0.039 (-0.103, 0.029)
Yellow Warbler	0.435 (0.316, 0.550)	0.452 (0.398, 0.508)	0.064 (-0.012, 0.136)	-0.005 (-0.019, 0.010)
Myrtle Warbler	0.492 (0.367, 0.606)	0.424 (0.275, 0.583)	0.025 (-0.062, 0.096)	0.024 (-0.025, 0.070)
Canada Warbler	0.552 (0.451, 0.650)	0.394 (0.299, 0.502)	0.034 (-0.009, 0.079)	-0.016 (-0.063, 0.030)
Wilson's Warbler	0.403 (0.026, 0.796)	0.655 (0.538, 0.749)	-0.048 (-0.344, 0.105)	0.032 (0.011, 0.053)

Notes:

1 For recruitment trend estimates, orange indicates a significant decline, and green indicates a significant increase (see Appendix C).

2 Yellow shading indicates species listed in Alberta as Sensitive, May be at Risk, or At Risk (Government of Alberta 2020). Pink shading indicates species also listed federally as Threatened or of Special Concern (Government of Canada 2023)

F3.0 Literature Cited

Bird Studies Canada and NABCI (2014). Bird Conservation Regions. *Published by Bird Studies Canada on behalf of the North American Bird Conservation Initiative*. [Online.] Available at http://www.birdscanada.org/research/gislab/index.jsp?targetpg=bcr.

DeSante, D. F., K. M. Burton, P. Velez, D. Froehlich, D. R. Kaschube, and S. Albert (2020). MAPS Manual: 2020 Protocol. [Online.] Available at https://birdpop.org/docs/misc/MAPSManual20.pdf.

DeSante, D. F., D. R. Kaschube, and J. F. Saracco (2015). Vital Rates of North American Landbirds. [Online.] Available at www.VitalRatesOfNorthAmericanLandbirds.org.

Gilks WR, Richardson S, Spiegelhalter DJ (1996) Introducing Markov chain Monte Carlo. In W. R. Gilks, S. Richardson, & D. J. Spiegelhalter (Eds.), *Markov chain Monte Carlo methods in practice* (pp. 1–20). Chapman and Hall.

Kellner, K. (2021). jagsUI: A wrapper around “rjags” to streamline “JAGS” analyses. R package version 1.5.2. https://CRAN.R-project.org/package=jagsUI.

Neate-clegg, M. H. C., J. F. Saracco, F. Rodríguez-Vásquez, and S. E. I. Jones (2025). Unraveling demographic patterns in tropical birds across an elevational gradient. Ornithological Applications 127:duae063.

Plummer, M. (2003). JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003), March 20-22, Vienna, Austria. ISSN 1609-395X.

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/. *R Foundation for Statistical Computing*. [Online.] Available at https://www.r-project.org/.

Saracco, J. F., R. B. Siegel, L. Helton, S. L. Stock, and D. F. DeSante (2019). Phenology and productivity in a montane bird assemblage: Trends and responses to elevation and climate variation. Global Change Biology 25:985–996.

Scholer, M. N., M. Strimas-Mackey, and J. E. Jankowski (2020). A meta-analysis of global avian survival across species and latitude. Ecology Letters 23:1537–1549.

Telenský, T., D. Storch, P. Klvaňa, and J. Reif (2024). Extension of Pradel capture–recapture survival-recruitment model accounting for transients. Methods in Ecology and Evolution 15:388–400.

Appendix G

Long-term temporal dynamics in boreal bird communities in the Athabasca oil sands region, Alberta, Canada

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Introduction: Ecological communities undergo constant changes over time as a result of both natural and anthropogenic influences. In this context, long-term monitoring data play an important role, especially at the community level, in terms of measuring biodiversity and distinguishing whether the cause is anthropogenic or a natural process, which often can be challenging to disentangle (Magurran et al. 2010).

Answering the question of what drives changes in community composition of wildlife communities such as birds, whether it is natural or anthropogenic, is not straightforward, especially in a landscape like the Athabasca oil sands region in Alberta where multiple disturbances such as energy sector footprints, forestry, and wildfires come into play (Shaw 2021). However, this understanding is becoming more important now as concerns regarding the local and cumulative impacts of oil sands development have been increasing (Dubé et al. 2021).

To address the cause of community-level changes, the key is to first develop a foundational understanding of the community and what changes are occurring. This knowledge can then be used to explore how such changes are influenced by environmental pressures. In Alberta, the response and change of bird communities to energy sector footprints have not been explicitly studied at the community level, especially in comparison to species-level provincial models. While some spatial studies have been conducted, for example, assessing community responses to energy sector linear footprints (Kalukapuge et al. 2024) and wildfire (Knaggs et al. 2020), our understanding of bird community dynamics at the temporal scale remains very limited even outside our study area (Collins 2000).

Here, we used an approach focused on evaluating β-diversity, which explains what makes species assemblages, in our case, bird communities, more or less similar across space and time. Measures of regional biodiversity (γ-diversity) constitute both the diversity at individual sites (α-diversity) and the differences between sites in species composition, which is what β-diversity represents (Vellend 2010; Anderson et al. 2011). As such, β-diversity and its components provide valuable insight into patterns of community change. In this report, we specifically examined β-diversity from temporal perspectives, focusing on how bird communities change over time and how both natural disturbance from wildfire and anthropogenic disturbance, such as energy sector footprints, influence those changes.

Question 1: How do bird communities change in composition (β-diversity) over time and what is the relative importance of the underlying mechanisms driving the β-diversity over time?

Methods: We estimated total β-diversity (total dissimilarity) of bird communities at each station across years using the '*beta.temp*' function from the 'Betapart' package (Baselga et al. 2012). We compared strictly consecutive years (year t and t + 1) to quantify temporal changes in community composition. This approach avoids comparisons between non-adjacent years separated by different temporal gaps. We used data collected from 34 MAPS stations from 2011 to 2024 and included only stations with at least five years of data in the analysis.

We used Sørensen and Jaccard dissimilarity; both are incidence-based (presence/absence) indices that quantify compositional dissimilarity from different perspectives. The Sørensen index gives more weight to shared species by comparing the number of shared species to the mean number of species in a single assemblage. The Jaccard index gives equal weight to shared and unique species by comparing the number of shared species to the total number of unique species across assemblages (Magurran and McGill 2010). Where the two indices result in similar outcomes, we can have more confidence in the mechanisms being identified.

We then assessed the relative contribution of different mechanisms of β-diversity following the framework initially developed for spatial β-diversity (Baselga 2010), commonly known as β-diversity partitioning. This approach partitions total beta diversity into two components: species turnover and nestedness. Species turnover quantifies the replacement of species between assemblages while nestedness accounts for compositional differences resulting from species-poor assemblages being subsets of species-rich assemblages. Nestedness thus shows patterns of species loss or gain reflecting how assemblages become different when one community constitutes a subset of another.

Summary and interpretation of Table 1 results: Total β-diversity values (βSOR and βJAC) represent the overall compositional dissimilarity in bird communities between consecutive years at each station. Greater β-diversity values indicate higher changes in species composition over time. Stations are ordered from highest to lowest βSOR.

Stations with similar total β-diversity may be different by ecological processes. For example, CRSL and SFEN both have relatively high total β-diversity. However, at CRSL, most of the dissimilarity is driven by species turnover (βJTU = 0.4521), indicating that species are being replaced between sampling units. In contrast, SFEN shows a much lower turnover component (βJTU = 0.2083) and a markedly higher nestedness component (βJNE = 0.2701), suggesting that community differences are primarily attributable to species loss or gain, rather than replacement. Overall, across most stations, turnover appears to be the dominant mechanism of temporal β-diversity. For example, stations like CRSL, MUSR, and MNDY show relatively high mean turnover values (i.e., βJTU = 0.4521, 0.4584, and 0.4549, respectively), indicating species replacement between years, while the nestedness component is consistently lower across stations. Exploring the components of β-diversity is therefore important to fully understand the processes that drive community-level change.

Table 1: Results from temporal beta diversity analysis of bird communities across 34 MAPS stations. Shown are mean values across consecutive year pairs for each station and standard deviations of total beta diversity (β_{total}; βSOR and βJAC), species turnover (βSTU and βJTU), and nestedness (βSNE and βJNE) components calculated for both Sørensen (SOR) and Jaccard (JAC) indices. Stations that were exposed to fire in 2016 are highlighted in yellow.

Station	Year pairs	Mean						Standard deviation					
		β_{total}		Turnover		Nestedness		β_{total}		Turnover		Nestedness	
		βSOR	βJAC	βSTU	βJTU	βSNE	βJNE	βSOR	βJAC	βSTU	βJTU	βSNE	βJNE
CRSL	7	0.4089	0.5746	0.2978	0.4521	0.1111	0.1225	0.0972	0.0994	0.0932	0.1101	0.0616	0.0671
MUSR	10	0.4039	0.5708	0.3067	0.4584	0.0972	0.1123	0.0846	0.0860	0.1152	0.1394	0.0495	0.0697
MNDY	7	0.3792	0.5479	0.3035	0.4549	0.0757	0.0929	0.0558	0.0582	0.1138	0.1442	0.0648	0.0937
GRGR	6	0.3694	0.5168	0.2688	0.3989	0.1005	0.1178	0.1848	0.2021	0.1762	0.2157	0.0662	0.0709
CREB	7	0.3264	0.4834	0.2400	0.3703	0.0864	0.1131	0.1100	0.1234	0.1375	0.1784	0.0728	0.1035
BMLN	6	0.3145	0.4700	0.2204	0.3531	0.0941	0.1168	0.1068	0.1271	0.0936	0.1271	0.0494	0.0569
BPND	13	0.3019	0.4579	0.2274	0.3628	0.0744	0.0951	0.0826	0.1000	0.0886	0.1172	0.0581	0.0803
HNGS	7	0.2989	0.4569	0.2016	0.3260	0.0972	0.1309	0.0654	0.0771	0.1024	0.1322	0.0730	0.0983
ODYS	6	0.2985	0.4567	0.2439	0.3861	0.0546	0.0705	0.0649	0.0751	0.0844	0.1068	0.0400	0.0546
HBVR	4	0.2943	0.4519	0.2422	0.3846	0.0520	0.0673	0.0649	0.0747	0.0843	0.1066	0.0304	0.0439
BISN	8	0.2904	0.4471	0.2627	0.4133	0.0277	0.0337	0.0612	0.0737	0.0570	0.0715	0.0365	0.0437
GWAY	10	0.2885	0.4450	0.2315	0.3728	0.0569	0.0721	0.0576	0.0703	0.0572	0.0768	0.0357	0.0438
MAKR	12	0.2883	0.4432	0.2210	0.3553	0.0672	0.0878	0.0709	0.0865	0.0821	0.1093	0.0636	0.0880
HNGN	10	0.2853	0.4339	0.2185	0.3503	0.0668	0.0835	0.1114	0.1301	0.0908	0.1248	0.0516	0.0604
CRLK	7	0.2597	0.4096	0.1779	0.2972	0.0817	0.1123	0.0568	0.0725	0.0688	0.0991	0.0808	0.1132
ENGS	7	0.2575	0.4061	0.1941	0.3205	0.0633	0.0855	0.0643	0.0790	0.0689	0.0932	0.0255	0.0354
CSTU	6	0.2573	0.4052	0.2231	0.3603	0.0342	0.0448	0.0685	0.0896	0.0699	0.0935	0.0363	0.0477
DEMP	6	0.2514	0.3944	0.1898	0.3142	0.0616	0.0802	0.0917	0.1213	0.0706	0.0984	0.0492	0.0639
ELBS	10	0.2502	0.3941	0.1545	0.2584	0.0957	0.1357	0.0801	0.1069	0.0873	0.1362	0.0594	0.0894
HSHO	6	0.2429	0.3898	0.2037	0.3365	0.0391	0.0532	0.0348	0.0448	0.0452	0.0643	0.0270	0.0399
PRES	12	0.2414	0.3834	0.1426	0.2450	0.0988	0.1383	0.0755	0.1007	0.0617	0.0933	0.0711	0.1015
HFSH	4	0.2365	0.3814	0.1096	0.1926	0.1268	0.1887	0.0384	0.0488	0.0675	0.1092	0.0950	0.1431
ELBN	10	0.2345	0.3743	0.1804	0.3016	0.0541	0.0727	0.0767	0.1015	0.0614	0.0869	0.0441	0.0582
HNGW	9	0.2274	0.3638	0.1606	0.2708	0.0667	0.0930	0.0846	0.1102	0.0730	0.1075	0.0516	0.0756
POPC	12	0.2271	0.3655	0.1744	0.2925	0.0526	0.0729	0.0691	0.0910	0.0623	0.0937	0.0375	0.0552
BCDS	8	0.2255	0.3667	0.1383	0.2401	0.0871	0.1266	0.0369	0.0502	0.0496	0.0793	0.0563	0.0862
CRCL	7	0.2115	0.3403	0.1596	0.2615	0.0518	0.0787	0.0969	0.1287	0.1108	0.1689	0.0558	0.0896
RUSL	6	0.2116	0.3463	0.1583	0.2651	0.0533	0.0811	0.0561	0.0767	0.0873	0.1305	0.0398	0.0661
SFEN	6	0.3392	0.4784	0.1404	0.2083	0.1987	0.2701	0.2162	0.2107	0.1959	0.2674	0.0670	0.1118
SNDR	7	0.3206	0.4839	0.2347	0.3730	0.0859	0.1108	0.0480	0.0546	0.0879	0.1185	0.0660	0.0935
SNDY	10	0.3364	0.4964	0.2569	0.3939	0.0794	0.1025	0.0961	0.1084	0.1285	0.1629	0.0763	0.1061
THEY	7	0.2706	0.4188	0.2096	0.3378	0.0609	0.0809	0.0907	0.1171	0.0938	0.1324	0.0489	0.0651
VWET	13	0.2772	0.4303	0.2207	0.3568	0.0565	0.0735	0.0657	0.0807	0.0686	0.0942	0.0430	0.0551
WPCK	4	0.2930	0.4486	0.2127	0.3468	0.0803	0.1017	0.0805	0.0995	0.0682	0.0936	0.0662	0.0815

Summary and interpretation of Table 2 results: The turnover ratios (βSTU/βSOR and βJTU/βJAC) show the proportion of total β-diversity caused by species replacement over time. A value close to 1 indicates that almost all compositional change is due to turnover. For example, at station BISN, the Sørensen-based turnover ratio (βSTU/βSOR) is 0.9046, meaning that the changes are substantially due to species being replaced rather than lost or gained. In contrast, at station SFEN, the turnover ratio is only 0.4141, suggesting nestedness accounts for a greater proportion of total β-diversity compared to turnover.

The "% Turnover" and "% Nestedness" columns further break down these contributions. For example, at BISN, 90.45% of total beta diversity is due to turnover and only 9.54% is due to nestedness (Sørensen index). Meanwhile, at SFEN, only 41.41% is due to turnover and a much higher 58.59% comes from nestedness. Figure 1 shows the distribution of MAPS stations according to the relative contribution of turnover and nestedness to temporal changes in community composition.

Table 2: Beta diversity partitioning results for species composition at each station, showing turnover ratios calculated using Sørensen (βSTU/βSOR) and Jaccard (βJTU/βJAC) indices. Percent contributions of turnover (%Turnover) and nestedness (%Nest:) components are also provided for each index, along with the dominant mechanism contributing to total beta diversity.

Station	Turnover ratio SOR (βSTU/βSOR)	Turnover ratio JAC (βJTU/βJAC)	% Turnover SOR	% Nest: SOR	%Turnover JAC	% Nest: JAC	Dominant mechanism	
							Sørensen	Jaccard
BISN	0.9046	0.9244	90.4553	9.5447	92.4413	7.5587	Turnover	Turnover
CSTU	0.8671	0.8893	86.7094	13.2906	88.9297	11.0703	Turnover	Turnover
HSHO	0.8389	0.8633	83.8914	16.1086	86.3350	13.6650	Turnover	Turnover
HBVR	0.8231	0.8509	82.3075	17.6925	85.0902	14.9098	Turnover	Turnover
ODYS	0.8170	0.8455	81.6988	18.3012	84.5499	15.4501	Turnover	Turnover
GWAY	0.8026	0.8378	80.2563	19.7437	83.7817	16.2183	Turnover	Turnover
MNDY	0.8003	0.8303	80.0314	19.9686	83.0299	16.9701	Turnover	Turnover
VWET	0.7962	0.8291	79.6203	20.3797	82.9146	17.0854	Turnover	Turnover
THEY	0.7748	0.8067	77.4760	22.5240	80.6718	19.3282	Turnover	Turnover
ELBN	0.7692	0.8058	76.9192	23.0808	80.5784	19.4216	Turnover	Turnover
POPC	0.7680	0.8003	76.8007	23.1993	80.0305	19.9695	Turnover	Turnover
MAKR	0.7667	0.8017	76.6676	23.3324	80.1722	19.8278	Turnover	Turnover
HNGN	0.7659	0.8075	76.5903	23.4097	80.7472	19.2528	Turnover	Turnover
SNDY	0.7639	0.7935	76.3875	23.6125	79.3473	20.6527	Turnover	Turnover
MUSR	0.7593	0.8031	75.9295	24.0705	80.3128	19.6872	Turnover	Turnover
DEMP	0.7549	0.7966	75.4947	24.5053	79.6616	20.3384	Turnover	Turnover
CRCL	0.7549	0.7685	75.4880	24.5120	76.8536	23.1464	Turnover	Turnover
ENGS	0.7540	0.7894	75.4019	24.5981	78.9419	21.0581	Turnover	Turnover
BPND	0.7535	0.7923	75.3474	24.6526	79.2306	20.7694	Turnover	Turnover
RUSL	0.7481	0.7656	74.8125	25.1875	76.5597	23.4403	Turnover	Turnover
CREB	0.7353	0.7659	73.5333	26.4667	76.5921	23.4079	Turnover	Turnover
SNDR	0.7321	0.7708	73.2084	26.7916	77.0844	22.9156	Turnover	Turnover
CRSL	0.7281	0.7868	72.8136	27.1864	78.6807	21.3193	Turnover	Turnover
GRGR	0.7279	0.7719	72.7850	27.2150	77.1914	22.8086	Turnover	Turnover
WPCK	0.7259	0.7732	72.5865	27.4135	77.3163	22.6837	Turnover	Turnover
HNGW	0.7064	0.7444	70.6366	29.3634	74.4360	25.5640	Turnover	Turnover
BMLN	0.7007	0.7513	70.0733	29.9267	75.1310	24.8690	Turnover	Turnover
CRLK	0.6851	0.7256	68.5132	31.4868	72.5626	27.4374	Turnover	Turnover
HNGS	0.6746	0.7134	67.4604	32.5396	71.3424	28.6576	Turnover	Turnover
ELBS	0.6174	0.6556	61.7393	38.2607	65.5592	34.4408	Turnover	Turnover
BCDS	0.6136	0.6547	61.3562	38.6438	65.4669	34.5331	Turnover	Turnover
PRES	0.5907	0.6391	59.0706	40.9294	63.9148	36.0852	Turnover	Turnover
HFSH	0.4636	0.5050	46.3567	53.6433	50.5043	49.4957	Nestedness	Turnover
SFEN	0.4141	0.4354	41.4097	58.5903	43.5422	56.4578	Nestedness	Nestedness

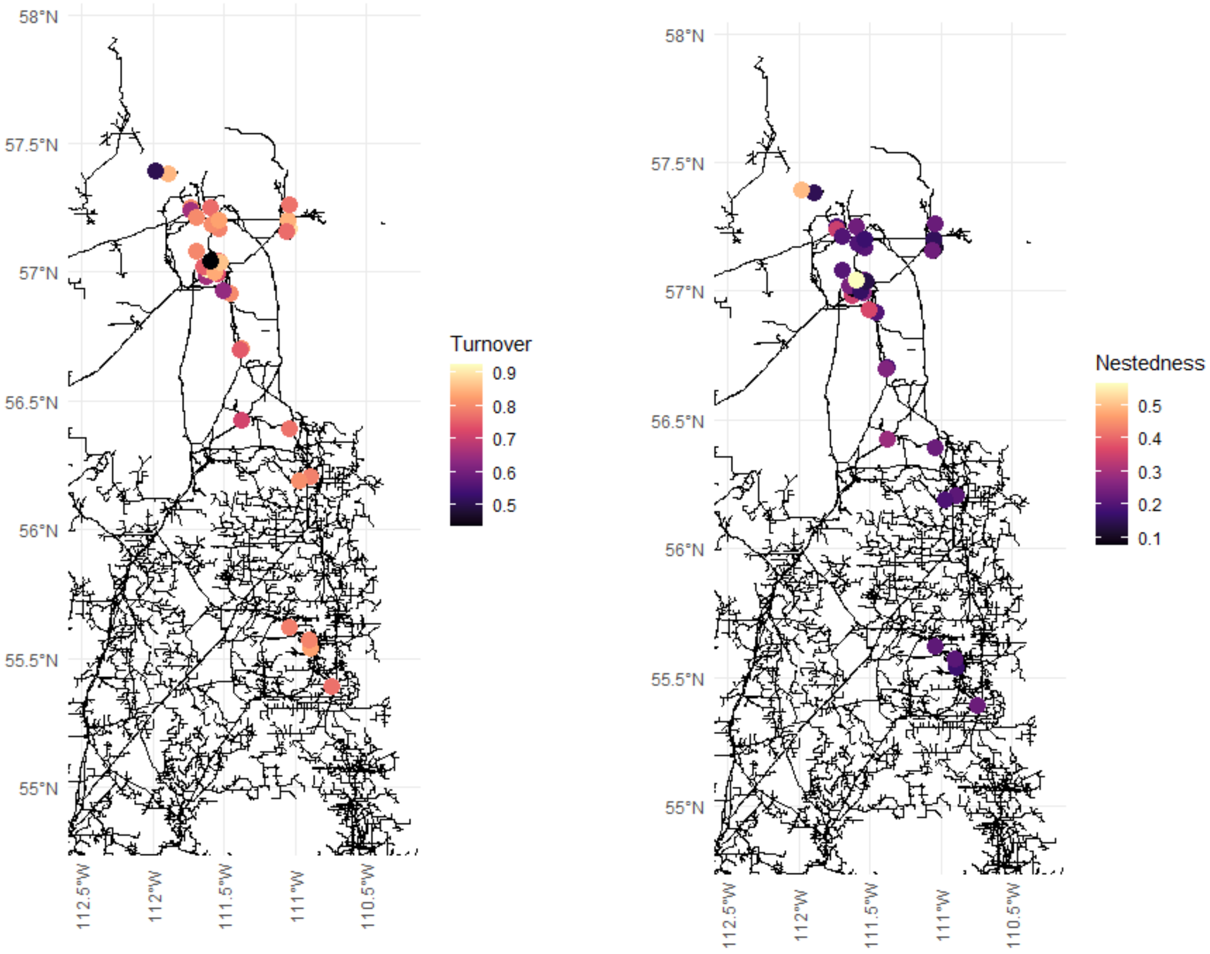


Figure 1: Distribution of β-diversity components (species turnover and nestedness) across 34 MAPS stations in the Athabasca oil sands region, Alberta, Canada. Station-level β-diversity components were calculated across multiple years, with turnover shown in the left panel and nestedness in the right panel. Color intensity represents the proportion of total β-diversity attributed to each component, with warmer colors indicating higher values. Mining activities predominate in the northern extent of the image, *in* situ activities in the southern extent. Black lines represent the linear feature (pipeline) network in the region.

Importance of the β-diversity and β-diversity partitioning analysis: Our findings highlight the importance of turnover as the primary mechanism of temporal community dynamics in the Athabasca oil sands region. This is an ecologically meaningful finding, as turnover implies that communities are not just losing or gaining species but undergoing reassembly, likely in response to changes in the environment. Partitioning temporal patterns of β-diversity into nestedness and turnover provides a finer view of how communities change over time in the region, allowing us to use relevant information to achieve better outcomes through land management and restoration practices that may not become evident from studies that look into total beta diversity alone. Monitoring how turnover and nestedness change over time is particularly valuable when total beta diversity appears stable, even as environmental conditions change (Angeler 2013).

Nestedness and turnover are opposite processes with distinct land management, restoration, and conservation implications. From a spatial perspective, sites with high turnover require a regional approach that considers multiple sites since turnover reflects species replacement between sites rather than species loss. In contrast, sites with high nestedness benefit from conservation planning that prioritizes sites with higher species diversity (Wright and Reeves 1992).

From temporal perspectives, as in this study, sites with dominant temporal nestedness, although rather infrequent among our study locations, suggest that bird communities in more recent years are primarily subsets of earlier communities, indicating potential species loss over time. This pattern could be addressed through targeted habitat restoration at key sites with high species diversity with the aim of recovery of lost species. Conversely, where most sites show high temporal turnover, as our findings suggest, it indicates that different years contribute distinct species to overall temporal diversity throughout the region. This requires land management and restoration strategies that account for dynamic bird assemblages and aim to guide turnover trajectories to achieve expected restoration outcomes from bird community perspectives. Dynamic communities identified in this study require more flexible and adaptive approaches rather than restoration plans based on single-year static assessments.

Question 2: What are the patterns of temporal dynamics in bird communities in the Athabasca oil sands region and do communities diverge, converge, or remain stable over time?

Methods: We used time lag analysis (TLA) to assess temporal dynamics in bird community composition following Collins et al. (2000, 2015) and Kampichler & van der Jeugd (2013). This method quantifies both directional and stochastic changes by regressing community dissimilarity against increasing time lags. TLA compares dissimilarity at different time intervals (lags) rather than modeling continuous time. By analyzing fixed time lags (e.g., 1-year, 2-year, etc.), this method quantifies how and how fast dissimilarity accumulates over time and detects whether communities diverge, converge, and fluctuate stochastically.

We transformed species abundance data using Hellinger transformation, following Legendre & Gallagher (2001). We then applied Hellinger distances (i.e., Euclidean distances of Hellinger-transformed data) for all possible year pairs within each time series. To prevent bias from smaller sample sizes at longer time lags, we followed Collins et al. (2000) and used square root transformation to the time lags before fitting a linear regression model between Hellinger distances and time lags.

We then used a Monte Carlo permutation test with 10,000 iterations to assess the statistical significance of the observed TLA slope (Thibault et al. 2004). In each iteration, we randomly shuffled species abundance across years and recalculated the slope to generate a null distribution. The *p*-value was calculated as the proportion of randomized slopes that were greater than or equal to the observed slope.

Significant (+) TLA slopes indicate divergence and community instability where species composition becomes increasingly different from its initial state as time progresses. This may result from directional changes driven by internal or external factors or from autocorrelated stochastic variability where past states influence present changes. Significant (-) slopes indicate convergence, meaning the community is returning toward a previous composition observed earlier in the time series. Non-significant or near-zero slopes suggest community stability or that species abundances fluctuate randomly without a clear temporal pattern indicating non-directional change. In this case, Hellinger distances between samples do not increase with time lags, suggesting that changes in species composition are short-term and stochastic with no consistent trend over time. This pattern reflects high stochasticity, where species abundances at a given time are independent of previous states, resembling a white noise process (Kampichler & van der Jeugd 2013).

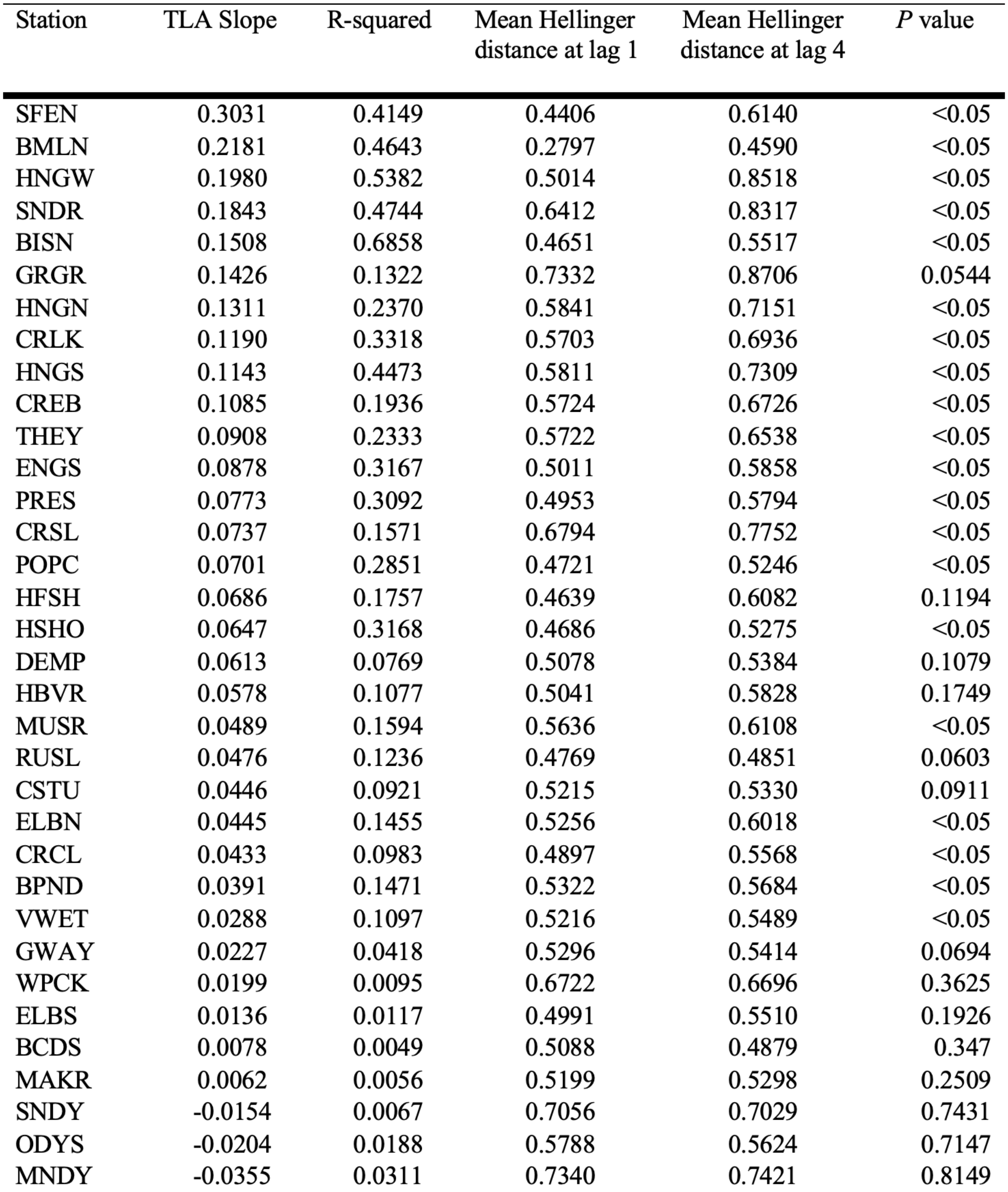
Shallower slopes indicate that most species fluctuate around a constant mean, with weak or limited long-term directional change, representing a relatively stable community. Steeper slopes indicate that a larger proportion of species undergoes directional or stochastic change, leading to higher temporal changes.

Summary and interpretation of *Time lag analysis (TLA)* results: The TLA results (Table 3, Figure 2) show how bird communities change over time across the MAPS stations in the Athabasca oil sands region including the direction of change (convergence, divergence, or stability) and the rate of change.

Stations like SFEN, BMLN, and HNGW have significant positive steeper TLA slopes, indicating strong directional divergence in community composition through time. SFEN and BMLN were early successional reclaimed habitats at the start of monitoring, and species turnover can be attributed to the development of the shrub and forest vegetation over time. The forest at HNGW was burned during the Horse River wildfire in 2016, and species turnover at this station may be attributed to the removal of the forest canopy and regenerating understory vegetation. The bird communities at these MAPS stations are becoming more dissimilar over time because a larger proportion of species undergoes directional change leading to higher temporal divergence. In contrast, stations like MNDY and SNDY have slightly negative (i.e., MNDY slope = -0.0355, p = 0.8149) slopes, suggesting either convergence or random fluctuations in species composition. Theses two stations have not experienced major habitat change since the start of monitoring. These sites may be experiencing community stabilization or high stochasticity where community composition varies unpredictably from year to year without a clear directional trend.

The R^2 value indicates how strong the signal is. For example, a significant positive relationship ($P<0.05$) with a small slope and a small R^2 value, such as at station CRCL (slope=0.0433, R^2 =0.0983), suggests that directional change is occurring but change is slow and stochastic variation between sample intervals is high. CRCL is an older reclaimed area adjacent to mature forest, and some vegetation is still undergoing successional change. A steeper slope and larger R^2 value, as seen at station BISN (slope=0.1508, R^2 =0.6858), indicates a stronger signal of directional change and less noise. BISN was also a younger successional reclaimed habitat at the start of monitoring and has undergone major habitat change with the vegetation growth over time.

Table 3: Model outputs of time lag analysis. TLA slope indicates the direction and magnitude of the change of community composition over time at different time lags. Significant (+) slopes suggest divergence, (-) slopes indicate convergence, and near zero and non-significant slopes reflect stable or stochastic dynamics. R-squared measures model fit, with higher values indicating stronger directional change.



Station	TLA Slope	R-squared	Mean Hellinger distance at lag 1	Mean Hellinger distance at lag 4	*P* value
SFEN	0.3031	0.4149	0.4406	0.6140	<0.05
BMLN	0.2181	0.4643	0.2797	0.4590	<0.05
HNGW	0.1980	0.5382	0.5014	0.8518	<0.05
SNDR	0.1843	0.4744	0.6412	0.8317	<0.05
BISN	0.1508	0.6858	0.4651	0.5517	<0.05
GRGR	0.1426	0.1322	0.7332	0.8706	0.0544
HNGN	0.1311	0.2370	0.5841	0.7151	<0.05
CRLK	0.1190	0.3318	0.5703	0.6936	<0.05
HNGS	0.1143	0.4473	0.5811	0.7309	<0.05
CREB	0.1085	0.1936	0.5724	0.6726	<0.05
THEY	0.0908	0.2333	0.5722	0.6538	<0.05
ENGS	0.0878	0.3167	0.5011	0.5858	<0.05
PRES	0.0773	0.3092	0.4953	0.5794	<0.05
CRSL	0.0737	0.1571	0.6794	0.7752	<0.05
POPC	0.0701	0.2851	0.4721	0.5246	<0.05
HFSH	0.0686	0.1757	0.4639	0.6082	0.1194
HSHO	0.0647	0.3168	0.4686	0.5275	<0.05
DEMP	0.0613	0.0769	0.5078	0.5384	0.1079
HBVR	0.0578	0.1077	0.5041	0.5828	0.1749
MUSR	0.0489	0.1594	0.5636	0.6108	<0.05
RUSL	0.0476	0.1236	0.4769	0.4851	0.0603
CSTU	0.0446	0.0921	0.5215	0.5330	0.0911
ELBN	0.0445	0.1455	0.5256	0.6018	<0.05
CRCL	0.0433	0.0983	0.4897	0.5568	<0.05
BPND	0.0391	0.1471	0.5322	0.5684	<0.05
VWET	0.0288	0.1097	0.5216	0.5489	<0.05
GWAY	0.0227	0.0418	0.5296	0.5414	0.0694
WPCK	0.0199	0.0095	0.6722	0.6696	0.3625
ELBS	0.0136	0.0117	0.4991	0.5510	0.1926
BCDS	0.0078	0.0049	0.5088	0.4879	0.347
MAKR	0.0062	0.0056	0.5199	0.5298	0.2509
SNDY	-0.0154	0.0067	0.7056	0.7029	0.7431
ODYS	-0.0204	0.0188	0.5788	0.5624	0.7147
MNDY	-0.0355	0.0311	0.7340	0.7421	0.8149

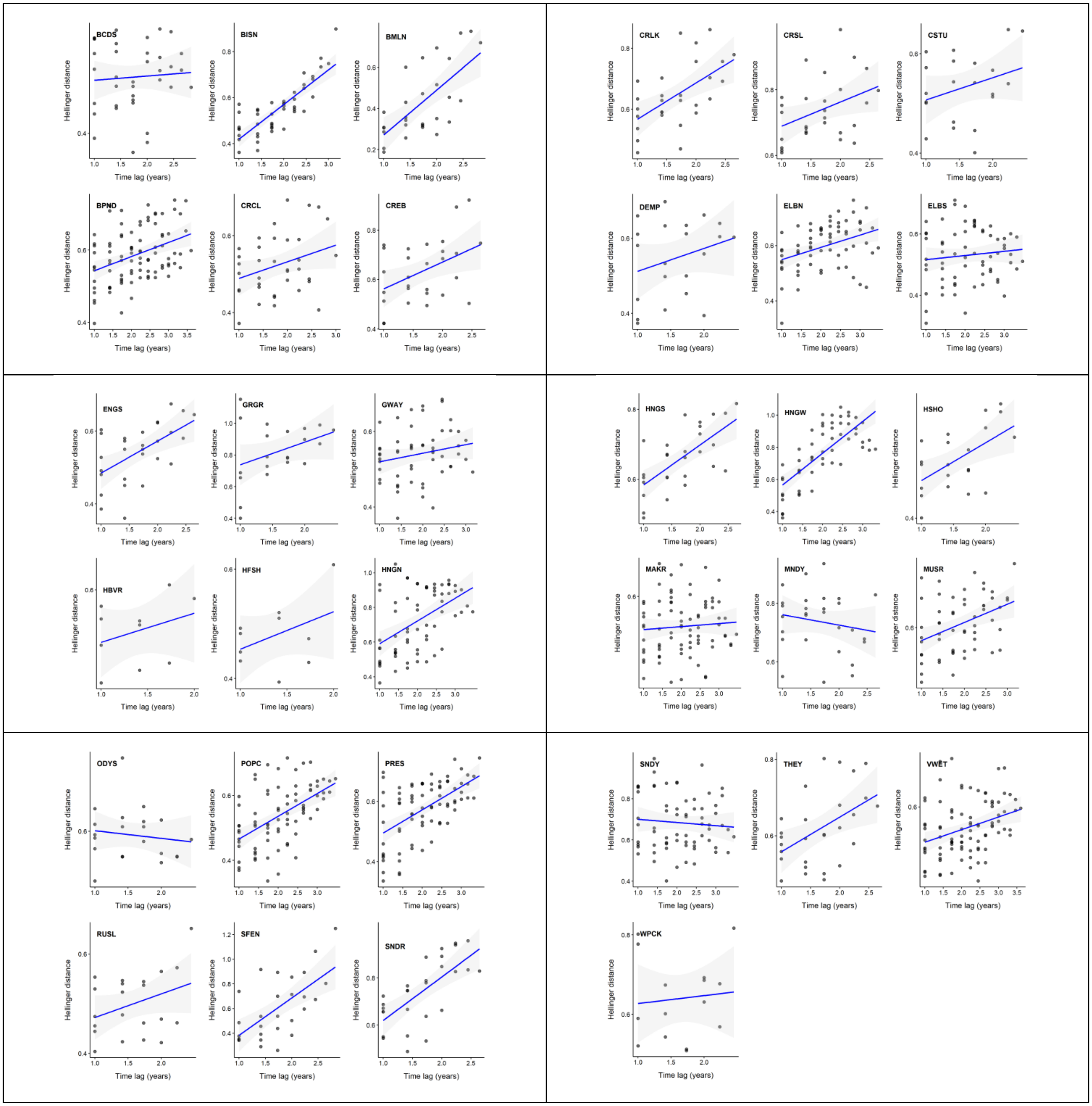


Figure 2: Time lag analysis (TLA) results for 34 monitoring stations in the Athabasca oil sands region. Each graph represents a station and the trend of community composition change over time, measured by Hellinger distance regressed against different time lags. The blue line represents the regression trend line, black dots indicate dissimilarity values, and the shaded gray area shows the 95% confidence interval.

Summary and interpretation of *Pearson correlation test* results

The results (Table 4) show consistent relationships between temporal changes in bird community composition and cumulative human footprint at both 1 km and 5 km spatial scales. A significant positive correlation between TLA slope and footprint at the 5 km scale (r = 0.375, *P* = 0.0289), as well as a marginally significant correlation at the 1 km scale (r = 0.334, *P* = 0.0536), suggests that bird communities in landscapes with greater cumulative human footprint show higher TLA slopes (Table 5). This corresponds to stronger directional changes in community composition over time, indicating that the change in dissimilarity in community composition between years increases more consistently and substantially as time progresses in areas with more cumulative footprints.

Table 4: Pearson correlation coefficients between time lag analysis TLA slope and cumulative human footprint proportions calculated at two spatial scales (1 km and 5 km radius landscapes centered on MAPS stations; footprint data from Saracco et al. 2022). (*) indicates statistical significance at $p \leq 0.05$.

TLA metric	Spatial scale	Correlation coefficient	*p* value
TLA slope	1 km	0.334	**0.0536**
	5 km	0.375	**0.0289***

Importance of TLA analysis and correlation test results: Overall, the results show that bird communities at most stations undergo a clear directional change over time and mostly diverge. Given the frequently observed directional change, each station appears to have its own magnitude of change, as indicated by varying TLA slopes (Figure 2). This suggests that station-specific environmental attributes may have substantial influence in determining temporal dynamics. Understanding that communities shift directionally over time highlights the potential to guide or convert community trajectories, for example, through effective land management and recovery measures to achieve restoration goals from a bird community perspective in areas impacted by energy sector human footprints.

There is a clear correlation with cumulative footprint amount (Table 4), indicating that the greater the footprint, the stronger the directional change and the greater the change in dissimilarity over time. This provides valuable insight into how reducing footprint amounts could help stabilize bird communities in the Athabasca oil sands region, presumably through the contribution of effective on-footprint vegetation recovery. Moreover, stronger correlations between footprint amounts and TLA matrices were observed at the larger (5 km). This highlights the importance of assessing these impacts at multiple spatial scales to better understand their influence on bird communities. Also, this analysis highlights the indispensable role of long-term community monitoring data in understanding how bird communities change over time in response to human footprints.

Question 3: How do individual species and specific time periods (years) contribute to the temporal dynamics (β-diversity) of bird communities in the Athabasca oil sands region, Alberta, Canada?

Another important aspect of β-diversity is understanding the contribution of individual species and sites to the total β-diversity. We used the method introduced by Legendre and De Cáceres (2013), which calculates species contributions to beta diversity (SCBD; the degree to which individual species drive variation among sampling units) and local site contributions to beta diversity (LCBD; ecological uniqueness of individual sampling units).

Because our study focuses on temporal rather than spatial variation in beta diversity, we treated each site–year combination as an individual sampling unit (equivalent to a "site" in spatial studies). Thus, LCBD values represent the ecological uniqueness of a given site in a specific year, reflecting its temporal distinctness relative to other years at the same site.

We used species abundance data across years to quantify station (site)-level species contribution to beta diversity (SCBD) and local contribution to beta diversity (LCBD) using the *'beta.div'* function in the 'adespatial' package in R (Legendre & De Cáceres, 2013). The LCBD and SCBD are based on the total beta diversity, which represents the total variance in the community composition matrix. For each station, we used Hellinger transformation on species abundance data, which penalizes the disproportionate influence of highly abundant species and makes the data suitable for analyses using Euclidean distances.

How to interpret LCBD and SCBD results

LCBD values represent the degree to which each sampling unit (year) contributes uniquely to beta diversity. They are calculated as the ratio of the squared Hellinger distance from each sampling unit to the centroid of the community matrix, divided by the sum of all squared distances (total beta diversity). Higher LCBD values indicate years with more unique species compositions (Figure 3) relative to the average temporal community structure at that station. SCBD values show species contribution to the total beta diversity by summing the squared deviations of each species across all sampling units. Species with higher SCBD values show greater variation in their abundances across years, thus contributing more substantially to temporal community turnover. For each station, we identified the top 10 species with the highest SCBD values (Figure 4) to determine which species contributed the most to the temporal beta diversity.

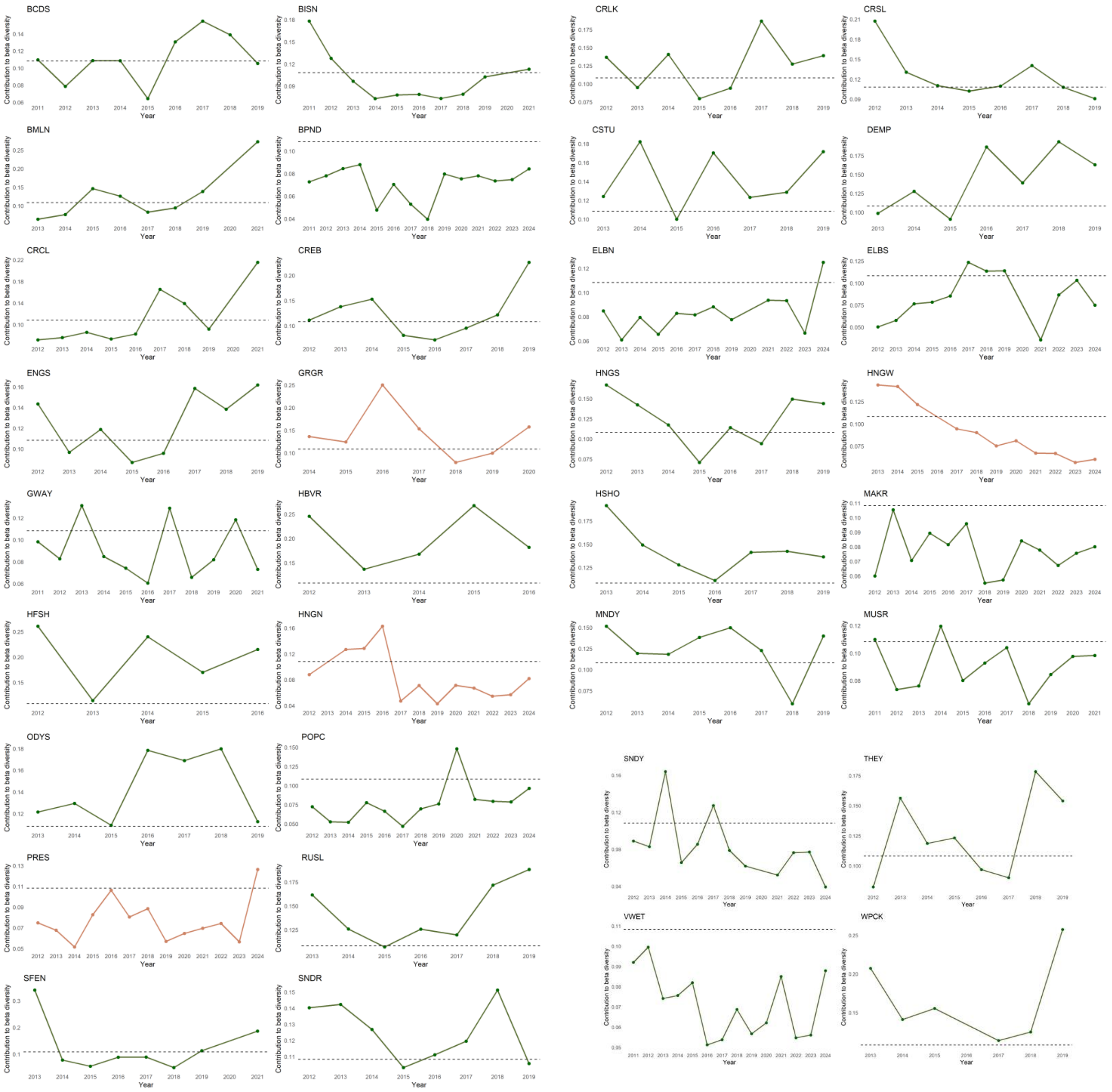


Figure 3. Local contribution to beta diversity (LCBD) values for 34 monitoring stations, showing the years that contribute the most to temporal β-diversity. Stations exposed to fire in 2016 are shown in orange. The dashed horizontal line represents the mean SCBD value across all stations.

Figure 4: Species contributions to beta diversity (SCBD) for 34 monitoring stations in the Athabasca oil sands region, Alberta. Each panel represents a station, showing the top 10 species that contribute most to the overall temporal changes in community composition. Bars indicate SCBD values, with higher values representing species that contribute more to beta diversity. Orange panels are the stations that were exposed to fire in 2016. The dashed vertical line represents the mean SCBD value across all stations.

Question 4: How does wildfire influence the temporal changes in composition of boreal bird communities in the Athabasca oil sands region?

We used redundancy analysis (RDA) and distance-based redundancy analysis (dbRDA), both constrained ordination techniques which incorporate the influence of environmental variables (i.e., fire status) in exploring community dissimilarity, unlike unconstrained ordination techniques which rely solely on compositional dissimilarities without incorporating environmental variables. Both analyses were performed using the ‘vegan’ package in R (Oksanen et al. 2022).

RDA evaluates species–environment relationships and shows individual species responses to environmental gradients allowing for a direct comparison of species composition between treatments (e.g., wildfire), and dbRDA, which operates on distance matrices (i.e., Bray–Curtis dissimilarity) rather than raw community data, allowing for the use of non-Euclidean dissimilarity measures. We used Hellinger-transformed abundance data to reduce the influence of dominant species and to make data suitable for RDA. The model included year and fire status (unburned vs. post-fire) as explanatory variables.

We performed dbRDA using Bray–Curtis dissimilarity (abundance data) and Jaccard dissimilarity (presence/absence data) to evaluate how fire history and year influence community composition. We then used RDA using the same predictors to examine direct relationships between environmental variables and species composition.

$$\textit{Bray–Curtis dissimilarity} \sim \textit{Year} + \textit{Fire status}$$

$$\textit{Jaccard} \sim \textit{Year} + \textit{Fire status}$$

Species scores were extracted to identify taxa most strongly associated with constrained ordination axes. We used permutation tests (n = 999) to assess the statistical significance of the overall model and individual predictors. We restricted permutation using station-level blocks to account for spatial (station-level) dependencies.

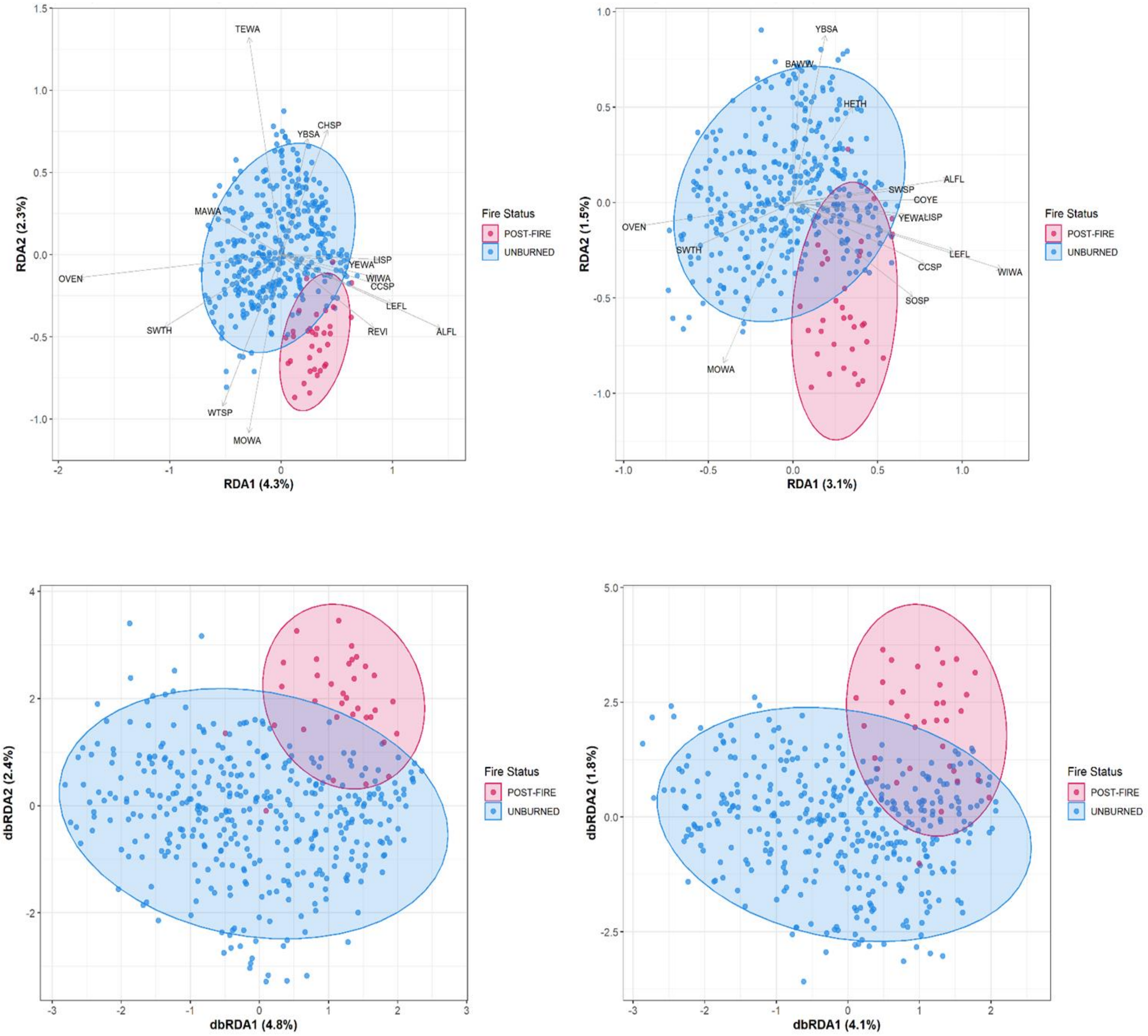


Figure 5: Ordination results from RDA (top) and dbRDA (bottom) showing community dissimilarity based on abundance data (Bray–Curtis; left plots) and incidence-based data (Jaccard; right plots). Assemblages in post-fire landscapes are represented by pink ellipses and unburned are shown in blue. In the RDA plots, species vectors indicate taxa that contribute most to variation along the ordination axes. Species like Yellow-bellied Sapsucker, Hermit and Swainson's Thrushes, White-throated Sparrow, Black-and-white and Mourning warblers and Ovenbird appear more closely aligned with unburned communities (blue ellipse). Species like Alder and Least flycatchers, Red-eyed Vireo, Clay-colored, Song, Lincoln's and Swamp sparrows, Common Yellowthroat and Yellow and Wilson's warblers appear to be closely associated with post-fire conditions (pink ellipse).

Table 5: Summary of constrained ordination results (RDA and dbRDA) assessing the effects of year and fire on bird community composition in the Athabasca oil sands region. The table presents model statistics (R^2, F-statistics, and *p*-values) for each ordination technique. (*) indicate statistical significance at $p < 0.05$.

Ordination technique		Model statistics			Year effect		Fire effect	
		R^2	F statistics	*p*-value	F statistics	*p*-value	F statistics	*p*-value
RDA	(*Bray–Curtis*)	6.57	14.25	0.001^*	15.25	0.001^*	13.25	0.001^*
RDA	(Jaccard)	4.6	9.76	0.001^*	10.57	0.001^*	8.95	0.001^*
dbRDA	(*Bray–Curtis*)	7.26	15.85	0.001^*	15.85	0.001^*	14.68	0.001^*
dbRDA	(Jaccard)	5.89	12.66	0.001^*	12.66	0.001^*	11.15	0.001^*

Summary and interpretation of *redundancy analysis* results

Redundancy Analysis (RDA) ordination shows significant differences in bird community composition between burned and unburned areas (Table 5). For abundance data (using Bray–Curtis dissimilarity), RDA explained 6.57% of the total variation in bird communities, with both year (F = 15.25, *p* = 0.001) and fire status (F = 13.25, *p* = 0.001) having significant effects on community composition. The ordination plot (Figure 5, left panel) shows clear separation between communities in post-fire (pink) and unburned (blue) areas. Species like Alder flycatcher (nesting and foraging within shrubby vegetation), Least flycatcher (nesting in shrubby vegetation) , Red-eyed vireo (nesting in shrubby vegetation), and Clay-colored sparrow (nesting and foraging in shrubby vegetation) appear to be closely associated with post-fire stations that can be attributable to their nesting and foraging habitat associations presumably because of the new early seral vegetation created post-fire, while forest obligate species like Ovenbird and Swainson's thrush are closely associated with unburned stations.

Distance-based RDA (dbRDA) showed even stronger patterns of community differentiation by fire status (Figure 5, right panel). Using Bray–Curtis dissimilarity for abundance data, dbRDA explained 7.26% of total variation (F = 15.85, *p* = 0.001), with communities in post-fire forming a distinct cluster in the ordination space. Similarly, presence/absence data (using Jaccard dissimilarity) explained 5.89% of variation (F = 12.66, *p* = 0.001), also showing significant effects of both year and fire on community composition.

Importance of RDA and dbRDA results

The ordination results demonstrate that wildfire plays a significant role in shaping boreal bird community composition in the Athabasca oil sands region. Both RDA and dbRDA showed clear separation between communities in burned and unburned areas with strong model support. This highlights the importance of incorporating fire into assessments to have a complete understanding of community dynamics in a region influenced by both natural and anthropogenic disturbance legacies.

Traditionally, bird community responses to post-fire conditions in the boreal forest have been attributed primarily to woodpeckers, but these results show that species associated with early seral habitats such as Alder Flycatcher, Least Flycatcher, Red-eyed Vireo, and Clay-colored Sparrow also strongly respond to post-fire conditions. Their association with post-fire conditions likely reflects their association with early seral vegetation that regenerates after fire.

Literature Cited

1. Anderson, M. J., Crist, T. O., Chase, J. M., Vellend, M., Inouye, B. D., Freestone, A. L., ... & Swenson, N. G. (2011). Navigating the multiple meanings of β diversity: A roadmap for the practicing ecologist. Ecology Letters, 14(1), 19–28.
2. Angeler, D. G. (2013). Revealing a conservation challenge through partitioned long-term beta diversity: Increasing turnover and decreasing nestedness of boreal lake metacommunities. Diversity and Distributions, 19(7), 772–781.
3. Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. Global Ecology and Biogeography, 19(1), 134–143.
4. Baselga, A., Orme, D., Villeger, S., De Bortoli, J., Leprieur, F., Logez, M., & Henriques-Silva, R. (2012). Partitioning beta diversity into turnover and nestedness components. Package ‘betapart’, Version 1.
5. Collins, S. L., Micheli, F., & Hartt, L. (2000). A method to determine rates and patterns of variability in ecological communities. Oikos, 91(2), 285–293.
6. Collins, S. L., & Xia, Y. (2015). Long-term dynamics and hotspots of change in a desert grassland plant community. The American Naturalist, 185(2), E30–E43.
7. Dubé, M. G., Dunlop, J. M., Davidson, C., Beausoleil, D. L., Hazewinkel, R. R., & Wyatt, F. (2021). History, overview, and governance of environmental monitoring in the oil sands region of Alberta, Canada. Integrated Environmental Assessment and Management, 18(2), 319–332
8. Kalukapuge, T., Leston, L. F., Martínez-Lanfranco, J. A., & Bayne, E. (2024). Response of boreal songbird communities to the width of linear features created by the energy sector in Alberta, Canada. Avian Conservation and Ecology, 19(2).
9. Kampichler, C., & van der Jeugd, H. P. (2013). Determining patterns of variability in ecological communities: Time lag analysis revisited. Environmental and Ecological Statistics, 20, 271–284.
10. Knaggs, M., Haché, S., Nielsen, S. E., Pankratz, R. F., & Bayne, E. (2020). Avian response to wildfire severity in a northern boreal region. Forests, 11(12), 1330.
11. Legendre, P., & De Cáceres, M. (2013). Beta diversity as the variance of community data: Dissimilarity coefficients and partitioning. Ecology Letters, 16(8), 951–963.
12. Legendre, P., & Gallagher, E. D. (2001). Ecologically meaningful transformations for ordination of species data. Oecologia, 129, 271–280.
13. Magurran, A. E., & McGill, B. J. (Eds.). (2010). Biological diversity: Frontiers in measurement and assessment. Oxford University Press.
14. Magurran, A. E., Baillie, S. R., Buckland, S. T., Dick, J. M., Elston, D. A., Scott, E. M., ... & Watt, A. D. (2010). Long-term datasets in biodiversity research and monitoring:

Assessing change in ecological communities through time. Trends in Ecology & Evolution, 25(10), 574–582.

15. Oksanen, J., Simpson, G. L., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., ... & Solymos, P. (2022). vegan: Community Ecology Package. R package version 2.6-4. https://CRAN.R-project.org/package=vegan
16. Saracco, J. F., Pyle, P., Kaschube, D. R., Kohler, M., Godwin, C. M., & Foster, K. R. (2022). Demographic declines over time and variable responses of breeding bird populations to human footprint in the Athabasca Oil Sands Region, Alberta, Canada. Ornithological Applications, 124(4), duac037.
17. Shaw, C. H., Rodrigue, S., Voicu, M. F., Latifovic, R., Pouliot, D., Hayne, S., ... & Kurz, W. A. (2021). Cumulative effects of natural and anthropogenic disturbances on the forest carbon balance in the oil sands region of Alberta, Canada: A pilot study (1985–2012). Carbon Balance and Management, 16, 1–18.
18. Thibault, K. M., White, E. P., & Ernest, S. M. (2004). Temporal dynamics in the structure and composition of a desert rodent community. Ecology, 85(10), 2649–2655.
19. Vellend, M. (2010). Conceptual synthesis in community ecology. The Quarterly Review of Biology, 85(2), 183–206.
20. Wright, D. H., & Reeves, J. H. (1992). On the meaning and measurement of nestedness of species assemblages. *Oecologia*, *92*, 416-428.