Appendix 1. Supplementary figures and tables

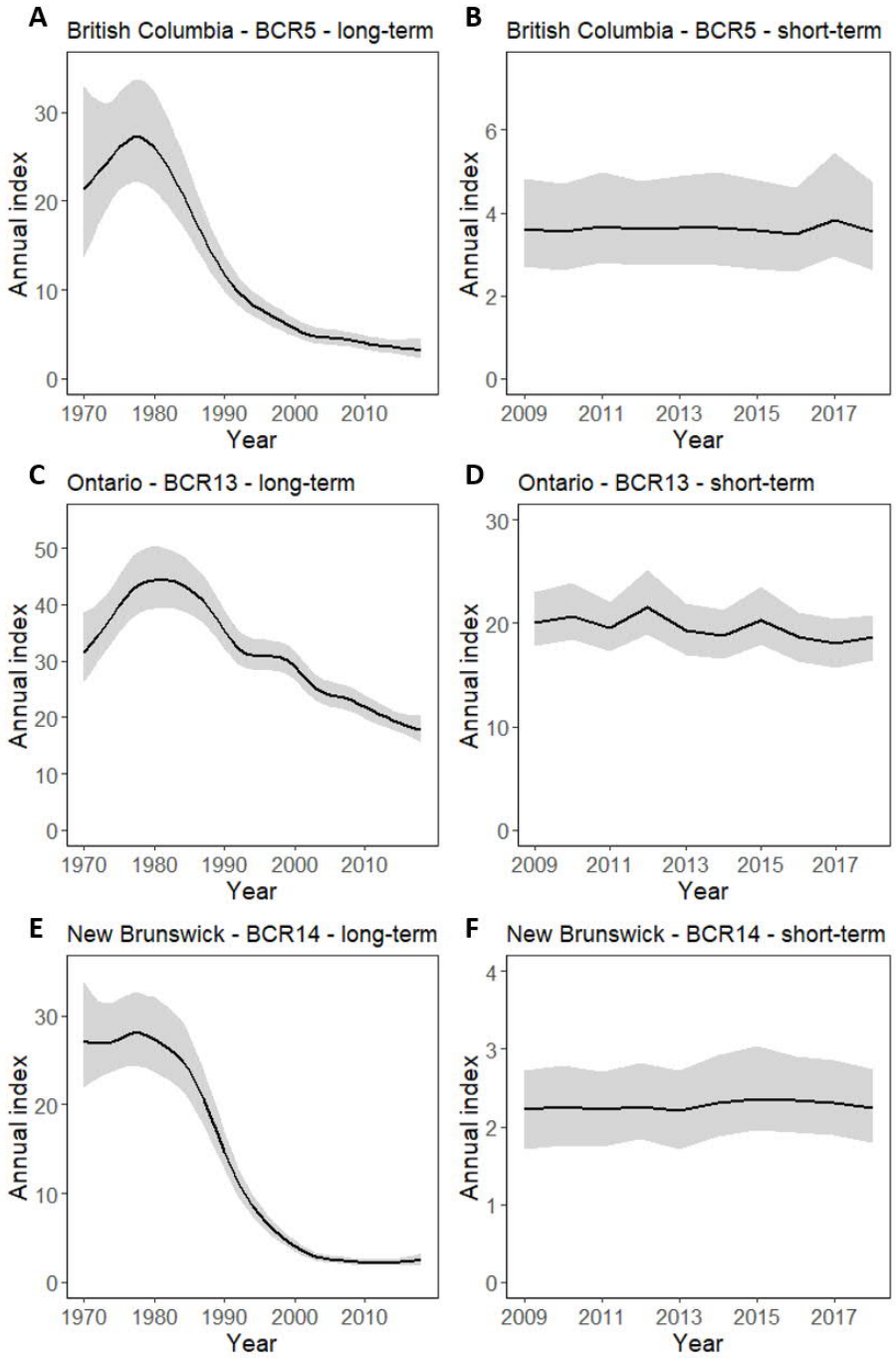


Figure A1.1. Annual indices of Barn Swallows in three BBS strata, British Columbia – BCR5 (A, B), Ontario – BCR13 (C, D) and New Brunswick – BCR14 (E, F), where breeding performance was studied. Long-term and short-term estimates of annual indices are from 1970 to 2018 (A, C, E) and 2009 to 2018 (B, D, F), respectively. Annual indices were calculated using a hierarchical Bayesian model with the GAM approach for 1970 to 2018 and the slope approach for 2009 to 2018.

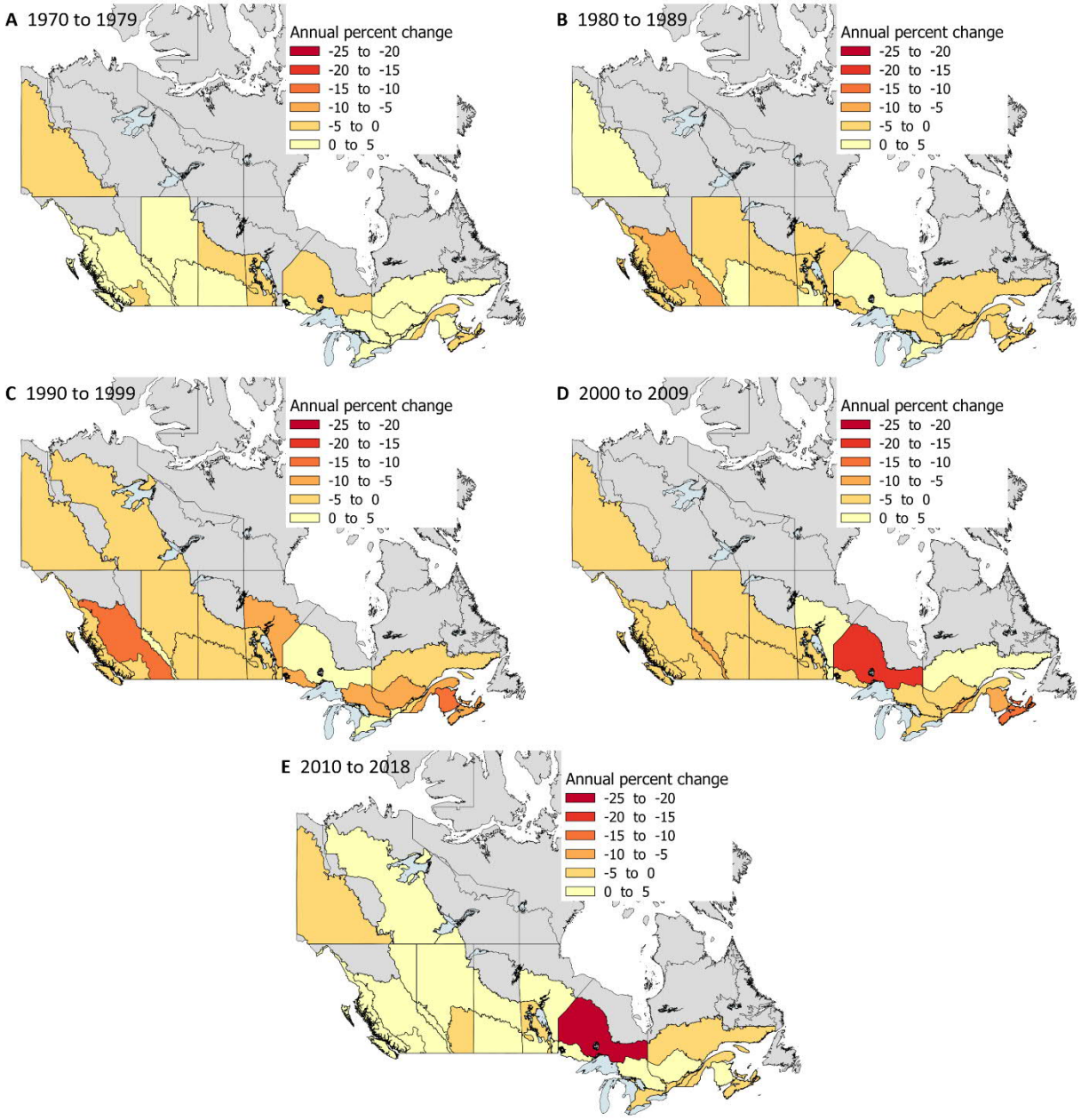


Figure A1.2. Average annual percent change in the Barn Swallow population in Canada from (A) 1970 to 1979, (B) 1980 to 1989, (C) 1990 to 1999, (D) 2000 to 2009 and (E) 2010 to 2018 stratified by intersections of province/territory region and BCR. The population trends use annual index data that represents the estimated average abundance of Barn Swallows on BBS routes run in a given year by an average observer in that stratum. The annual indices were calculated using hierarchical Bayesian models using the slope approach. In the model, we extracted the annual indices for the time periods indicated in each panel and chose the slope approach because of the constant rate of change assumption. Barn Swallows either are not present or have insufficient data in regions shaded gray.

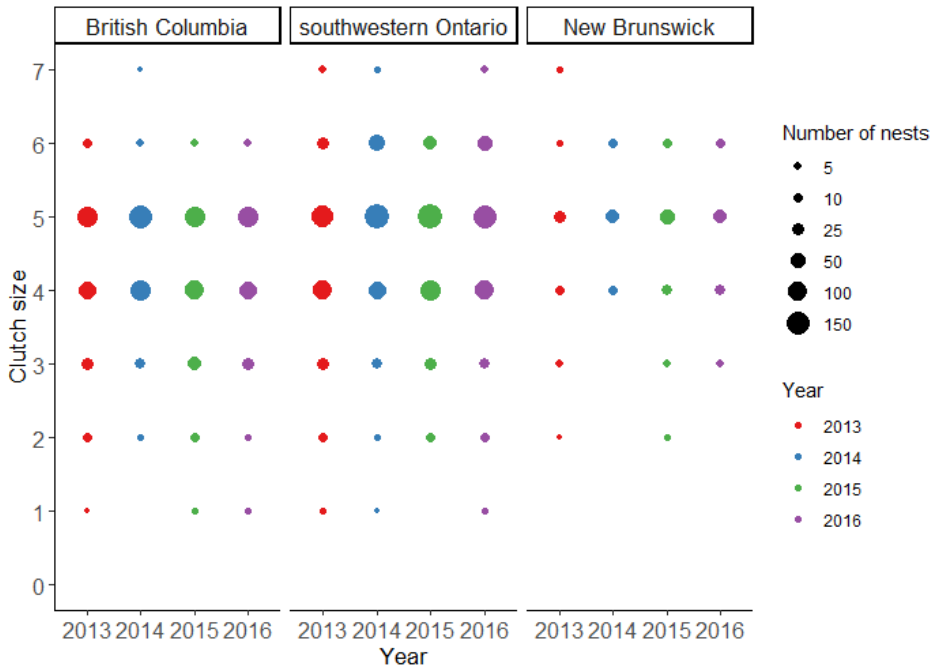


Figure A1.3. Number of nests organized by year, clutch size (number of eggs) and study region (BC, southwestern Ontario and New Brunswick).

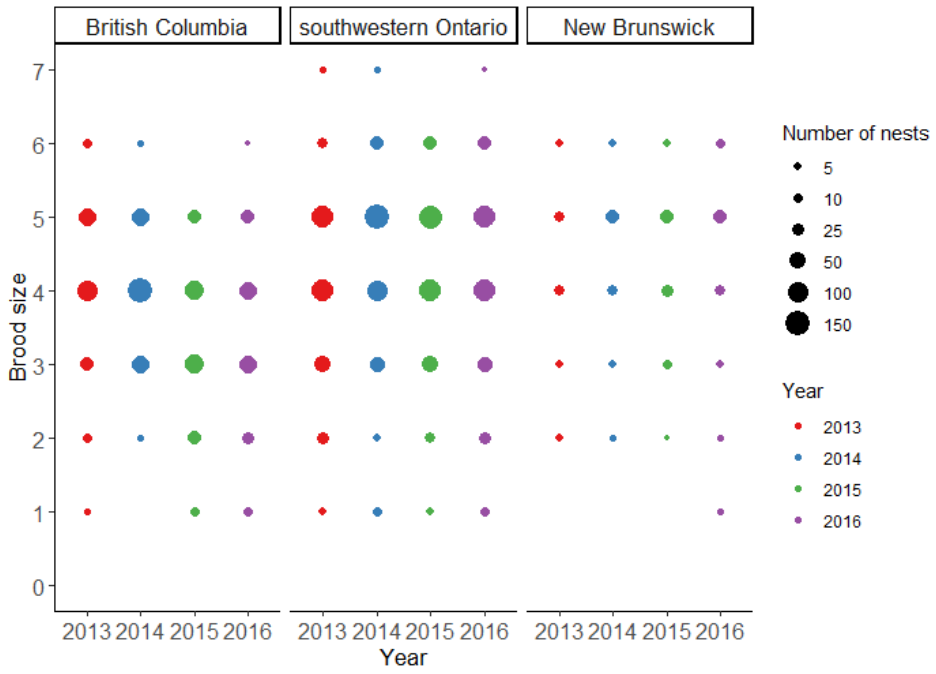


Figure A1.4. Number of nests organized by year, brood size (number of nestlings) and study region (BC, southwestern Ontario and New Brunswick).

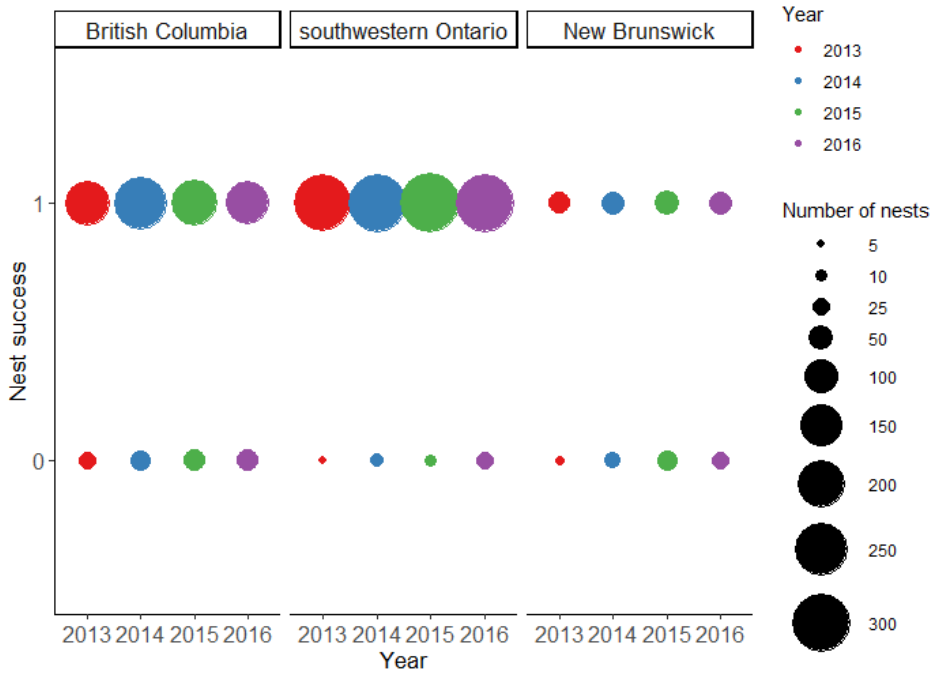


Figure A1.5. Number of successful (1) and unsuccessful (0) nests organized by year and study region (BC, southwestern Ontario and New Brunswick).

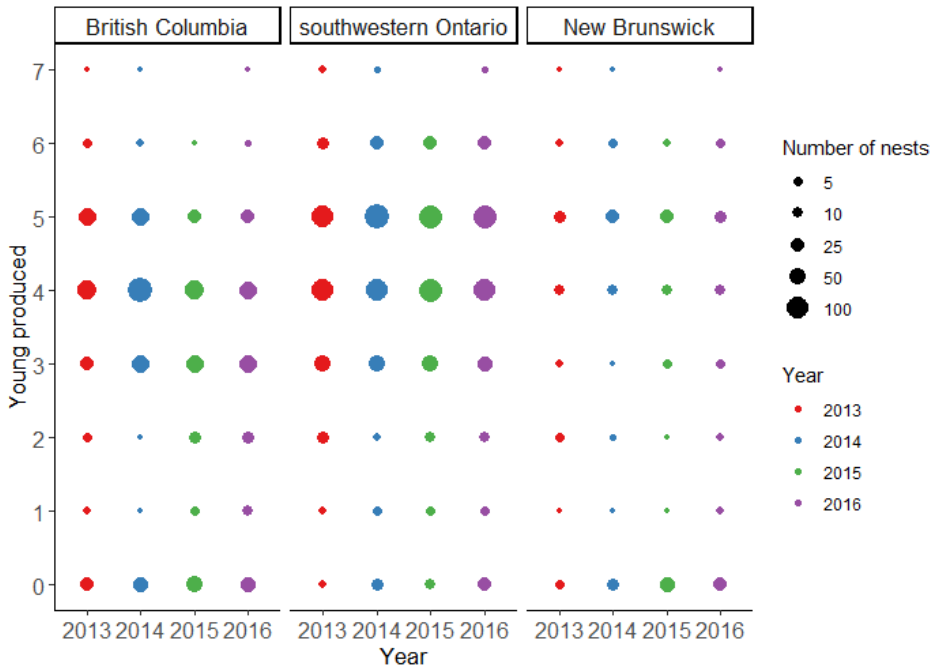


Figure A1.6. Number of nests organized by year, number of young produced (brood size multiplied by nest success for a individual nest) and study region (BC, southwestern Ontario and New Brunswick).

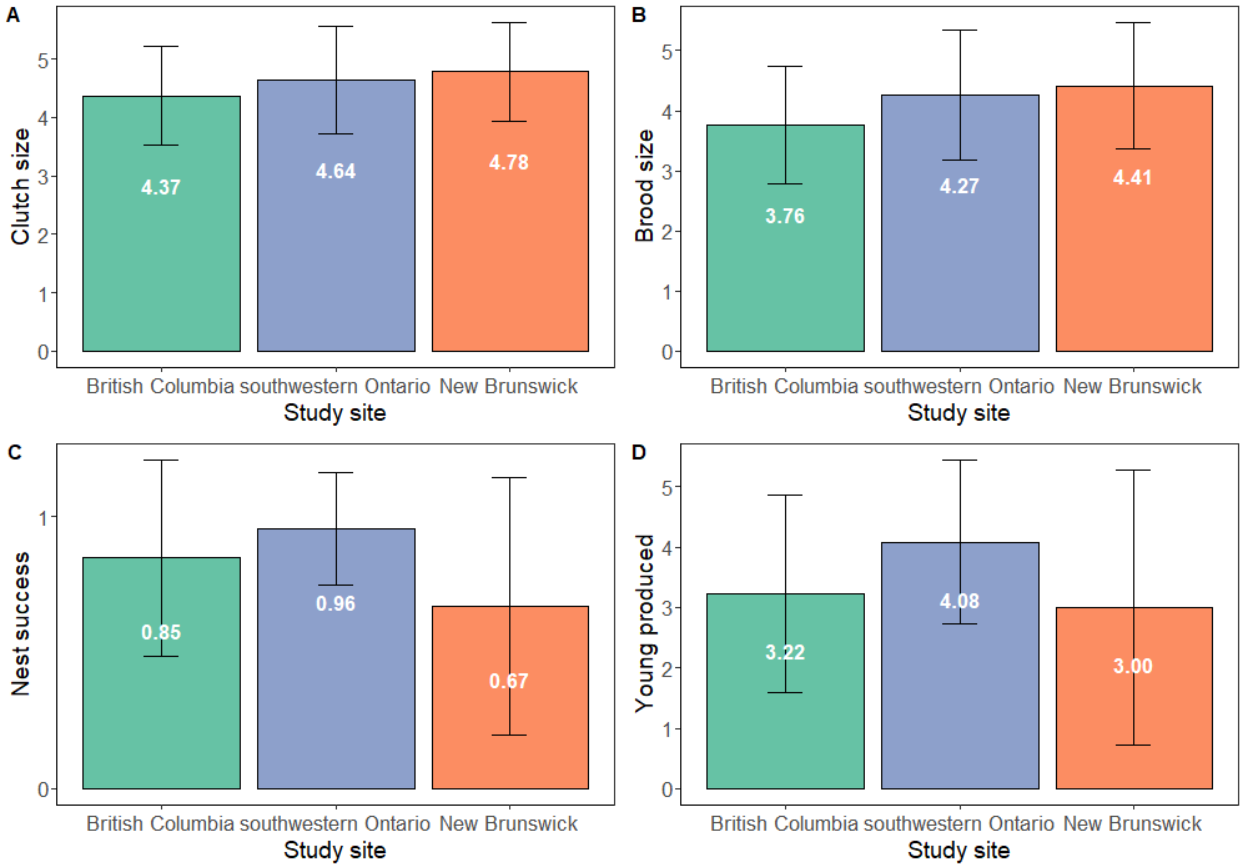


Figure A1.7. Mean + SD (error bars) of Barn Swallow breeding performance measures (A – clutch size, B – brood size, C – nest success and D – number of young produced) at study sites from 2013 to 2016. Mean values are indicated inside the bars in white.

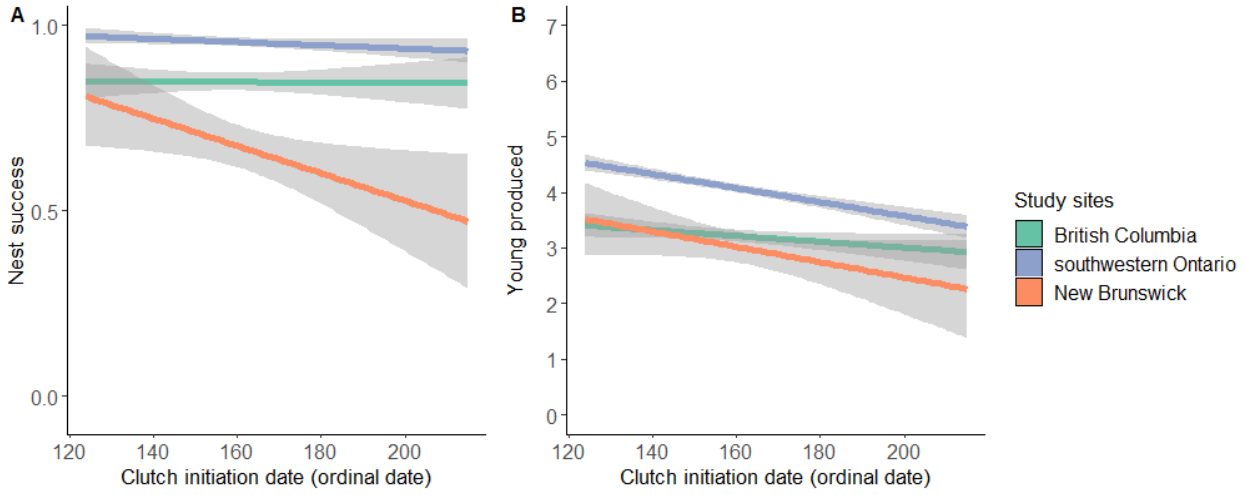


Figure A1.8. Relationship between Barn Swallow breeding performance (A – nest success, B – number of young produced) and clutch initiation date at study sites from 2013 to 2016. Shaded gray area around lines represent standard error.

Table A1.1. Level of support for relationships between Barn Swallow breeding performance and spatial (study region) and temporal (clutch initiation date and year) factors, based on model selection. Generalized linear mixed-models were used to estimate the relationships, with a binomial distribution for nest success and a zero-inflated Poisson distribution for number of young produced. Study region (British Columbia, southwestern Ontario and New Brunswick) and year (2013, 2014, 2015 and 2016) were treated as categorical variables. Clutch initiation date was treated as a continuous variable and was centred and scaled (standardized). An interaction term was included between study region and year in some candidate models. In all models, there was a random effect for colony. Presented here are the number of model parameters (k), small-samples Akaike's Information Criteria ($AIC_C$), change in $AIC_C$ ($\Delta AIC_C$), Akaike weights ($w_i$) and log likelihood for each candidate model.

| Response variable | Model | k | AICc | ΔAICc | $w_i$ |
|---|---|---|---|---|---|
| Nest success | Region + Year + Clutch initiation date | 7 | 1527.61 | 0.00 | 0.35 |
| | Region * Year + Clutch initiation date | 13 | 1527.79 | 0.18 | 0.32 |
| | Region * Year | 12 | 1529.02 | 1.40 | 0.17 |
| | Region + Year | 6 | 1529.27 | 1.66 | 0.15 |
| | Region + Clutch initiation date | 4 | 1545.38 | 17.77 | 0.00 |
| | Region | 3 | 1547.07 | 19.46 | 0.00 |
| | Clutch initiation date + Year | 5 | 1565.26 | 37.65 | 0.00 |
| | Year | 4 | 1567.39 | 39.78 | 0.00 |
| | Clutch initiation date | 2 | 1582.61 | 55.00 | 0.00 |
| | Intercept | 1 | 1584.63 | 57.02 | 0.00 |
| Young produced | Region * Year + Clutch initiation date | 13 | 9117.30 | 0.00 | 0.96 |
| | Region + Year + Clutch initiation date | 7 | 9123.62 | 6.32 | 0.04 |
| | Region + Clutch initiation date | 4 | 9131.62 | 14.33 | 0.00 |
| | Region * Year | 12 | 9136.56 | 19.27 | 0.00 |
| | Region + Year | 6 | 9143.09 | 25.79 | 0.00 |
| | Region | 3 | 9148.61 | 31.31 | 0.00 |
| | Clutch initiation date + Year | 5 | 9152.45 | 35.16 | 0.00 |
| | Clutch initiation date | 2 | 9158.96 | 41.66 | 0.00 |
| | Year | 4 | 9171.91 | 54.62 | 0.00 |
| | Intercept | 1 | 9176.00 | 58.71 | 0.00 |

Table A1.2. Model estimates and associated measures from best-fitting generalized linear mixed-models estimating the effect of spatial (study region) and temporal (clutch initiation date and year) factors on Barn Swallow breeding performance. In all models, there was a random effect for colony. British Columbia was the reference study region and 2013 was the reference year.

| Response variable | Predictor variables | Estimate | SE | Lower 95% CI | Upper 95% CI | z | P |
|---|---|---|---|---|---|---|---|
| Nest success | Intercept | 2.42 | 0.24 | 1.95 | 2.89 | 10.15 | < 0.001 |
| | Year - 2014 | -0.52 | 0.23 | -0.96 | -0.07 | -2.28 | 0.022 |
| | Year - 2015 | -0.82 | 0.22 | -1.25 | -0.38 | -3.68 | < 0.001 |
| | Year - 2016 | -0.98 | 0.22 | -1.42 | -0.54 | -4.39 | < 0.001 |
| | Region - southwestern Ontario | 1.34 | 0.24 | 0.87 | 1.80 | 5.64 | < 0.001 |
| | Region - New Brunswick | -1.10 | 0.28 | -1.65 | -0.56 | -3.96 | < 0.001 |
| | Clutch initiation date | -0.14 | 0.07 | -0.27 | 0.00 | -1.93 | 0.054 |
| Young produced | Intercept | 1.40 | 0.04 | 1.32 | 1.47 | 36.18 | < 0.001 |
| | Year - 2014 | -0.02 | 0.05 | -0.12 | 0.08 | -0.46 | 0.648 |
| | Year - 2015 | -0.22 | 0.06 | -0.33 | -0.11 | -3.84 | < 0.001 |
| | Year - 2016 | -0.23 | 0.06 | -0.34 | -0.11 | -3.76 | < 0.001 |
| | Region - southwestern Ontario | 0.02 | 0.05 | -0.07 | 0.12 | 0.45 | 0.651 |
| | Region - New Brunswick | 0.01 | 0.09 | -0.17 | 0.18 | 0.10 | 0.923 |
| | Clutch initiation date | -0.05 | 0.01 | -0.08 | -0.03 | -4.59 | < 0.001 |
| | Year - 2014 : Region - southwestern Ontario | 0.08 | 0.06 | -0.05 | 0.21 | 1.23 | 0.218 |
| | Year - 2015 : Region - southwestern Ontario | 0.23 | 0.07 | 0.09 | 0.37 | 3.26 | 0.001 |
| | Year - 2016 : Region - southwestern Ontario | 0.25 | 0.07 | 0.11 | 0.40 | 3.48 | 0.001 |
| | Year - 2014 : Region - New Brunswick | 0.16 | 0.12 | -0.08 | 0.40 | 1.28 | 0.202 |
| | Year - 2015 : Region - New Brunswick | 0.23 | 0.13 | -0.02 | 0.49 | 1.82 | 0.068 |
| | Year - 2016 : Region - New Brunswick | 0.20 | 0.13 | -0.05 | 0.46 | 1.55 | 0.121 |

Table A1.3. Type-III ANOVA results from best-fitting generalized linear mixed-models estimating the effect of spatial (study region) and temporal (clutch initiation date and year) factors on Barn Swallow breeding performance.

| Response variable | Predictor variables | Df | Chi-square | P |
|---|---|---|---|---|
| Nest success | Intercept | 1 | 103.10 | < 0.001 |
| | Year | 3 | 21.90 | < 0.001 |
| | Region | 2 | 81.07 | < 0.001 |
| | Clutch initiation date | 1 | 3.71 | 0.054 |
| Young produced | Intercept | 1 | 1309.30 | < 0.001 |
| | Year | 3 | 27.51 | < 0.001 |
| | Region | 2 | 0.21 | 0.901 |
| | Clutch initiation date | 1 | 21.09 | < 0.001 |
| | Year : Region | 6 | 18.43 | 0.005 |

Table A1.4. Level of support for relationships between average breeding performance factors and Barn Swallow annual indices in the subsequent year, based on model selection. General linear mixed-models were used to estimate the relationships with a normal distribution for annual indices and a random effect for year. Annual indices were calculated using a hierarchical Bayesian model with the first-difference approach on BBS data collected in the strata that encompass each field site. Our breeding performance data were found in the British Columbia-BCR 5, Ontario-BCR 13 and New Brunswick-BCR 14 BBS strata. For each stratum, the annual indices were divided by the average annual index across the evaluated time period resulting in a response variable that represented deviations from the average annual index. An interaction term was included between breeding performance variables and study region in some candidate models. The breeding performance factors and year were treated as continuous variables and were centred and scaled (standardized). Presented here are the number of model parameters (k), small-samples Akaike's Information Criteria ($AIC_C$), change in AICC ($\Delta AIC_C$), Akaike weights ($w_i$) and log likelihood for each candidate model.

| Model | k | AICc | ΔAICc | $w_i$ |
|---|---|---|---|---|
| Intercept | 1 | -52.96 | 0.00 | 0.98 |
| Mean colony size | 2 | -43.12 | 9.83 | 0.01 |
| Mean young produced | 2 | -42.95 | 10.01 | 0.01 |
| Mean nest success | 2 | -42.90 | 10.06 | 0.01 |
| Region | 3 | -36.44 | 16.52 | 0.00 |
| Mean colony size + Region | 4 | -26.27 | 26.69 | 0.00 |
| Mean young produced + Region | 4 | -26.00 | 26.96 | 0.00 |
| Mean nest success + Region | 4 | -25.85 | 27.10 | 0.00 |
| Mean nest success * Region | 6 | -11.32 | 41.63 | 0.00 |
| Mean young produced * Region | 6 | -10.05 | 42.90 | 0.00 |
| Mean colony size * Region | 6 | -8.24 | 44.72 | 0.00 |

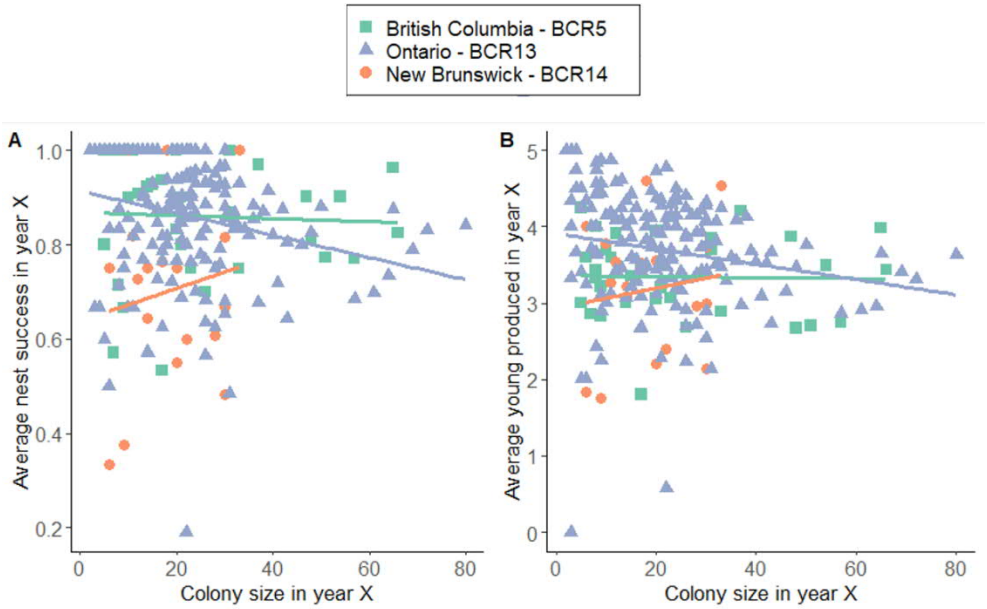


Figure A1.9. Relationship between colony size in year X and breeding performance (A – nest success, B – number of young produced) in year X from 2006 to 2018 to test for density dependence.

Table A1.5. Level of support for relationships between local colony size from year X and local breeding performance (nest success and young produced) in year X to test density dependence. In models where nest success was the response variable, generalized linear mixed-models estimated the relationships and used a beta distribution. In models where young produced was the response variable, general linear mixed-models were used to estimate the relationships and used a normal distribution. An interaction term was included between colony size and study region in some candidate models. In all models, there was a random effect for colony. Presented here are the number of model parameters (k), small-samples Akaike's Information Criteria ($AIC_C$), change in AICC ($\Delta AIC_C$), Akaike weights ($w_i$) and log likelihood for each candidate model.

| Response variable | Model | k | AICc | ΔAICc | $w_i$ |
|---|---|---|---|---|---|
| Nest success | Colony size * Region + Year | 17 | -402.92 | 0.00 | 0.35 |
| | Colony size * Region | 6 | -402.73 | 0.19 | 0.32 |
| | Colony size + Region | 4 | -401.88 | 1.04 | 0.21 |
| | Colony size + Region + Year | 15 | -400.55 | 2.37 | 0.11 |
| | Colony size | 2 | -393.94 | 8.98 | 0.00 |
| | Colony size + Year | 13 | -391.84 | 11.08 | 0.00 |
| | Region + Year | 14 | -387.41 | 15.51 | 0.00 |
| | Region | 3 | -382.74 | 20.18 | 0.00 |
| | Year | 12 | -379.96 | 22.96 | 0.00 |
| | Intercept | 1 | -376.60 | 26.32 | 0.00 |
| Young produced | Region | 3 | 510.85 | 0.00 | 0.51 |
| | Colony size + Region | 4 | 511.93 | 1.08 | 0.30 |
| | Intercept | 1 | 514.16 | 3.31 | 0.10 |
| | Colony size | 2 | 514.91 | 4.06 | 0.07 |
| | Colony size *Region | 6 | 516.63 | 5.78 | 0.03 |
| | Region + Year | 14 | 523.02 | 12.18 | 0.00 |
| | Year | 12 | 524.31 | 13.46 | 0.00 |
| | Colony size + Region + Year | 15 | 525.73 | 14.89 | 0.00 |
| | Colony size + Year | 13 | 526.10 | 15.25 | 0.00 |
| | Colony size * Region + Year | 17 | 531.03 | 20.18 | 0.00 |

Table A1.6. Model estimates and associated measures from the best-fitting models estimating the effect of local colony size, region and temporal factors (year) in year X on local breeding performance in year X at colonies to test density dependence. British Columbia was the reference study region and 2006 was the reference year in the models.

| Response variable | Predictor variables | Estimate | SE | Lower 95% CI | Upper 95% CI | z/t | P |
|---|---|---|---|---|---|---|---|
| Nest | Intercept | 2.50 | 1.00 | 0.54 | 4.46 | 2.50 | 0.012 |
| Success | Colony size | -0.21 | 0.11 | -0.43 | 0.01 | -1.84 | 0.066 |
| | Region - New Brunswick | -0.61 | 0.27 | -1.14 | -0.09 | -2.30 | 0.022 |
| | Region - southwestern Ontario | 0.05 | 0.19 | -0.32 | 0.43 | 0.28 | 0.779 |
| | Year - 2007 | 0.00 | 1.20 | -2.35 | 2.35 | 0.00 | 1.000 |
| | Year - 2008 | -0.43 | 1.02 | -2.42 | 1.56 | -0.42 | 0.675 |
| | Year - 2009 | -0.96 | 1.01 | -2.94 | 1.03 | -0.95 | 0.345 |
| | Year - 2010 | -0.64 | 1.01 | -2.62 | 1.34 | -0.63 | 0.527 |
| | Year - 2011 | -0.90 | 1.00 | -2.86 | 1.07 | -0.89 | 0.371 |
| | Year - 2012 | -1.09 | 1.00 | -3.05 | 0.87 | -1.09 | 0.276 |
| | Year - 2013 | -0.28 | 1.00 | -2.23 | 1.67 | -0.28 | 0.779 |
| | Year - 2014 | -0.51 | 0.99 | -2.45 | 1.43 | -0.51 | 0.609 |
| | Year - 2015 | -0.97 | 0.99 | -2.92 | 0.97 | -0.98 | 0.327 |
| | Year - 2016 | -1.10 | 1.00 | -3.05 | 0.86 | -1.10 | 0.270 |
| | Year - 2017 | -1.08 | 1.02 | -3.09 | 0.92 | -1.06 | 0.290 |
| | Colony size : Region - New Brunswick | 0.75 | 0.33 | 0.10 | 1.39 | 2.28 | 0.023 |
| | Colony size : Region - southwestern Ontario | -0.09 | 0.13 | -0.34 | 0.17 | -0.68 | 0.495 |
| Young | Intercept | 3.35 | 0.14 | 3.07 | 3.62 | 24.23 | < 0.001 |
| produced | Region - New Brunswick | -0.20 | 0.24 | -0.66 | 0.27 | -0.83 | 0.411 |
| | Region - southwestern Ontario | 0.37 | 0.15 | 0.07 | 0.67 | 2.39 | 0.021 |

Table A1.7. Type-III ANOVA results from best-fitting models estimating the effect of local colony size, region and temporal factors (year) in year X on local breeding performance in year X at colonies to test density dependence.

| Response variable | Predictor variables | Df | Chi-square | P |
|---|---|---|---|---|
| Nest Success | Intercept | 1 | 6.25 | 0.012 |
| | Colony size | 1 | 3.37 | 0.066 |
| | Region | 2 | 9.88 | 0.007 |
| | Year | 11 | 25.51 | 0.008 |
| | Colony size : Region | 2 | 7.38 | 0.025 |
| Young produced | Intercept | 1 | 587.24 | < 0.001 |
| | Region | 2 | 11.62 | 0.003 |

Table A1.8. Level of support for relationships between local breeding performance (mean nest success and mean young produced) in year X and percentage point difference in local colony size from year X to year X+1 to test recruitment. General linear mixed-models were used to estimate the relationships with a normal distribution for percentage point difference in colony size from year X to year X+1 and a random effect for BBS strata (transect of province/territory and BCR) and colony; colony was nested in BBS stratum. Presented here are the number of model parameters (k), small-samples Akaike's Information Criteria ($AIC_c$), change in AICC ($\Delta AIC_c$), Akaike weights ($w_i$) and log likelihood for each candidate model.

| Model | k | AICc | ΔAICc | $w_i$ |
|---|---|---|---|---|
| Mean young produced + Year | 13 | 2147.51 | 0.00 | 0.70 |
| Mean nest success + Year | 13 | 2149.20 | 1.69 | 0.30 |
| Year | 12 | 2170.56 | 23.04 | 0.00 |
| Mean young produced | 2 | 2216.68 | 69.16 | 0.00 |
| Mean nest success | 2 | 2218.08 | 70.57 | 0.00 |
| Intercept | 1 | 2247.44 | 99.92 | 0.00 |

Table A1.9. Model estimates and associated measures from the best-fitting models estimating the effect of local breeding performance (mean nest success and mean young produced) in year X on the percentage point difference in local colony size from year X to year X+1 to test recruitment. 2006 was the reference year in the models.

| Predictor variable | Estimate | SE | Lower 95% CI | Upper 95% CI | t | P |
|---|---|---|---|---|---|---|
| Intercept | 8.94 | 33.25 | -56.23 | 74.12 | 0.27 | 0.788 |
| Mean young produced | 11.31 | 2.34 | 6.72 | 15.89 | 4.84 | < 0.001 |
| Year - 2007 | 39.46 | 40.96 | -40.82 | 119.75 | 0.96 | 0.336 |
| Year - 2008 | 10.95 | 34.68 | -57.01 | 78.92 | 0.32 | 0.752 |
| Year - 2009 | -13.93 | 34.61 | -81.77 | 53.91 | -0.40 | 0.688 |
| Year - 2010 | -14.41 | 34.47 | -81.98 | 53.15 | -0.42 | 0.676 |
| Year - 2011 | -1.09 | 34.10 | -67.94 | 65.75 | -0.03 | 0.974 |
| Year - 2012 | -31.93 | 34.11 | -98.77 | 34.92 | -0.94 | 0.350 |
| Year - 2013 | -2.86 | 33.78 | -69.07 | 63.35 | -0.09 | 0.933 |
| Year - 2014 | -7.42 | 33.65 | -73.36 | 58.52 | -0.22 | 0.826 |
| Year - 2015 | -9.49 | 33.66 | -75.46 | 56.48 | -0.28 | 0.778 |
| Year - 2016 | -6.75 | 33.99 | -73.36 | 59.86 | -0.20 | 0.843 |
| Year - 2017 | -20.67 | 35.26 | -89.78 | 48.45 | -0.59 | 0.558 |

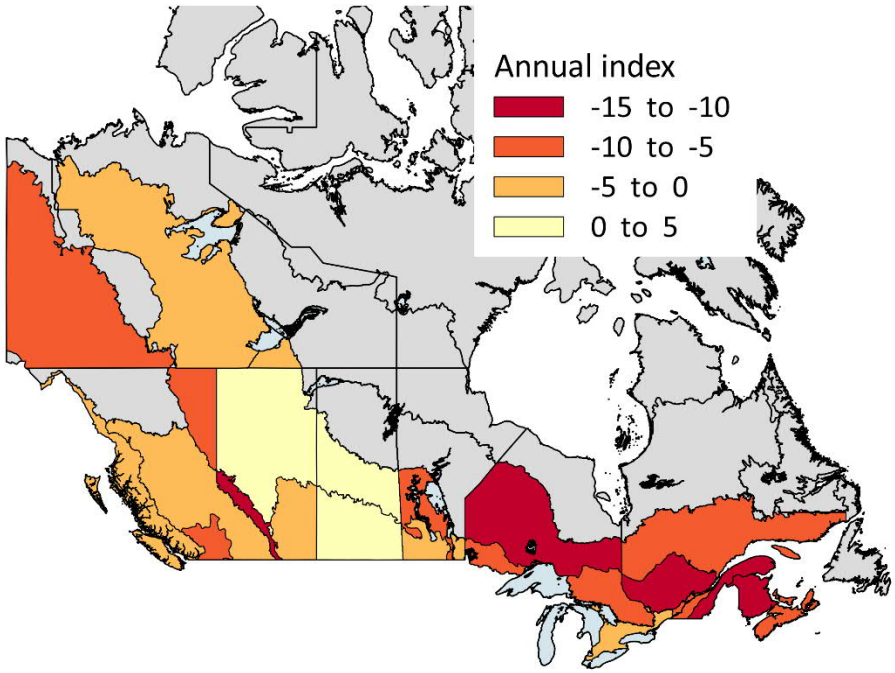


Figure A1.10. Average annual percent change in the Bank Swallow population in Canada from 1970 to 2018 stratified by intersections of region (state/province/territory) and BCR. The population trends use annual index data that represents the estimated average abundance of Bank Swallow on BBS routes run in a given year by an average observer in that stratum. The annual indices were calculated using hierarchical Bayesian models using the GAM approach. In regions shaded gray there are no BBS routes, Bank Swallows are not present or Bank Swallows have insufficient data.

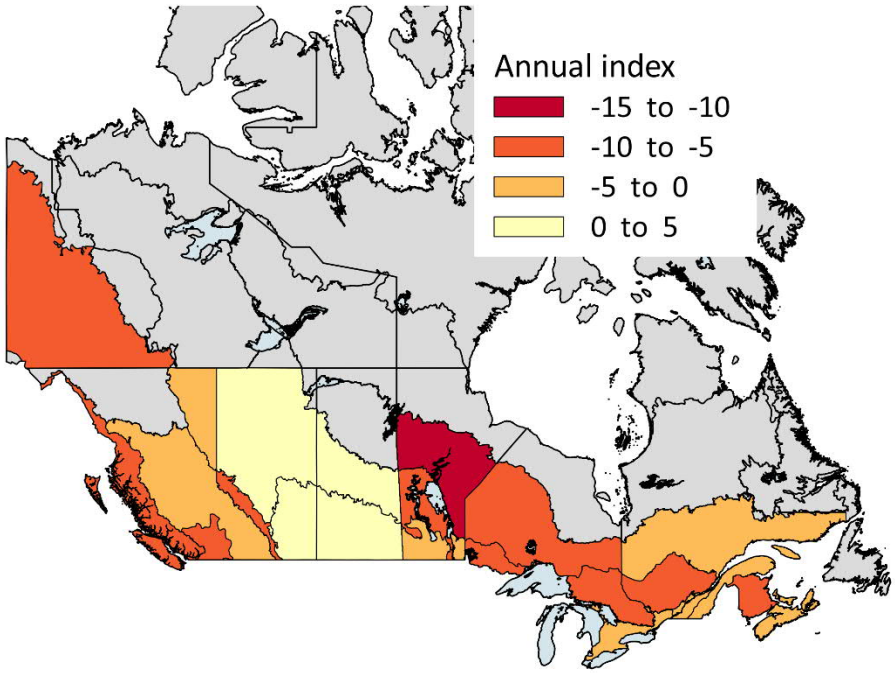


Figure A1.11. Average annual percent change in the Cliff Swallow population in Canada from 1970 to 2018 stratified by intersections of region (state/province/territory) and BCR. The population trends use annual index data that represents the estimated average abundance of Cliff Swallow on BBS routes run in a given year by an average observer in that stratum. The annual indices were calculated using hierarchical Bayesian models using the GAM approach. In regions shaded gray there are no BBS routes, Cliff Swallows are not present or Cliff Swallows have insufficient data.

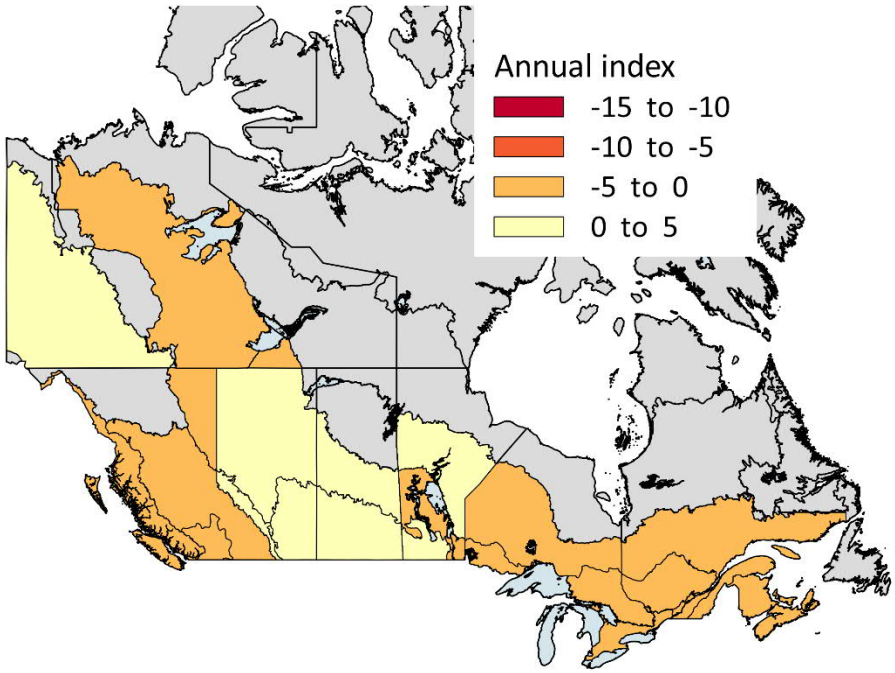


Figure A1.12. Average annual percent change in the Tree Swallow population in Canada from 1970 to 2018 stratified by intersections of region (state/province/territory) and BCR. The population trends use annual index data that represents the estimated average abundance of Tree Swallow on BBS routes run in a given year by an average observer in that stratum. The annual indices were calculated using hierarchical Bayesian models using the GAM approach. In regions shaded gray there are no BBS routes, Tree Swallows are not present or Tree Swallows have insufficient data.

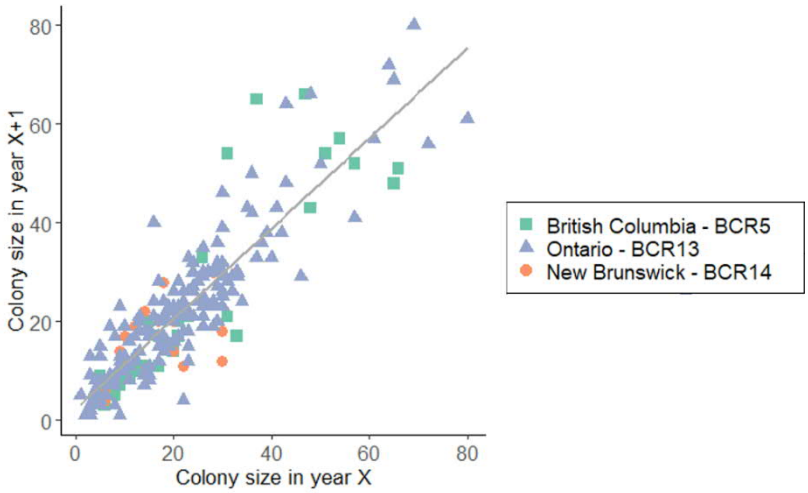


Figure A1.13. Relationship between colony size in year X and colony size in year X+1 from 2006 to 2018. The colony size per year was calculated. For each data point, the local colony size in year X was linked to local colony size the following breeding season (i.e., year X+1).