## Supplementary materials

## Table S1 – Number of years with data that each species in each cell had for the estimation of anomalies (variations across years). Pipilo erythrophthalmus was removed from the analysis due to the lack of enough data to estimate migratory speed.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Cell** **Number** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Species** | **39** | **40** | **45** | **46** | **47** | **48** | **49** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **69** | **70** | **71** | **72** |
| *Archilochus colubris* |  |  |  |  | 9 |  |  |  | 9 | 8 |  | 11 | 10 | 9 | 8 | 10 | 14 | 8 | 8 | 13 | 13 | 14 | 11 | 13 |  | 11 | 10 | 9 |
| *Catharus fuscescens* |  | 9 | 13 |  |  | 8 |  | 11 | 10 | 8 |  | 13 | 11 |  | 13 | 12 | 15 |  |  | 15 | 16 | 15 | 14 | 14 |  |  | 8 | 9 |
| *Coccyzus americanus* |  |  |  |  |  |  |  |  |  |  |  | 10 |  |  |  |  | 8 |  |  |  |  |  | 13 | 11 |  | 9 | 9 | 11 |
| *Contopus virens* |  |  |  |  | 10 | 11 |  | 8 | 8 |  |  | 15 | 10 | 8 | 15 | 13 | 14 | 12 | 9 | 15 | 14 | 13 | 14 | 13 | 8 | 12 | 11 | 12 |
| *Dolichonyx oryzivorus* |  |  | 10 |  | 8 | 12 |  | 11 | 11 | 9 |  | 13 |  |  | 8 | 14 | 15 |  |  | 11 |  | 12 | 15 | 10 |  |  |  | 8 |
| *Dumetella carolinensis* | 9 |  | 11 |  | 9 | 11 |  |  | 11 |  | 9 | 12 | 13 |  |  |  |  | 10 | 14 | 12 | 12 | 9 |  |  |  | 12 | 10 |  |
| *Empidonax minimus* | 9 | 8 | 12 |  | 10 | 12 |  | 14 | 15 | 9 |  | 15 | 12 | 9 | 16 | 12 | 14 | 12 |  | 16 | 16 | 16 | 15 | 12 |  | 10 |  | 10 |
| *Empidonax traillii* |  |  |  |  |  |  |  |  | 8 |  |  | 13 | 8 |  | 8 | 8 | 11 |  |  | 14 | 10 | 15 | 10 | 13 |  | 9 |  | 10 |
| *Empidonax virescens* |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  | 9 |  | 9 |  | 10 | 10 | 11 |
| *Geothlypis formosa* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 9 |  | 9 |
| *Geothlypis trichas* | 10 | 8 | 13 |  | 9 | 12 | 8 | 12 | 12 | 11 | 9 | 13 | 12 | 8 | 13 | 13 | 12 | 9 |  | 16 | 8 | 14 | 14 | 9 | 8 | 9 | 8 | 10 |
| *Hirundo rustica* |  |  | 9 |  | 11 | 12 |  |  | 10 | 8 | 8 | 13 | 13 | 9 | 11 | 10 | 13 | 10 |  | 16 | 11 | 16 | 14 | 13 |  | 10 | 11 | 14 |
| *Icteria virens* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 8 | 9 |
| *Icterus galbula* | 9 |  | 13 |  | 12 | 12 | 8 | 14 | 15 |  | 10 | 16 | 14 | 10 | 16 | 14 | 13 | 11 | 13 | 16 | 15 | 16 | 14 |  | 9 | 14 | 15 | 15 |
| *Icterus spurius* |  |  |  |  |  |  |  |  |  |  |  | 10 |  |  | 8 |  | 13 | 8 |  | 10 | 14 | 15 | 8 | 12 |  | 12 | 11 | 10 |
| *Mniotilta varia* | 8 | 11 | 11 |  | 11 | 13 |  | 11 | 15 | 14 |  | 14 | 13 | 9 | 15 | 12 | 15 | 9 |  | 16 | 16 | 16 | 15 | 13 |  | 10 | 11 | 14 |
| *Myiarchus crinitus* | 9 |  | 9 |  | 10 | 12 | 8 | 11 | 12 | 10 | 8 | 15 | 13 | 11 | 12 | 14 | 15 | 11 | 12 | 16 | 14 | 16 | 15 | 16 | 10 | 12 | 13 | 16 |
| *Oreothlypis ruficapilla* |  | 9 | 15 |  | 11 | 13 | 9 | 13 | 11 | 10 |  | 15 | 13 | 9 | 15 | 12 | 15 | 12 |  | 16 | 16 | 15 | 14 |  |  | 11 | 12 | 8 |
| *Parkesia motacilla* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 13 |  | 9 |  | 12 | 11 | 12 | 8 | 10 | 10 | 14 |
| *Passerina caerulea* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Passerina cyanea* |  |  |  |  |  |  |  |  |  |  |  | 13 | 11 |  | 11 |  | 11 | 10 | 9 | 15 | 8 | 11 | 14 | 9 | 8 | 12 | 12 | 12 |
| *Petrochelidon pyrrhonota* |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |
| *Pheucticus ludovicianus* | 9 | 8 | 9 |  | 11 | 12 | 9 | 12 | 14 | 9 | 9 | 16 | 14 | 11 | 16 | 14 | 16 | 12 | 11 | 16 | 16 | 16 | 16 | 16 |  | 11 | 12 | 14 |
| *Pipilo erythrophthalmus* |  |  |  |  | 9 |  |  |  |  |  |  | 9 | 8 |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |
| *Piranga olivacea* | 8 |  |  |  | 8 | 11 |  |  | 10 |  |  | 14 | 11 | 9 | 14 | 11 | 15 |  |  | 15 | 16 | 15 | 15 | 15 |  | 12 | 13 | 15 |
| *Piranga rubra* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  | 10 |  |  |
| *Polioptila caerulea* | 8 |  |  |  | 11 | 11 |  |  |  |  | 9 | 16 | 16 | 11 | 8 | 9 | 14 | 13 | 10 | 16 | 16 | 16 | 11 | 16 | 10 | 14 | 14 | 15 |
| *Protonotaria citrea* |  |  |  |  |  |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  | 8 | 9 | 13 |  |  | 8 | 10 | 10 |  |

#### Table S1 – Continued.

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|  | **Cell Number** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Species** | **73** | **74** | **75** | **76** | **77** | **78** | **79** | **80** | **81** | **82** | **83** | **84** | **85** | **86** | **87** | **88** | **89** | **90** | **91** | **92** | **93** | **94** | **95** | **96** | **104** | **105** | **106** | **107** |
| *Archilochus colubris* | 15 |  | 10 | 10 |  |  | 12 | 9 |  |  |  |  | 10 |  |  | 8 |  | 9 |  |  |  | 9 |  |  |  |  |  |  |
| *Catharus fuscescens* | 16 |  |  |  |  |  | 13 |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Coccyzus americanus* | 11 |  |  | 8 | 11 |  | 10 | 11 |  |  | 8 |  |  | 12 | 10 | 9 | 8 | 9 | 11 |  |  |  |  |  | 8 |  | 8 | 8 |
| *Contopus virens* | 16 |  | 13 | 13 | 14 | 9 | 16 | 10 |  |  | 10 | 9 | 10 | 13 | 9 |  |  | 10 | 10 |  |  | 9 |  |  |  |  |  |  |
| *Dolichonyx oryzivorus* | 11 |  |  |  |  |  | 10 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 11 |  |
| *Dumetella carolinensis* |  |  | 10 |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Empidonax minimus* | 10 |  |  |  |  | 8 |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Empidonax traillii* | 14 |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |
| *Empidonax virescens* | 14 |  |  | 11 | 9 | 9 | 13 |  |  |  | 8 | 9 | 10 |  | 9 |  |  | 11 | 10 |  |  |  |  |  |  |  |  |  |
| *Geothlypis formosa* | 10 |  |  | 12 | 10 |  | 11 | 10 |  |  | 10 |  |  | 11 | 11 |  |  | 12 |  |  |  |  |  |  |  |  |  |  |
| *Geothlypis trichas* |  |  |  | 9 | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |
| *Hirundo rustica* | 13 |  |  | 10 | 14 | 11 | 14 |  |  |  | 9 | 11 | 9 | 8 | 11 | 11 | 8 | 10 | 9 |  | 8 | 9 |  |  | 11 | 8 | 13 |  |
| *Icteria virens* |  |  | 8 | 12 | 12 |  |  | 11 |  | 8 | 9 | 9 | 12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Icterus galbula* |  |  | 12 | 8 | 9 | 10 |  | 9 |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Icterus spurius* | 15 |  | 10 | 10 | 13 | 9 | 15 | 11 |  |  | 8 | 8 | 9 | 13 | 8 | 11 |  | 9 | 11 |  |  |  |  |  | 8 | 8 |  |  |
| *Mniotilta varia* | 16 | 10 |  | 10 | 11 | 11 | 11 | 9 |  |  | 13 | 8 |  |  |  |  |  |  |  |  |  | 9 | 11 |  |  |  |  |  |
| *Myiarchus crinitus* | 16 | 8 | 15 | 13 | 12 | 10 | 16 | 10 | 9 | 9 | 12 | 9 | 13 | 10 | 11 | 12 | 10 | 14 | 14 | 10 | 11 | 9 |  |  | 12 | 11 |  |  |
| *Oreothlypis ruficapilla* |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Parkesia motacilla* | 15 |  |  | 10 | 10 | 10 | 14 |  |  |  | 10 | 9 | 9 | 8 |  |  |  | 11 | 9 |  |  |  |  |  |  |  |  |  |
| *Passerina caerulea* | 8 |  |  |  |  |  | 11 |  |  |  |  |  | 8 | 9 |  | 11 |  | 11 | 10 |  |  |  |  |  |  |  |  |  |
| *Passerina cyanea* | 13 | 8 | 9 | 10 | 14 | 12 | 16 | 9 |  | 8 | 14 | 12 | 12 | 8 |  | 12 | 8 | 14 | 9 |  |  |  |  |  |  | 8 |  |  |
| *Petrochelidon pyrrhonota* | 9 |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Pheucticus ludovicianus* | 15 |  | 10 | 12 | 10 | 10 | 12 |  |  |  | 12 | 8 |  | 13 |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |
| *Pipilo erythrophthalmus* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Piranga olivacea* | 16 |  |  | 11 | 14 | 12 | 16 |  |  |  | 14 | 10 | 11 | 14 | 10 |  |  | 10 |  |  |  | 8 |  |  |  |  |  |  |
| *Piranga rubra* | 11 | 8 | 13 | 10 | 10 |  | 13 | 10 | 8 | 9 | 11 |  | 11 | 11 |  | 11 | 9 | 12 | 11 |  |  |  |  |  | 9 |  |  |  |
| *Polioptila caerulea* | 15 | 8 | 11 | 10 | 15 | 13 |  |  |  |  | 9 | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Protonotaria citrea* | 12 |  | 9 | 9 | 10 |  | 13 | 8 | 9 | 8 |  |  | 10 |  |  | 11 |  | 11 | 12 |  | 11 |  |  |  |  |  |  |  |

#### Table S1 – Continued.

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|  | **Cell Number** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Species** | **39** | **40** | **45** | **46** | **47** | **48** | **49** | **51** | **52** | **53** | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **66** | **67** | **69** | **70** | **71** | **72** |
| *Sayornis phoebe* | 10 |  | 12 |  | 12 | 12 | 8 | 12 | 12 | 11 | 9 | 13 | 12 | 10 | 13 | 14 | 13 | 13 |  | 13 | 12 | 15 | 12 |  |  |  |  |  |
| *Seiurus aurocapilla* | 9 | 11 | 10 |  | 9 | 13 | 8 | 12 | 15 | 12 |  | 15 | 13 | 9 | 16 | 14 | 15 |  |  | 16 | 16 | 15 | 15 | 14 |  | 10 | 12 | 15 |
| *Setophaga americana* |  |  | 9 |  |  | 12 |  |  | 10 | 11 |  | 11 | 11 |  | 9 | 8 | 15 | 13 | 8 | 14 | 14 | 13 | 10 | 15 | 10 | 13 | 12 | 14 |
| *Setophaga caerulescens* |  |  | 12 |  |  |  |  | 8 | 14 | 8 |  |  |  | 8 | 13 | 10 | 14 |  |  | 8 | 16 | 15 | 13 | 16 |  |  |  | 12 |
| *Setophaga cerulea* |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  |  | 8 | 10 | 8 | 11 |  | 9 | 10 | 10 |
| *Setophaga citrina* |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 9 |  | 12 | 9 | 13 |  | 9 | 11 | 11 |
| *Setophaga discolor* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 12 |  |  |  |  |  | 12 | 11 |  | 9 |  | 9 |
| *Setophaga dominica* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 |  | 8 |  |  |  |  | 8 | 10 | 12 | 9 |
| *Setophaga fusca* |  |  | 10 |  | 8 | 10 |  |  | 12 | 9 |  | 12 | 12 |  | 15 | 10 | 15 |  |  | 15 | 15 | 15 | 13 | 12 |  | 10 | 9 | 11 |
| *Setophaga magnolia* |  |  | 14 |  | 8 | 12 |  | 9 | 13 | 11 |  | 14 | 12 | 9 | 16 | 10 | 16 |  |  | 16 | 16 | 16 | 13 | 15 |  | 10 | 12 | 13 |
| *Setophaga pensylvanica* | 8 | 9 | 15 |  | 11 | 13 |  | 12 | 14 | 10 |  | 15 | 12 | 9 | 15 | 12 | 15 | 8 |  | 16 | 16 | 16 | 14 | 13 |  | 10 | 11 | 13 |
| *Setophaga petechia* | 10 | 10 | 14 | 8 | 12 | 13 | 9 | 14 | 15 | 10 | 10 | 16 | 15 | 11 | 16 | 15 | 16 | 12 | 10 | 16 | 15 | 16 | 15 | 16 | 8 | 13 | 14 | 16 |
| *Setophaga pinus* |  |  |  |  |  | 11 | 8 |  | 10 | 8 |  |  |  |  | 10 | 9 |  |  |  |  |  | 11 | 8 |  |  | 8 |  |  |
| *Setophaga ruticilla* | 9 | 10 | 14 |  | 11 | 12 | 8 | 13 | 15 | 9 | 10 | 16 | 12 | 11 | 16 | 13 | 16 | 11 | 9 | 16 | 16 | 16 | 15 | 16 |  | 10 | 12 | 16 |
| *Setophaga striata* |  |  | 12 |  |  |  |  |  | 11 | 9 |  | 11 | 10 |  | 9 | 8 | 15 | 9 |  | 14 | 13 | 10 | 11 | 12 |  | 10 |  | 9 |
| *Setophaga tigrina* |  |  | 8 |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |  | 10 | 10 |  |  | 9 |  |  |  |  |
| *Setophaga virens* |  | 10 | 13 |  |  | 13 | 8 | 11 | 15 | 13 |  | 14 | 12 | 9 | 16 | 12 | 16 |  |  | 16 | 16 | 16 | 14 | 16 |  | 10 | 13 | 14 |
| *Spizella passerina* | 10 |  | 13 |  | 11 | 10 | 8 | 8 | 9 | 8 | 9 | 15 | 12 | 9 | 15 | 12 |  | 10 | 11 | 14 | 10 | 13 | 11 |  |  |  |  |  |
| *Stelgidopteryx serripennis* |  |  |  |  | 10 | 11 |  |  | 9 |  |  | 14 | 12 | 10 | 11 | 8 | 13 | 12 | 10 | 16 | 14 | 16 | 12 | 13 | 9 | 13 | 12 | 12 |
| *Tachycineta bicolor* | 10 | 9 | 13 |  | 11 | 12 | 9 | 13 | 14 | 10 | 8 | 15 | 13 | 11 | 15 | 16 | 15 | 9 | 10 | 16 | 16 | 16 | 16 |  | 11 | 13 | 14 | 15 |
| *Troglodytes aedon* | 8 |  |  |  | 9 | 10 |  | 11 | 10 |  | 8 | 13 | 11 | 8 | 12 | 12 | 14 | 11 | 11 | 16 | 11 | 16 | 15 | 10 |  | 13 | 10 | 13 |
| *Tyrannus tyrannus* |  |  | 9 |  |  | 9 |  |  | 10 | 10 |  | 14 |  | 9 | 10 | 11 | 16 | 8 | 10 | 12 | 12 | 16 | 14 | 12 | 11 | 12 | 9 | 12 |
| *Vermivora cyanoptera* | 8 |  |  |  | 12 |  |  |  |  |  |  | 16 | 10 | 9 |  | 9 | 13 |  |  | 11 | 13 | 15 | 15 | 16 |  | 10 | 10 | 10 |
| *Vireo flavifrons* | 8 |  |  |  | 10 | 9 |  |  |  |  |  | 14 | 10 |  |  | 11 | 10 | 9 |  | 11 | 8 | 10 | 11 | 11 |  | 11 | 11 | 10 |
| *Vireo gilvus* |  |  | 11 |  | 8 | 11 |  | 14 | 15 | 8 |  | 15 | 12 | 11 | 13 | 13 | 16 | 12 | 9 | 16 | 16 | 16 | 15 | 15 | 10 | 13 | 12 | 10 |
| *Vireo griseus* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 10 | 10 |  | 11 | 8 | 10 | 11 | 12 |
| *Vireo olivaceus* | 9 | 8 | 9 |  | 8 | 10 |  | 11 | 11 | 9 | 9 | 14 | 13 | 11 | 16 | 10 | 15 | 13 | 9 | 15 | 15 | 16 | 15 | 15 | 9 | 14 | 16 | 15 |
| *Vireo solitarius* |  |  | 8 |  |  | 11 |  | 8 | 10 | 9 |  | 11 | 10 | 8 | 11 | 11 | 15 | 9 |  | 13 | 15 | 15 | 14 | 14 |  | 10 | 12 | 11 |

#### Table S1 – Continued.

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|  | **Cell Number** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Species** | **73** | **74** | **75** | **76** | **77** | **78** | **79** | **80** | **81** | **82** | **83** | **84** | **85** | **86** | **87** | **88** | **89** | **90** | **91** | **92** | **93** | **94** | **95** | **96** | **104** | **105** | **106** | **107** |
| *Sayornis phoebe* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Seiurus aurocapilla* | 15 |  |  | 10 | 14 | 12 | 14 |  |  |  | 13 | 11 | 10 | 12 |  |  |  | 9 | 11 |  |  | 9 | 11 |  |  |  |  |  |
| *Setophaga americana* | 15 |  | 13 | 10 | 10 | 10 | 15 | 11 | 10 | 9 | 14 | 13 | 11 | 9 | 10 | 13 | 9 | 14 | 13 | 8 |  | 8 | 10 | 8 |  | 10 |  |  |
| *Setophaga caerulescens* | 16 |  |  |  |  | 9 | 14 |  |  |  | 8 | 9 | 10 |  |  |  |  | 10 | 10 |  |  |  |  |  |  |  |  |  |
| *Setophaga cerulea* | 9 |  |  |  | 8 | 10 | 9 |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Setophaga citrina* | 13 |  |  | 11 | 12 | 12 | 13 | 11 |  |  | 14 | 10 | 10 | 10 | 11 | 11 |  | 13 | 10 |  |  |  |  |  | 8 |  |  |  |
| *Setophaga discolor* | 11 |  |  | 11 | 11 |  | 12 | 9 |  |  | 9 |  | 10 |  |  |  |  | 8 |  |  |  | 8 |  |  |  |  |  |  |
| *Setophaga dominica* | 10 |  |  | 10 | 10 | 10 | 11 | 10 |  |  | 8 | 8 | 10 | 10 |  |  |  | 11 |  |  |  |  |  |  |  |  |  |  |
| *Setophaga fusca* | 12 |  |  | 8 |  | 8 | 9 |  |  |  | 9 |  |  | 11 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Setophaga magnolia* | 16 |  |  | 10 | 8 |  | 13 |  |  |  |  |  |  | 11 |  |  |  |  |  |  |  |  | 12 |  |  |  |  |  |
| *Setophaga pensylvanica* | 14 |  |  | 8 | 8 | 8 | 12 |  |  |  | 12 | 10 |  | 12 |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |
| *Setophaga petechia* | 14 |  |  | 9 | 8 | 10 | 12 |  |  |  |  | 8 | 8 | 10 |  |  |  | 8 |  |  |  | 10 | 11 | 9 |  |  |  |  |
| *Setophaga pinus* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Setophaga ruticilla* | 16 |  | 9 | 9 | 9 | 11 | 15 |  |  |  | 12 | 11 | 10 | 10 |  |  |  | 11 | 9 |  |  | 9 | 12 |  |  |  |  |  |
| *Setophaga striata* | 15 |  |  | 8 | 8 |  | 15 |  |  |  | 12 |  |  |  |  |  |  | 10 |  |  |  |  |  |  |  |  | 9 | 11 |
| *Setophaga tigrina* |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |
| *Setophaga virens* | 16 |  | 8 | 9 | 13 | 10 | 13 |  |  |  | 13 | 11 |  | 13 |  |  |  |  |  |  |  |  | 12 | 8 |  |  |  |  |
| *Spizella passerina* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Stelgidopteryx serripennis* | 12 |  | 10 | 11 | 15 | 10 | 15 | 8 |  |  | 10 | 10 | 10 |  |  |  |  |  | 8 |  |  | 8 |  |  |  |  |  |  |
| *Tachycineta bicolor* |  |  |  | 8 | 13 | 13 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 10 | 11 | 8 |  |  |  |  |
| *Troglodytes aedon* |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |
| *Tyrannus tyrannus* | 14 |  | 11 | 11 | 12 | 8 | 13 | 9 |  |  | 8 | 11 | 10 | 10 | 10 | 11 |  | 9 | 11 |  | 8 | 9 |  |  | 10 | 10 | 9 | 8 |
| *Vermivora cyanoptera* | 16 |  |  | 10 | 8 |  | 8 |  |  |  |  |  |  | 10 |  |  |  |  |  |  |  | 8 |  |  |  |  |  |  |
| *Vireo flavifrons* | 14 |  | 10 | 10 | 10 | 9 | 12 | 10 |  |  | 11 | 9 | 9 |  | 11 |  |  | 13 | 12 |  |  |  |  |  | 8 |  | 8 |  |
| *Vireo gilvus* | 16 |  |  | 9 |  |  | 11 |  |  |  |  |  |  | 9 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Vireo griseus* | 14 | 8 | 11 | 11 | 13 | 8 |  |  | 8 |  | 13 | 10 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| *Vireo olivaceus* | 16 | 11 | 15 | 11 | 15 | 11 | 16 | 11 | 9 | 8 | 14 | 12 | 12 | 12 | 11 | 13 | 9 | 14 | 12 |  |  | 9 |  |  | 12 | 10 | 15 | 8 |
| *Vireo solitarius* | 11 |  |  |  | 10 | 10 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

#### Table S2. Species traits and estimated migration speed (km/day). Bird traits used in model 3 to investigate species-specific traits influence on migratory speed. Sensitivity estimates were from Youngflesh et al. (2021). First arrival date was estimated from our dataset (details in Methods). Diet information was from La Sorte & Graham (2021). Body mass data was from Dunning (2008), as cited by Horton et al. (2019). Overwintering latitude data was from Youngflesh et al. (2021). Migration time data is from Birds of the World (2022). Hand-wind index information from Sheard et al. (2020). The estimated migration speed and variance are from our study. We did not have enough variation on migration time and diet to include those variables in our final model. *Pipilo erythrophthalmus* was removed from the analysis due to the lack of enough data to estimate migratory speed.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species name | Family | Species sensitivity (days per day) | First arrival date (ordinal day) | Diet | Body mass (g) | Overwintering Latitude (degrees) | Migration time | Hand-wing Index | Estimated mean speed (km/day) | Standard deviation of speed (km/day) |
| *Archilochus colubris* | Trochilidae | 0.004 | 96.4 | Nectarivore | 4 | 16.46 | Diurnal | 65 | 53.4 | 25.3 |
| *Catharus fuscescens* | Turdidae | 0.023 | 107.7 | Insectivore | 31.9 | -13.56 | Nocturnal | 27.7 | 58.9 | 33 |
| *Coccyzus americanus* | Cuculidae | 0.12 | 116.8 | Insectivore | 64 | -9.52 | Nocturnal | 43 | 71.3 | 105 |
| *Contopus virens* | Tyrannidae | 0.151 | 115.5 | Insectivore | 13.9 | -1.15 | Nocturnal | 30.9 | 64.7 | 52.7 |
| *Dolichonyx oryzivorus* | Icteridae | 0.078 | 112.7 | Insectivore | 31.5 | -20.47 | Nocturnal | 35.4 | 82.6 | 56.7 |
| *Dumetella carolinensis* | Mimidae | 0.098 | NA | Insectivore | 35.3 | 19.78 | Nocturnal | 18.7 | 79.7 | 40.5 |
| *Empidonax minimus* | Tyrannidae | 0.052 | NA | Insectivore | 10 | 17.71 | Nocturnal | 22.8 | 97.1 | 80.4 |
| *Empidonax traillii* | Tyrannidae | 0.108 | NA | Insectivore | 13.4 | 7.19 | Nocturnal | 23.5 | 146.5 | 114.5 |
| *Empidonax virescens* | Tyrannidae | 0.097 | 119.5 | Insectivore | 12.6 | 7.09 | Nocturnal | 28 | 77.3 | 97.5 |
| *Geothlypis formosa* | Parulidae | 0.068 | 104.4 | Insectivore | 14 | 14.62 | Nocturnal | 24.9 | 70.9 | 48.4 |
| *Geothlypis trichas* | Parulidae | 0.169 | NA | Insectivore | 9.5 | 21.03 | NA | 16.1 | 44.1 | 17 |
| *Hirundo rustica* | Hirundinidae | 0.09 | 87.4 | Insectivore | 18.5 | -0.45 | Diurnal | 51.2 | 80.5 | 134.6 |
| *Icteria virens* | Parulidae | 0.12 | 118.1 | Insectivore | 24.9 | 16.39 | Nocturnal | 21.3 | 117.9 | 127.7 |
| *Icterus galbula* | Icteridae | 0.114 | 105.3 | Insectivore | 32.8 | 15.3 | Nocturnal | 27.4 | 82 | 43.4 |
| *Icterus spurius* | Icteridae | 0.029 | 105.6 | Omnivore | 19.4 | 13.36 | Nocturnal | 26.9 | 77.8 | 75.7 |
| *Mniotilta varia* | Parulidae | 0.09 | 88.4 | Insectivore | 10.9 | 16.97 | Nocturnal | 25.5 | 56 | 32 |
| *Myiarchus crinitus* | Tyrannidae | 0.17 | 104.1 | Insectivore | 32.1 | 12.87 | Nocturnal | 21.4 | 67.8 | 87.1 |
| *Oreothlypis ruficapilla* | Parulidae | 0.177 | NA | Insectivore | 8.1 | 21.85 | Nocturnal | 23.5 | 77.5 | 47.4 |
| *Parkesia motacilla* | Parulidae | 0.232 | 81.2 | Insectivore | 19.9 | 14.6 | NA | 29.7 | 48.9 | 28.3 |
| *Passerina caerulea* | Emberizidae | 0.044 | 106.7 | Omnivore | 27.4 | 18.27 | NA | 19.8 | 138.4 | 182.7 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species name | Family | Species sensitivity (days per day) | First arrival date (ordinal day) | Diet | Body mass (g) | Overwintering Latitude (degrees) | Migration time | Hand-wing Index | Estimated mean speed (km/day) | Standard deviation of speed (km/day) |
| *Passerina cyanea* | Emberizidae | 0.09 | 107.9 | Granivore | 14.7 | 17.39 | Nocturnal | 22.6 | 47.6 | 22.3 |
| *Petrochelidon pyrrhonota* | Hirundinidae | 0.021 | 97.1 | Insectivore | 26.5 | -22.99 | Diurnal | 47.6 | 79.3 | 28.1 |
| *Pheucticus ludovicianus* | Cardinalidae | 0.072 | 106.8 | Omnivore | 42 | 11.49 | Nocturnal | 27.6 | 75.3 | 31.2 |
| *Pipilo erythrophthalmus* | Passerellidae | 0.266 | NA | Omnivore | 42 | 31.34 | Nocturnal | 13.6 | NA | NA |
| *Piranga olivacea* | Cardinalidae | 0.149 | 103.6 | Insectivore | 28.2 | -0.52 | Nocturnal | 32.3 | 54.3 | 28.1 |
| *Piranga rubra* | Cardinalidae | -0.006 | 106.1 | Insectivore | 29.1 | 6.54 | Nocturnal | 30.3 | 57.1 | 27 |
| *Polioptila caerulea* | Polioptilidae | 0.093 | 90.4 | Insectivore | 5.8 | 22.93 | Diurnal | 19.1 | 41.6 | 18.9 |
| *Protonotaria citrea* | Parulidae | 0.039 | 96.5 | Insectivore | 14.3 | 13.25 | Nocturnal | 29.9 | 46.8 | 31.9 |
| *Sayornis phoebe* | Tyrannidae | 0.446 | NA | Insectivore | 19.7 | 26.99 | Diurnal | 20.6 | 39.2 | 13.1 |
| *Seiurus aurocapilla* | Parulidae | 0.145 | 104 | Insectivore | 18.8 | 17.87 | Nocturnal | 24.6 | 52.5 | 26.7 |
| *Setophaga americana* | Parulidae | 0.236 | 83 | Insectivore | 7.8 | 19.38 | Nocturnal | 29.2 | 39.1 | 27.8 |
| *Setophaga caerulescens* | Parulidae | 0.117 | 108.7 | Insectivore | 10.1 | 17.64 | Nocturnal | 24.4 | 109.7 | 118.1 |
| *Setophaga cerulea* | Parulidae | 0.023 | 100.4 | Insectivore | 9 | 1.75 | Nocturnal | 34.2 | 43.3 | 41.2 |
| *Setophaga citrina* | Parulidae | 0.069 | 93.3 | Insectivore | 10.5 | 17.41 | Nocturnal | 20.9 | 39.6 | 14.4 |
| *Setophaga discolor* | Parulidae | 0.081 | 102.9 | Insectivore | 7.6 | 20.19 | Nocturnal | 20.6 | 42.1 | 17.7 |
| *Setophaga dominica* | Parulidae | 0.313 | 80.6 | Insectivore | 9.7 | 20.08 | Nocturnal | 27.5 | 48.6 | 29.9 |
| *Setophaga fusca* | Parulidae | 0.11 | 107.1 | Insectivore | 9.7 | 3.92 | Nocturnal | 33.3 | 73.5 | 45.9 |
| *Setophaga magnolia* | Parulidae | 0.119 | 115.1 | Insectivore | 8.1 | 16.76 | Nocturnal | 22.6 | 116.3 | 85.1 |
| *Setophaga pensylvanica* | Parulidae | 0.106 | 110.9 | Insectivore | 9.3 | 12.73 | Nocturnal | 26.7 | 78.9 | 42.2 |
| *Setophaga petechia* | Parulidae | 0.058 | 108.6 | Insectivore | 10.2 | 9.3 | Nocturnal | 27.5 | 70.3 | 49.6 |
| *Spizella passerina* | Emberizidae | 0.283 | NA | Granivore | 12.2 | 27.35 | Nocturnal | 24.2 | 37.2 | 16.5 |
| *Stelgidopteryx serripennis* | Hirundinidae | 0.101 | 84.3 | Insectivore | 14 | 15.54 | Diurnal | 50.9 | 50.8 | 76.3 |
| *Tachycineta bicolor* | Hirundinidae | 0.454 | NA | Insectivore | 20.5 | 22.62 | Diurnal | 54.3 | 35.1 | 16.9 |
| *Troglodytes aedon* | Troglodytidae | 0.226 | NA | Insectivore | 10.8 | 28.43 | Nocturnal | 13.7 | 62.8 | 36.4 |
| *Tyrannus tyrannus* | Tyrannidae | 0.082 | 99.5 | Insectivore | 39.9 | -12.23 | Diurnal | 33.9 | 53.2 | 29.5 |
| *Spizella passerina* | Emberizidae | 0.283 | NA | Granivore | 12.2 | 27.35 | Nocturnal | 24.2 | 37.2 | 16.5 |

Table S2 **–** (continued).

Table S2 **–** (continued).

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species name | Family | Species sensitivity (days per day) | First arrival date (ordinal day) | Diet | Body mass (g) | Overwintering Latitude (degrees) | Migration time | Hand-wing Index | Estimated mean speed (km/day) | Standard deviation of speed (km/day) |
| *Vermivora cyanoptera* | Parulidae | 0.099 | 96.3 | Insectivore | 8.9 | 17.4 | Nocturnal | 25.2 | 41.6 | 16.6 |
| *Vireo flavifrons* | Vireonidae | 0.073 | 90.3 | Insectivore | 18 | 13.08 | Nocturnal | 34.1 | 36.4 | 18.5 |
| *Vireo gilvus* | Vireonidae | 0.189 | 103 | Insectivore | 12.7 | 18.98 | Nocturnal | 23.9 | 63.5 | 45.4 |
| *Vireo griseus* | Vireonidae | 0.045 | 96.1 | Insectivore | 11.4 | 19.22 | Nocturnal | 17.3 | 38.6 | 23.4 |
| *Vireo olivaceus* | Vireonidae | 0.21 | 97.4 | Insectivore | 16.1 | -7.13 | Nocturnal | 24.1 | 39 | 14.6 |
| *Vireo solitarius* | Vireonidae | 0.24 | NA | Insectivore | 15.3 | 25.82 | Nocturnal | 29.7 | 50.2 | 43.2 |

#### Table S3. Comparison of bird in flight speed (km/day) and bird migration front speed (km/day, this study), average migratory distance (km), and proportion of time spent in stopover site versus migrating. These nine species are the ones we found flight speed data in the literature.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Species name | Flight Speed (km/day) | Migratory Speed (km/day) | Migration distance (km)10 | Proportion of time at stopover site |
| *Dumetella carolinensis* | 5521 | 80 | 2305 | 0.86 |
| *Tyrannus tyrannus* | 5762 | 53 | 7082 | 0.91 |
| *Spizella passerina* | 6723 | 37 | 1883 | 0.94 |
| *Icterus galbula* | 7444 | 82 | 3039 | 0.89 |
| *Passerina cyanea* | 7685 | 48 | 2356 | 0.94 |
| *Tachycineta bicolor* | 7686 | 35 | 2930 | 0.95 |
| *Hirundo rustica* | 10327 | 80 | 6918 | 0.92 |
| *Setophaga striata* | 15368 | 85 | 7025 | 0.94 |
| *Archilochus colubris* | 19209 | 53 | 1531 | 0.97 |

Sources: 1, 2, 3, 4, 5 - Cooke, 1933; 6 - Pennycuick, 1997, Elliott and Kaiser, 2009; 7 - Alerstam et al., 2007, Cooke, 1933, Elliott and Kaiser, 2009, DeLuca et al., 2015; 8 - DeLuca et al.,

#### **Equations**

**Model 1:**

Equation S1

Indexes:

- cell

- year

Data:

– green-up speed (log10(km/day))

– cell latitude in degrees

Fixed effects:

– intercept (green-up speed log10(km/day))

Random terms:

– residual error term

– variance of the residual error term of green-up speed ()

Smooth term:

– smooth function (table-top) to model the non-linear relationship between green-up speed () and latitude ()

**Model 2:**

Equation S2

Indexes:

- species

- cell

- year

Data:

– bird migration speed (log10(km/day))

– green-up date anomaly (days, within each cell across years)

– green-up speed anomaly (log10(km/day), within each cell across years)

– migratory range (categorical variable where =1 is the migratory range and =0 is the breeding range)

– cell latitude in degrees

Fixed effects:

– intercept (bird migration speed in the breeding range, = 0)

– change in intercept of the effect of migratory range ()on bird migration speed

– effect of green-up date anomaly () on bird migration speed () in the breeding rage (= 0)

– effect of green-up speed anomaly () on bird migration speed () in the breeding rage (= 0)

– change in slope of the effect of green-up date anomaly () on the migratory range (= 1)on bird migration speed

– change in slope of the effect of green-up speed anomaly () on the migratory range (= 1)on bird migration speed

Random terms:

– random intercept for species ()

– random intercept for year ()

– random intercept for a species () in a cell ()

– residual error term

– variance of bird migration speed () according to species ()

– variance of bird migration speed () according to year ()

– variance of bird migration speed () according to species () in a cell ()

– variance of the residual error term of bird migration speed ()

Smooth term:

– smooth function (table-top) to model the non-linear relationship between bird migration speed () and latitude ()

**Model 3:**

Equation S3

Indexes:

- species

- cell

- year

Data:

– bird migration speed (log10(km/day))

– migratory sensitivity (change in arrival day per day of green-up; days/day)

– first arrival date (days)

– body mass (grams)

– overwinter latitude (degrees)

– hand-wing index (wing shape)

– cell latitude in degrees

Fixed effects:

– intercept (baseline bird migration speed in log10(km/day))

– effect of migratory sensitivity () on bird migration speed ()

– effect of first arrival date () on bird migration speed ()

– effect of body mass () on bird migration speed ()

– effect of overwinter latitude () on bird migration speed ()

– effect of hand-wing index () on bird migration speed ()

Random terms:

– random intercept for species ()

– random intercept for year ()

– random intercept for a species () in a cell ()

– residual error term

– variance of bird migration speed () according to species ()

– variance of bird migration speed () according to year ()

– variance of bird migration speed () according to species () in a cell ()

– variance of the residual error term of bird migration speed ()

Smooth term:

– smooth function (table-top) to model the non-linear relationship between bird migration speed () and latitude ()

**Model 4:**

Equation S4

Indexes:

- species

- cell

- year

Data:

– bird relative arrival anomaly (days, within each cell and species and across years)

– bird migration speed prior to arrival z-score (within each cell and species and across years)

– bird first arrival date z-score (within each cell and species and across years)

– green-up date z-score (within each cell and across years)

Fixed effects:

– intercept

– relative effect of bird migration speed prior to arrival z-score () on bird relative arrival anomaly ()

– relative effect of bird first arrival date z-score () on bird relative arrival anomaly ()

– relative effect of green-up date z-score () on bird relative arrival anomaly ()

Random intercepts:

– random intercept for species ()

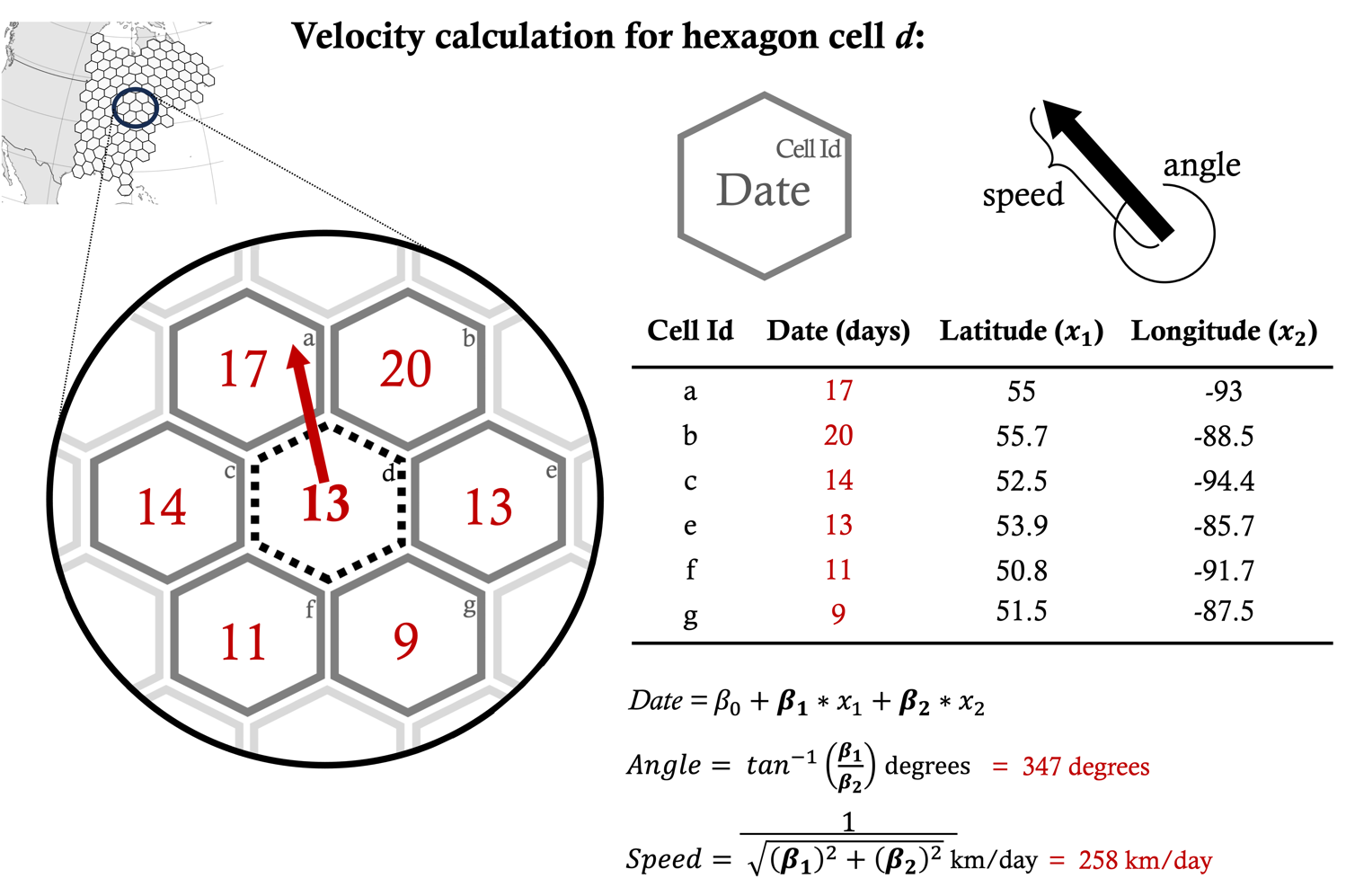
– random intercept for a species () in a cell ()

– residual error term

– variance of bird relative arrival anomaly () according to species ()

– variance of bird relative arrival anomaly () according to species () in a cell ()

– variance of the residual error term of bird relative arrival anomaly ()



Equation S7

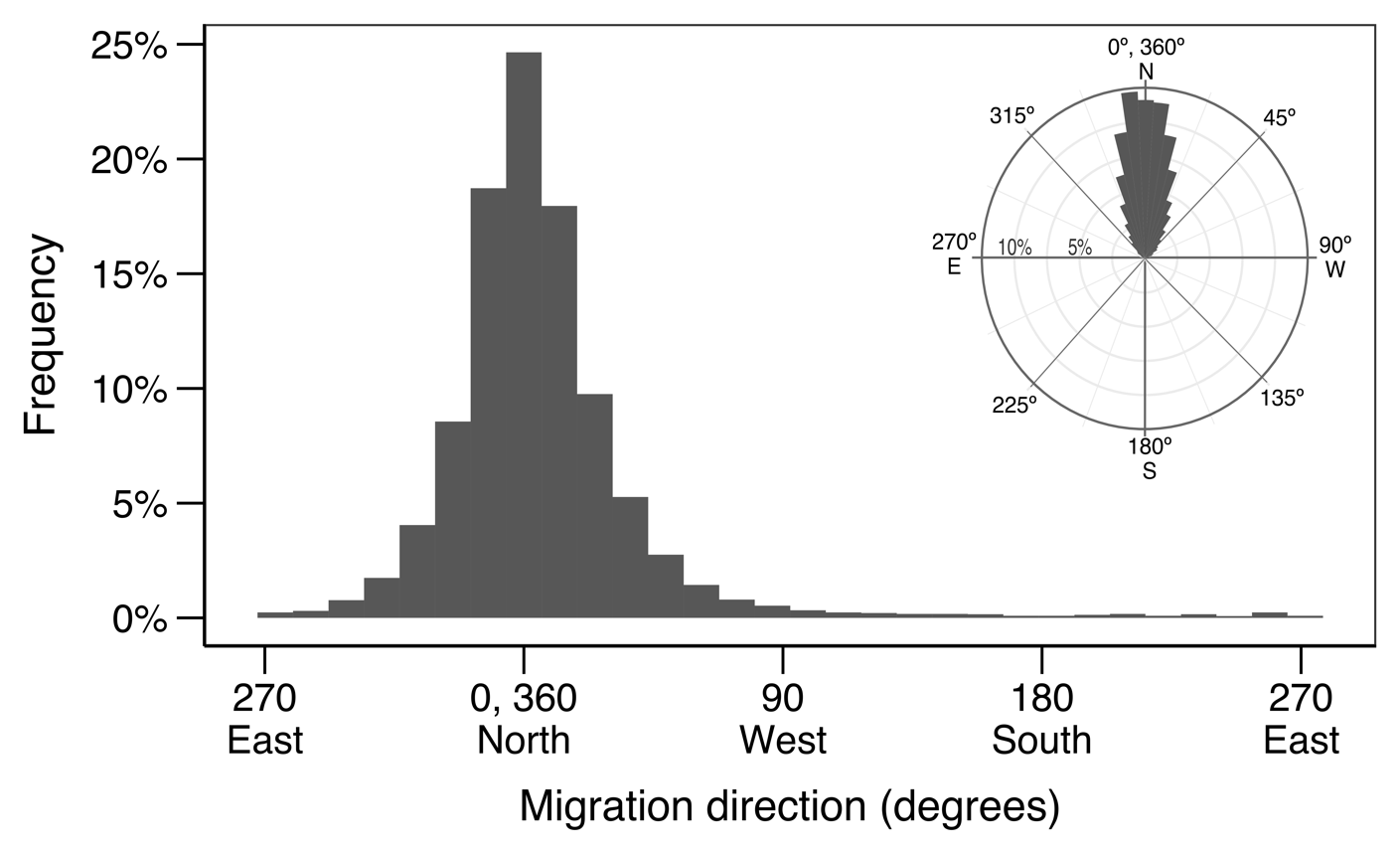
Equation S6

Equation S5

#### Figure S1 – Example of bird migration front and green-up propagation wave velocity (speed and direction, i.e. vector with magnitude and direction) calculation for hexagon cell *d* (dashed black) in the study area. Each cell has a bird arrival date or green-up date (Date) associated with it, as well as a unique id (Cell Id, letters) and geographic coordinates (Latitude and Longitude). For calculating the bird migration speed for cell *d*, for example, we gathered data on bird arrival date and geographic coordinates for all its neighboring cells (*a*, *b*, *c*, *e*, *f*, and *g*). Using Equation S5 from the figure, we fitted a linear regression in R (using the *lm* function from the base *stats* package, version 4.2.1 package) the arrival dates (Date, response) against latitude () and longitude (). We used Equation S6 and the estimates of and to calculate the direction of the vector of bird migration (angle in degrees), which represents the direction the migration front was moving to (represented by the direction of the arrow in the figure). With Equation S4 and the estimates of and , we calculated the magnitude of the vector, which is the speed in kilometers per day. Equation S7 is the inverse of the Pythagorean Theorem; the Pythagorean Theorem gives a measure of magnitude in the units of Equation S5 (day/km), so its inverse provides a measure of speed (km/day). Values in dark red represent hypothetical arrival dates, which were used to estimate a speed and direction (values close to Eq. S5 and S6) that were represented by the red arrow in the map. When the dates of a focus cell (cell *d* in this example) were very similar to the values in the neighboring cells, the estimates of and became very close to zero. Using those estimates in Equation S7 (which has the inverse of those coefficients) resulted in large calculated speed values (one divided by a very small number). Two cases of calculated speed values that exceeded 3000 km/day were removed from the analysis.

#### 

#### Figure S2 – Example of bird migration speed prior to arrival calculation for hexagon cell *a* (dashed black) in the study area. Each cell has a bird arrival date or green-up date (Date) associated with it, as well as a unique id (Cell Id, letters) and geographic coordinates (Latitude and Longitude). For calculating the bird migration speed prior to arrival for cell *a*, for example, we gather data bird arrival date and geographic coordinates for the first cell where a species arrived in a given year. For example, in year one the species first arrived at cell *g*, so we calculated prior migration speed of arrival as the distance between the center of cell *a* from cell *g*, divided by the difference in arrival time between them (red arrow). In year two, if the species first arrived at cell *e*, we calculated migration speed prior to arrival according to that location.



#### Figure S3. Distribution of the migration direction of all species in all years and cells, showing that birds are mostly moving North

#### A screenshot of a graph AI-generated content may be incorrect.

Figure S4. Sensitivity analysis to identify high-leverage points. The grey histogram shows the distribution of 500 simulated mean migration speeds after randomly removing one neighboring cell per grid cell in each iteration. For each of the four species, we performed this procedure 500 times. Vertical dashed black lines indicate the 0.05 and 0.95 quantiles of the distribution, and the solid black line marks the originally estimated mean speed. Rug marks along the x-axis show the mean speed from each simulation. The analysis shows that speed estimates are not driven by any single neighboring cell, indicating robustness to variation in arrival date data. This supports the chosen grid cell size as a balance between geographic resolution and temporal accuracy. Estimated velocities exhibit smooth spatial patterns, consistency across years, and fall within biologically plausible ranges, suggesting that noise does not dominate the observed migration patterns.

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