Full annual cycle model to aid Rusty Blackbird conservation planning

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Smithsonian Conservation Biology Institute
Migratory Bird Center

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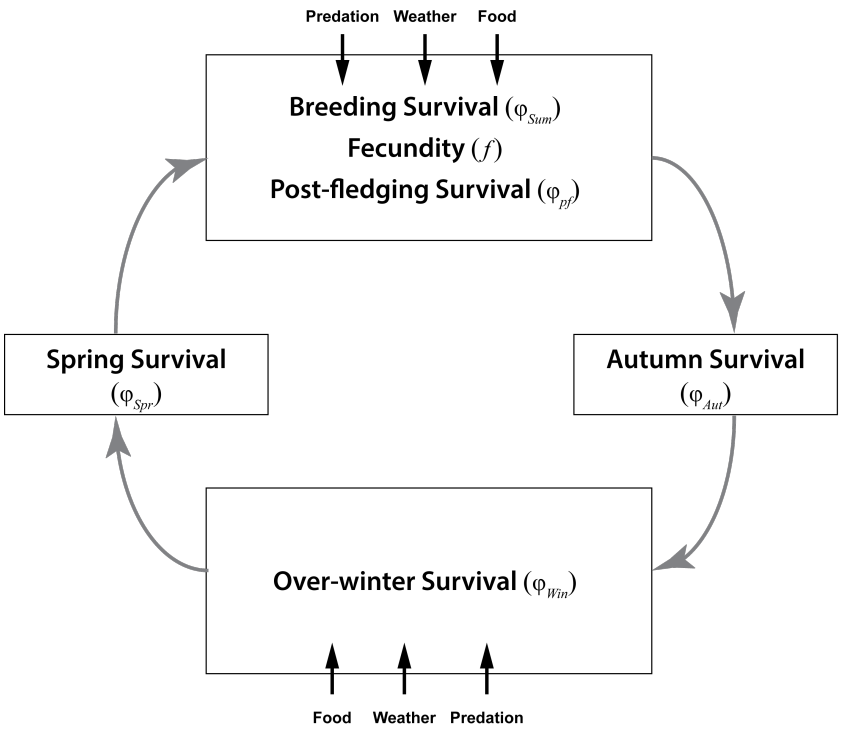
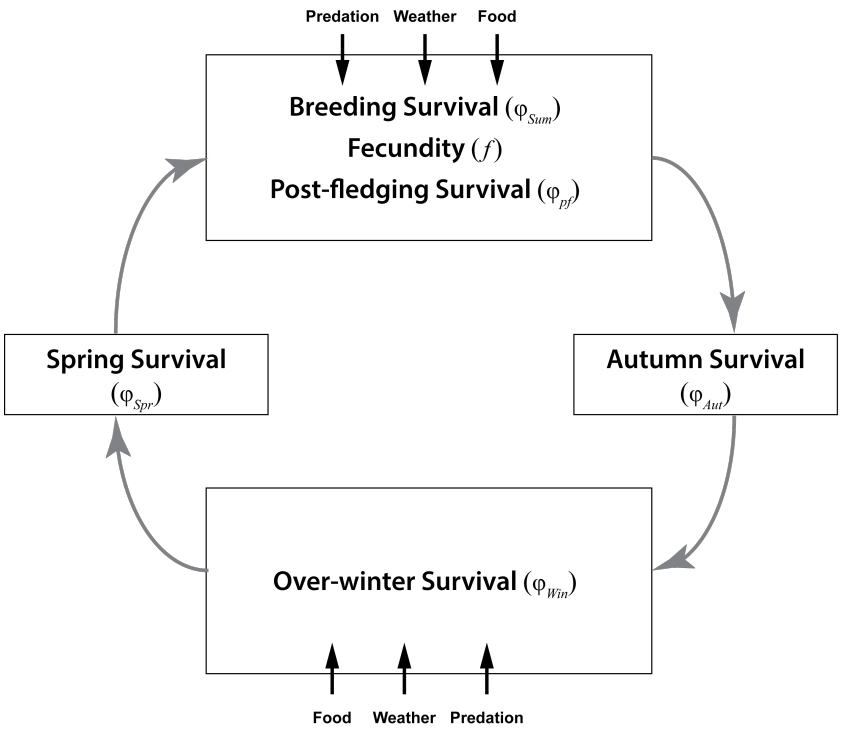
Population limitation in migratory birds



adapted from Sherry & Holmes 1995

Population limitation in migratory birds



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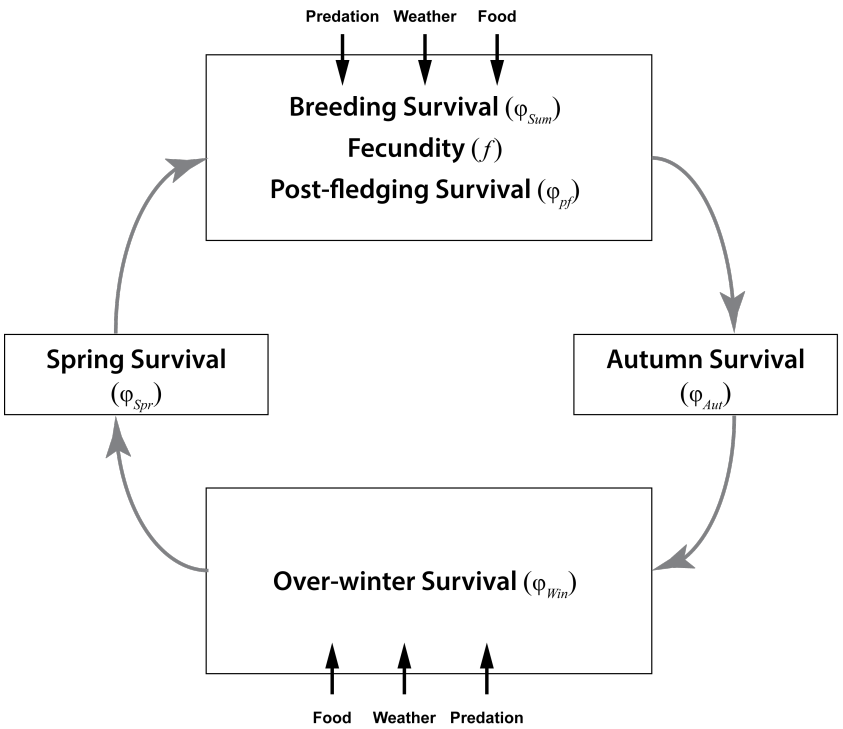
- Limitation can occur during any period of the annual cycle

Population limitation in migratory birds



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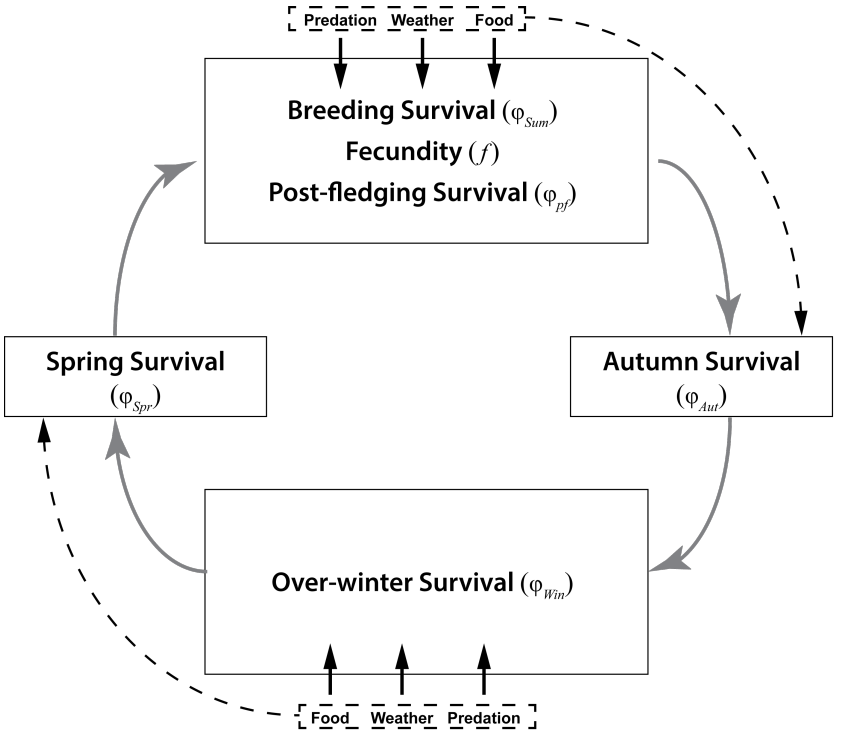
- Limitation can occur during any period of the annual cycle
- Limitation can occur during >1 period of the annual cycle

Population limitation in migratory birds

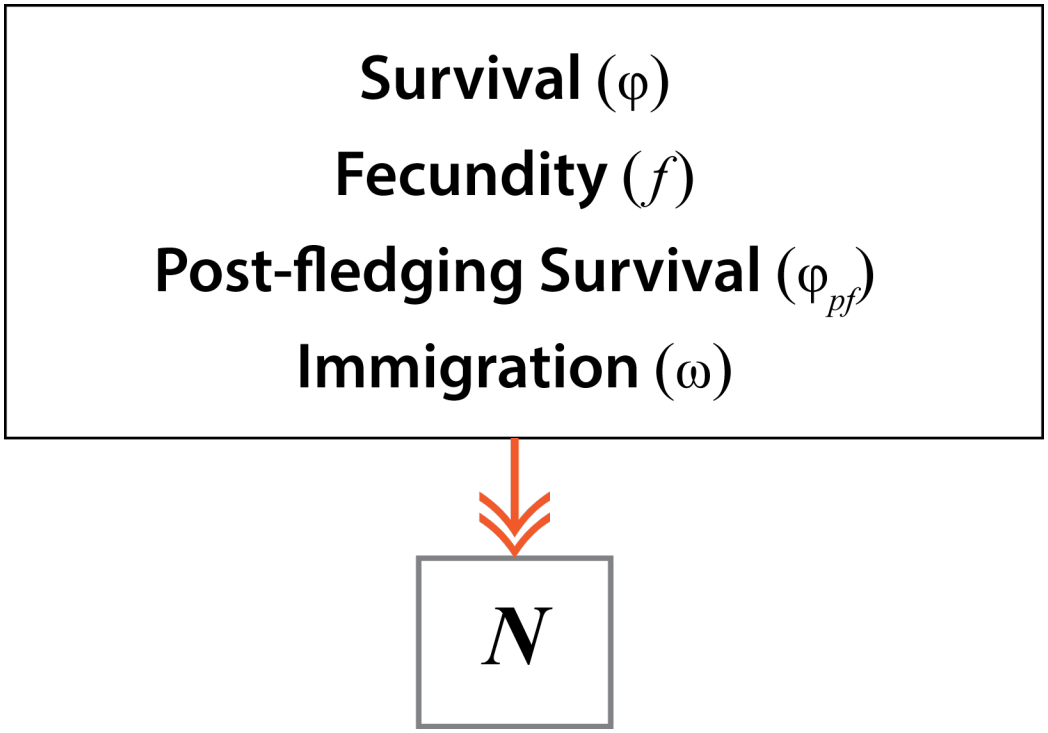


adapted from Sherry & Holmes 1995

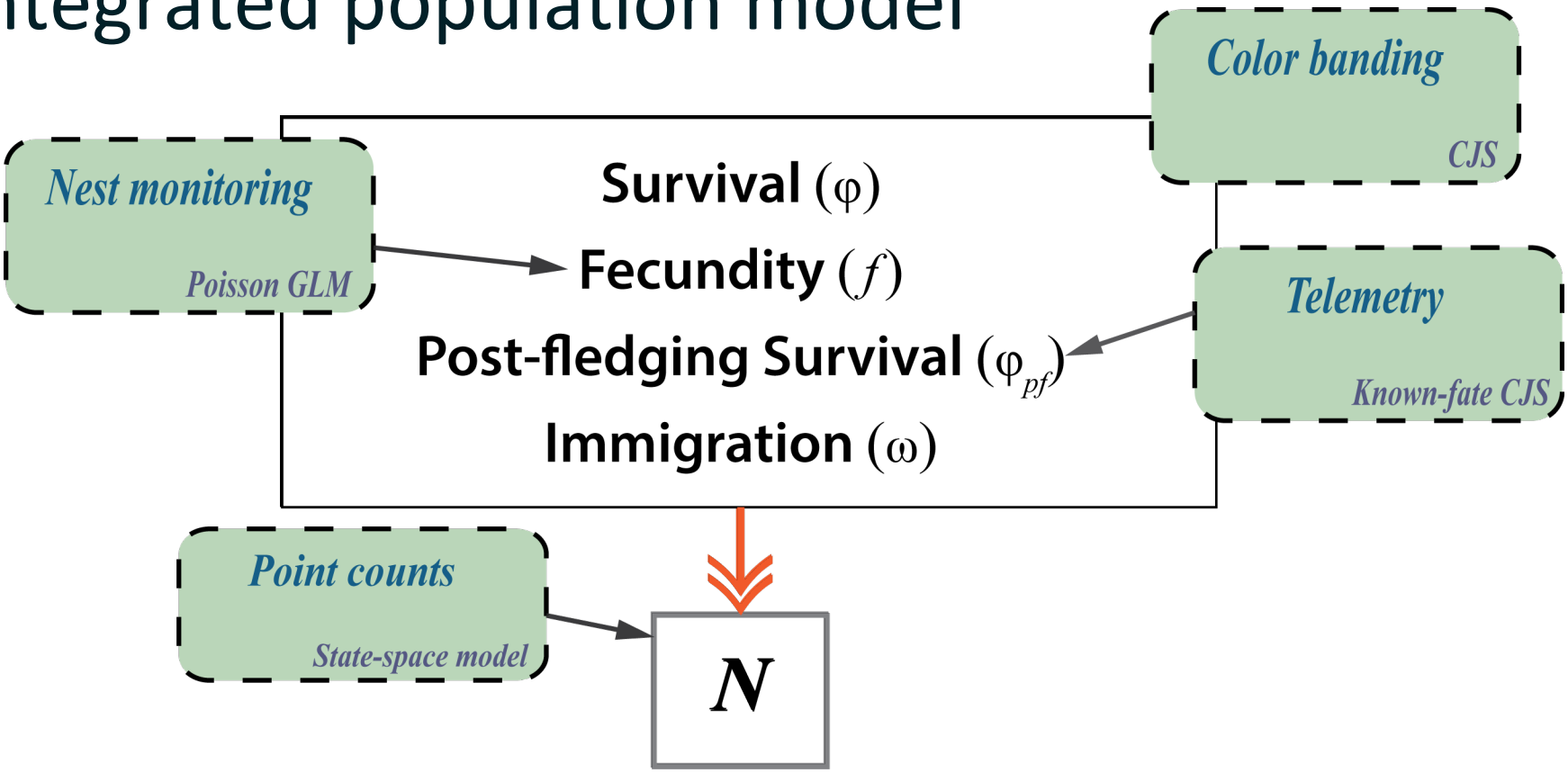
- Limitation can occur during any period of the annual cycle
- Limitation can occur during >1 period of the annual cycle
- Periods of the annual cycle are inextricably linked

Demographics cannot be understood outside of the full annual cycle

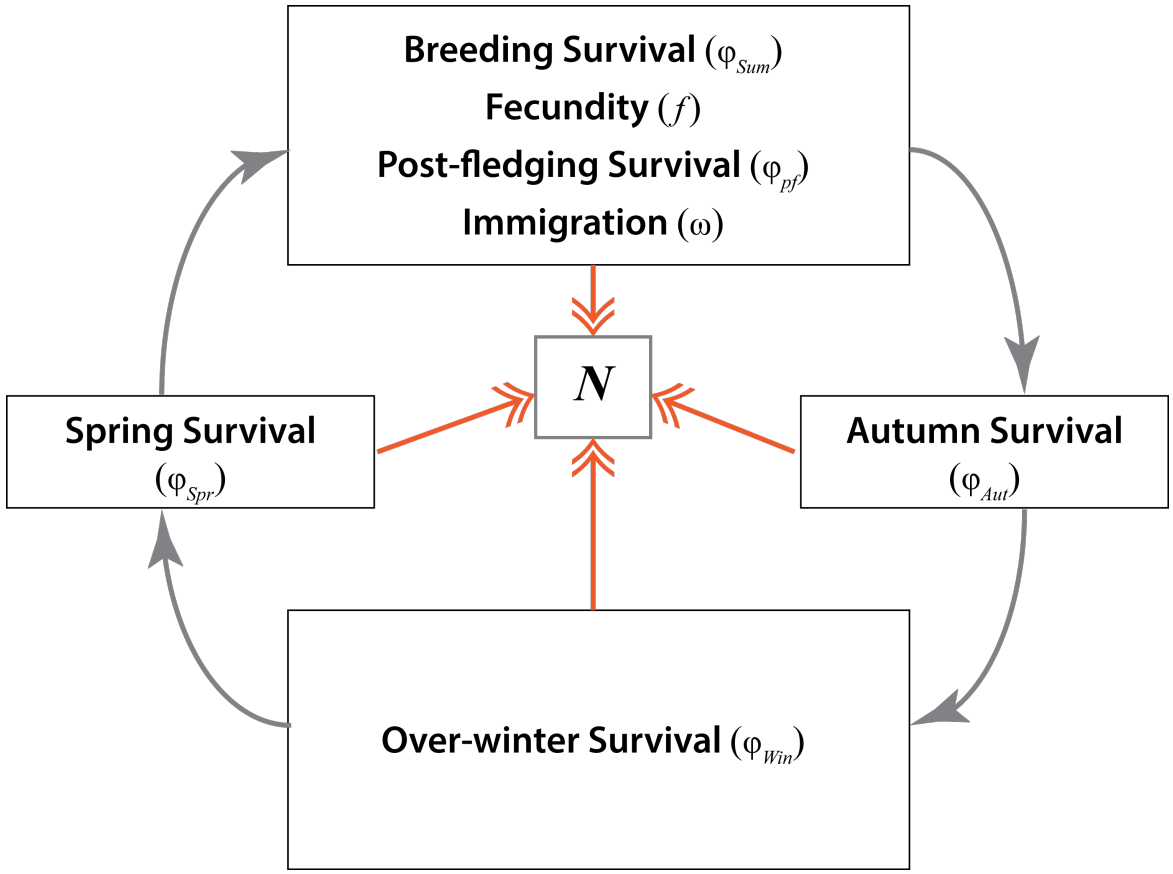
Integrated population model



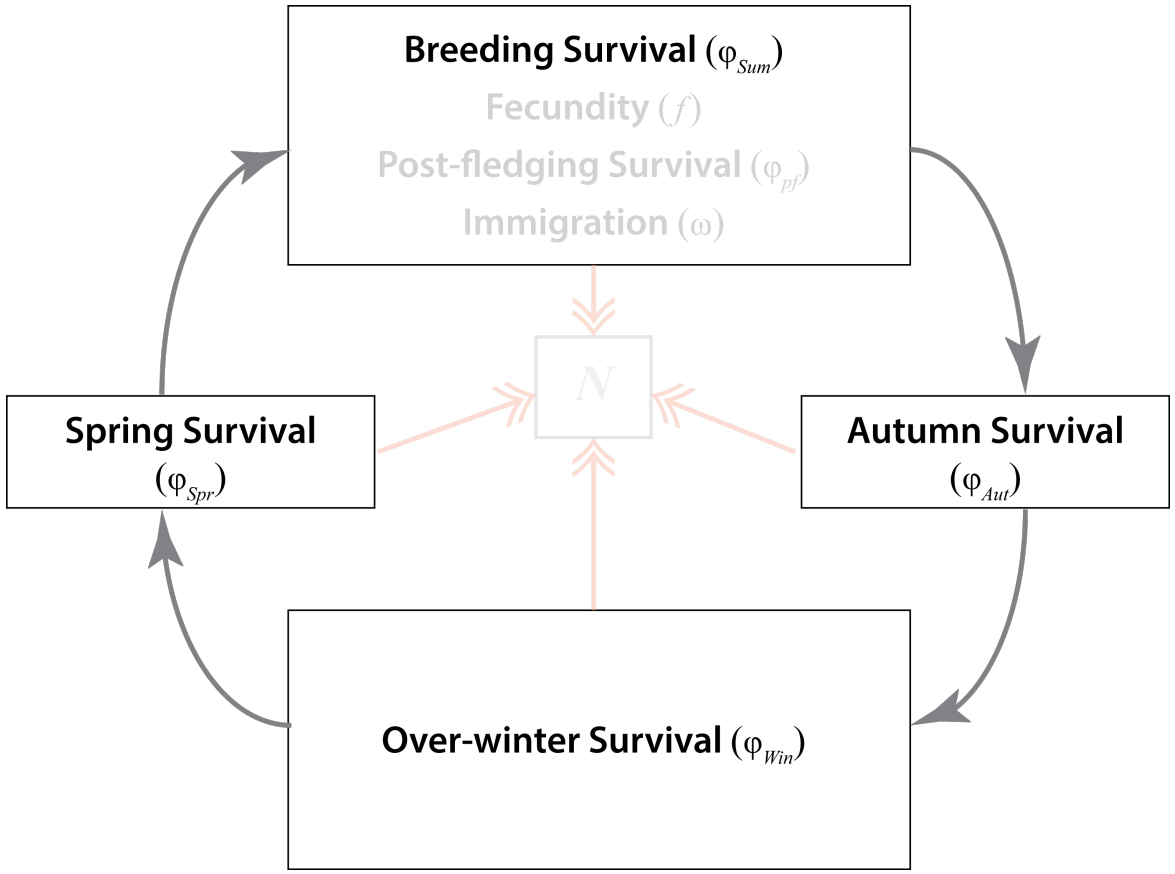
Integrated population model



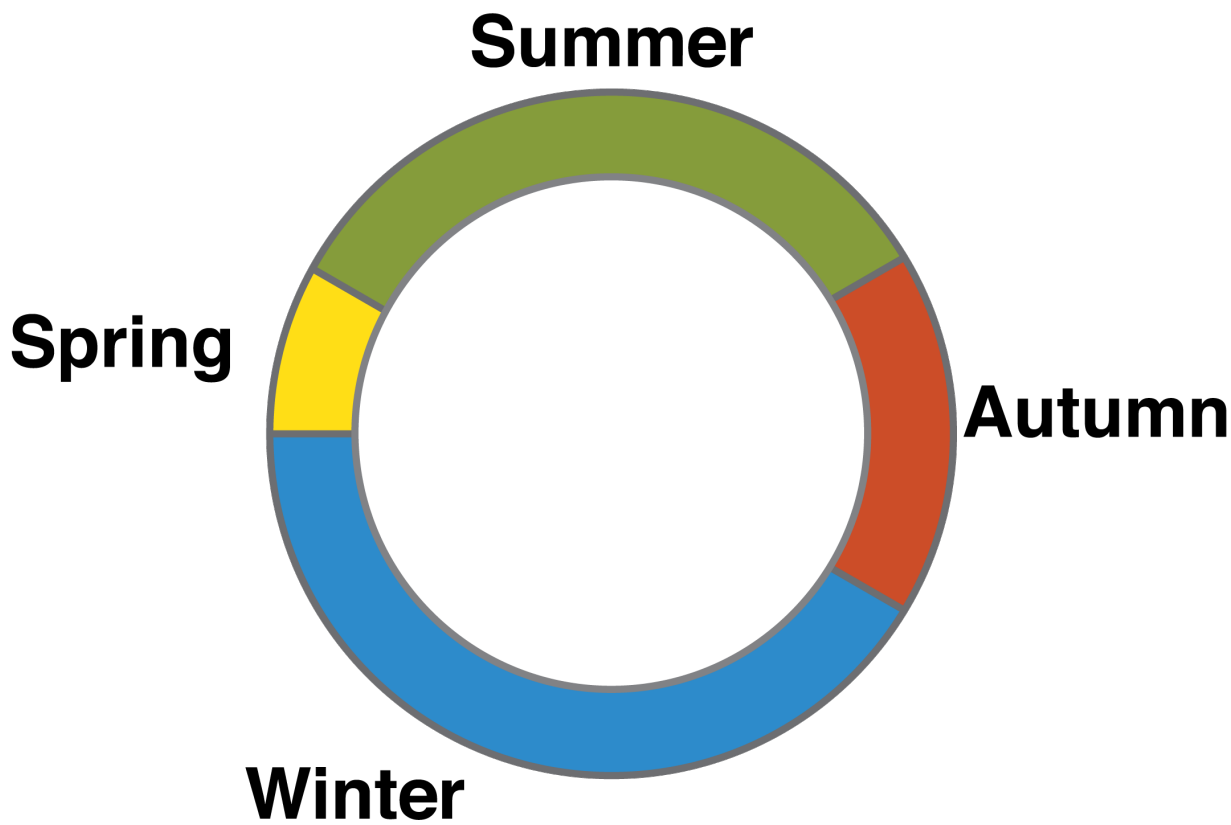
Full-annual-cycle integrated population model



Full-annual-cycle integrated population model

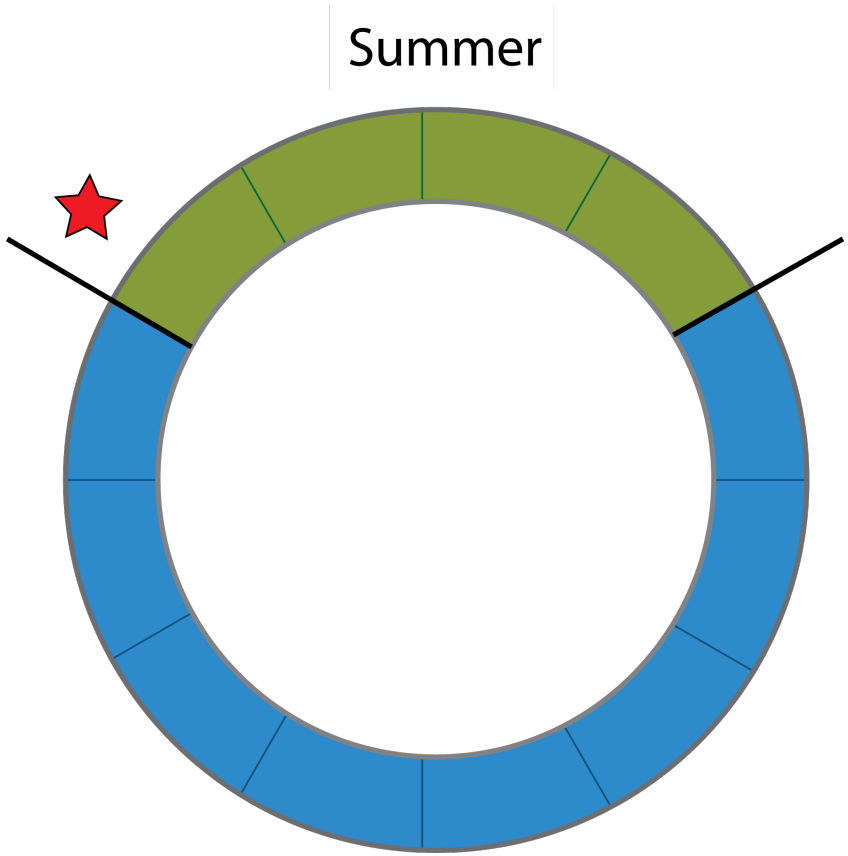


Integrated survival model



$$\Phi_{\text{Annual}} = \varphi_{\text{Sum}}\varphi_{\text{Aut}}\varphi_{\text{Win}}\varphi_{\text{Spr}}$$

Seasonal survival – Summer perspective



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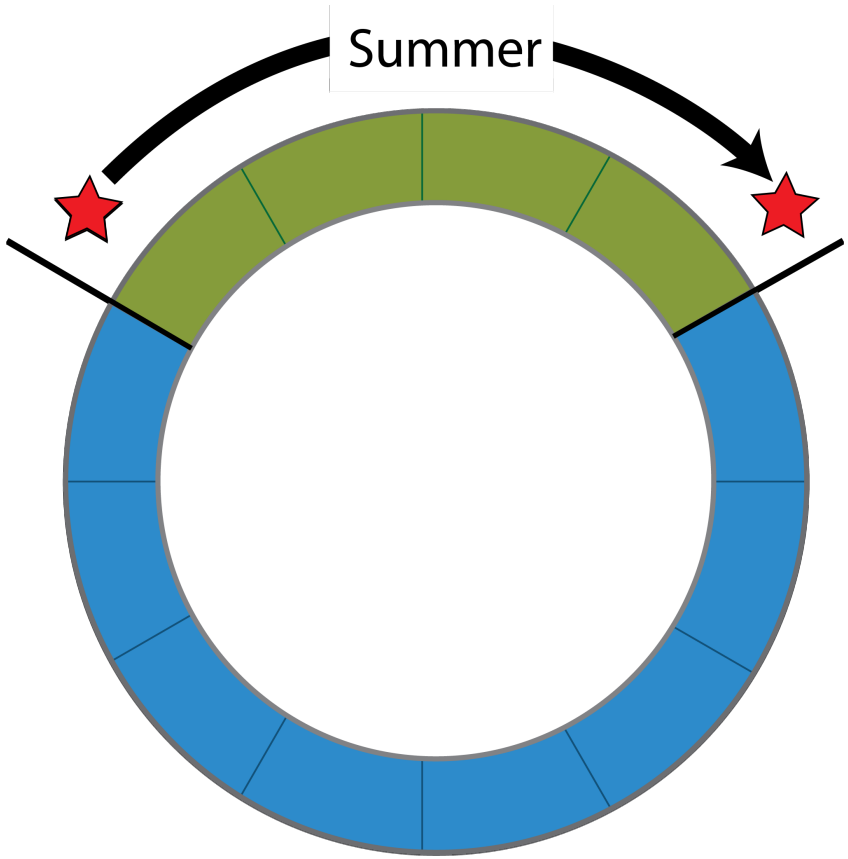

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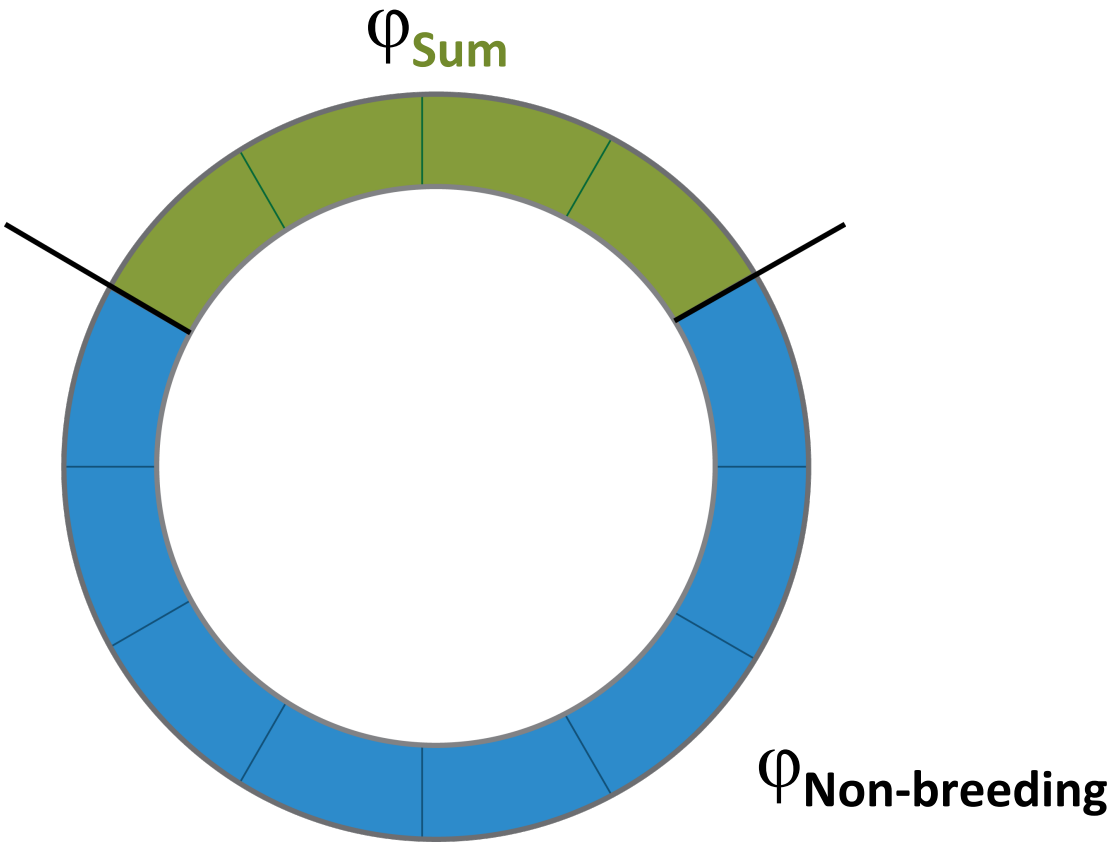
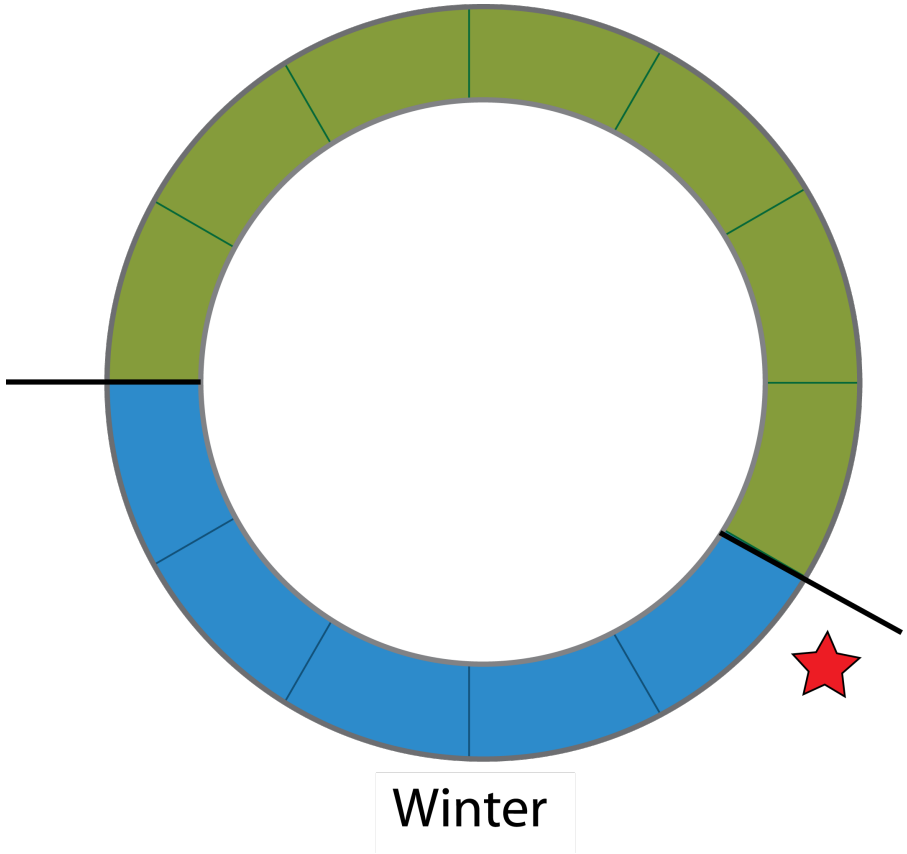


Seasonal survival – Winter perspective



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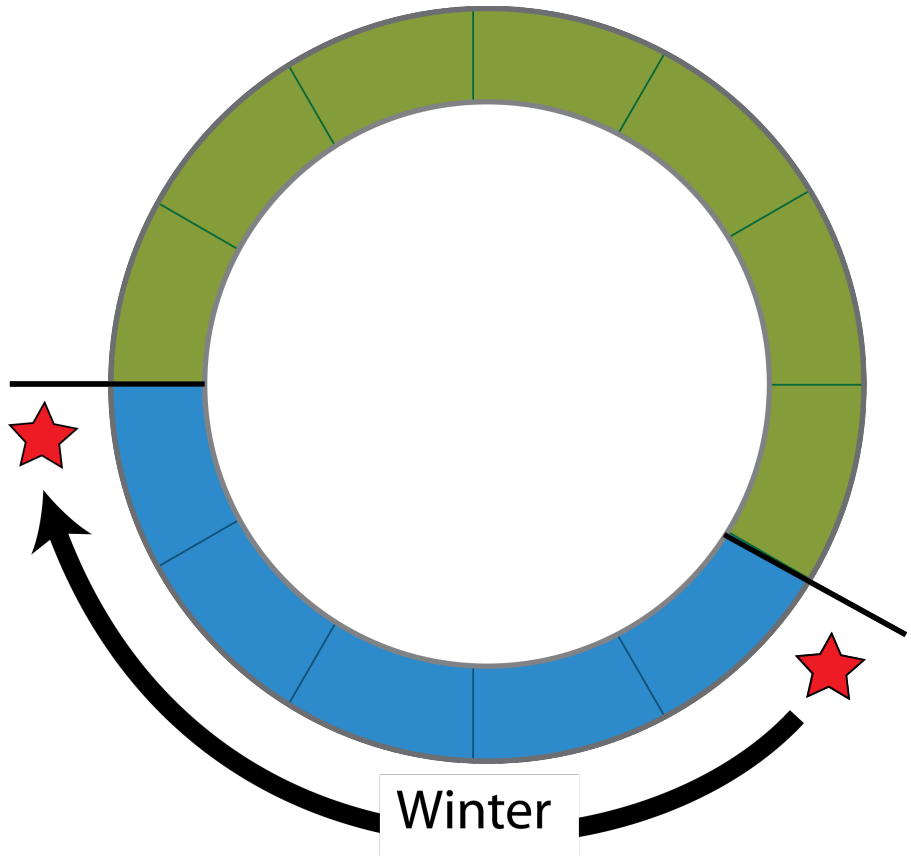

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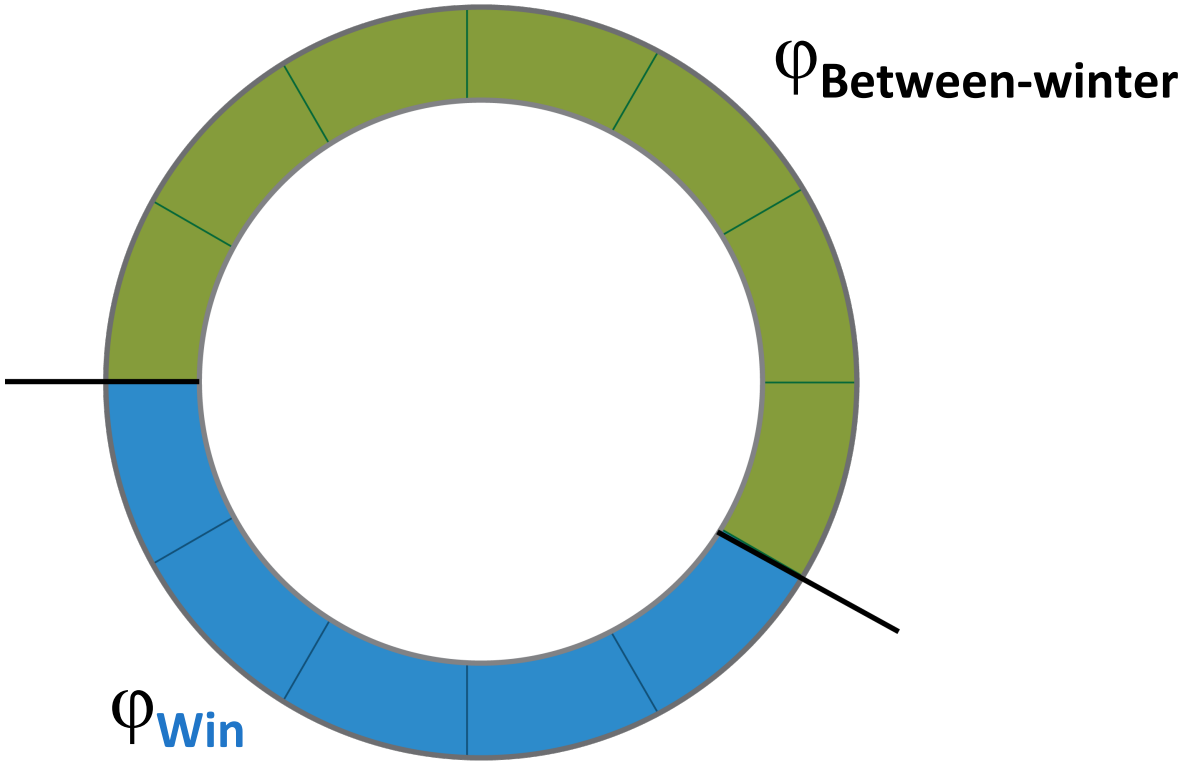
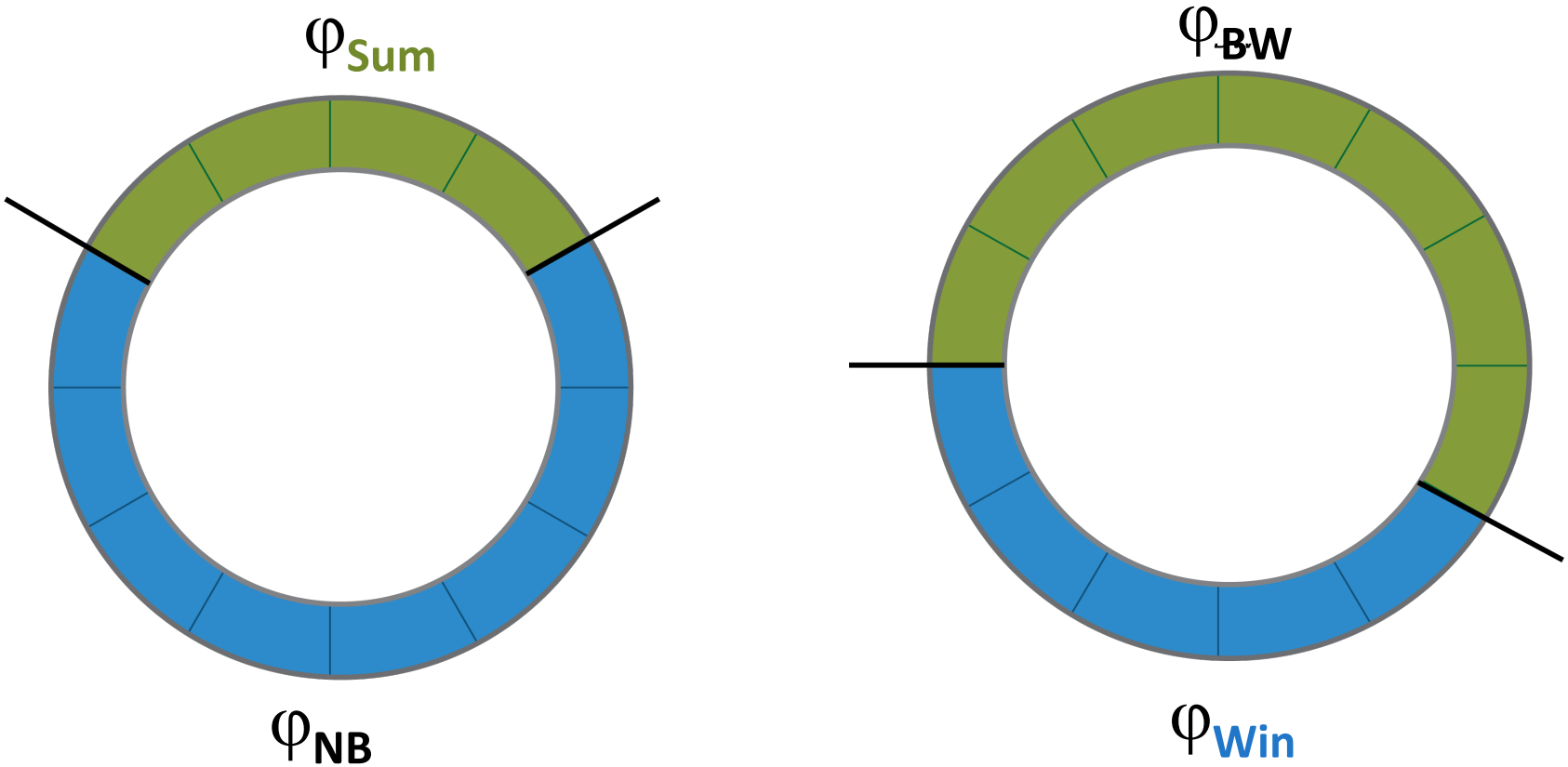


Seasonal survival – Integrated perspective



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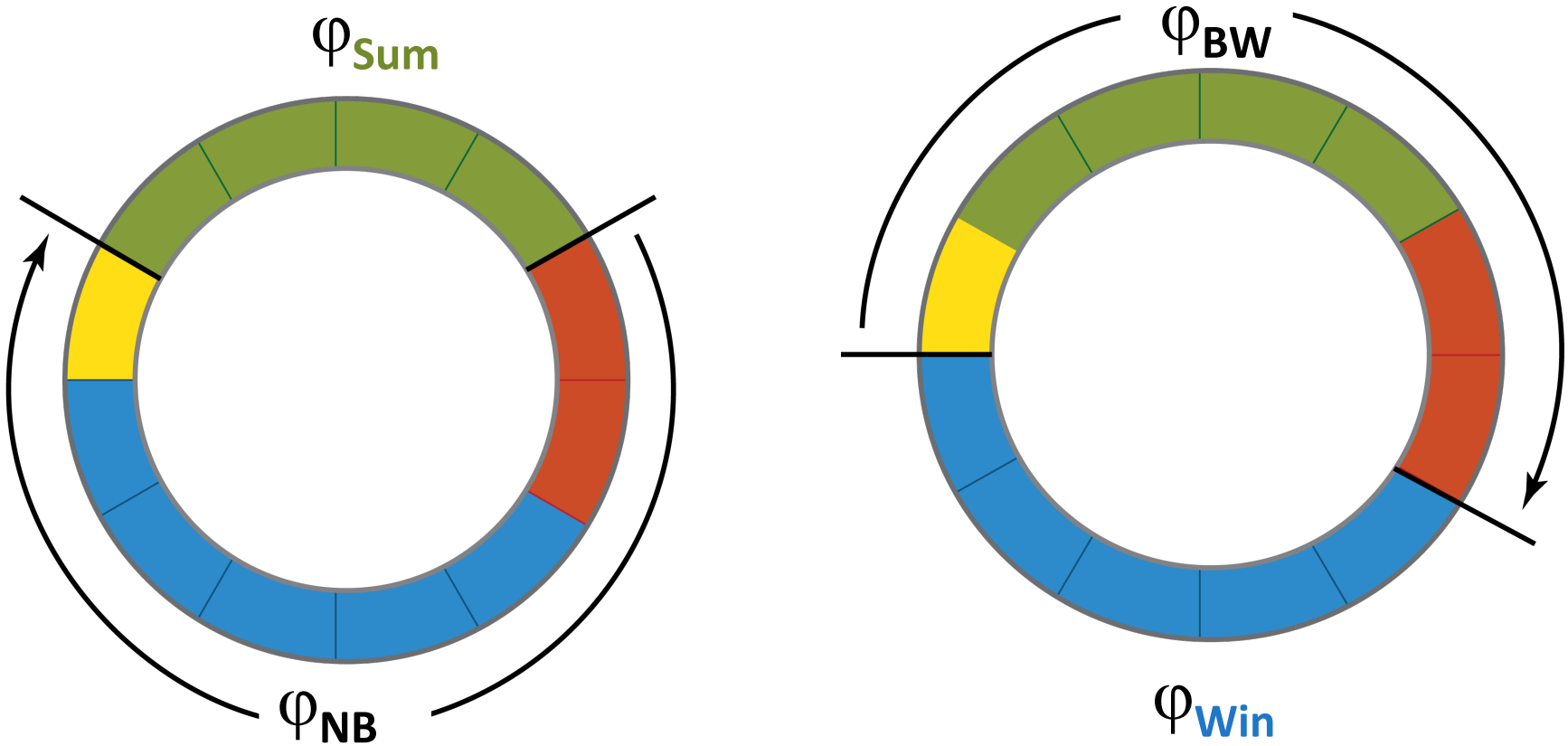


Seasonal survival – Integrated perspective

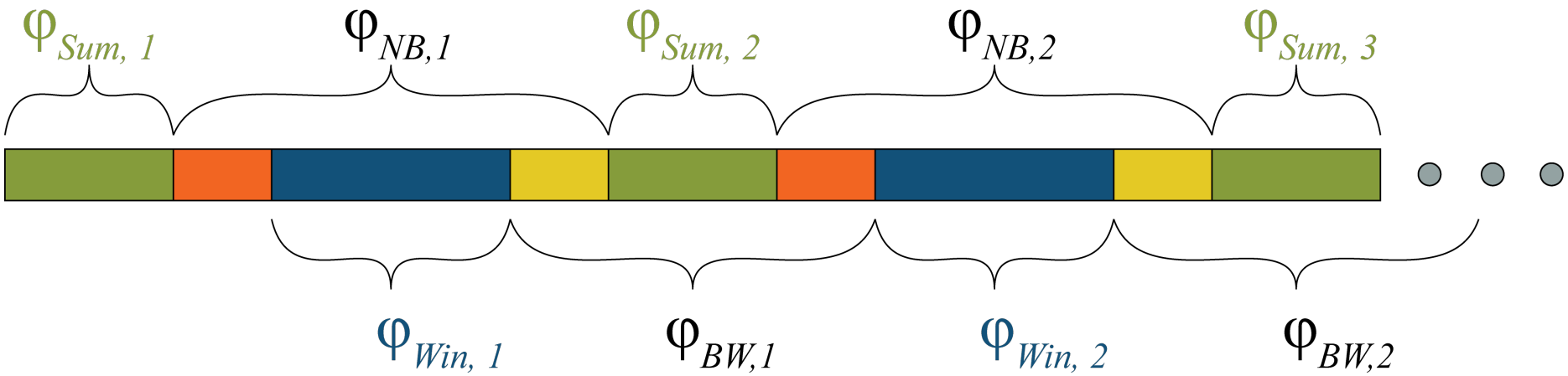
$$\varphi_{NB} = \varphi_{Aut}\varphi_{Win}\varphi_{Spr}$$

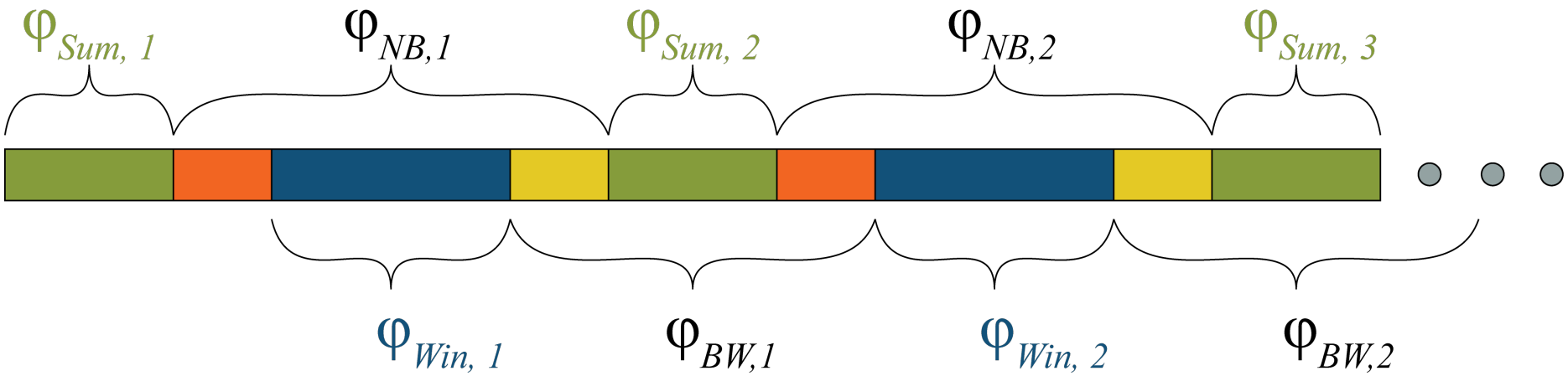
$$\varphi_{BW} = \varphi_{Spr}\varphi_{Sum}\varphi_{Aut}$$

Seasonal survival – Integrated perspective

$$\varphi_{NB} = \varphi_{Aut}\varphi_{Win}\varphi_{Spr}$$

$$\varphi_{BW} = \varphi_{Spr}\varphi_{Sum}\varphi_{Aut}$$

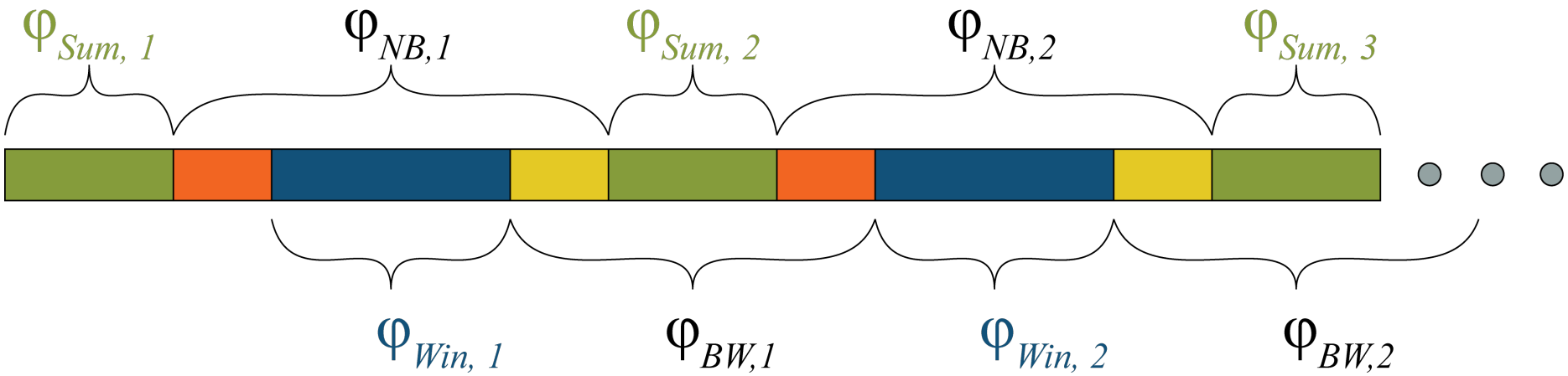

φSum, 1
φNB,1
φSum, 2
φNB,2
φSum, 3
φWin, 1
φBW,1
φWin, 2
φBW,2



$$\varphi_{NB,\,1} = \varphi_{Aut,\,1}\varphi_{Win,\,1}\varphi_{Spr,\,1}$$

$$\varphi_{BW,\,1} = \varphi_{Spr,\,1}\varphi_{Sum,\,2}\varphi_{Aut,\,2}$$

$$\varphi_{NB,\,2} = \varphi_{Aut,\,2}\varphi_{Win,\,2}\varphi_{Spr,\,2}$$



$$\varphi_{NB,\,1} = \varphi_{Aut,\,1}\varphi_{Win,\,1}\varphi_{Spr,\,1}$$

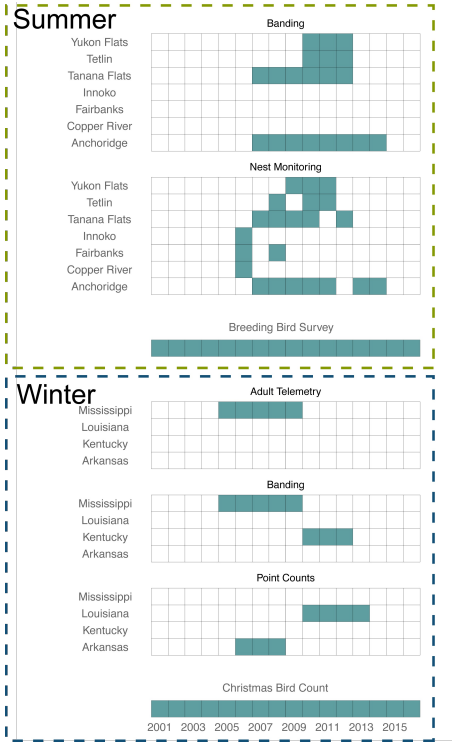
$$\varphi_{BW,\,1} = \varphi_{Spr,\,1}\varphi_{Sum,\,2}\varphi_{Aut,\,2}$$

$$\varphi_{NB,\,2} = \varphi_{Aut,\,2}\varphi_{Win,\,2}\varphi_{Spr,\,2}$$

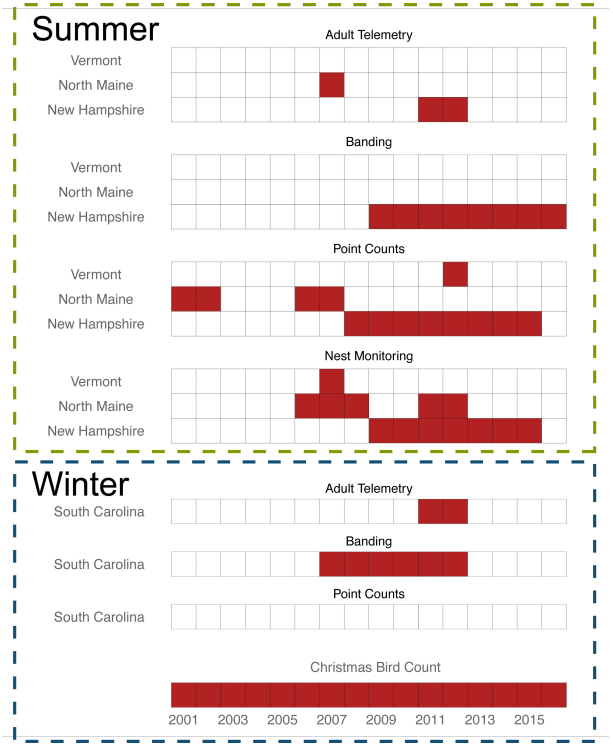
The data

Current Rusty Blackbird data

West



East



Current Rusty Blackbird data

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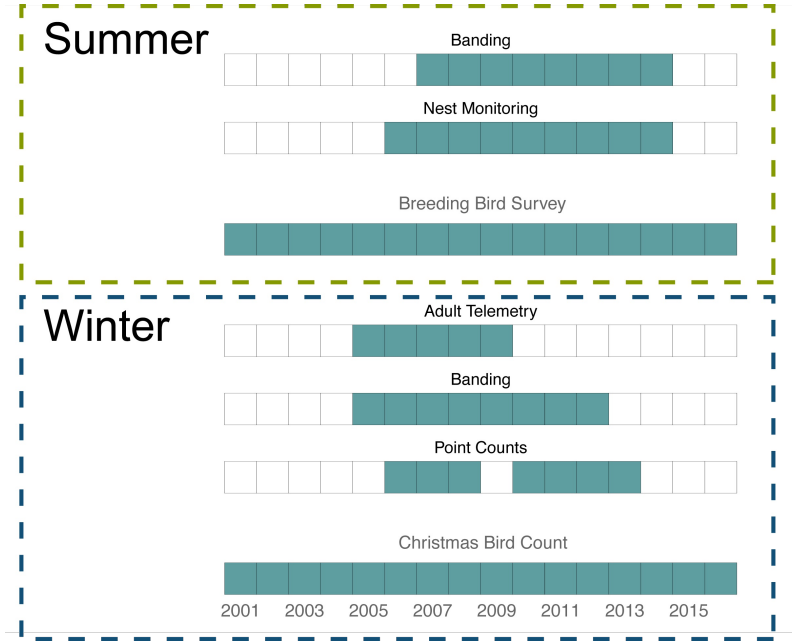

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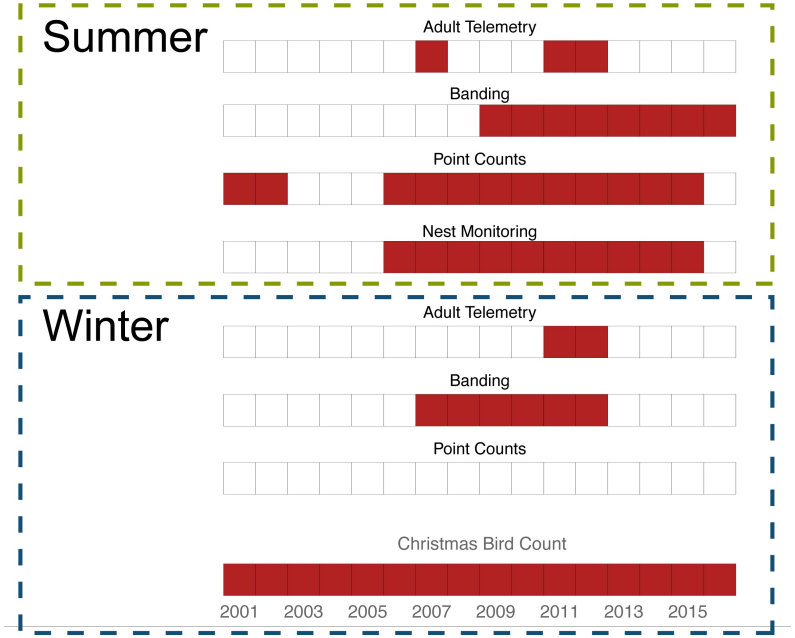

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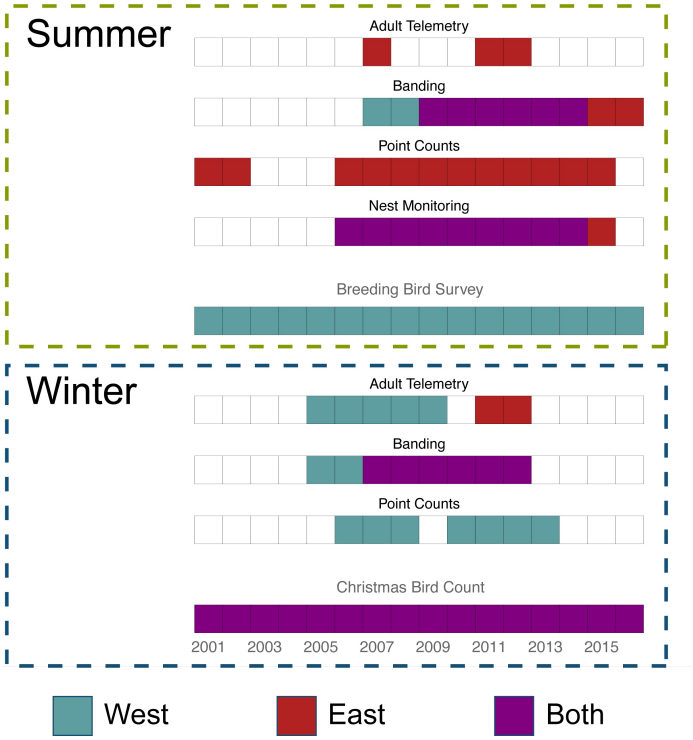

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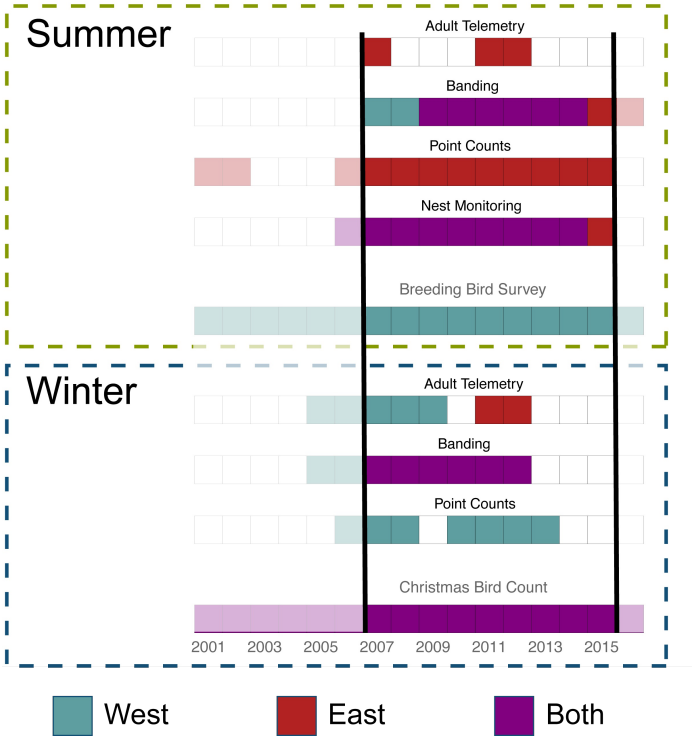
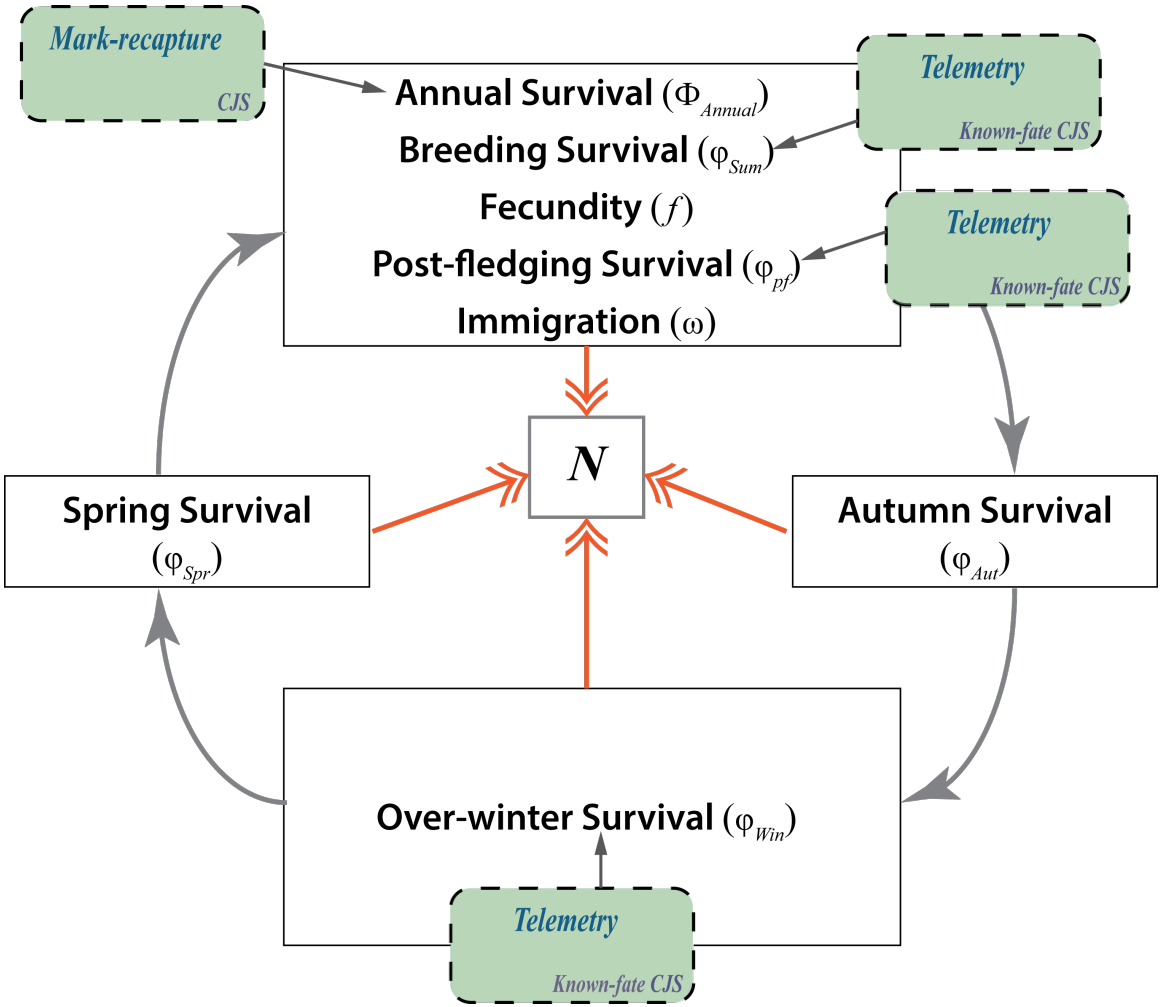
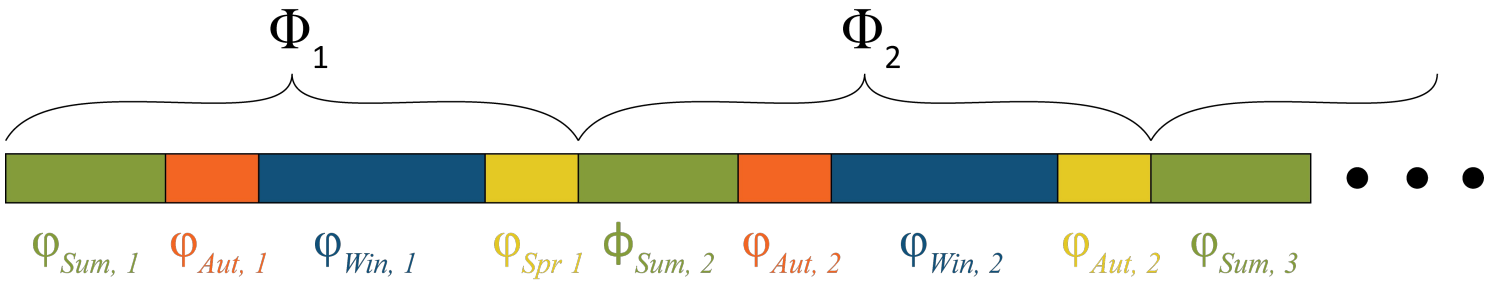


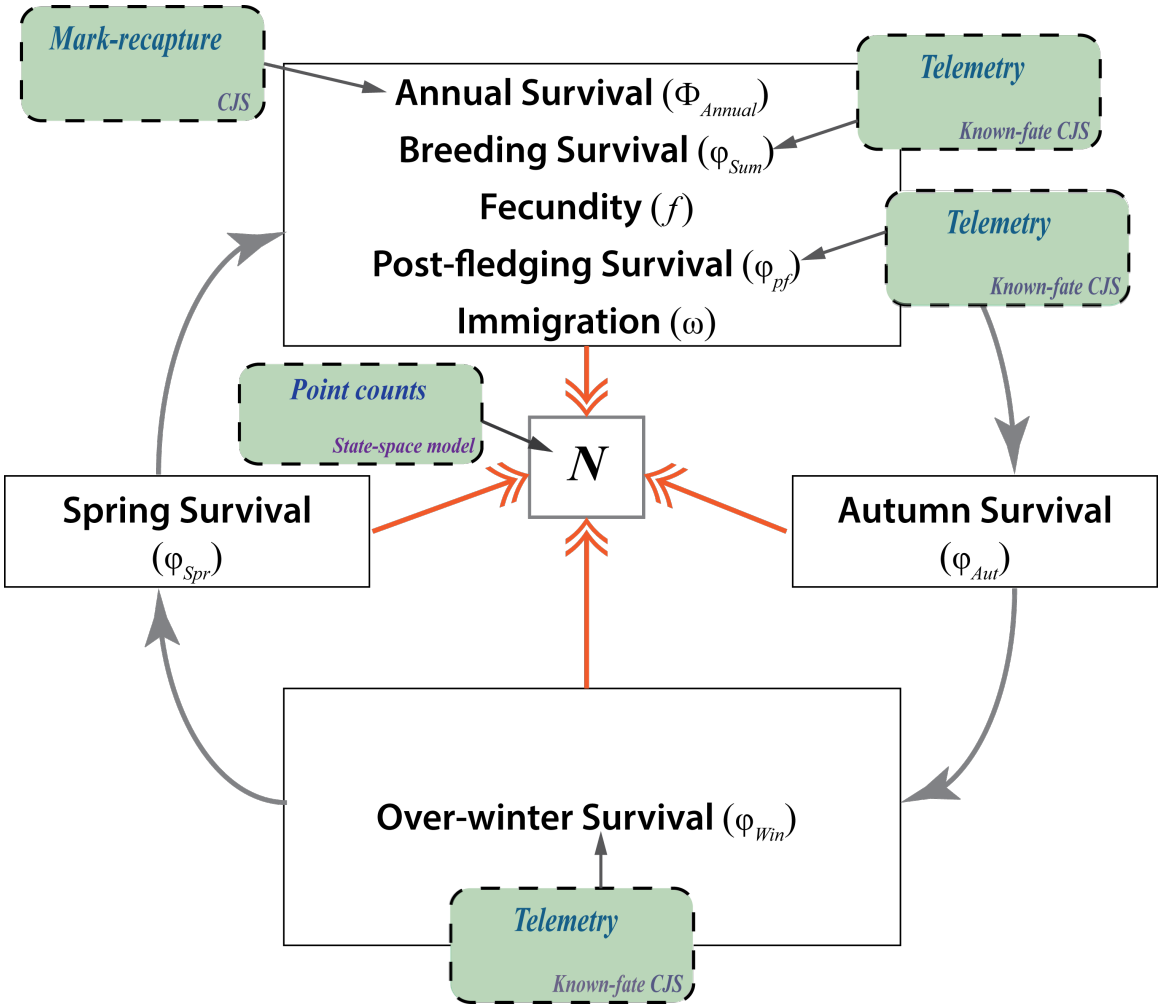

Mark-recapture
CJS
Telemetry
Known-fate CJS
Telemetry
Known-fate CJS
Annual Survival (Φ_{Annual})
Breeding Survival (φ_{Sum})
Fecundity (f)
Post-fledging Survival (φ_{pf})
Immigration (ω)
N
Spring Survival
(φ_{Spr})
Autumn Survival
(φ_{Aut})
Over-winter Survival (φ_{Win})
Telemetry
Known-fate CJS

Rusty Blackbird survival



$$\Phi_1 = \varphi_{Sum,\ 1}\varphi_{Aut,\ 1}\varphi_{Win,\ 1}\varphi_{Spr,\ 1}$$

$$\Phi_2 = \varphi_{Sum,\ 2}\varphi_{Aut,\ 2}\varphi_{Win,\ 2}\varphi_{Spr,\ 2}$$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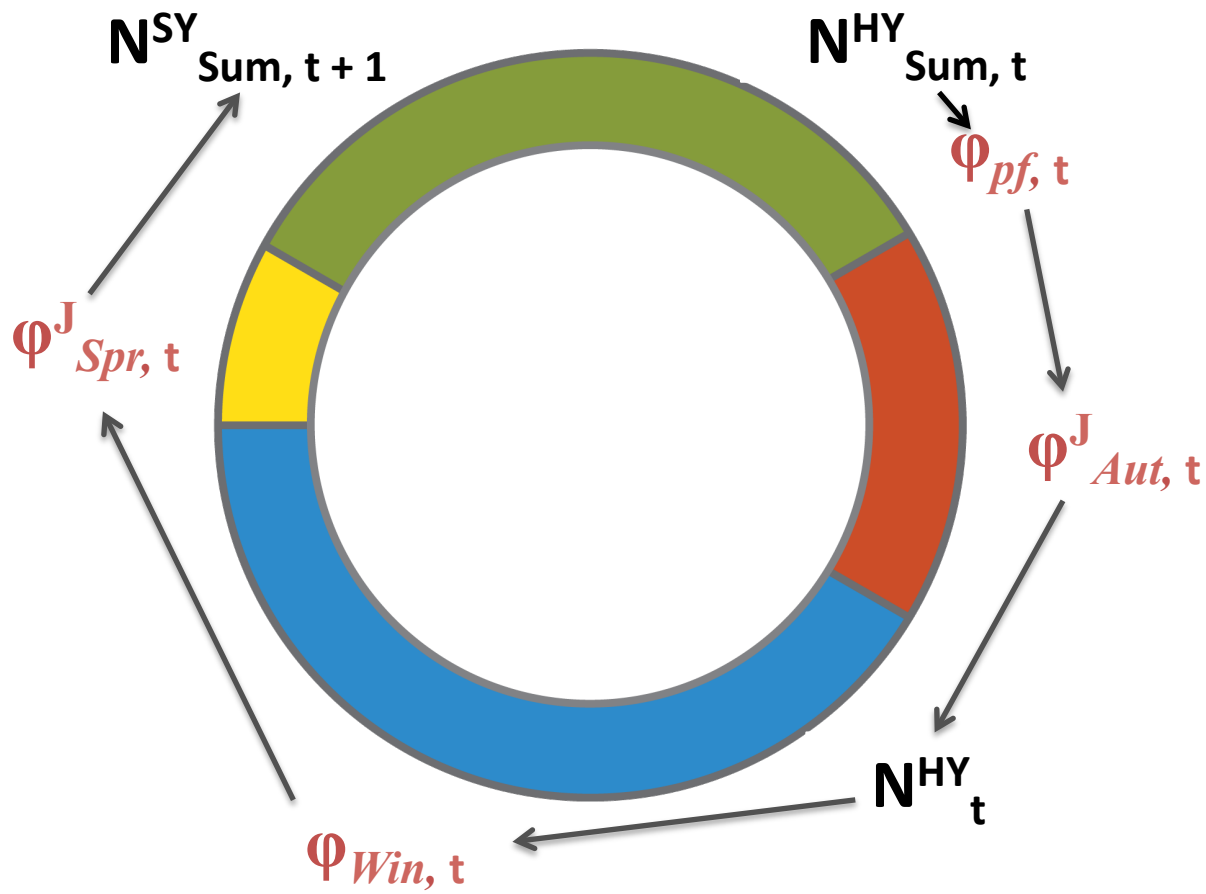
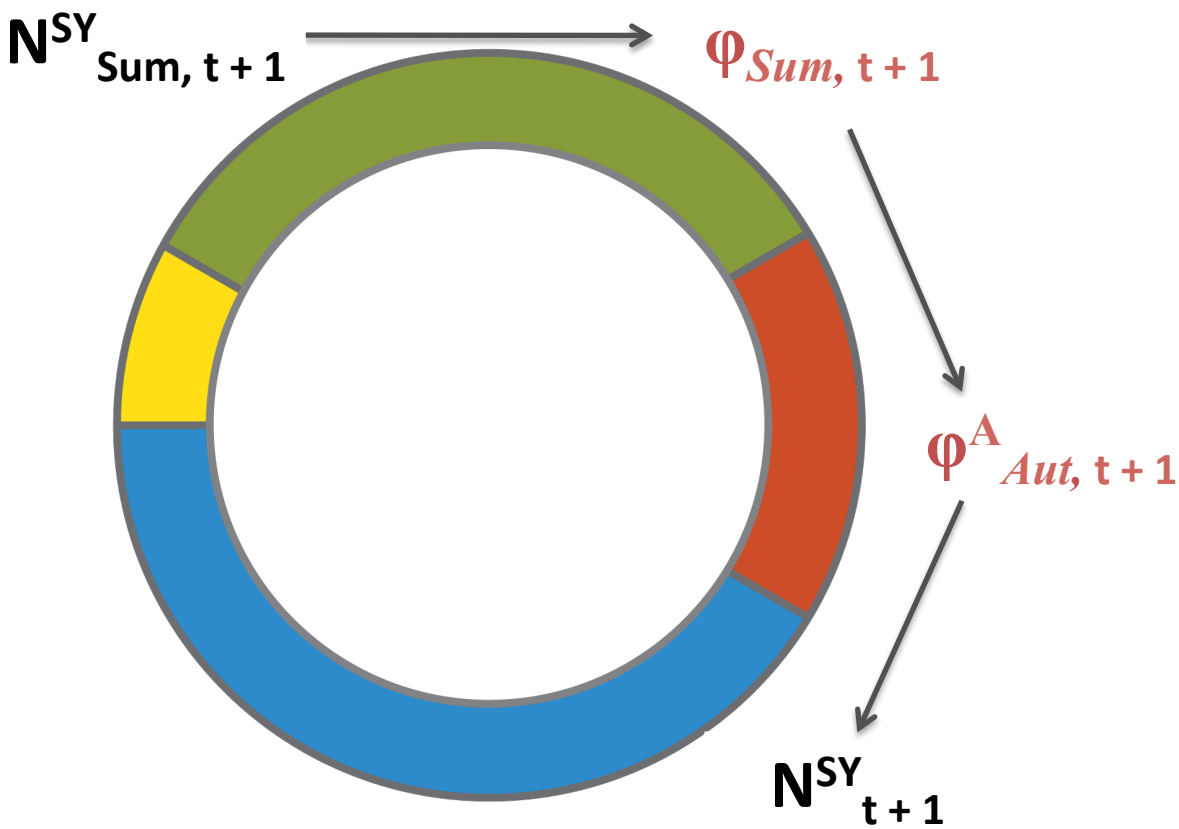
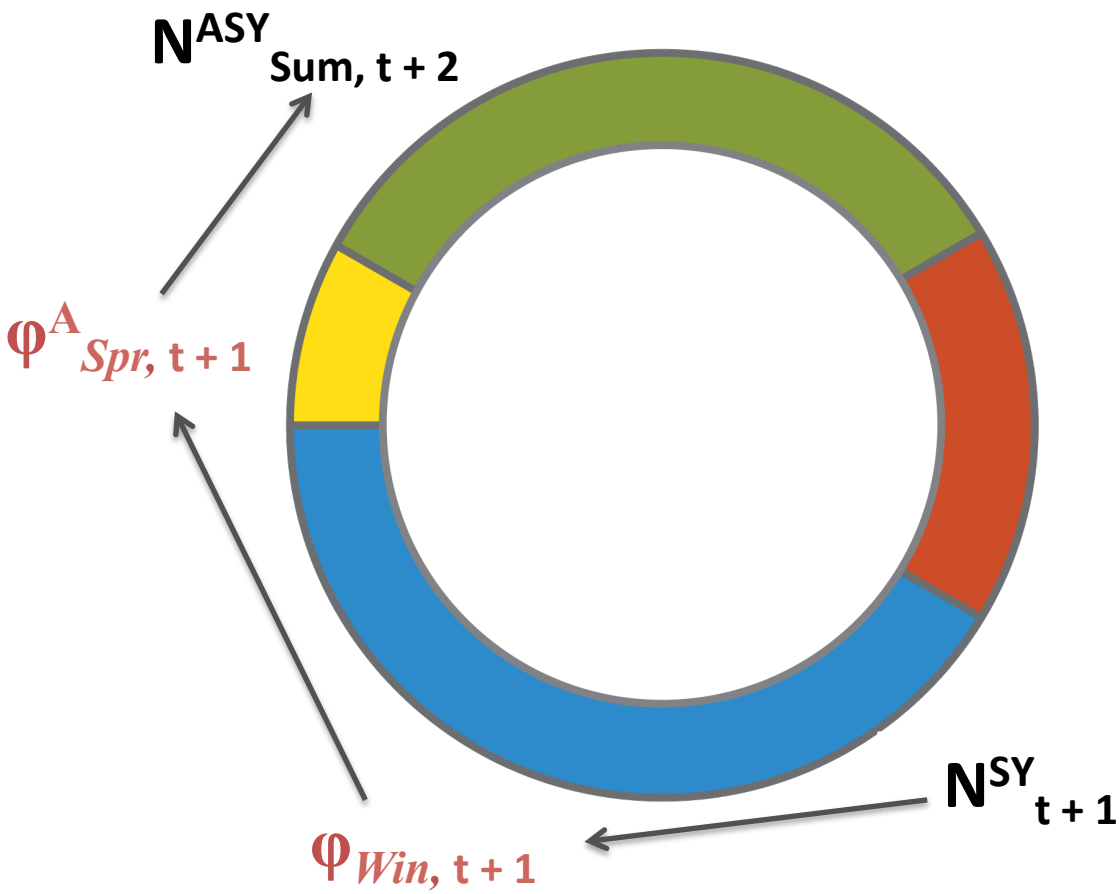
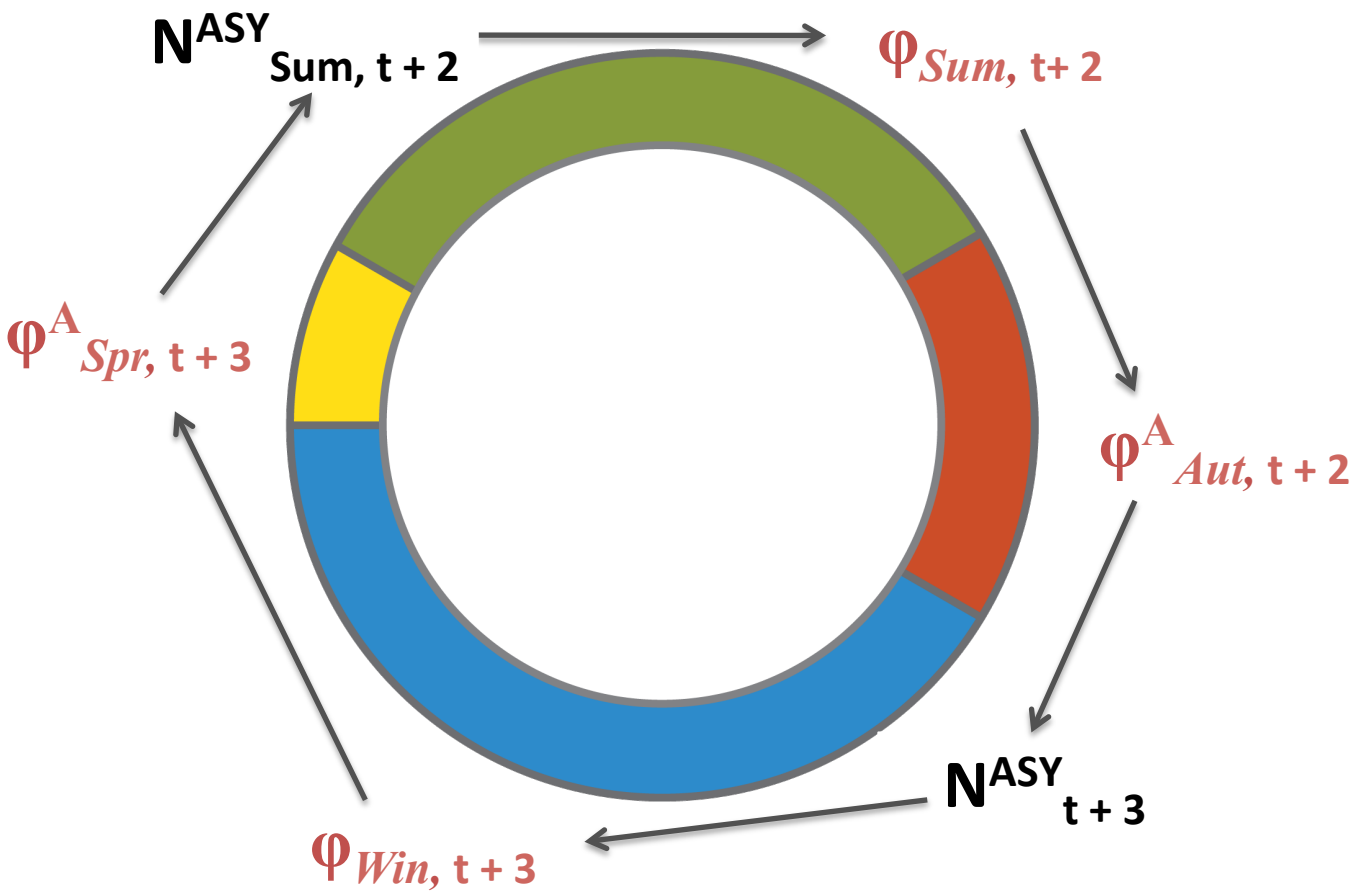

$N^{SY}_{Sum,\ t+1}$
$N^{HY}_{Sum,\ t}$
$\varphi_{pf,\ t}$
$\varphi^{J}_{Spr,\ t}$
$\varphi^{J}_{Aut,\ t}$
N^{HY}_{t}
$\varphi_{Win,\ t}$


$N^{SY}_{Sum,\ t+1}$
$\varphi_{Sum,\ t+1}$
$\varphi^{A}_{Aut,\ t+1}$
N^{SY}_{t+1}


$N^{ASY}_{Sum,\ t+2}$
$\varphi^{A}_{Spr,\ t+1}$
N^{SY}_{t+1}
$\varphi_{Win,\ t+1}$


$N^{ASY}_{Sum,\ t+2}$
$\varphi_{Sum,\ t+2}$
$\varphi^{A}_{Aut,\ t+2}$
N^{ASY}_{t+3}
$\varphi_{Win,\ t+3}$
$\varphi^{A}_{Spr,\ t+3}$

Population size

State-space model

Winter state model:

$N^{HY}_{Win,t} \sim \text{Binomial}(N^{HY}_{Sum,\,t-1}, \varphi_{pf,\,t-1} \times \varphi^{J}_{Aut,\,t})$

$N^{SY}_{Win,t} \sim \text{Binomial}(N^{SY}_{Sum,\,t-1}, \varphi_{Sum,t-1} \times \varphi^{A}_{Aut,t})$

$N^{ASY}_{Win,\,t} \sim \text{Binomial}(N^{ASY}_{Sum,\,t-1}, \varphi_{Sum,t-1} \times \varphi^{A}_{Aut,t})$

$N^{Imm}_{Win,\,t} \sim \text{Poisson}(\lambda_t)$

$$\mathbf{N_t = N^{HY}_{Win,t} + N^{SY}_{Win,t} + N^{ASY}_{Win,t} + N^{Imm}_{Win,t}}$$

N^{HY}_{Wiin}= Hatch-year

N^{SY}_{Win} = Second-year

N^{ASY}_{Win} = After second-year

N^{Imm}_{Win} = Immigrant (age?)

Population size

State-space model

Summer state model:

$N^{HY}_{Sum,\,t} \sim \text{Poisson}(0.5 \times f_t \times [N^{SY}_{Sum,t} + N^{ASY}_{Sum,t}])$

$N^{SY}_{Sum,t} \sim \text{Binomial}(N^{HY}_{Win,t}, \varphi_{Win,t} \times \varphi^{J}_{Spr,t})$

$N^{ASY}_{Sum,t} \sim \text{Binomial}([N^{SY}_{Win,t} + N^{ASY}_{Win,t}], \varphi_{Win,t} \times \varphi^{A}_{Spr,t})$

N^{HY}_{Sum} = Hatch-year

N^{SY}_{Sum} = Second-year

N^{ASY}_{Sum} = After second-year

f = Per capita fecundity

Population size

CBC_t = Total CBC count

State-space model

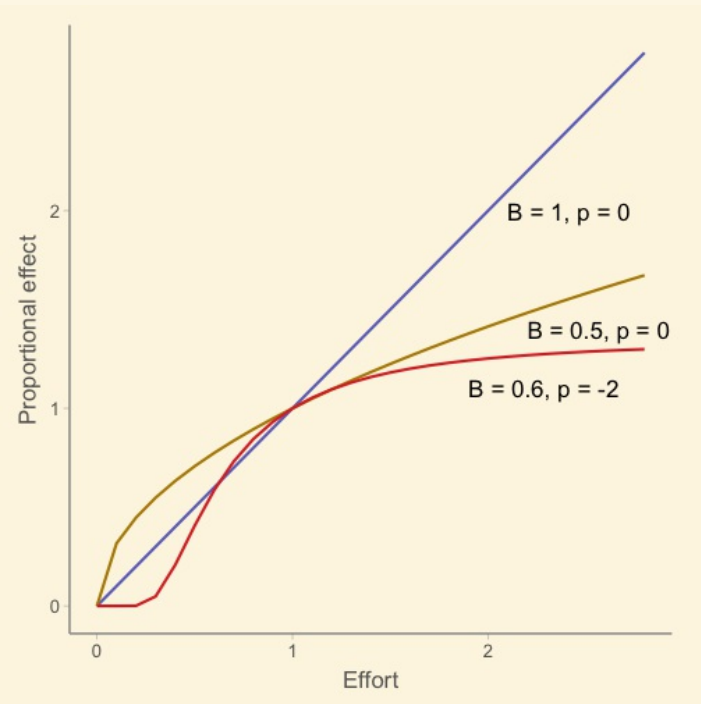
Winter observation model:

$$CBC_t \sim \text{Poisson}(E[N_t])$$

$$E[N_t]) = N_t \times \exp(\Psi_t)$$

Christmas Bird Count

Link & Sauer (2007)



$$\Psi_t = B[(\xi_t/\bar{\xi})^p - 1]/p$$

- If:
  - $B = 1, p \approx 0$: Linear
  - $0 < B < 1, p \approx 0$: Diminishing
  - $B > 0, p < 0$: Asymptotic

Christmas Bird Count

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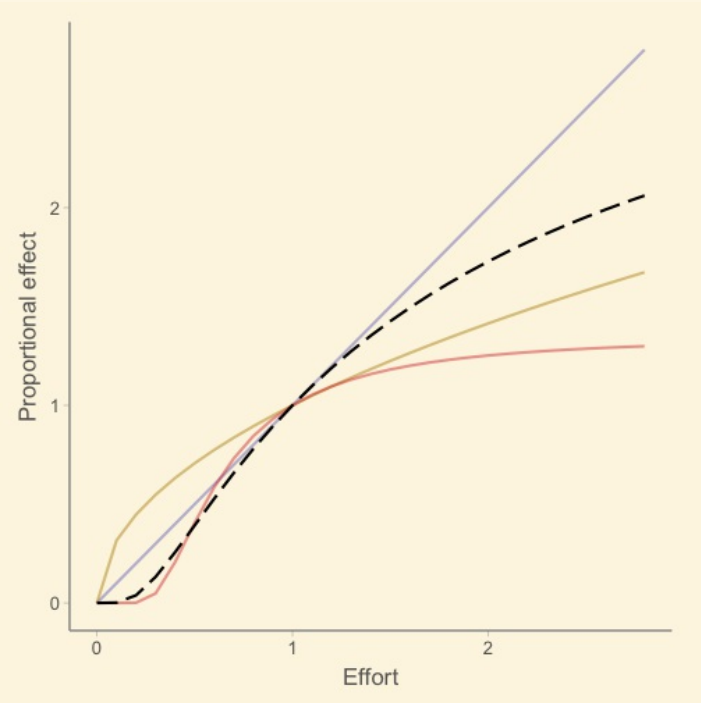
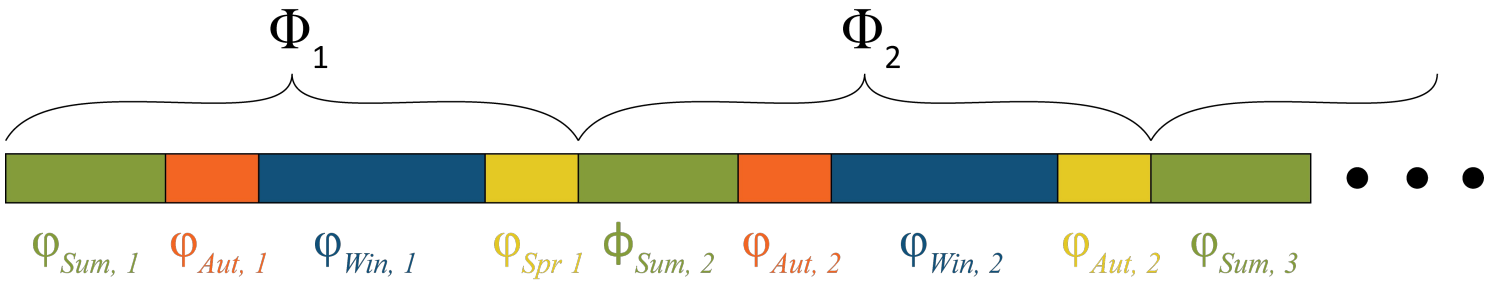


$$\Psi_t = B[(\xi_t/\bar{\xi})^p - 1]/p$$

- Rusty Blackbird estimates:
  - $B = 1.02\ (0.81 : 1.65)$
  - $p = -0.77\ (-1.29 : -0.09)$

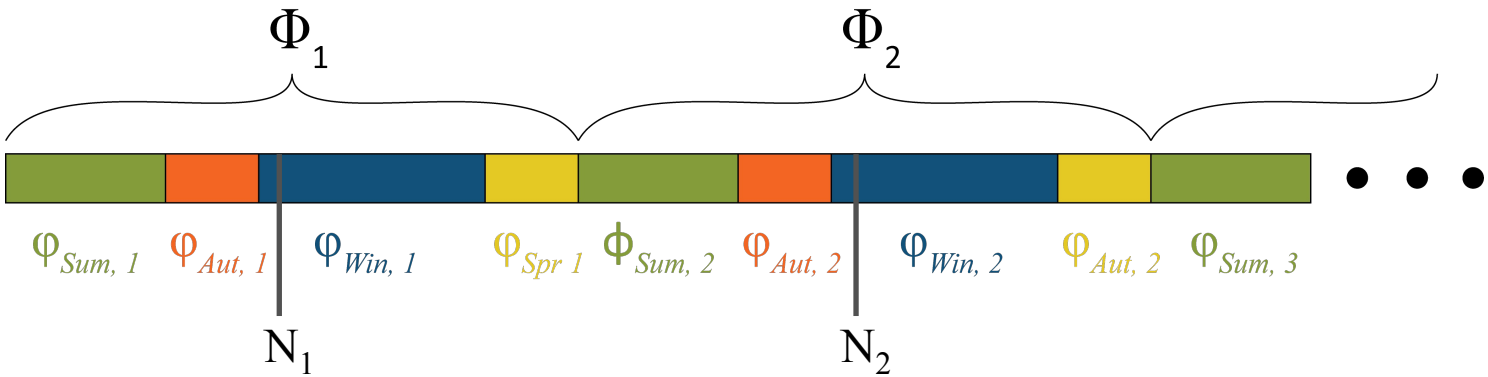
Rusty Blackbird survival



$$\Phi_1 = \varphi_{Sum,\ 1}\varphi_{Aut,\ 1}\varphi_{Win,\ 1}\varphi_{Spr,\ 1}$$

$$\Phi_2 = \varphi_{Sum,\ 2}\varphi_{Aut,\ 2}\varphi_{Win,\ 2}\varphi_{Spr,\ 2}$$

Rusty Blackbird survival

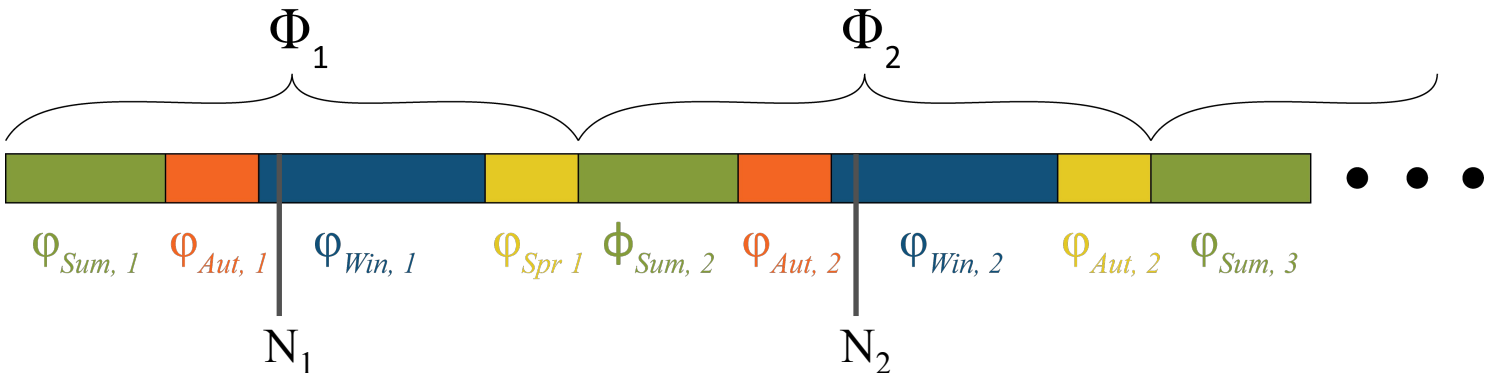


$$\Phi_1 = \varphi_{Sum,\ 1}\varphi_{Aut,\ 1}\varphi_{Win,\ 1}\varphi_{Spr,\ 1}$$

$$N_2 = N_1\ \varphi_{Win,\ 1}\varphi_{Spr,\ 1}\varphi_{Sum,\ 2}\varphi_{Aut,\ 2}$$

$$\Phi_2 = \varphi_{Sum,\ 2}\varphi_{Aut,\ 2}\varphi_{Win,\ 2}\varphi_{Spr,\ 2}$$

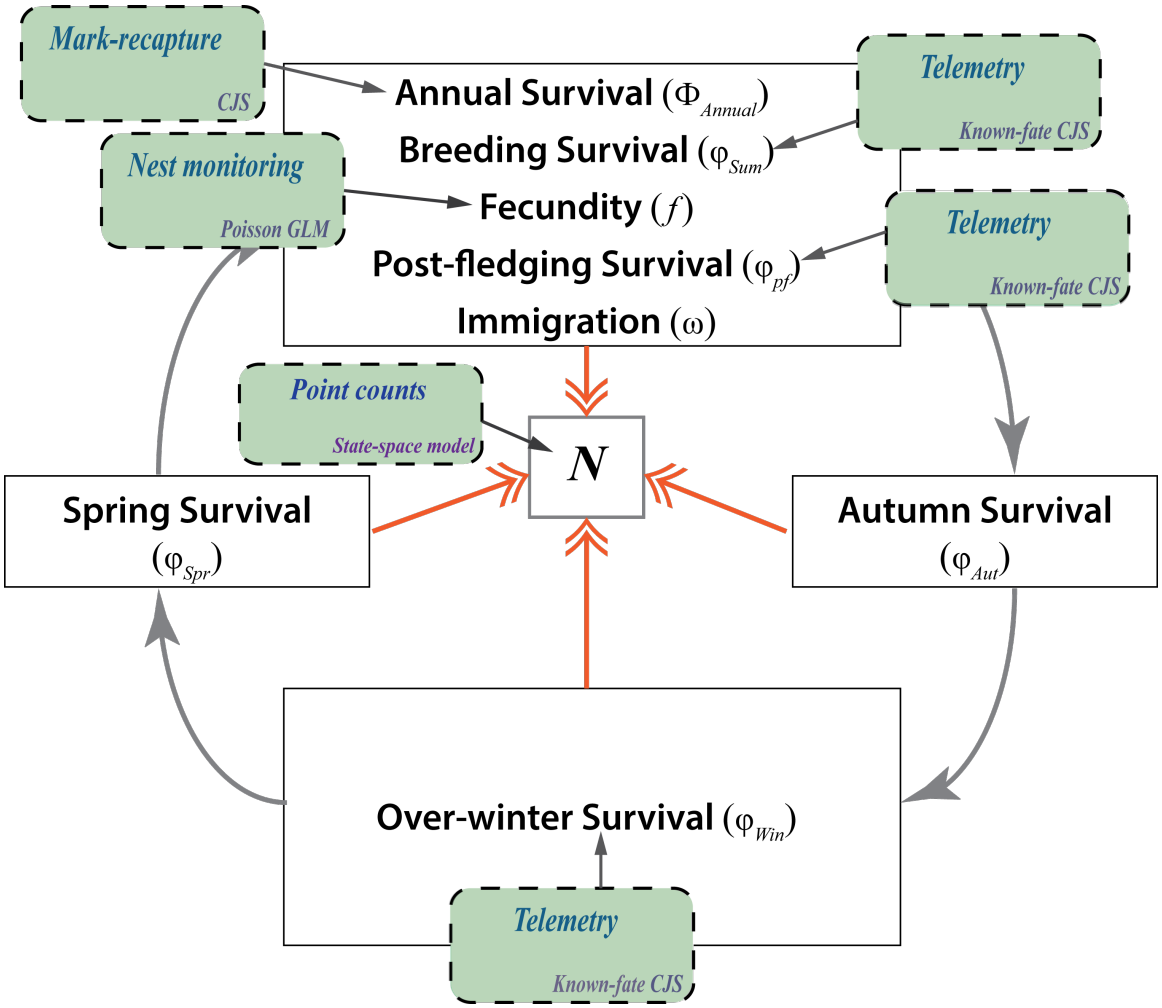
Rusty Blackbird survival



$$\Phi_1 = \varphi_{Sum,\,1}\varphi_{Aut,\,1}\varphi_{Win,\,1}\varphi_{Spr,\,1}$$

$$N_2 = N_1\,\varphi_{Win,\,1}\varphi_{Spr,\,1}\varphi_{Sum,\,2}\varphi_{Aut,\,2}$$

$$\Phi_2 = \varphi_{Sum,\,2}\varphi_{Aut,\,2}\varphi_{Win,\,2}\varphi_{Spr,\,2}$$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Fecundity & Immigration

Poisson GLM

$$J_t \sim \text{Poisson}\left(R_t \times f_t\right)$$

$$\log(f_t) = \mu_f + \epsilon_{f_t}$$

$$\epsilon_{f_t} \sim \text{Normal}(0, \sigma_f^2)$$

$$N_{Imm_t} \sim \text{Poisson}(\lambda_{Imm_t})$$

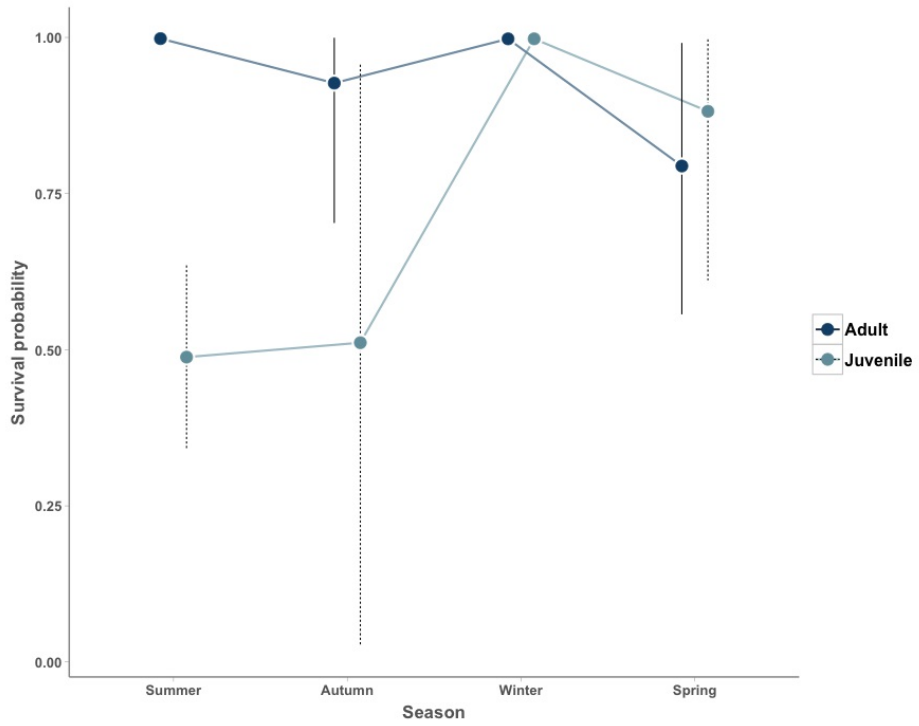
$$\log(\lambda_{Imm_t}) = \mu_{Imm} + \epsilon_{Imm_t}$$

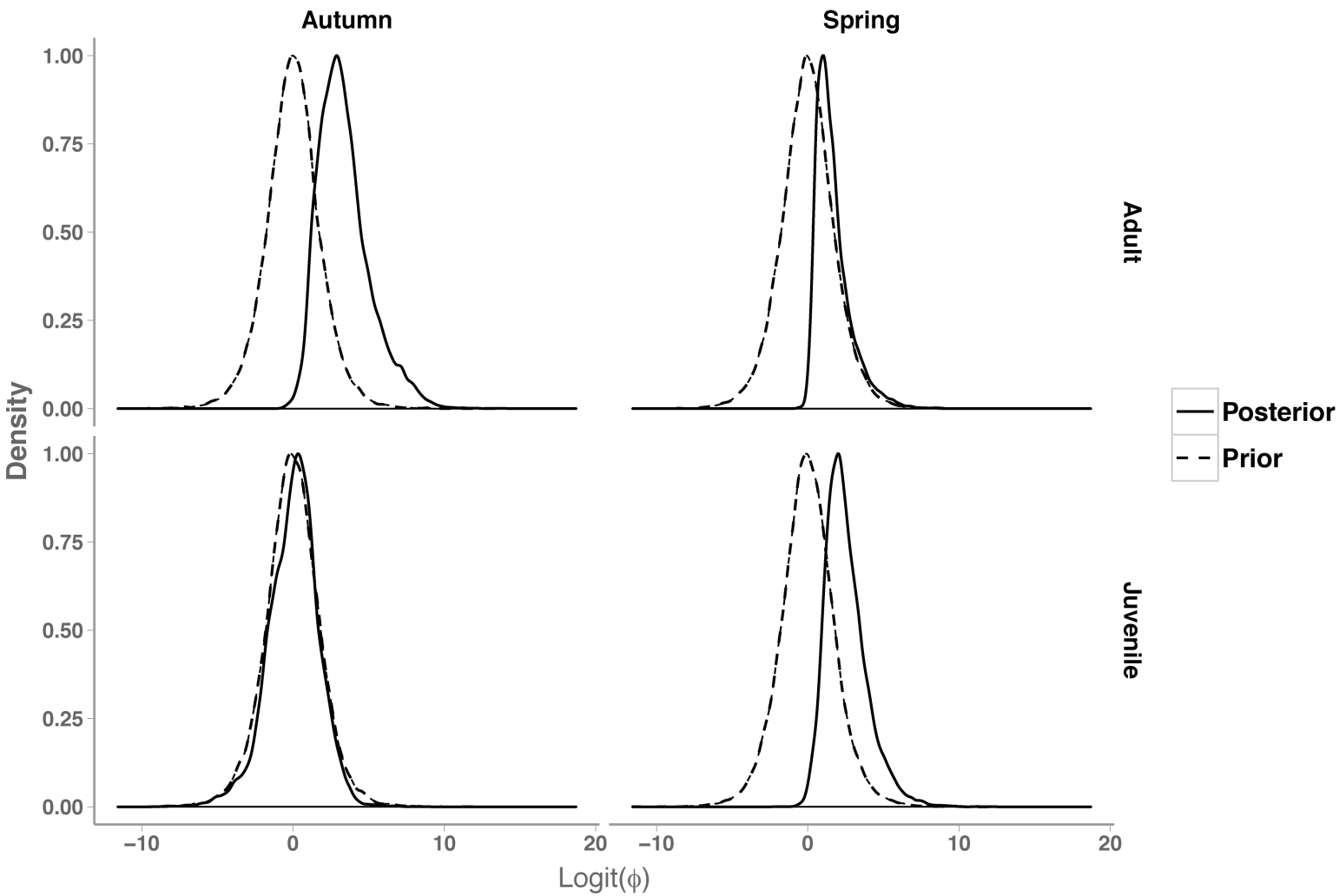
$$\epsilon_{Imm_t} \sim \text{Normal}(0, \sigma_{Imm}^2)$$

J_t - Total # offspring year *t*

R_t - # nests monitored year *t*

Rusty Blackbird seasonal survival




Autumn
Spring
Adult
Juvenile
Density
1.00
0.75
0.50
0.25
0.00
−10
0
10
20
Logit(ϕ)
Posterior
Prior

Decomposition of population growth variance

Caswell 2001:

$$\mathbf{p} = \left(\Phi_1, \ldots, \Phi_n, f_1, \ldots, f_n, \ldots\right)$$

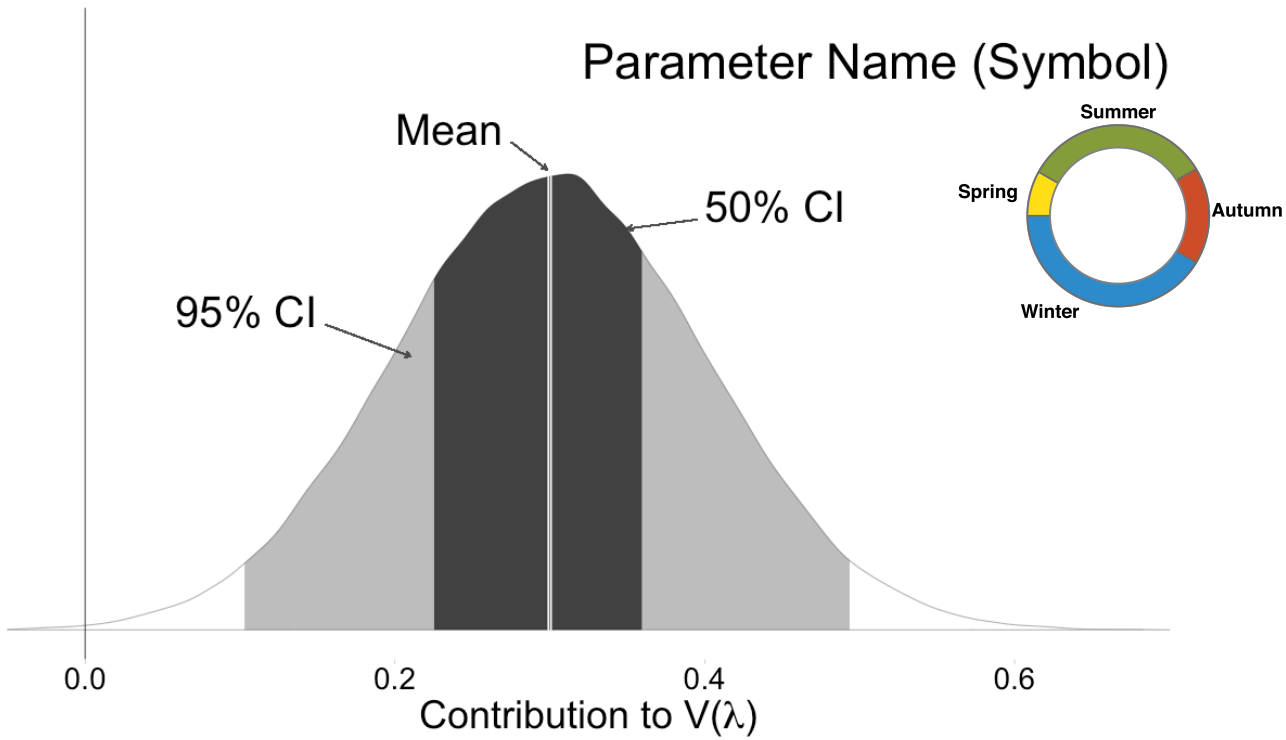
$$V(\lambda) = \sum_{ij} \mathrm{Cov}(p_i, p_j) \frac{\delta\lambda}{\delta p_i} \frac{\delta\lambda}{\delta p_j}$$

$\mathrm{Cov}(p_i, p_j)$: Covariance of p_i and p_j

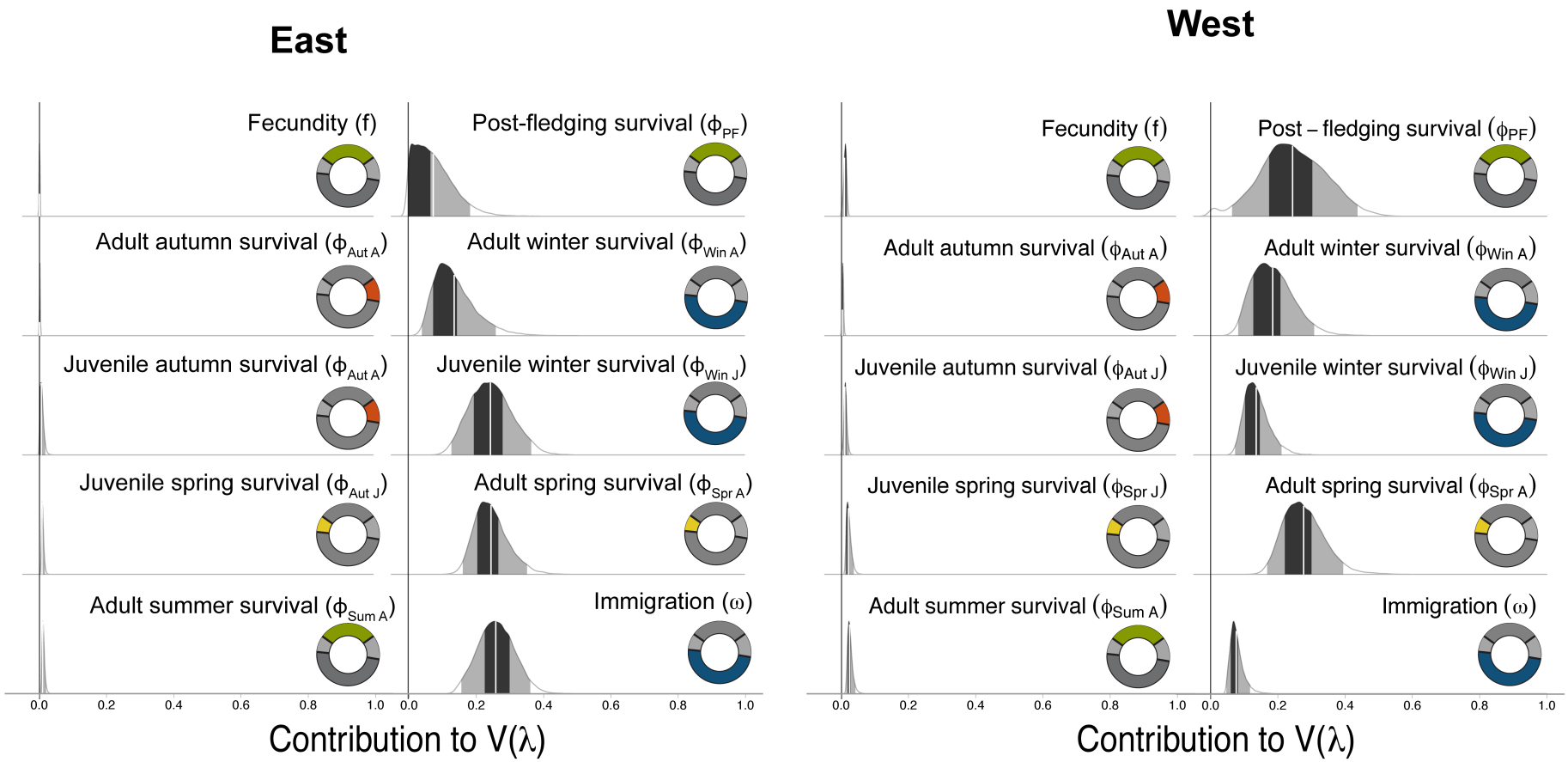
$\frac{\delta\lambda}{\delta p_i}$: Sensivity of λ to p_i

$\frac{\delta\lambda}{\delta p_j}$: Sensivity of λ to p_j

Contribution posteriors



Demographic drivers of population dynamics



Future directions

- Breeding counts
- Informative priors
- Site variation
- Age-specific winter survival

Questions?