Killer Whale Demography

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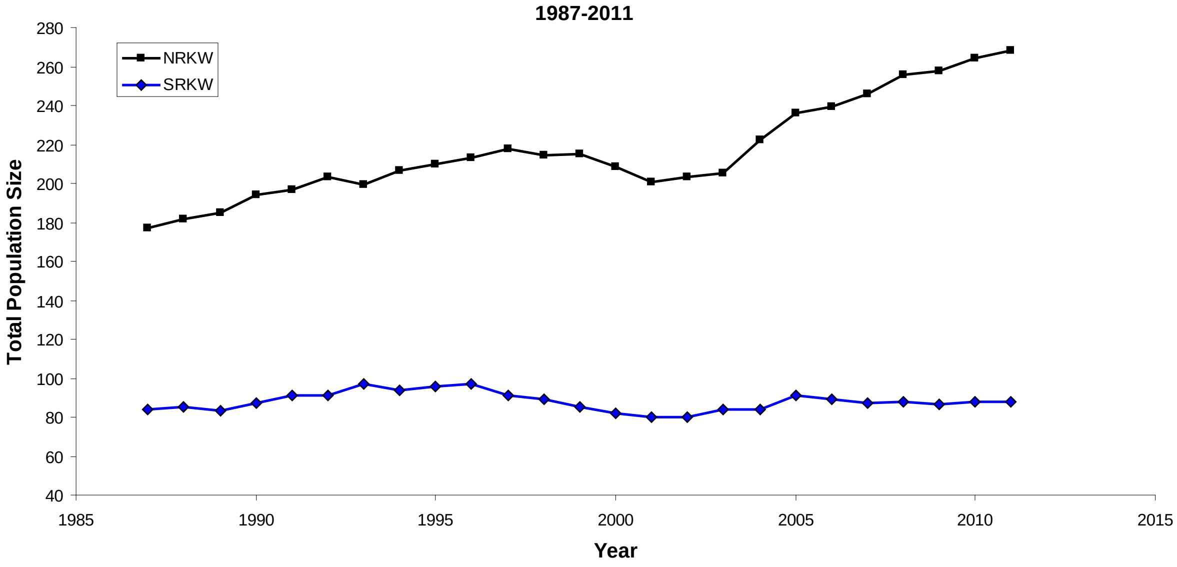
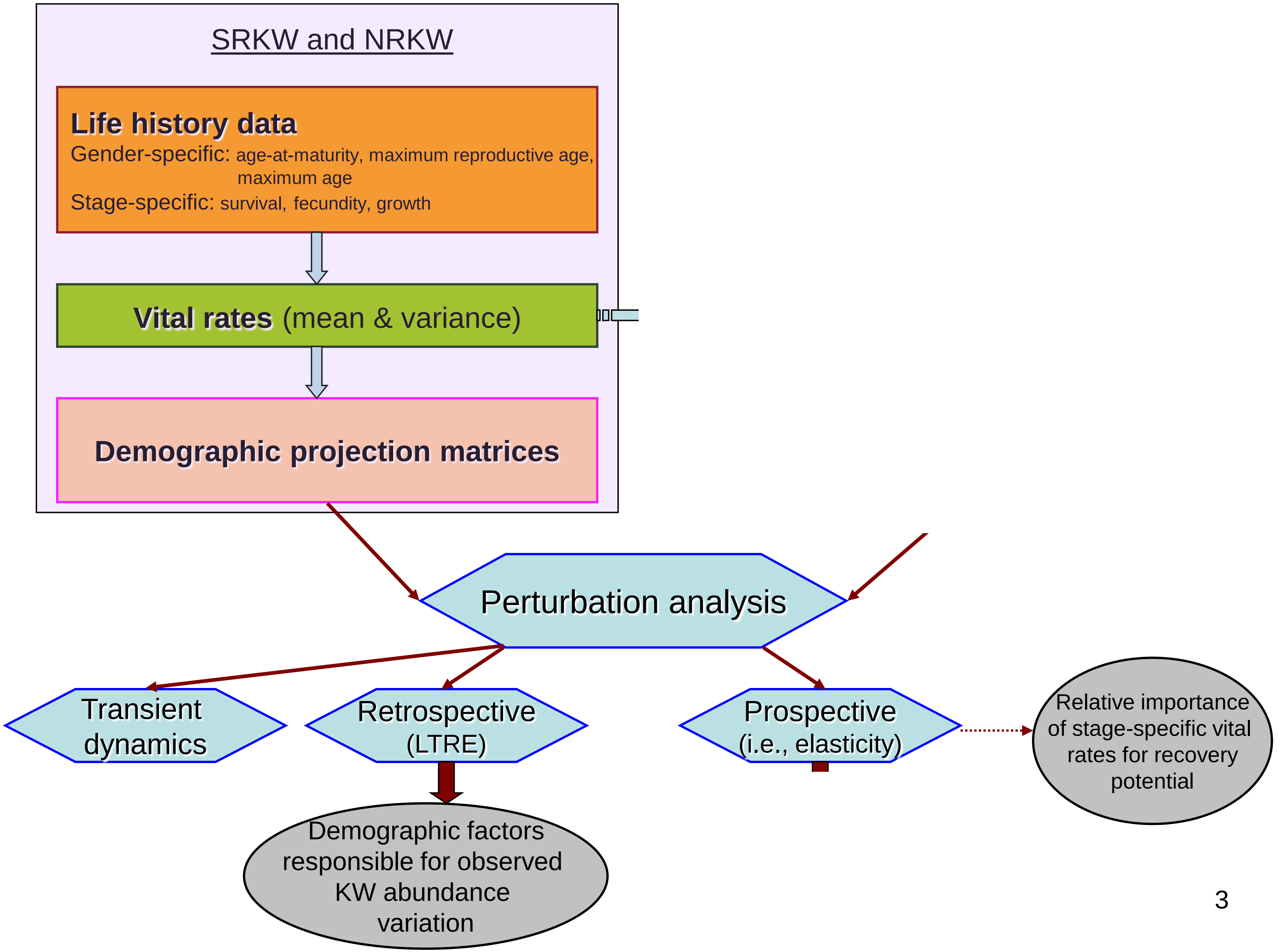
Context

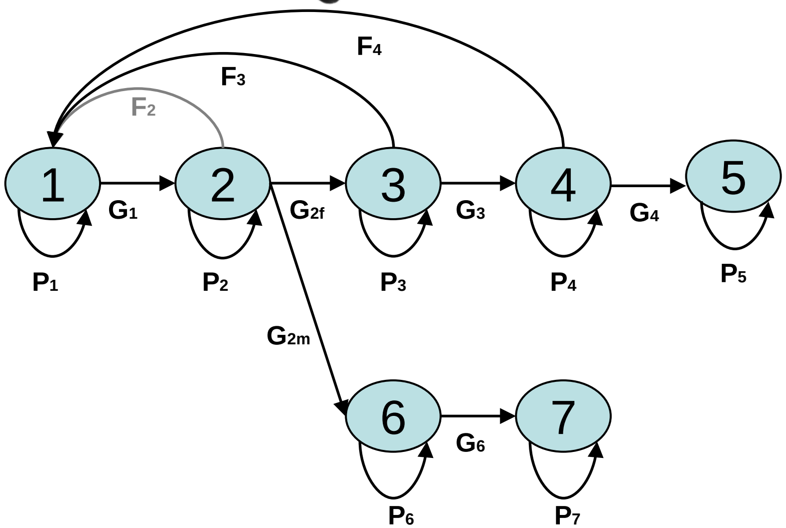
- SRKW < 100 for the last generation with an average of 85 in the last decade
- NRKW generally increasing for the last generation with 268 individuals at the end of 2011
- Correlations between RKW vital rates & Chinook abundance detected by previous studies (e.g., Ward et al. 2009, Ford et al. 2010)





SRKW and NRKW
Life history data
Gender-specific: age-at-maturity, maximum reproductive age, maximum age
Stage-specific: survival, fecundity, growth
Vital rates (mean & variance)
Demographic projection matrices
Perturbation analysis
Transient dynamics
Retrospective (LTRE)
Prospective (i.e., elasticity)
Relative importance of stage-specific vital rates for recovery potential
Demographic factors responsible for observed KW abundance variation

RKW base model



$$\mathbf{M} = \left(\begin{array}{ccccc|cc} 0 & F_2 & F_3 & F_4 & 0 & 0 & 0 \\ G_1 & P_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{2f} & P_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_3 & P_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_4 & P_5 & 0 & 0 \\ \hline 0 & G_{2m} & 0 & 0 & 0 & P_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & G_6 & P_7 \end{array}\right)$$

1: Calves (viable 0.5-year old)

2: Juveniles (ages 2-9; undetermined sex)

3: Female 1

4: Female 2

5: Female 3

6: Male 1

7: Male 2

$$N_t = \begin{pmatrix} n_{t,1} \\ n_{t,2} \\ \cdot \\ \cdot \\ \cdot \\ n_{t,7} \end{pmatrix}$$

$$N_{t+1} = \lambda_M N_t$$

Population growth rate

Matrix elements vs. vital rates

- Matrix elements are a combination of vital rates

$\left(\sigma_i = \text{survival}; \mu_i = \text{fecundity}; \gamma_i = \text{transition}; \phi = \text{sex ratio} \right)$

- Under a two-sex, birth-flow model:

$$\mathrm{P}_i = \sigma_i \left(1 - \gamma_i\right)$$
$$\mathrm{G}_i = \sigma_i \gamma_i$$
$$\mathrm{F}_i = \sigma_1^{0.5} \left(\left(1 + \mathrm{P}_i\right) \mu_i + \mathrm{G}_i \mu_{i+1} \right) / 2$$
$$\mathrm{G}_1 = \sigma_1^{0.5}$$
$$\mathrm{G}_{2f} = \sigma_2 \gamma_2 \phi_f$$
$$\mathrm{G}_{2m} = \sigma_2 \gamma_2 \phi_m$$

$$\sigma_{i,t} = \frac{n_{i,t+1}}{n_{i,t}}$$

$\gamma_i =$ reciprocal of stage i duration (fixed)

$$\mu_{i,t} = \frac{\text{\# viable calves by females in stage } i \text{ at year } t}{\text{\# females in stage } i \text{ at year } t}$$

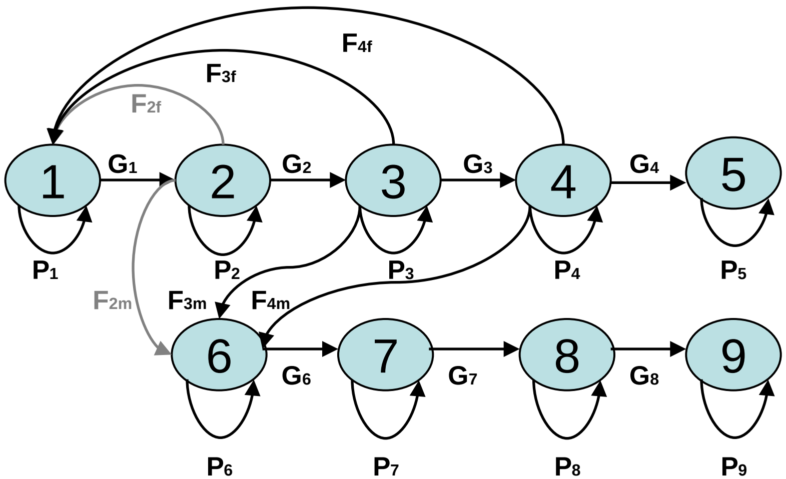
$\phi_f =$ average proportion of females

$\phi_m =$ average proportion of males

Vital rates as random variables

- Prospective perturbation analysis
  - Vital rates (survival & fecundity) drawn from lognormal and beta distributions
- Retrospective perturbation analysis
  - Matrix construction breaking down the variance of λ into the contributions from the variances in the vital rates → LTRE

Alternative RKW models



* Sex identification at birth

* Females only

$$
M = \begin{pmatrix}
0 & F_{2f} & F_{3f} & F_{4f} & 0 & 0 & 0 & 0 & 0 \\
G_1 & P_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & G_2 & P_3 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & G_3 & P_4 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & G_4 & P_5 & 0 & 0 & 0 & 0 \\
0 & F_{2m} & F_{3m} & F_{4m} & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & G_6 & P_7 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & G_7 & P_8 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & G_8 & P_9
\end{pmatrix}
$$

1: Female Calves

2: Female juveniles

3: Young reproductive females

4: Old reproductive females

5: Post-reproductive females

6: Male calves

7: Male juveniles

8: Young mature males

9: Old mature males

Criteria for selection of 1987-2011

- Demographic data based on direct observations (as opposed to reconstructions)
  - Numerous assumptions needed to reconstruct demographics of earlier years of the time series (greater uncertainty in early years)

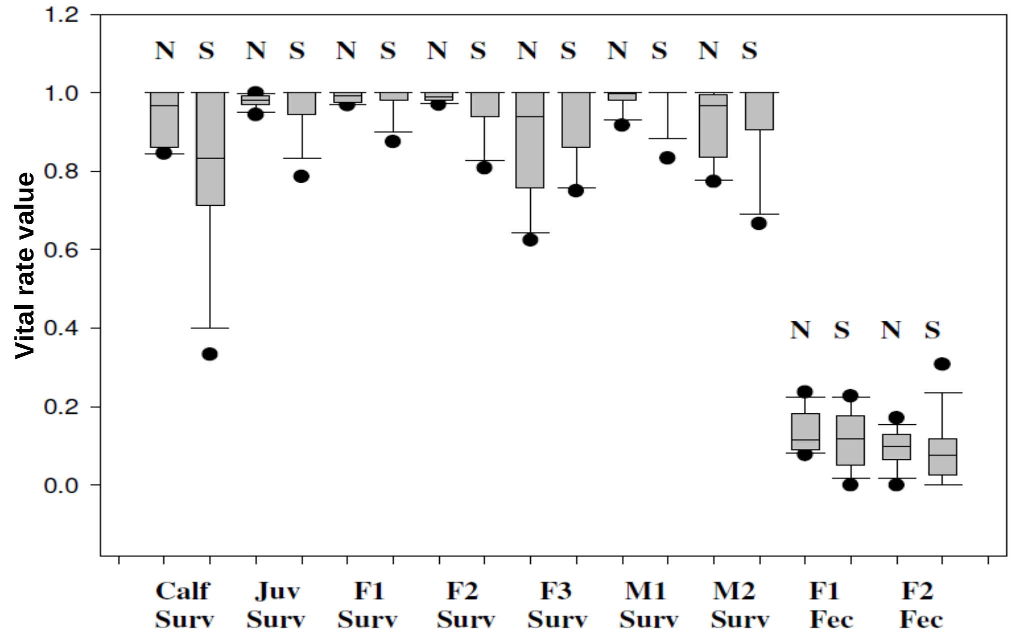
- Minimizing influence of 1962-1973 live-capture fishery on population structure
  - Fishery removed juveniles & young males (anomalous population structure)

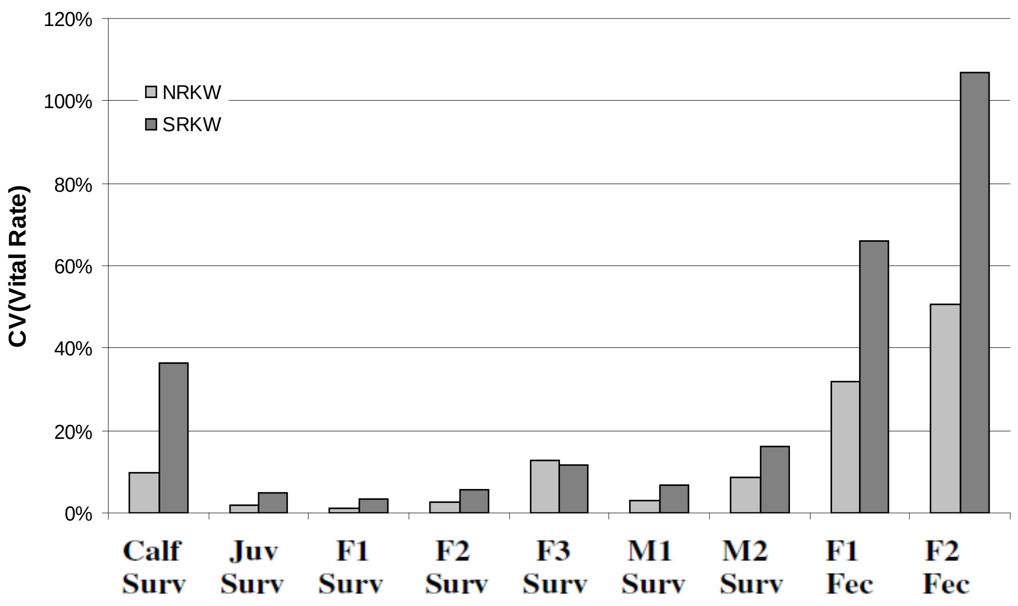
- At least 1 generation (25 years)
  - 75% alive in 2011 born during 1987-2011

Results

Pure RKW demographic models

Vital rates



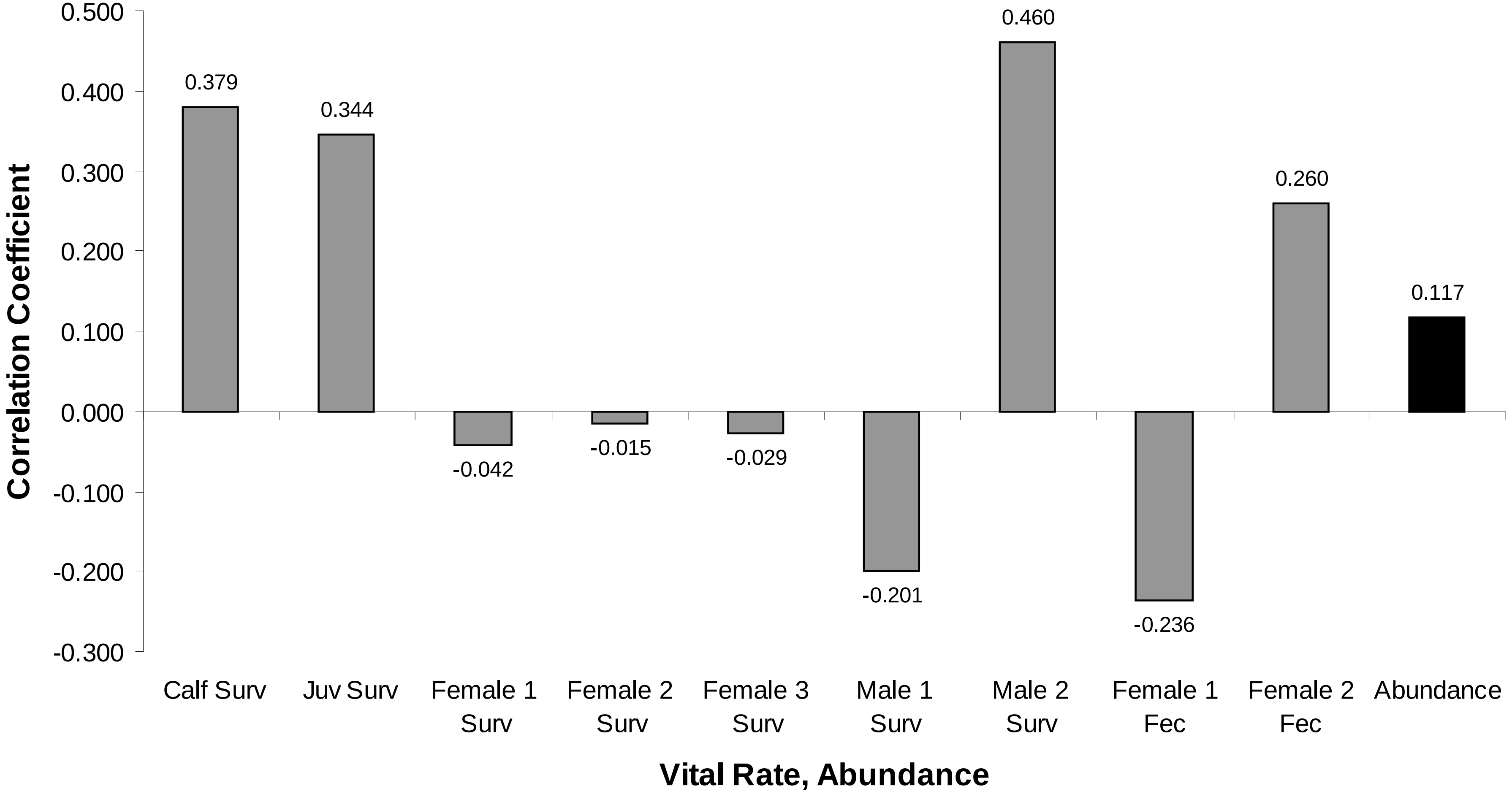


* Greater vital rate variability in SRKW than in NRKW

* Lower viable-calf survival in SRKW than in NRKW

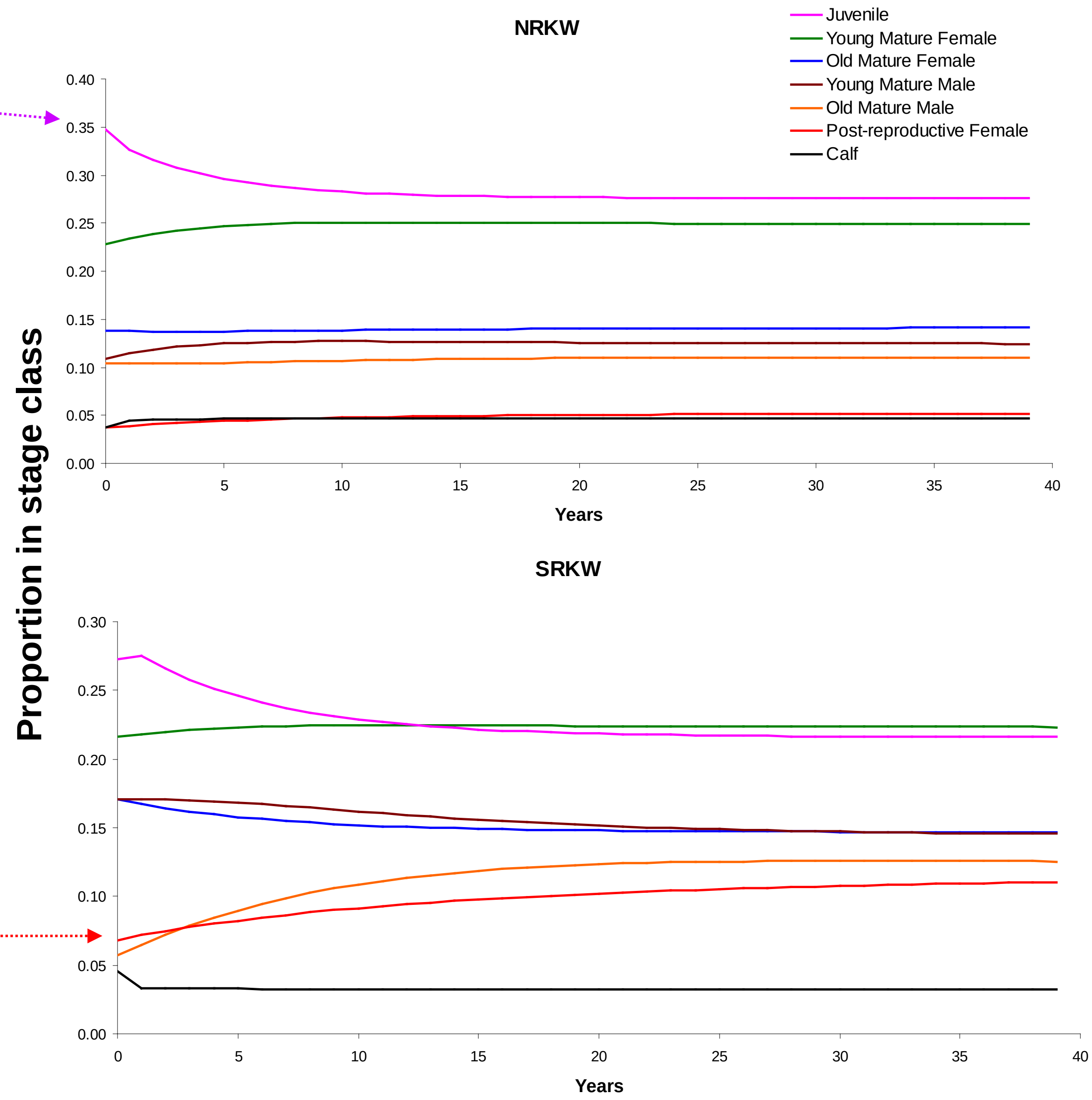
* Lower fecundity of older females in SRKW than in NRKW

NRKW-SRKW Covariation

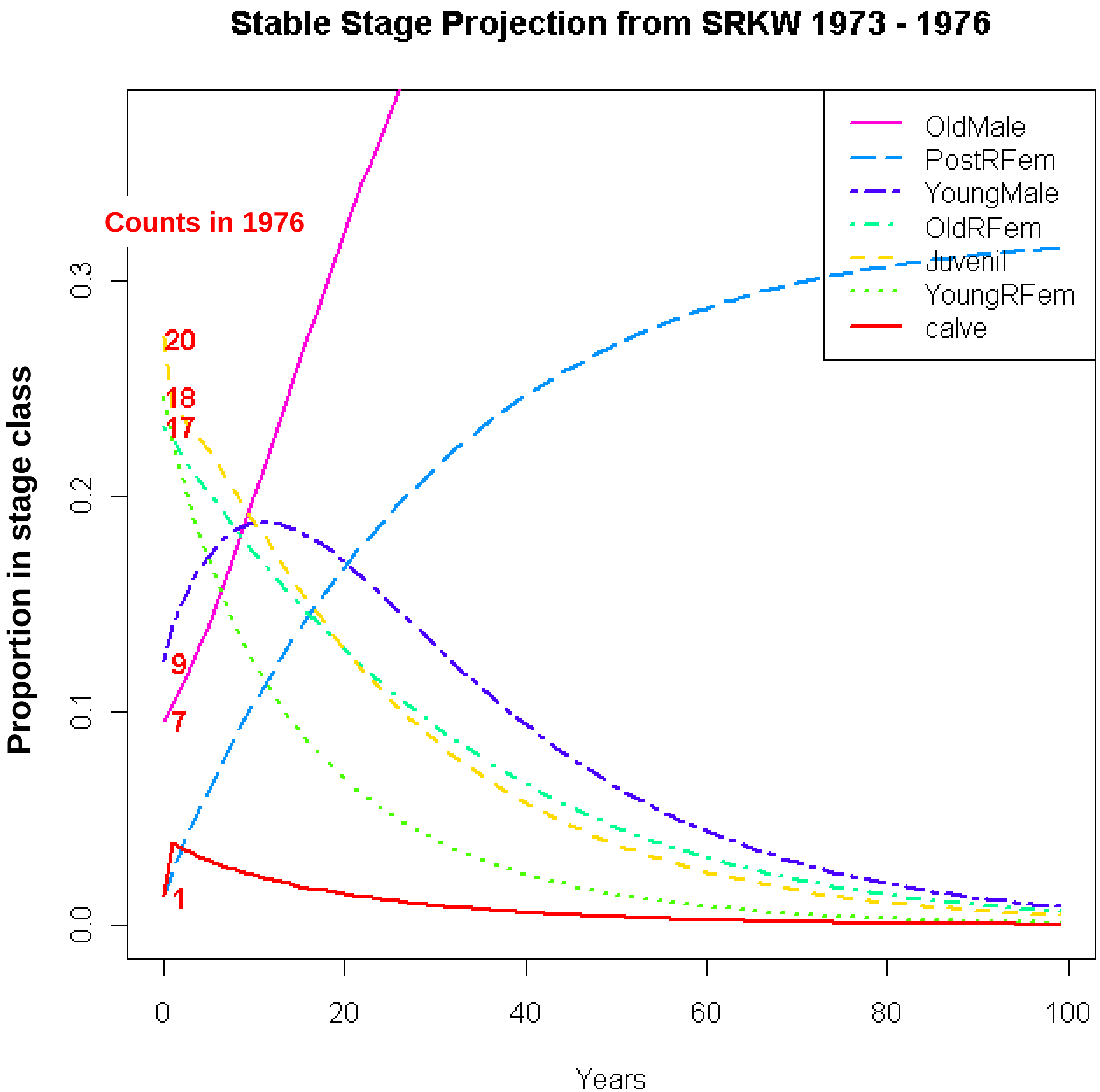


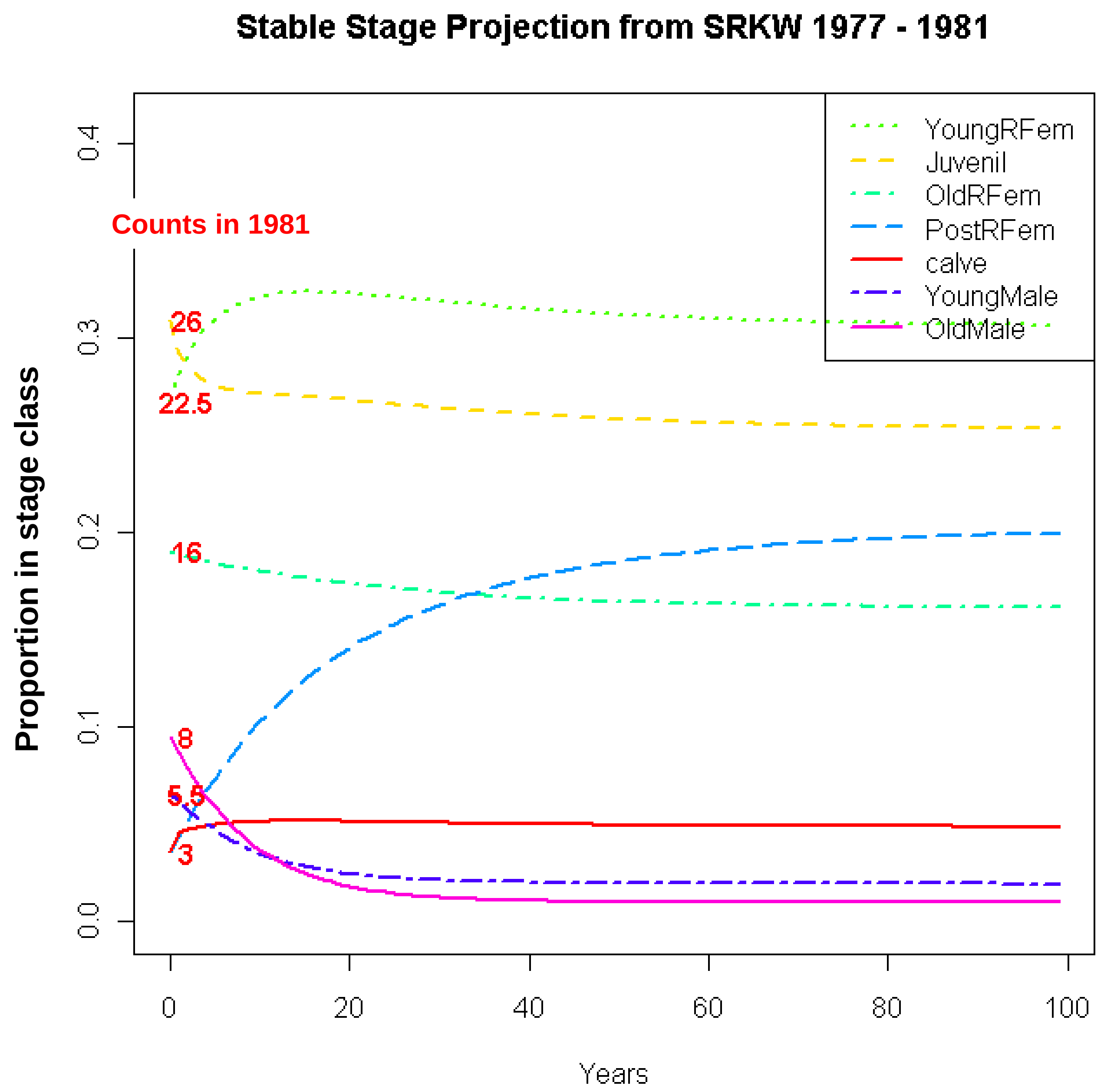
Current stage distribution closer to the stable stage distribution in NRKW than in SRKW s

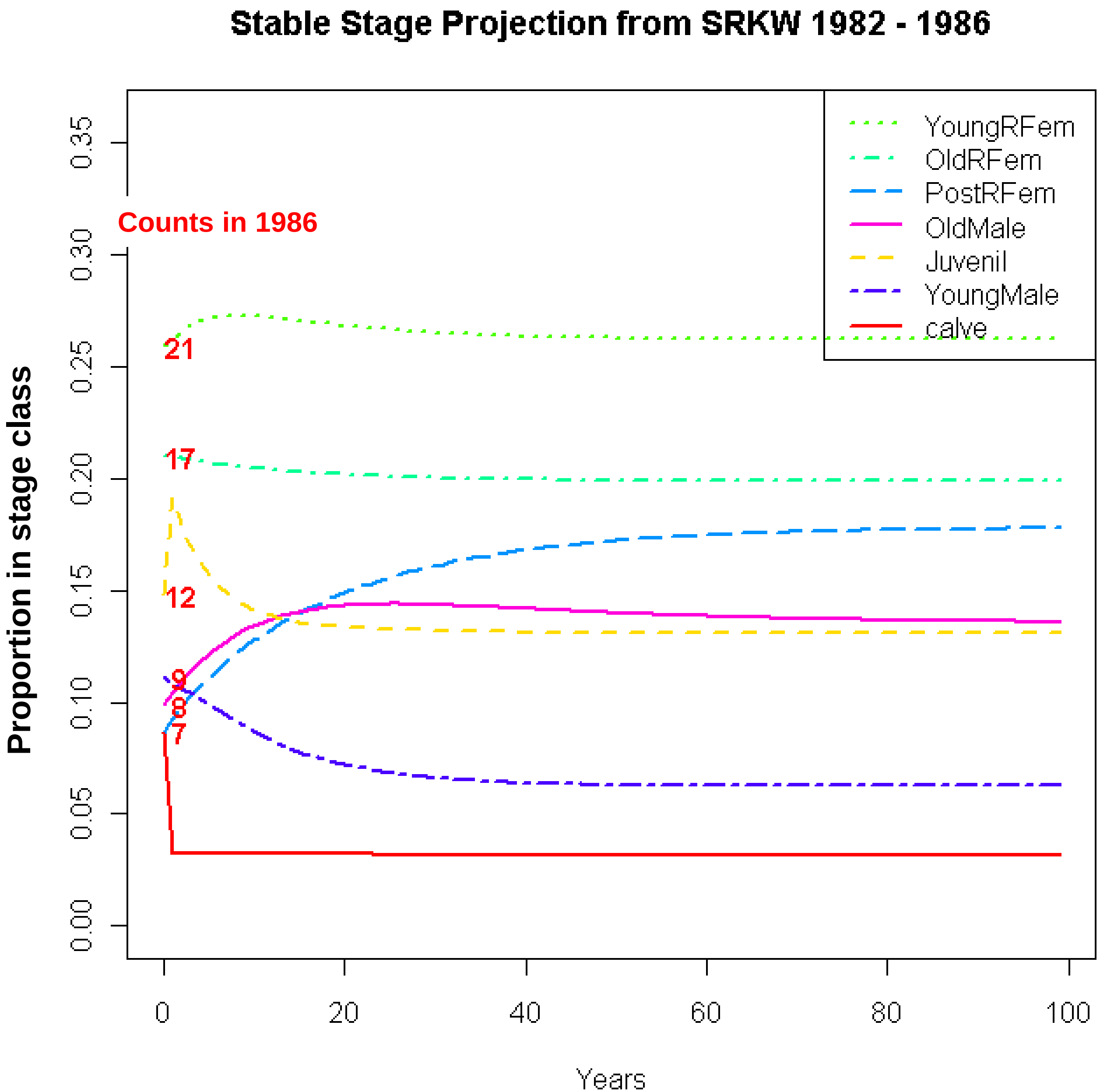
Higher proportion of juveniles in NRKW



Higher proportion of post-reproductive females in SRKW


Stable Stage Projection from SRKW 1973 - 1976
Counts in 1976
20
18
17
9
7
1
OldMale
PostRFem
YoungMale
OldRFem
Juvenil
YoungRFem
calve
Proportion in stage class
0.0
0.1
0.2
0.3
0
20
40
60
80
100
Years


Stable Stage Projection from SRKW 1977 - 1981
Counts in 1981
26
22.5
16
8
5.5
3
YoungRFem
Juvenil
OldRFem
PostRFem
calve
YoungMale
OldMale
Proportion in stage class
0.0
0.1
0.2
0.3
0.4
0
20
40
60
80
100
Years



Stable Stage Projection from SRKW 1982 - 1986
Counts in 1986
21
17
12
9
8
7
YoungRFem
OldRFem
PostRFem
OldMale
Juvenil
YoungMale
calve
Proportion in stage class
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0
20
40
60
80
100
Years

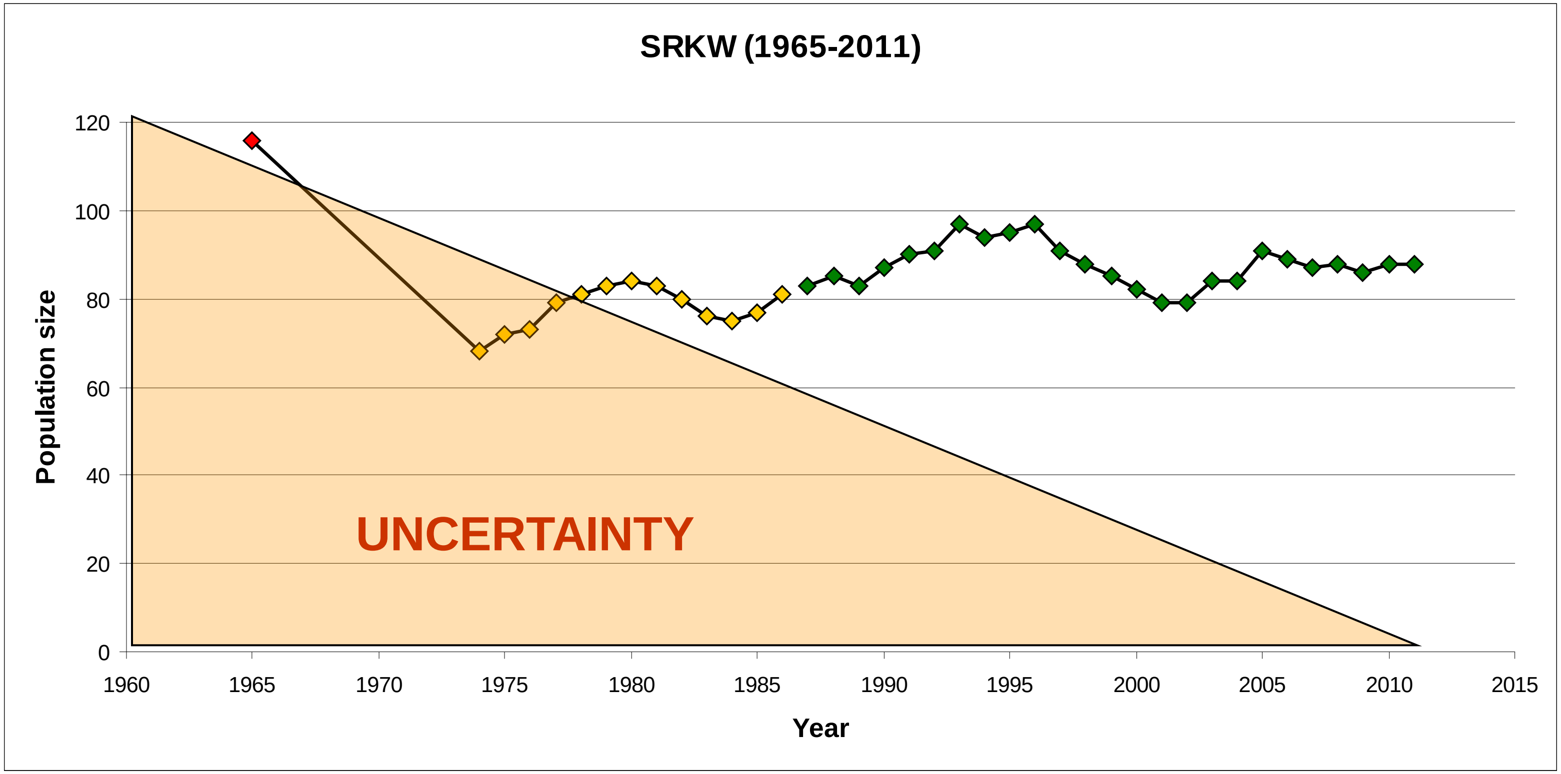
Population growth

Last generation (1987-2011)

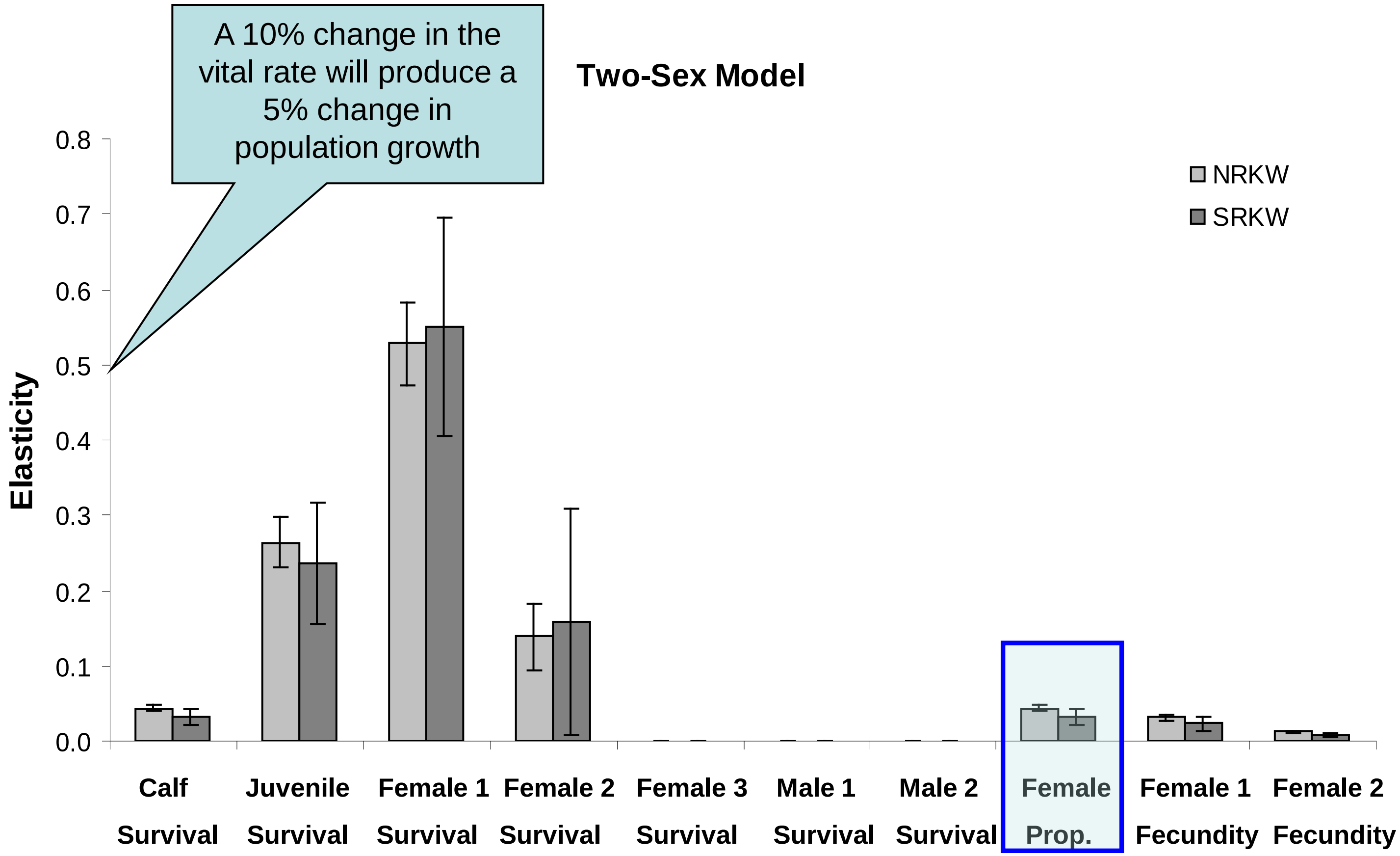
- SRKW : 0.9909 (i.e., annual decline of 0.91%)
- Minimum length of time horizon for projections of SRKW population growth: 35 y → from transient dynamics

- NRKW : 1.0165 (i.e., annual increase of 1.65%)
- Minimum length of time horizon for projections of NRKW population growth: 20 y → from transient dynamics

Time series length vs. uncertainty



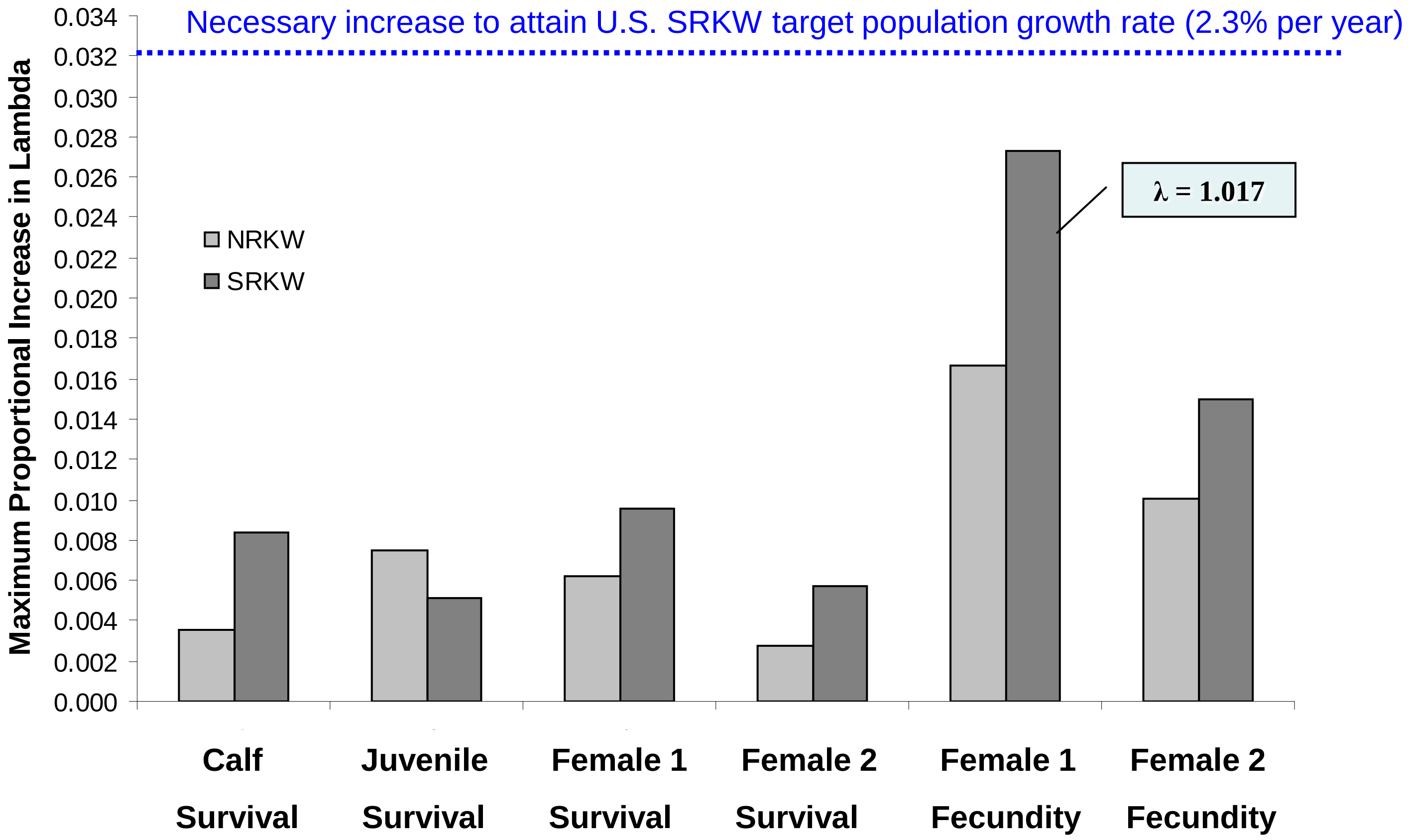
Sensitivity of population growth to changes in vital rates (prospective)



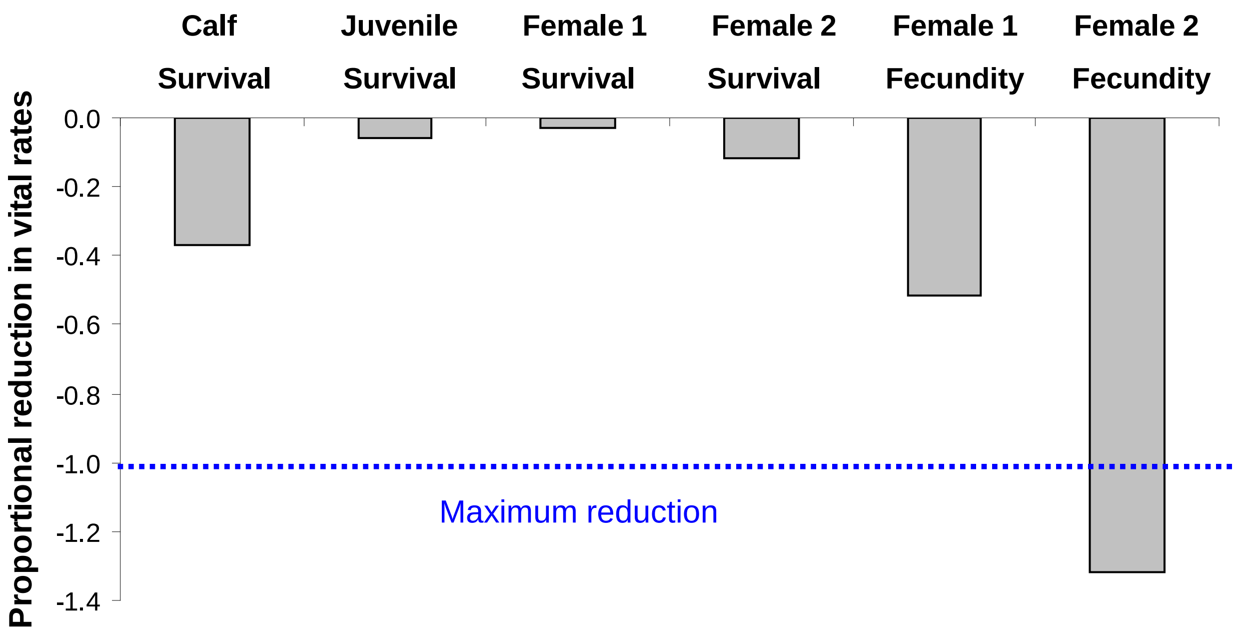
$$\varepsilon_{vr} = \frac{\text{Proportional change in population growth rate}}{\text{Proportional change in the vital rate}}$$

Maximum increase in population growth from maximization of individual vital rates

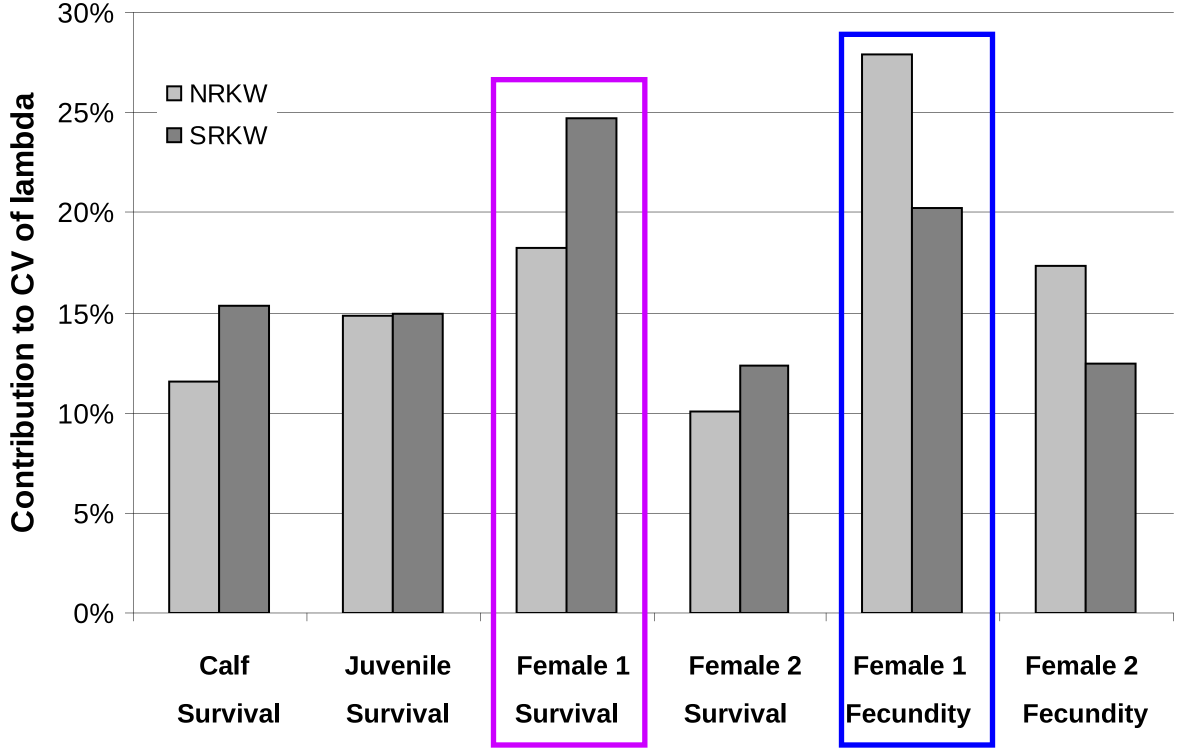
(1.0 for survival; upper 95% CL for fecundity)



NRKW vital rate reduction required to produce stationarity (λ=1.0)



Life Table Response Experiments at the matrix-element level (retrospective)



- NRKW: Fecundity of young reproductive females had largest contribution
- SRKW: Survival of young reproductive females had largest contribution

Greatest benefits to λ

- Avoiding reductions to survival of young reproductive females (Female-1)
- Increasing fecundity rates (particularly of Female-1)

RKW demographic differences

- Lower λ and viability in SRKW
  - lower viable-calf survival
  - lower fecundity of old reproductive females
  - greater variability in vital rates
  - greater proportion of post-reproductive females
  - lower average proportion of juveniles transitioning into young reproductive females

Next

- Bring RKW/Chinook interactions into perturbation analyses
  - Explore sensitivity of λ to Chinook abundance
    - Terminal run
    - Ocean abundance