WATS 6900 – Ecohydraulics
WEEK 14: Life-cycle models

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DEPARTMENT OF WATERSHED SCIENCES

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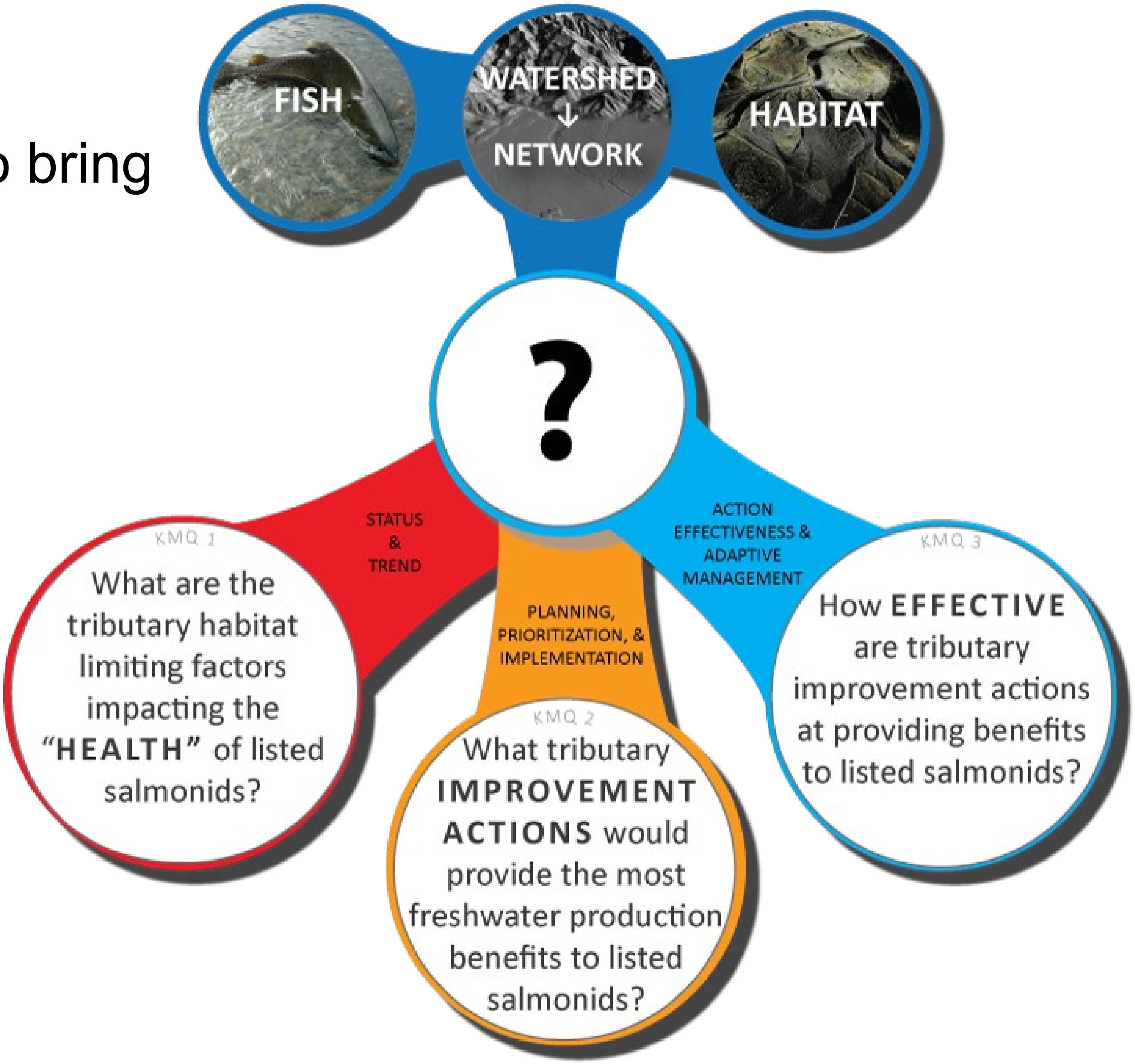
Reasonable and Prudent Alternatives

RPA 35: Tributary Habitat Implementation 2010 to 2018

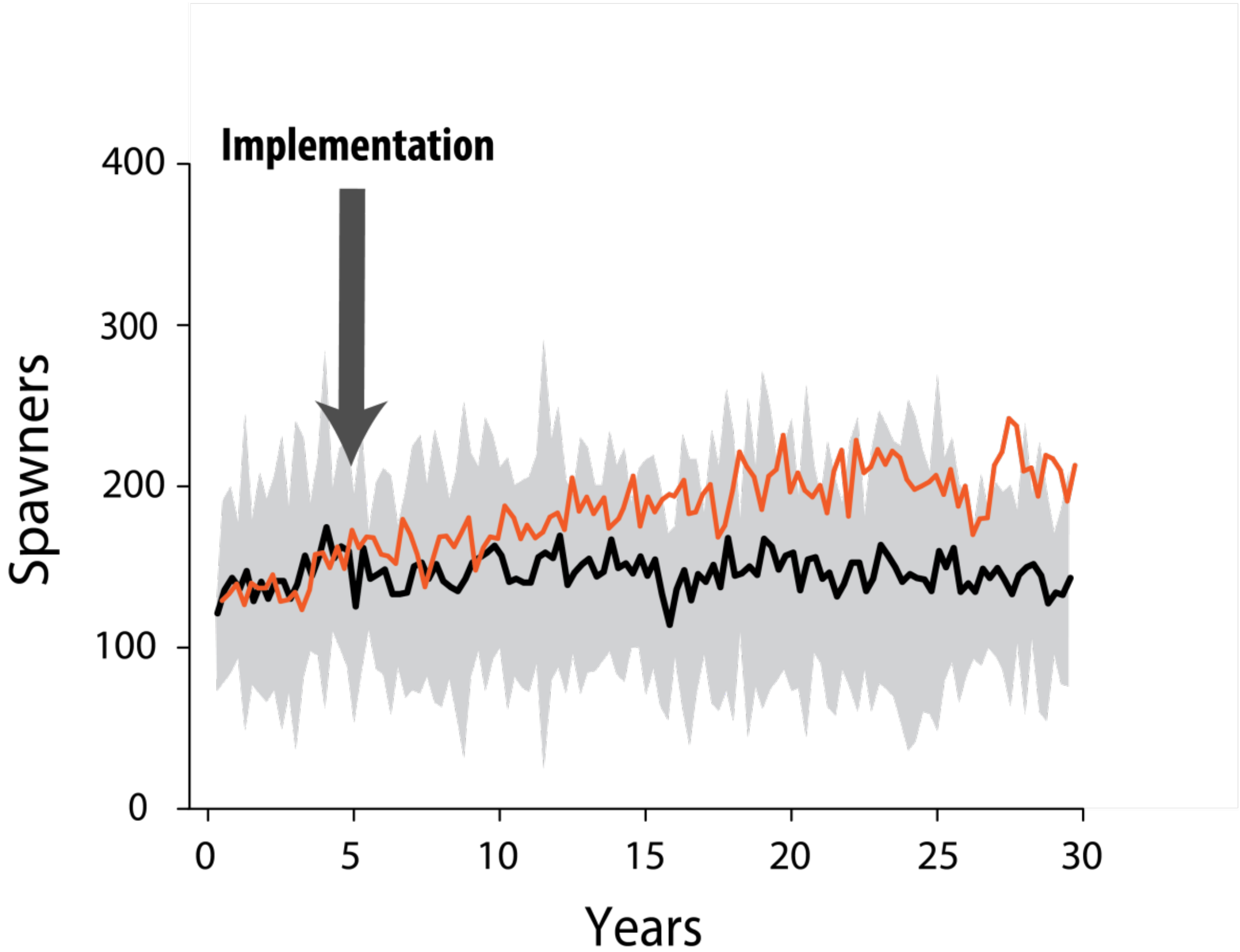
- The Action Agencies will identify additional habitat projects for implementation based on the population specific overall habitat quality improvement still remaining in Table 5 below. Projects will identify location, treatment of limiting factor, targeted population or populations, appropriate reporting metrics, and estimated biological benefits based on achieving those metrics. Pertinent new information on climate change and potential effects of that information on limiting factors will be considered.

Key Management Questions:

- How to improve tributary habitat to bring about population benefits to listed salmonids?



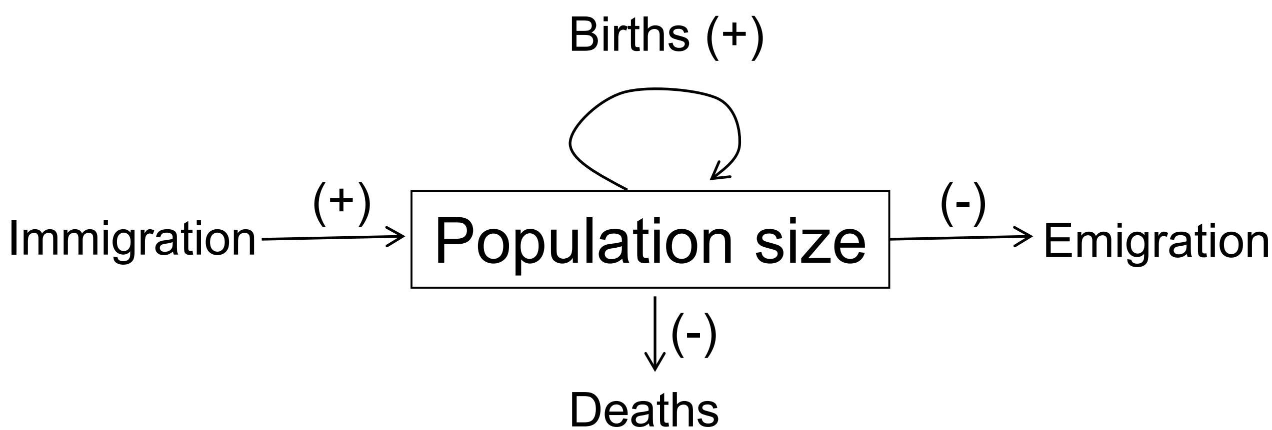
Evaluating alternative actions



Populations

- Group of individuals that live together and reproduce
- Limits defined by movement, gene flow
- Units often considered "stocks"
- Another Mass Balance Equation

$$N_{t+1} = N_t + B + I - (D + E)$$



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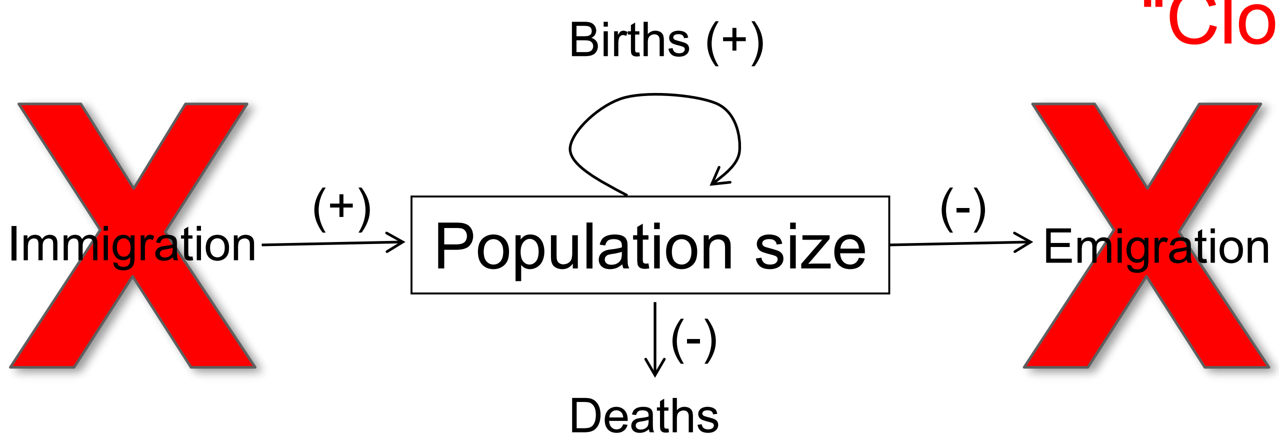
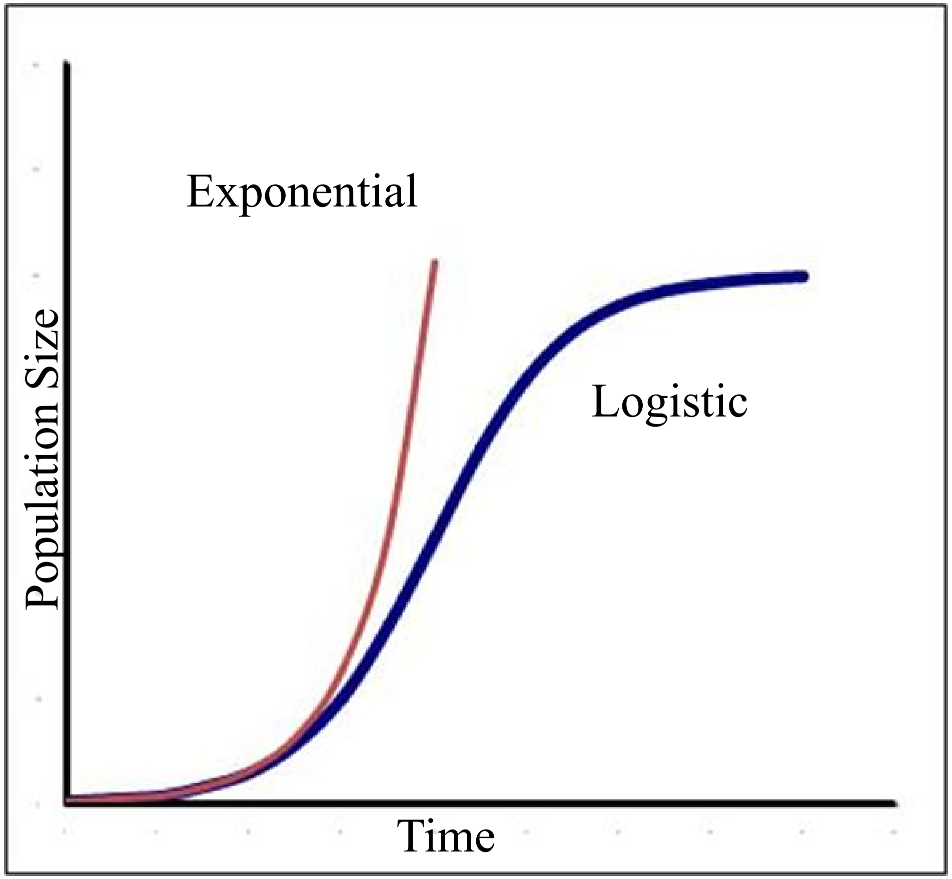
$$N_{t+1} = N_t + B + I - (D + E)$$

Populations often considered “Closed”



Often Bad Assumption!

Population growth



- Exponential Growth

$N_{t+1} = N_t + B – D$ *or* $\Delta N = B – D$

b and *d* are instantaneous birth and death [births/(individual*time)]

$B = bN, D = dN$

$dN/dt = (b-d)N,$

$b-d=r$ or intrinsic rate of increase

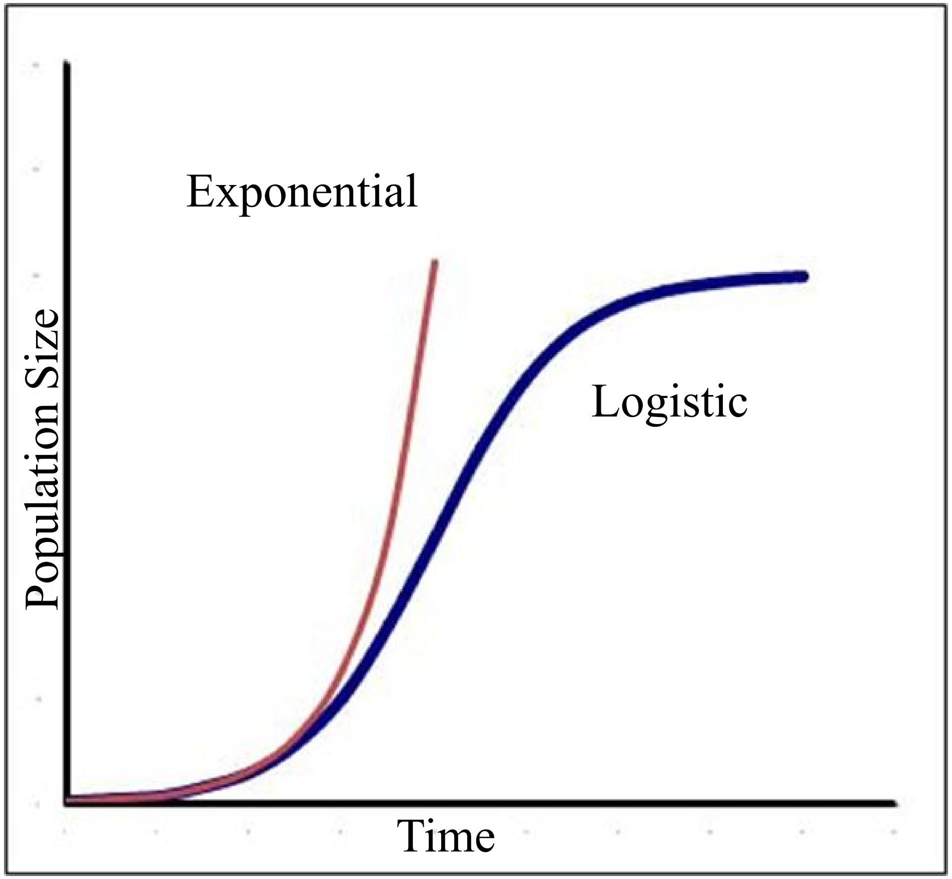
$r = ln(\lambda), e^r=\lambda$ or finite rate of increase

$dN/dt =rN$ or population growth rate

$N_t = N_0e^{rt}$ or population size at time *t*

$N_t = K/1+((K-N_0)/N0)e^{-rt}$

Population growth



- Logistic Growth

$dN/dt = rN(1-N/K)$

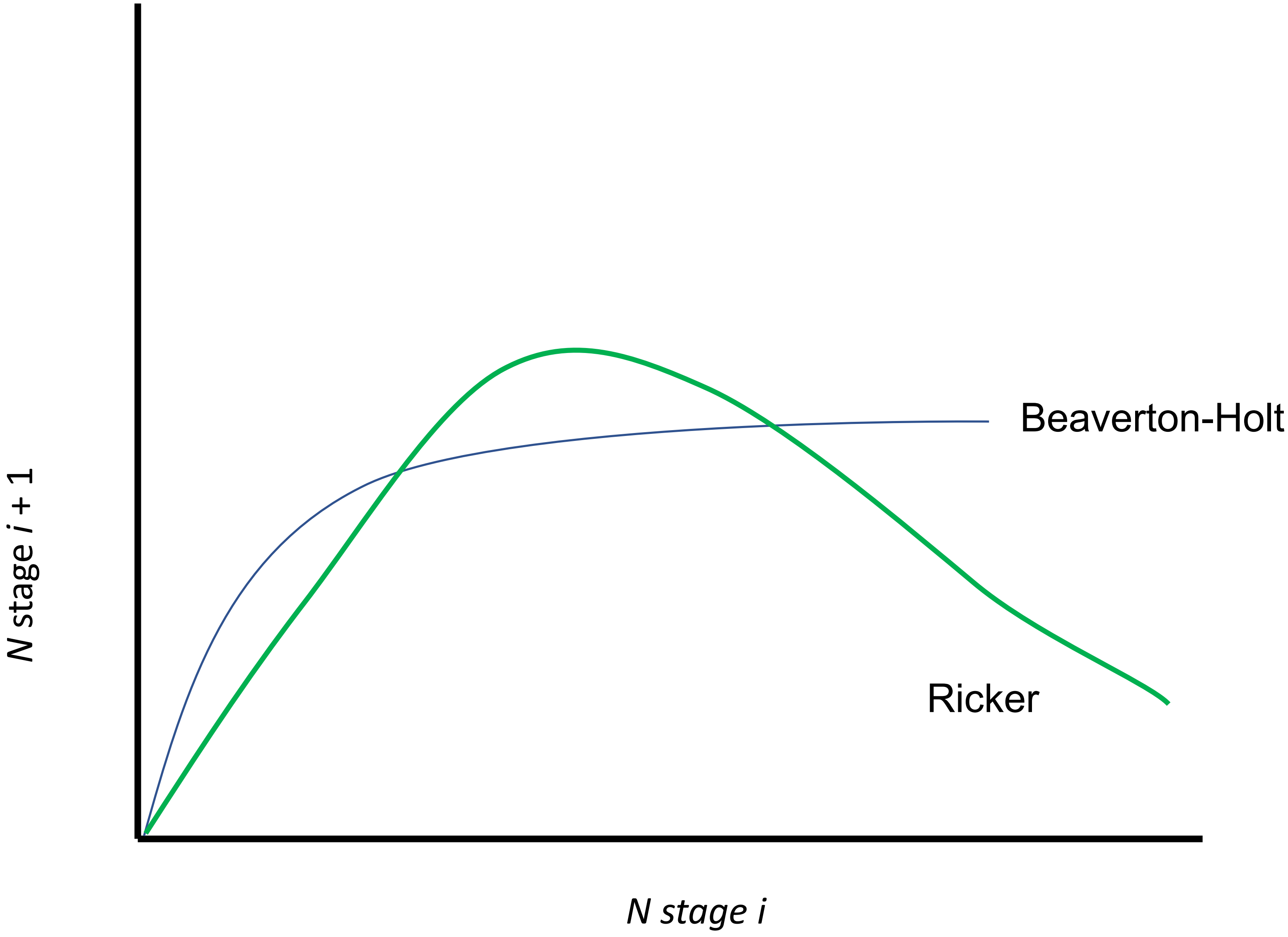
or population growth rate

K=carrying capacity

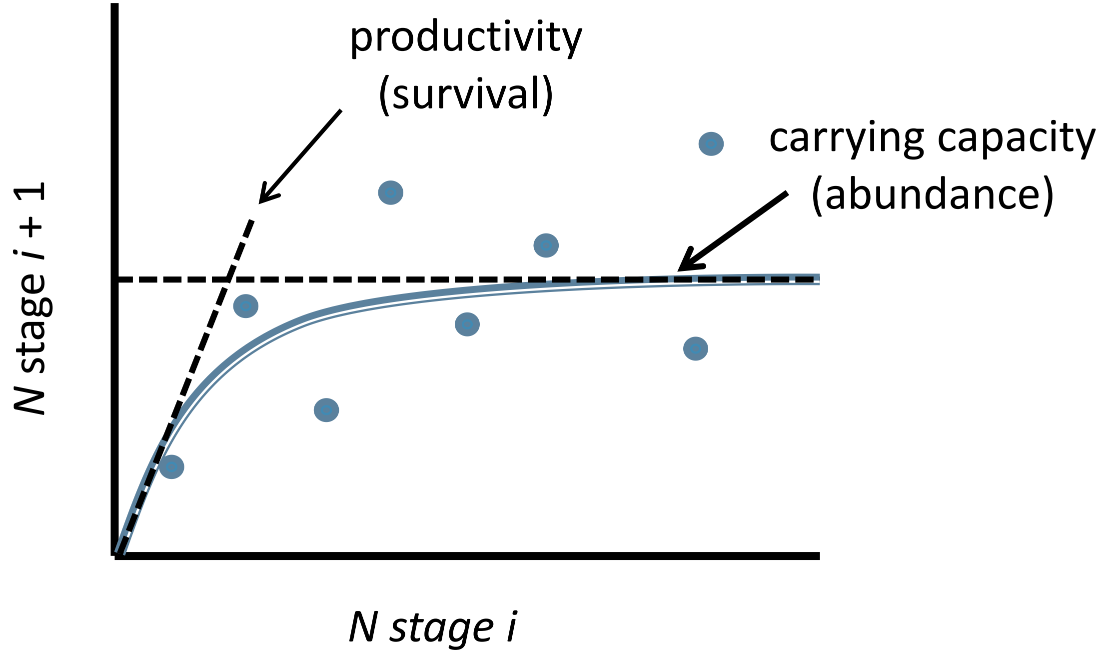
$N_t = K/1+((K-N_0)/N_0)e^{-rt}$

or population size at time t

Density Dependent Population Models



Beverton-Holt Spawner-Recruit Model



$$N_{i+1} = \frac{N_i}{\frac{1}{prod.} + \frac{1}{capacity} N_i}$$

Relate this to freshwater habitat = juveniles / spawner

Age/ Stage-structured Population Models

(increased biological realism)

- Birth and death rates not constant as assumed for logistic growth models
  - ➢ Age to sexual maturity affects fecundity
  - ➢ Death rates are age dependant
- Age structure affects population growth
- Consider deterministic age-structured models
  - ➢ Life tables
  - ➢ Leslie / Lefkovitch matrix models

Age/ Stage-structured Population Models

- Closed population, no genetic structure, no time lags (same as for logistic growth)
- Age-specific survival and fecundity are constant
- Methods for estimating survival:
  - Best: maximum-likelihood methods using capture-recapture data (see Nichols et al. 2000)
  - Next: Cohort analysis – horizontal life table
  - Poor: Vertical life table – snapshot of population, less reliable, assumes stationary age distribution

Life Tables

Measured Values

Age class # Fecundity

Table 3.1 Standard life-table calculations.[a]

x	$S(x)$	$b(x)$	$l(x) = S(x)/S(0)$	$g(x) = l(x+1)/l(x)$	$l(x)b(x)$	$l(x)b(x)x$	Initial estimate $e^{-rx}l(x)b(x)$	Corrected estimate $e^{-rx}l(x)b(x)$
0	500	0	1.0	0.80	0.0	0.0	0.000	0.000
1	400	2	0.8	0.50	1.6	1.6	0.780	0.736
2	200	3	0.4	0.25	1.2	2.4	0.285	0.254
3	50	1	0.1	0.00	0.1	0.3	0.012	0.010
4	0	0	0.0		0.0	0.0	0.000	0.000
				$R_0 = \Sigma l(x)b(x)$	= 2.9 offspring	$\Sigma = 4.3$	$\Sigma = 1.077$	$\Sigma = 1.000$

$G = \dfrac{\Sigma l(x)b(x)x}{\Sigma l(x)b(x)}$	= 1.483 years
r (estimated) = $\ln(R_0)/G$	= 0.718 individuals/(individual • year)
Correction added to estimated r	= 0.058
r (Euler)	= 0.776 individuals/(individual • year)

[a] The x, $S(x)$, and $b(x)$ columns are supplied. All others are calculated from these.

Gotelli 2008

% Survival to age X

Survival to t+1

Calculated Values

Table 3.1 Standard life-table calculations.[a]

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4	0	0	0.0		0.0	0.0	0.000	0.000
				$R_0 = \Sigma l(x)b(x)$	= 2.9 offspring	$\Sigma = 4.3$	$\Sigma = 1.077$	$\Sigma = 1.000$

Net reproductive rate →

Generation time →

$G = \dfrac{\Sigma l(x)b(x)x}{\Sigma l(x)b(x)}$	= 1.483 years
r (estimated) = $\ln(R_0)/G$	= 0.718 individuals/(individual • year)
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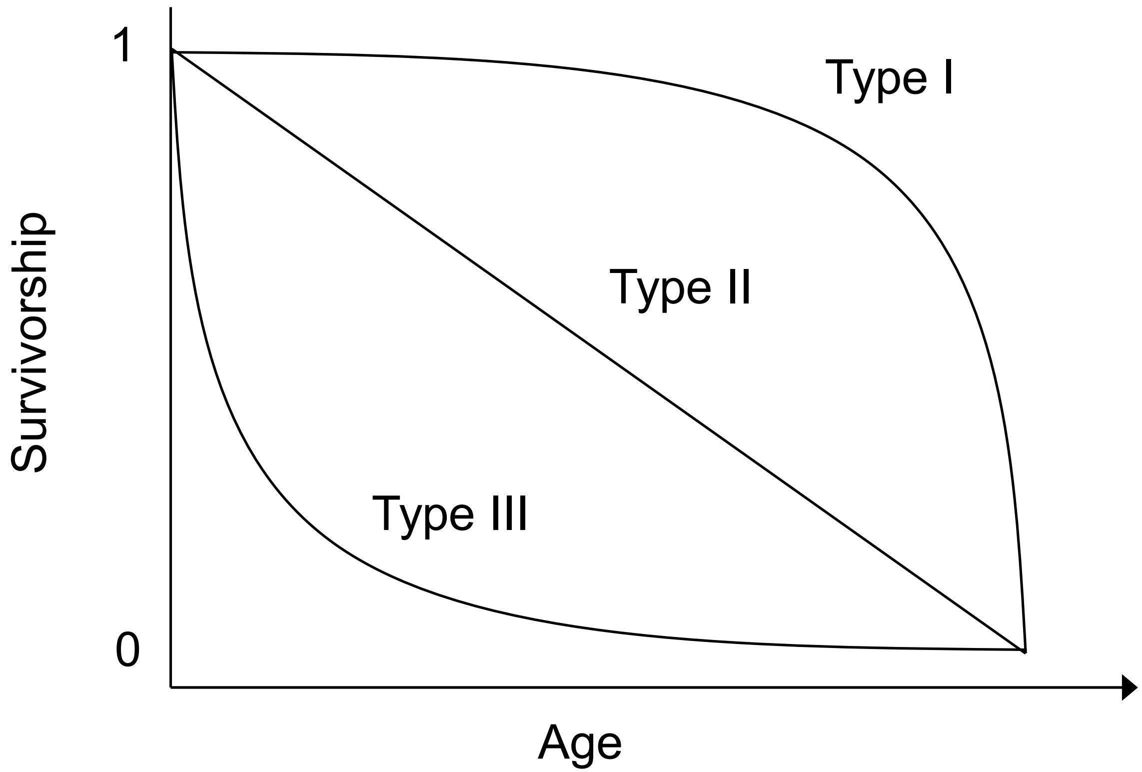
Gotelli 2008

Idealized Survivorship Curves



Akcakaya et al. 1999

Calculating population growth rate

- Approximate Value:

$$r \approx \frac{\ln\left(R_0\right)}{G}$$

- Exact value: solve Euler equation by iteration

$$1 = \sum_{x=0}^{k} e^{-rx} l(x) b(x)$$

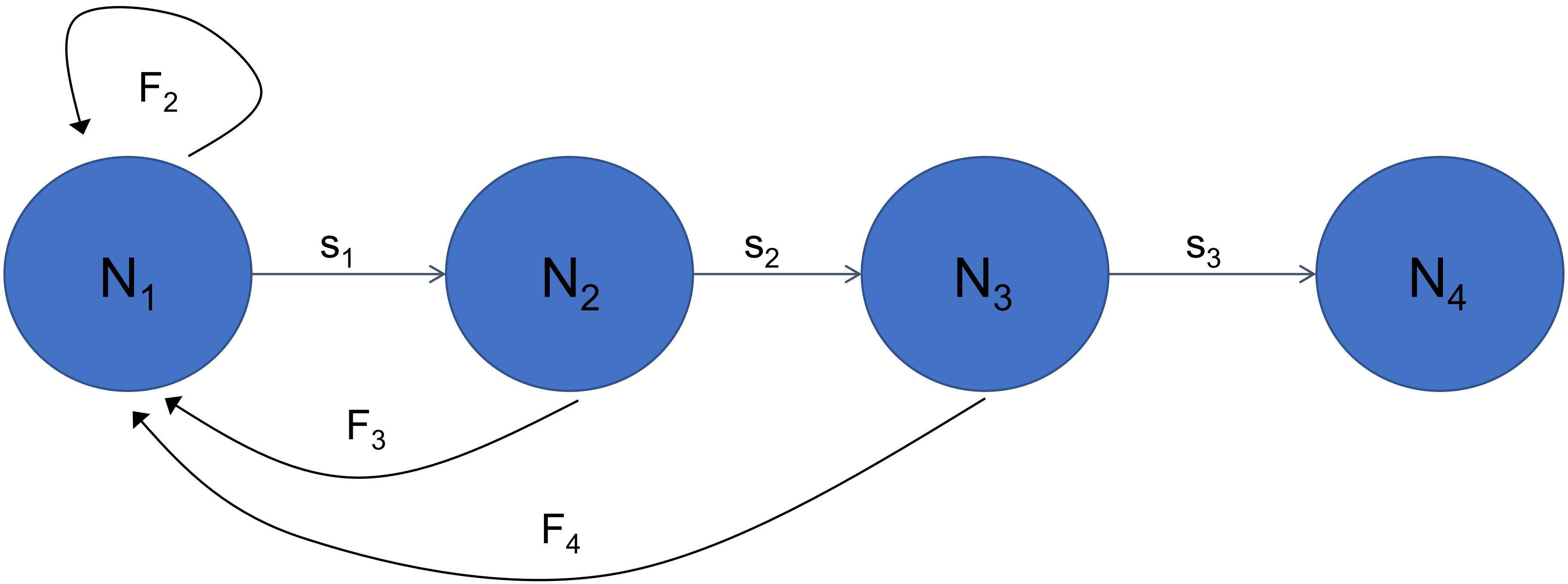
Population Matrix Models

- Leslie matrix (Leslie 1945): Project age structure and calculate λ, given age-specific survival and fecundity
- Lefkovitch matrix (Lefkovitch 1965): modify matrix to account for animals remaining in same stage

Age-structured Matrix Model

$$\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}(t+1) = \begin{bmatrix} F_1 & F_2 & F_3 & F_4 \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & 0 \end{bmatrix}\begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}(t)$$

Live cycle drawing:



Leslie matrix:

$$A = \begin{bmatrix} f_2 s_1 & f_3 s_2 & f_4 s_3 & 0 \\ s_1 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & 0 \end{bmatrix}$$

In matrix notation this is easier:

$$\boldsymbol{n}(t+1) = \boldsymbol{A}\ \boldsymbol{n}(t)$$

Projecting forward

- Increment population annually
- N(t+1) = **A** • N(t); **A** = transition matrix

$$\begin{bmatrix} N_1(t+1) \\ N_2(t+1) \\ N_3(t+1) \\ N_4(t+1) \end{bmatrix} = \begin{bmatrix} f_2 s_1 & f_3 s_2 & f_4 s_3 & 0 \\ s_1 & 0 & 0 & 0 \\ 0 & s_2 & 0 & 0 \\ 0 & 0 & s_3 & 0 \end{bmatrix} \cdot \begin{bmatrix} N_1(t) \\ N_2(t) \\ N_3(t) \\ N_4(t) \end{bmatrix}$$

Example calculation (matrix multiplication)

$$N_0(t+1) = f_2 s_1 N_1(t) + f_3 s_2 N_2(t) + f_4 s_3 N_3(t) + 0 N_4(t)$$

Population finite growth rate as

λ = finite rate of increase

λ = 1.0 means population remains constant

- $\lambda = 1.2$ means population increases 20% per year
- For our example population λ = 0.93
- This means that the population will decrease 7% per year over the long run

Age/ Stage-structured Population Models

- Since age-specific birth and death rates are constant, population will reach a *stable age distribution*
  - Proportion in each age constant, even though population growing
- If population also stable (λ=1), then reach *stationary age distribution*
- Asymptotic vs. transient dynamics

Can we calculate λ from our (Leslie) population projection matrix?

- λ is defined as solution to characteristic equation:
- $\det(\mathbf{A} - \lambda\mathbf{I}) = 0$
- λ is also called the **dominant eigenvalue** of the Leslie projection matrix
- We can calculate λ fairly easily using a software program such as Matlab or Gauss once we've estimated values for **A**

Snake River spring/summer Chinook projection matrix

$$A = \begin{bmatrix} & & \mu S_1 b_3 m_3 / 2 & \mu S_1 b_4 m_4 / 2 & \mu S_1 b_5 m_5 / 2 \\ S_2 & & & & \\ & S_3 & & & \\ & & (1 - b_3) S_4 & & \\ & & & (1 - b_4) S_5 & \end{bmatrix}$$

Recovery and Management Options for Spring/Summer Chinook Salmon in the Columbia River Basin

Peter Kareiva,[1] Michelle Marvier,[2] Michelle McClure[1]*

SCIENCE VOL 290 3 NOVEMBER 2000

Survival Estimates

- S_x is probability of survival to age x from age x-1
- $S_2 = [zS_z + (1-z)S_d]S_e$
- Survival during 2nd yr of life =
- [(proportion of fish transported)(survival during transport) + (proportion of fish migrating in-river)(in-river survival)](survival in estuary & into ocean)

Survival Estimates

$\mu = (1\text{-}h_{ms})S_{ms}(1\text{-}h_{sb})S_{sb}$

Survival during upstream migration =

(proportion not harvested in main stem)(Survival rate in mainstem)(proportion not harvested in subbasin)(survival rate in subbasin)

Fecundity estimates

- $F_3 = \mu\ S_1 b_3 m_3/2$
- Fecundity of 3rd age class (jacks) =
- (Survival in upstream migration)(1st yr survival)(probability of breeding as a 3-yr old)(no. of eggs per 3-yr old female)/2

Projection matrix for Poverty Flat index stock

$$
\begin{bmatrix}
 & & 0.326 & 5.013 & 39.65 \\
0.013 & & & & \\
 & 0.8 & & & \\
 & & 0.79 & & \\
 & & & 0.70 &
\end{bmatrix}
$$

Long-term population projection for Poverty Flat index stock

- $\lambda = 0.76$
- This implies a 24% decline per year in population size for this stock if these rates are correct and if they remain the same in the future.

Conclusions from Karevia et al.

- Numerical experiments: looked at where reduction in mortality by life-stage would provide the greatest benefit overall population
- Concluded that restoration to spawning and rearing habitat and estuary provide the greatest benefit
- Took focus off the hydrosystem (including dam breaching)

SUFA review of Karevia et al. (and BiOp analyses)

- Numerical experiments: are just that- no feasibility
- Suggested modest reduction in mortality is misleading- can translate to >200% increase in survival

(Note: overall survival is the product of survival over life-stages $S_{LC}=S_1*S_2*S_3$... Cannot multiply mortalities, must covert to survival (1-mortality))

- Did not include density dependence
- Extinction probability based on definition ≤1
- Delayed mortality

COMPASS
Matrix Model

add density dependence

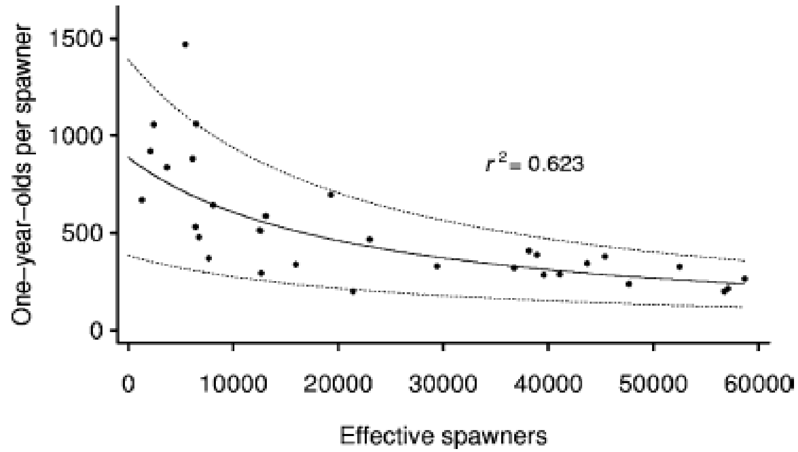


Figure 2. Relationship between 1-year-olds (juvenile recruits) per effective spawner (defined in text) versus effective spawners for Snake River spring and summer Chinook salmon. Solid line is the best-fit Beverton-Holt curve (see text).

The Interplay between Climate Variability and Density Dependence in the Population Viability of Chinook Salmon

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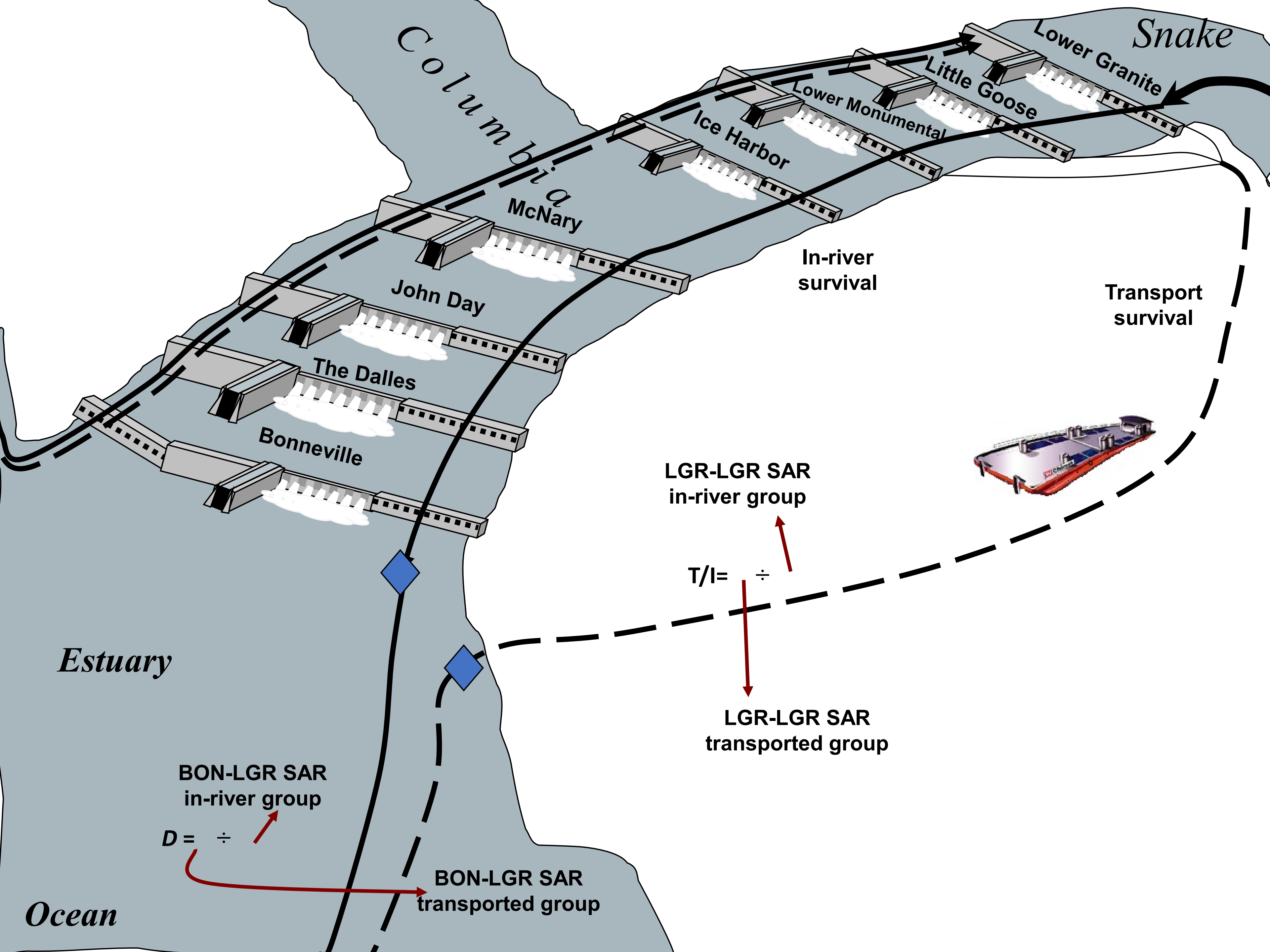
National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, WA 98112, U.S.A.

Conservation Biology Volume 20, No. 1, 190–200

DOI: 10.1111/j.1523-1739.2006.00300.x



Columbia
Snake
Lower Granite
Little Goose
Lower Monumental
Ice Harbor
McNary
John Day
The Dalles
Bonneville
In-river
survival
Transport
survival
LGR-LGR SAR
in-river group
T/I= ÷
LGR-LGR SAR
transported group
Estuary
BON-LGR SAR
in-river group
D = ÷
BON-LGR SAR
transported group
Ocean