Watershed Production Model Development

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CHaMP/ISEMP Watershed Production Model

- "All models are wrong, but some are useful"
  - George E.P. Box

- **For What is the Watershed Production Model Useful?**
  - **Integration of multiple CHaMP and ISEMP components into estimates of current and future population dynamics for each watershed of interest**
    - **Biological and empirical models, prior research, expert opinion, etc.**

  - Watershed Management
  - Comparisons of habitat management strategies
  - Sensitivity analyses – determination of which parameters to which fish populations are sensitive, to guide further research and management decisions
  - Validation of CHaMP products
  - Etc.

Beverton Holt Based Spawner Recruit Model

$$N_{k,i+1,t+1} = \frac{N_{k,i,t}}{\frac{1}{p_{k,i,t}} + \frac{1}{c_{k,i,t}} N_{k,i,t}}$$

- $N_{k,i,t}$ = number if fish at location k, life stage i, time t
- $p_{k,i,t}$ = productivity
- $c_{k,i,t}$ = capacity

Strategies for estimating model inputs (p, c, and additional fish behavioral parameters) vary from watershed to watershed

Beverton Holt Spawner Recruit Model

Productivity

$$p_{k,i,t} = Sr_{k,i,t} \times \frac{\sum_{q=1}^{n} [E_{i,q}] \times [L_{q,k}]_t}{\sum_{q=1}^{n} [L_{q,k}]_t}$$

Capacity

$$c_{k,i,t} = \sum_{j=1}^{n} [H_{k,j,t} * D_{k,j,i,t}]$$

$$H_{k,j,t} = \sum_{q=1}^{Q} [M_{k,j,q,t} * [A_{k,t} * L_{k,q,t}]]$$

User Input		Definition
$Sr_{k,l,t}$		site (k) average maximum survival rate from one stage (k) to the next in the life history of the species given average conditions
$Ek_{,i,q,t}$		Scalar showing the importance of land-use type (q) for overall productivity at life stage (i)
$Ak * Lqk_{k,q,t}$	$L_{k,q}$	Proportion of Land Area in site (K) of land use classifictation (q)
	A_k	Water Surface Area of site (k)
$D_{k,j,l,t}$		Maximum density, in fish per unit area area for site (k) and habitat classification (j)
$M_{k,j,q,t}$		Proportion of Each Defined Habitat Type in Land Use Classification (q) for habitat type (j)
$A_{k,t}$		Water Surface Area of site (K)

Watershed Production Model Features

- Flexible enough to simulate both steelhead and salmon populations
- Flexible enough to enable multiple parameterization strategies
  - Simple to extremely detailed and complex
- Models can be run on spatial scale(s) specified by user
  - Multiple locations within a watershed and cross-site migration at various life stages can be integrated into model
  - **Spawning fish returned to imprinted site at fry life stage**
- Hatchery fish can interactions can be modeled
  - Hatchery fish, wild fish, and multiple flavors of inter-bred fish tracked uniquely

White = New Features Since August 2013 Update

Watershed Production Model Features

- O. Mykiss specific capabilities
  - Anadromous and resident fish, and their interactions, can be modeled concurrently
  - **Spawning fish (Steelhead and Resident Rainbow) can have non-zero mortality rates after spawning**
  - **Steelhead and Resident Rainbow tracked separately (and don't compete directly) in early life stages**
- Inputs can include distributions of migration timing for smolts and adult spawners
  - **Behavioral parameters specified uniquely for males and females**
  - **Males and Females tracked separately. Differential behavior inputs give rise to differential male/female populations across various life stages**
- Model Coded in R
  - Open source code
  - Input files in .csv format

White = New Features Since August 2013 Update

Watershed Production Model Features

- Model can be used to simulate step function and/or trend function changes in input parameters
- Stochasticity can be Included
  - Spatial and temporal variability and correlation structures can be specified with inputs
    - Real variation is highly spatially and temporally correlated, and this correlation can have drastic effects on results
    - Ignoring correlated parameters can severely bias results and/or lead to damping of real spikes and trends in population numbers
  - Uncertainty in parameters can be specified to generate Monte-Carlo estimates of uncertainty in results

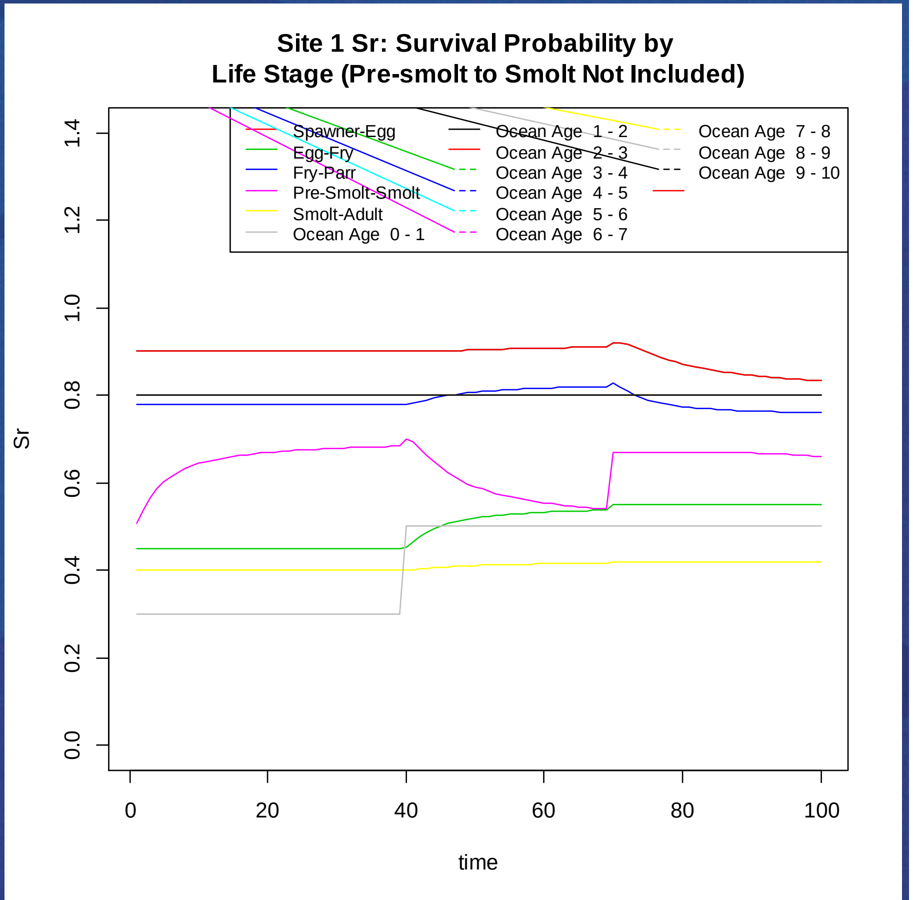
Including Temporal Trends and/or Step Function Changes in Parameters

T=1..39	Life Stage	Life Stage	Estimated Survival to Next Stage	AlphaR.N	AlphaT.N	AlphaS.N	Alpha.N	Future Target Survival	Change Rate Parameter
	N[2]	Spawner-Egg	0.9	200	120	160	160	0.9	0
	N[3]	Egg-Fry	0.45	200	120	160	160	0.45	0
	N[4]	to Parr	0.78	200	120	160	160	0.78	0
	N[6]	to Smolt	0.5	200	120	160	160	0.7	0.3
	N[7]	to Adult Age 0	0.4	200	120	160	160	0.4	0
	N[8]	to Adult Age 1	0.3	200	120	160	160	0.3	0

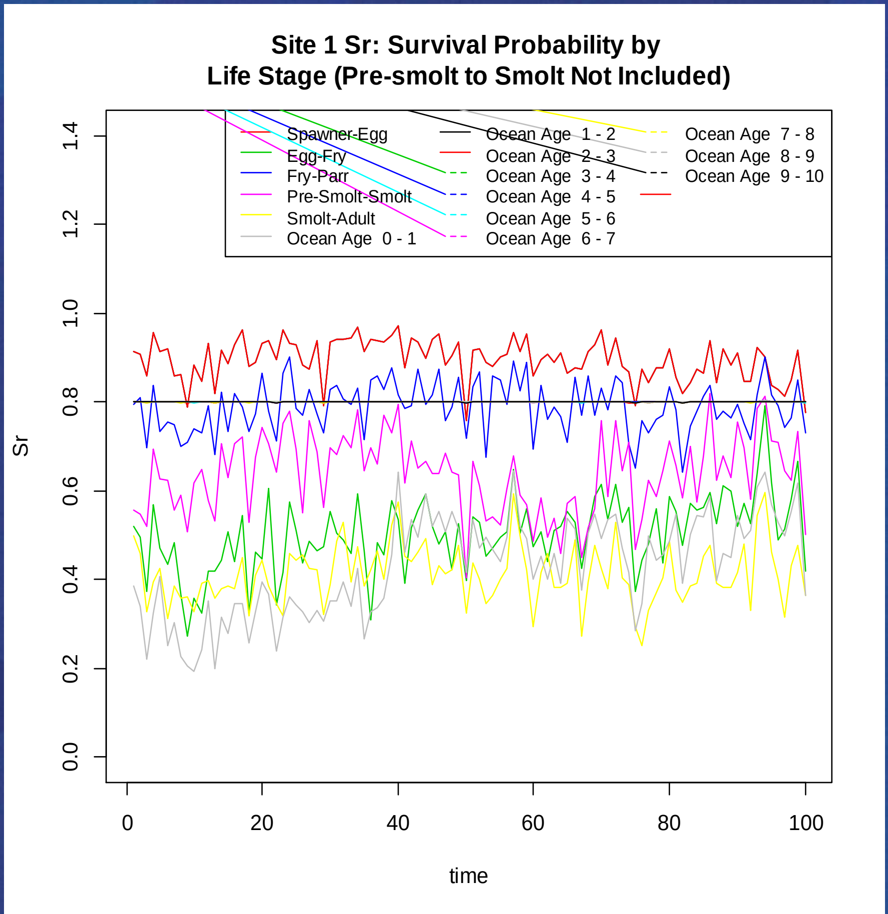
T=40..69	Life Stage	Life Stage	Estimated Survival to Next Stage	AlphaR.N	AlphaT.N	AlphaS.N	Alpha.N	Future Target Survival	Change Rate Parameter
	N[2]	Spawner-Egg	0.9	200	120	160	160	0.92	0.05
	N[3]	Egg-Fry	0.45	200	120	160	160	0.55	0.25
	N[4]	to Parr	0.78	200	120	160	160	0.83	0.15
	N[6]	to Smolt	0.7	200	120	160	160	0.5	0.15
	N[7]	to Adult Age 0	0.4	200	120	160	160	0.42	0.15
	N[8]	to Adult Age 1	0.5	200	120	160	160	0.5	0.15

T=70..100	Life Stage	Life Stage	Estimated Survival to Next Stage	AlphaR.N	AlphaT.N	AlphaS.N	Alpha.N	Future Target Survival	Change Rate Parameter
	N[2]	Spawner-Egg	0.92	200	120	160	160	0.8	0.1
	N[3]	Egg-Fry	0.55	200	120	160	160	0.55	0
	N[4]	to Parr	0.83	200	120	160	160	0.75	0.25
	N[6]	to Smolt	0.67	200	120	160	160	0.43	-99
	N[7]	to Adult Age 0	0.42	200	120	160	160	0.42	0.01
	N[8]	to Adult Age 1	0.5	200	120	160	160	0.97	0

Survival Parameters vs. Time, without Stochasticity Included



Survival Parameters vs. Time, with Year-Year, Site-Site, and Within Site Stochasticity Included



Effect of Variability in Carrying Capacity at Differing Levels of Spatial Correlation

Stochasticity of Carrying Capacity (D, fish / sq. meter) was applied at different spatial levels.

Variance levels of each parameter are exactly equal.

Differences are due to the spatial levels at which variation is correlated

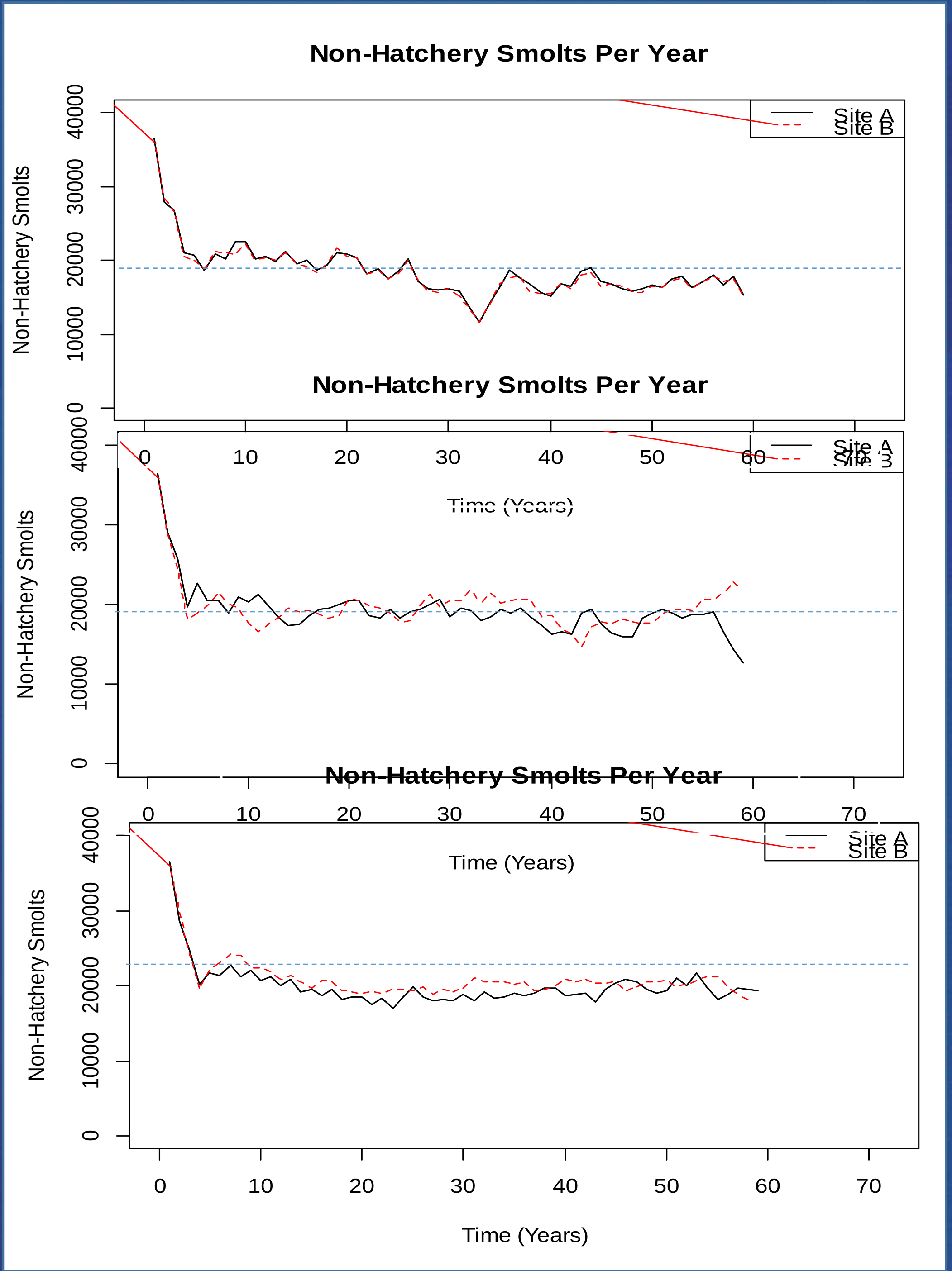
Highly correlated variation tends have greater impact overall results, while the impact of "pure" variation (independent at all spatial levels) tends to be small.

Note: In this example, site-A and Site-B have same parameter value means. This not necessary; parameters can be correlated but have different mean values.

Year-Year: Independent
Site-Site: Correlated
Within Site: Correlated

Year-Year: Independent
Site-Site: Independent
Within Site: Correlated

Year-Year: Independent
Site-Site: Independent
Within Site: Independent



Watershed Production Model Development

- What's Complete?
  - R-code and input file templates are Complete and ready to use!
    - Ongoing revision and code support in 2014
    - Potential Integration of model with ocean based or other models?
- What is TBD
  - Parameterization of Individual Watersheds

    John Day: Carl Saunders, ELR

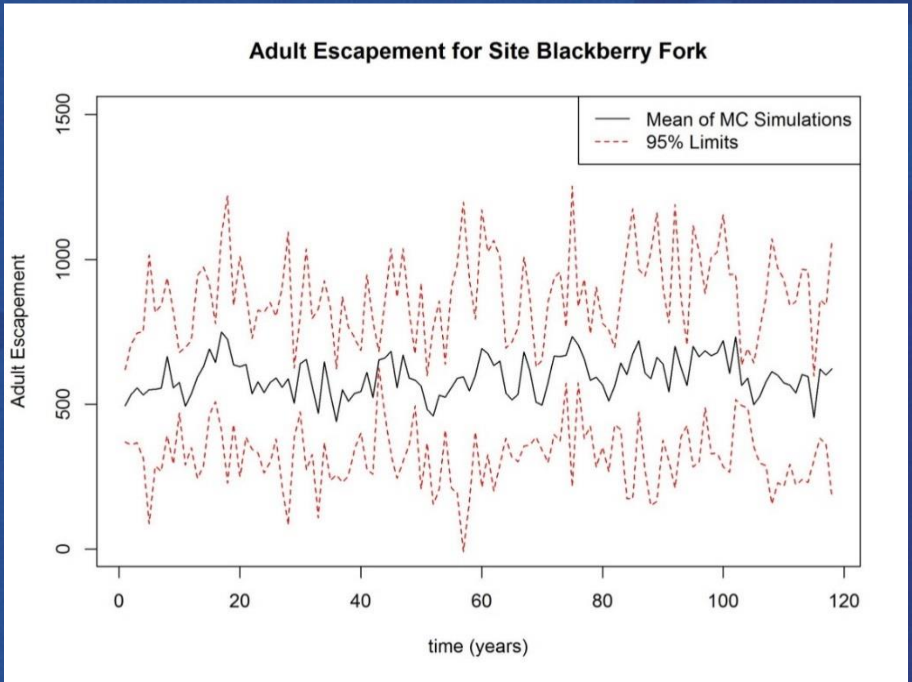
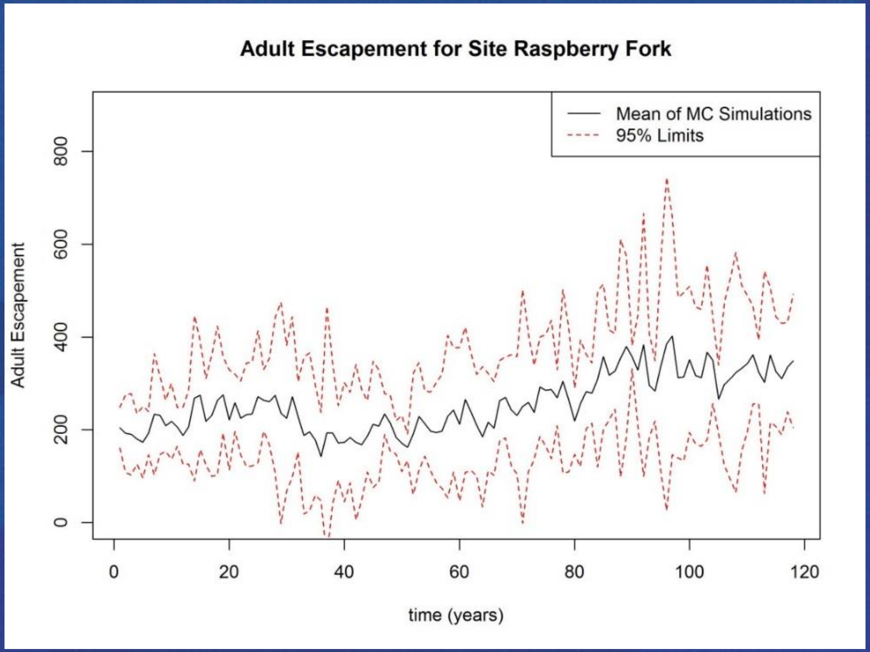
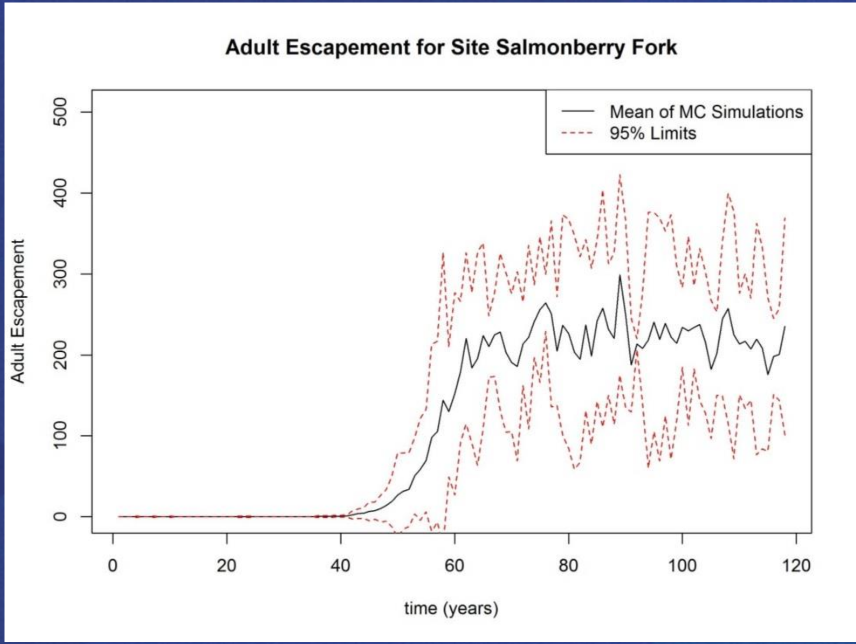
    Lemhi: Joe Benjamin, QCI

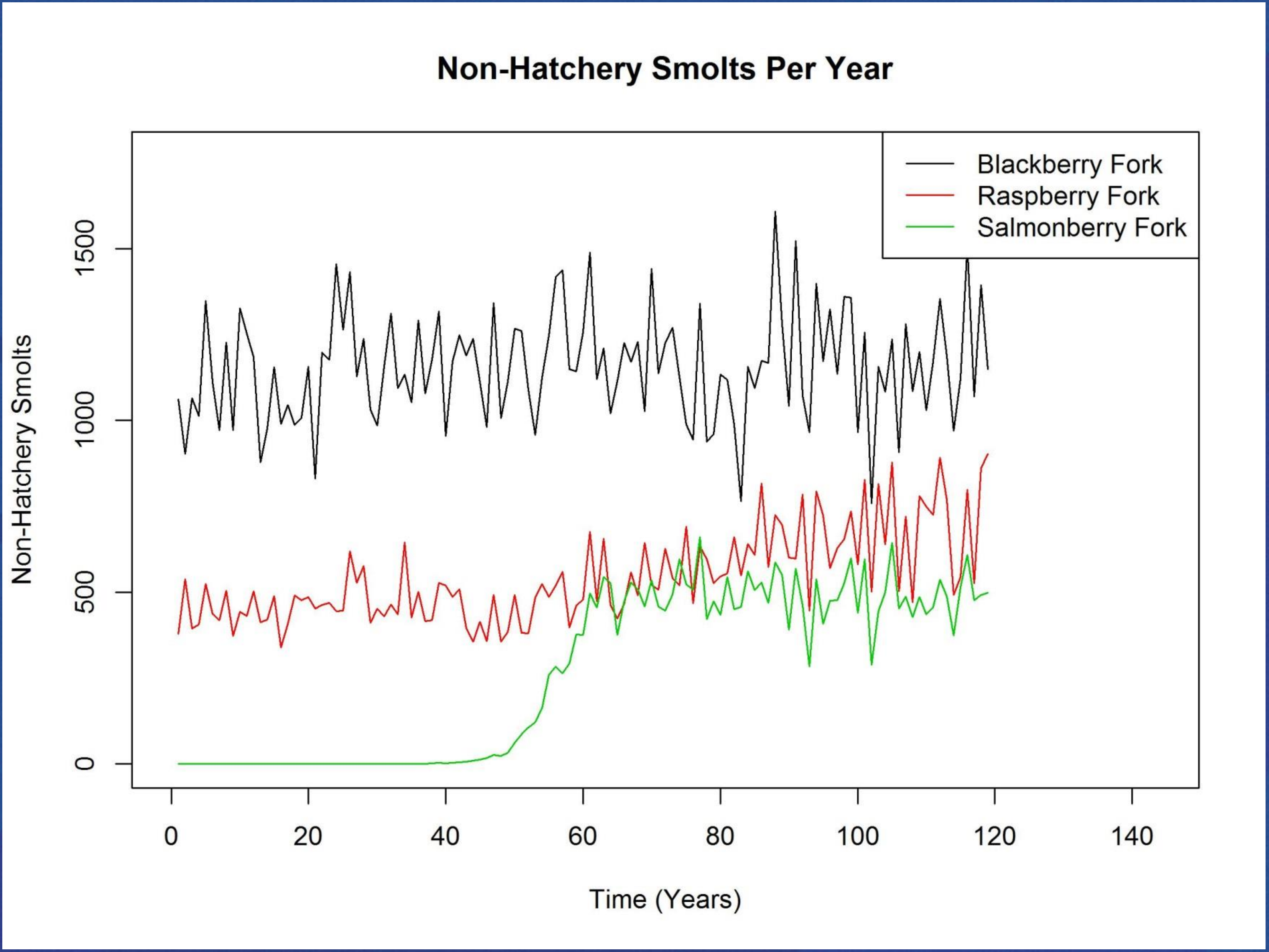
    Entiat and Wenathcee: James Murphy, Terraqua

Initial Parameterization and Model TBD Feb 2014

Example Results (Backup)

CHaMP / ISEMP Watershed Production Model

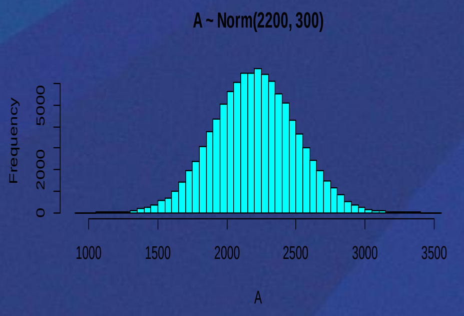

Adult Escapement for Site Blackberry Fork
Mean of MC Simulations
95% Limits
Adult Escapement
0
500
1000
1500
0
20
40
60
80
100
120
time (years)

Adult Escapement for Site Raspberry Fork
Mean of MC Simulations
95% Limits
Adult Escapement
0
200
400
600
800
0
20
40
60
80
100
120
time (years)

Adult Escapement for Site Salmonberry Fork
Mean of MC Simulations
95% Limits
Adult Escapement
0
100
200
300
400
500
0
20
40
60
80
100
120
time (years)



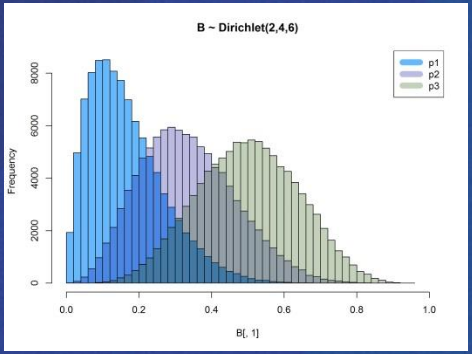
Non-Hatchery Smolts Per Year
Blackberry Fork
Raspberry Fork
Salmonberry Fork
Non-Hatchery Smolts
0
500
1000
1500
0
20
40
60
80
100
120
140
Time (Years)

Watershed Production Model Stochasticity

- Normal Random Variables
  - Used for Most Input Parameter Stochasticity



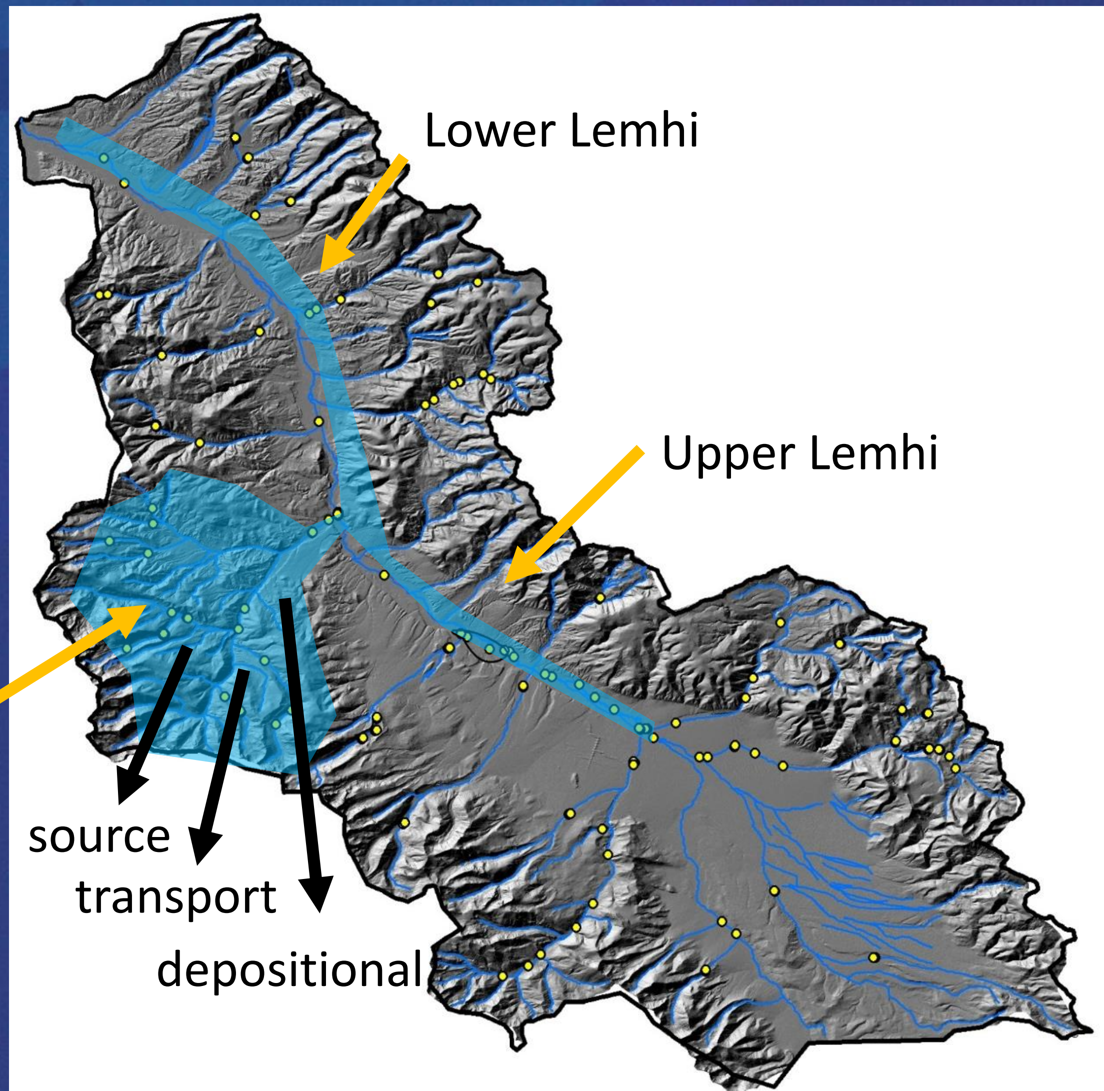
- Dirichlet Random Variables
  - Used for Proportions or Probabilities
    - Including Multivariate Scenarios – i.e. more than two possible outcomes
      - i.e. Steelhead Pre-smolt of age X may remain as pre-smolt, spawn, or smolt
      - Proportions or probabilities must sum to 1.



Lemhi

Lemhi River

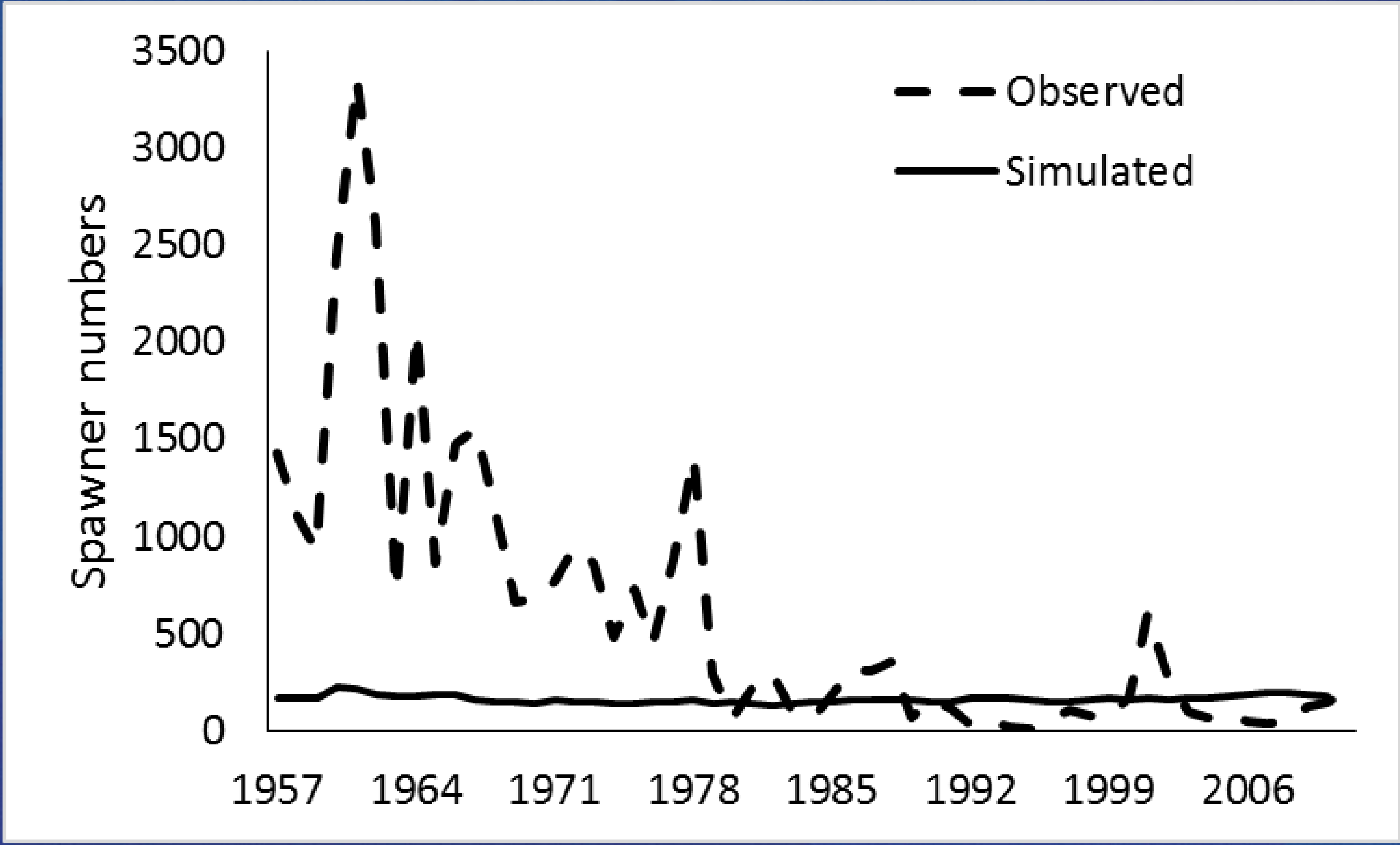
- Spatial structure
  - Coarse = main-stem segment or tributary
  - Intermediate = one
  - Fine = geomorphic class



Lemhi River: Parameters

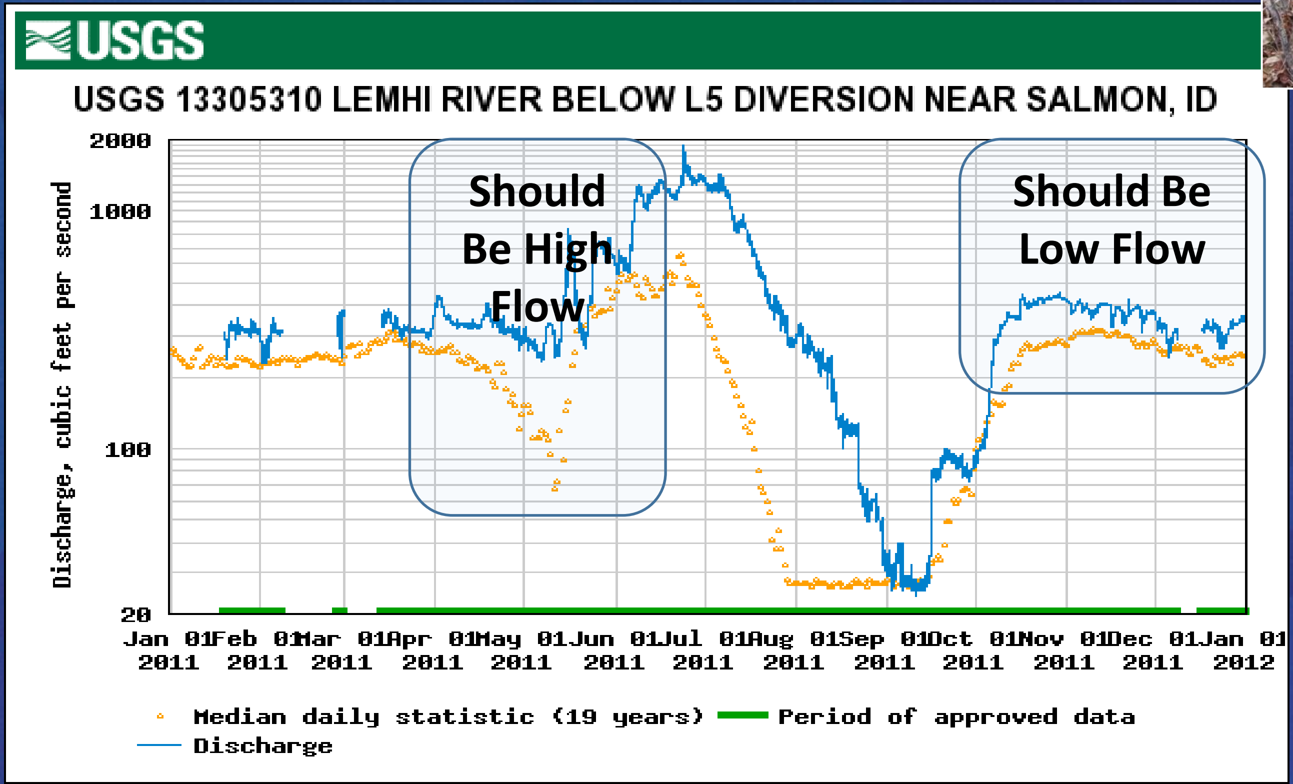
- Carrying capacity
  - Use the maximum density of fish from ISEMP data or previous studies
  - Total surface area of water
- Productivity
  - Multistate model to estimate parr – presmolt survival
    - Mark-resight, rotary screw traps, PIT tag detections
  - Literature values for egg – fry (Bjornn 1978)
- Movement
  - Populated 100% empirically: Parr - adult
    - IPTDS in every existing/reconnected tributary
  - Literature based for fry

Lemhi River: Simulated vs. empirical: Chinook spawners

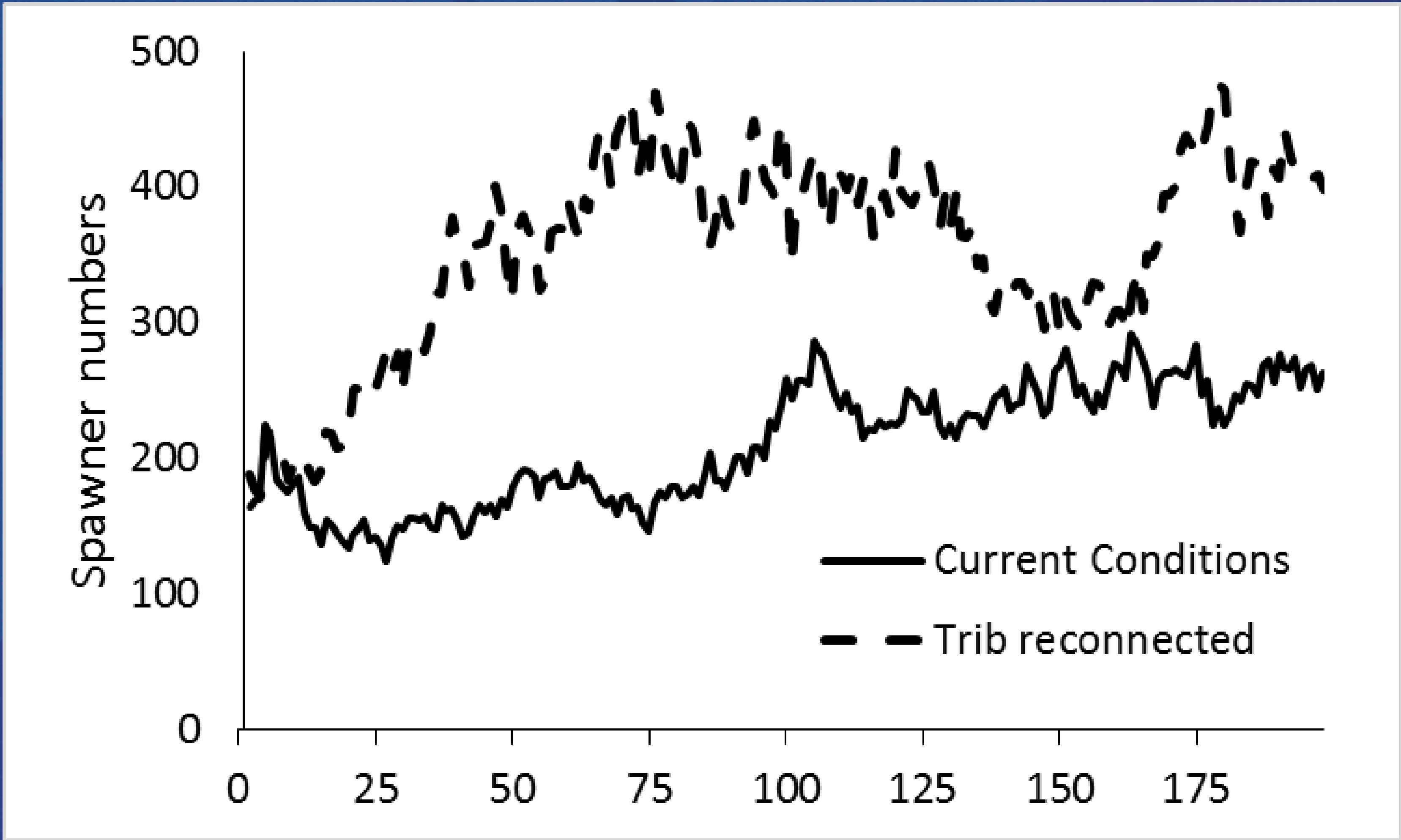


Lemhi River: Restoration actions

- Tributary reconnection



Lemhi River: Reconnect tributary

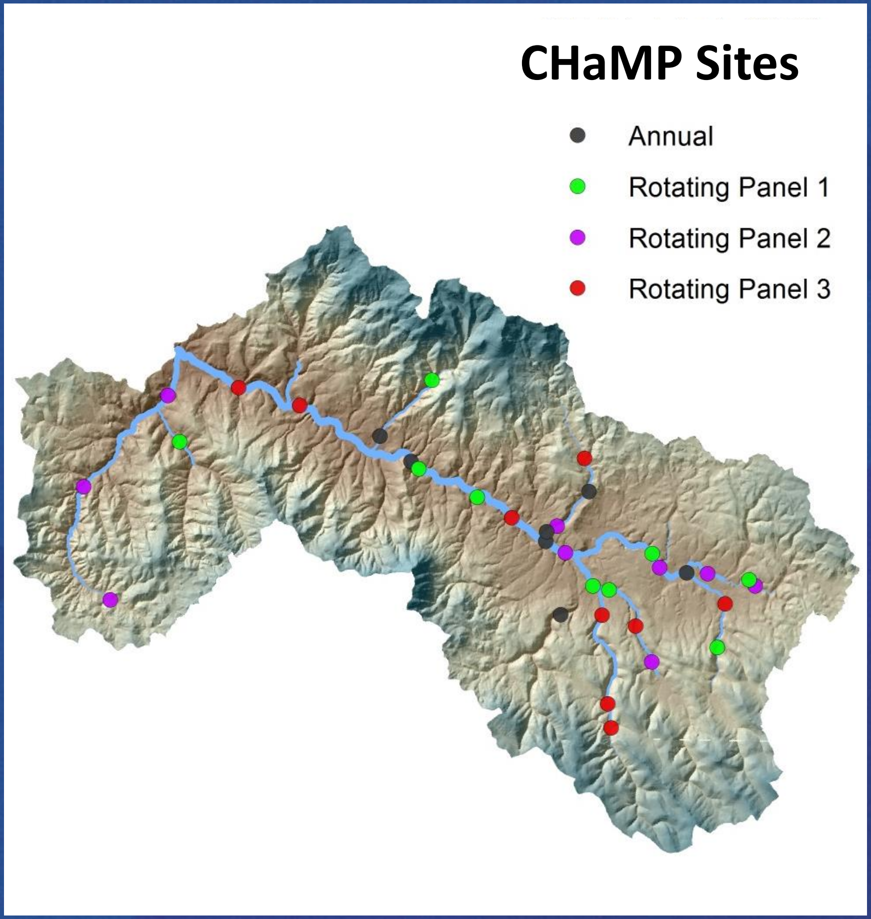


Next Steps for Idaho Rivers

- Identify limiting habitat by life stage
  - Currently assume water is limiting factor
- Chinook in Sesech River
- Inputs for *O. mykiss* in Lemhi and Sesech rivers
- Other restoration scenarios
- Sensitivity analysis

John Day

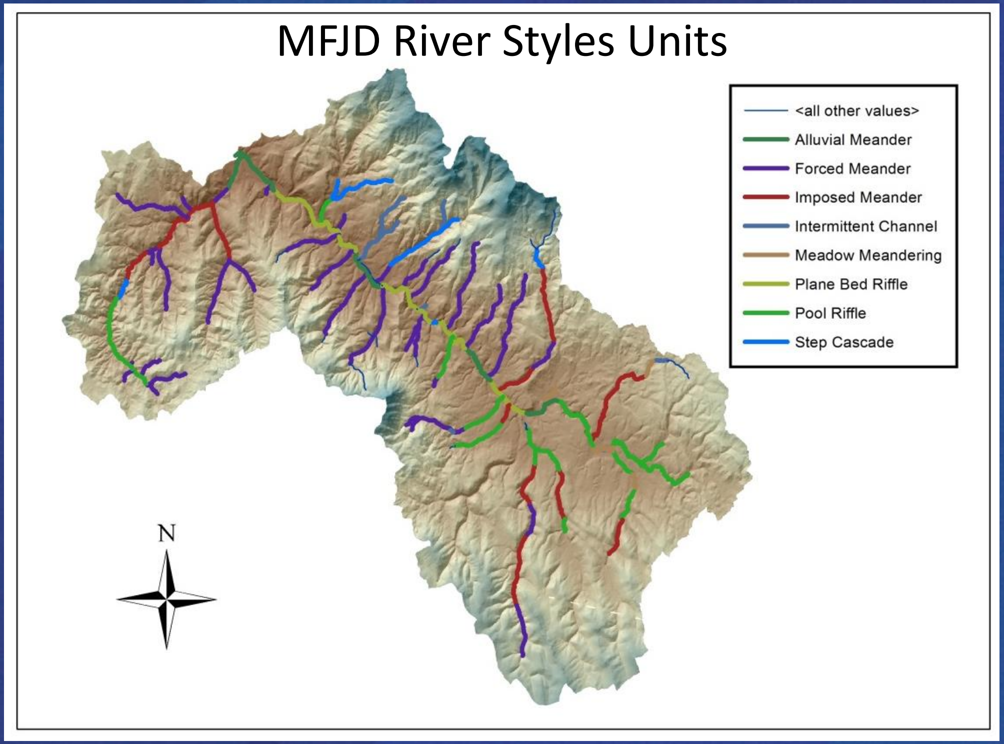
John Day River: Spatial structure



- Initially parameterize life-cycle model for Middle Fork John Day IMW
- Later South Fork John Day
- Initial models for Steelhead

John Day River: spatial structure

- 2 hierarchical levels:
  - Top level = 3 river Segments
  - Stratify watershed by summer temperature
  - 2nd level = River Styles geomorphic classifications



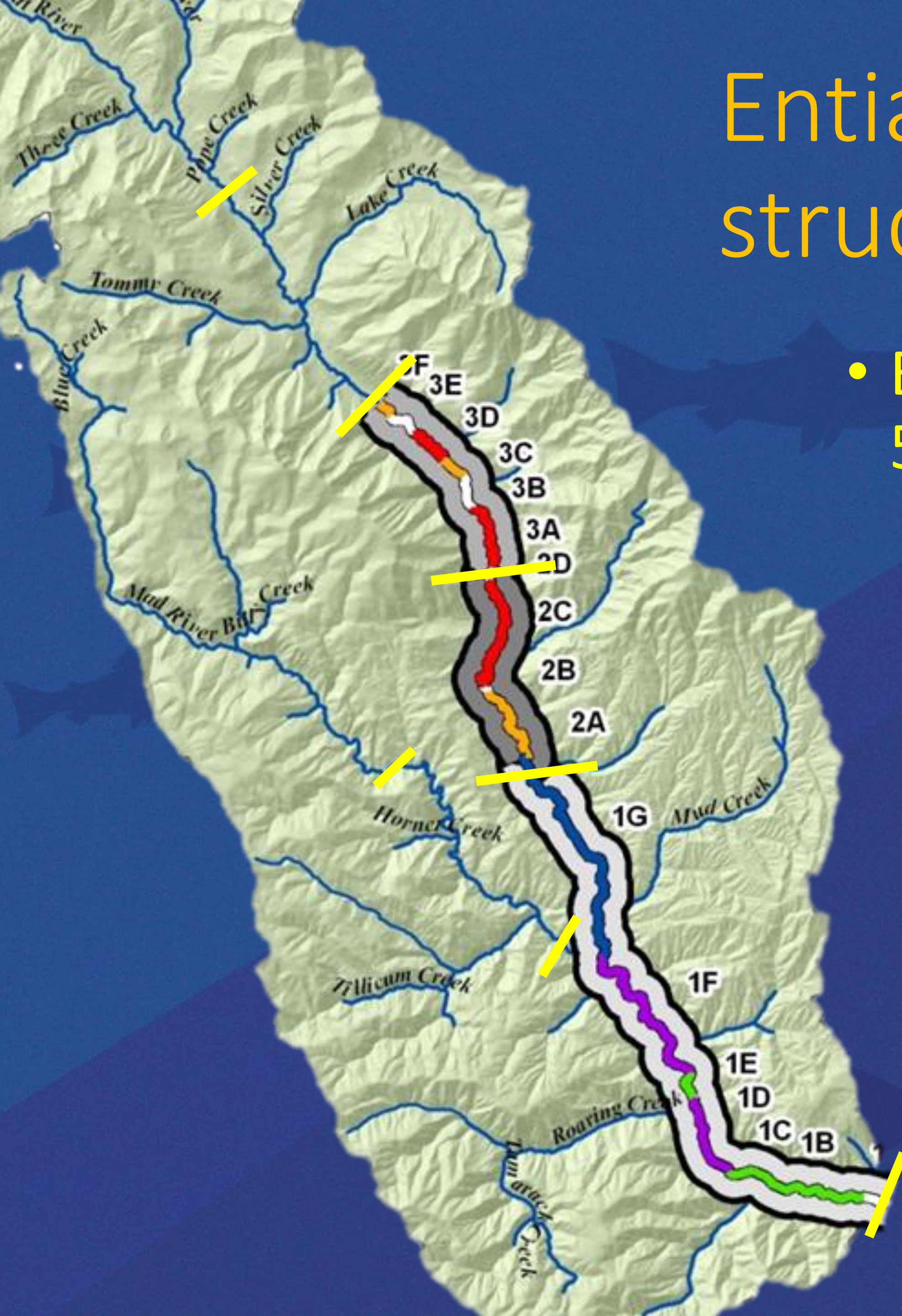
John Day: capacity parameters

- Egg capacity
  - HSI
  - Account for superimposition, adult size distribution, eggs per female
- Juvenile capacity
  - NREI capacity estimates
- Watershed roll-up based on total stream length within River Style unit

John Day River: Production/Survival

- Survival of egg and parr stages based on literature values
- Juvenile survival
  - STEP 1: Develop watershed wide relationship between growth and survival
  - STEP 2: Link habitat variables to fish growth/size
    - CHaMP metrics
    - Temperature
  - STEP 3: Integrate survival estimates to reflect habitat at the River Style unit and continuous temperature predictions
- Columbia and ocean life stages modeled using Smolt-to-Adult return rates

Upper Columbia



Entiat River: spatial structure (steelhead)

- Entiat subbasin divided into 5 river segments
  - 4 IMW
  - 1 Status and Trends

Entiat River: spatial structure

- 2 hierarchical levels:
  - Top level = 5 river segments
  - 2nd level = Habitat quality index values

Valley segment 1

Habitat quality index

- Categorical ranking of habitat quality
- Relate CHaMP habitat data to ISEMP fish data by identifying important habitat variables
- Develop predictive models to relate future habitat values to future fish densities
- Changes in habitat variables will simulate future restoration activities and their effects on fish densities
- Can incorporate hydrological/NREI metrics

Habitat quality index and population dynamics

- Use HQI as covariate in survival estimation
- Set carrying capacities as function of HQI values
- As restoration changes habitat features, HQI improves, then survival and carrying capacity increases.

Current status and future work

- Developing HQI for Entiat and Wenatchee
- Survival estimation for Entiat and Wenatchee fish
- Working with agencies for Wenatchee data