Shaping Seasonal Flows to Favor Salmon & Energy Production

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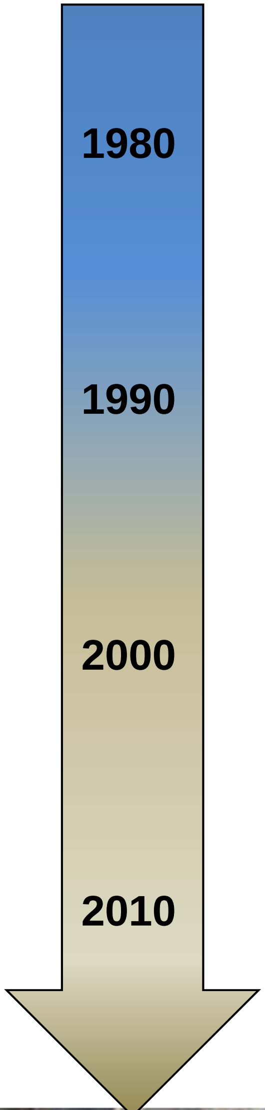
Oak Ridge National Laboratory

Symposium on Science and Strategies for Conservation of Land & Stream Flows through...Financial Incentives

2011 Annual meeting

American Fisheries Society

Seattle, WA



The Natural Flow Paradigm
scientific or unscientific?

- Natural flow paradigm
  - Variation is important
  - Evolution argument is tautological
- We are not smart enough to understand why historical flow regimes are important, but we know they are best.
- Are all deviations equally bad for fishes?

The Science-based Flow Paradigm

Which aspects of natural or regulated flow regimes are ecologically important?

- Quantify cause-effect relationships
- Identify pathways and features of flow under selection
- Assign value to ecological effects
- Design decision tools to consider ecological values of alternative flow regimes

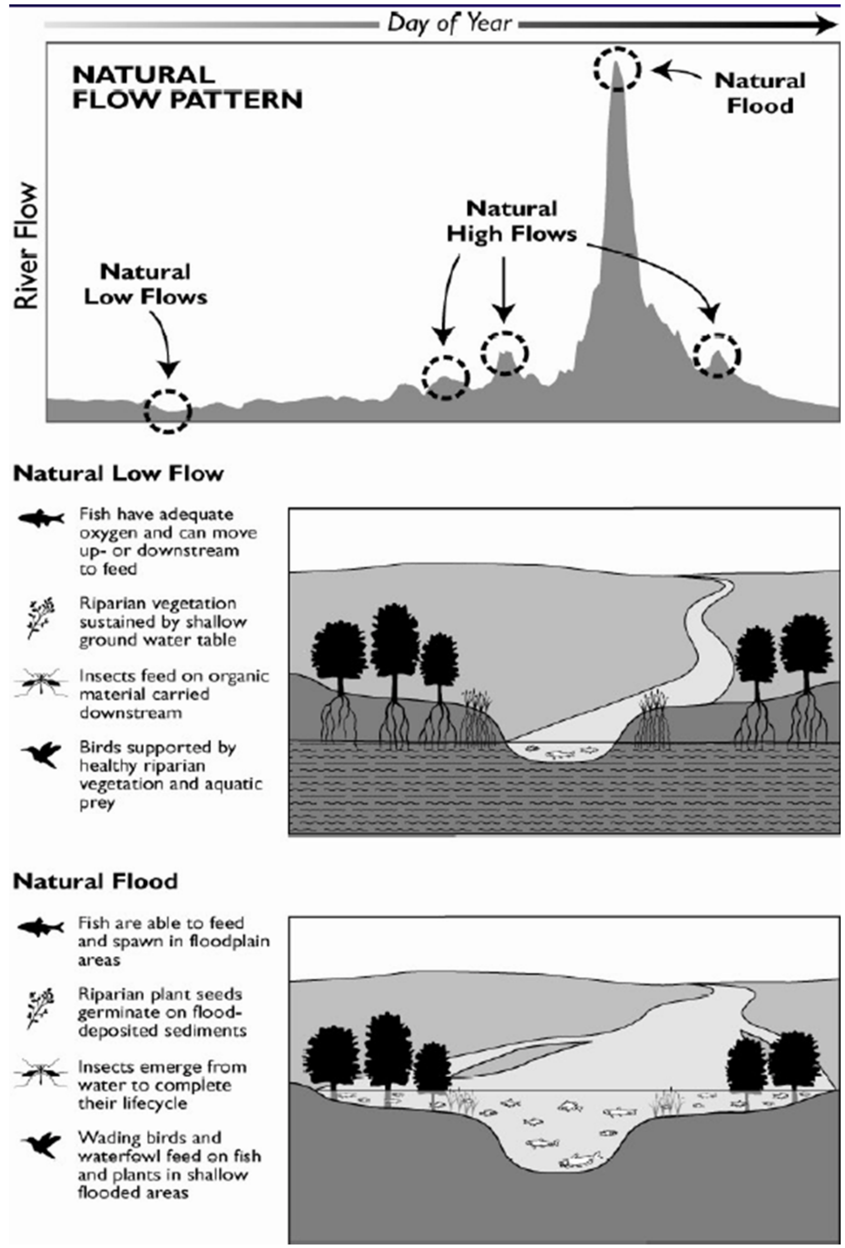
Postulated linkages flow regime & fishes

•-Direct effects at different time scales:

- Rare flood events shape channels
- **Large woody debris adds flow complexity, ecotones**
- Persistent shallow, slow habitat for refuge & nursery
- **Redd scouring & dewatering**

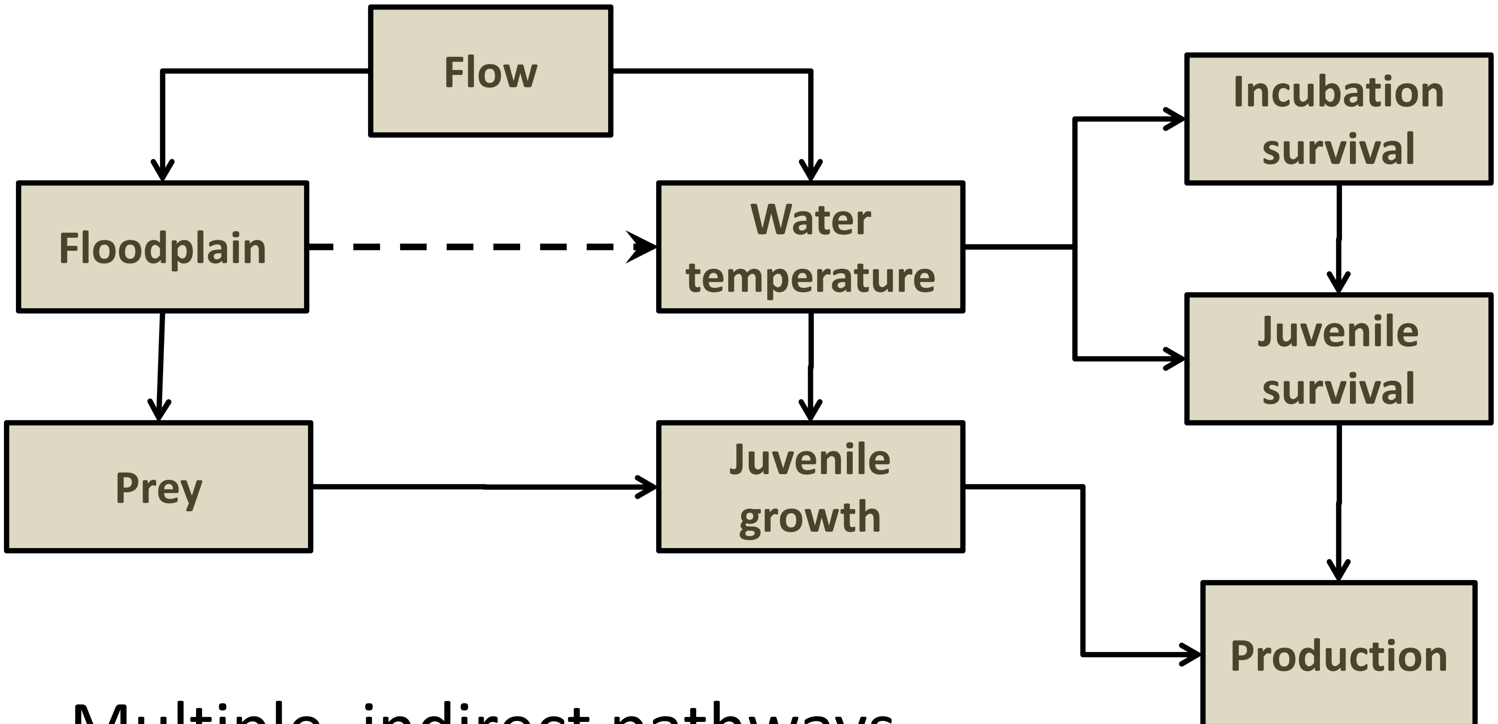
• Indirect effects are neglected

- **Intermittent habitat reconnection**
- **Temperature**
- **Floodplain & riparian vegetation**
- Prey availability
- **Predator habitat**



Unknown source:

No simple relationship between salmon production and flow



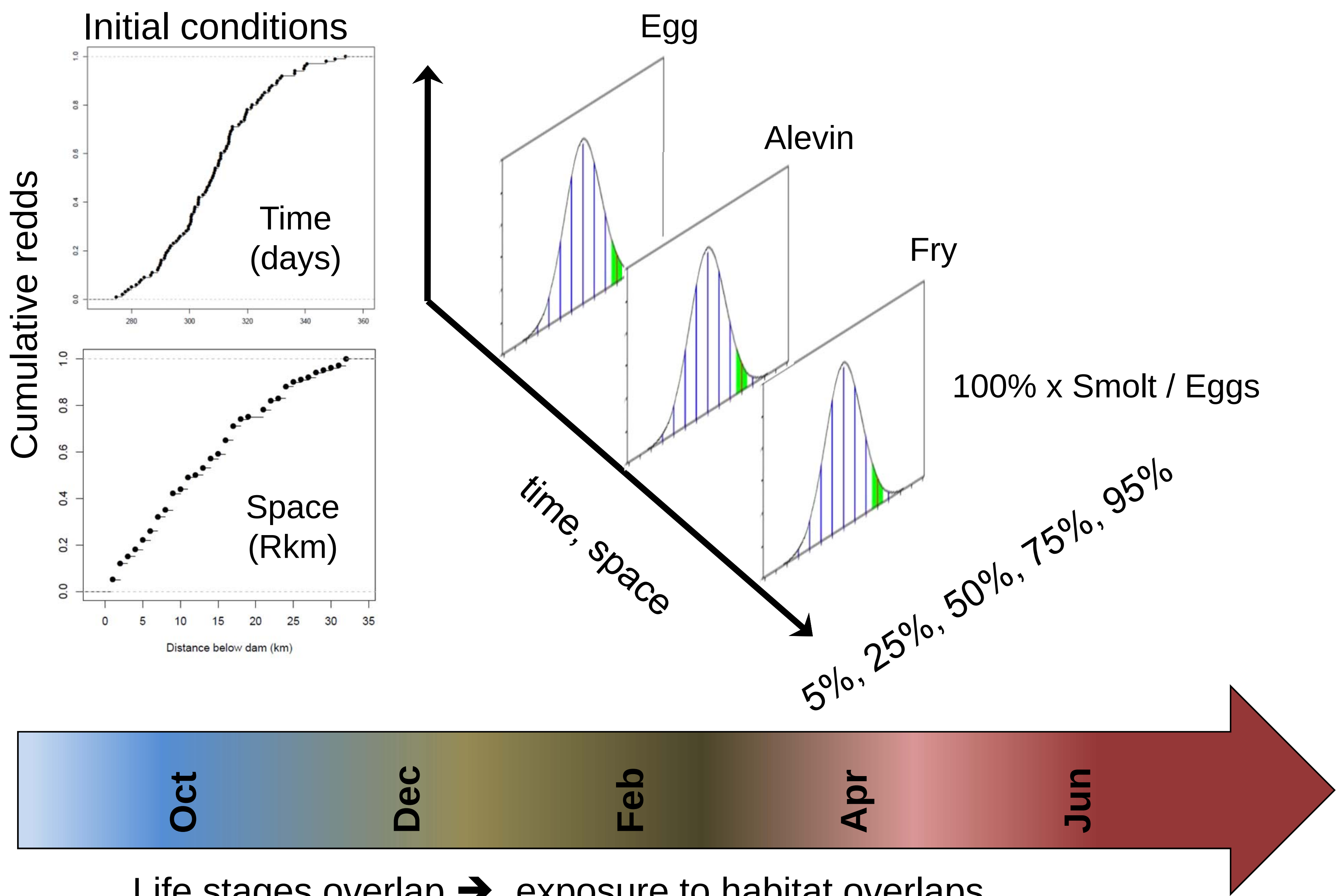
Multiple, indirect pathways mediated by temperature, prey, ...

Now and Then

Tuolumne River fall Chinook salmon

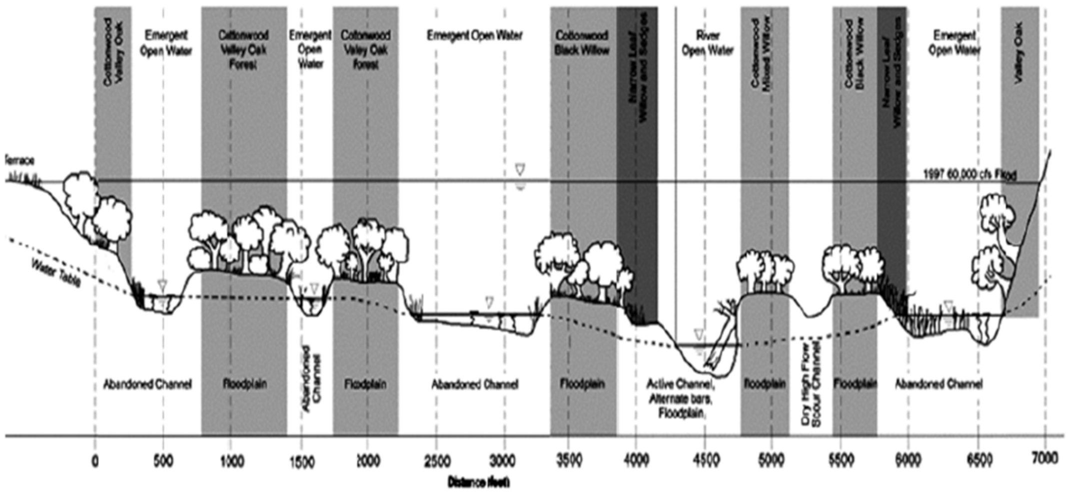
	Jager and Rose 2003	*This study*
Flow regime (decision variables)	2-week constant	Weibull model for fall and spring pulse flow
Habitat	WUA by riffle, pool-run Density dependence, scouring/dewatering redds	Overbank flow ➔ floodplain inundation➔ growth
Temperature	Important driver of development, growth, and survival	Important driver of development, growth, and survival
Salmon model	IBM & SEPM coded in FORTRAN	Quantile model coded in R
Processes	Predation, bioenergetics, movement	Bioenergetics, movement
Optimization	Simulated annealing (months of clock-time)	Evolutionary algorithm (days of clock-time)

Quantile space-time modeling



Life stages overlap ➔ exposure to habitat overlaps

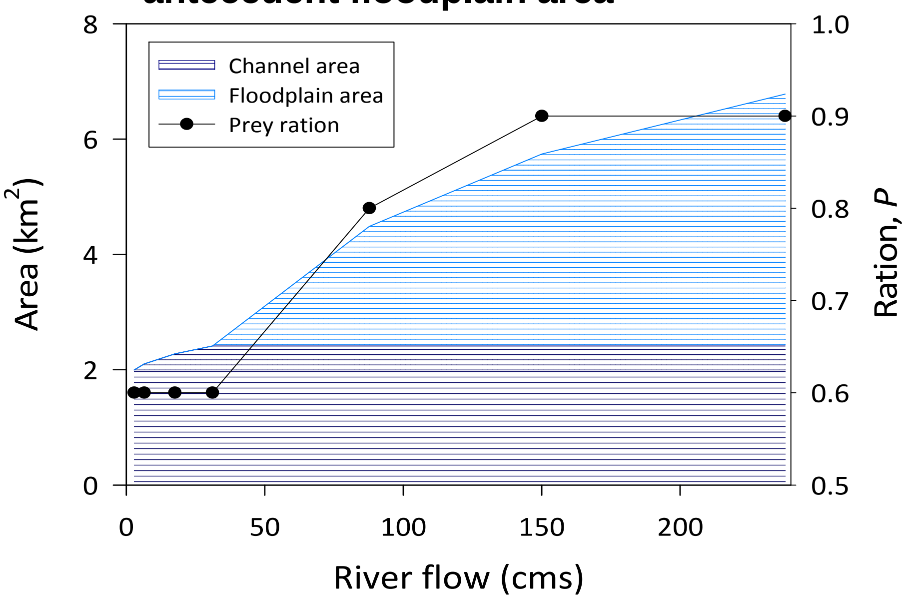
Overbank flow, floodplain, feeding



Cross-section after restoration of floodplain. Tuolumne River TAC 2000

Inundated area (bottom-left) from Mark Gard (FWS)

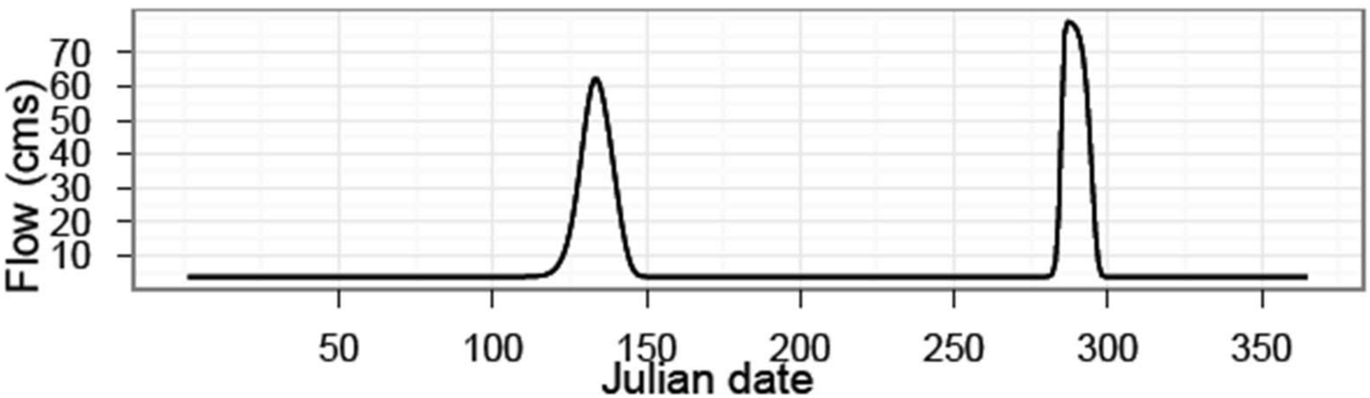
Ration assumed to increase w/ antecedent floodplain area



Mainstem (left) **Floodplain (right)**

Opperman photo in Jeffres et al. 2008

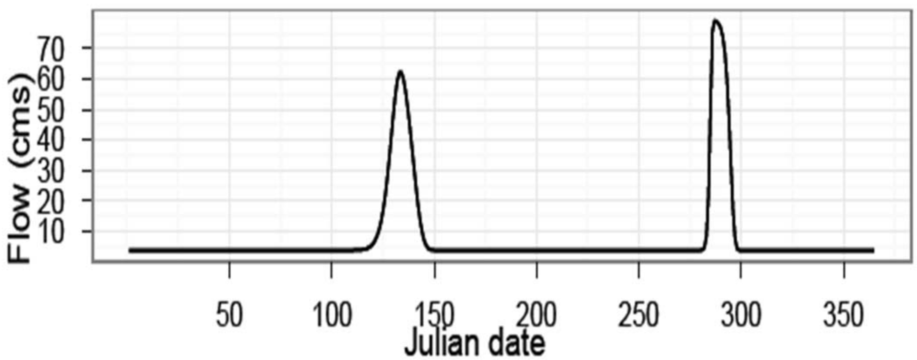
Weibull pulse-flow model
fall and spring

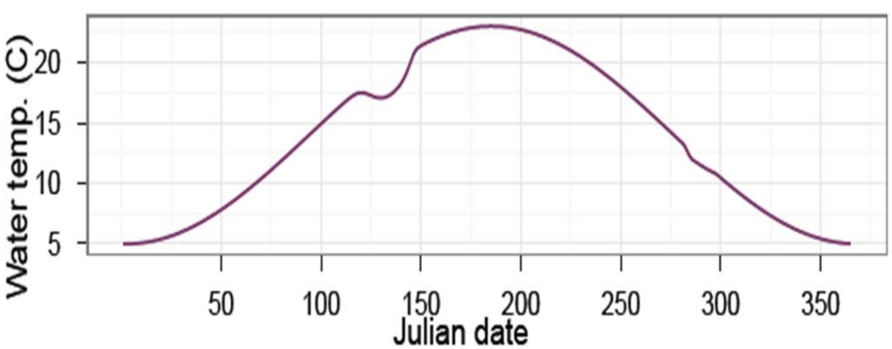


- **Specify total annual flow**
- **Five parameters describe flow regime**

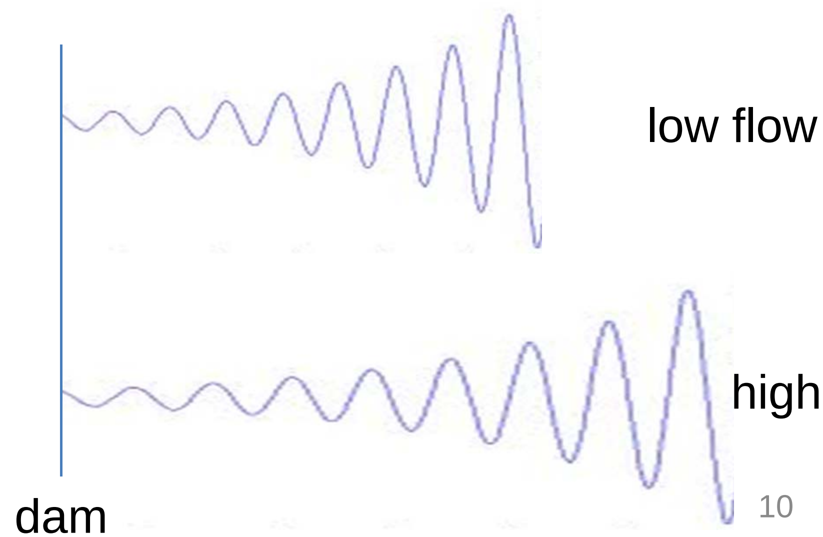
- Steepness
- Fall pulse start date
- Fall duration
- Spring pulse start date
- Spring pulse duration

Temperature-mediated effects





- Most important parameter in sensitivity analyses
- Modified thermal regime below dams

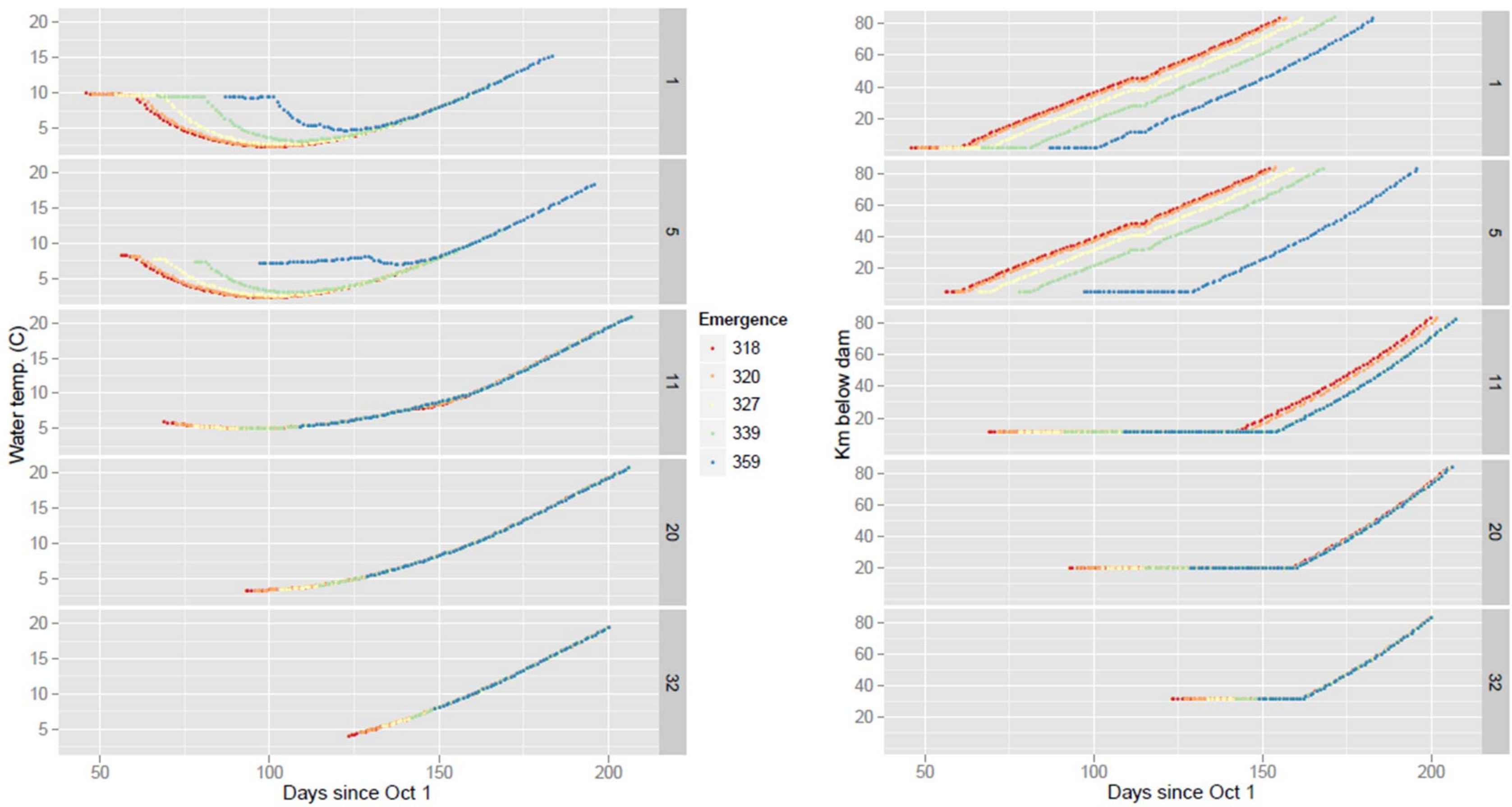


Evolution of space-time quantiles

Juveniles

upstream

downstream



upstream

downstream

Movement is delayed until reaching 1/3 minimum smolt size.
Later redds take longer to grow to this size.

Simulate Salmon Production

Incubation, juvenile rearing & production

- Functions of temperature
  - Egg, alevin development
  - Egg, alevin survival
  - Juvenile growth (also weight, ration = f(floodplain inundation))
  - Juvenile survival (also length)
- Production is a product of survival through lifestages
- Quantiles weighted to evaluate objective function

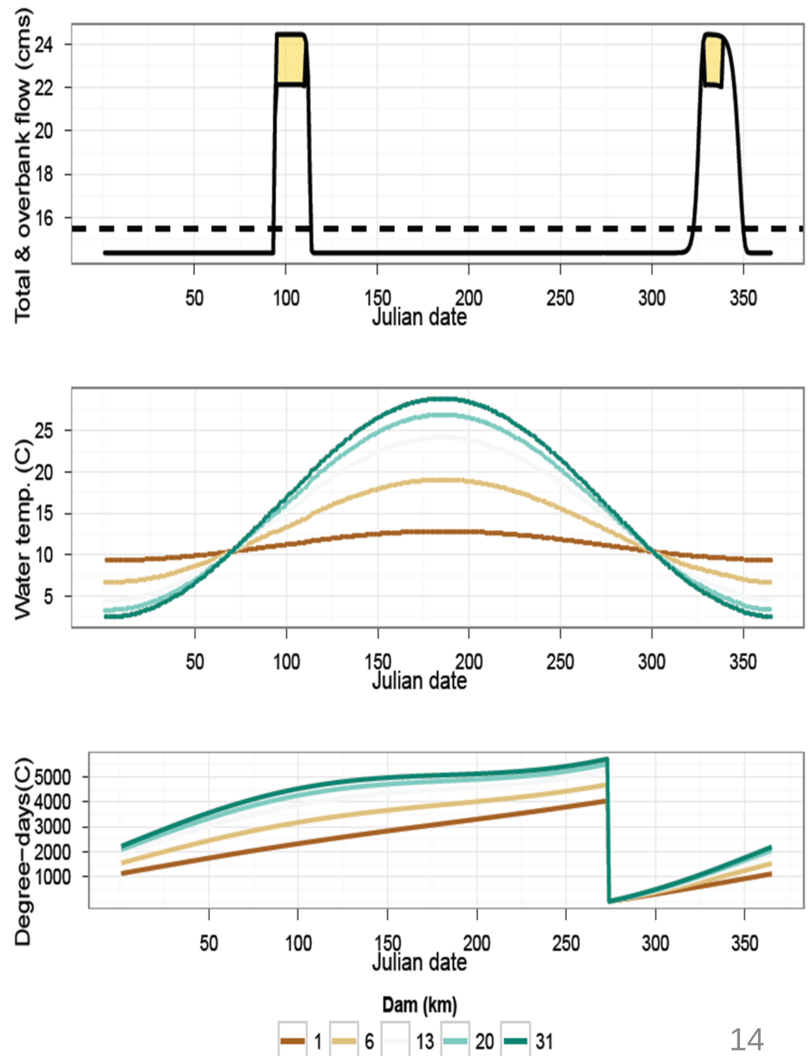
Optimization

- Identified pulse flow parameters that maximized fraction of eggs surviving to become smolt
- Evolutionary algorithm maximized **salmon production per egg**
- Integer problem, 10,000 ‘individuals’ (parameter combinations) per generation.
- Results presented for median total annual flow
- Optimum achieved after 8 generations

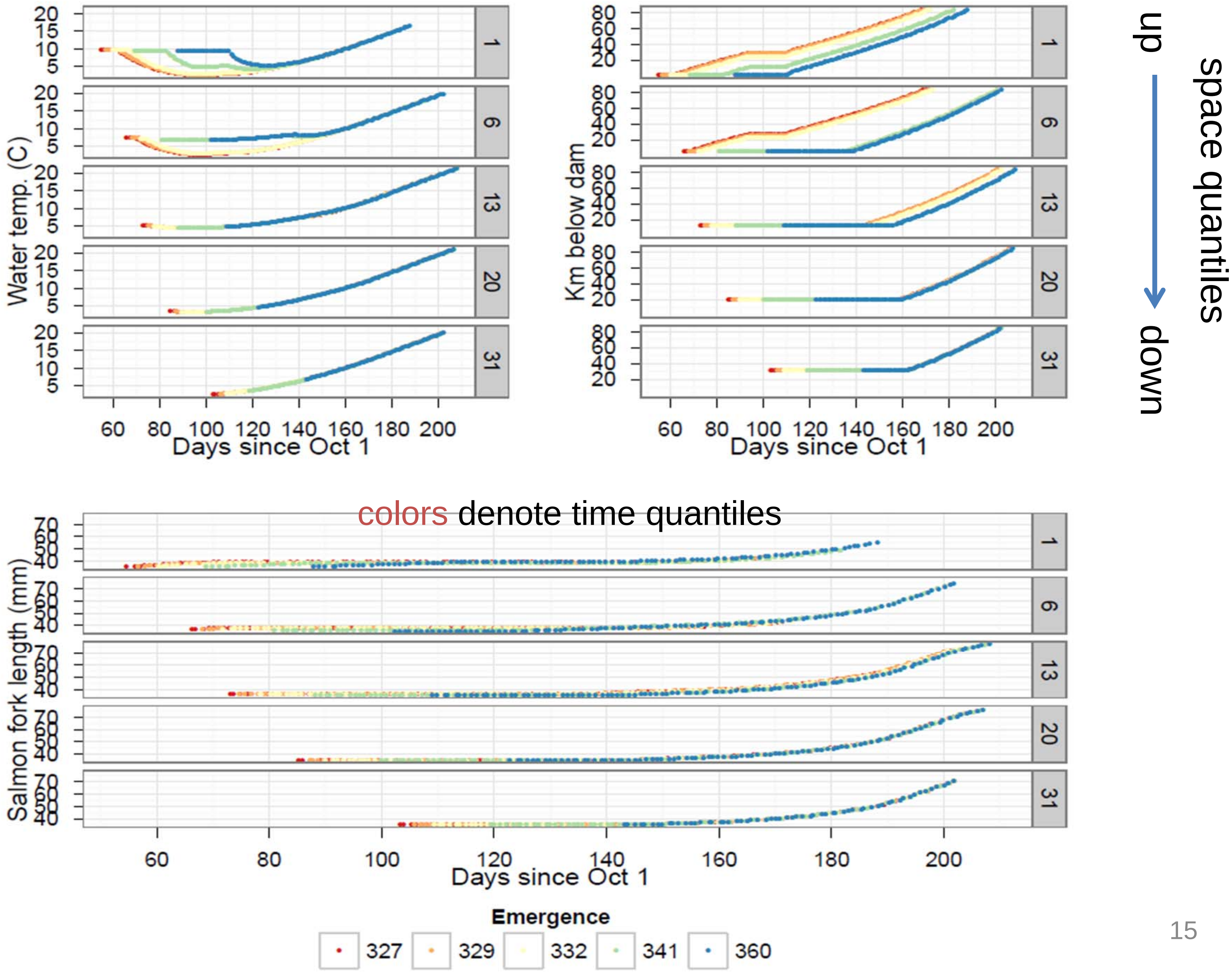
Optimal flow regime

60%ile, 489 $hm^3 y^{-1}$ (avg 15 cms d^{-1})

- Best flow regime ➔ 6.45% survival of eggs
  - fitness=0.0645
  - steepness=15
  - JdayFall = 326
  - JdelFall = 22
  - JdaySpr = 94
  - JdelSpr = 19
- 1.31% produced by corresponding flat flow regime (top, dashed)
- Both optimal pulse flows inundated floodplains (top, gold "fingertips").
- Optimal pulse flows have broad peaks
- Optimal fall pulse later than expected (moderating winter temperatures?)
- Preliminary results for a wetter year show earlier fall pulse.

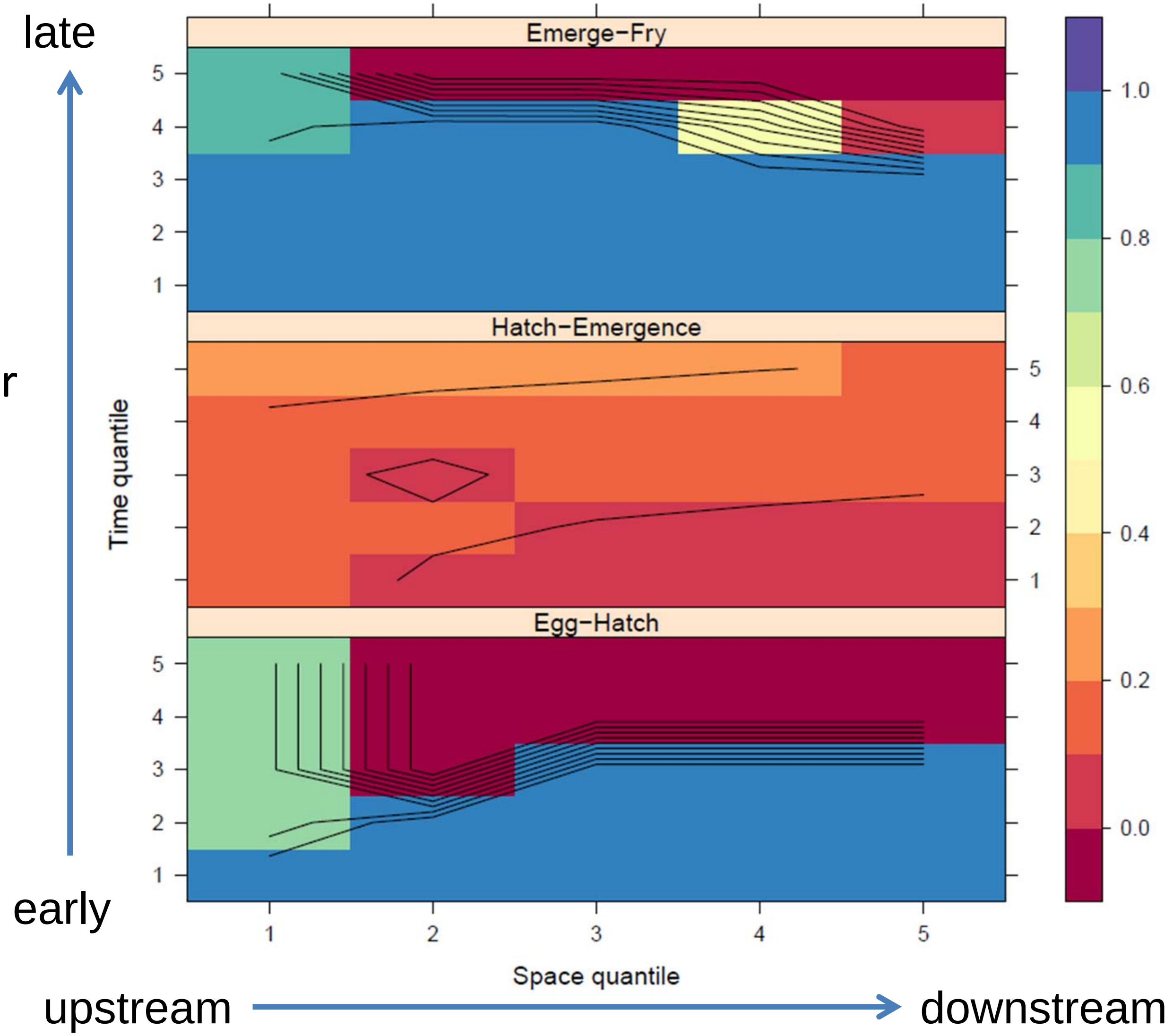


Temperature, location, & size of juvenile quantiles



Patterns in survival by quantile

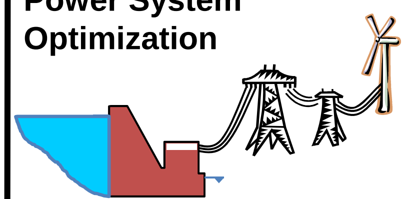
- Early redds had an advantage during two periods.
- For late redds, those closer to the dam fared better than those farther downstream.
- Compared with a flat 15 cms flow regime, alevin survival is notably higher.



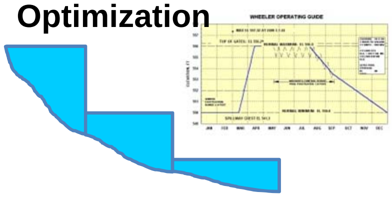
Energy-Water Optimization

OPERATIONS & DISPATCH	PLANNING & FORECASTING	OBJECTIVES & POLICY

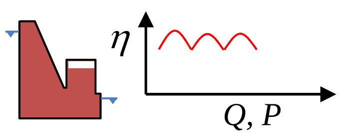
Level 4 — **Power System Optimization**



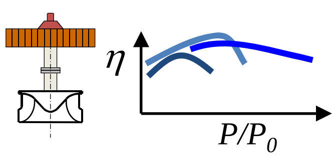
Level 3 — **Reservoir System Optimization**



Level 2 — **Project Optimization**



Level 1 — **Unit Optimization**



Issues and Inputs:
- determination of relative values
- determination of priorities
- operating agency agreements and boundaries
- defining energy and water markets
- defining mitigation markets
- data (meteorologic, hydrologic, plant and machine condition, power system status)

Optimization Features:
- scalar or vector objective function
- real-time, short-term, long-term
- future values of water and energy
- deterministic or stochastic
- implementation of objectives and constraints
- historical or synthetic time series input
- solution algorithm (LP, GP, DP)
- optimization software (e.g. RiverWare, Vista, CHEOPS)

Supporting Models:
- ecologic
- meteorologic
- hydrologic
- hydraulic & hydrodynamic
- power system
- economic

Supporting Technology
- advanced hydroturbine designs (aerating and fish-friendly)
- advanced flow measurement systems

Energy Supply Objectives

Annual Energy Production
Peak Energy Output
Annual Revenue
System Stability
Shaping and Firming
O&M Cost Control

Ecological Objectives

Sustainability
Fish Passage, Entrainment
Populations
Habitat Protection
Water Quality
Minimum Flows

Water Supply Objectives

Thermoelectric Cooling Water
Municipal Water Supply
Industrial Water Supply
Agricultural Water Supply

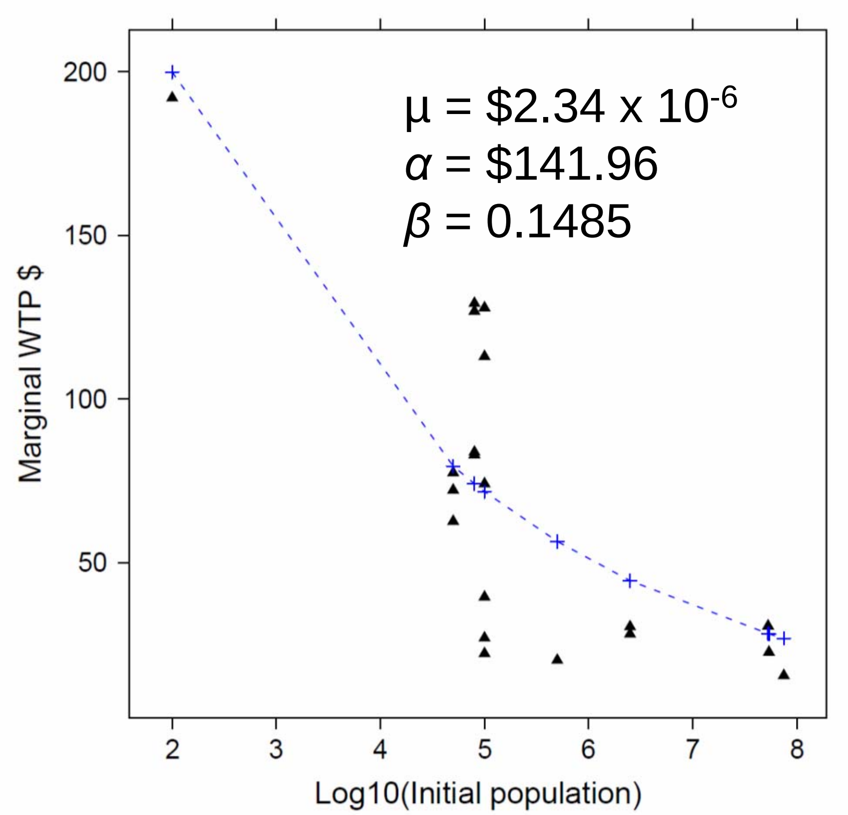
Non-Power Objectives

Flood Control
Navigation
Recreation

How to compare benefits of flow to salmon and energy?

- Ecological valuation has been used to assign value to fish populations.
- Meta-analysis of contingent valuation studies of salmon
- Coauthors: Rebecca Efroymson, ‘Debo Oladosu
- Data provided by J. Loomis

Value of salmon highest when rare



Valuation model

$$MV(x) = H'(x) + P'(x)$$

$$H'(x) = \begin{cases} 0, & x \le x^* \\ \mu, & x > x^* \end{cases}$$

$$P'(x) = \alpha e^{-\beta x}$$

MV = Marginal value (1,000 fish)
H = Marginal use value (harvest)
P = Non-use value (preservation)
*x** = Estimated threshold population size below which harvest value is zero

The Frontier

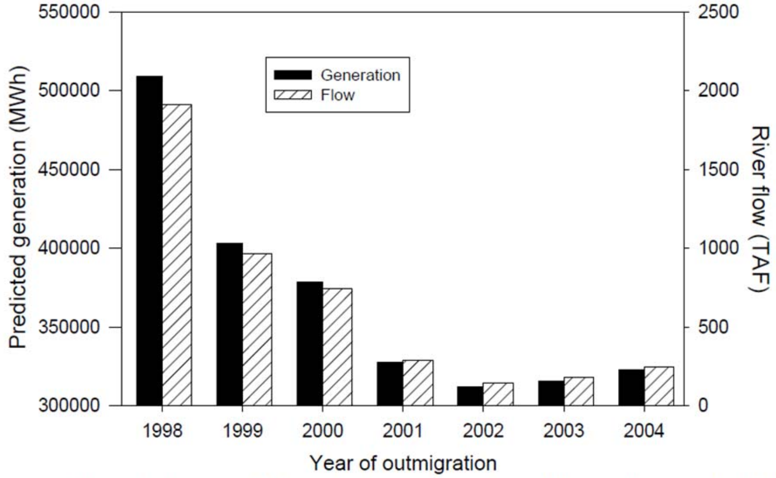
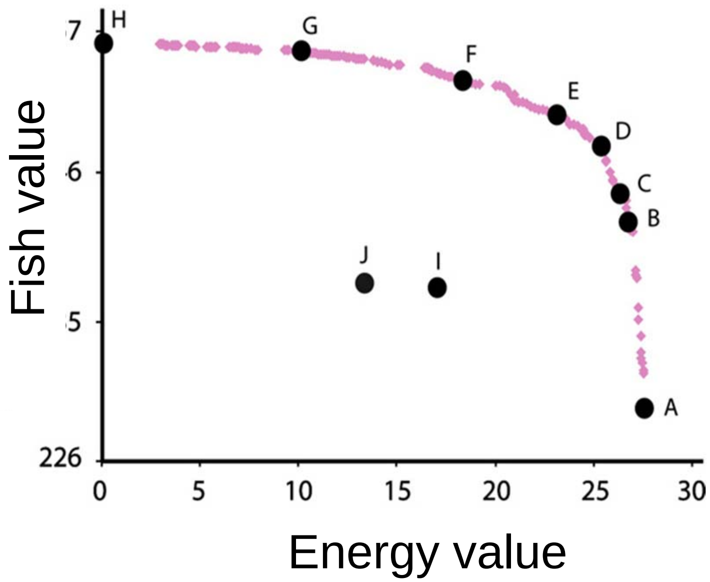


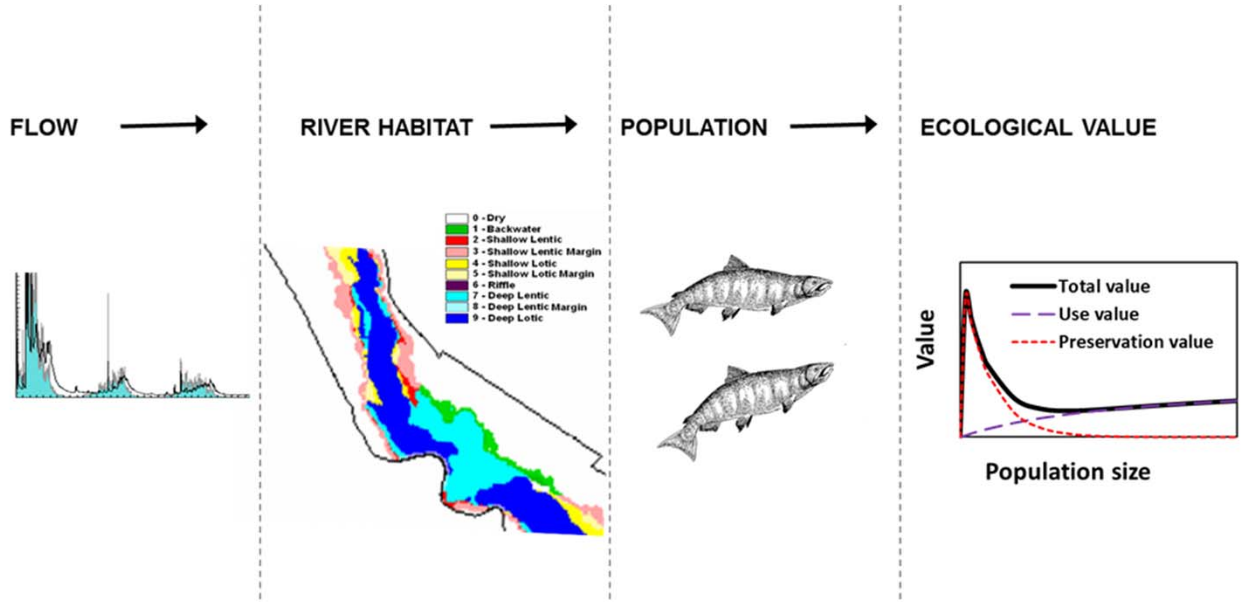
Figure 8. Relationship between ORCM-simulated generation and cumulative river flow over the 330 days simulated by the ORCM model in each year. Source: Jager and Sale (2006)



Modified from Polasky et al. 2008

- Benefits of flow for salmon & hydropower are broadly aligned
- Differences in the value of flows at different times may produce trade-offs

Summary



- New tool for assessing seasonal flow benefits to salmon
- Designed to incorporate known benefits of overbank flows
- Indirect vs. direct pathways linking flow and salmon
- Can be used to evaluate habitat-for-flow substitution options
- Regulate flows for both ecological & energy objectives

Acknowledgements

- Funding: US Department of Energy's (DOE) Energy Efficiency & Renewable Energy Office, Wind and Water Power Technologies Program
- Brennan Smith, ORNL program manager
- Mark Bevelhimer, ORNL, environmental task leader
- DOE lab collaborators: John Hayse & Sam Saha (ANL), Ken Ham (PNNL)
- Tuolumne experts, Dean Marston, Tim Heyne, Carl Mesick (Cal. Dept. Fish & Game)