The use of bioenergetics modeling to predict effects of climate change on individual fish, fish populations and fish communities

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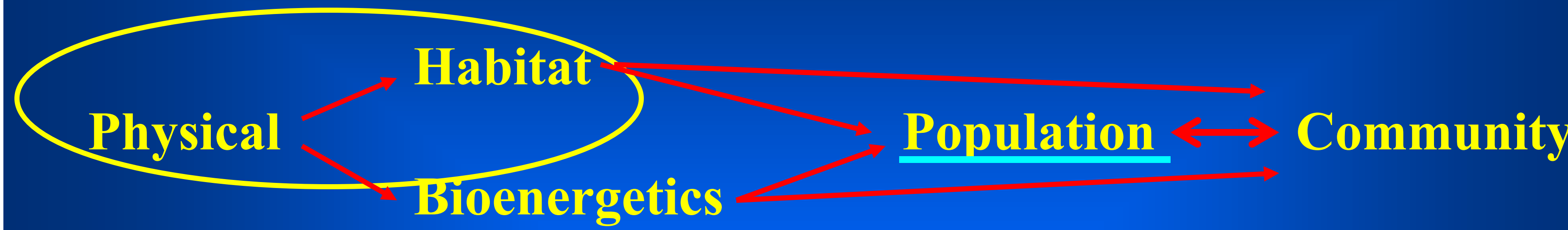
USGS, WFRC, Columbia River Research Laboratory
Cook, Washington

Linking models to predict effects -- Yakima River Basin



Mark Mastin & Frank Voss (WaWSC) - Physical models

Chris Lynch, (BOR-Yakima) - Water management (RiverWare)

Jim Hatten & Tom Batt – Habitat criteria, GIS, DSS

Matt Mesa & Jill Hardiman – Bioenergetics

Pat Connolly – Fish pop analyses, Cohort survival

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Development & Application of a Decision Support System for Water Management Investigations in the Upper Yakima River (DSS)

Bovee[1], Waddle[1], Talbert[1], Hatten[2] & Batt[2]

USGS Open-File Report

http://pubs.er.usgs.gov/usgspubs/ofr/ofr20081251

[1] Fort Collins Science Center; [2] Columbia River Research Lab

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Yakima River DSS

Physical models:

1) River2D
2) SNTEMP (max daily temp)
3) Sediment transport models
4) RiverWare (BOR)

Habitat model (Delphi-type—expert opinion)

species- & life stage-specific:

1) Redd scour
2) Habitat time series – suitable area x life stage
3) Max. temperature
4) Fish passage - flow

Climate change scenarios & biological endpoints

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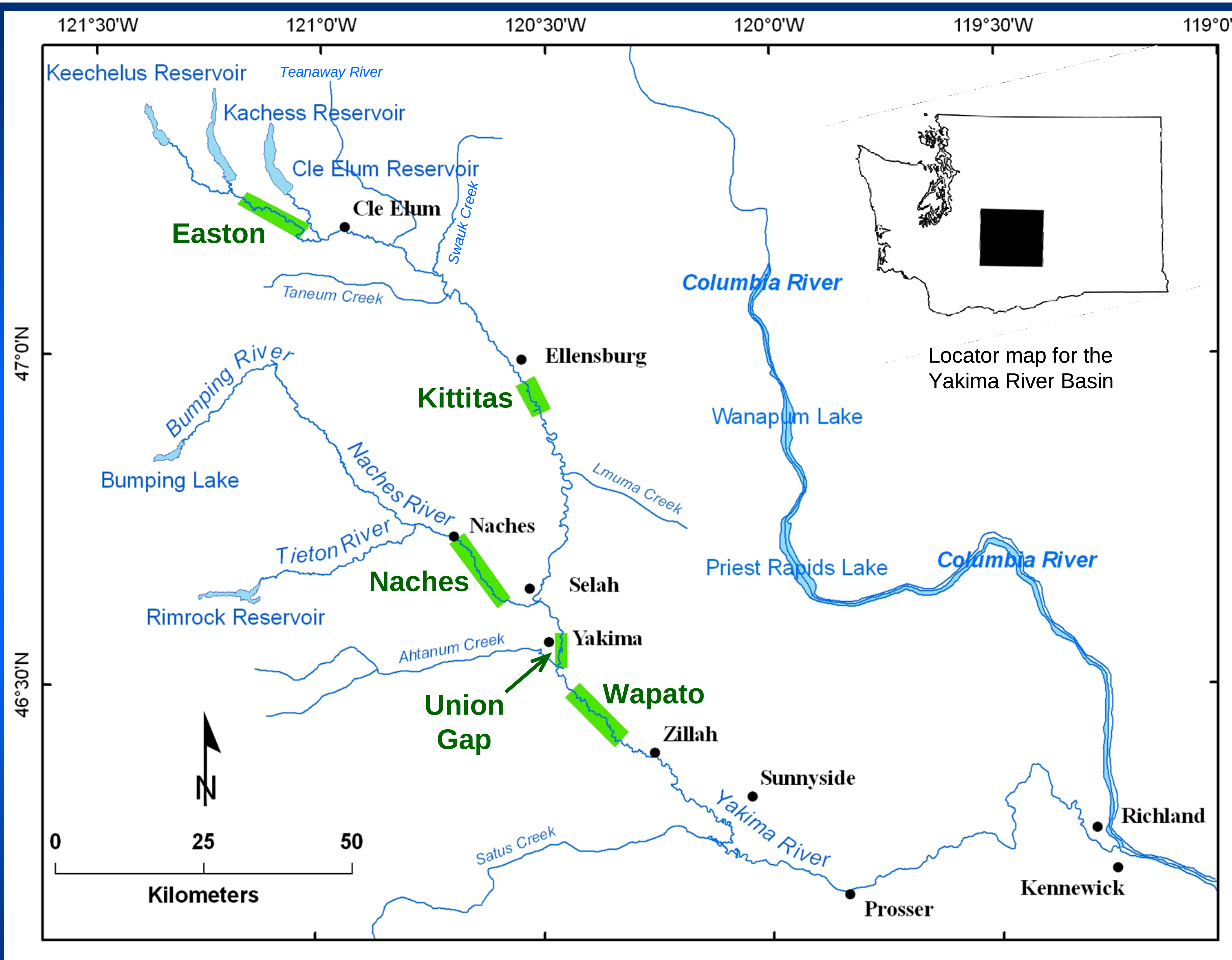
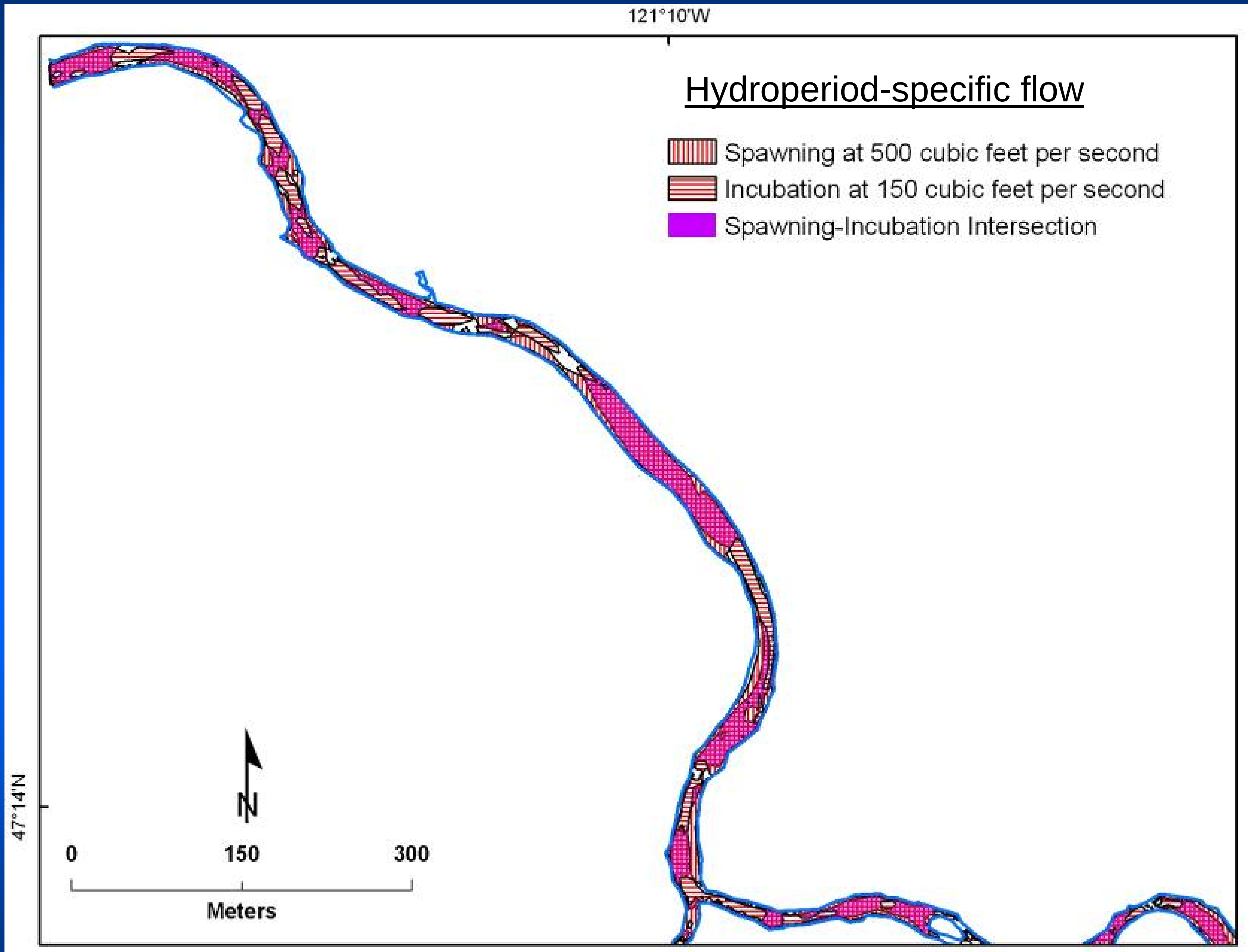

121°30'W
121°0'W
120°30'W
120°0'W
119°30'W
119°0'W
47°0'N
46°30'N
Keechelus Reservoir
Teanaway River
Kachess Reservoir
Cle Elum Reservoir
Cle Elum
Swauk Creek
Easton
Taneum Creek
Columbia River
Ellensburg
Locator map for the
Yakima River Basin
Bumping River
Kittitas
Wanapum Lake
Bumping Lake
Naches River
Lmuma Creek
Naches
Tieton River
Priest Rapids Lake
Columbia River
Naches
Selah
Rimrock Reservoir
Ahtanum Creek
Yakima
Union
Gap
Wapato
Zillah
N
Sunnyside
Yakima River
Richland
0
25
50
Kilometers
Satus Creek
Kennewick
Prosser

> 6,000 mi^2



121°10'W
Hydroperiod-specific flow
Spawning at 500 cubic feet per second
Incubation at 150 cubic feet per second
Spawning-Incubation Intersection
N
47°14'N
0
150
300
Meters

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NEW Yakima River Models (DSS)

1. Existing DSS - add climate change scenarios
   1981-2005, 2020-2029, 2040-2049
   Mastin, MC. 2008. http://pubs.er.usgs.gov/usgspubs/sir/sir20085124

2. Existing Bioenergetics model parameters to determine effects of temp & flow on fish

3. BioE & Physical outputs to derive Population effects (using cohort survival model)

4. BioE & Pop model outputs to predict species interactions (i.e., fish community effects)

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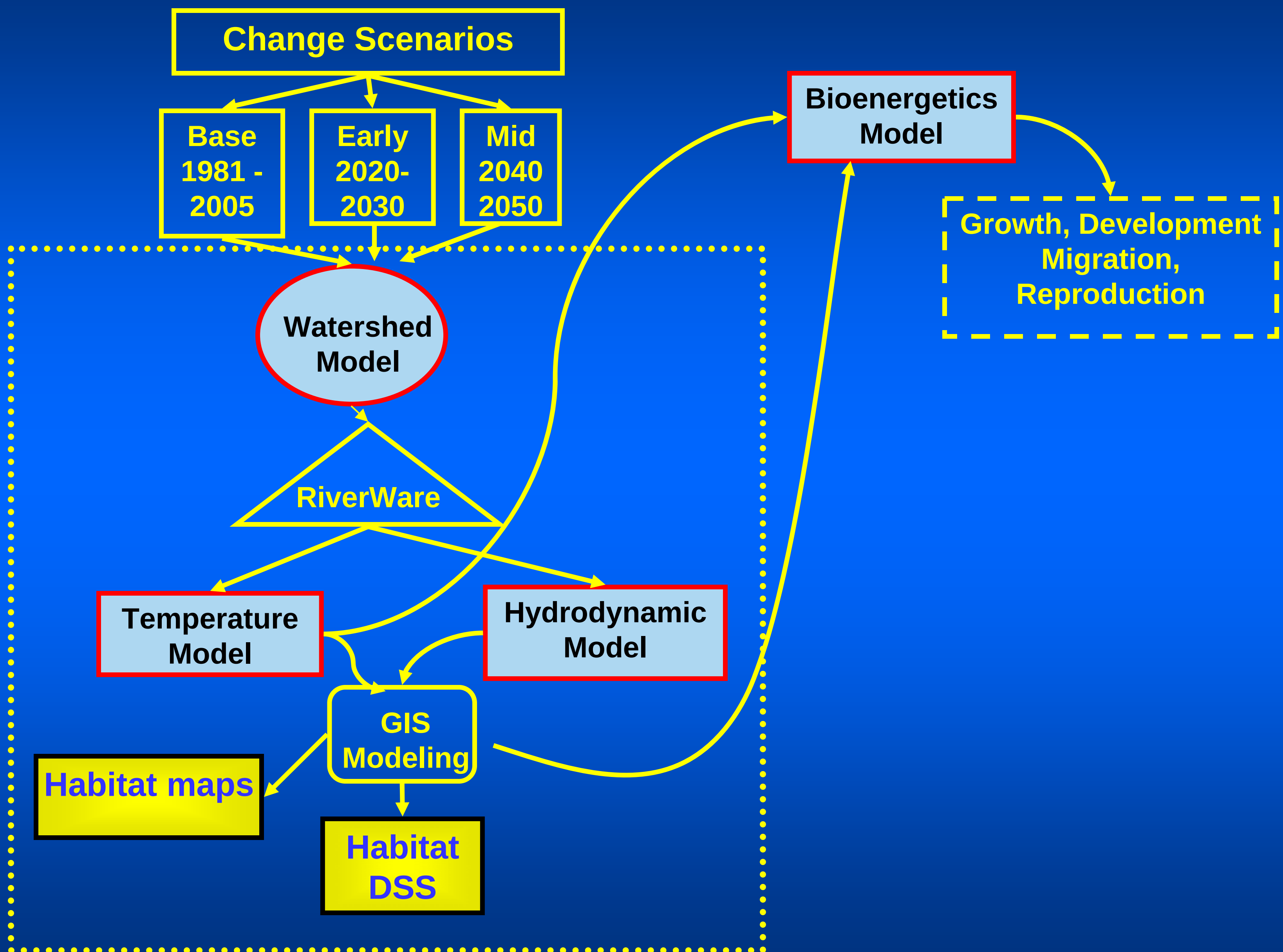

Change Scenarios
Base 1981 - 2005
Early 2020-2030
Mid 2040 2050
Watershed Model
RiverWare
Temperature Model
Hydrodynamic Model
GIS Modeling
Habitat maps
Habitat DSS
Bioenergetics Model
Growth, Development Migration, Reproduction

USGS

Bioenergetics models

- Conservation of energy
- Balanced equation:
- Growth = Consumption – Respiration – Egestion – Excretion
- $G = C - R - Eg - Ex$
- Temp, activity, diet & fish size (life stage) dependent
- Model parameters developed for ~48 species

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Bioenergetics Models

Input data	Input parameters
Growth increment	*Cmax*
Period of growth	Respiration
Diet composition	Activity
Energy density	SDA (std. dyn. action)
Temperature	Excretion
Activity (flow)	Egestion
	Growth
	Reproductive loss

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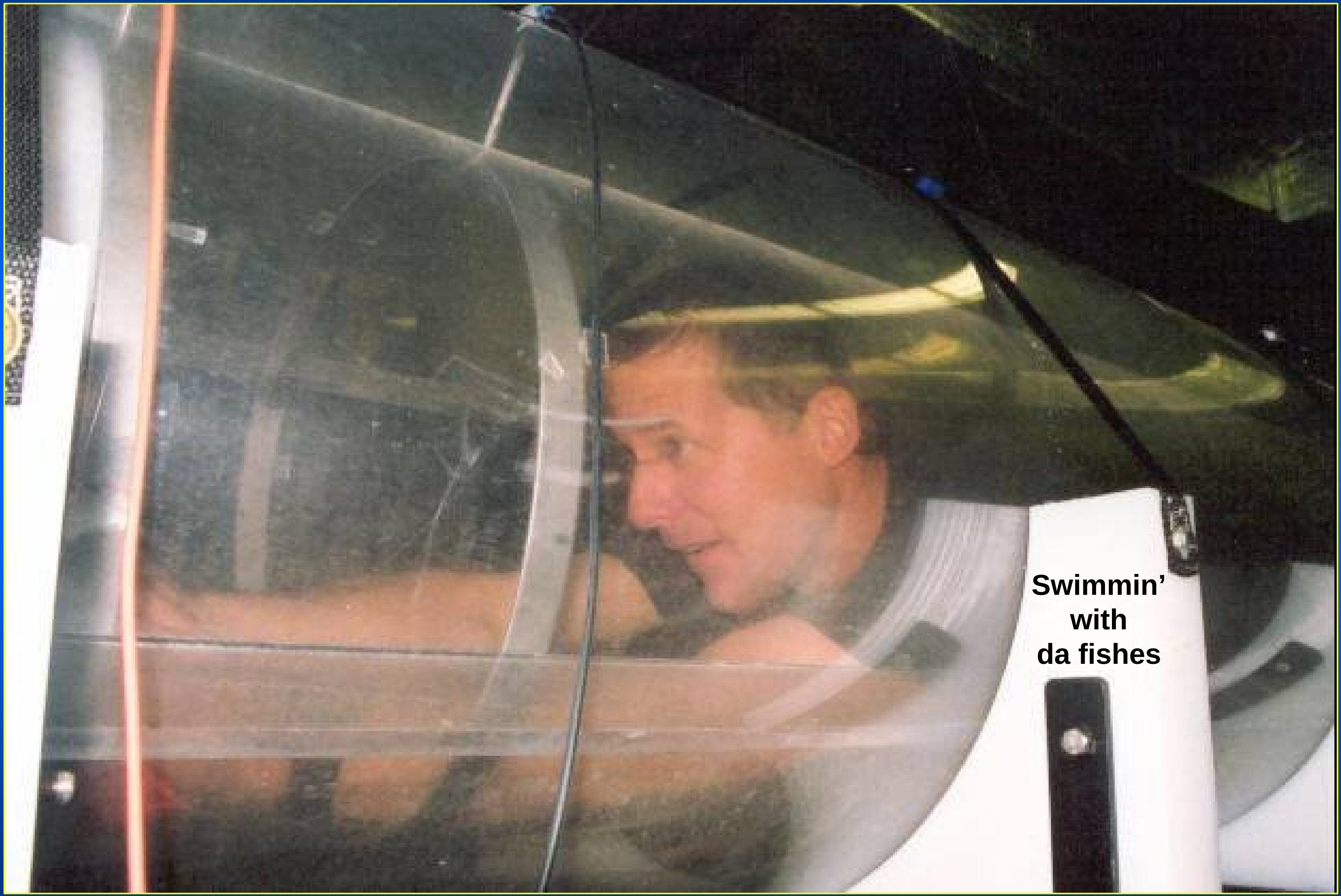
Blazka-type Respirometer

Bioenergetics – Adult Chinook



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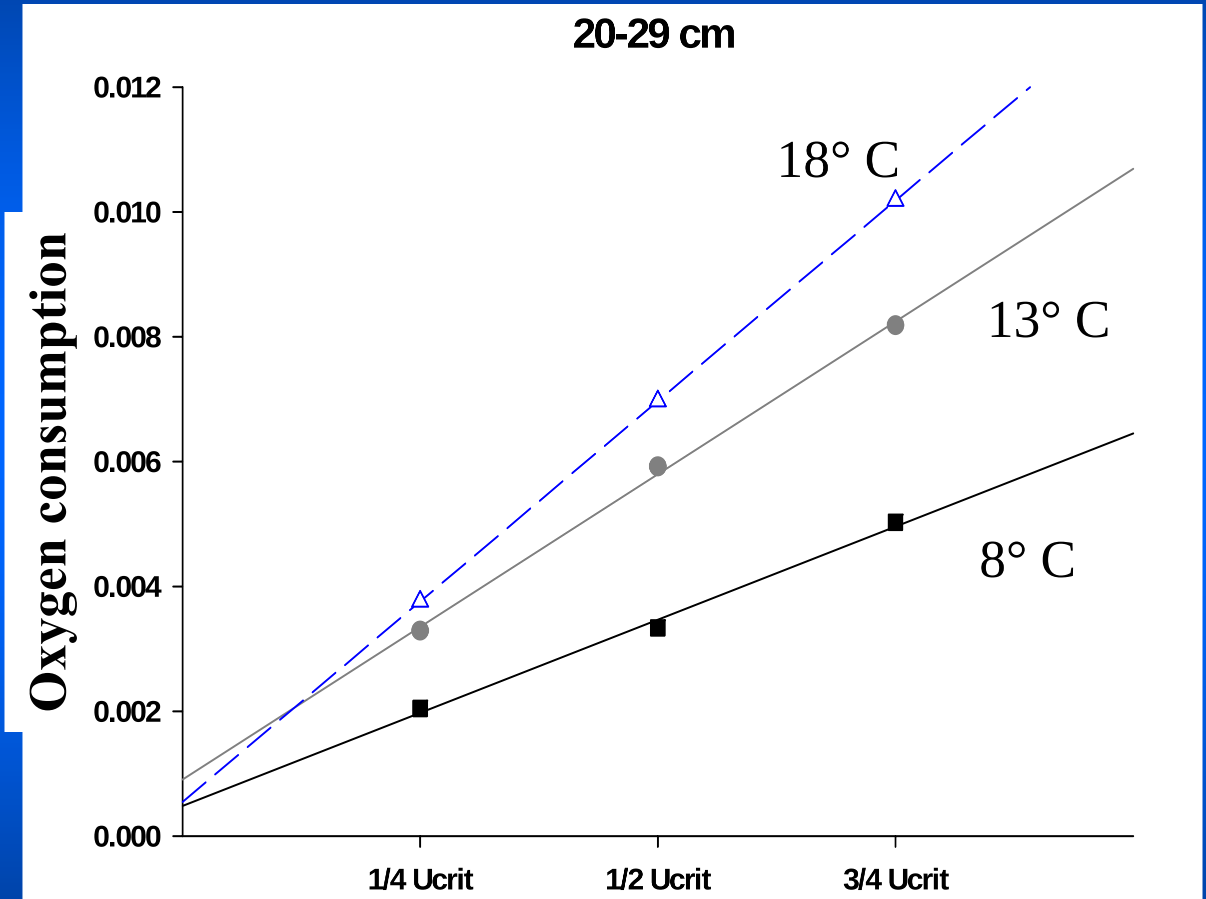
Oxygen consumption ↑ w/ swim speed & temp

$$G = C - \underline{R} - Ex - Eg$$



Ucrit = Critical swim speed = max sustainable

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Bioenergetics models can:

- Predict food (i.e., prey) needed to grow a given amount
- Predict growth given food & temperature
- Hindcast or forecast growth w/ time series
- Provide "bounds" to answers
  - (e.g., min – max growth for temp scenario)
- Project from individuals to populations

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Seasonal changes in water temp & non-native prey increase predator impacts on Columbia River salmonids

Sauter, Petersen & Maule. in review

Has variation in water temp & non-native prey fish (American shad) influenced predation on juvenile salmon?

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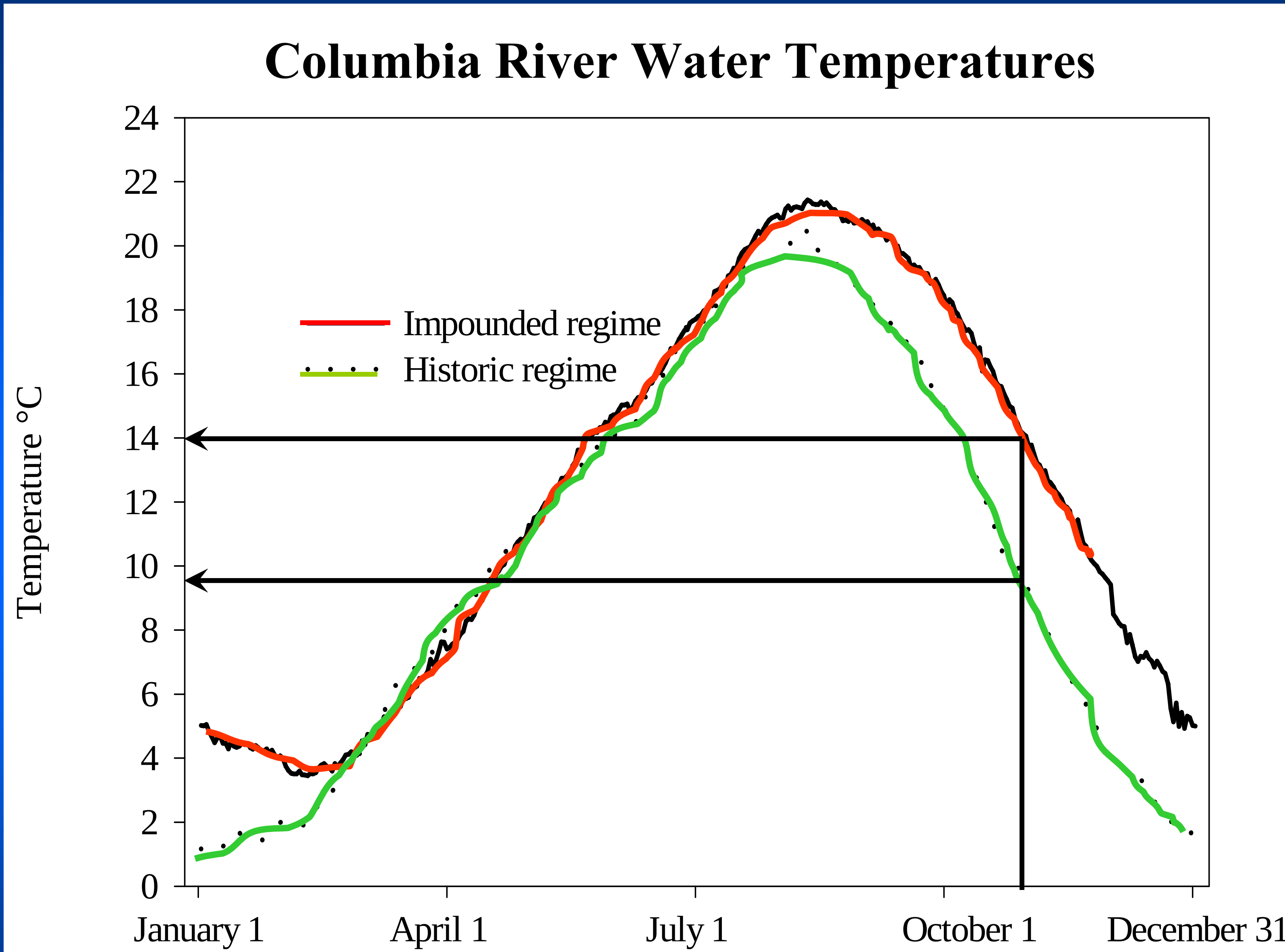

Columbia River Water Temperatures
Temperature °C
24
22
20
18
16
14
12
10
8
6
4
2
0
Impounded regime
Historic regime
January 1
April 1
July 1
October 1
December 31

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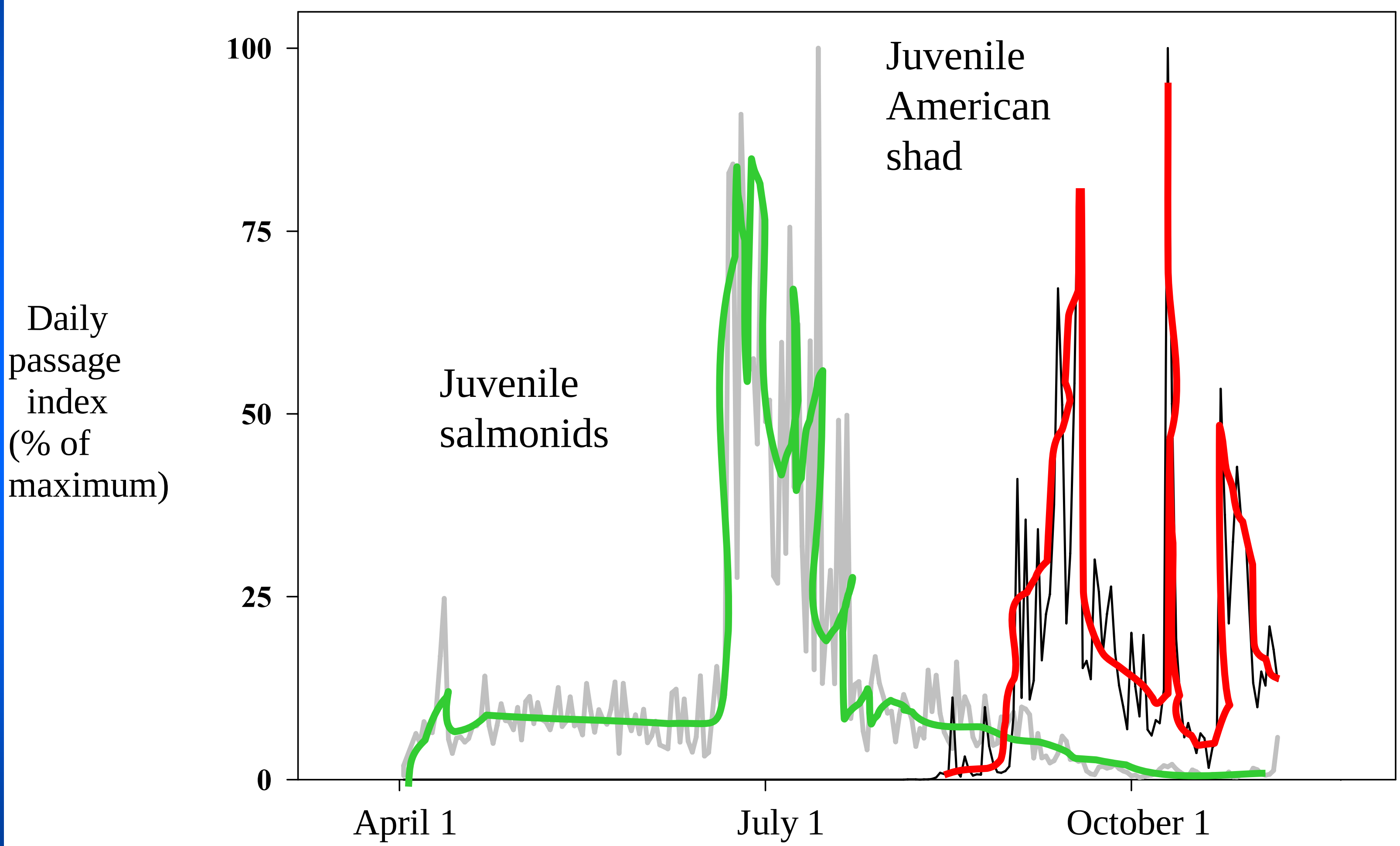
Seasonal passage of juvenile anadromous fishes
John Day Dam, 2000



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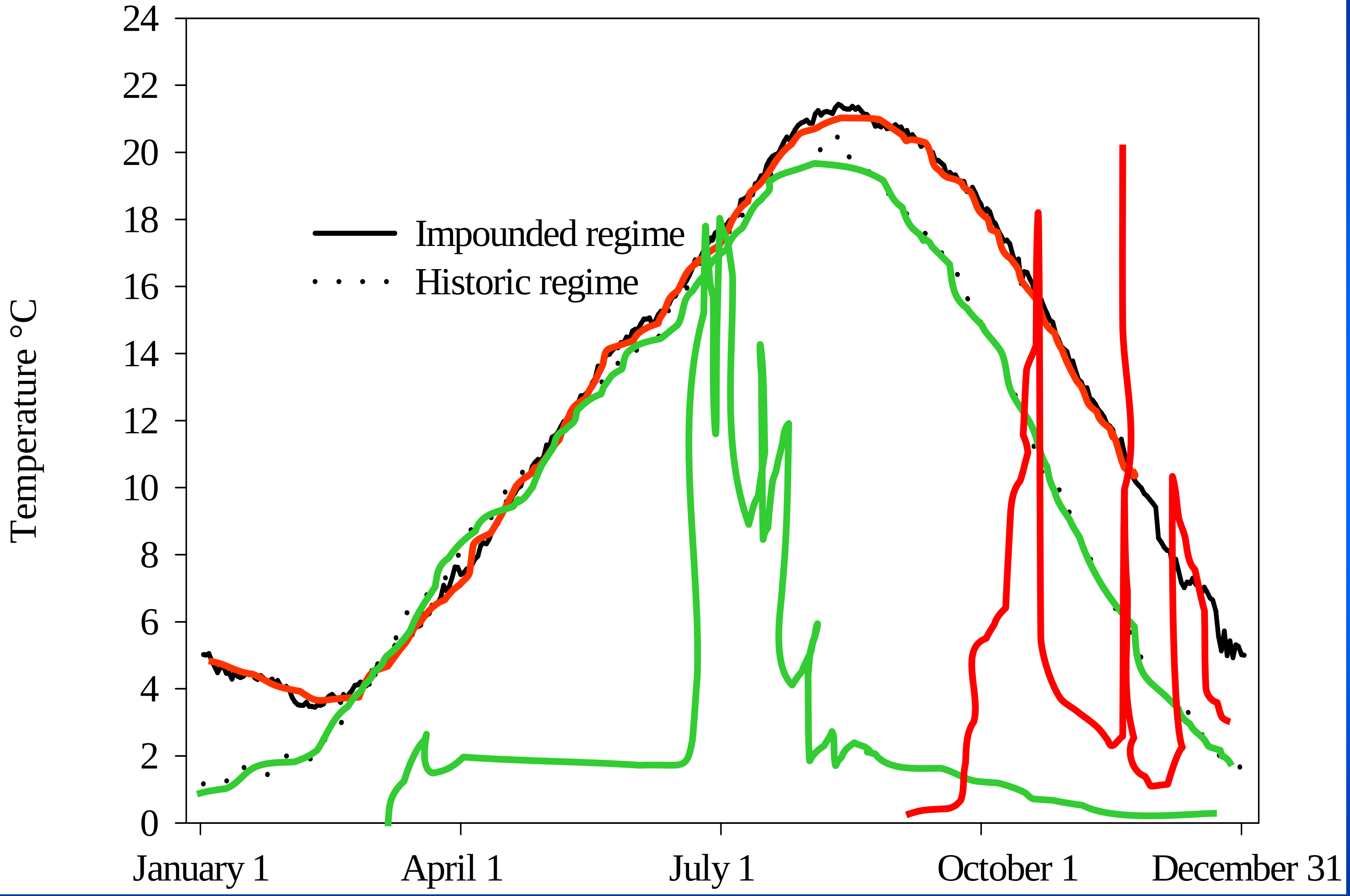

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Impounded regime
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Do these higher temperatures & the presence of juvenile Am. shad give native & non-native predators an extended growing season?

Significance: bigger predators eat more & are more fecund

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Did these changes alter predator consumption?

Bioenergetics modeling compared scenarios:

1. Current conditions –
   current temps with American shad
2. Current temps without shad
3. Historic temps with shad
4. Historic temps without shad

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Models predicted increased growth & predation

Increased salmonid predation

PREDATOR	TEMP	TEMP & SHAD
Northern pikeminnow	7.0%	10.8%
Smallmouth bass	16.1%	43.4%
Walleye	4.4%	21.4%

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Models predicted increased growth & predation

PREDATOR	TEMP	TEMP & SHAD	Opt. Temp. Growth
Northern pikeminnow	7.0%	10.8%	20 - 23° C
Smallmouth bass	16.1%	43.4%	26 - 29° C
Walleye	4.4%	21.4%	20 - 28° C

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Overall: 27.5 % salmonids consumed were result of increased growth of predators

NOAA-Fisheries (2000) - 10% reduction in 1st yr mortality = 41.5% increase in population growth rate (λ)

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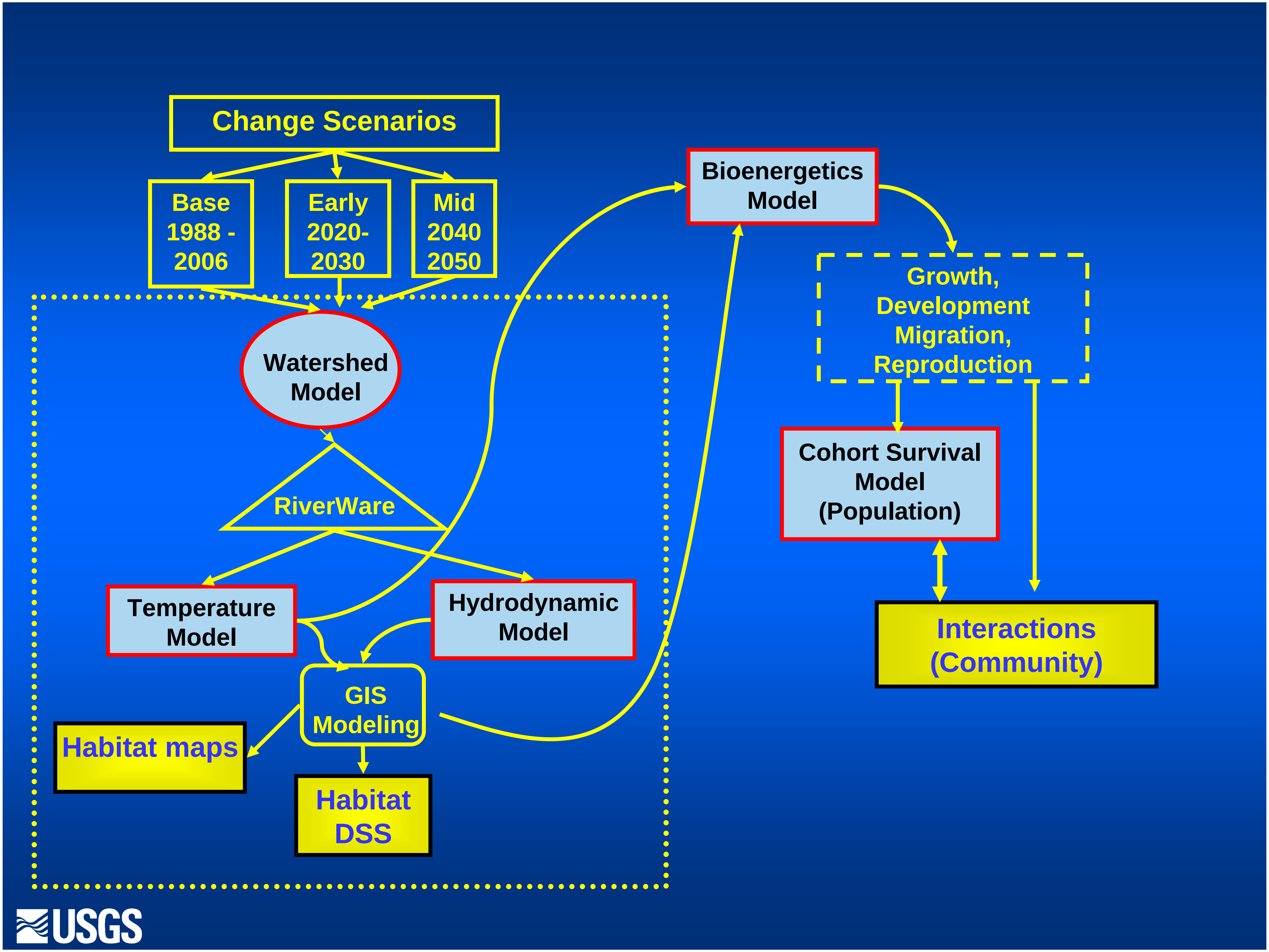

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Habitat maps
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Bioenergetics Model
Growth, Development Migration, Reproduction
Cohort Survival Model (Population)
Interactions (Community)
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PCON Salmonid Life History / Cohort Model

Pat Connolly
USGS, Columbia River Research Laboratory

pconnolly@usgs.gov

- Adults
  - Initial escapement
    - Spawners
  - Years in ocean
    - 1 to 4
  - Fecundity
    - Egg — age relation
    - Egg — length relation

- Survival
  - Egg-to-Fry
  - Fry-to-Parr
    - Downstream migration (STHD)
  - Parr-to-Smolt
  - Smolt-to-Adult
  - Adult-to-Spawner
    - Escapement

Population Trend (+/-)

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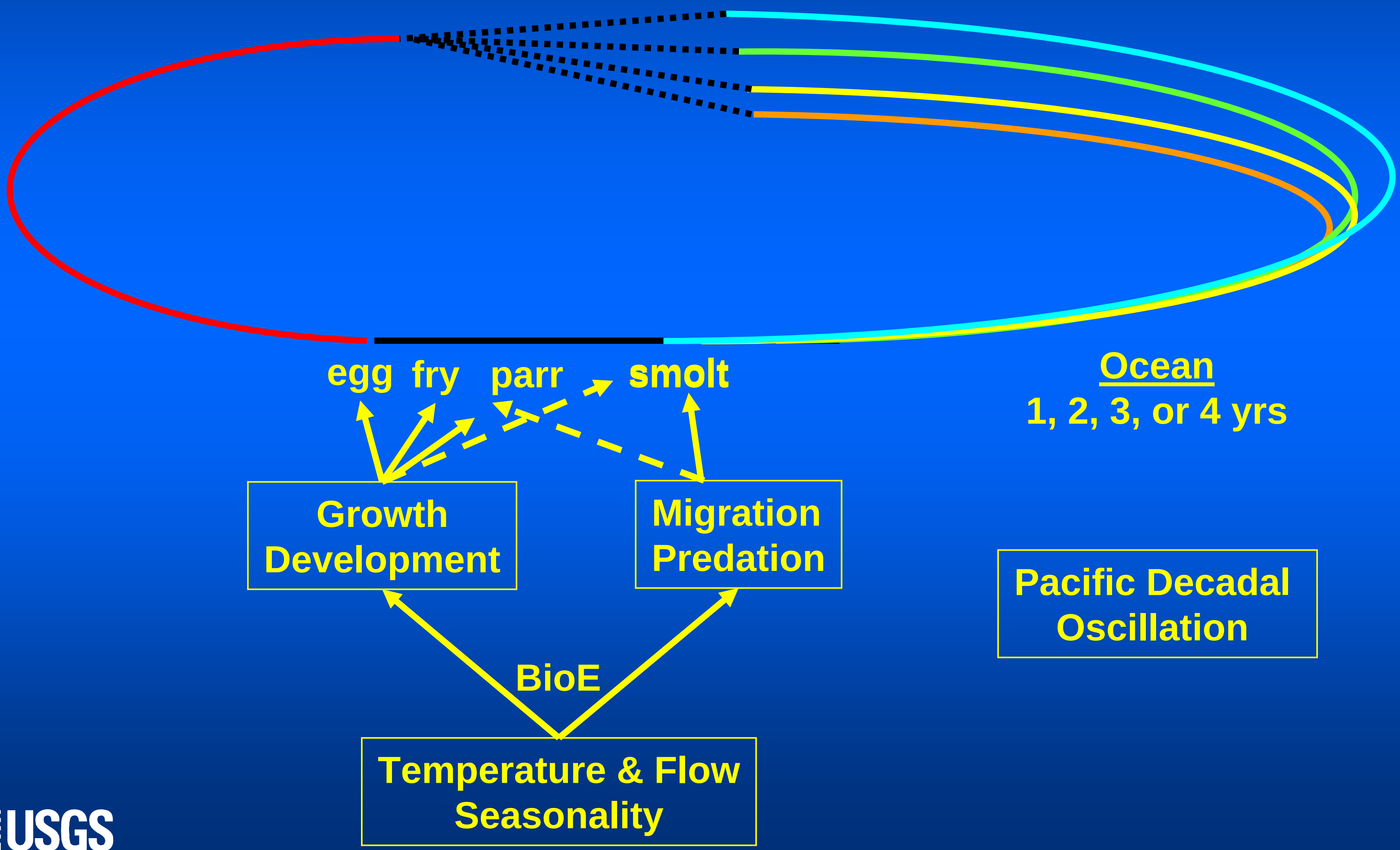
Published Population-level Models

- Crozier, LG et al. 2008. Global Change Biology 14: 236-249.

- Spromberg, JA & JP Meador. 2006. Ecological Modeling 199: 240-252

Chinook cohort analysis

Reproduction: migration, fecundity, gamete quality



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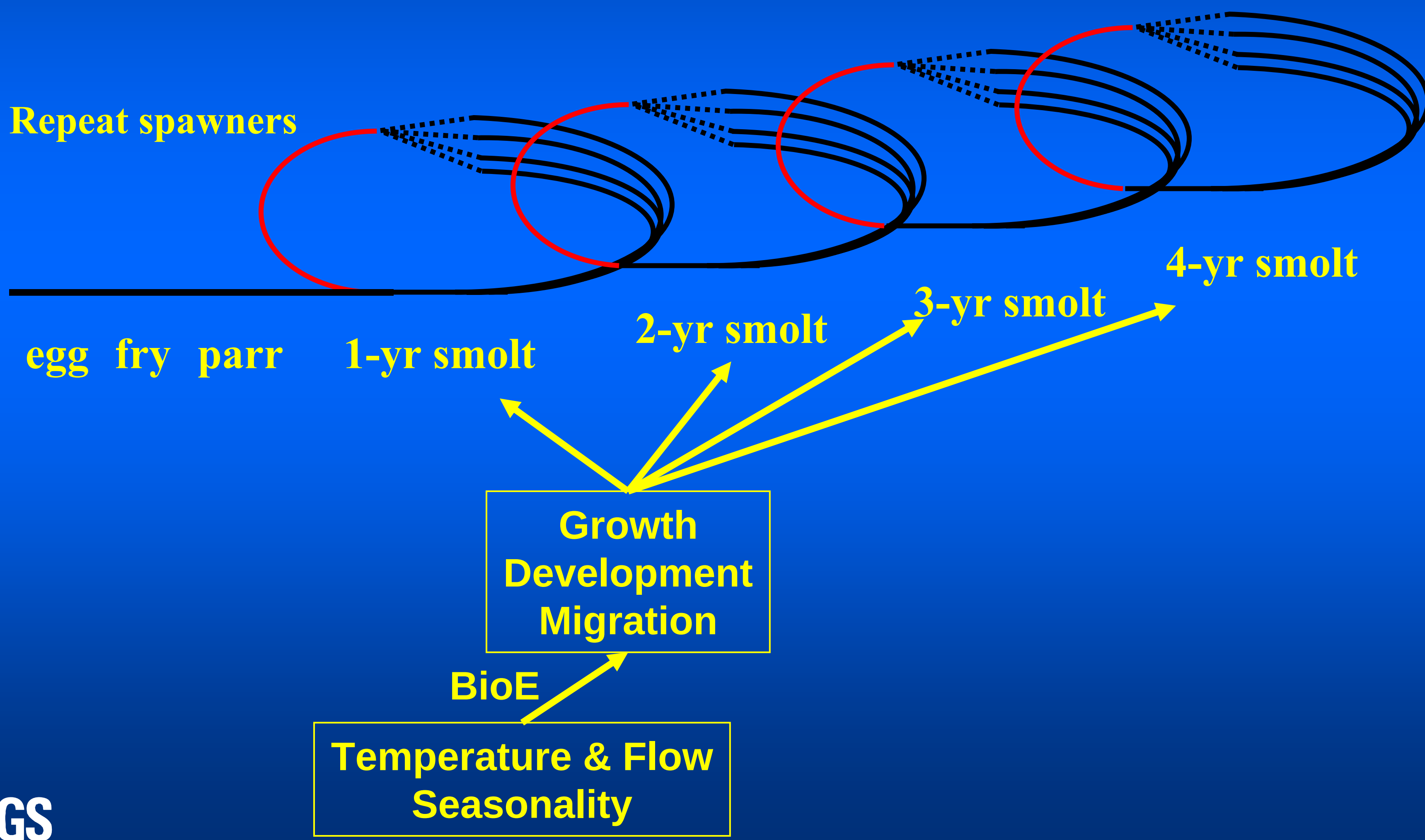
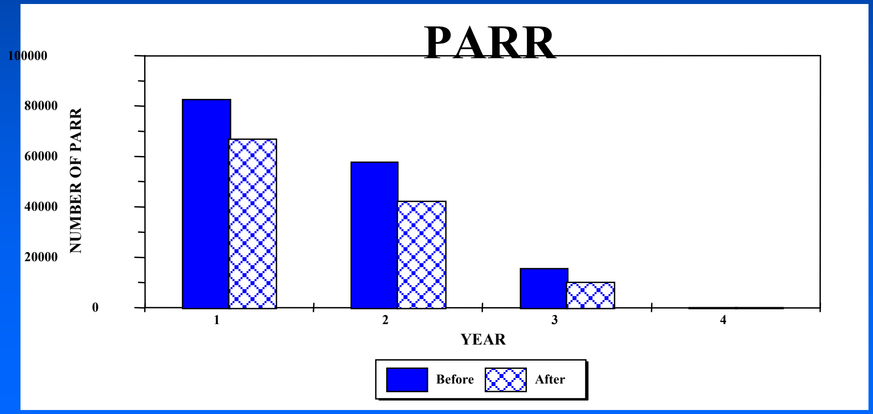
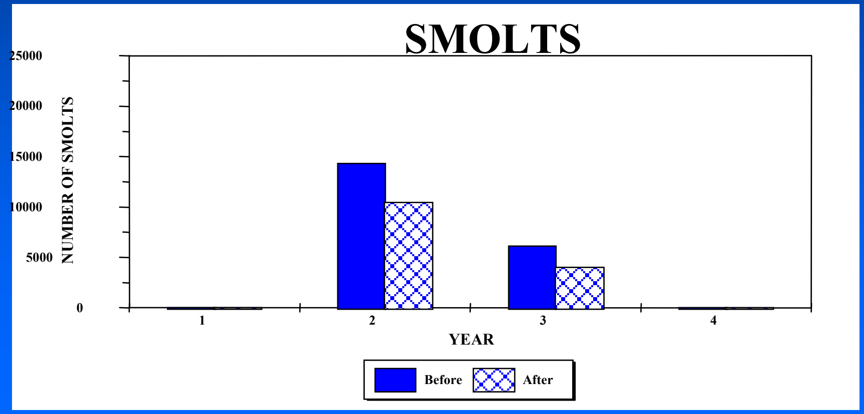
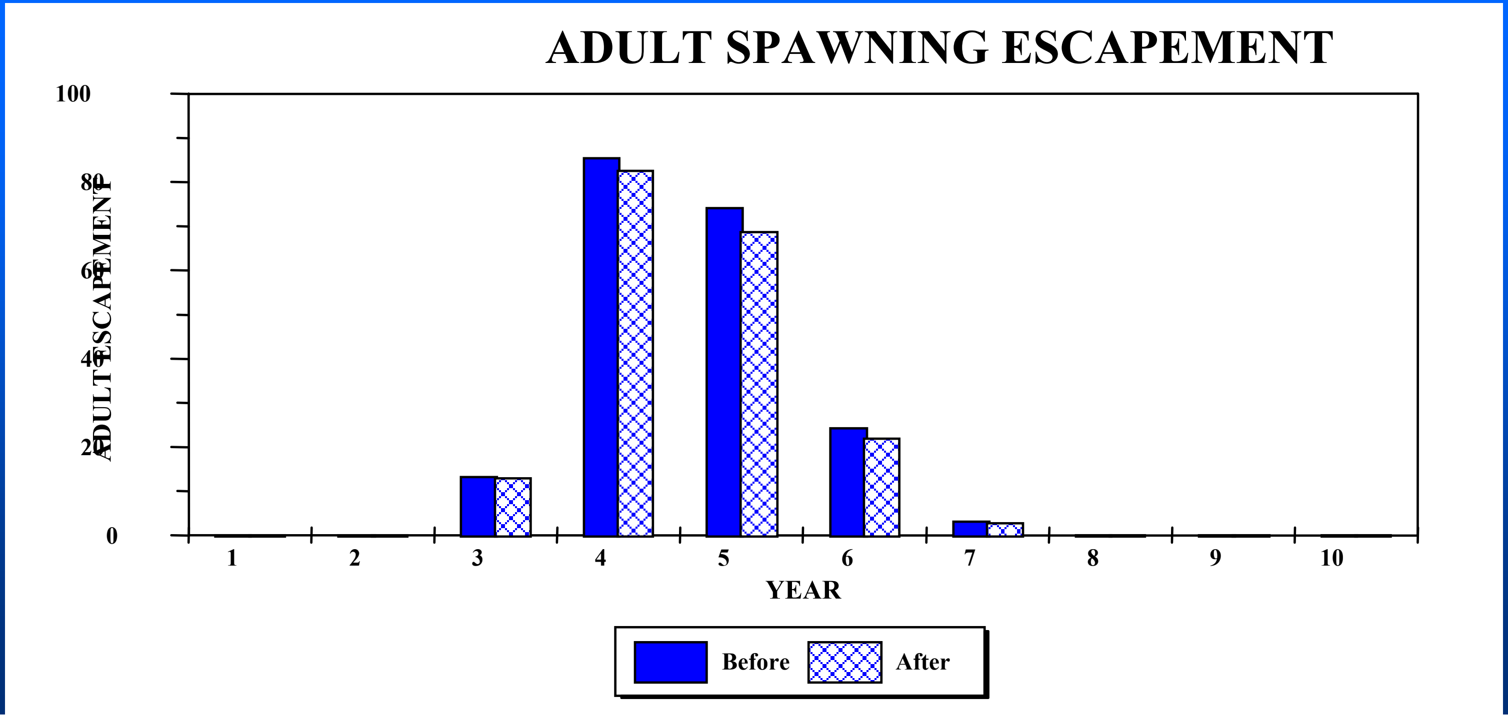
Steelhead cohorts



Temperature increase:
10% reduced instream survival (STHD)







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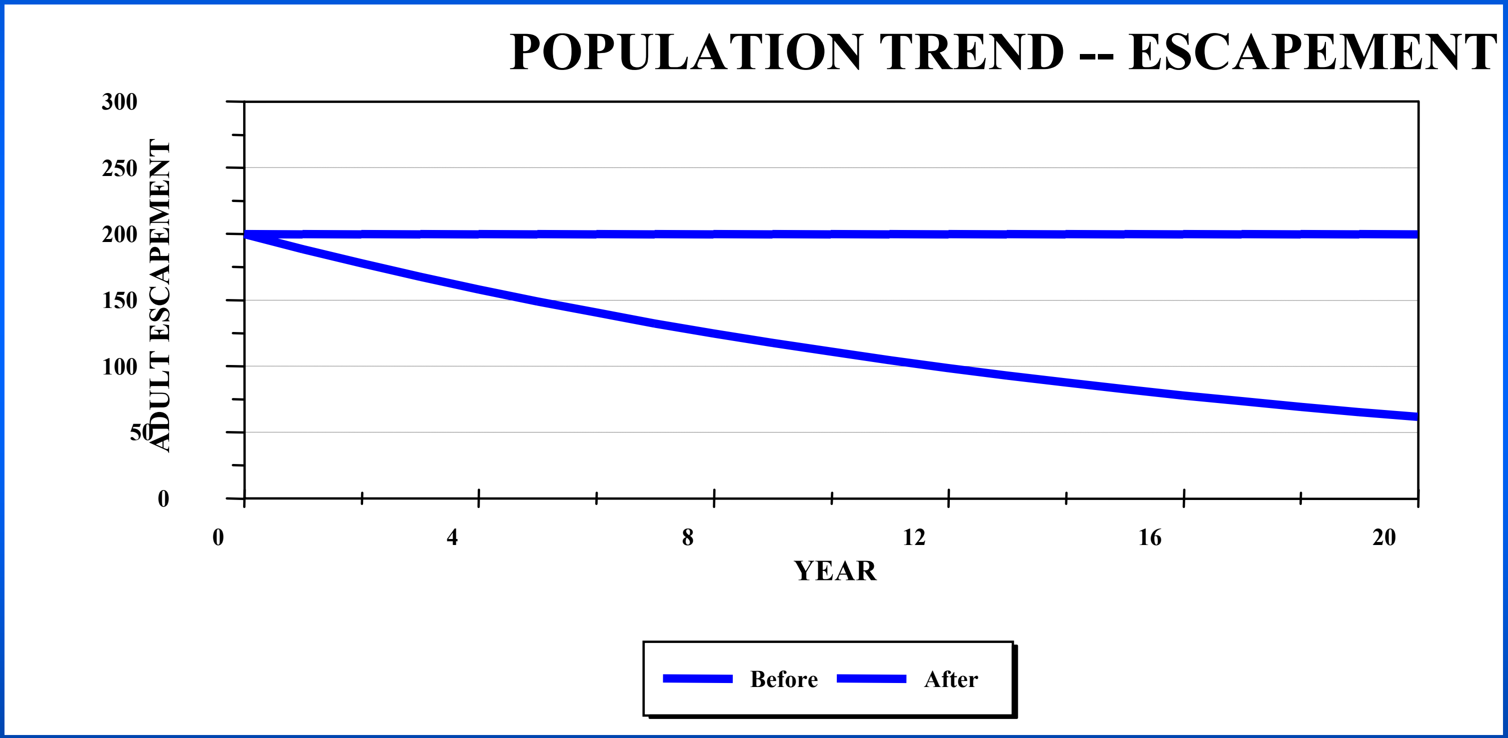
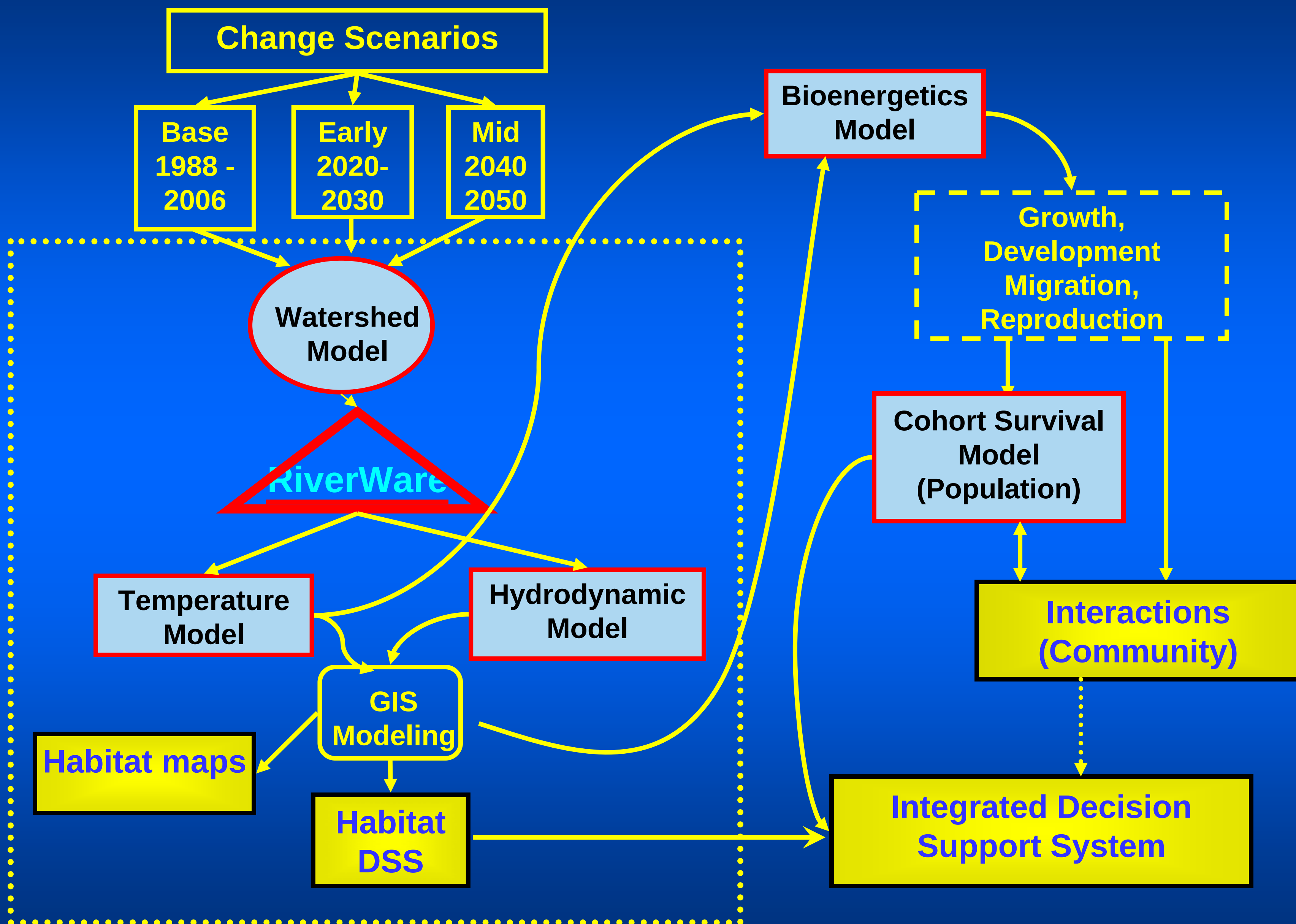
10% Reduced Instream Survival



Decision Support System



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