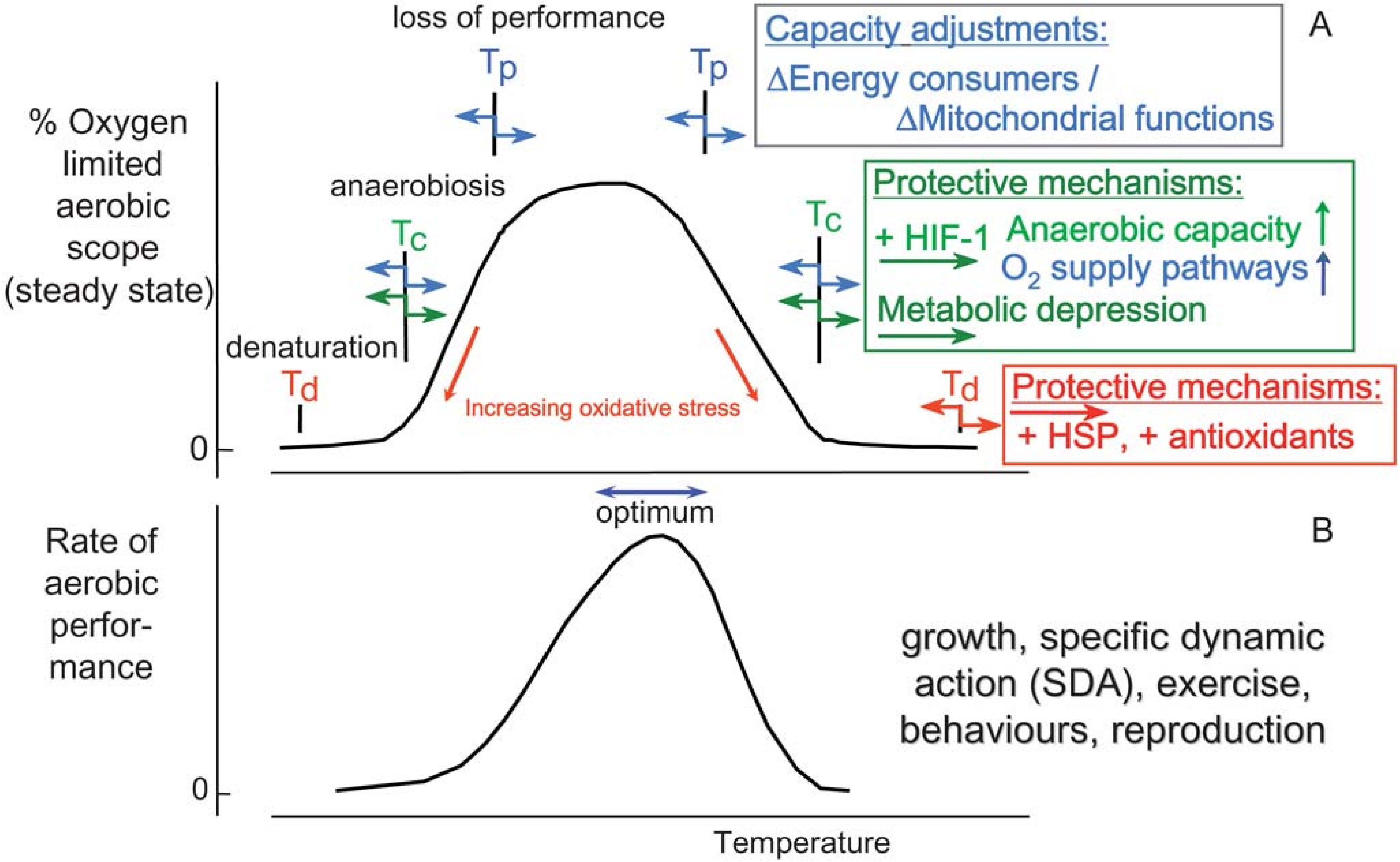
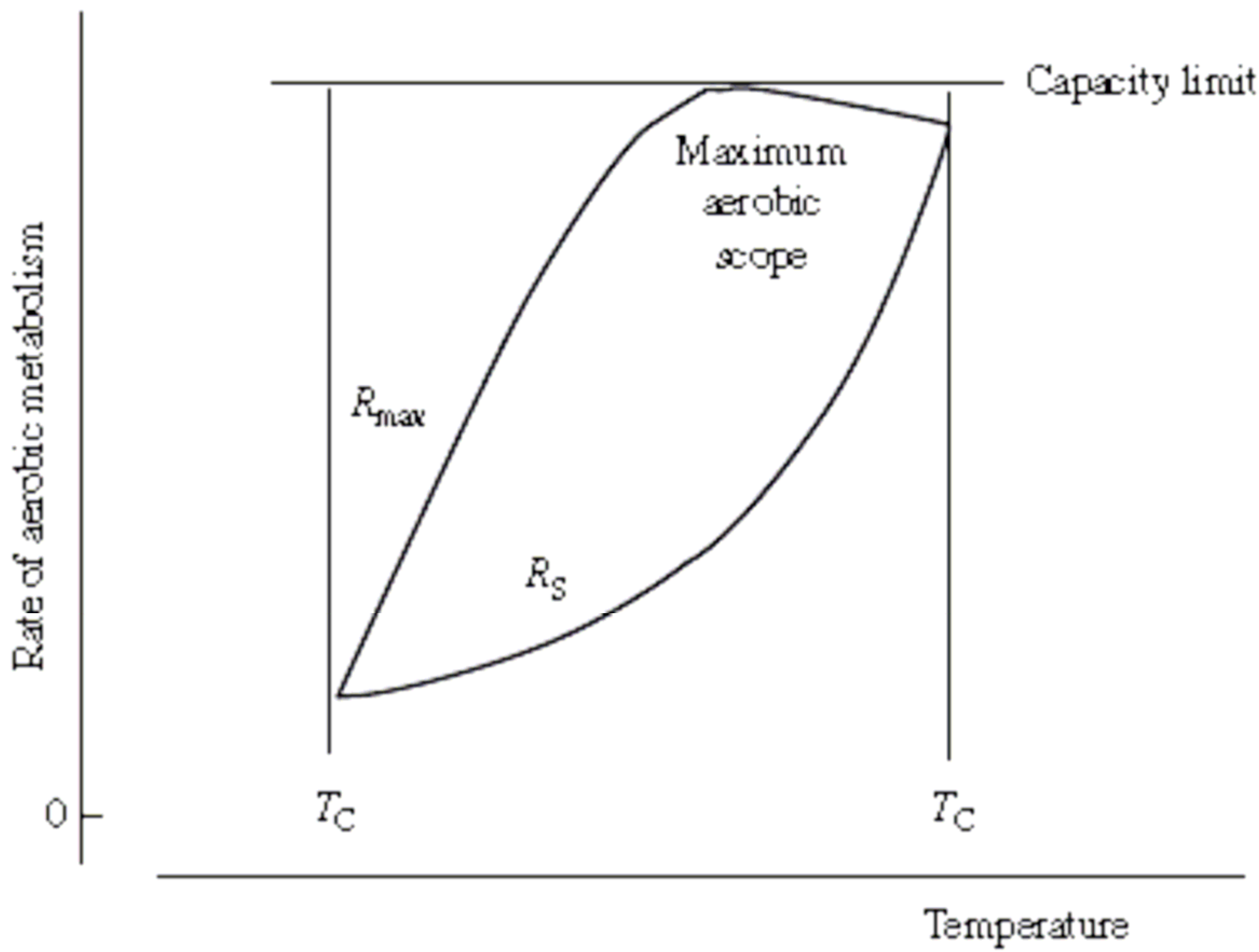
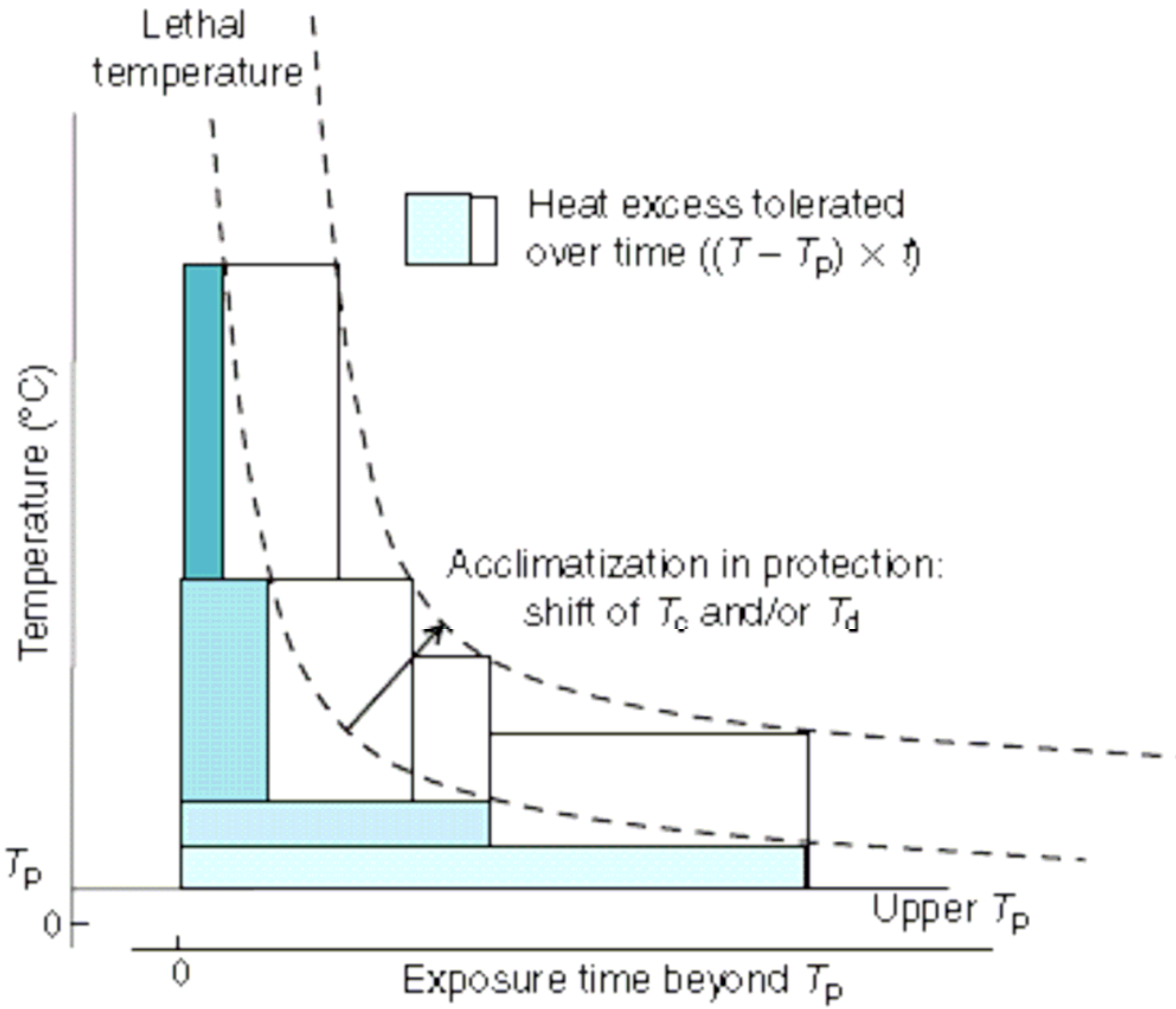
Thermal Tolerance

- Models from your readings
- More papers posted

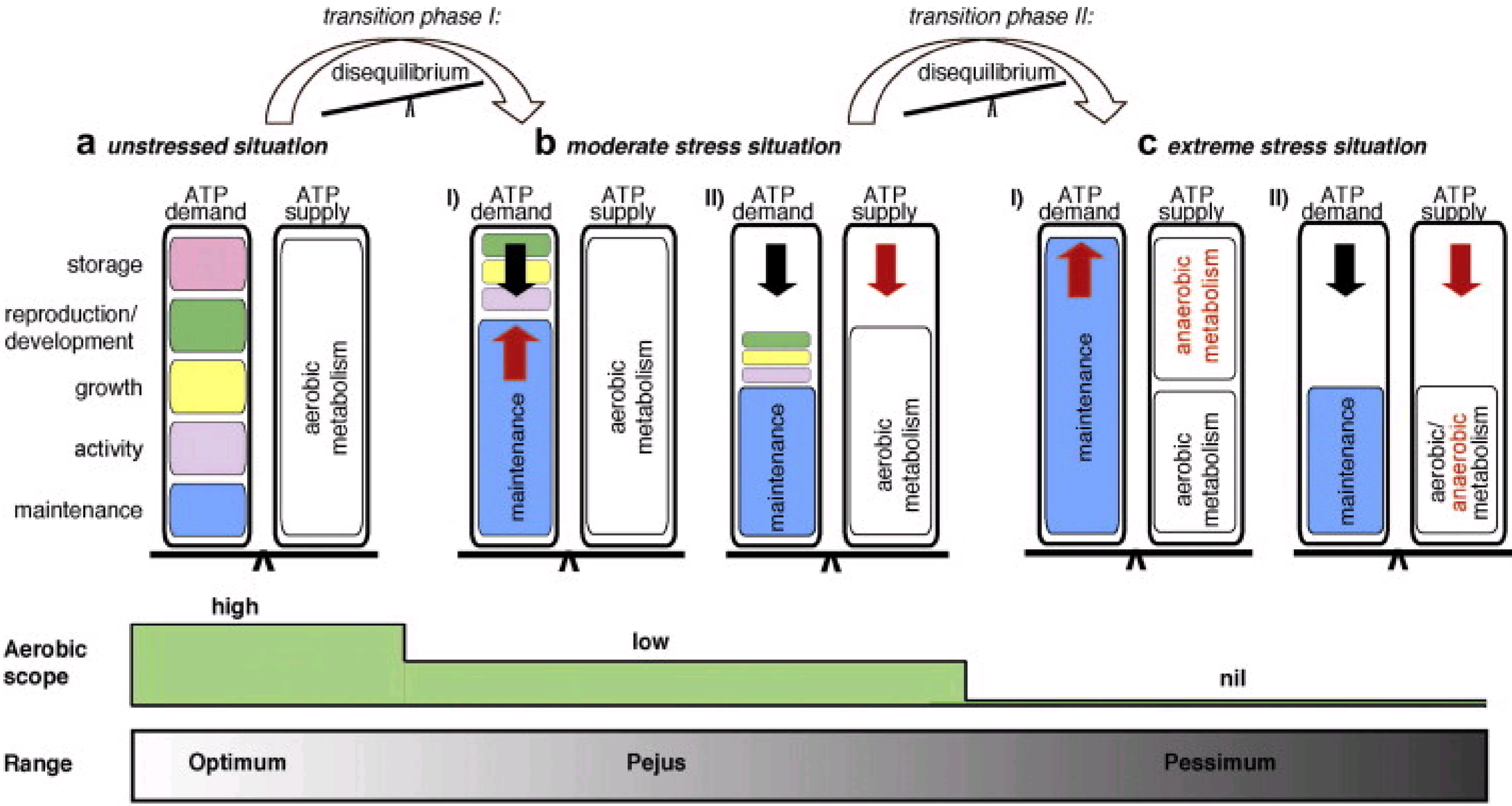

A
B
loss of performance
Tp
Tp
Capacity adjustments:
ΔEnergy consumers /
ΔMitochondrial functions
% Oxygen limited aerobic scope (steady state)
anaerobiosis
Tc
Tc
Protective mechanisms:
+ HIF-1
Anaerobic capacity
O2 supply pathways
Metabolic depression
denaturation
Td
Td
Increasing oxidative stress
Protective mechanisms:
+ HSP, + antioxidants
0
optimum
Rate of aerobic perfor-mance
growth, specific dynamic action (SDA), exercise, behaviours, reproduction
0
Temperature



Capacity limit
Maximum aerobic scope
R_{max}
R_S
Rate of aerobic metabolism
0
T_C
T_C
Temperature



Lethal temperature
Heat excess tolerated over time ((T – Tp) × t)
Temperature (°C)
Acclimatization in protection: shift of Tc and/or Td
Tp
0
Upper Tp
0
Exposure time beyond Tp



transition phase I:
disequilibrium
transition phase II:
disequilibrium
a unstressed situation
b moderate stress situation
c extreme stress situation
ATP demand
ATP supply
storage
reproduction/ development
growth
activity
maintenance
aerobic metabolism
I)
II)
anaerobic metabolism
aerobic/ anaerobic metabolism
high
low
nil
Aerobic scope
Range
Optimum
Pejus
Pessimum

Effects of Water Temperature on Growth and Physiology of Different Populations of Redband Trout (*Oncorhynchus mykiss gairdneri*)

John Cassinelli & Christine M. Moffitt

Rainbow/Redband Distribution

(Behnke 1992)

Coastal rainbow trout

Sacramento, Kern, McCloud River redband trout

Columbia River redband trout

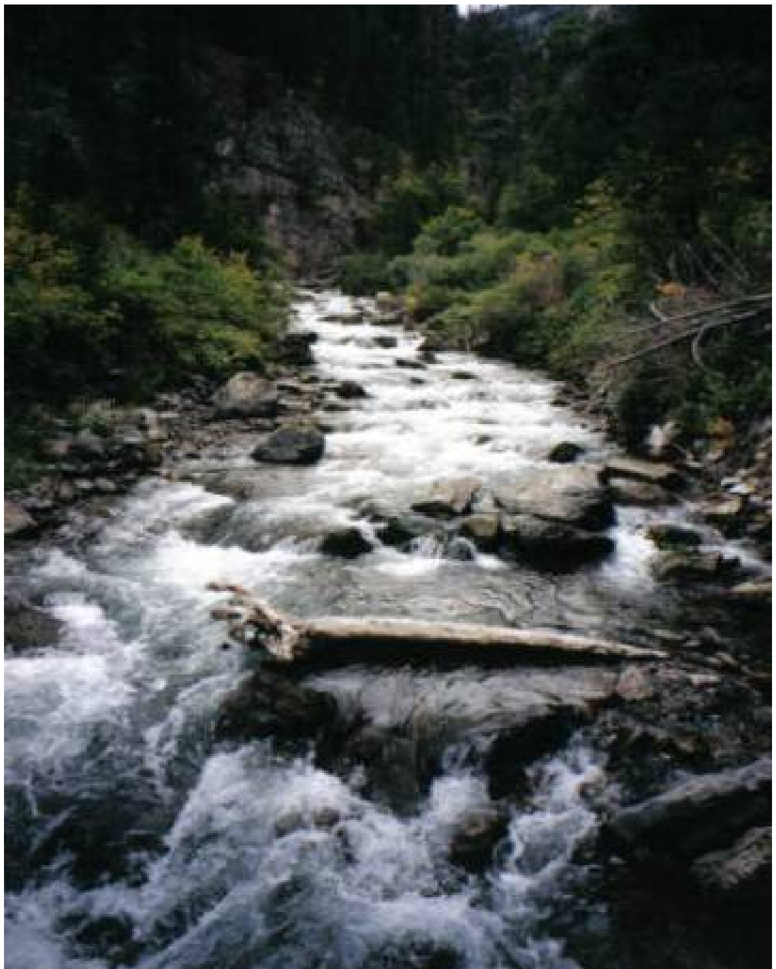
www.sccd.org

Redband Trout in the Columbia Basin

- Native to western North America
- Occur east of the Cascade Range to barrier falls in the Pend Oreille, Spokane, Snake, and Kootenai River basins and in the upper Fraser River basin
- Three redband variations found in the basin
  - Lake variation known as kamloops found in some larger lakes
  - Steelhead that migrate to and from the ocean
  - Resident stream populations

• **In southern Idaho,**
redband trout are native in the Snake River drainage below Shoshone Falls

Redband trout occupy two major types of habitat within the Snake River Basin



Montane Habitat

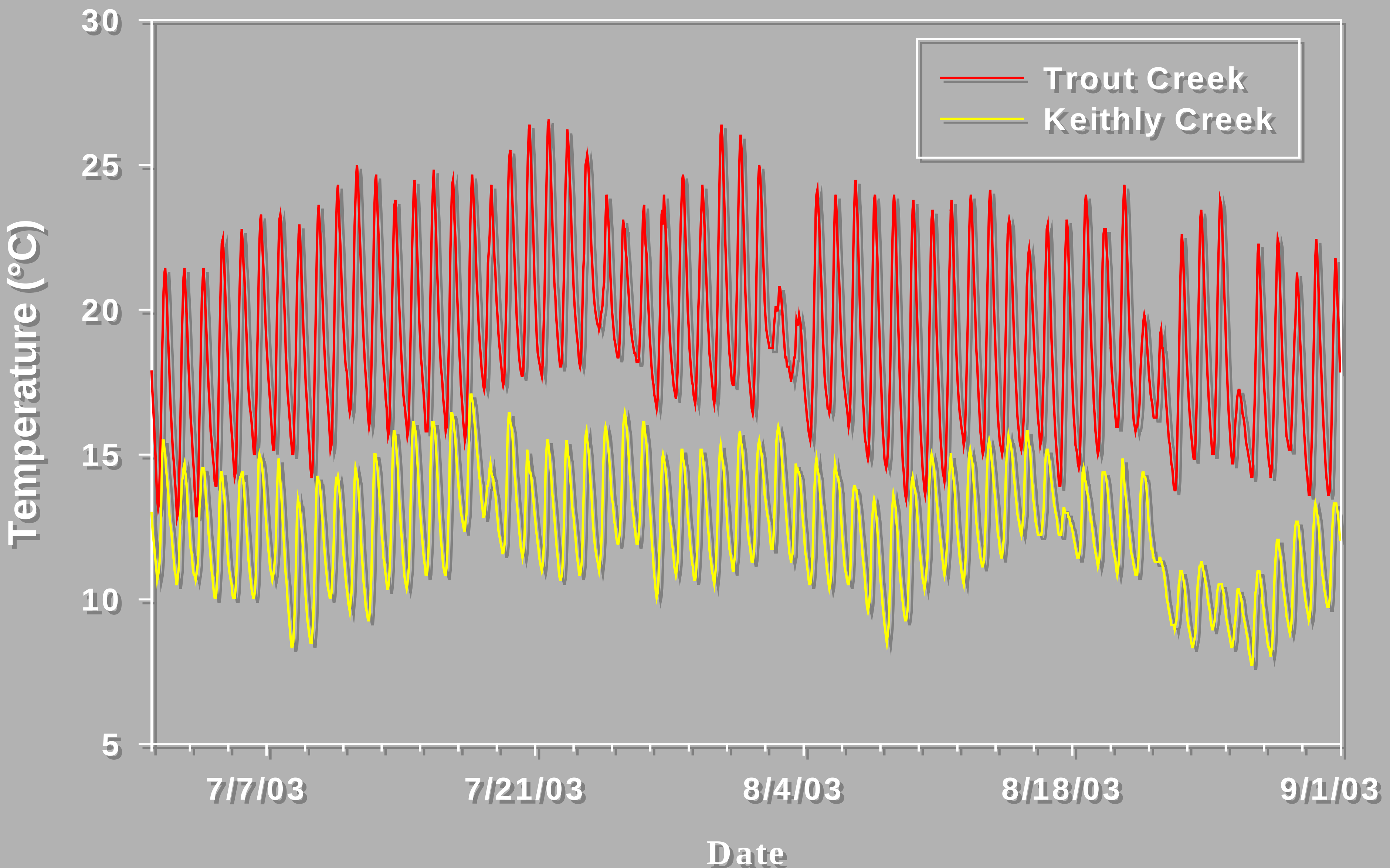
- high elevation
- steeper gradient
- larger substrate
- higher flows
- cool water temps

Redband trout occupy two major types of habitat within the Snake River Basin

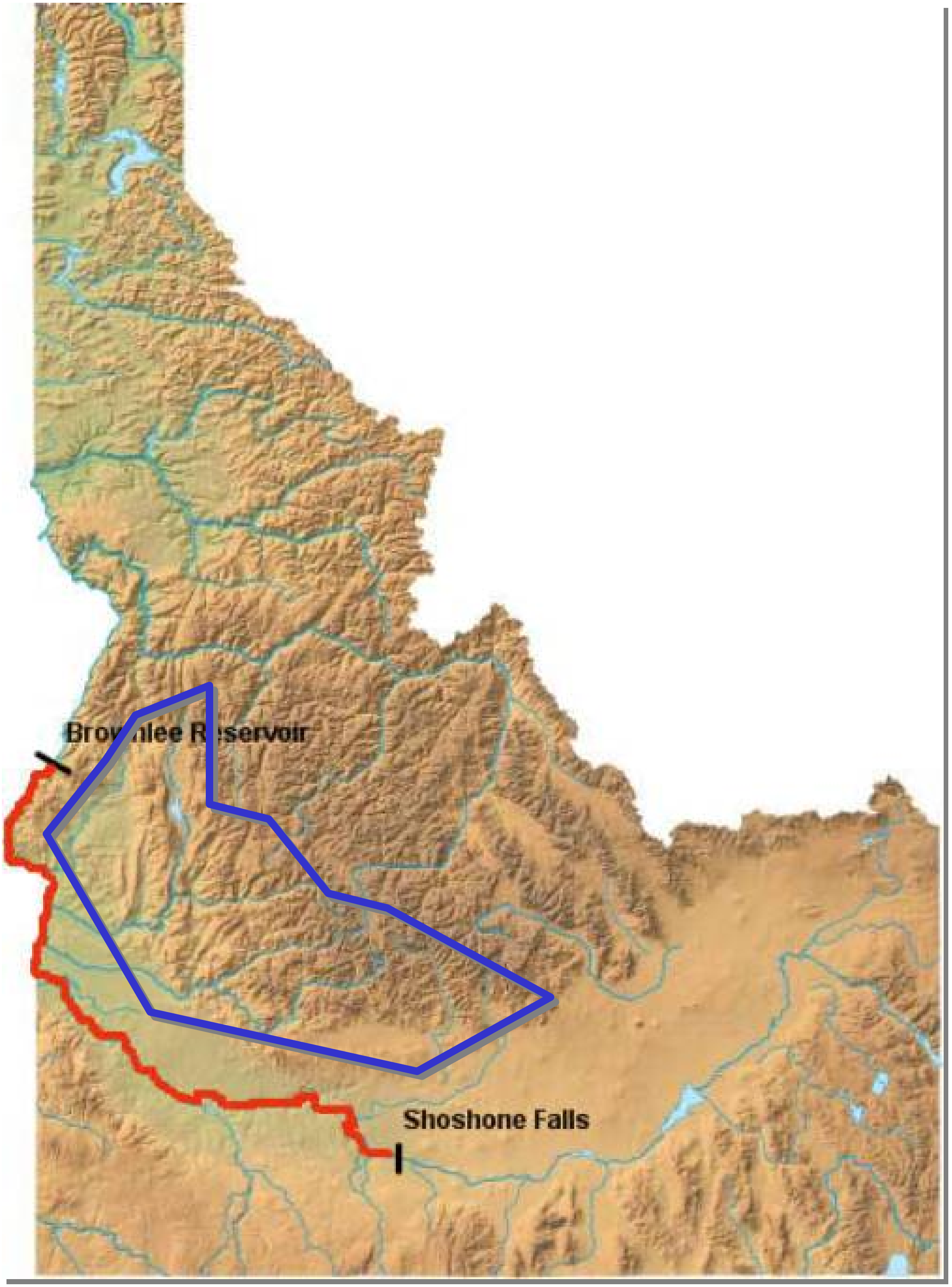
Desert Habitat

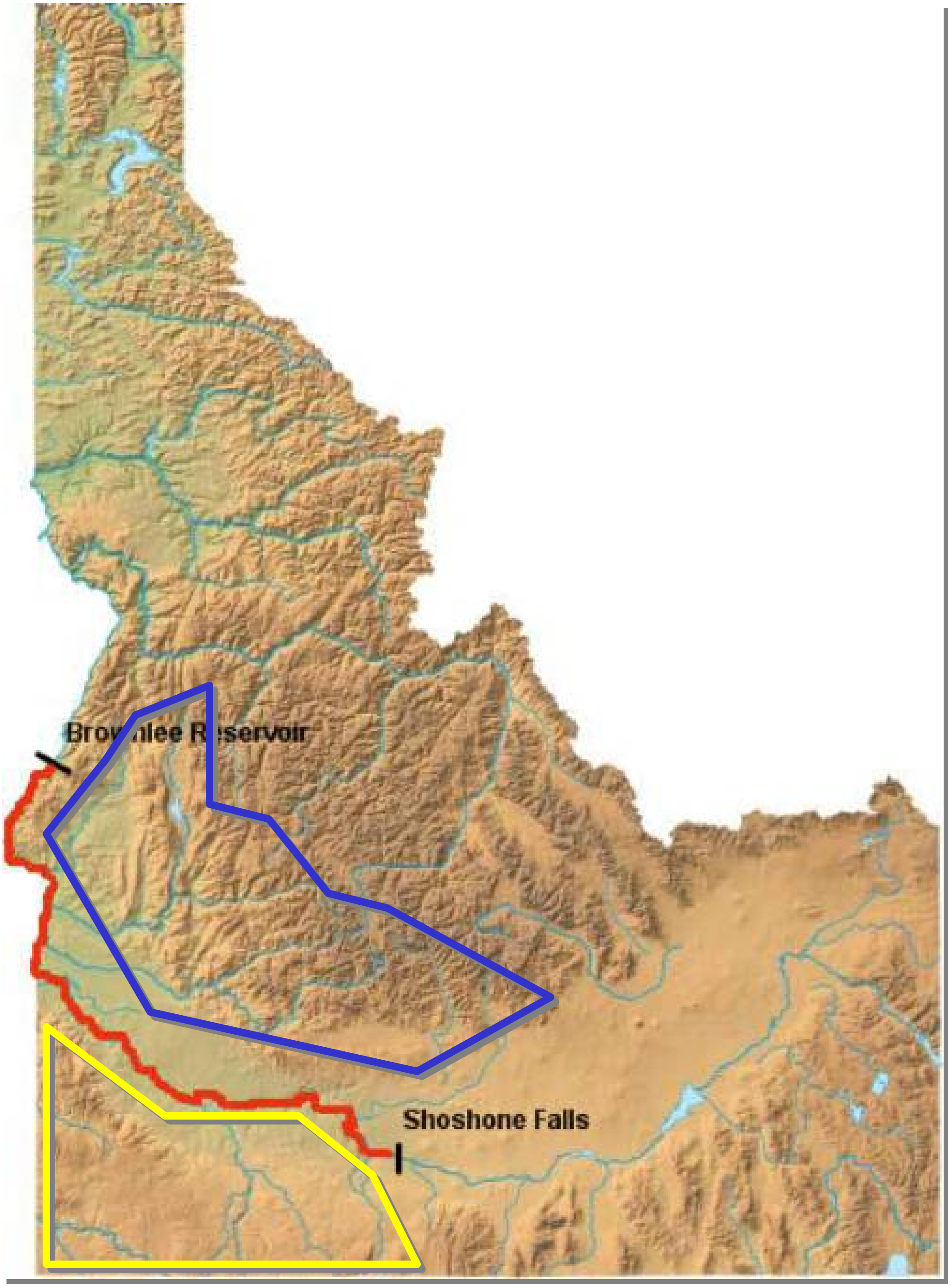
- low elevation
- lower gradient
- smaller substrate
- lower flows
- warm water temps

Desert and Montane Water Temperatures




Brownlee Reservoir
Shoshone Falls


Brownlee Reservoir
Shoshone Falls


Shoshone Falls

Redband Trout

- Species of special concern
- Petitioned for listing under ESA
  - Kootenai River population (Montana)
  - Great Basin (Oregon, Nevada, & California)
  - Interior Snake River (Idaho)

Redband Trout

- **In April of 1995, all redband trout in the Snake River from Brownlee Reservoir to Shoshone Falls were petitioned for listing under the ESA**
- **The petition was modified in July of ‘95 to exclude forested, higher elevation watersheds and include lower elevation desert rivers and streams**
- **petition denied by the USFWS because the desert and montane populations could not be differentiated**

- **Numerous studies have reported the upper critical temperatures for rainbow trout to range from 26.9 to 29.8°C**
- **Behnke (1992) and Zoelick (1999) have both reported desert populations of redband trout actively feeding at temperatures from 26 to 28.3°C in the Owyhee and Big Jacks drainages**

Behnke and others have suggested that populations of desert redband may have evolved physiological mechanisms that enable them to withstand high temperatures

Redband Trout

- Desert stream temperatures in Idaho can reach diel peaks as high as 32°C in
  n

  in fluctuating diel temperature cycles
  les

  es

  on critical thermal maxima (CTM), incipient lethal
  hal temperature (ILT), or chronic lethal maxima
  M)

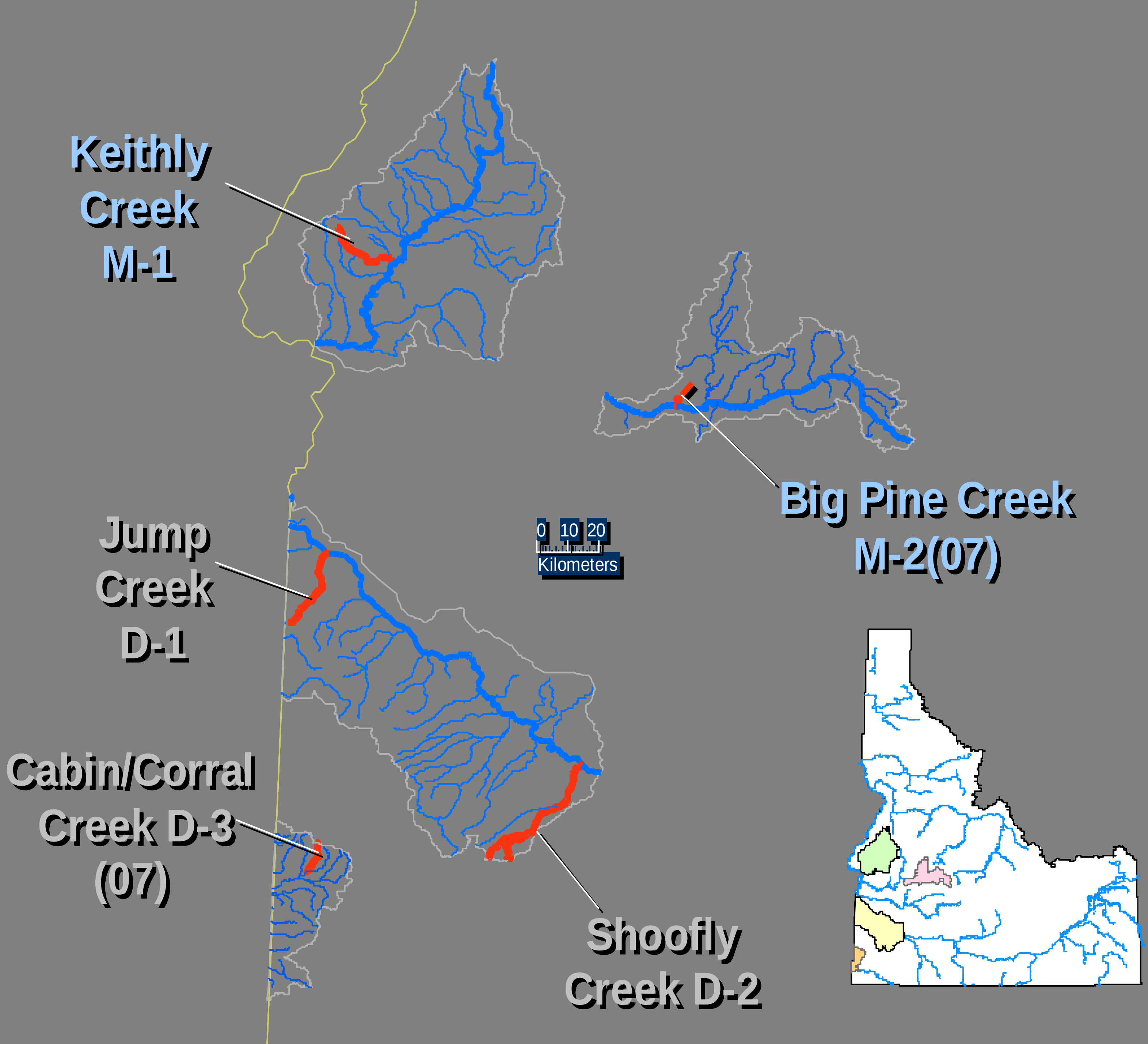
)

  ose the fish's natural environment provide results
  hat are more ecologically relevant.

  t.

Objectives

- Collect gametes from desert and montane wild stocks
- Rear progeny in a controlled laboratory setting to a similar size for testing
- Compare survival, growth, and physiology in simulated desert and montane diel water temperature cycles
- Compare performance and upper lethal temperatures in extreme diel cycles of subyealing fish
- Repeat trials for two years



Keithly Creek M-1
Big Pine Creek M-2(07)
Jump Creek D-1
Cabin/Corral Creek D-3 (07)
Shoofly Creek D-2
0 10 20
Kilometers

Collecting and Rearing

Fish synchronized to size and degree-day

March | April | May | June | July

Field gamete collection

Main Objective - Compare survival, growth, and physiology of desert and montane populations in simulated desert and montane diel water temperature cycles, repeated for two years

Design

- Two diel temperature cycles
  - Montane 9 - 16 °C
  - Desert 18 - 26 °C
- Each stock randomly assigned to 2 tanks in each temperature treatment
- Tests run for 35 d

Variables Evaluated

- Growth (wt & length)
- Mortality
- Feed consumption and feed conversion/ efficiency
- Body proximate analysis
- Plasma cortisol
- Muscle and liver heat shock protein 70 (hsp70

Heat Shock Protein 70 (hsp70)

- hsp70 has been described as the major stress inducible protein in rainbow trout cells
- Muscle and liver samples removed from euthanized fish and analyzed using Western Blotting

- Blot membranes scanned as digital image and the density of each blot was measured using ImageJ software which reads the brightness of each pixel
- Calculated a ratio of the density of each blot by dividing the blot density by the density of a human standard from that same gel

Sampling

T0 Baseline - Weigh, measure remove samples for hsp and proximate analysis

June **July** **August**

Sampling

T0 Baseline - Weigh, measure remove samples for hsp and proximate analysis

T1 ~ 2.5 weeks - Sample 5 fish each tank, weigh and measured tissues collected for hsp analysis

June July August

Sampling

T0 Baseline - Weigh, measure remove samples for hsp and proximate analysis

T1 ~ 2.5 weeks - Sample 5 fish each tank, weigh and measured tissues collected for hsp analysis

June July August

T2 ~ 5 weeks - All fish weighed, measured; plasma collected, body saved for proximate analysis, tissues collected for hsp analysis

Statistical Analysis

Within Years

- Models tested all stocks & then wild stocks only
- 2 x 4(6) and 2 x 3(5) Factorial Design

  Factor A = Temperature Treatment

  Factor B = Stock
- Repeated measures split plot design

Between Years

- Repeat stocks tested using year as a blocking variable
- MANOVA run for all single measurement variables

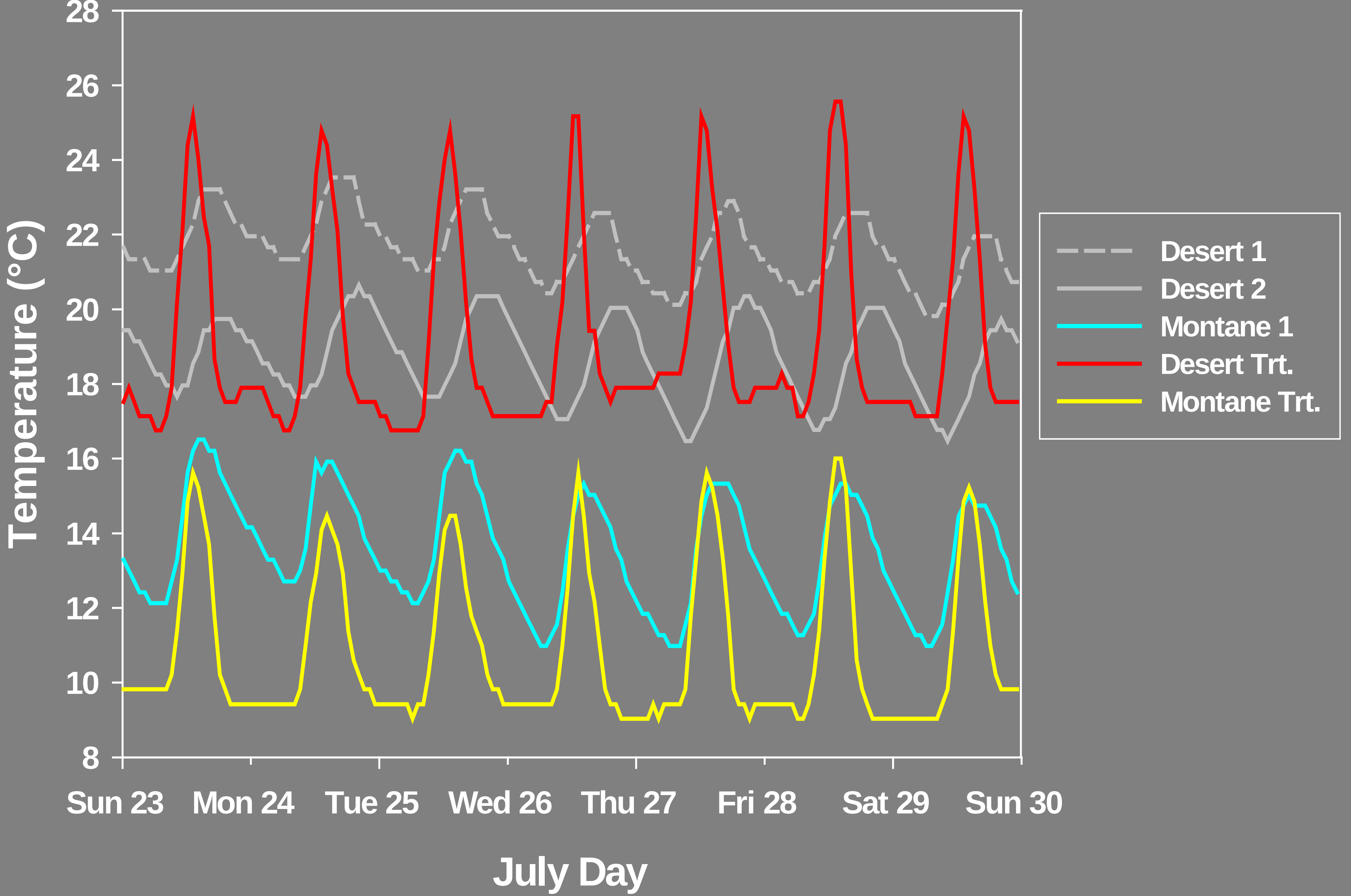
Results

- Survival high for all stocks in both temperature treatments

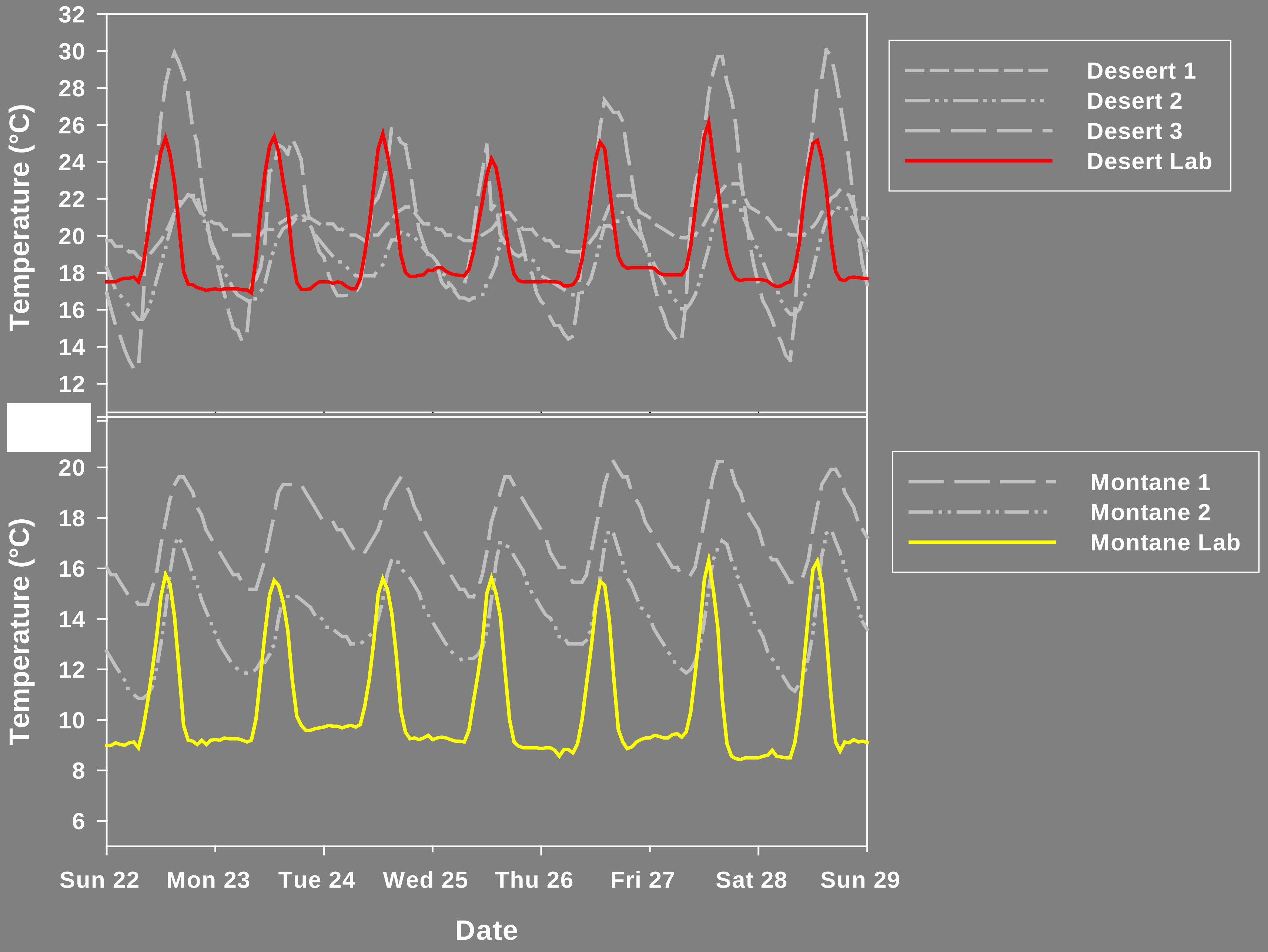
- Wild fish remained on bottom of tank, more secretive

- Hatchery fish used surface

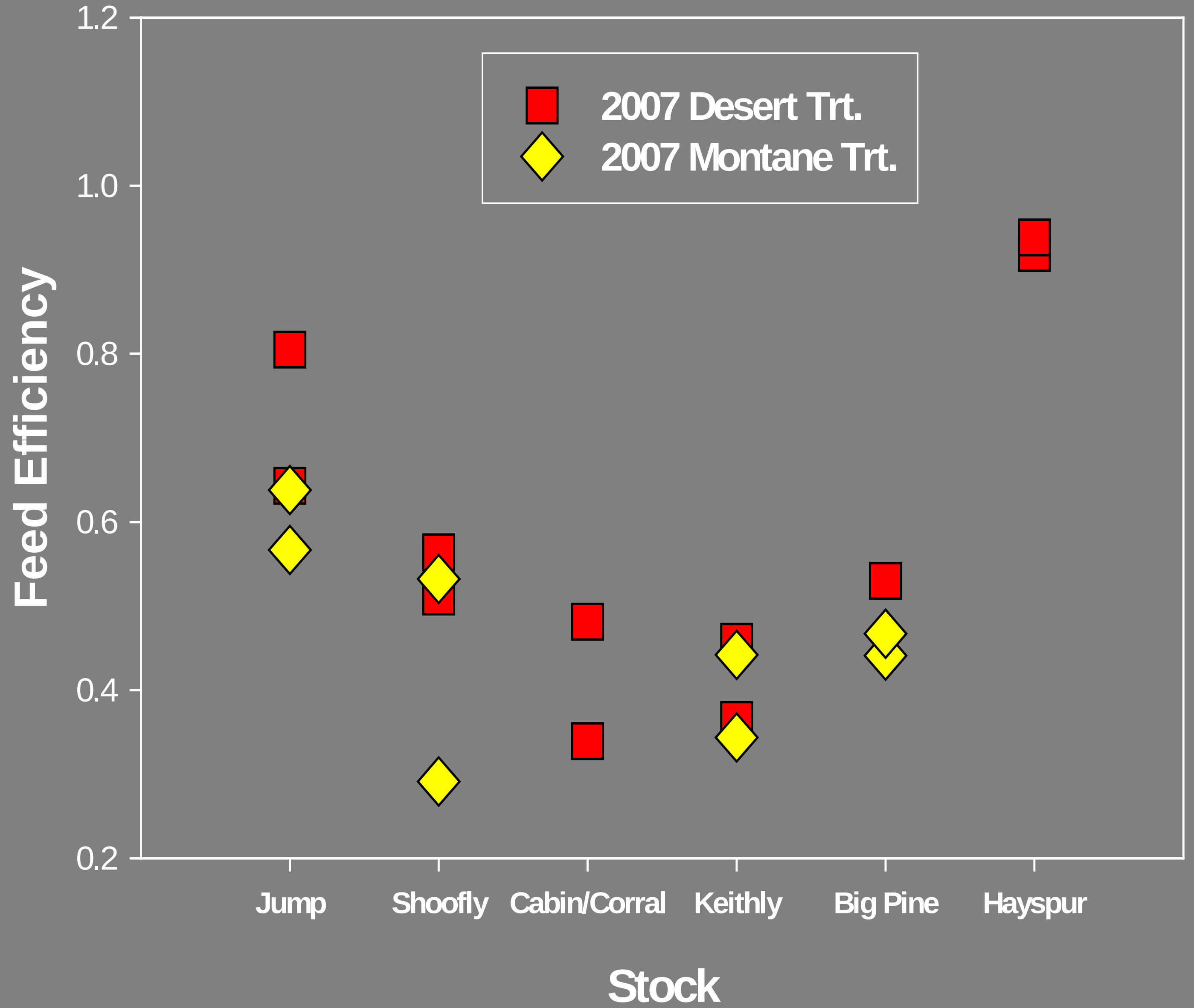
Lab vs. Field Observed Temperatures 2006



Lab vs. Field Observed Temperatures 2007



Feed Efficiency by Stock and Treatment



WITH HATCHERY

Stock: $P \leq 0.01$

Temp: $P \leq 0.07$

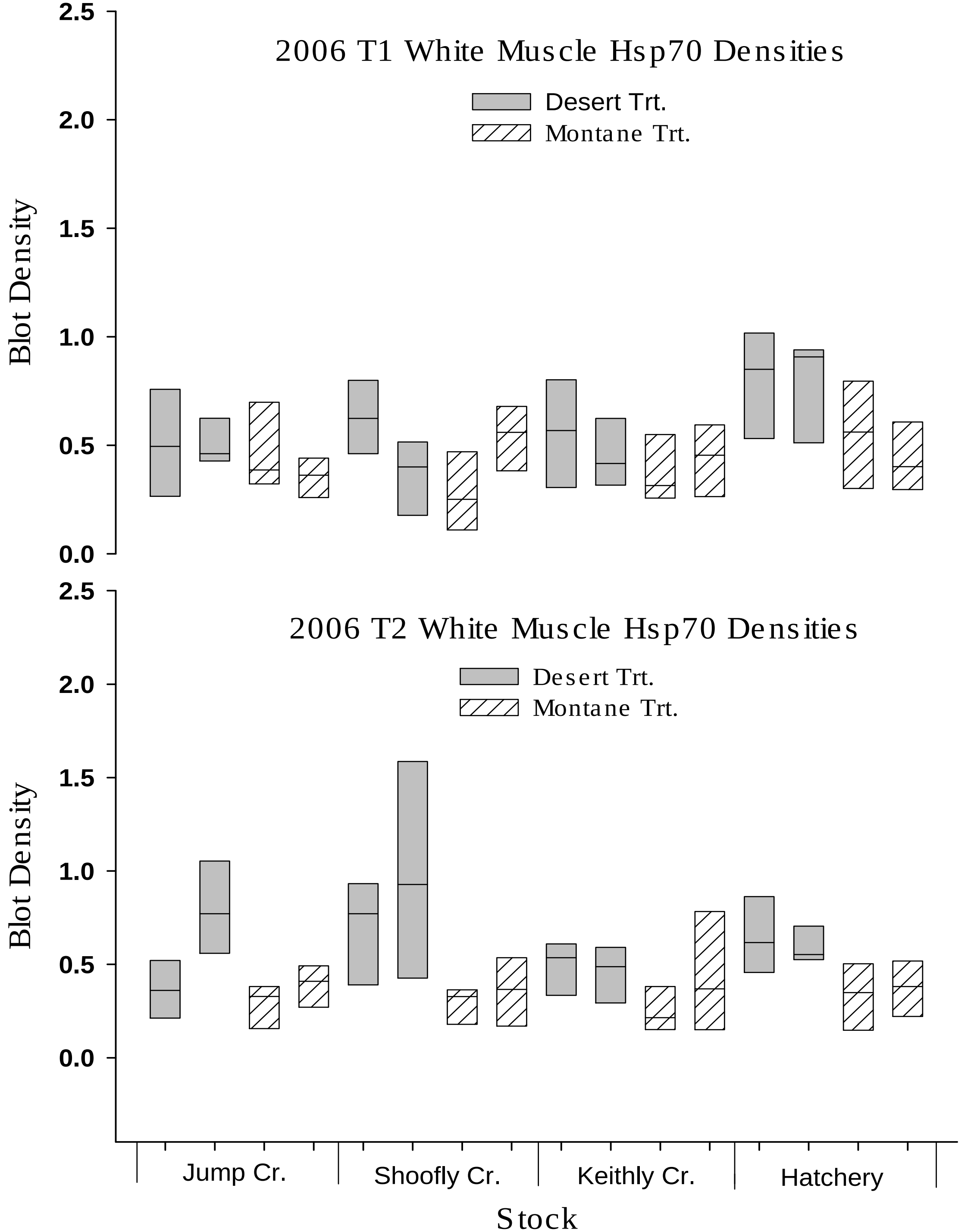
Stock x Temp: $P \geq 0.70$

WILD FISH ONLY

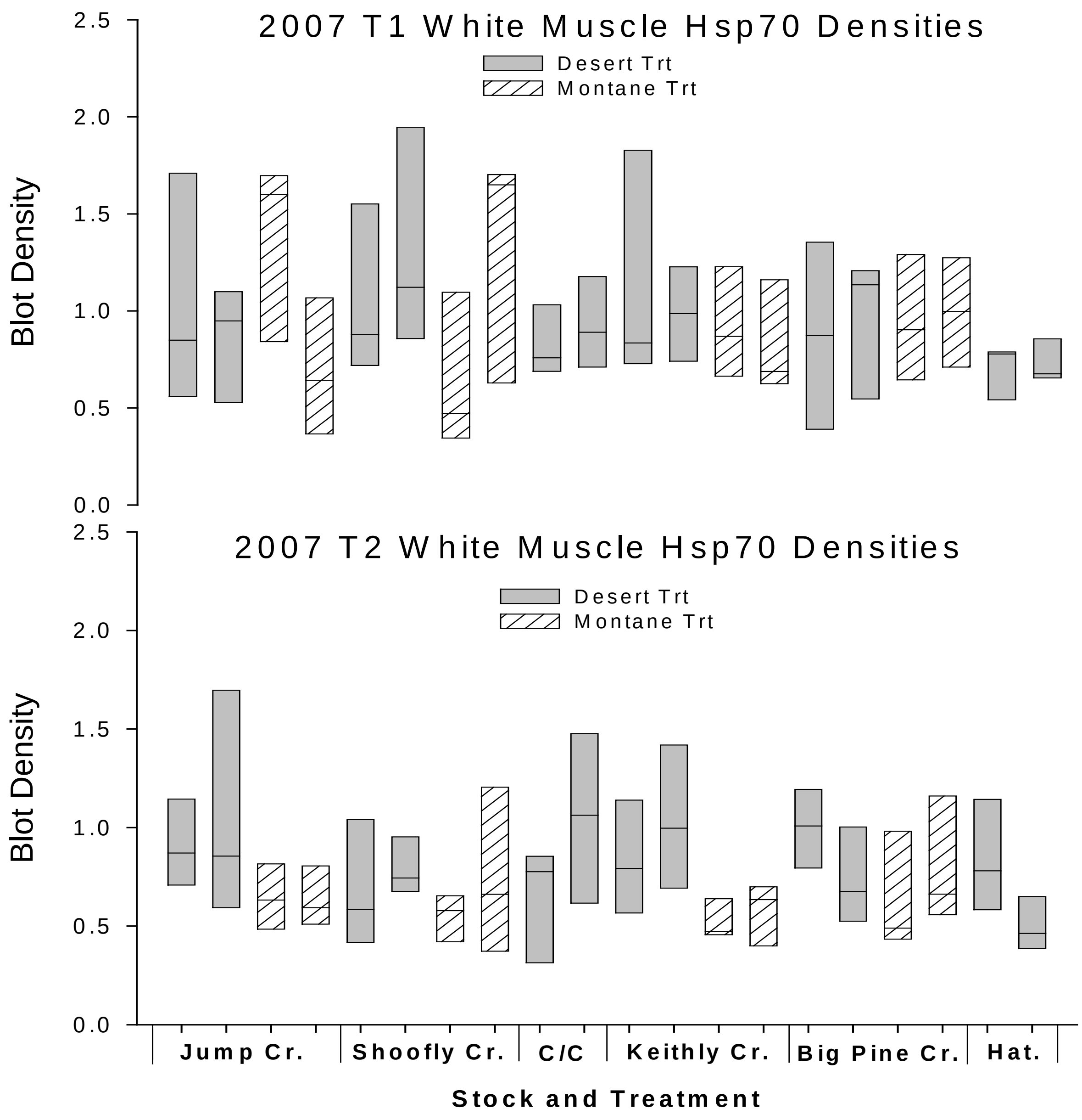
Stock: $P \leq 0.02$

Temp: $P \leq 0.09$

Stock x Temp: $P \geq 0.80$



2006 T1 White Muscle Hsp70 Densities
Desert Trt.
Montane Trt.
Blot Density
2.5
2.0
1.5
1.0
0.5
0.0
2006 T2 White Muscle Hsp70 Densities
Desert Trt.
Montane Trt.
Blot Density
2.5
2.0
1.5
1.0
0.5
0.0
Jump Cr.
Shoofly Cr.
Keithly Cr.
Hatchery
Stock


2007 T1 White Muscle Hsp70 Densities
Desert Trt
Montane Trt
Blot Density
2.5
2.0
1.5
1.0
0.5
0.0
2007 T2 White Muscle Hsp70 Densities
Desert Trt
Montane Trt
Blot Density
2.5
2.0
1.5
1.0
0.5
0.0
Jump Cr.
Shoofly Cr.
C/C
Keithly Cr.
Big Pine Cr.
Hat.
Stock and Treatment

Results

- **Liver hsp70 differed among treatments but not among stocks and increased over time in both years**
- **Lipid and protein efficiencies significant different between stocks but not treatments in both years**
- **Cortisol levels differed among stocks and treatments in ’06 but not in ’07 and in both years all levels were low and did not indicate a stress response**

Summary

- In year 1, growth and feed efficiency differed

differed among wild stocks and

eatments

atments

ly among stocks in both year 2 and between

en years

n years

sert and montane stocks

e stocks

stocks

fish not surprising

prising

in a contained environme

ironment

Summary

- **Hsp 70 levels differed among treatments in white muscle tissue after 35 d in ’06 but not in ’07**

- **Fish in the desert treatment had consistently higher white muscle hsp70 levels and those levels increased over time**

Conclusions

- **Fish in diel temperature cycles are able to withstand higher maximum temperatures than in trials using constant temperatures – EG recovery time- repair…**

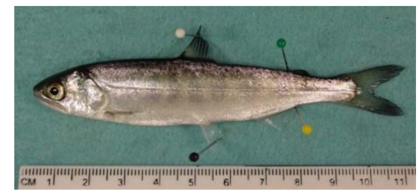
- **Desert-adapted and montane stocks of redband trout of the Snake River proved versatile, dynamic, and adaptive to a wide range of water temperatures**

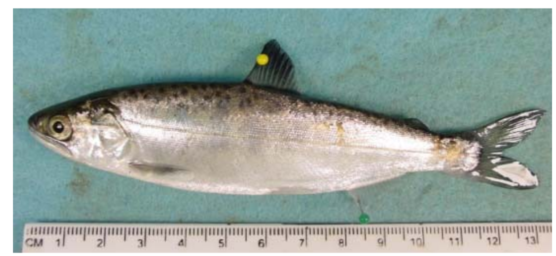
Additional Stressors

- Longer exposure, repeated exposure?? Lower reproductive opportunities???

Validation of a Bioenergetics Model for Early-Rearing Snake River Fall Chinook Salmon

John M. Plumb[1,3], Christine M. Moffitt[1], William P. Connor[2], and Ken F. Tiffan[3]





Background

Chips and Wahl (2008)

- Local adaptations should be considered in bioenergetics models

Current Chinook salmon bioenergetics model…

- For stream-type or spring Chinook salmon
- Evaluated for great lakes hatchery populations

No model for juvenile ocean-type Chinook salmon

- Juvenile fish prefer higher temperatures
- High optimum temperatures for growth (20°C) for wild-reared Snake River salmon

Objectives

1) Use bioenergetics modeling to account for known factors that affect fish growth and compare to observed growth in laboratory.

2) Determine if bioenergetics can predict variation in weight over time for fish having different...

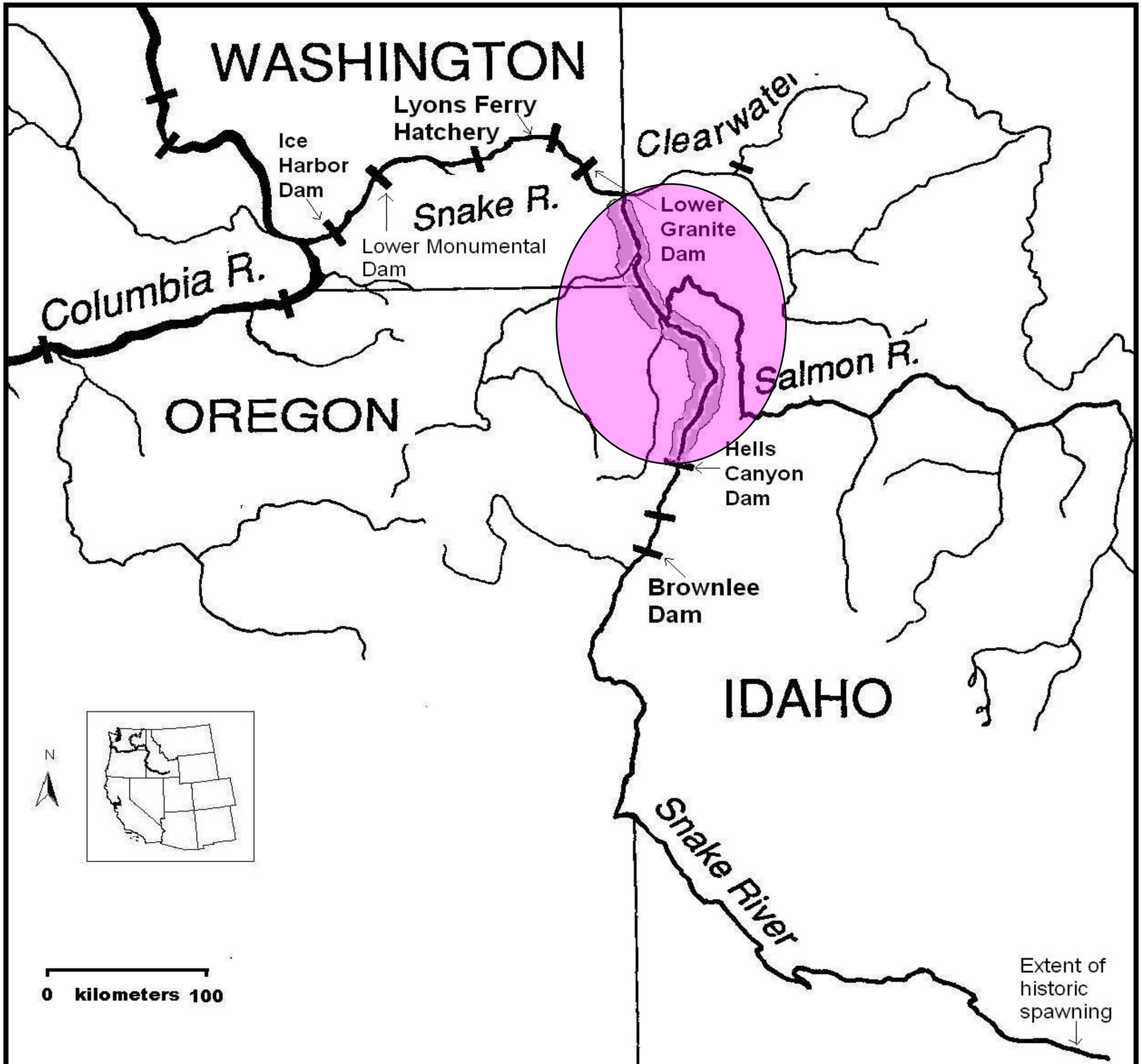
   1) initial weights

   2) growth durations

   3) temperature exposures

   4) rearing types (wild vs. hatchery)

Snake River Fall Chinook



Bioenergetics Models

Bioenergetics models:
Based on Mass-Balance relationship between food, metabolism, and growth.

A series of laboratory-calibrated linear models that predict daily physiological processes, used to estimate the accrual of mass given fish size, food consumption, and water temperature.

$$W_{t+1} = W_t + [C_t - (SDA_t + R_t + F_t + E_t)]$$

Consumption (C_t)

Metabolic processes ($SDA_t + R_t + F_t + E_t$)

Specific Consumption Rate

$C = C_{max}\ p{*}\ fc(T)$ *, where*

C = gram prey per gram of fish per day

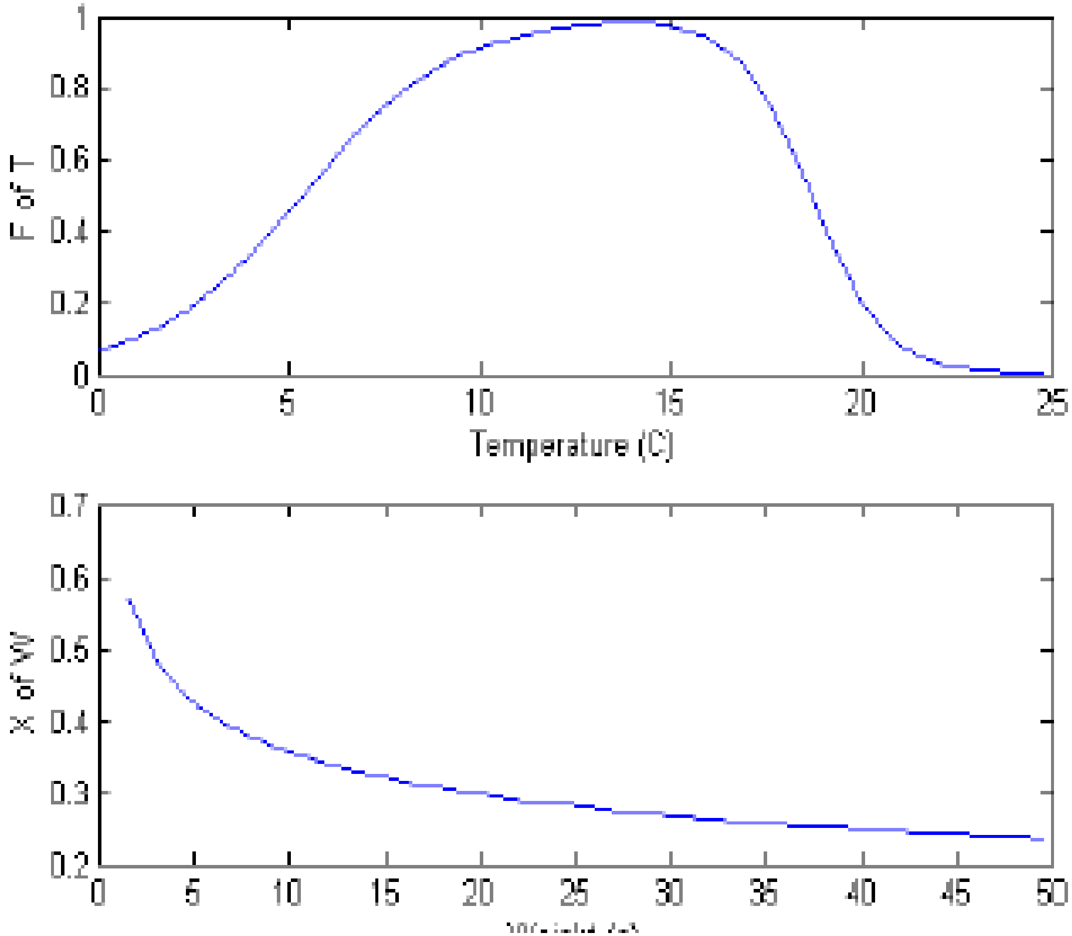
C_{max} = *max specific feeding rate that is affected by mass, and temperature relationships*

fc(T) = temperature dependent consumption

T is water temperature

C max is related to temperature and weight

$$C_{max} = a_c * W^{bc}$$


F of T
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
Temperature (C)
X of W
0.7
0.6
0.5
0.4
0.3
0.2
0
5
10
15
20
25
30
35
40
45
50

Temperature Adjustment

Used bioenergetics model of Stewart & Ibarra (1991)

Adjusted Thornton and Lessem (1978)

- Used values reported by Geist et al. (2010)
- Account for higher consumption at higher temperatures

Parameter	Stewart & Ibarra (1991)	Adjustment
CQ temp K1	5	Not adjust
CTO, Temp K2	10	20
CTM, Temp K3	15	21
CTL Temp K4	24	27
CK1	0.36	Not adjust
CK4	0.01	Not adjust

Validation Data

1) Geist et al. (2010)
   - Wild Snake River fall Chinook salmon
   - Small initial weights (~ 1.5 g)
   - Growth over 30 d
   - 8 tanks from 14 to 22 °C

2) Yanke (2003 study)
   - Hatchery Snake River fall Chinook salmon
   - Larger initial weights (~ 7 g)
   - 3 tanks at 15, 18, & 21°C (9 tanks total)
   - Growth over 80 d

3) Yanke (2004 study)
   - Hatchery Snake River fall Chinook salmon
   - Intermediate initial weights (~ 4 g)
   - 4 tanks at 16, 20, 24, & 28 °C (12 tanks total)
   - Growth over 42 d at 15, 18, & 21°C

Validation Data

4) Brett et al. 1982

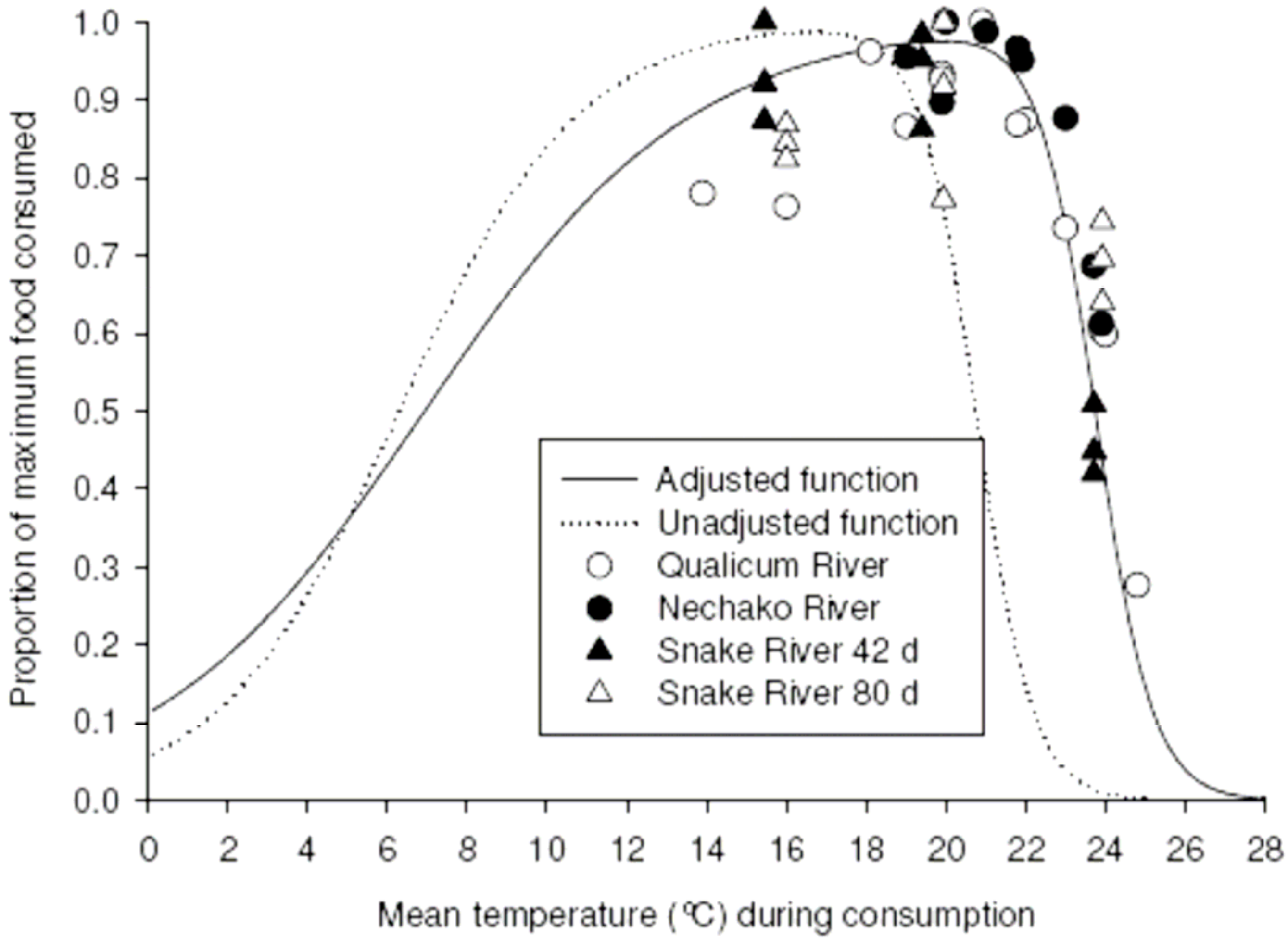
- – Chinook salmon, 2.5 – 3.2 g
- – Nechako River 30 d
- - Qualicum River 30 d

Model Simulations

1) All laboratory fish were fed an *ad libitum* ration
   - Assume fish ate daily at max consumption
   - BioMoist pellets ~ 34% indigestible

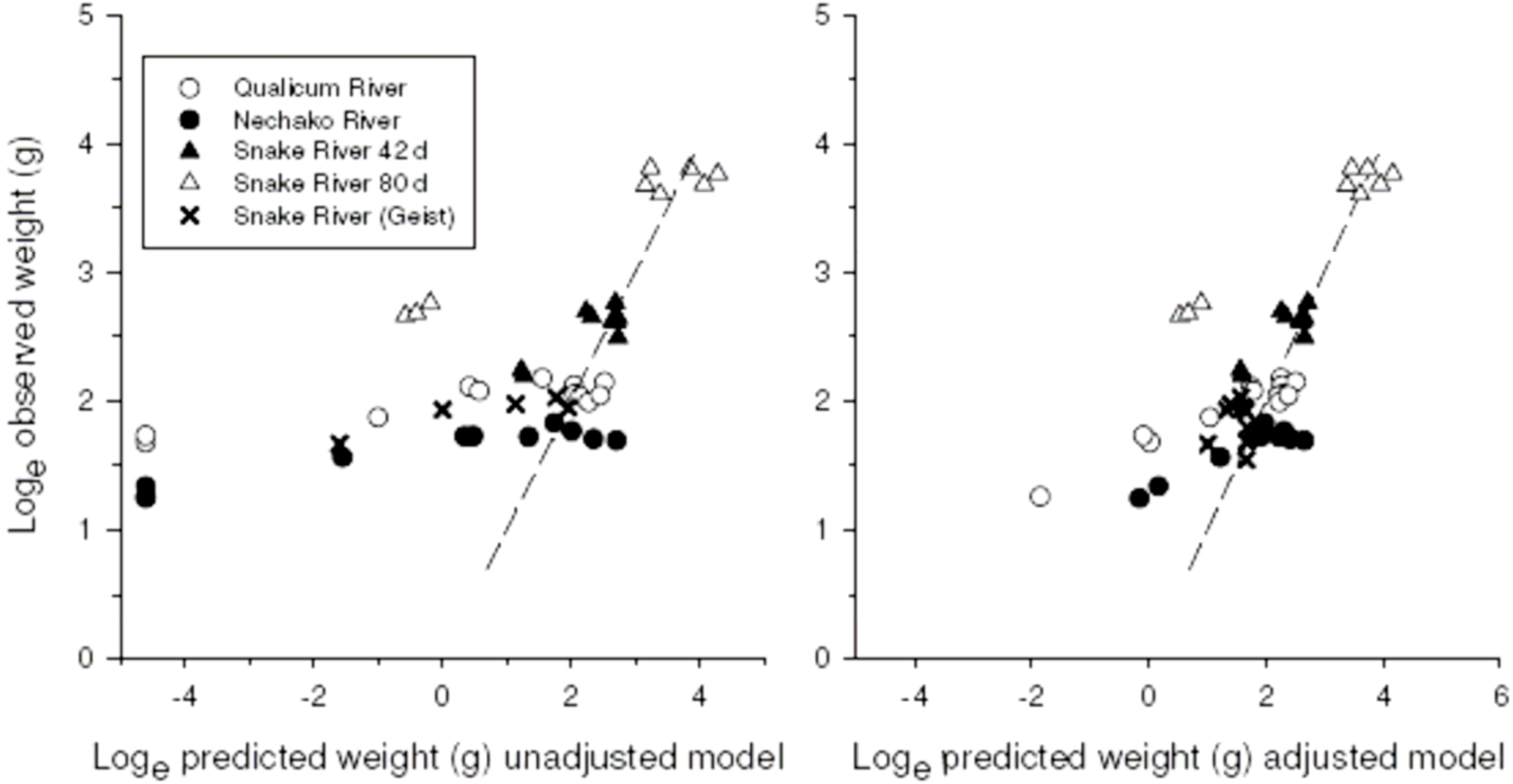
2) Use daily tank temperatures
   - Use mean from Geist et al. (2010)
   - Use empirical data from Yanke (2003 & 2004)

3) Compare mean fish weights observed in each tank over time to those predicted by the bioenergetics model



Proportion of maximum food consumed
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
Mean temperature (°C) during consumption
Adjusted function
Unadjusted function
Qualicum River
Nechako River
Snake River 42 d
Snake River 80 d

Model Comparisons



Conclusion

- Adjustment for locally-adapted population was warranted.

- Published values of optimum and maximum limits for growth were sufficient for model adjustment.

- Adjusted model should be considered when estimating the growth or consumption of ocean-type Chinook salmon.