# Salmonid Health: Effects of Parasites and Pathogens

A Concurrent Session at the 34th Annual Salmonid Restoration Conference held in Fortuna, CA from April 6-9, 2016.

# Session Overview

- Session Coordinator:
  - Cynthia LeDoux-Bloom, Ph.D., AECOM

The purpose of the session is to learn about the current status of important viral, bacterial, and parasitic pathogens and their physiological and behavioral effects on Pacific salmonids. Specifically, Infectious Hematopoietic Necrosis Virus, Renibacterium salmoninarum, Myxobolus cerebralis, Ceratonova shasta (aka Ceratomyxa), Ichthyophthirius multifiliis, and other emerging pathogens will be addressed. Topics include stress associated pathogenesis from trapping, handling, tagging, holding, transport, poor water quality conditions, drought, climate change, and pathogen-host relationship imbalances.

# Presentations

(Slide 4) Presence and Prevalence of Parasites and Pathogens in Pacific NW Salmonids
Cynthia Le Doux-Bloom, Ph.D., AECOM

(Slide 38) An Outbreak of Ichthyophthirius multifiliis in the Klamath and Trinity Rivers in 2014 with Updated 2015 Results
Michael Belchik, Yurok Tribal Fisheries Program

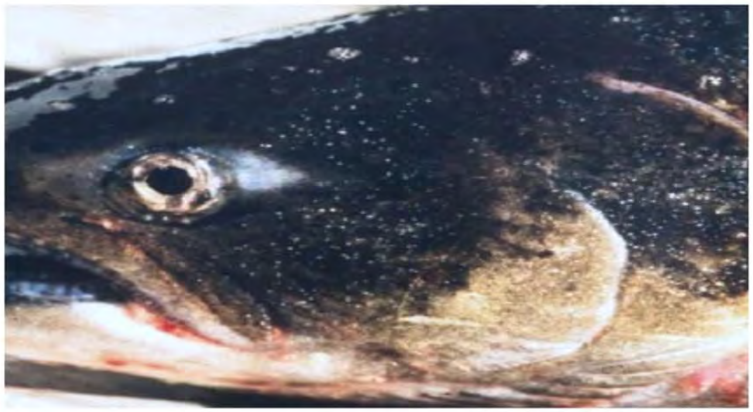
(Slide 56) Ceratonova shasta: Timing of Myxospore Release from Juvenile Chinook Salmon (Oncorhynchus tshawytscha)
Scott Benson, Humboldt State University.

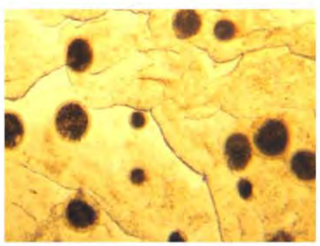
(Slide 102) Ceratonova shasta Disease Impacts on Juvenile Chinook Salmon in the Klamath River Basin: Perspectives from a 10 year Fish Health Monitoring Program
Kimberly True, U.S. Fish and Wildlife Service

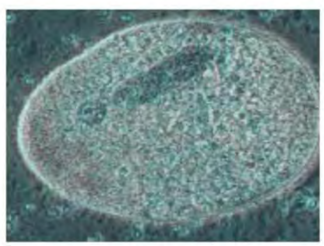
(Slide 128) A Conceptual Plan to Remedy Major Fish Pathogens in the Klamath-Trinity Basin
Joshua Strange, Ph.D., Stillwater Sciences

Panel Discussion- Linking Salmonid Health and Restoration Planning **not included
Overall fish health has been identified as a critical factor affecting population fitness across every salmonid life history stage; however, recovery efforts rarely prioritize disease diagnoses, prevalence, or prevention. The results of very expensive, large scale habitat restoration efforts aimed at salmon recovery can be superseded by unknown and unstudied microscopic infectious agents and organisms.

# SALMONID HEALTH:
## Effects of Parasites and Pathogens







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Report states parasite blinded salmon; virus found in brains - Microsoft Internet Explorer provided by AECOM

http://www.times-standard.com/general-news/20160323/report-states-parasite-blinded-salmon-virus-found-in-brains

Report states parasite blinde...

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# Eel River
# 03/23/2016

Home News

# Report states parasite blinded salmon; virus found in brains

A Chinook salmon with clouded eyes showed signs of blindness during an Oct. 20, 2015 survey on the lower Eel River. A preliminary report from UC Davis found that the cause of the blindness was from a parasite commonly known as a fluke. courtesy of Eric Stockwell

*By Will Houston, Eureka Times-Standard*

POSTED: 03/23/16, 10:45 PM PDT | UPDATED: 1 WEEK, 6 DAYS AGO | 0 COMMENTS



MOST POPUL

DAY WEEK NEWS SPORTS BIZ A&E

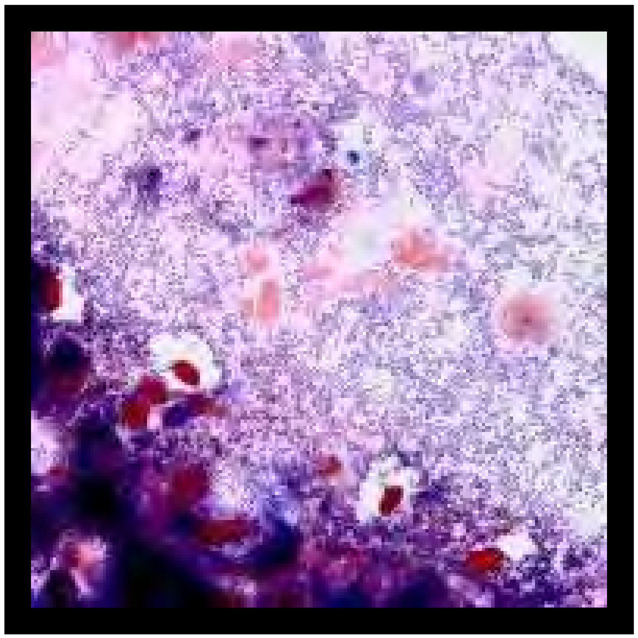
## Parasites & Pathogens: Not something normally on fish biologists or restorationists radar, but should be…

- Dr. Bill Cox, Fish Pathologist, Dept. Fish & Wildlife
- Wood et al.(2013). Marine protected areas facilitate parasite populations among four fished host species of central Chile. Journal of Animal Ecology 82, 1276–1287
- Chapman et al. (2015). Variation in parasite communities and health indices of juvenile *Lepomis gibbosus* across a gradient of watershed land-use and habitat quality. Ecological Indicators 57 (2015) 564–572.
- Do our studies and projects facilitate parasite populations? Increase pathogen prevalence? Cause disease?

# Session Overview

- Overview of known pathogens and diseases (me)
- Ich in the Klamath (Michael)
- *Ceratonova shasta* myxospore release timing (Scott)
- *C. shasta* in the Klamath (Kimberly)
- Remedy for pathogens in the Klamath (Josh)
- Panel Discussion: Parasites & Restoration

# Presence and Prevalence of Pathogens and Diseases in PNW Salmonids



*Renibacterium salmoninarum*

Bacterial Kidney Disease

**Cynthia Le Doux-Bloom, Ph.D.**
**Senior Fish & Aquatic Wildlife Scientist**

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# Goals

- Describe the known pathogens and diseases
- Provide sources for investigating the pathogens and diseases recorded in your watershed
- Provide reporting methods to USFWS
- Identify signs of infection and disease in the field
- Understand the capacity that pathogens have to derail recovery, yet remain unconsidered in the project planning or assessment processes

# Concepts and Terms

- Most fish are infected/infested with parasites
- Parasite vs. Pathogen
- Infection vs. Disease
- Transmission
  - Horizontal
  - Vertical
  - Both
  - Host

# Reduce Stress & Pathogen Transmission

**Reduce Cortisol**

- Use source water filled bags, buckets, or tubes to measure, weigh, and/or transport fishes
- Use dark containers with lids
- Work in low or no light conditions
- Avoid allowing fish to touch any non-smooth surface

**Reduce Horizontal Transmission**

- Disinfect gloves and hands between handling fishes
- Avoid overcrowding in nets, buckets, traps, and seines
- Remove fish frequently from traps (hourly)
- Plan restoration sites that remain connected during low flow conditions

# Stress: Its Role in Fish Health

## Biological Stressors

- Population density
- Aggression, territoriality, lateral swimming space requirements
- Parasites

## Chemical Stressors

- Poor Water Quality
- Pollution
- Diet composition
- Nitrogenous and other metabolic wastes

# Stress: Its Role in Fish Health

**Physical Stressors**

- Temperature
- Light
- Sound/Noise/Pressure
- Dissolved Gases

**Procedural Stressors**

- Capture
- Holding
- Handling
- Tagging/Clipping
- Transporting

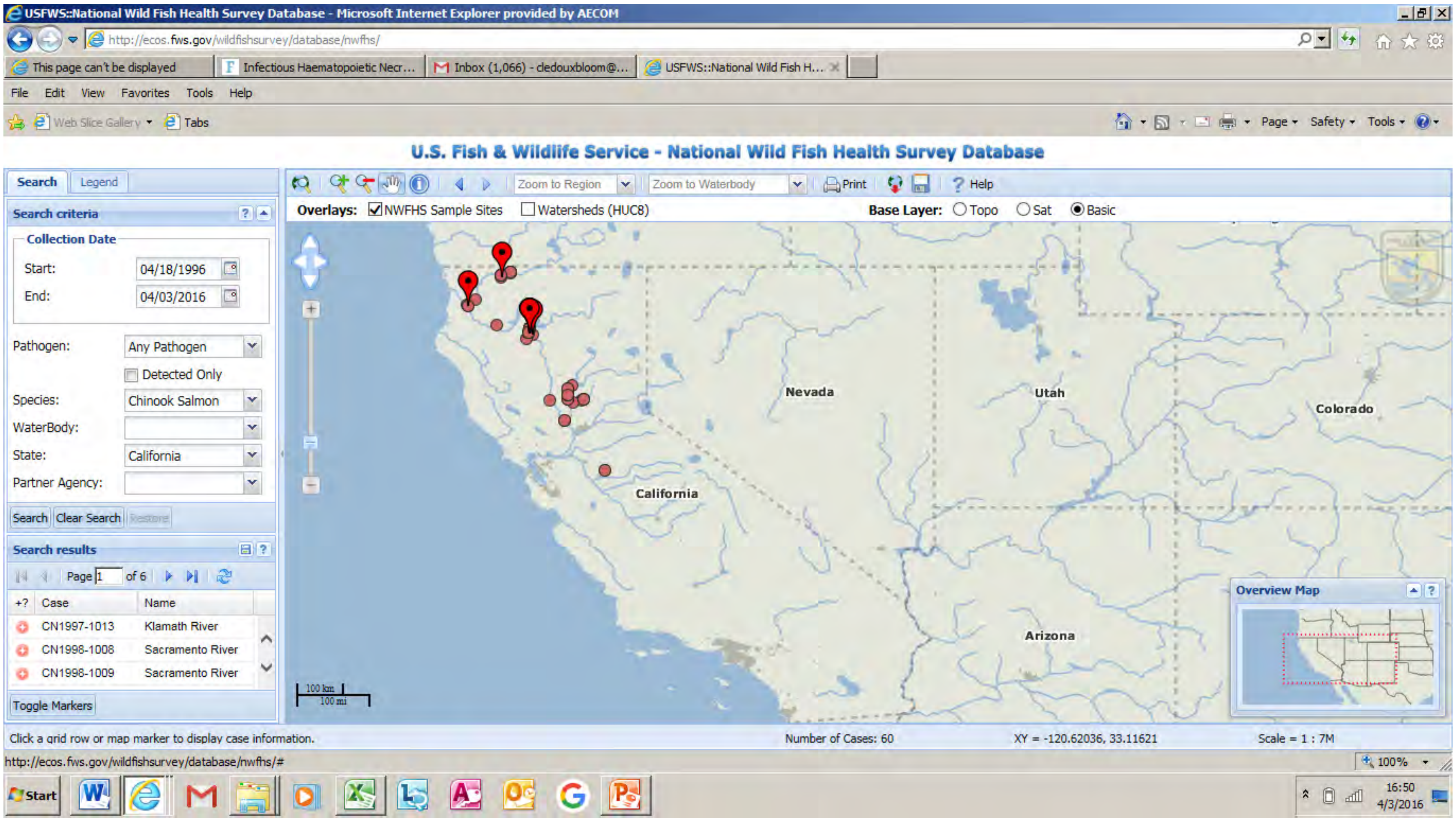
**Alarm Reaction ("Fight or Flight" Response)**
**=Stressed Out Fish**

# Types of Fish Diseases

- Viral (e.g., Infectious Hematopoietic Necrosis)
- Bacterial (e.g., Kidney, Red Mouth)
- Fungus
- Protozoan (External) (e.g., Ich)
- Protozoan (Internal) (e.g., Enteronecrosis)
- Trematode, Cestodes, and others…
- Copepod Parasites (e.g., lice) and more…

# USFWS National Wild Fish Health Survey

## http://ecos.fws.gov/wildfishsurvey/database/nwfhs/



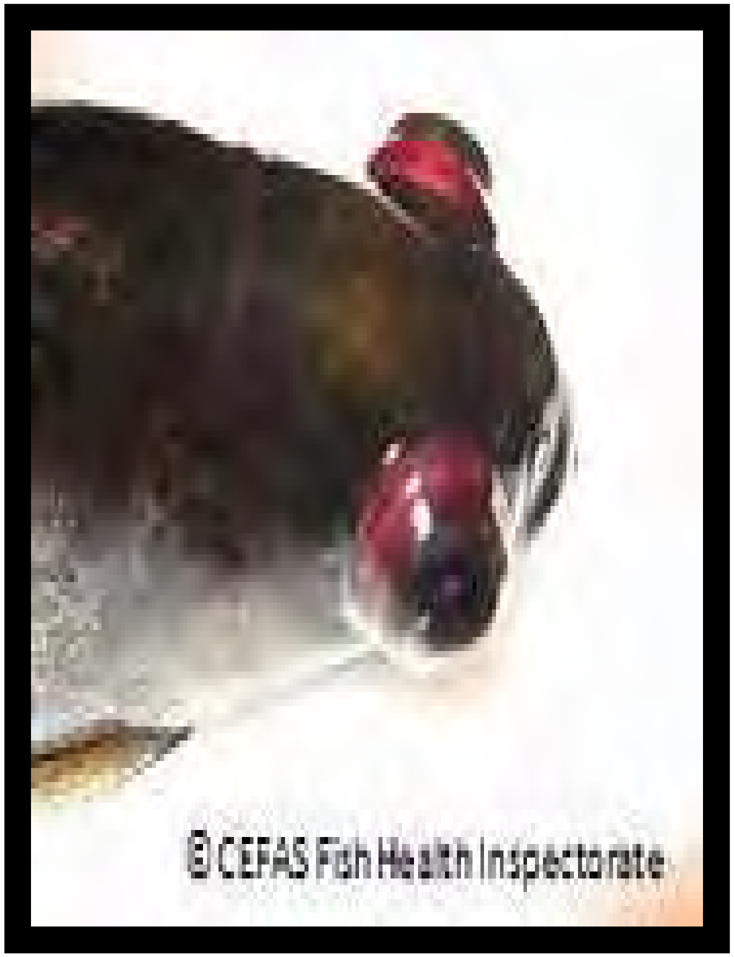
# Pathogen Presence and Ratio of Times Tested to Detection Rate by Basin

| Pathogen | Disease | Eel 2007 (1 yr) | Klamath 1997-2014 (14 yrs) | Sacramento 1997-2014 (17yrs) | San Joaquin 1999-2014 (11 yrs) |
|---|---|---|---|---|---|
| IHNV | IHN | 2:0 | 23:2 | 383:47 | 135:0 |
| *Aeromonas salmonicida* | Furunculosis | 0:0 | 23:0 | 49:5 | 31:0 |
| *Flavobacterium columnaris* | Columnaris | 0:0 | 17:0 | 2015 + | 6:1 |
| *Ichthyophthirius multifiilis* | Ich | ? | 20:9 | 2015 + | ? |
| *Renibacterium salmoninarum* | Bacteria Kidney Disease (BKD) | 1:0 | 12:2 | 55:8 | 1:1 |
| Yersinia ruckeri | Redmouth | 1:0 | 29:0 | 223:2 | 65:0 |
| *Ceratonova shasta* | Enteronecrosis | 0:0 | 26:19 | 24:19 | 4:0 |
| *Myxobolus cerebralis* | Whirling | 0:0 | 14:0 | 49:3 | 6:0 |

**Pathogen: *Infectious Hematopoietic Necrosis Virus***
**Disease: Infectious Hematopoietic Necrosis (IHN)**

- Viral (1)
- Most salmonids susceptible- juveniles highly
- Horizontal Transmission
- Vertical Transmission
- Outbreak related to immune suppression
- Survivors remain carriers
- Present in Klamath & Sacramento Basin

# Clinical Signs: IHN




# Pathogen: *Aeromonas salomonicida*
# Disease: Furunculosis

- Bacterium
- Horizontal Transmission
- Disease precipitated by poor water quality
- Susceptibility increases with mucous damage
- High Mortality in Salmonids
- Survivors remain  carriers
- Sacramento Basin

# Clinical Signs: Furunculosis

**Kamble, R. (2015). Aeromonas salmonicida furunculosis in an adult male. Int.J.Curr.Microbiol.App.Sci 4(2): 59-63**

Furunculosis by *Aeromonas salmonicida in a 67 year old immunocompetent male*

## Pathogen: *Flavobacterium columnaris*
## Disease: Columnaris or Cottonmouth

- Bacterium
- Variety of fishes of all ages
- Horizontal Tranmission and via carcasses
- Outbreak caused by high water temperatures, low DO, crowding, and handling
- Sacramento and San Joaquin Basins

# Clinical Signs: Columnaris

# **Pathogen*: Renibacterium salmoninarun*** 
# **Disease: Bacterial Kidney Disease (BKD)**

- Bacterium
- Most salmonids- rare in juveniles
- Outbreak caused by high water temperatures, low flows, and crowding
- Klamath, Sacramento, and San Joaquin Basins

# Clinical Signs: BKD


## **Pathogen: *Yersinia ruckeri***
## **Disease: Yersiniosis or Enteric Red Mouth**

- Bacterium
- Affects a variety of fishes of all ages
- Horizontal Transmission
- Outbreak caused by high water temperature
- Survivors remain  carriers
- Sacramento Basin

# Clinical Signs: Red Mouth

**De Keukeleire et al. (*2014). Yersinia ruckeri*, an unusual microorganism isolated from a human wound infection. New Microbes and New Infections 4(2): 134-135**

## Pathogen: *Ichthyophthirius multifiliis*
## Disease: Ich or White Spot

- External Protozoan (1)
- Horizontal Transmitted
- Effects all fishes
- Outbreak caused by high water temperatures, low flows, and crowding
- Klamath and Sacramento Basins
- Michael will present more info

# Clinical Signs: Ich

# Pathogen: *Ceratonova shasta*
# Disease: Enteronecrosis

- Internal Protozoan (2)
- Salmonids- juveniles highly susceptible
- Host Transmitted- Scott & Kimberly will explain
- Outbreak caused by high water temperature, low flow, and crowding with infected fish
- Klamath and Sacramento Basins
- Scott and Kimberly will provide more info

# Clinical Signs: Enteronecrosis

# Pathogen: *Myxobolus cerebralis*
# Disease: Whirling

- Protozoan (Internal)
- Mainly Salmonids- juveniles highly susceptible
- Oligochaete worm intermediate host
- Pathogen released into water post mortality
- Outbreak may be linked to water pH-
- Sacramento Basin

# Clinical Signs: Whirling Disease

# Summary

- Prevalence of Aquatic Pathogens Increasing
- Poor WQ and Handling Cause Stress and Facilitate Disease Outbreak
- Sacramento Basin- salmon most highly tested and tests + for 8 pathogens
- Klamath Basin- salmon test + for 4 pathogens
- San Joaquin Basin- salmon test + for 2 pathogens
- Eel Basin remains untested/uninvestigated

# Take Home Messages

- Know the pathogens present in your watersheds
- Think about how ALL your activities could facilitate pathogen or disease transmission
- Reduce transmission- Reduce handling & disinfect
- BOL for signs of gross pathological infection during surveys
- Photograph and collect suspected infected fishes
- Report incidences to the USFWS Fish Health Center

# Acknowledgments

USFWS
Fish Health Center

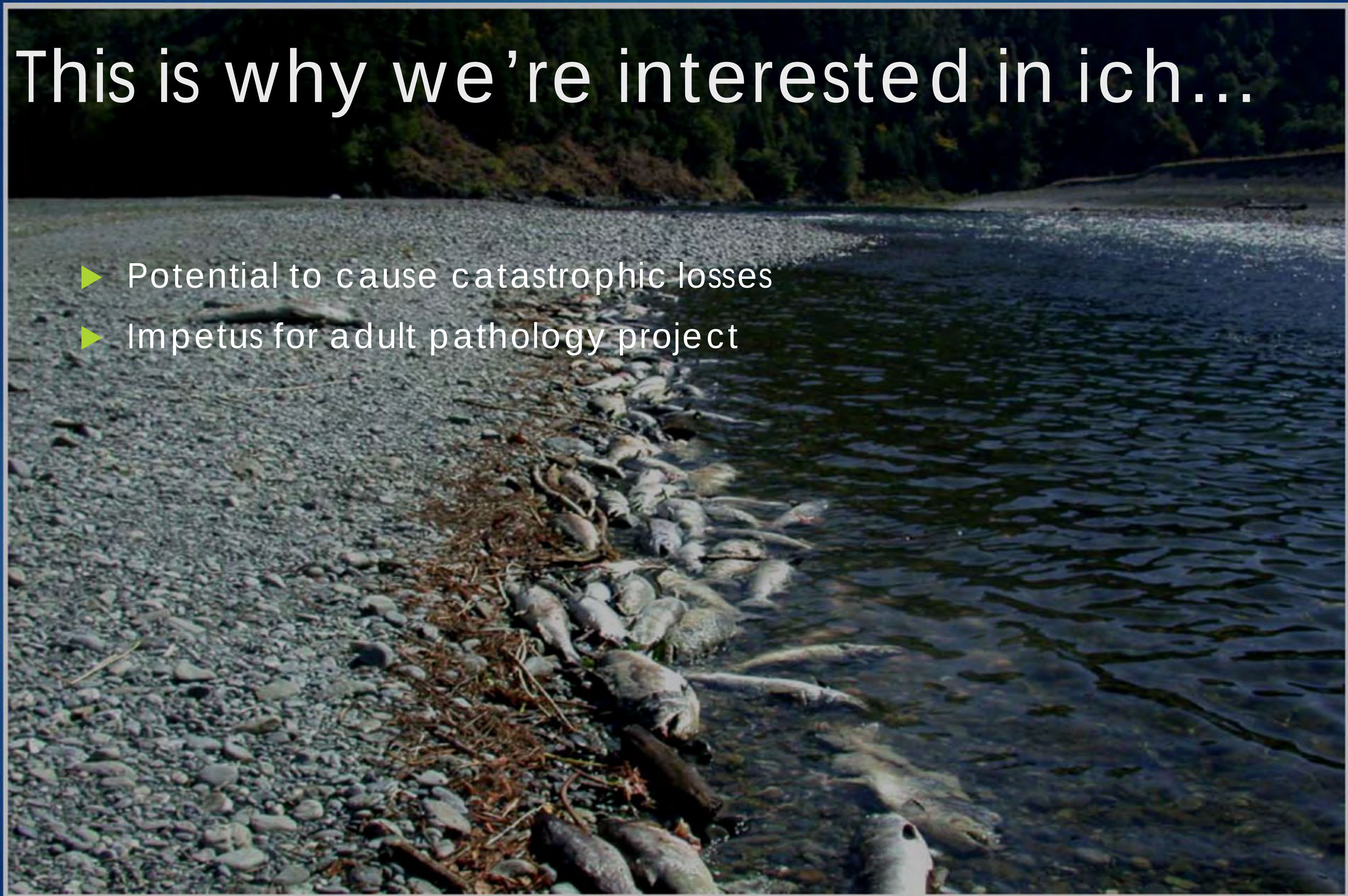
http://fishpathogens.net/

# 2015 Ich Sampling and Results

Klamath River

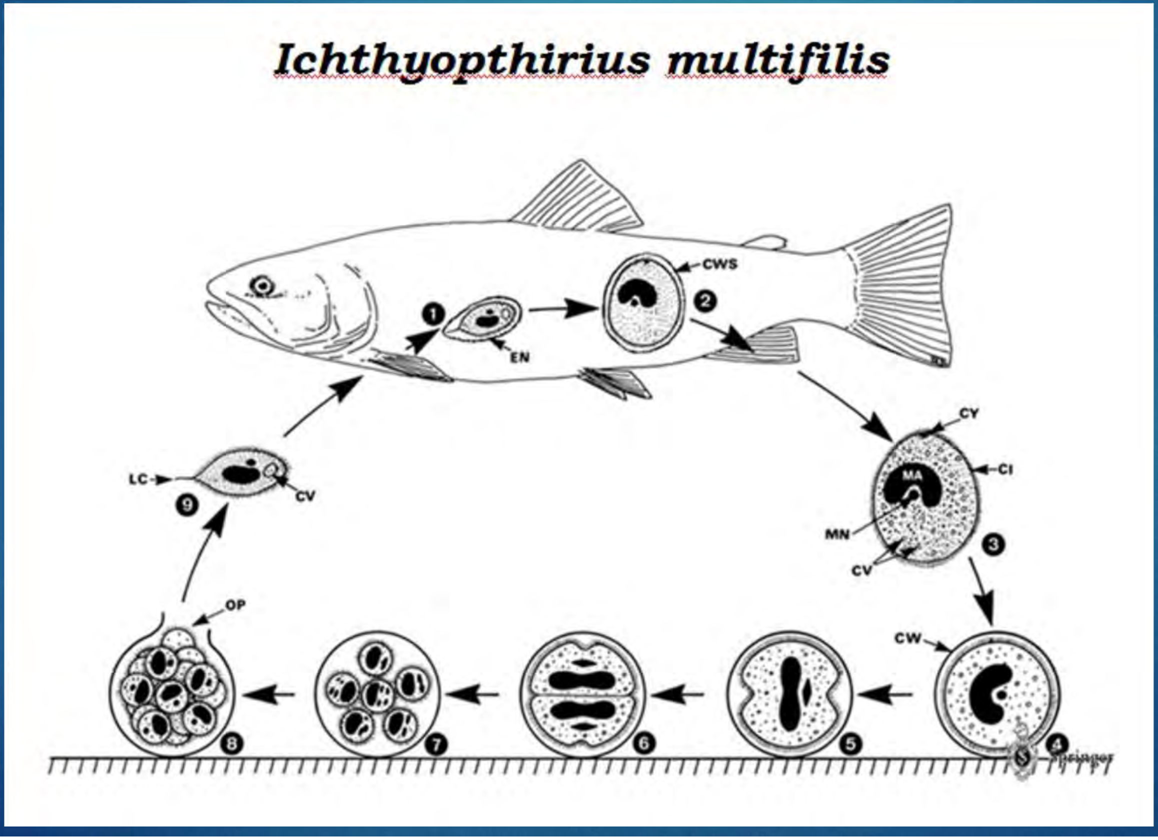
YUROK TRIBAL FISHERIES PROGRAM

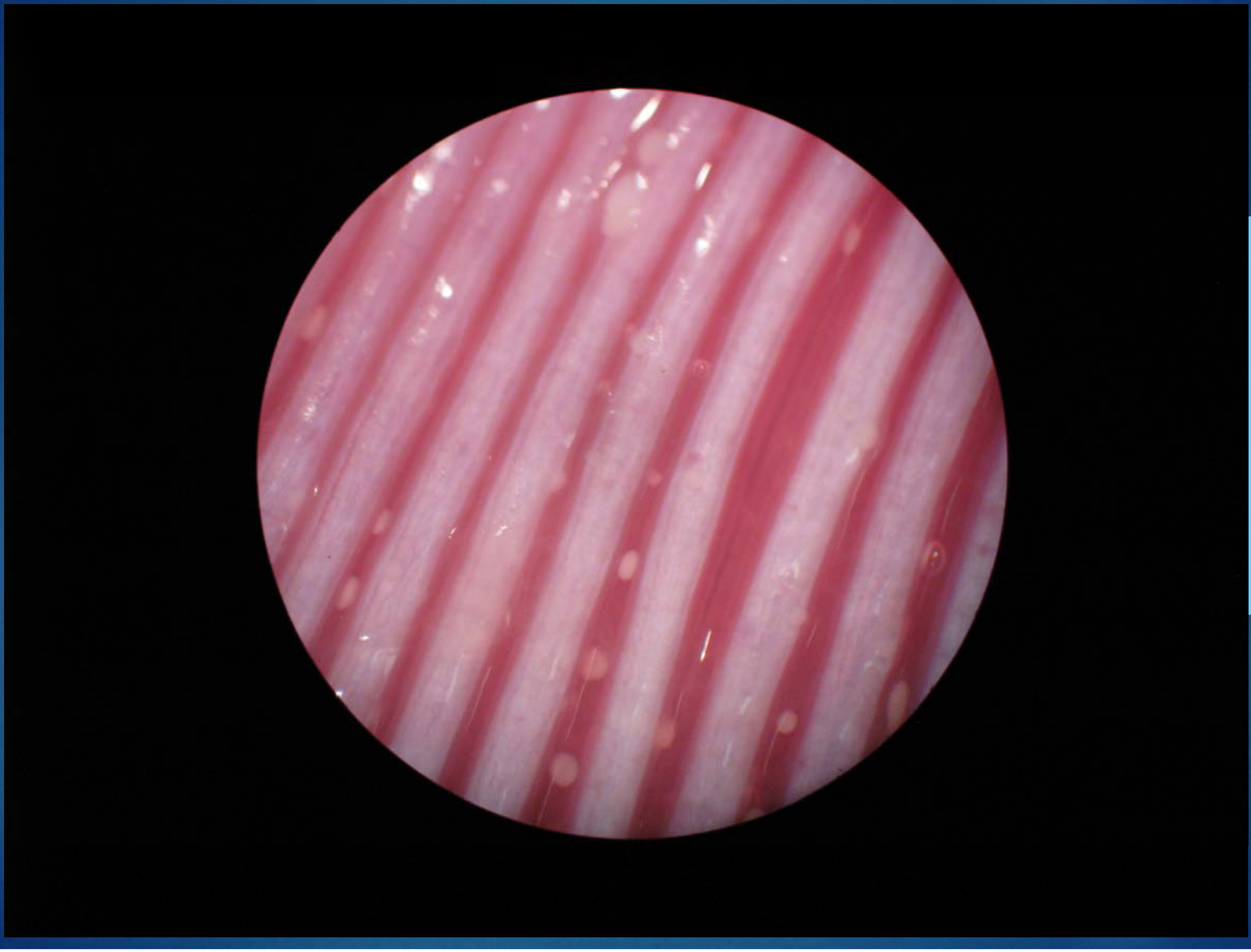
# This is why we're interested in ich…



- Potential to cause catastrophic losses
- Impetus for adult pathology project

Life cycle of Ich showing the parasitic trophonts stages (#1 and 2), the mature ciliated trophont stage (#3) attaches to benthic substrate before dividing into tomites (#6-8), which are then released as the ciliated theront stage (#9) that must actively swim and find a suitable host within approximately 24 to 72 hours. (Figure and caption from Strange 2010b).





# YTFP Adult Pathology Project

- Done since 2003
- Only ich detected was in 2003 until 2014
  - Problems with false positives due to metacercaria
- 2014 and 2015 Project started early due to:
  - High numbers of fish at Blue Creek
  - Controversy over preventative flows

# Blue Creek Thermal Refuge

# 2015 Ich Sampling Effort

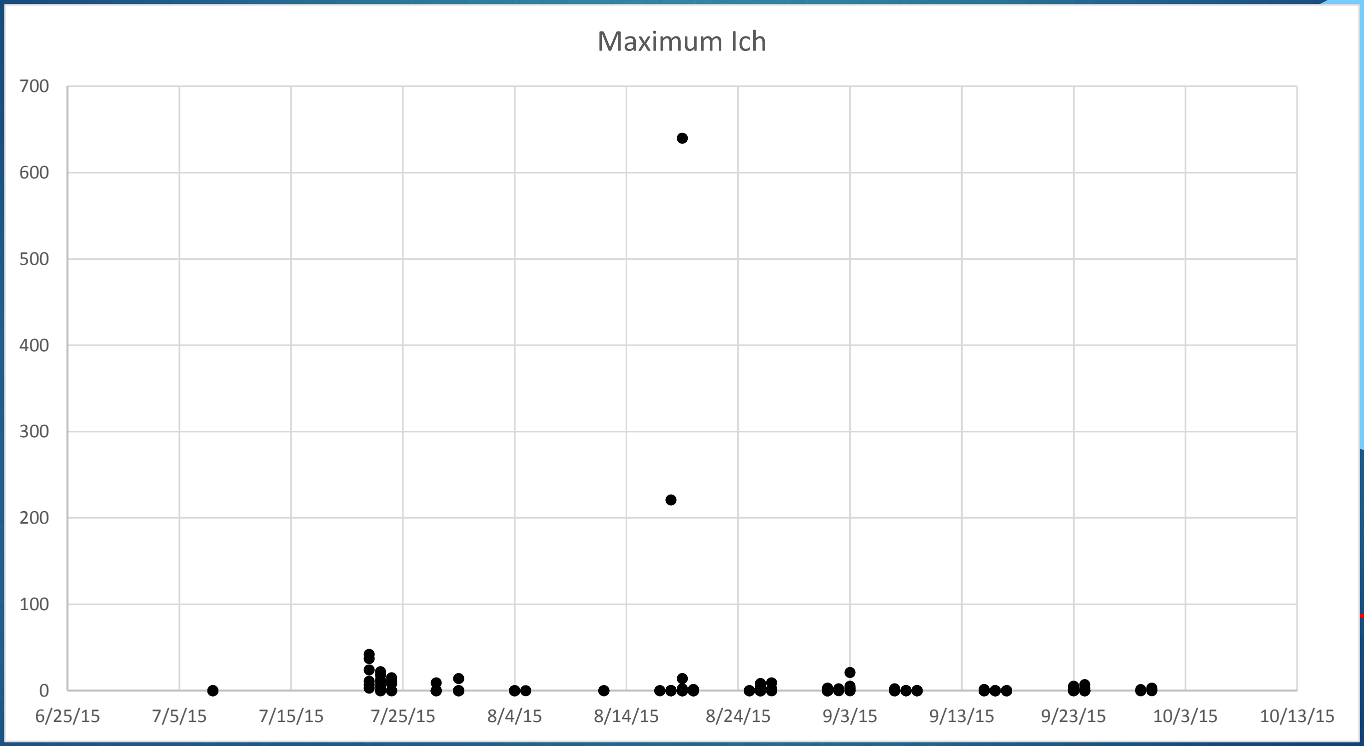
- Started on July 8; mostly at Blue Creek
- Large numbers of adult salmonids (many steelhead) holding in refugia at Blue Creek due to high mainstem river temperatures
- 209 total adult salmonids sampled
- Ich detected a month earlier than 2014 (July 22)
- Quickly rising ich; fish trapped at Blue Creek refuge;
- But then: flows arrive, significant rain, and then, smoke
- Temperatures dropped significantly

# Timeline:

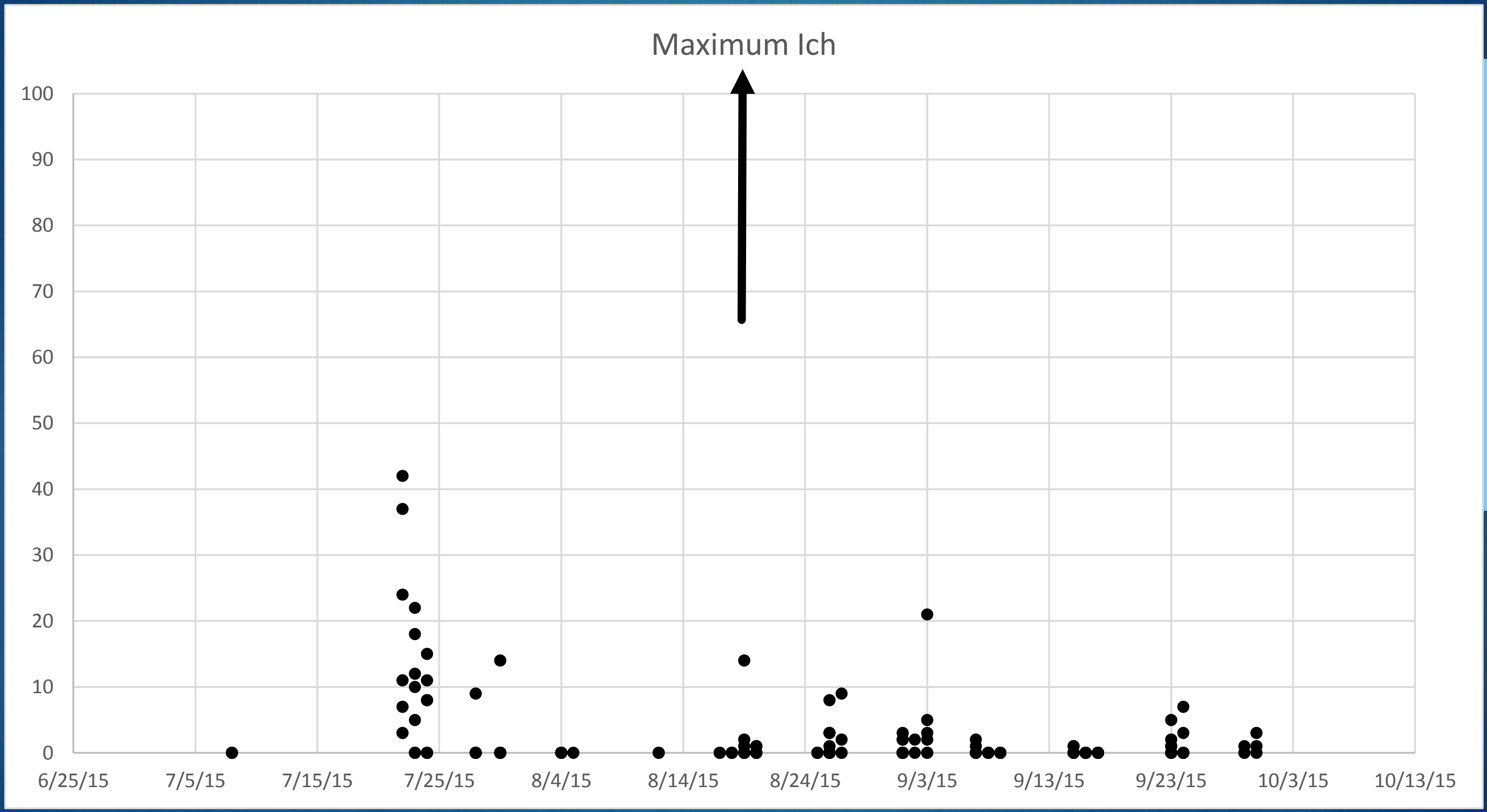
- July 8, sampling begins at Blue Creek; later moved to Tectah and Weitchpec
- August 17, flows increase in lower Klamath as fall flow releases arrive downriver (compare to August 26th in 2014); early increases from Hoopa Boat Dance, then from fall flows program of Bureau of Reclamation
- Daily updates provided to managers (Bureau of Reclamation)
- Weekly updates provided to KFHAT, other interested parties

# Results

- Ich did not increase as rapidly on the Yurok Reservation in 2015 as it did in 2014

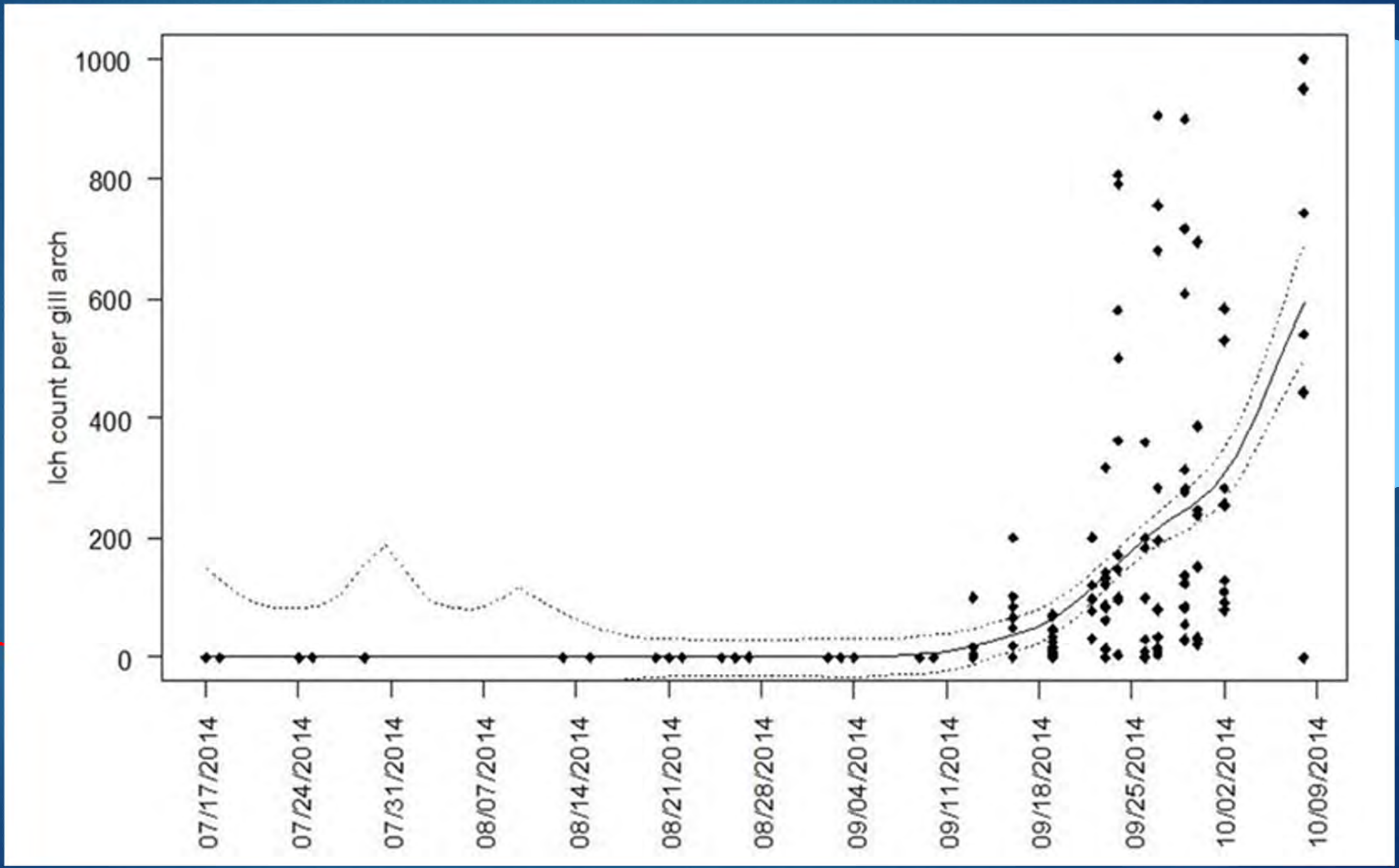


# Another Look with different Y-scale

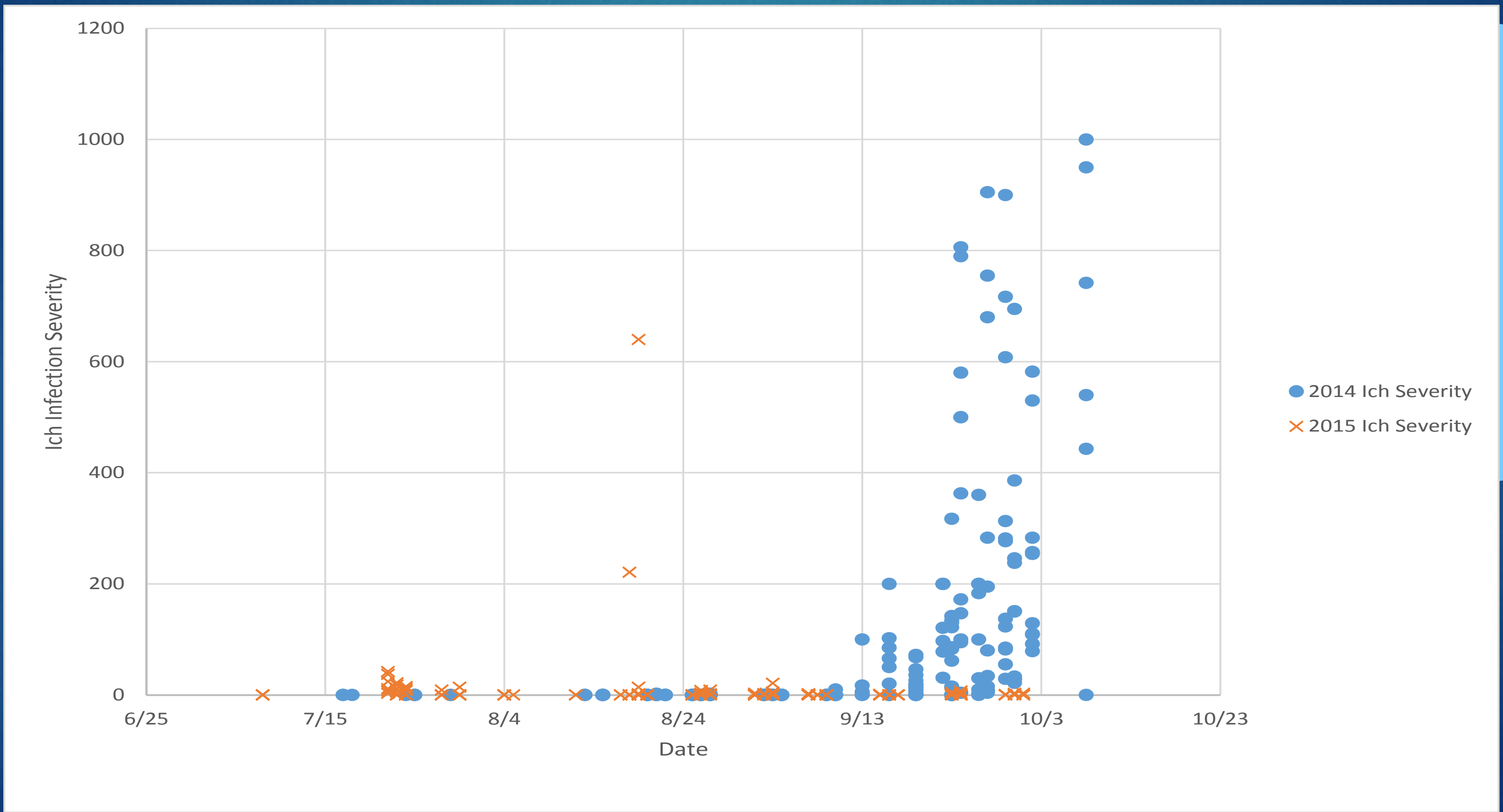


# Compare with 2014 Results

- Ich increased rapidly on the Yurok Reservation in 2014



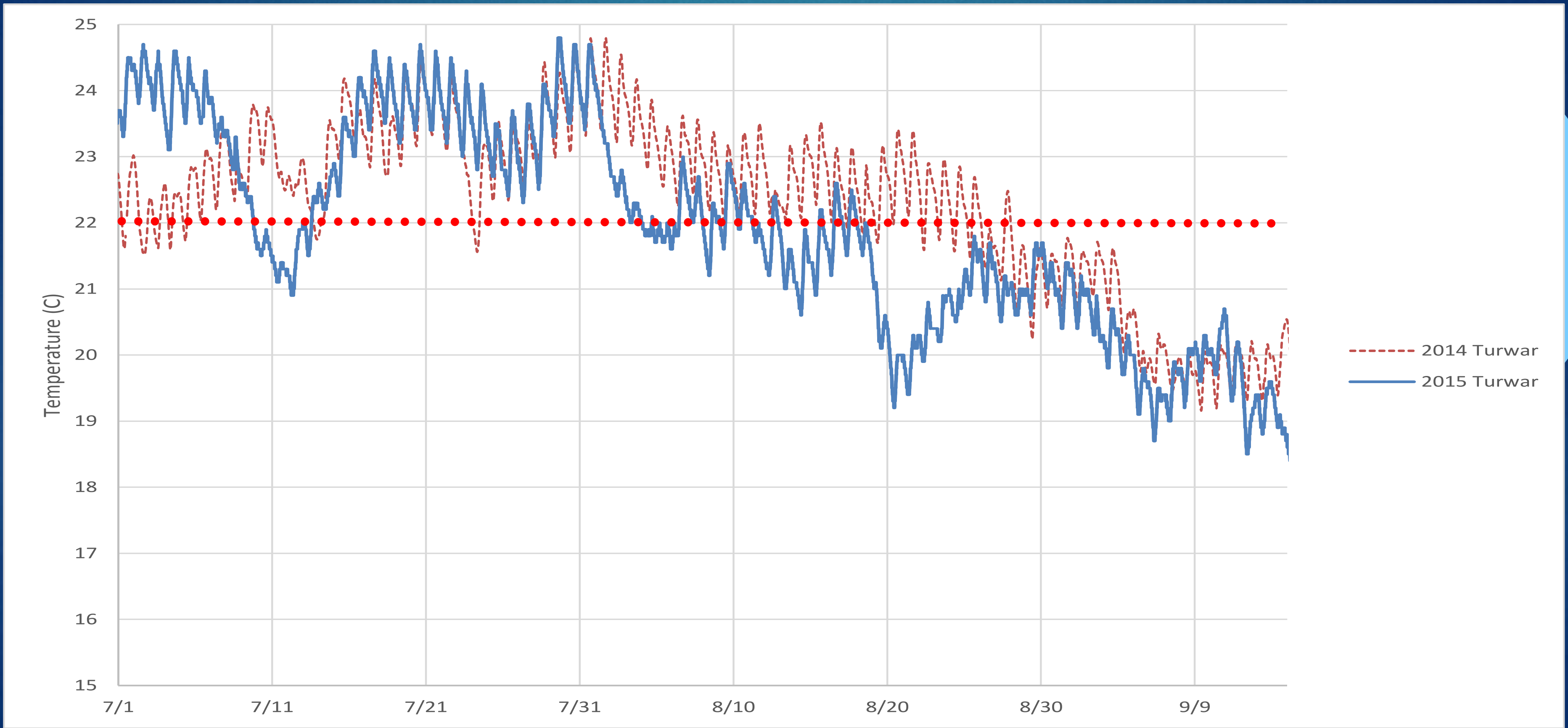
# 2014 and 2015 Ich Results



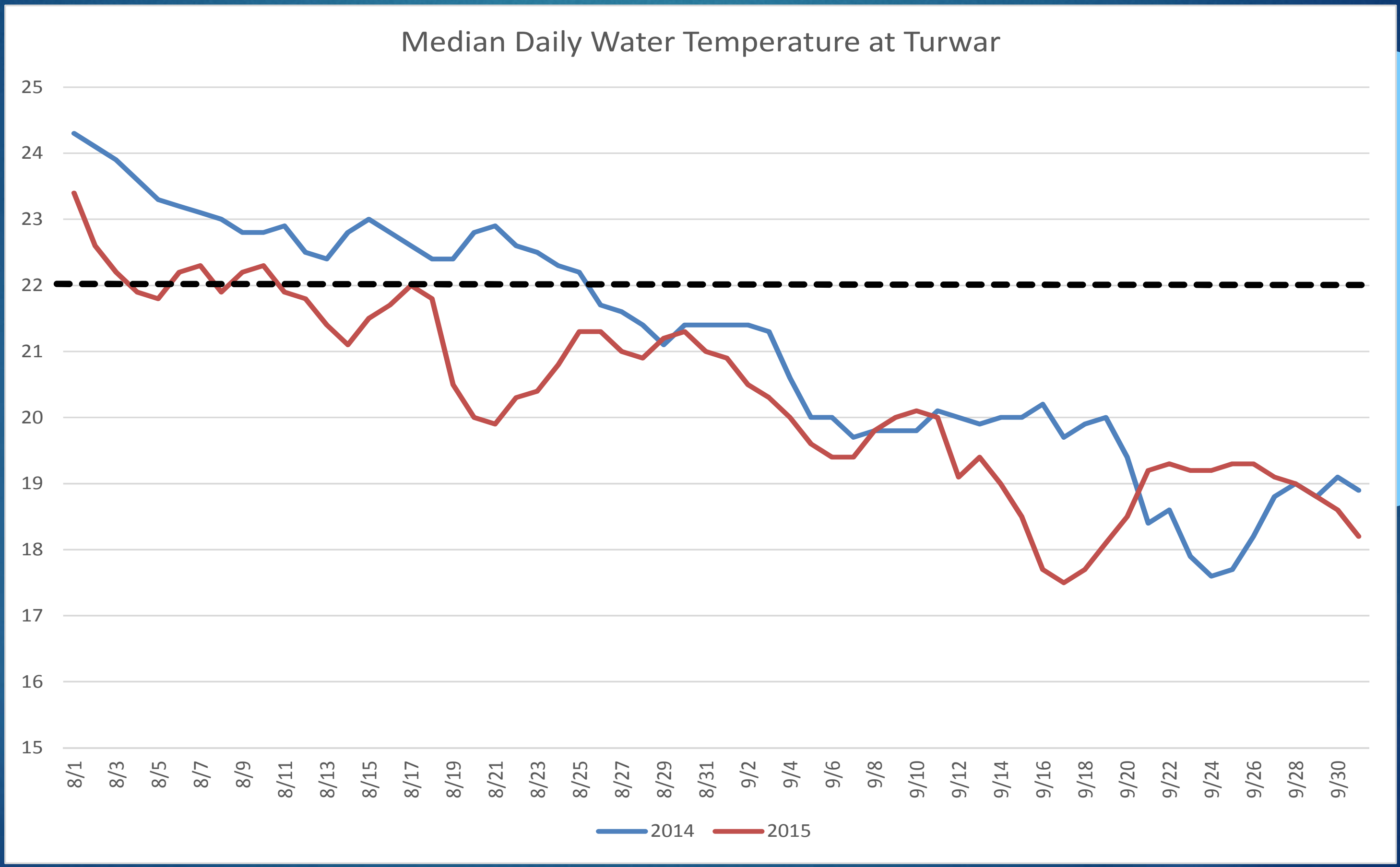
# What differences were there between 2014 and 2015

- Increased flows started earlier in 2015 (August 17 versus August 26
- Water temperatures were lower in mid summer and during the fall migration
- Adult salmonid densities were lower at Blue Creek Refugia
- The fall run was much smaller

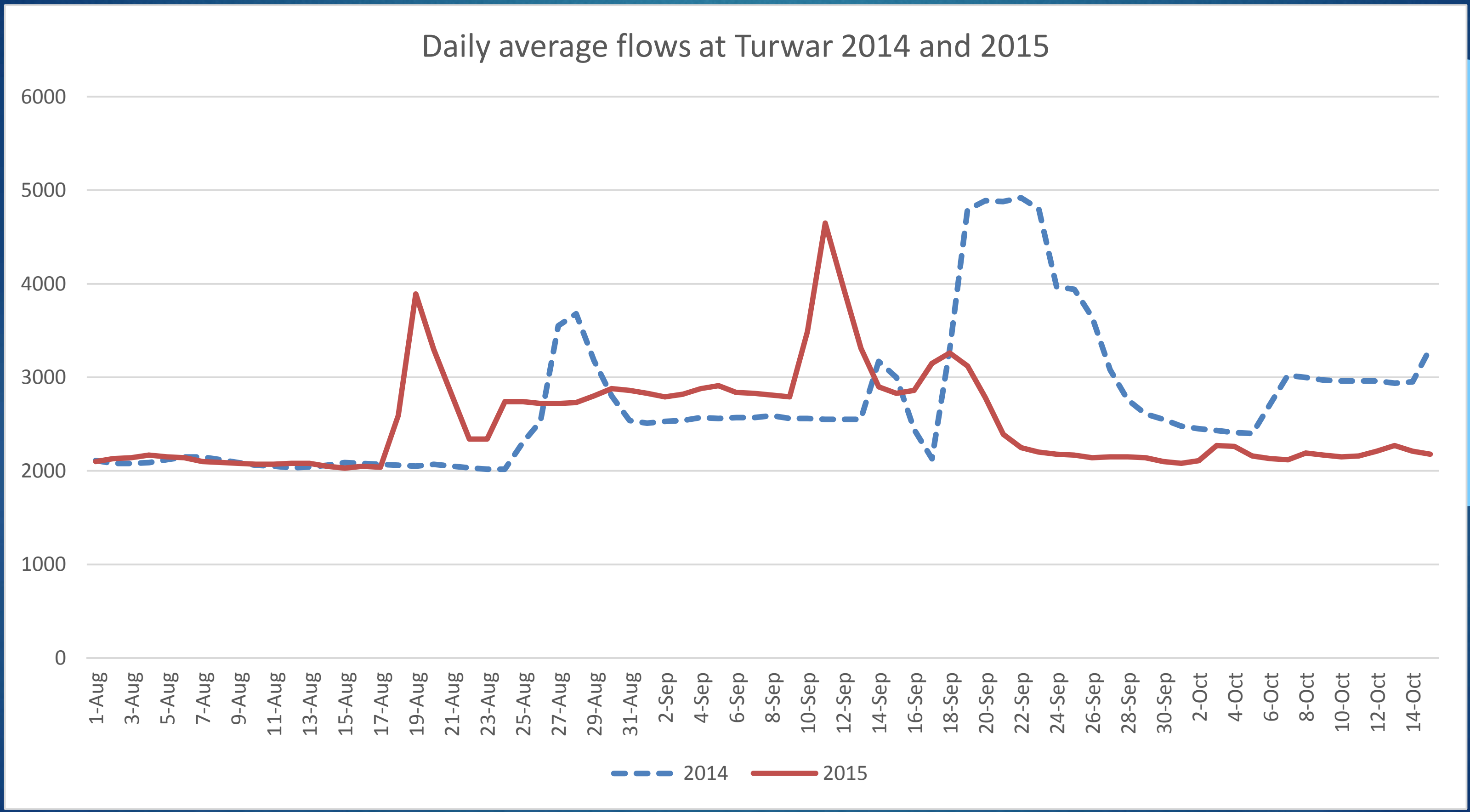
# Water Temperatures in the Lower Klamath River in 2014 and 2015



# Median Water Temperature



# Flows at Turwar



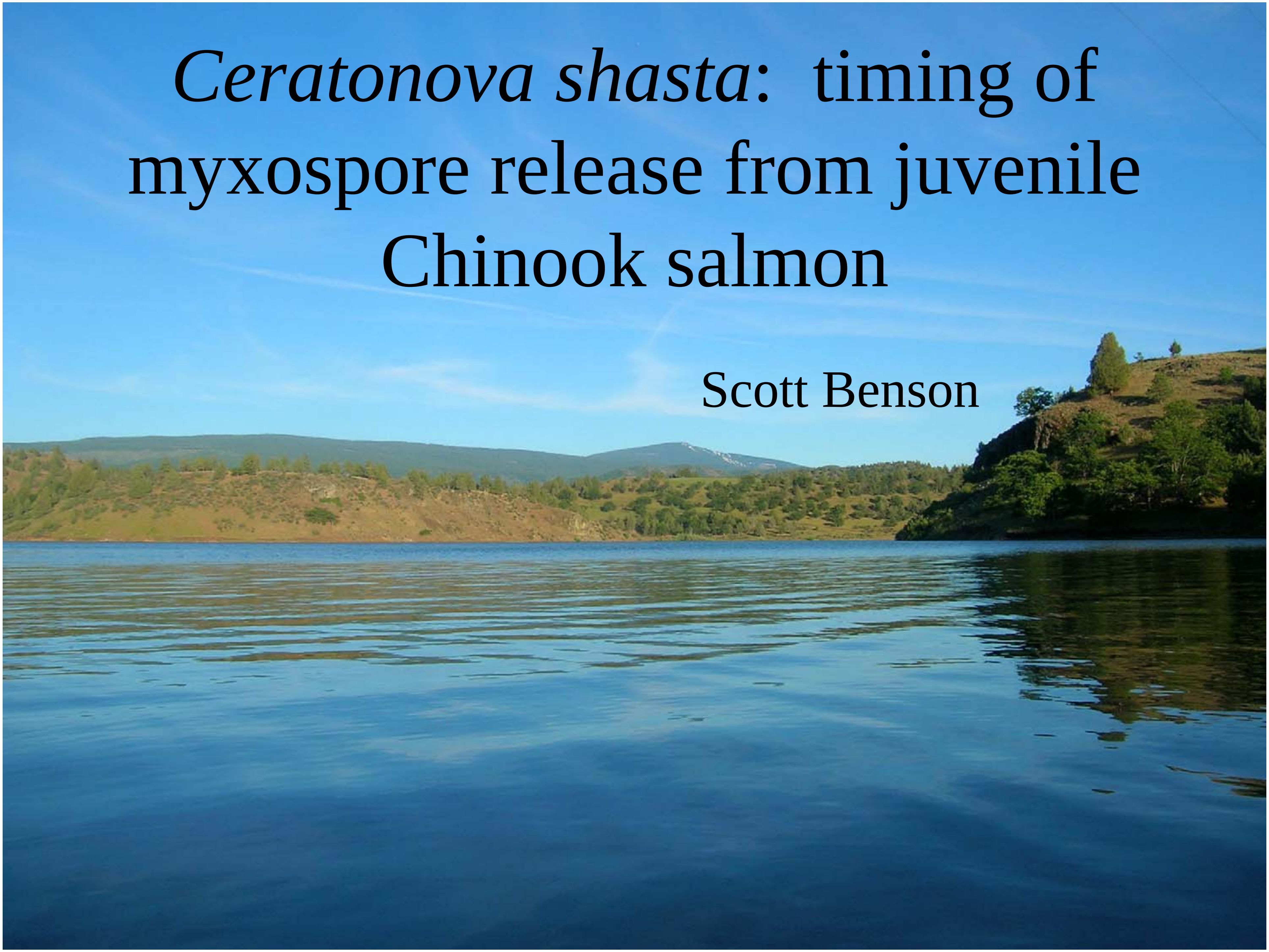
# Effect of Increased Flows

- Decreases chance of theront to find another fish because of increased turbulence and velocity
- Can directly advect tomonts away from areas with higher fish densities
- Decreases fish density
- Lowers temperatures
  - Allows for migration to occur instead of fish being “stranded” at Blue Creek
  - Increases life span of ich (slowing reproduction rate)
  - Increases general fish health and resistance to ich


Questions?

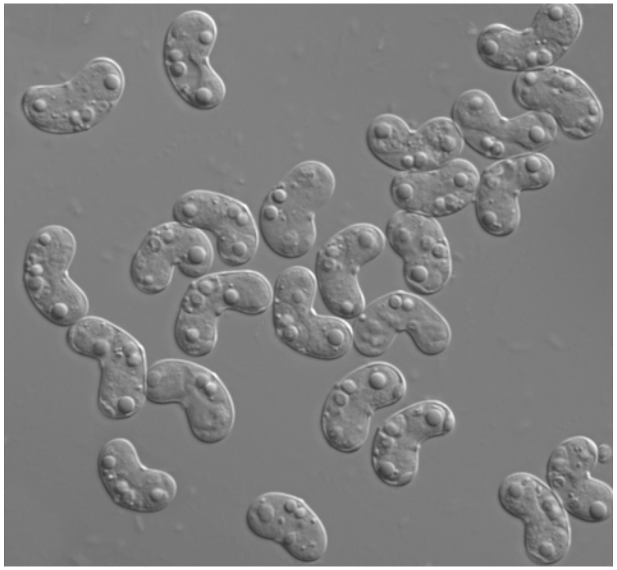
# *Ceratonova shasta*: timing of myxospore release from juvenile Chinook salmon

Scott Benson



# *Ceratonova shasta*

- Phylum Myxozoa
  - Class Myxosporea (2,180+ species)
- Spore-forming microparasites



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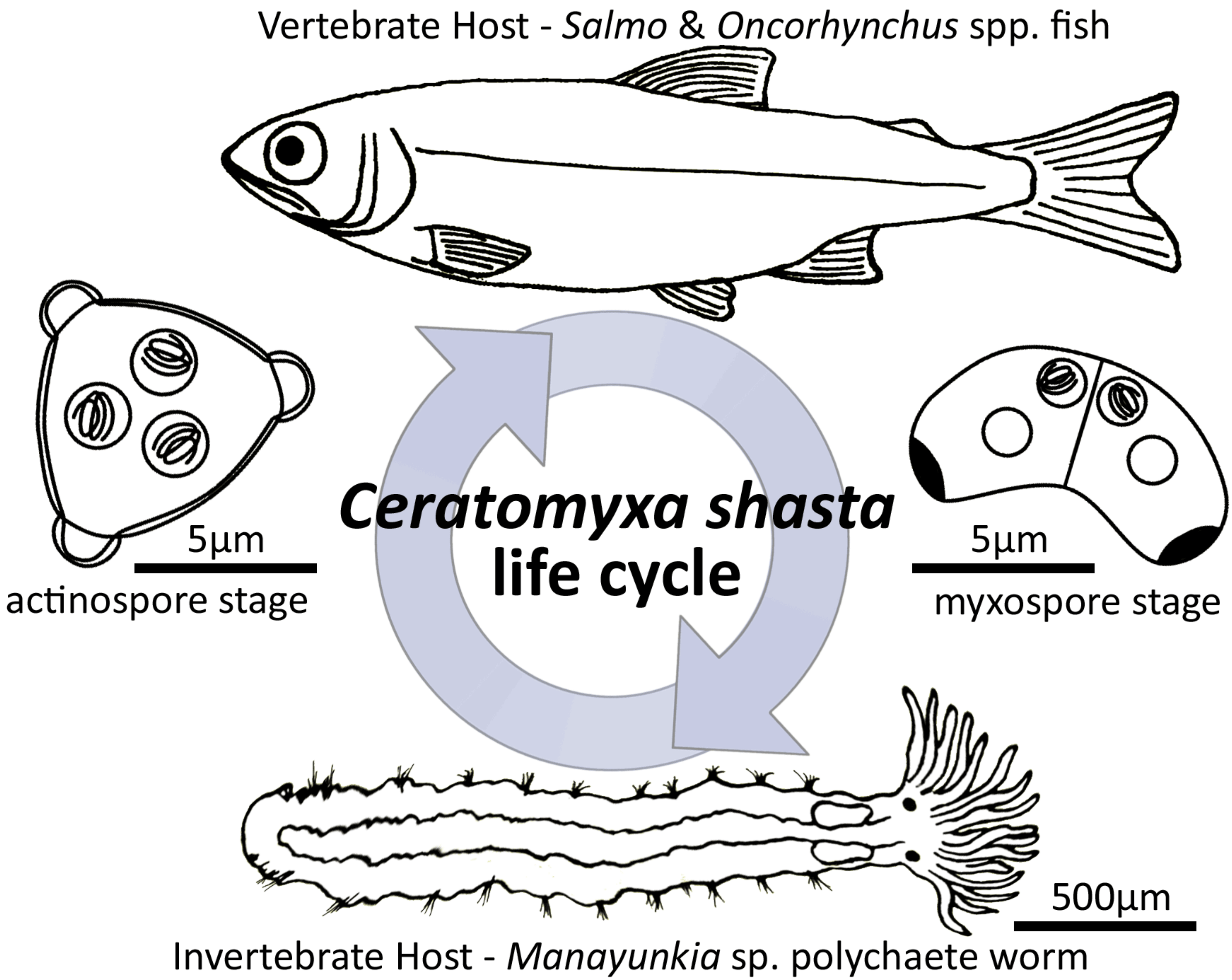
http://microbiology.science.oregonstate.edu

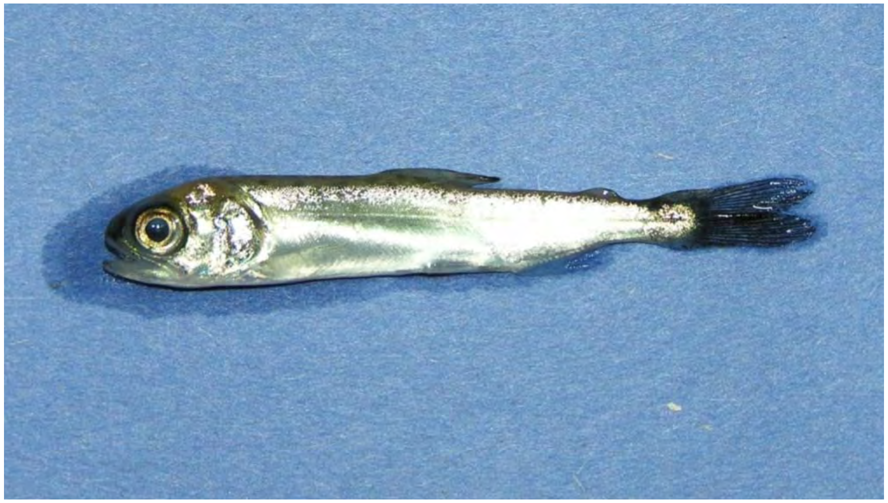



http://fishpathogens.net/image/cslifecyclegif (illustration by S. Atkinson)

# *Ceratonova shasta*: disease

- Salmonid host: intestinal tissue
  - Swelling
  - Hemorrhaging
  - Necrosis
    - Ascites (accumulation of fluid in body cavity)
    - Inability to absorb nutrients
    - Impaired osmoregulation
- Ceratomyxosis: typically fatal

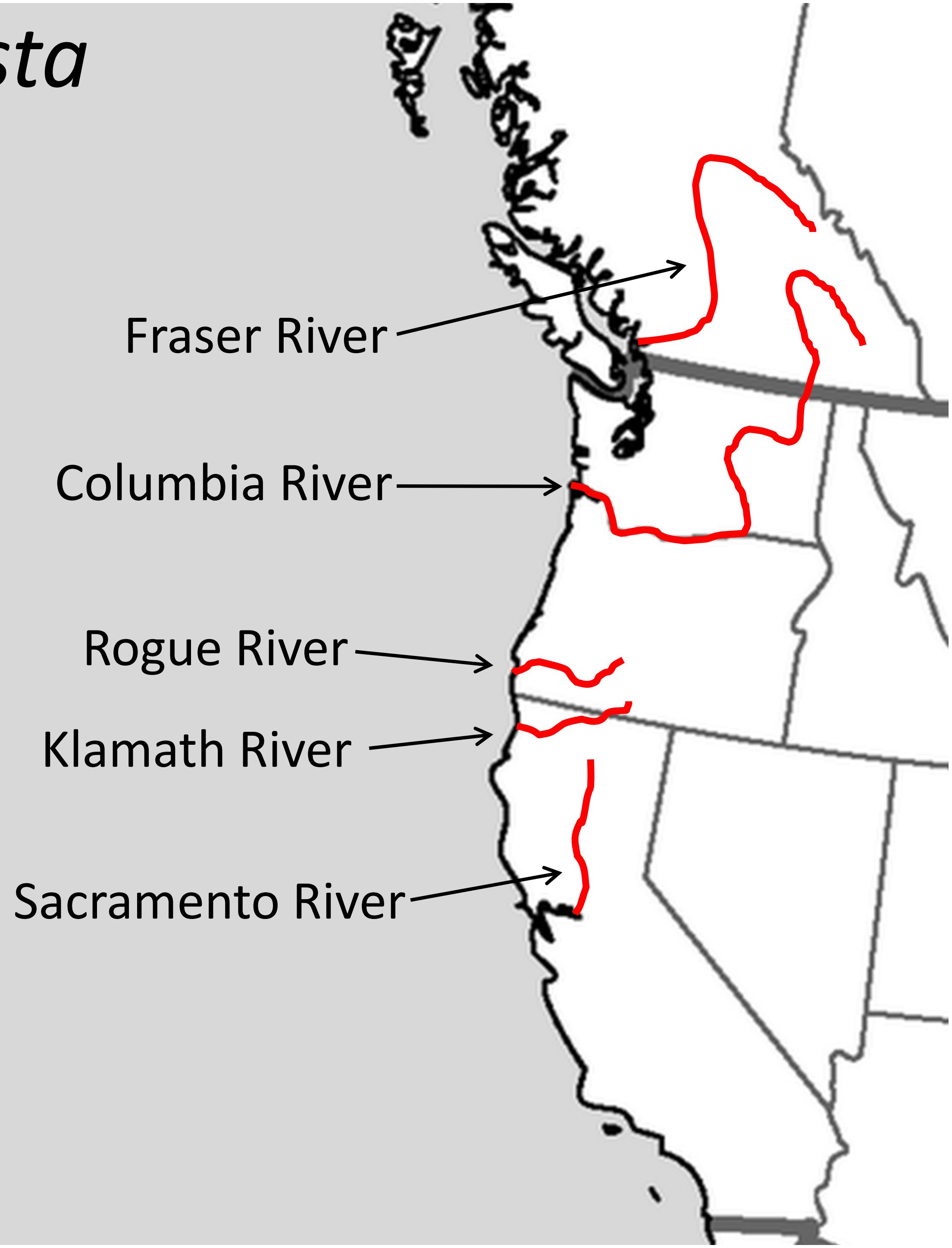
# Ceratomyxosis:  Clinical Signs




# *Ceratonova shasta* Distribution

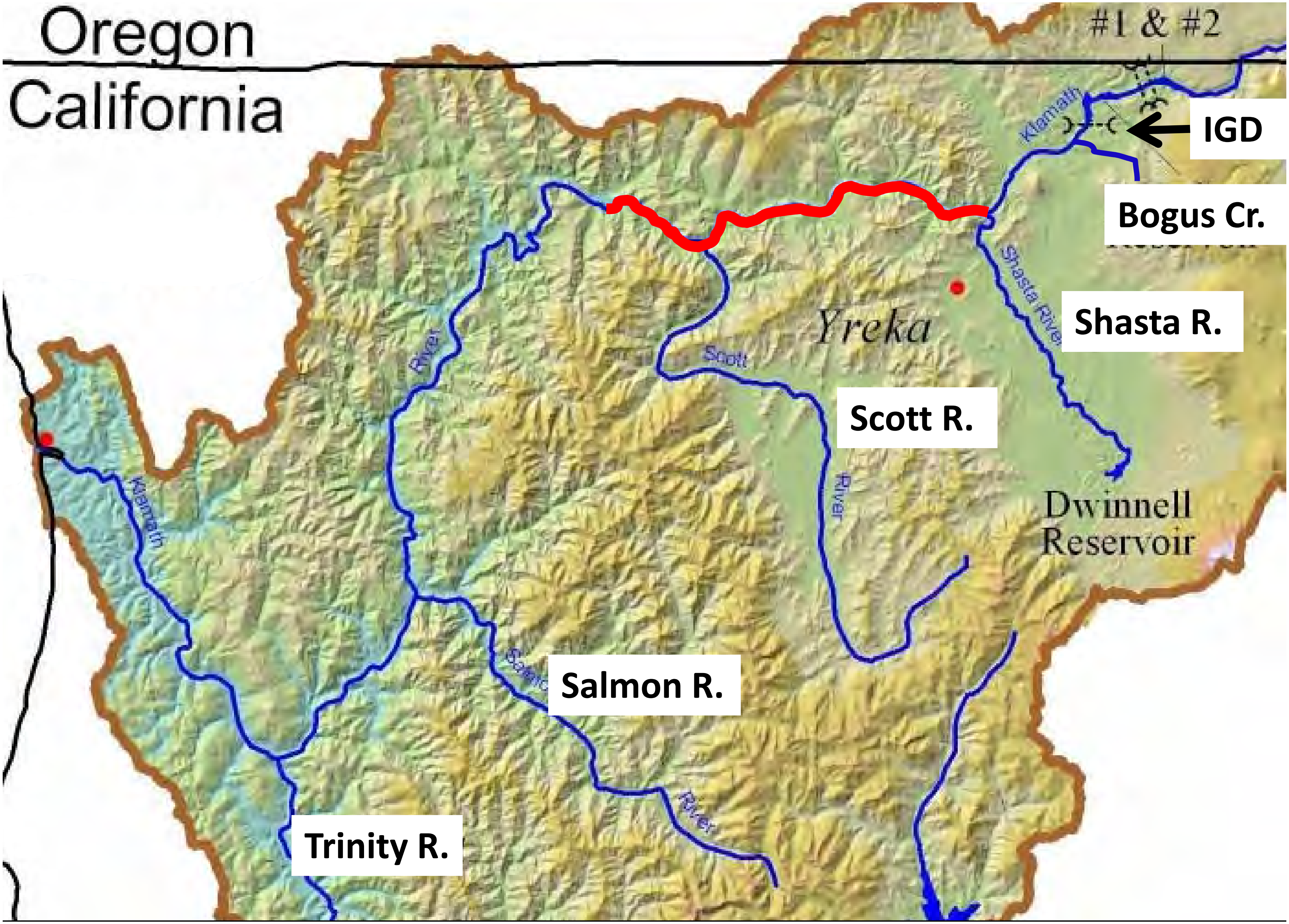
Not ubiquitous within drainages:

i.e.  Main stem Klamath River is infective to fish, but tributaries are not



# *Ceratonova Shasta*: Klamath River

- Extensive loss of juvenile Chinook salmon, 10+ years
- Nichols & True 2007: IGH juvenile Chinook salmon
  - Infected within 5 days of release
  - 3 weeks: 65% infected
  - No histological evidence of recovery
- Generally about 25% to 30%
  - Varies by year and detection method
- Fujiwara et al. 2011: disease effect at population level
  - Bogus Creek & Shasta River: increased juvenile mortality
    - Migrate through entire "hot zone"




http://www.usbr.gov/mp/kbao/maps/1_basin.jpg

# Possible Control Measures

- Eliminate polychaetes
  - Infection rate ≤ 8%
  - Must remove nearly all ⟶ not feasible
- Remove adult Chinook salmon carcasses
  - 10% of carcasses produce 90% of myxospores
  - Must remove nearly all ⟶ not feasible
    - Would also remove significant nutrient source

# Study Objectives

1. Describe timing of myxospore release from juvenile Chinook salmon

2. Estimate total # myxospores released from a juvenile Chinook salmon

3. Estimate # released from an adult Chinook salmon

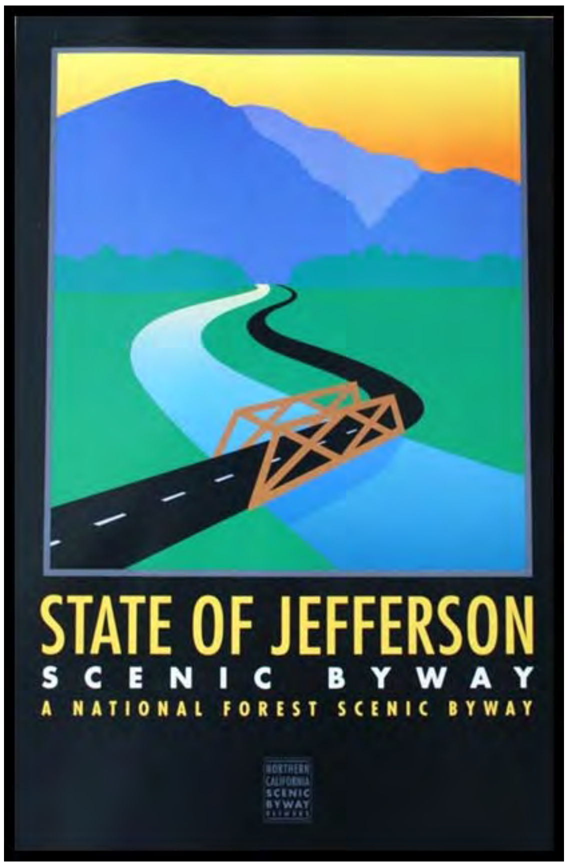
# Methods

- Expose fish to *C. shasta*
  - Cages in Klamath River, 3 days

IACUC: 09/10.F.39-A

# Iron Gate Hatchery


OREGON
CALIFORNIA
PACIFIC OCEAN
US 101
ENLARGED AREA
Yreka
HWY 96
I-5
HWY 299
Eureka
N
16 km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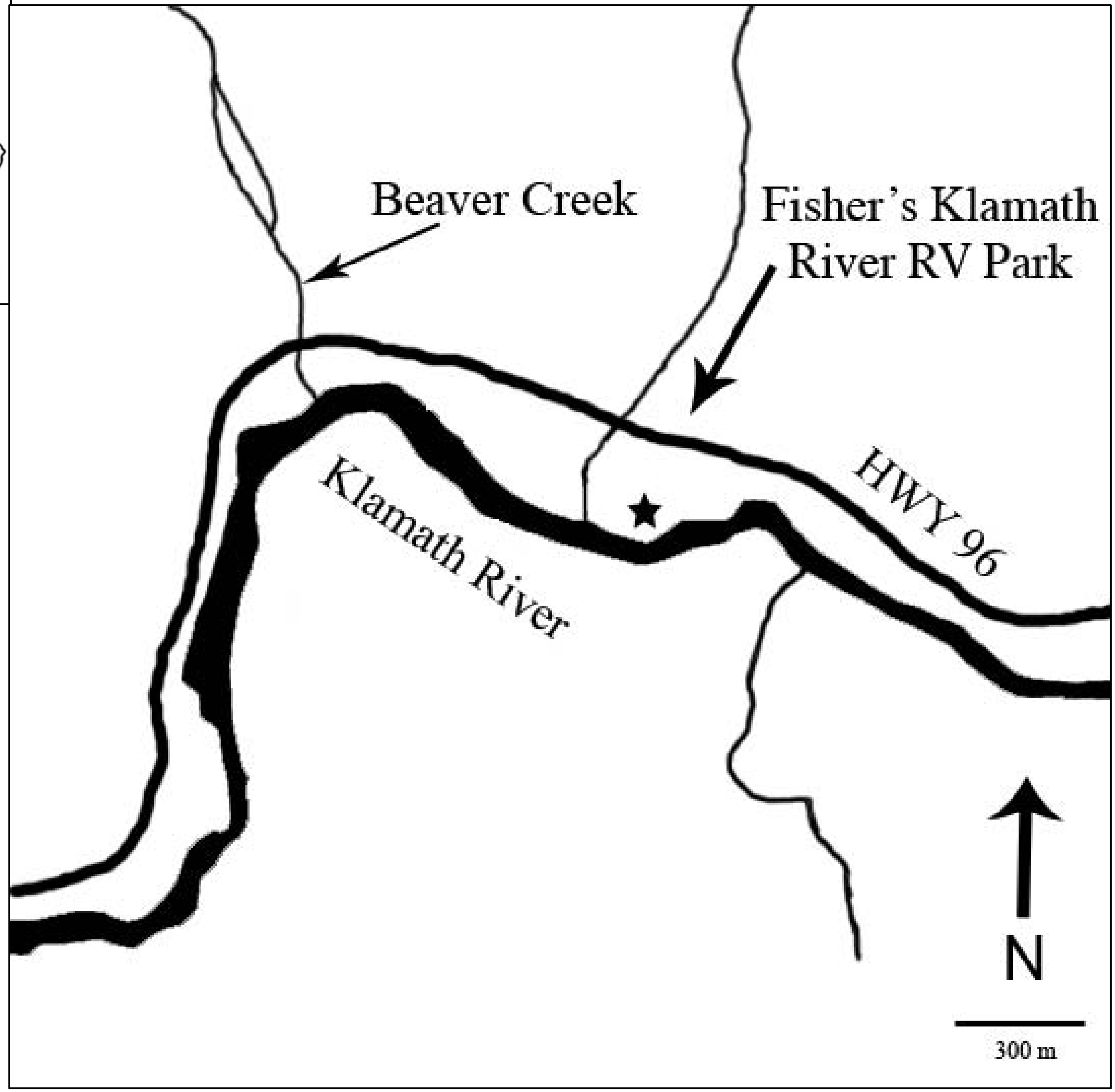
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Fisher's Klamath River RV Park
Klamath River
HWY 96
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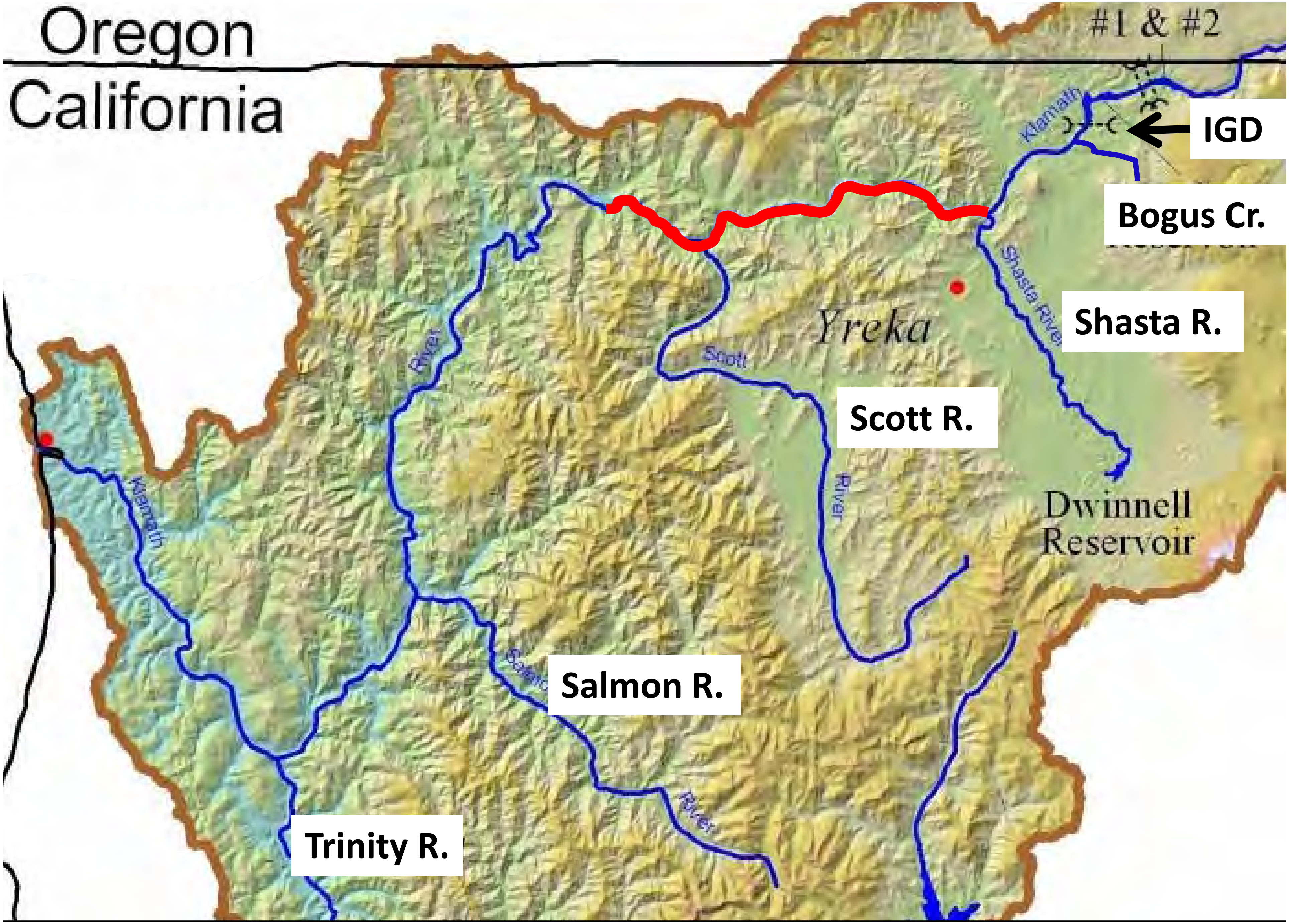
300 m

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# Exposure

# Methods

- Expose fish to *C. shasta*
  - Cages in Klamath River, 3 days
- Rear in lab at stable temperature
  - Separate, independent, closed tanks

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FP-5
FP-6
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FP-10
FP-17
FP-18
FP-19
FP-20


ACE

# Methods

- Expose fish to *C. shasta*
  - Cages in Klamath River, 3 days
- Rear in lab at stable temperature
  - Separate, independent, closed tanks
- Collect water samples: parasite DNA

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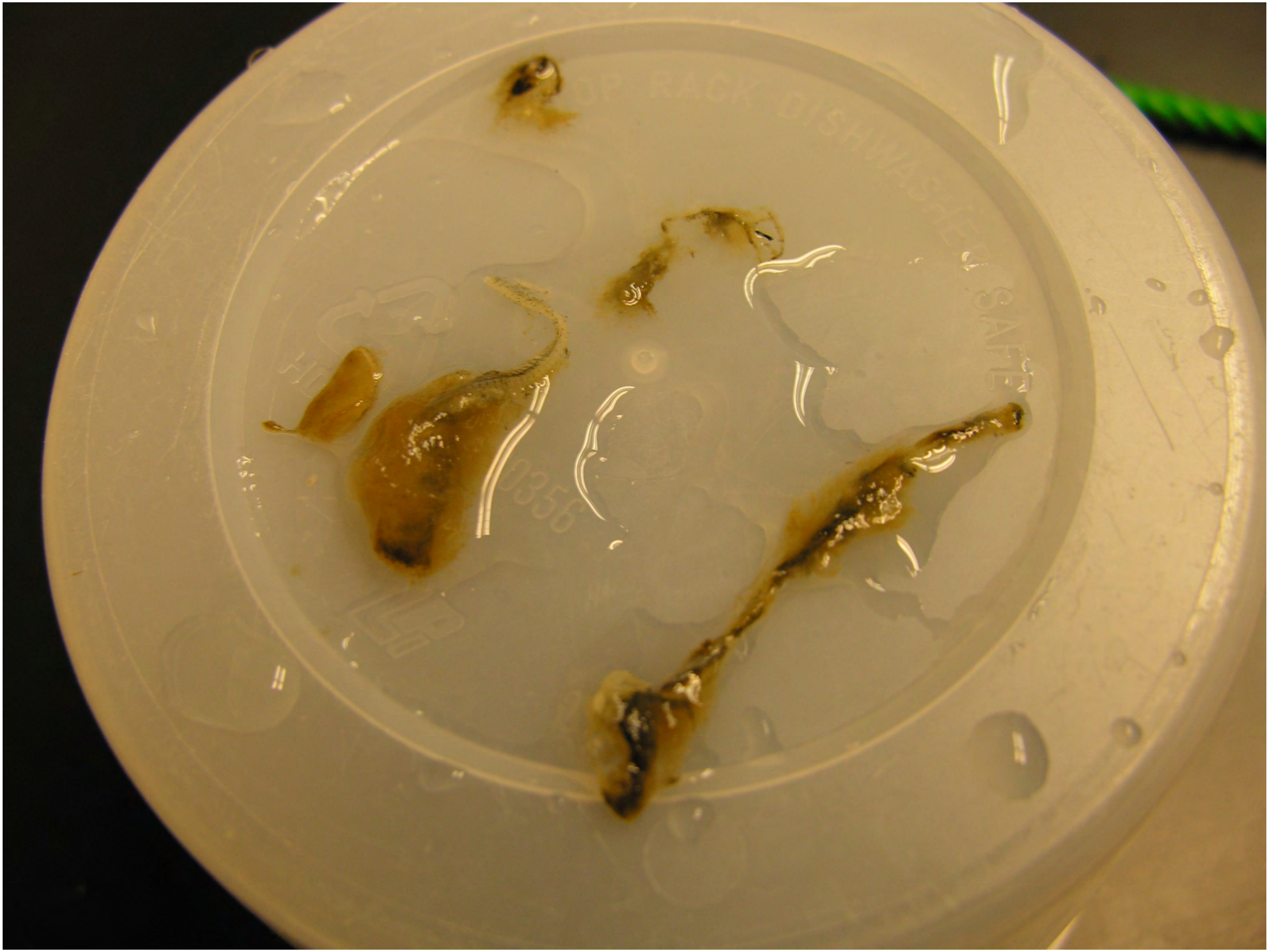
# Methods: Water Sampling

- 1 liter water samples
- Vacuum through filter membrane, 5μm pores
- Store membrane in 95% ethanol, or freeze
- Run QPCR assay on membrane

# Methods: Mortalities

- Swab inside vent
- View gut contents
  - Myxospores?
- Return to tank
  - Decomposition


RACK
SAFE
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# Methods

- Expose fish to *C. shasta*
  - Cages in Klamath River, 3 days
- Rear in lab at stable temperature
  - Separate, independent, closed tanks
- Collect water samples: parasite DNA
- 4 Trials: May, July 2010; June, July 2011

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# 2010 Results

| Exposure | | | % Mortality | | Mortality Dates | | |
|---|---|---|---|---|---|---|---|
| **Date** | **Temp (°C)** | **C. shasta (spores/l)** | **Total** | **w/spores** | **First (dpe)** | **Mean (dpe)** | **Last (dpe)** |
| May 2010 | 11.5 | 1 - 10 | 80 (32/40) | 62.5 (25/40) | 13 | 21 | 39 |
| July 2010 | 22.3 | 1 -10 | 87.5 (35/40) | 70 (28/40) | 10 | 17 | 41 |

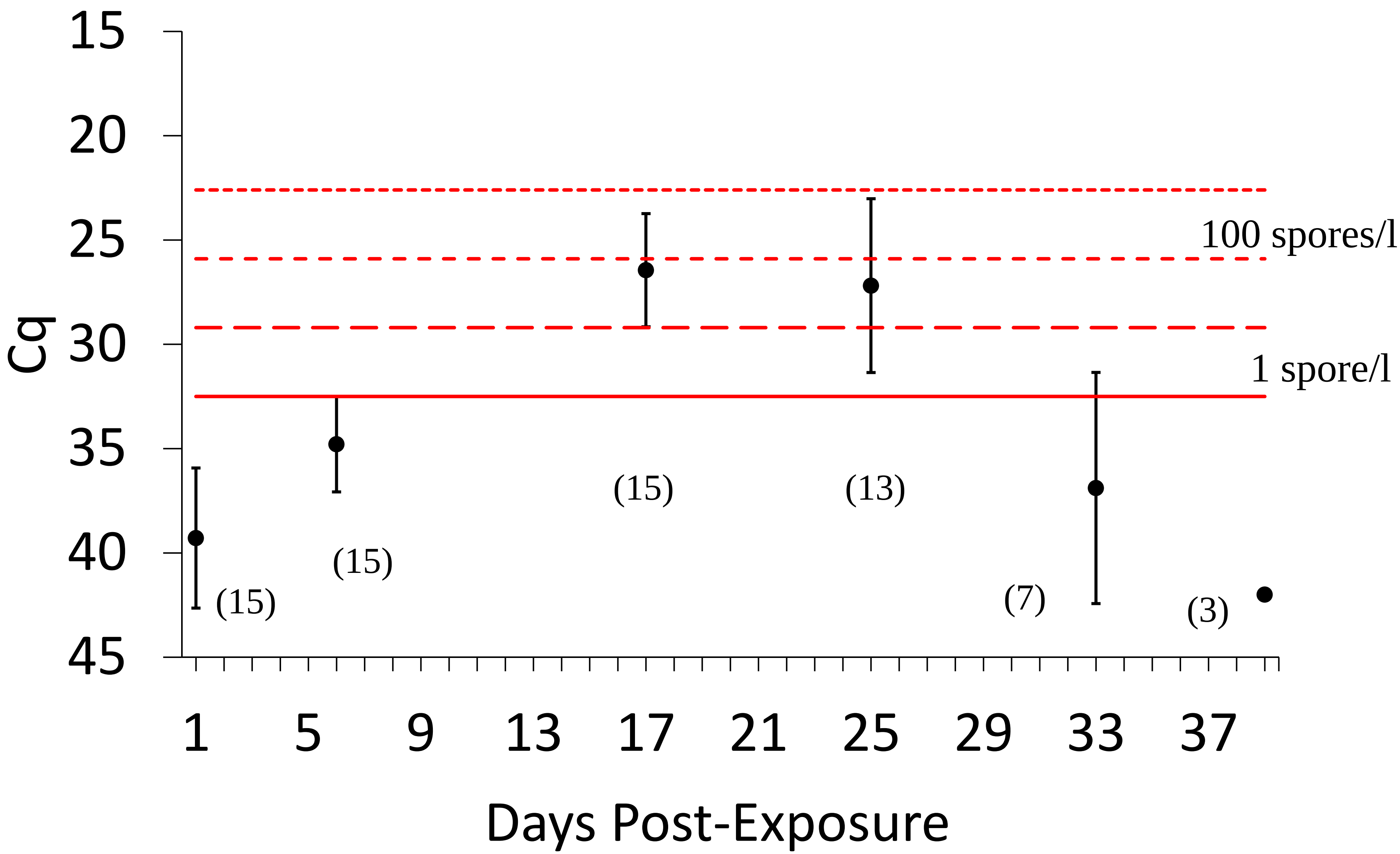



Figure 5. July 2010 exposure group. Concentration of *Ceratonova shasta* DNA (presumably myxospores) in one-liter water samples drawn from tanks holding pairs of exposed Chinook salmon which both ultimately died.

# Changes for 2011 Experiments:

- Decrease number of tanks
  - Analyze all samples instead of a subset
- One fish per tank
  - Samples represent individuals
- Unexposed control fish
  - Assess cross contamination, handling stress mortality, background infection at the hatchery

# 2011 Results

| Exposure | | | % Mortality | | Mortality Dates | | |
|---|---|---|---|---|---|---|---|
| **Date** | **Temp (°C)** | **C. shasta (spores/l)** | **Total** | **w/spores** | **First (dpe)** | **Mean (dpe)** | **Last (dpe)** |
| June 2011 | 16.1 | 1 -10 | 0 | 0 | 17* | | |
| July 2011 | 21.1 | 1 -10 | 40 (2/5) | 20 (1/5) | 15 | 18 | 21 |

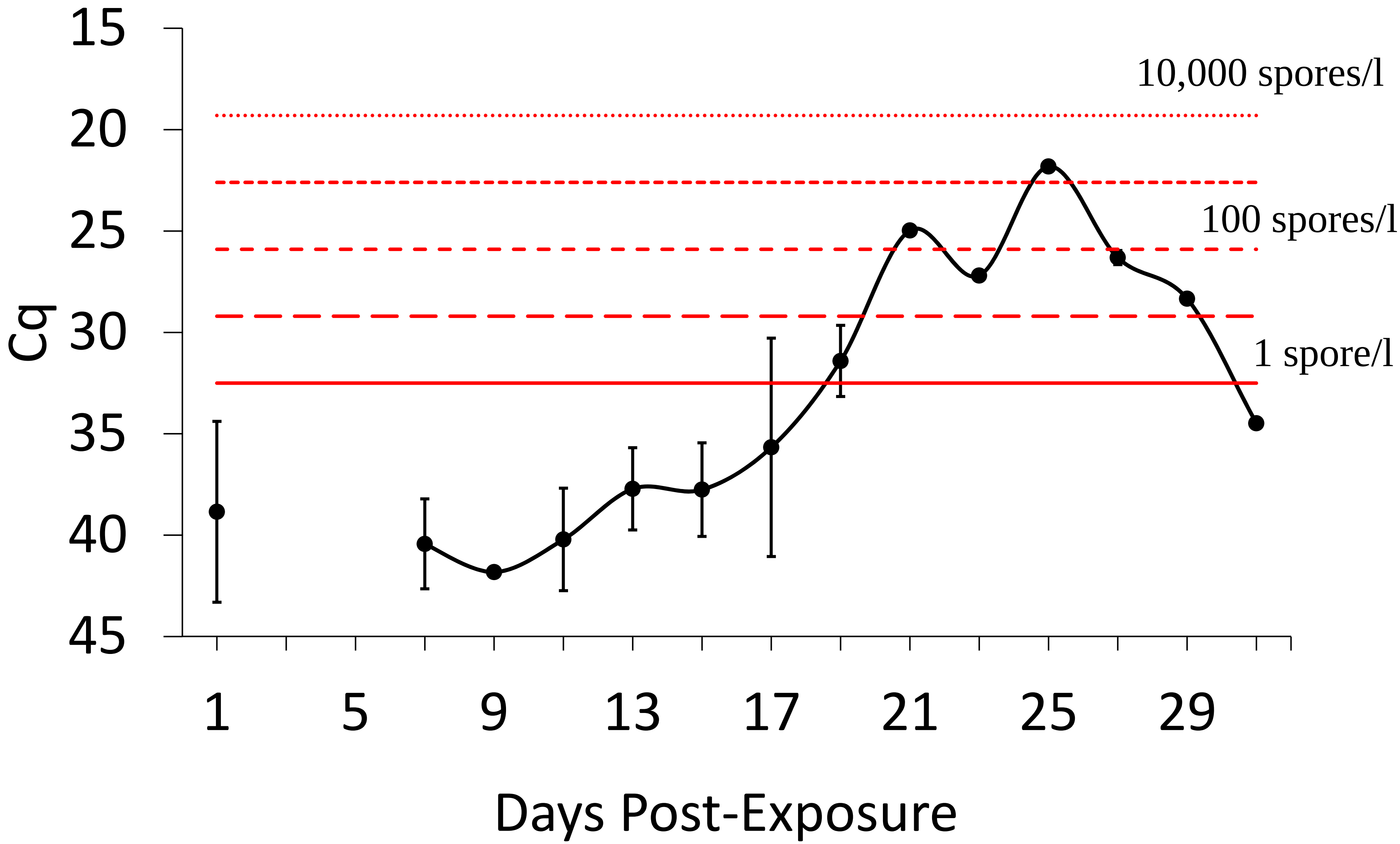



Figure 11. July 2011 exposure. Concentration of *Ceratonova shasta* DNA, presumably myxospores, in tank FP-1 over time. Each point represents the average of two one-liter water samples.

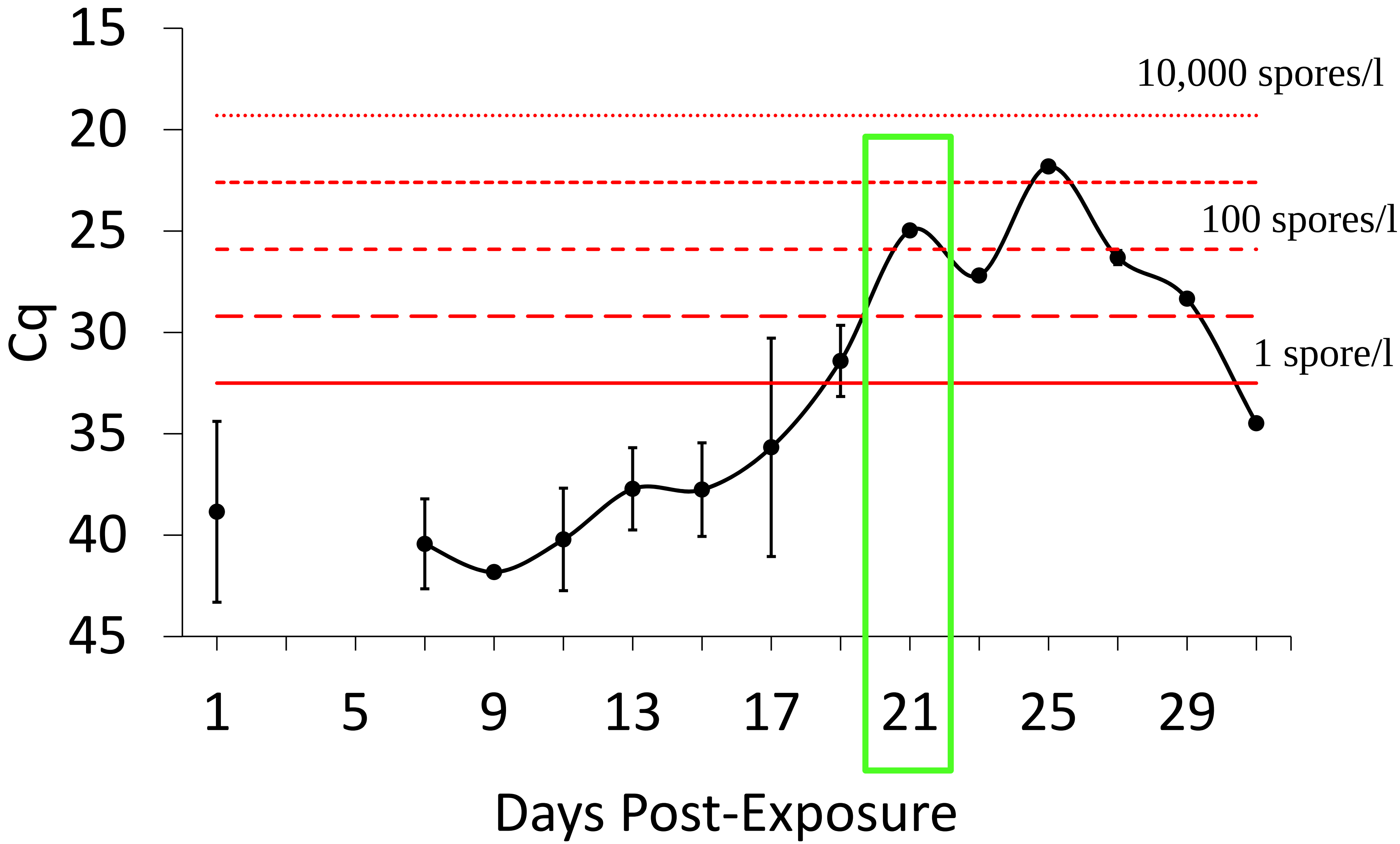
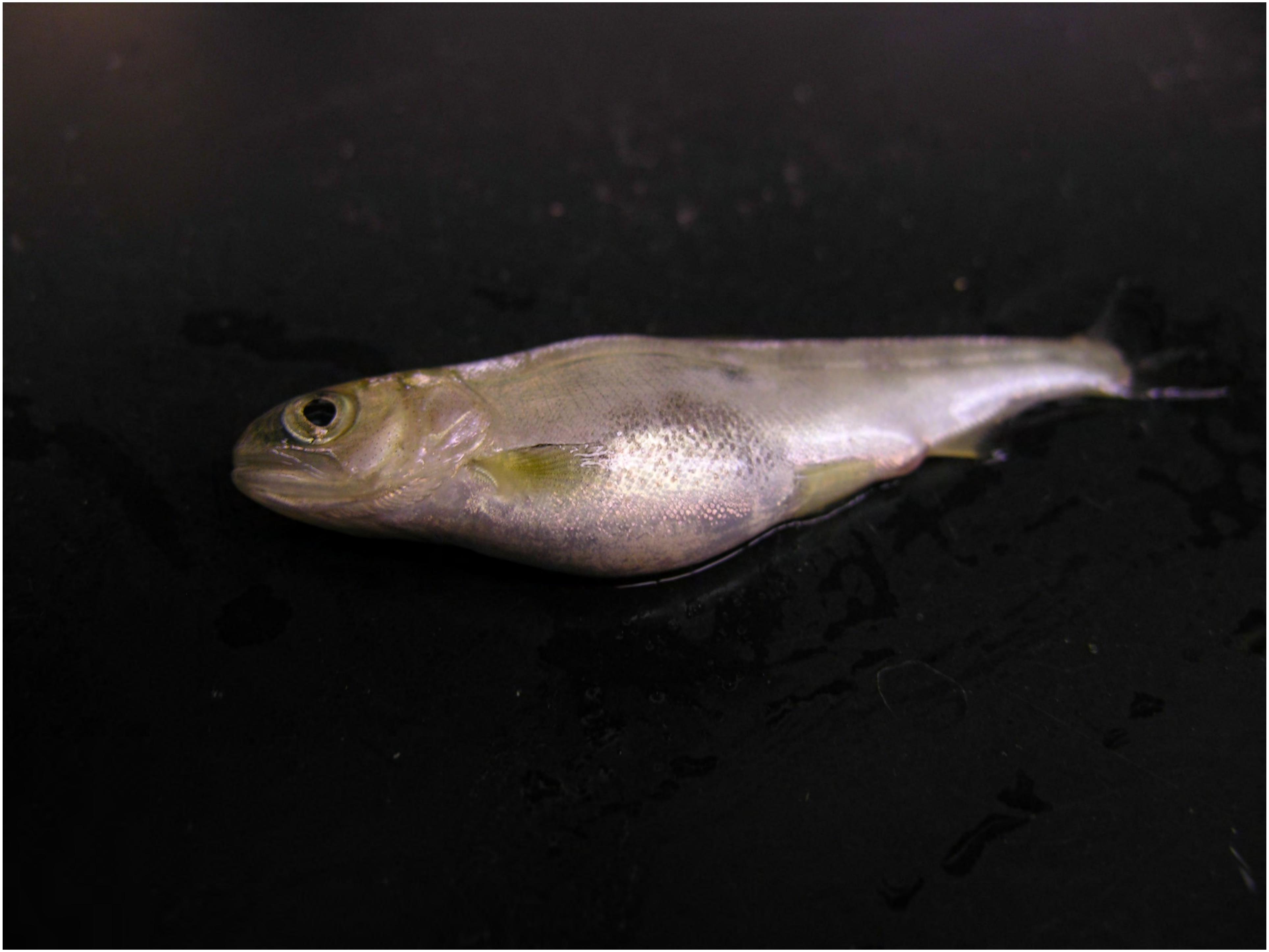
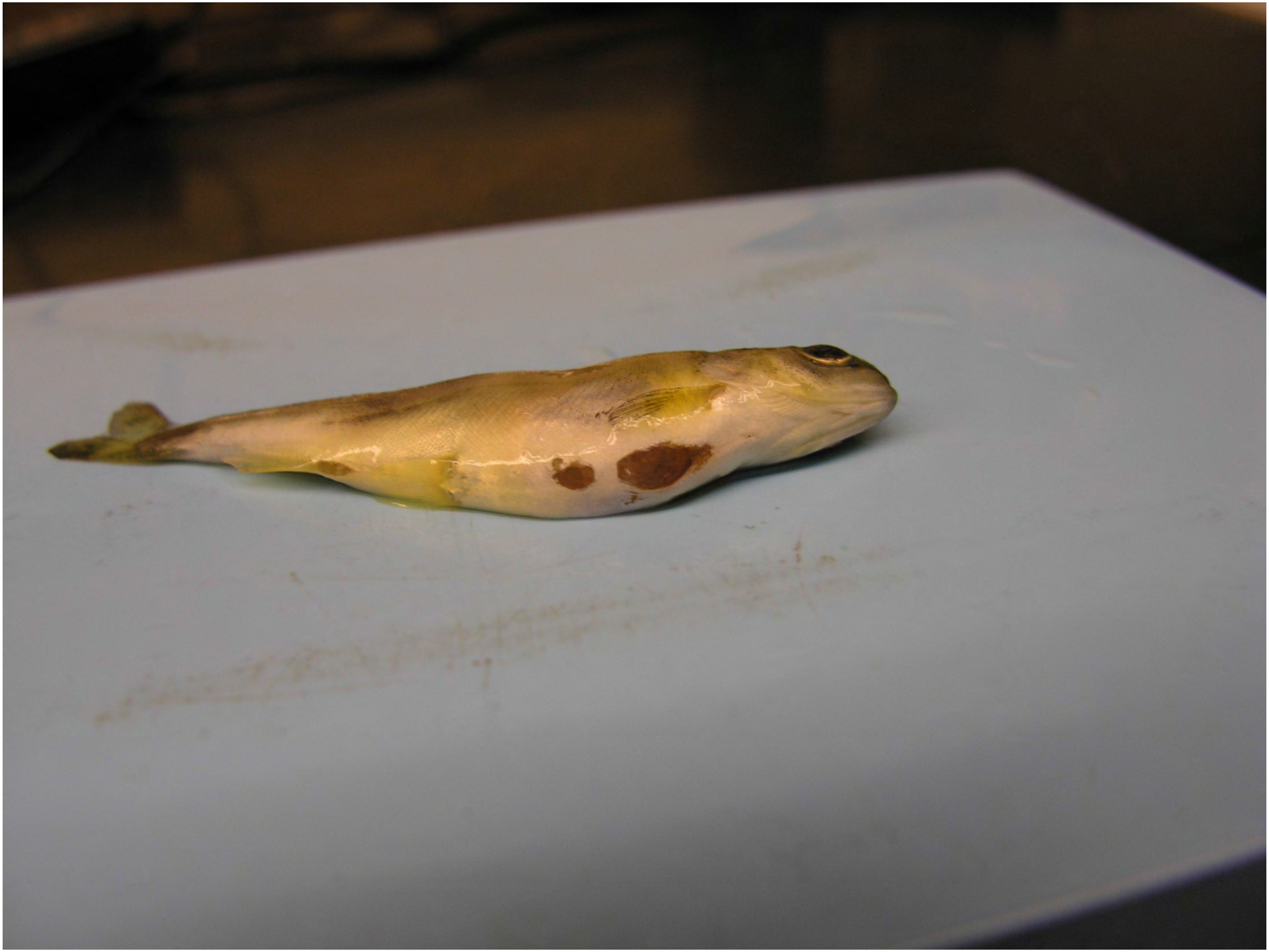



Figure 11. July 2011 exposure. Concentration of *Ceratonova shasta* DNA, presumably myxospores, in tank FP-1 over time. Each point represents the average of two one-liter water samples.





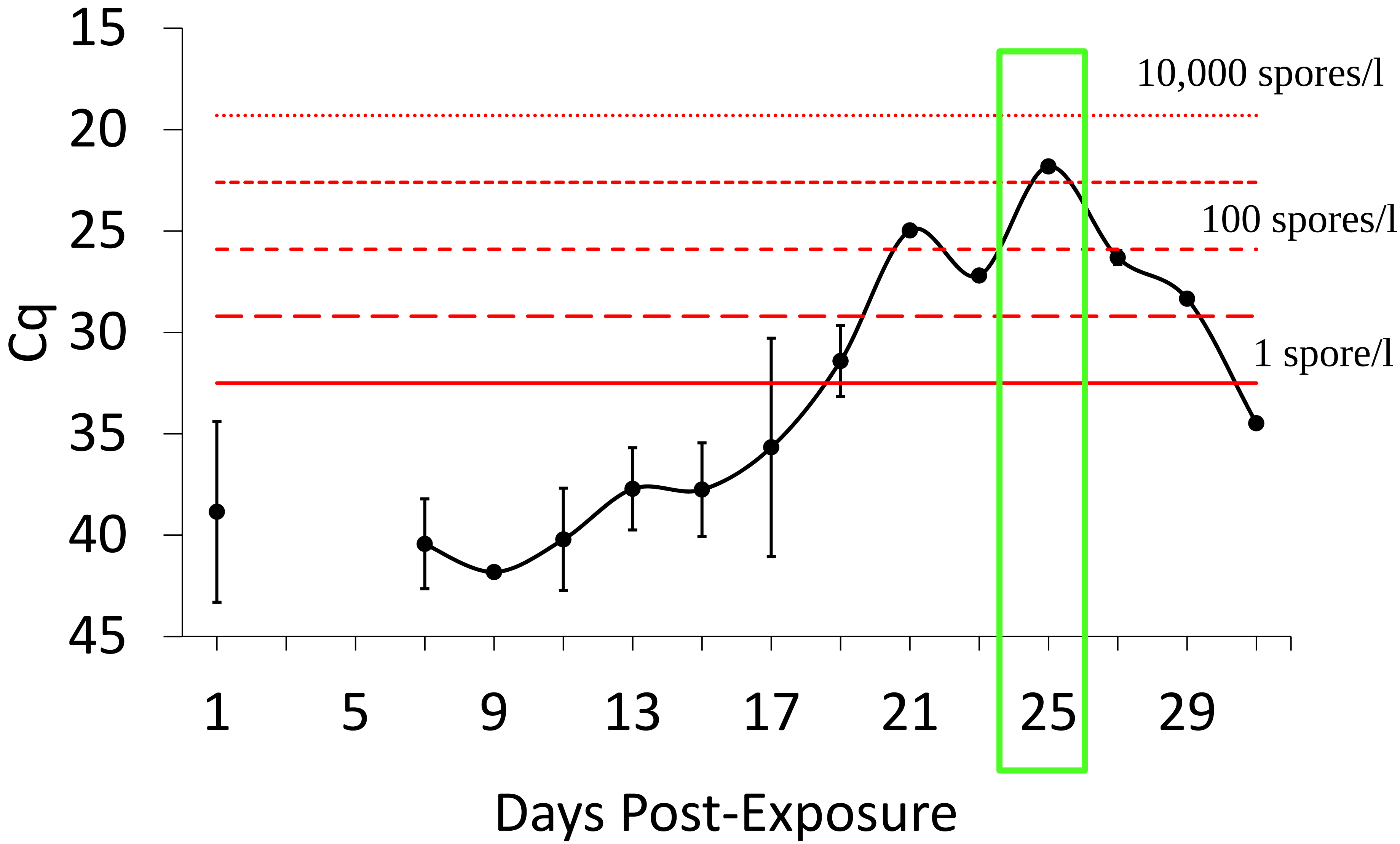



Figure 11. July 2011 exposure. Concentration of *Ceratonova shasta* DNA, presumably myxospores, in tank FP-1 over time. Each point represents the average of two one-liter water samples.

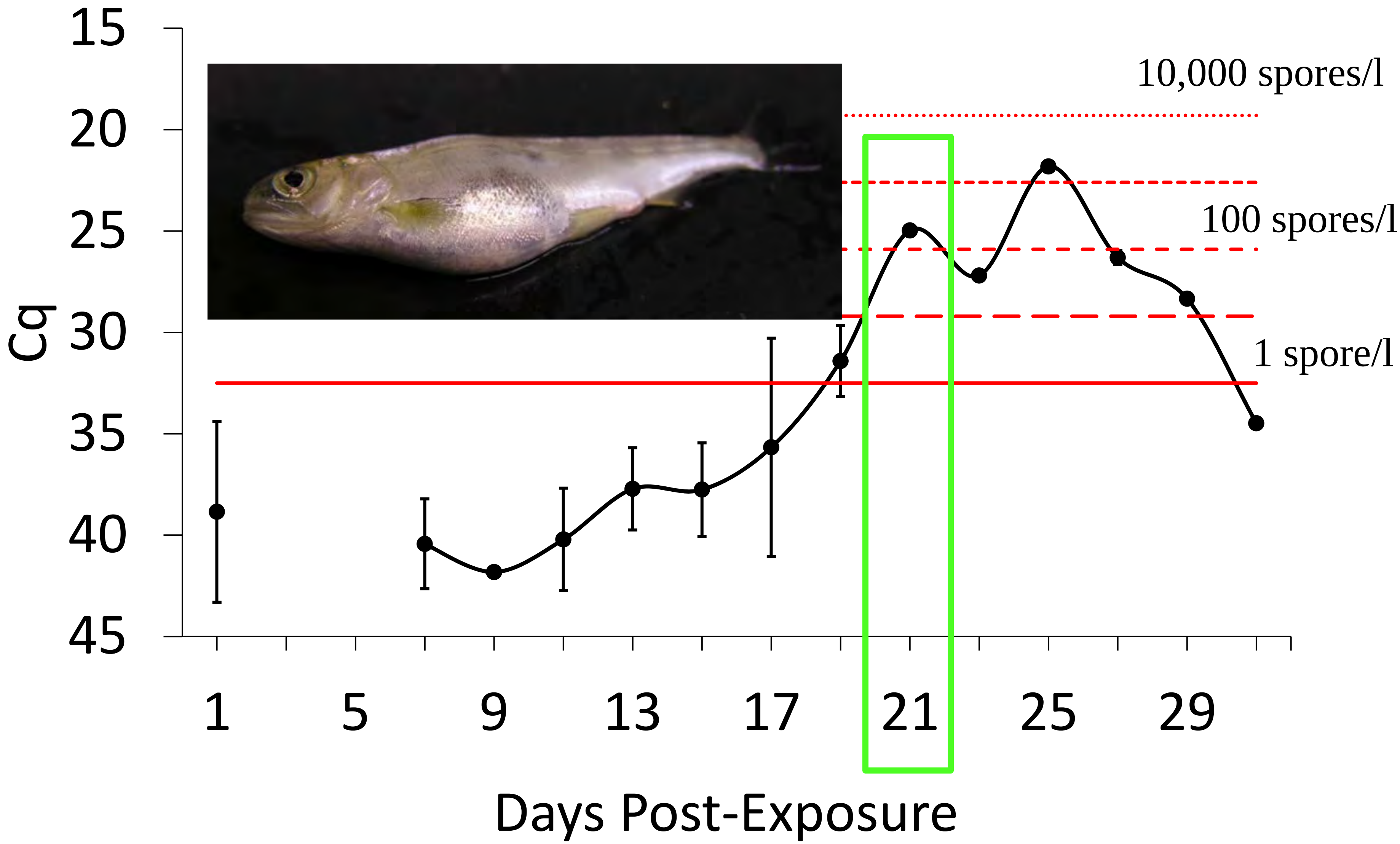



Figure 11. July 2011 exposure. Concentration of *Ceratonova shasta* DNA, presumably myxospores, in tank FP-1 over time. Each point represents the average of two one-liter water samples.

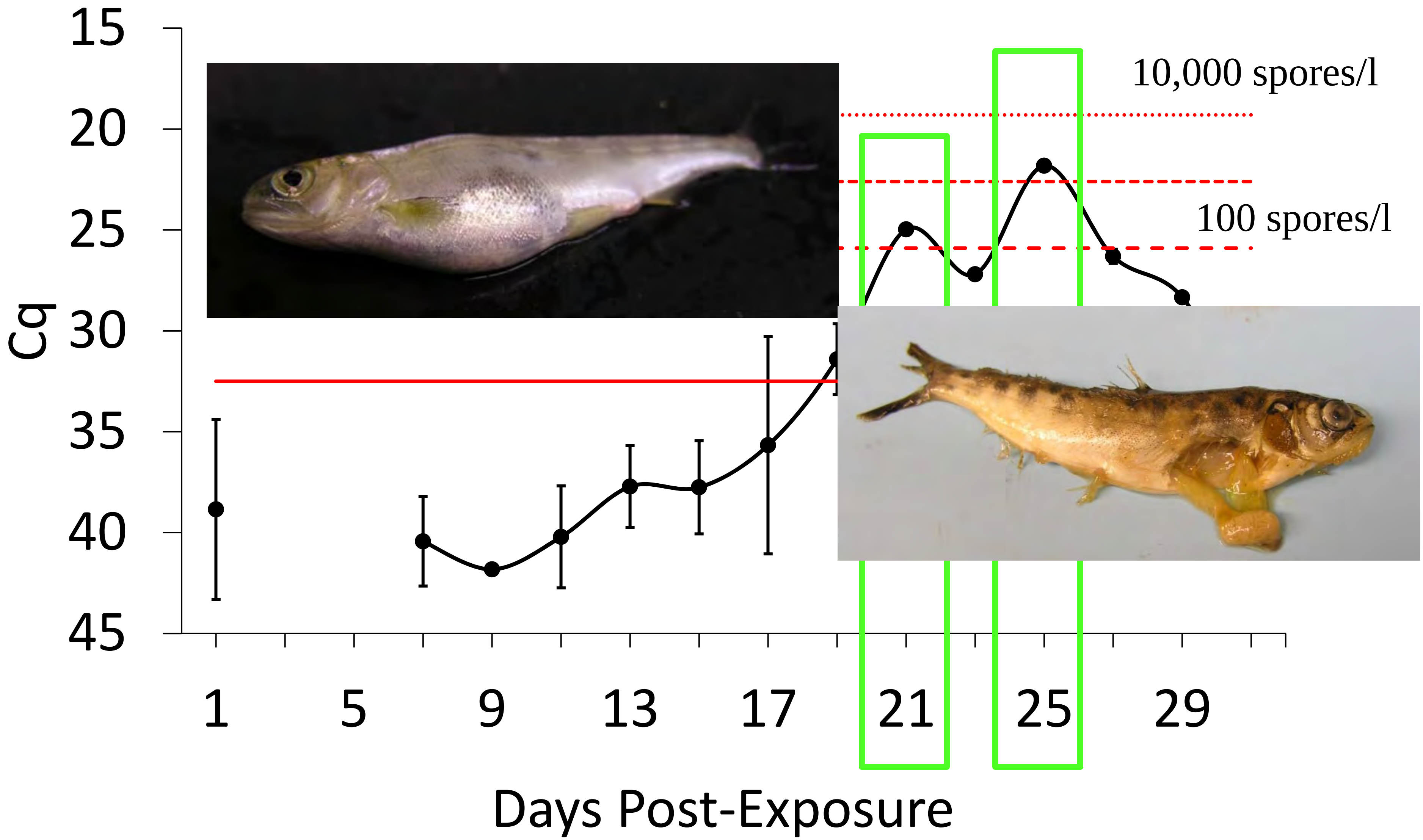



Figure 11. July 2011 exposure. Concentration of *Ceratonova shasta* DNA, presumably myxospores, in tank FP-1 over time. Each point represents the average of two one-liter water samples.

# Results: Myxospores Counts

- Estimate total myxospores per fish
  - Based on July 2011 exposure group
  - **n=2**
- # Myxospores per IGH cohort
  - Lower than in histological study (Ray 2010)
- # Myxospores per adult carcass/spawning run
  - Higher than published counts (CA-NV FHC Studies)
- # Myxospores: IGH cohort > adult spawning run

# Conclusions

# Conclusions

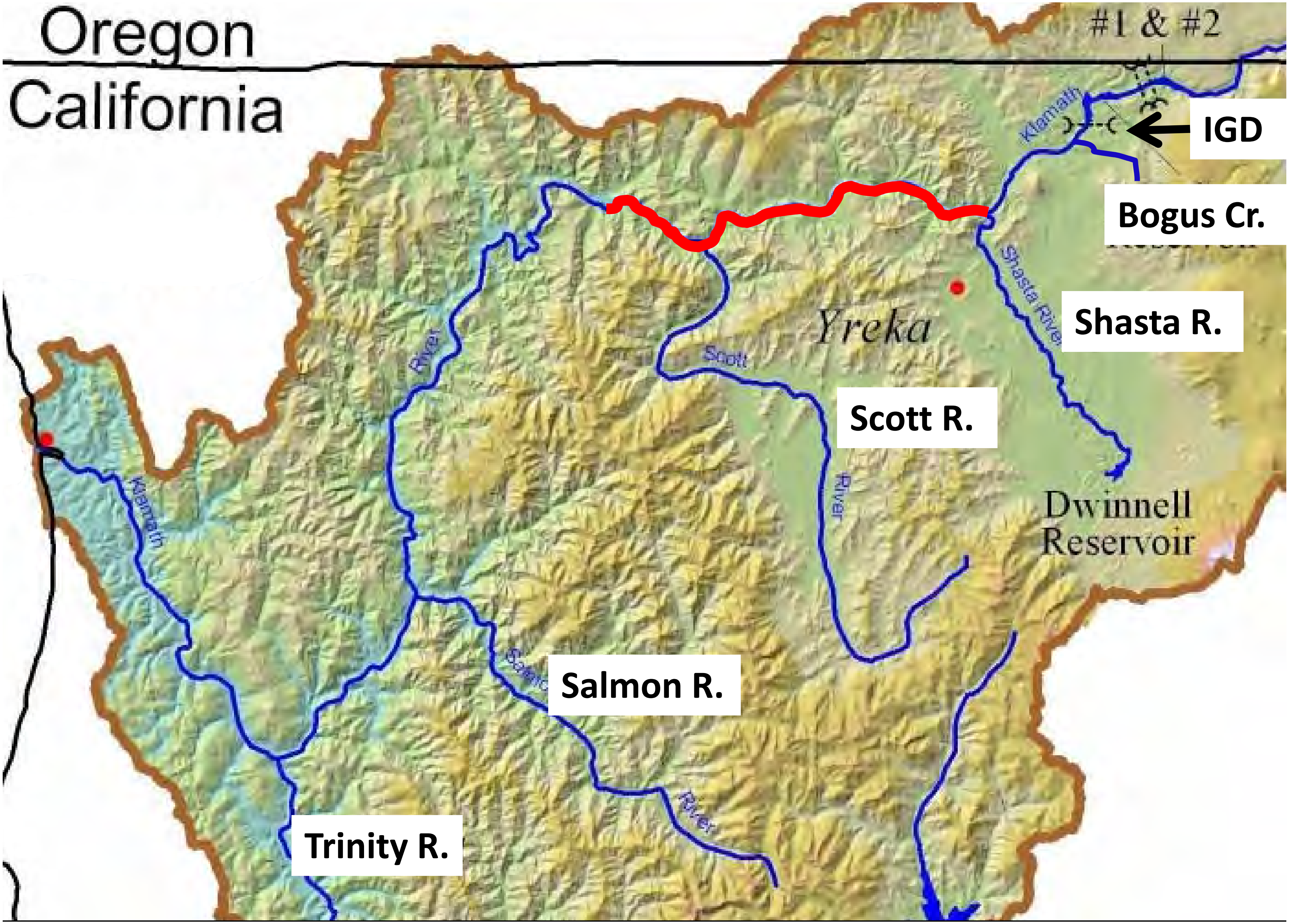
- Peak *C. shasta* DNA (presumably myxospores):

  1. Time of death
  2. Exposure of viscera (decomposition)
     - 2 ½ - 4 ½ weeks post-exposure

- Juvenile Chinook cohort may produce more myxospores than a run of spawning adults, but……

# Conclusions

- Myxospores: 2 ½ - 4 ½  weeks post-exposure
  - Median time IGH → estuary 30 - 34 days
  - Myxospores released below “hot zone”




http://www.usbr.gov/mp/kbao/maps/1_basin.jpg

# Conclusions

- Initial question: why do 10% of adult carcasses produce 90% of the myxospores?

# Acknowledgements


- Humboldt State University (Arcata, CA)
  - Committee:
    - Gary Hendrickson (chair)
    - Peggy Wilzbach
    - Darren Ward
  - Anthony Desch
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- Funding: U.S. Department of Commerce & NOAA/NMFS
  - Federal appropriation project: Disease Reduction in Klamath River Salmon
- California Department of Fish and Wildlife
  - Iron Gate Fish Hatchery (Hornbrook, CA)
- Oregon State University (Corvallis, OR)
  - Jerri Bartholomew, Gerri Buckles, Sascha Hallett, and many graduate students
- U.S. Fish & Wildlife Service CA-NV Fish Health Center (Anderson, CA)
  - Kim True, Ron Stone, J. Scott Foott
- Fisher’s Klamath River RV Park (Klamath River, CA)

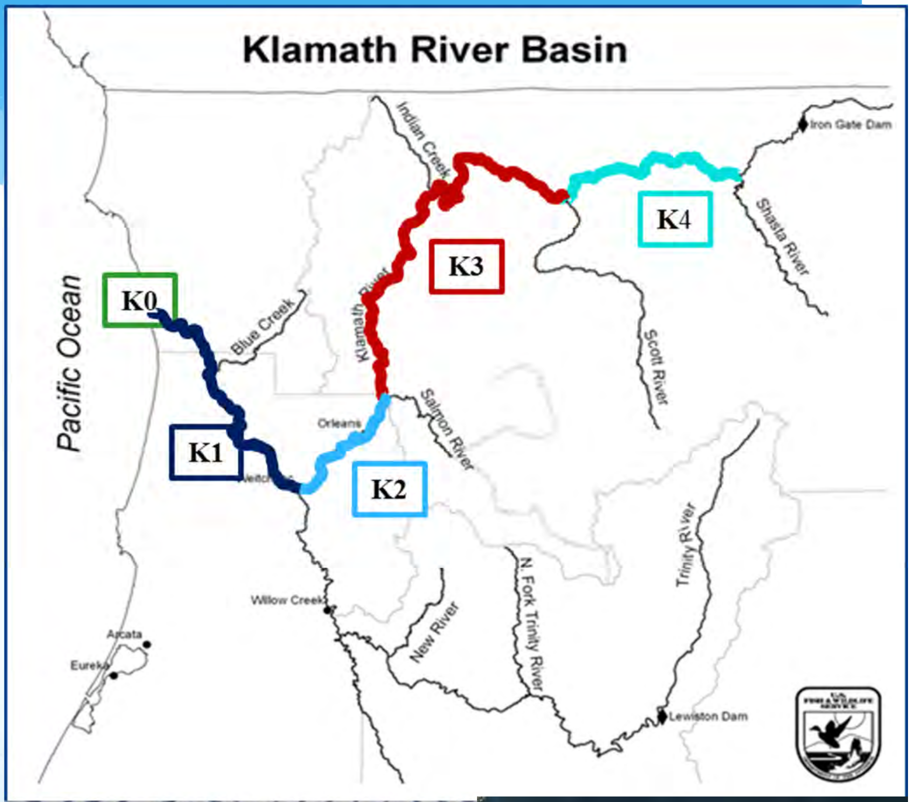

US Fish and Wildlife Service

# *Ceratonova shasta* Disease Impacts on Juvenile Chinook salmon in the Klamath Basin: Perspectives from a 10-year Fish Health Monitoring Program

Kimberly True, Anne Voss
and Scott Foott
USFWS CA-NV Fish Health Center

# KRFHMP Objectives

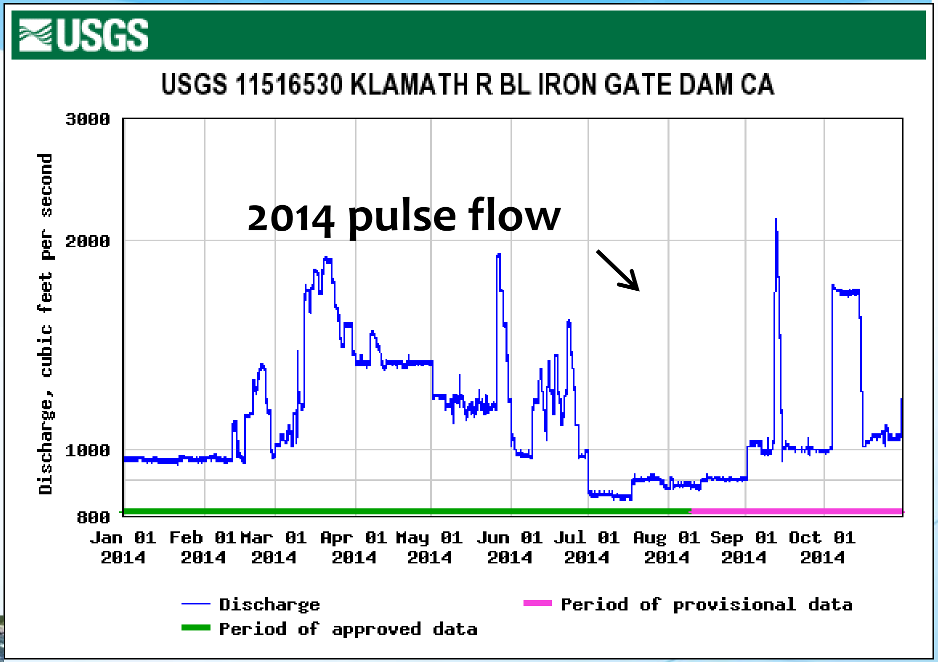
- **Parasite prevalence in natural Chinook salmon in upper reaches**
- **Cs POI and severity in IGH CWT**
  - Exposure Period (Weeks at Large)
  - Parasite load (DNA copy number)
- **Diagnostic Casework**
  - Mortality event
  - Juvenile myxospore contribution




# KRFHMP Objectives

**Compare environmental conditions between years (temp/flow)**

- Temp: Below IGD & Seiad Valley
- Flows: USGS Flow Gauges




**Variable Environmental Years:**

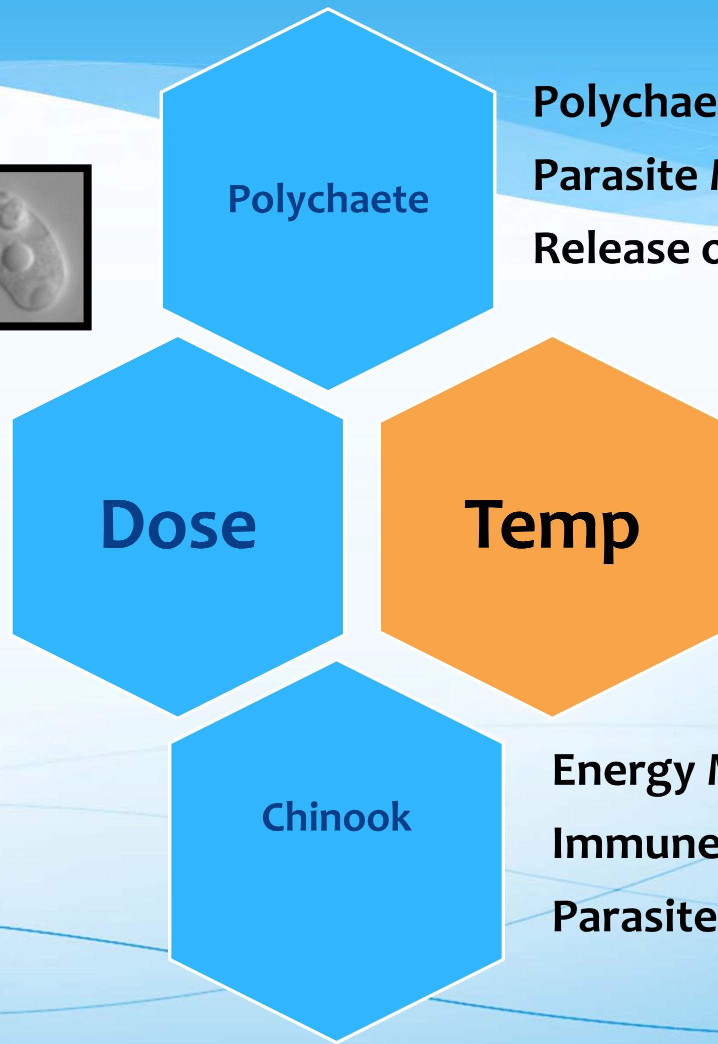
- High temp/low flows 2008
- Low Temp/cool spring 2010-2011
- Drought years 2013-2015

# Temperature Influence on Disease Dynamics

Polychaete Reproduction

Parasite Maturation

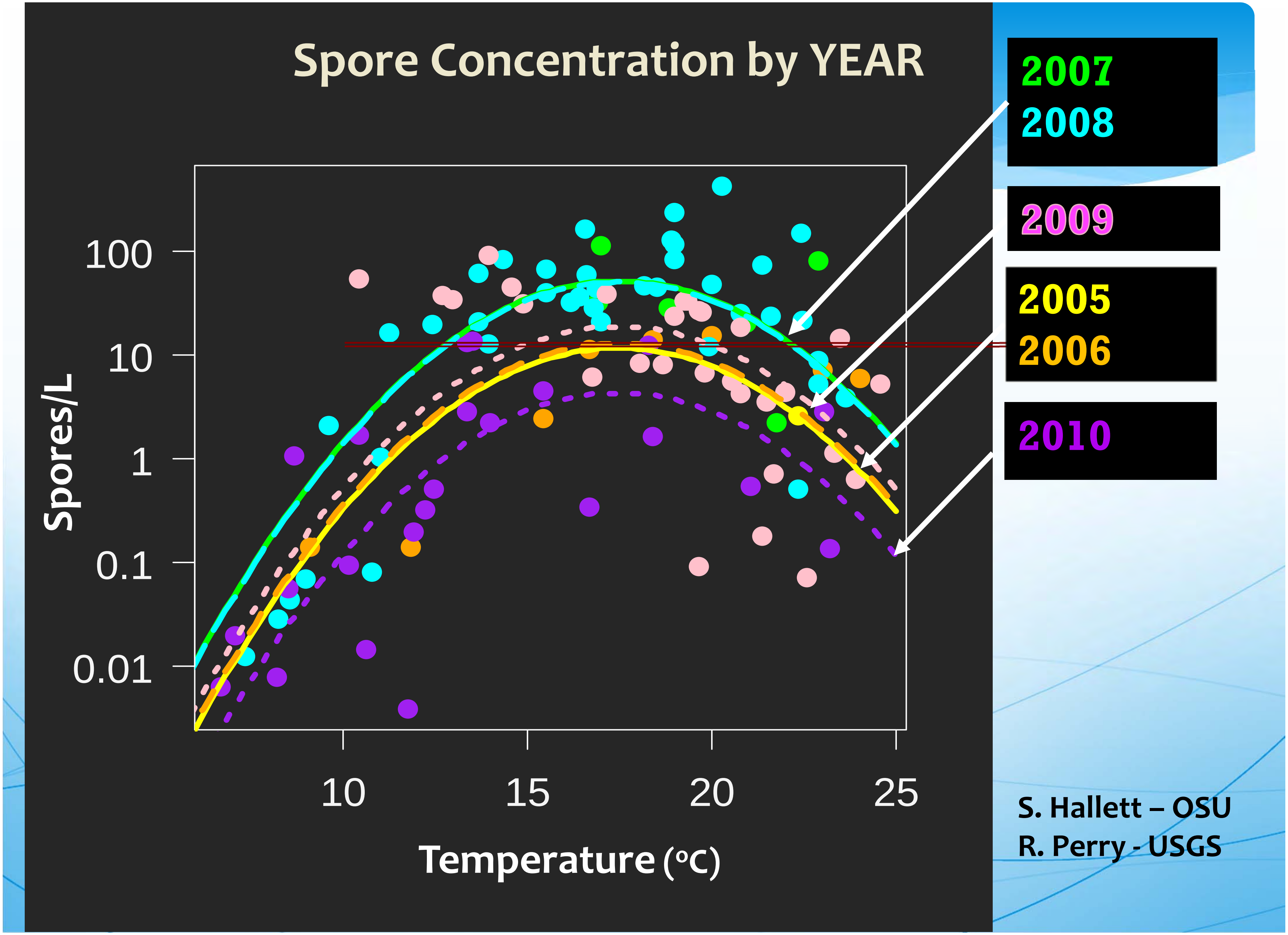
Release of Actinospores




Energy Metabolism

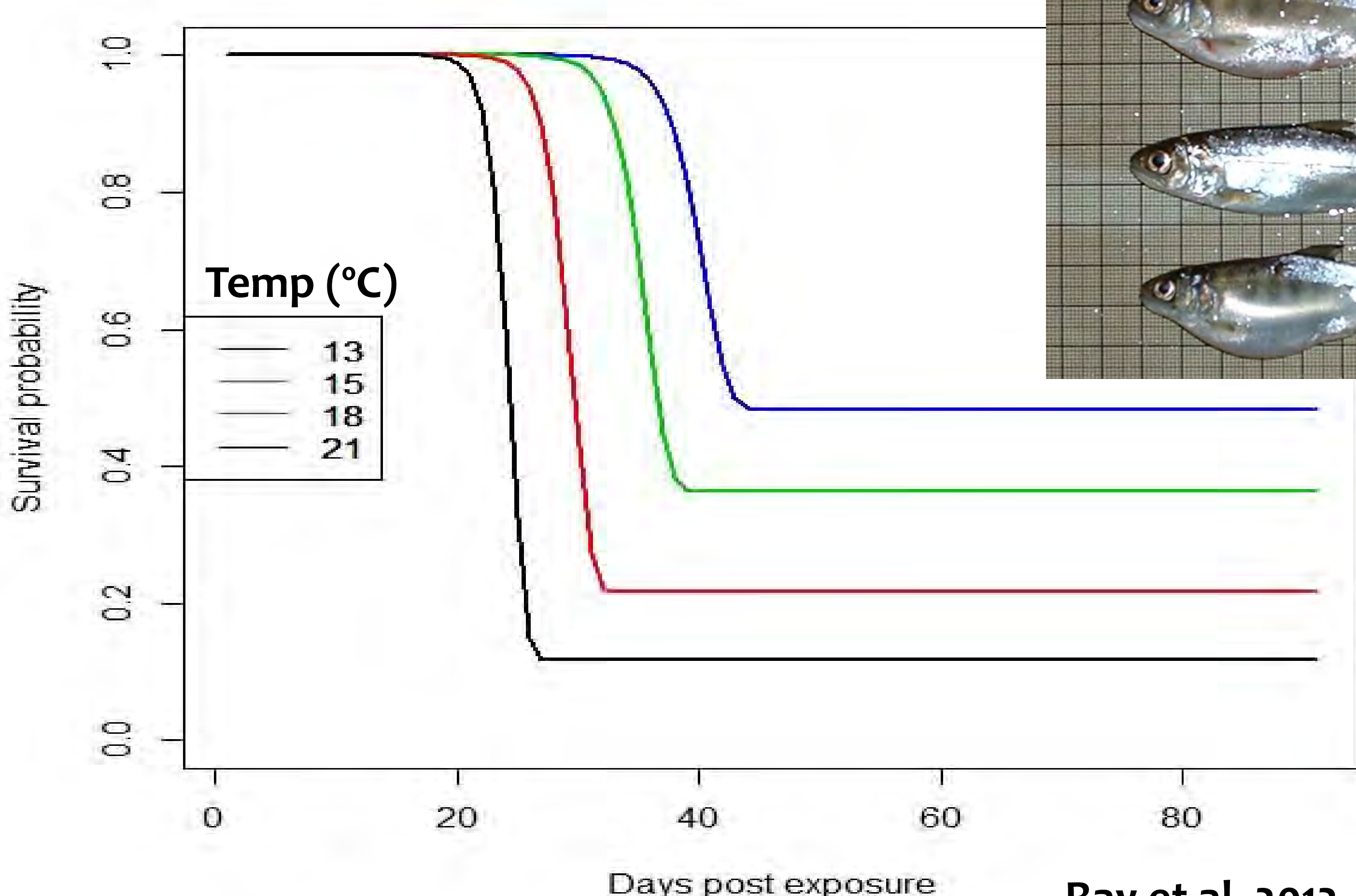
Immune Response

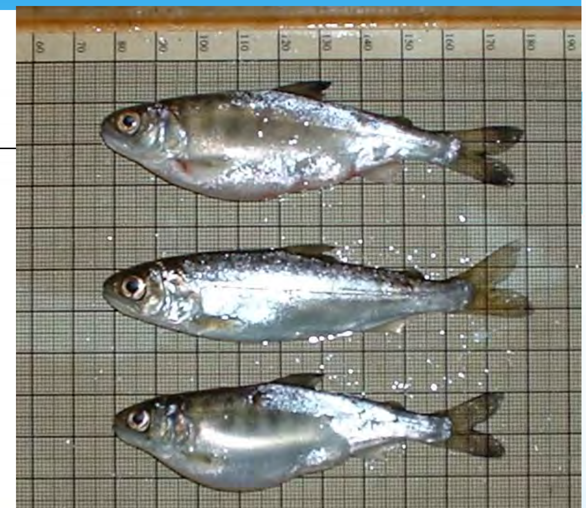
Parasite Proliferation



Spore Concentration by YEAR
2007
2008
2009
2005
2006
2010
Spores/L
100
10
1
0.1
0.01
10
15
20
25
Temperature (°C)
S. Hallett – OSU
R. Perry - USGS

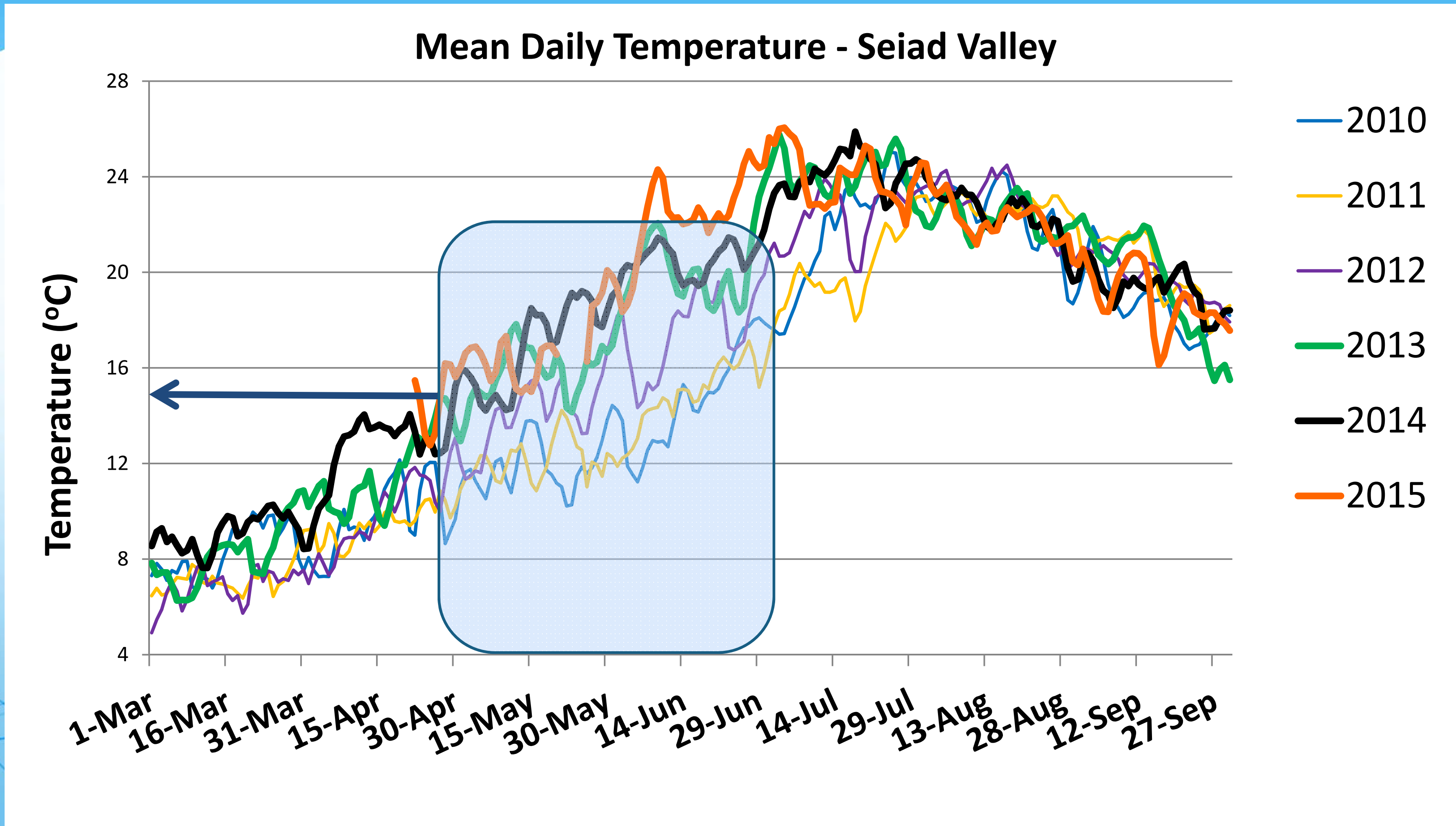
# Effects of Exposure and Holding Temps



Ray et al. 2012

# Temperature Profile 2010-2015

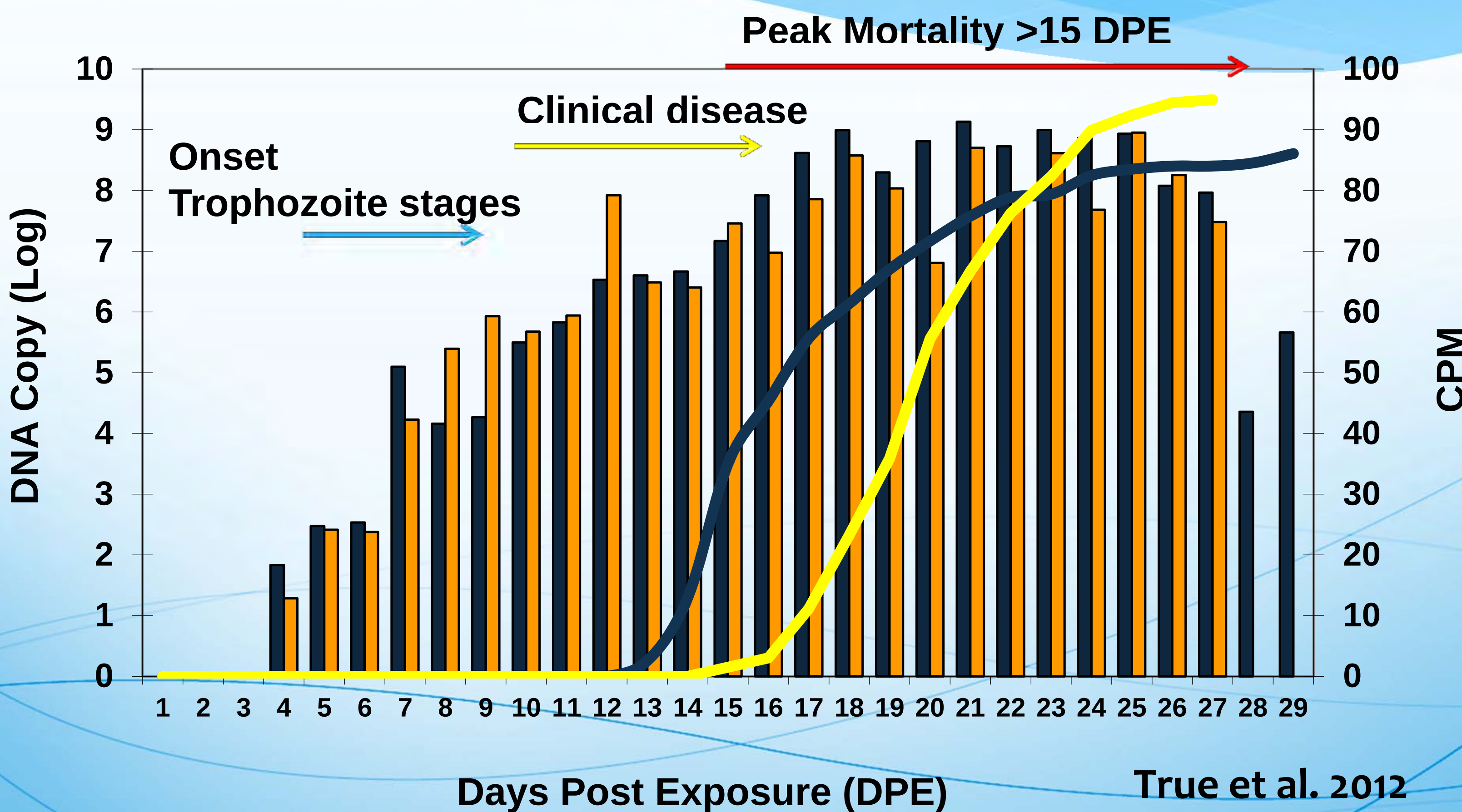


# Annual Cs POI (QPCR)

| Year | Peak Migration (May-July) | Naturals | IGH CWT | Environmental Characteristics |
|---|---|---|---|---|
| **2015** | **91%** | **75%** | **90%** | **Drought** |
| **2014** | **81%** | **76%** | **79%** | **Drought** |
| **2013** | 46% | 25% | 46% | **Extremely Dry** |
| **2012** | 30% | 4% | 42% | Cool Spring temps |
| **2011** | 17% | 17% | 16% | Low Temp / High Flow |
| **2010** | 17% | 10% | 27% | Low Temp / Low Flow |
| **2009** | **45%** | **48%** | **52%** | **High Temp / Low Flow** |
| **2008** | **49%** | **(MOC)** | **31%** | **High Temp / Low Flow** |
| **2007** | 31% | (MOC) | 78% | **High Temp / Low Flow** |
| **2006** | 34% | (MOC) | 51% | Low Temp / High Flow |
| **2005** | **62%** | **31%** | **50%** | **High Temps/High Flow** |

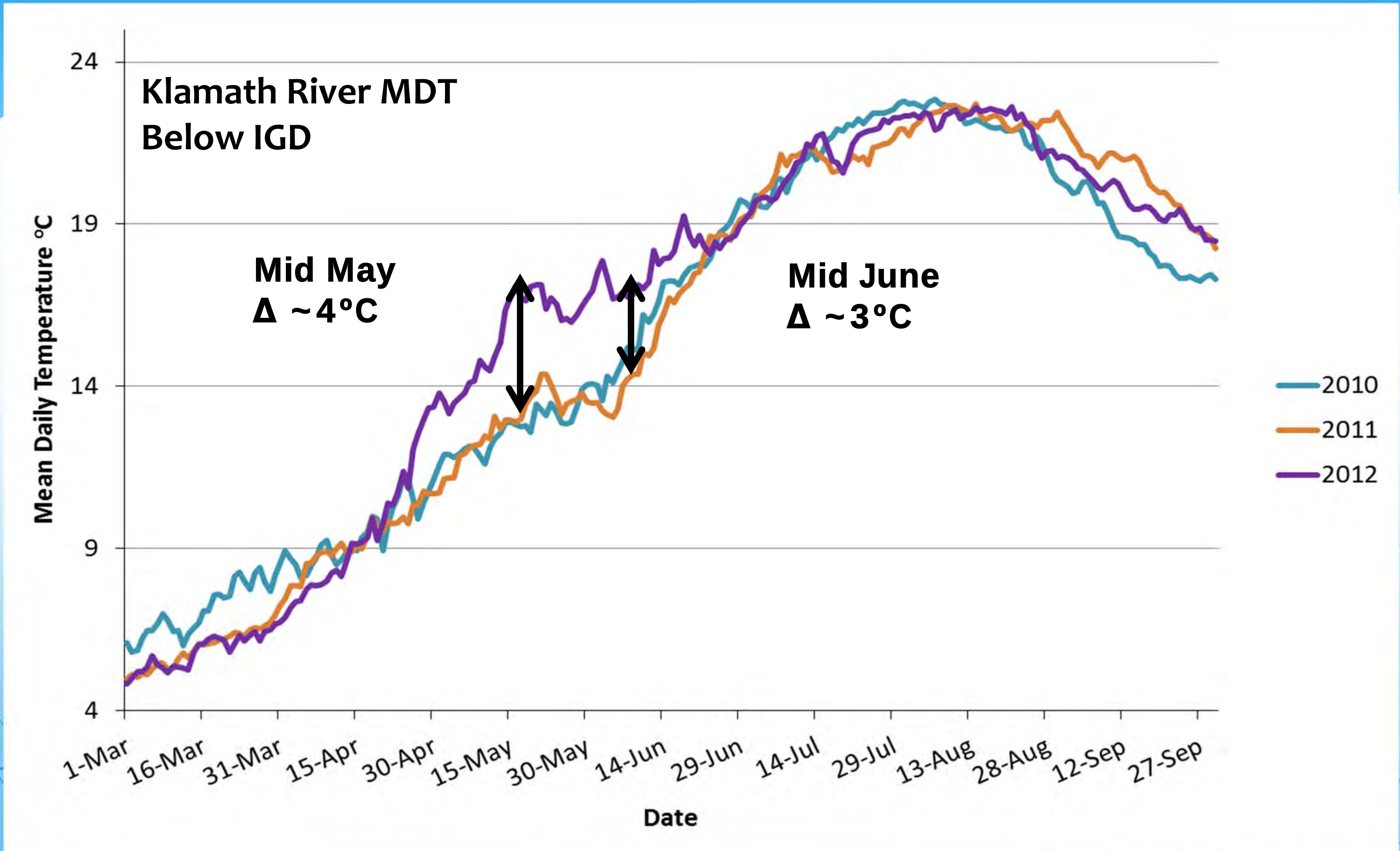
# C. *shasta* Prognosis
# Disease Pathology and Parasite Load

TRH CHK - 20 MDD, 87% CPM Myxospore Production 19%
IGH COHO – 17 MDD, 98% CPM 34%

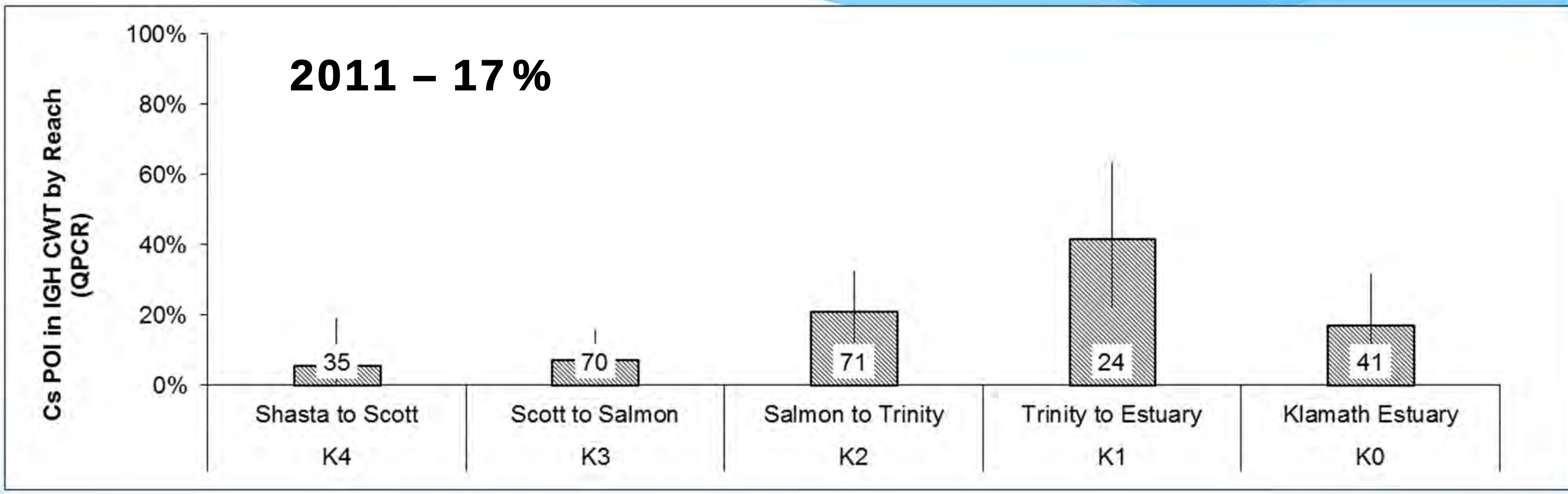


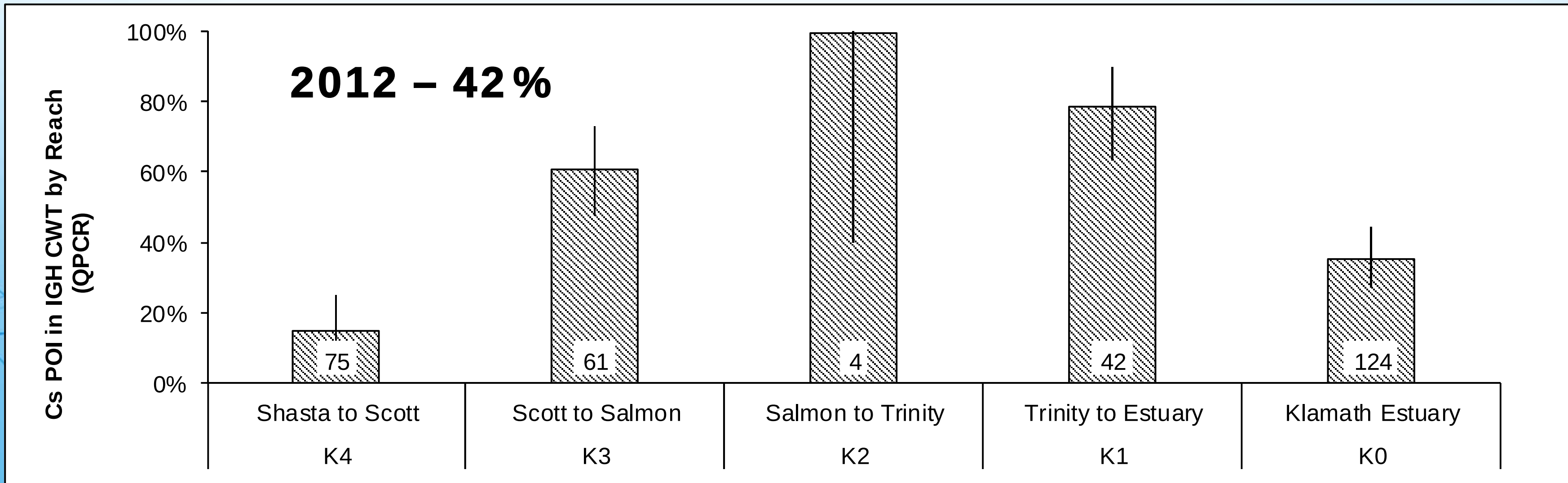

True et al. 2012

# Temperature Profile 2012

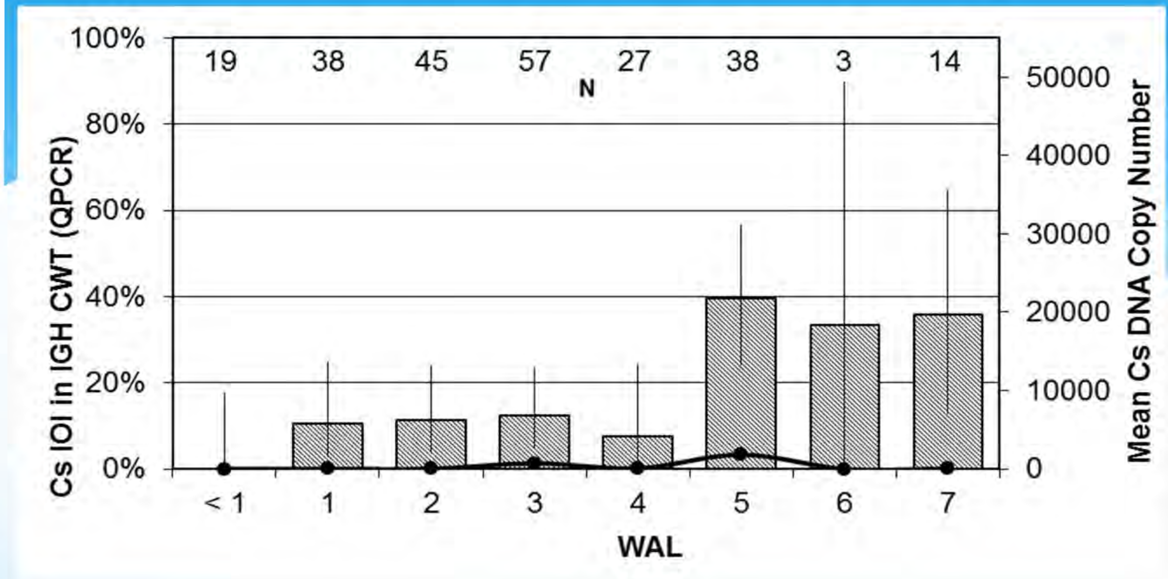


# IGH CWT – *C. shasta* POI by Reach



# IGH CWT – Cs POI at Weeks At Large




**2011 - Low POI**

Peak POI 5-7 WAL

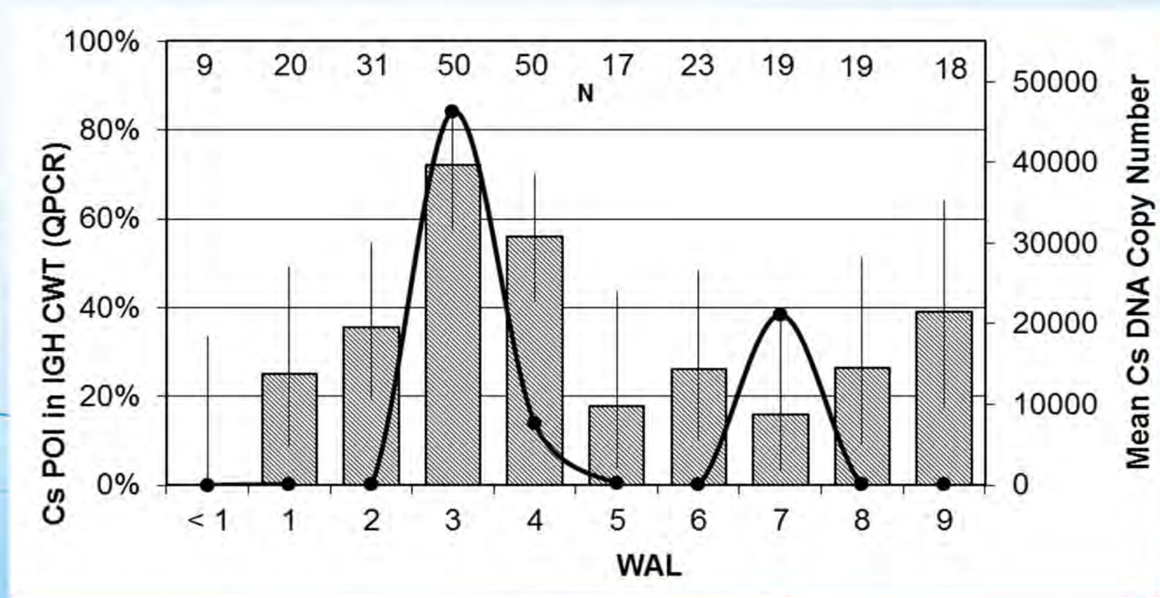
1K DNA copy number

**2012 Intermediate POI**

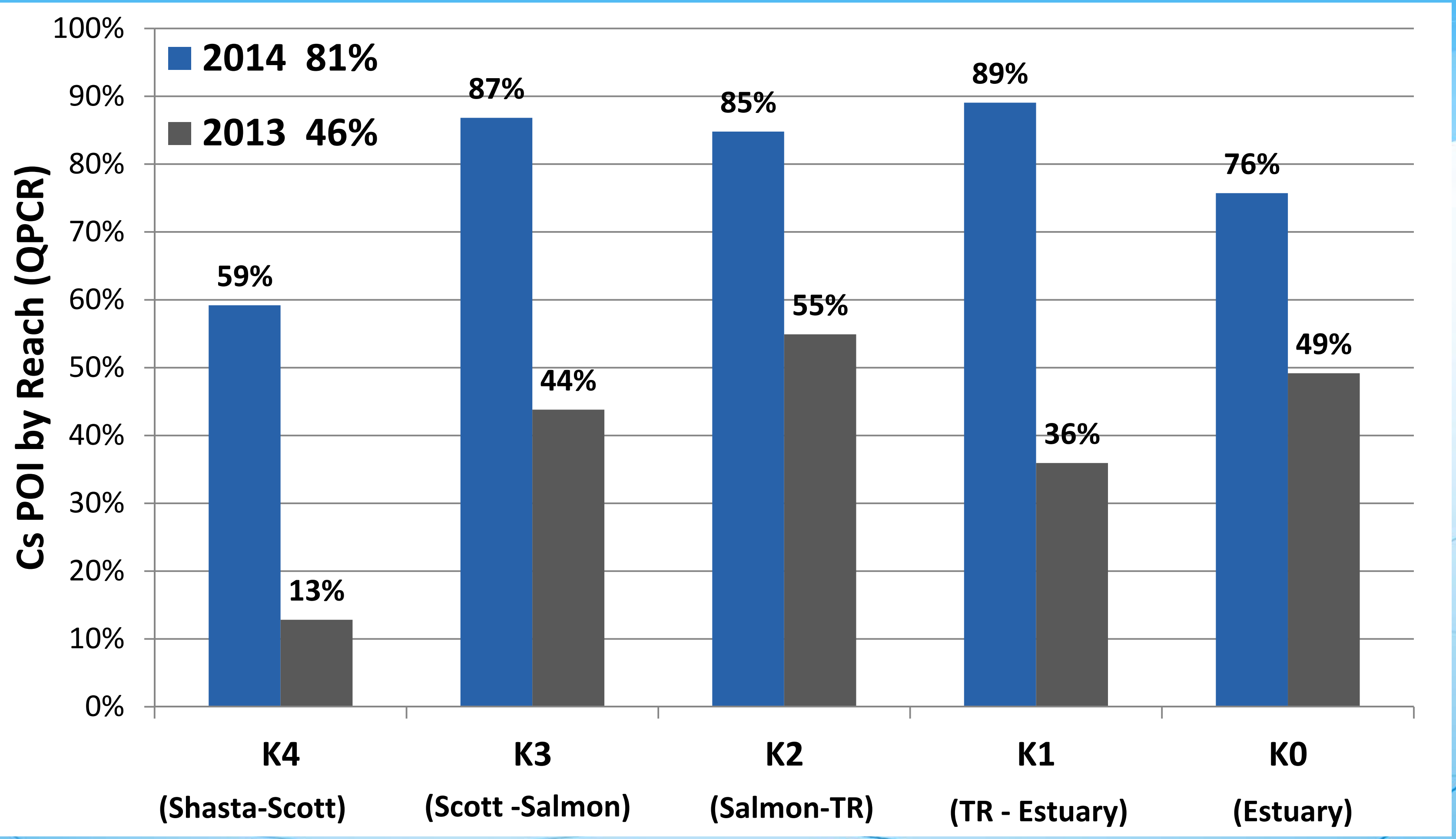
Peak POI 3 WAL

46K DNA - 3WAL

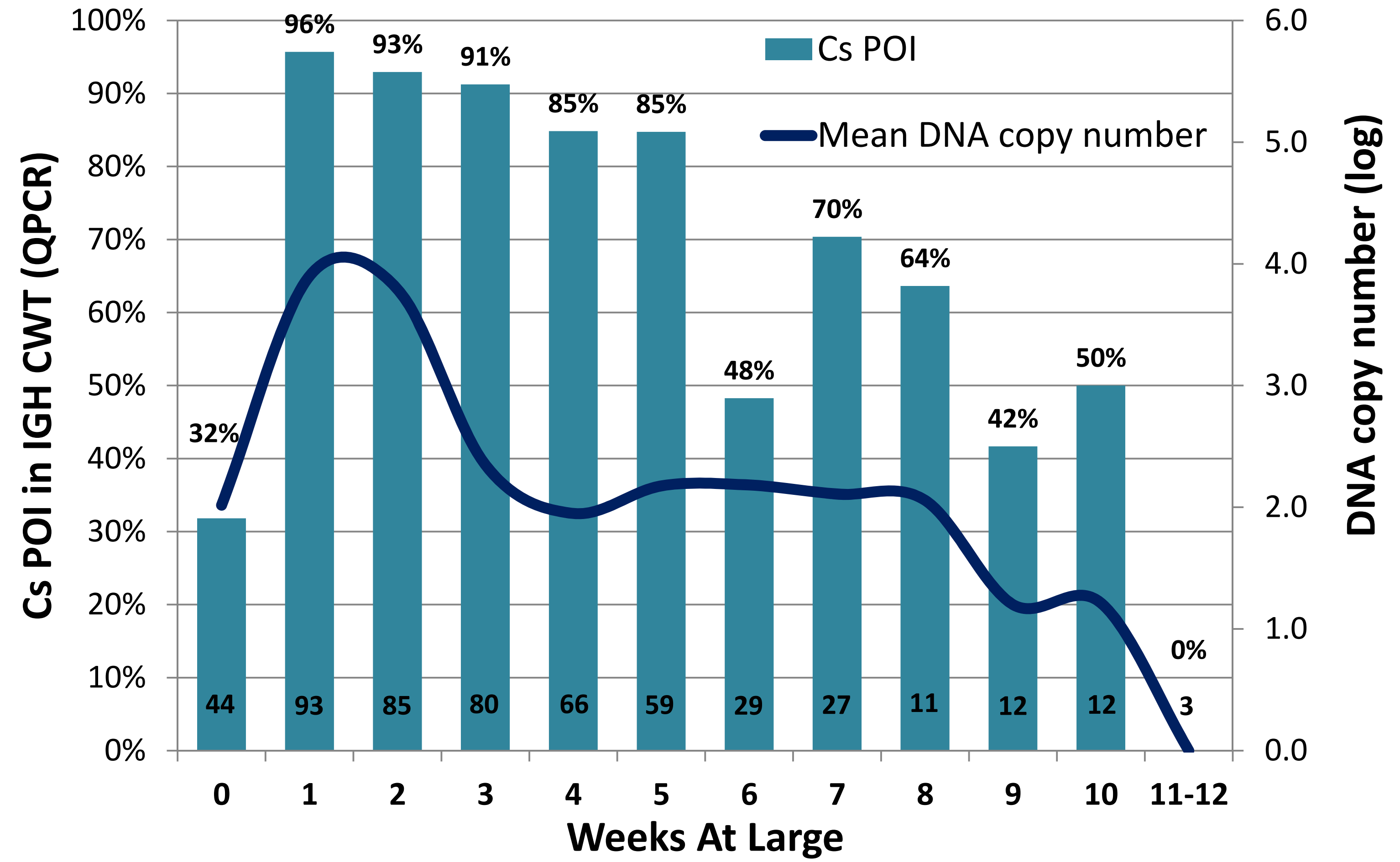
20K DNA - 7WAL



# Cs POI by Reach (Peak Migration)

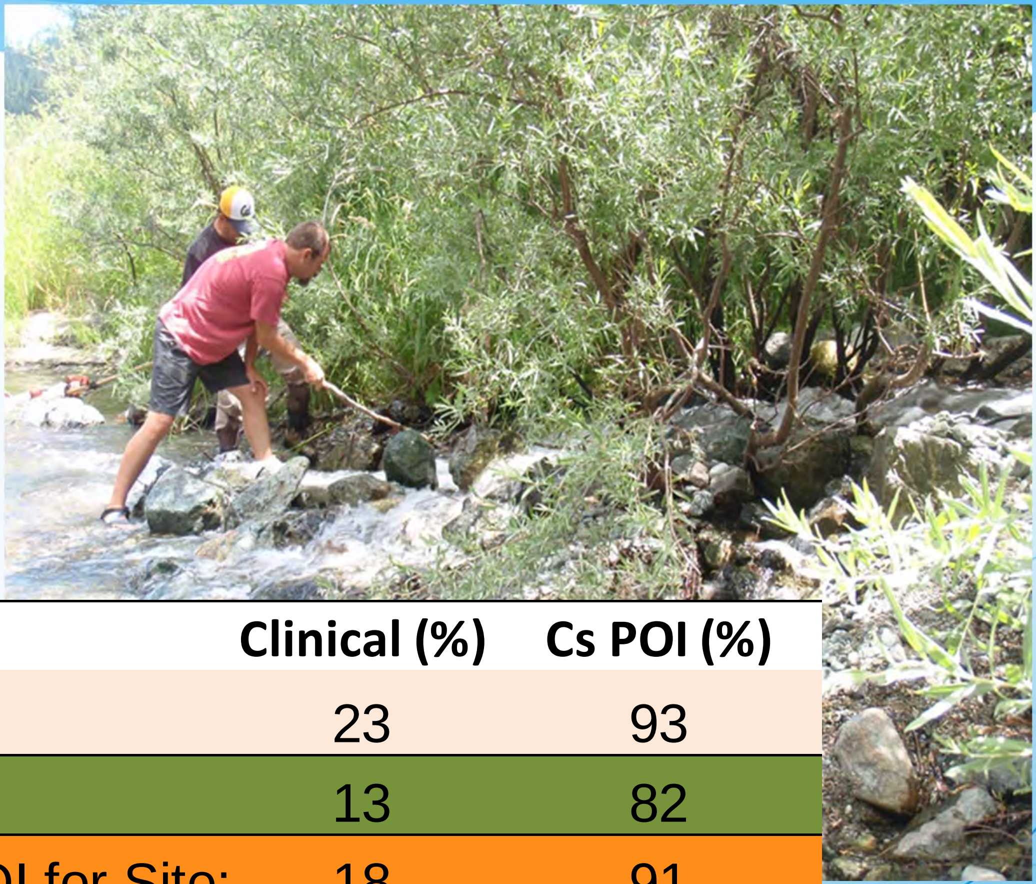


# 2014 IGH CWT – Infectious Load at Weeks at Large
## (CWT 79% , Naturals 76%, All Fish 78%)



# Ti Crk Diagnostic Exam – June 16 2014

* Clinical (end stage) disease
* Myxospore production



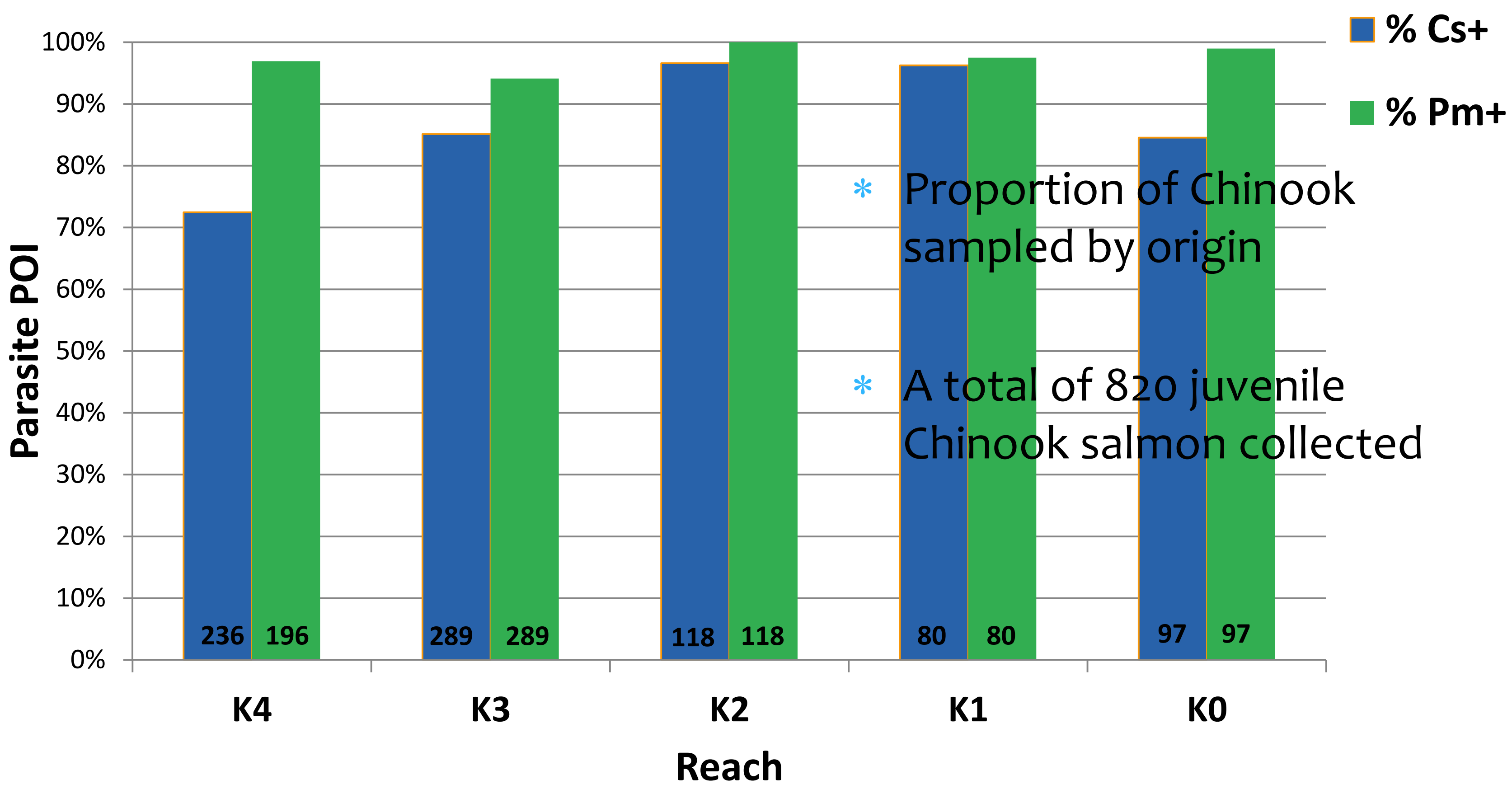
| Ti Crk - Seine Sets | Clinical (%) | Cs POI (%) |
|---|---|---|
| Unmarked Chinook | 23 | 93 |
| CWT Chinook N=17 | 13 | 82 |
| Overall Cs Clinical & POI for Site: | 18 | 91 |

# Ti Crk IGH CWT - WAL 1-3

| Collection Site & Date | CWT Cs POI | WAL Group | Cs POI for Group | Release Date | Days Post Release | Mean DNA Copy Number |
|---|---|---|---|---|---|---|
| TI Crk. | 82% (14/17) | | | | | 14805 |
| Thermal Refugia | | <1(0) WAL | +1/1 (100%) | 6/13/2014 | 3 | 6 |
| 16-Jun-14 | | 1 WAL | +1/2 (50%) | 6/10/2014 | 6 | 9 |
| | | 2 WAL | +5/6 (83%) | 5/30/2014 | 16 | 40951 |
| | | 3 WAL | +7/8 (88%) | 5/23/2014 | 23 | 358 |
| | | | | 5/20/14 (1 fish) | 26 | |

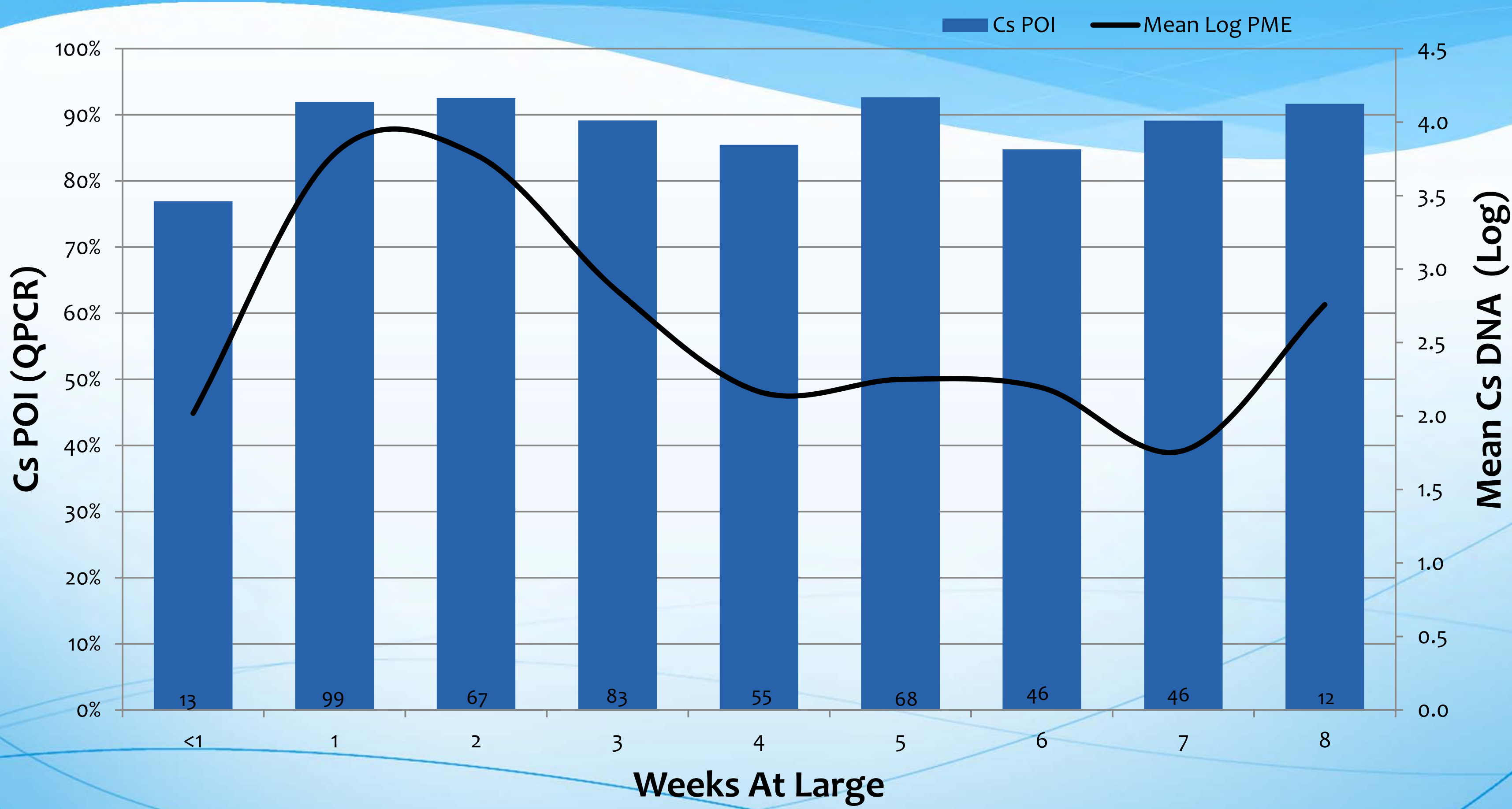
* Cs POI 83% at 2 WAL (16 d) post release
* High parasite load at 41,000 copies
* MDT (May 30-June 16) 19.6°C

# 2015 Cs and Pm POI (All Fish – Peak Migration)
## (Cs POI 84%  Pm POI 97%)




* Proportion of Chinook sampled by origin
* A total of 820 juvenile Chinook salmon collected

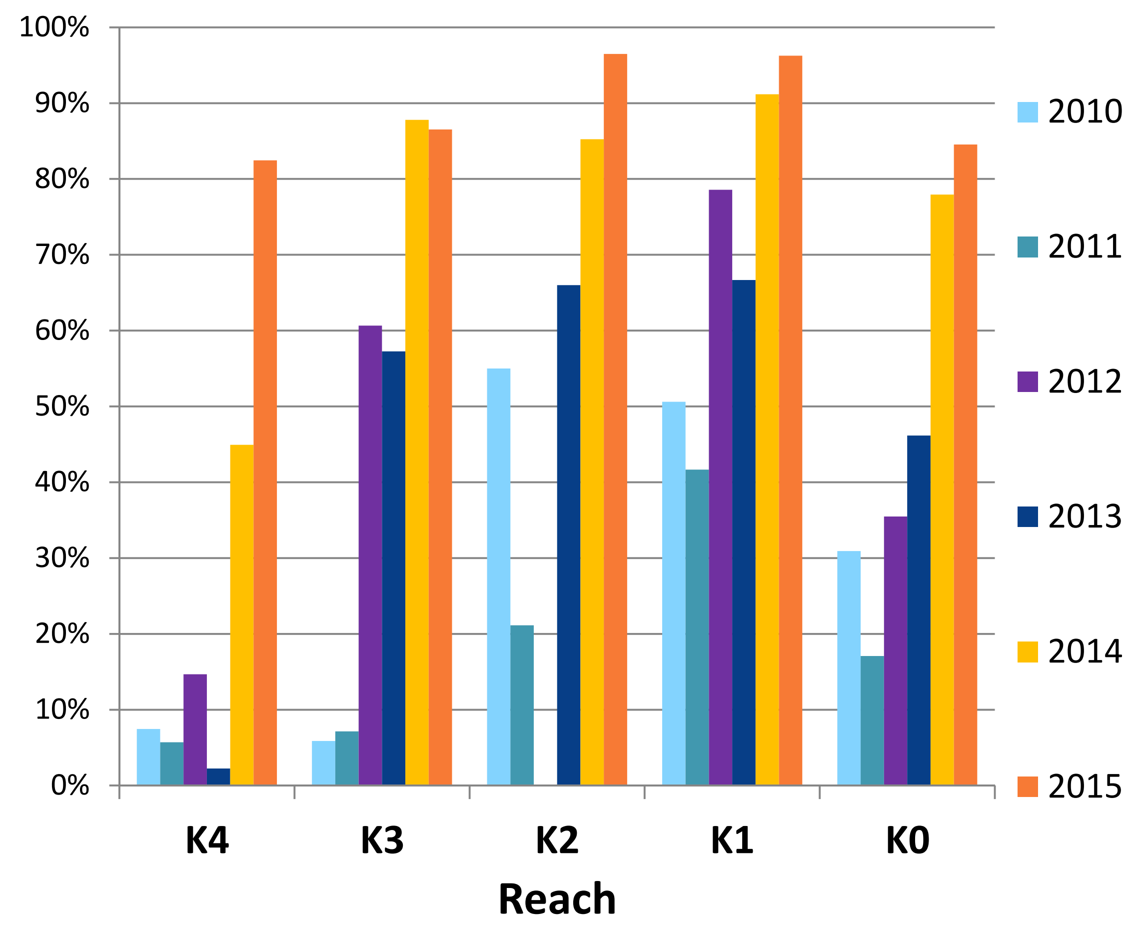
# 2015- IGH CWT WAL - 90% Cs POI



# *Ceratonova shasta* POI by Reach 2010-2015

**Decade of Cs POI in juvenile CHK during outmigration**

- **Large variation in environmental conditions**
- **Temperature/Dose drive POI & severity of infection**



# Summary

**Cs POI in high temp years: 2008-2009 & 2014-2015**

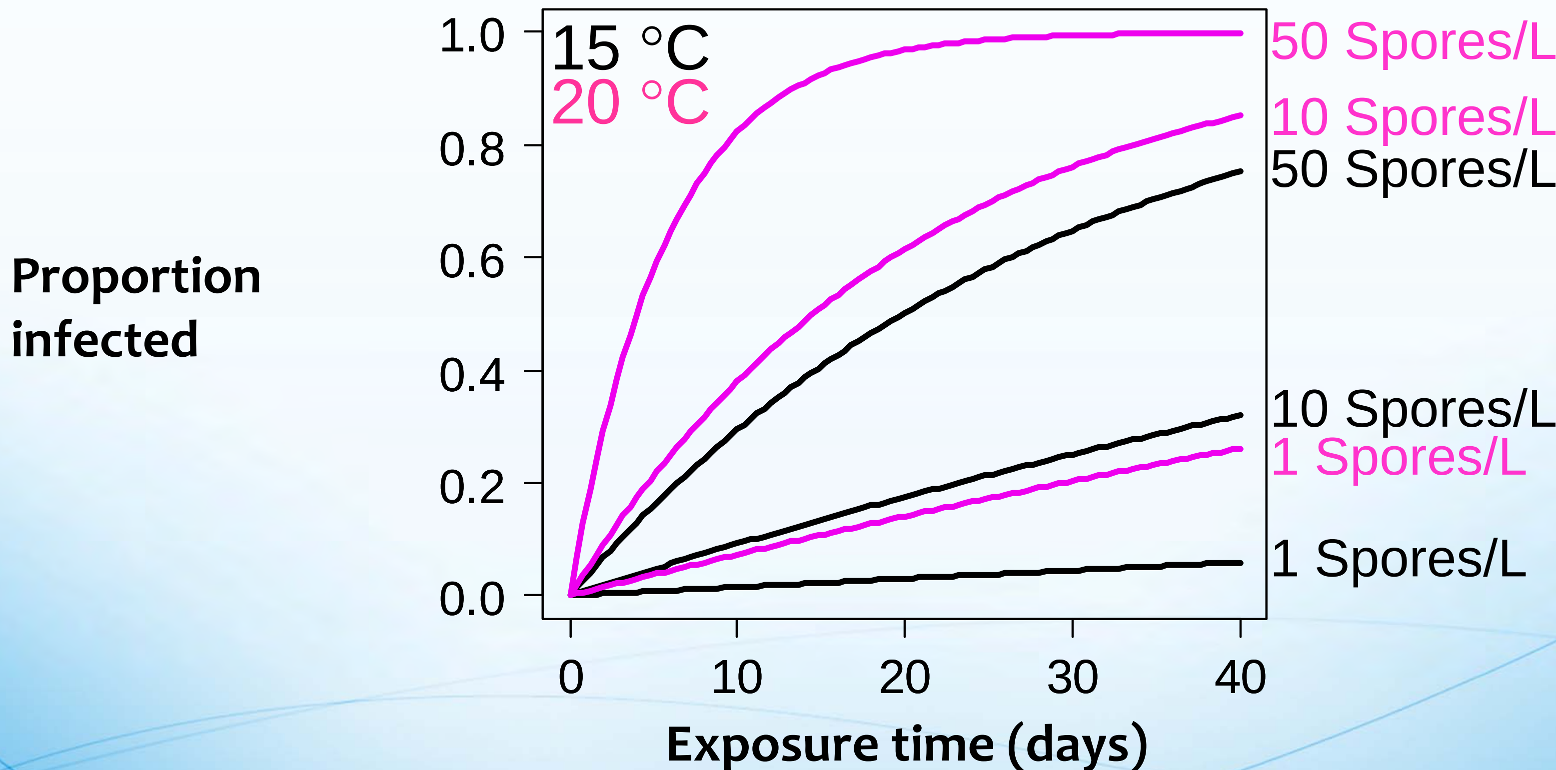
- Early infection onset in upper reaches
- Rapid disease development: IGH CWT at 1-3 WAL
- High parasite load and mortality due to enteronecrosis
  - Juvenile mortality event (mid June - 2014)
  - Additional myxospore input from outmigrating juveniles (16dpe)

**Environmental Implications / Disease Modeling**

- Climate modeling predicts similar trends - earlier onset and protraction of warm periods
- Thermal limits exacerbate endemic disease
- Disease modeling well underway to assess impact at population level

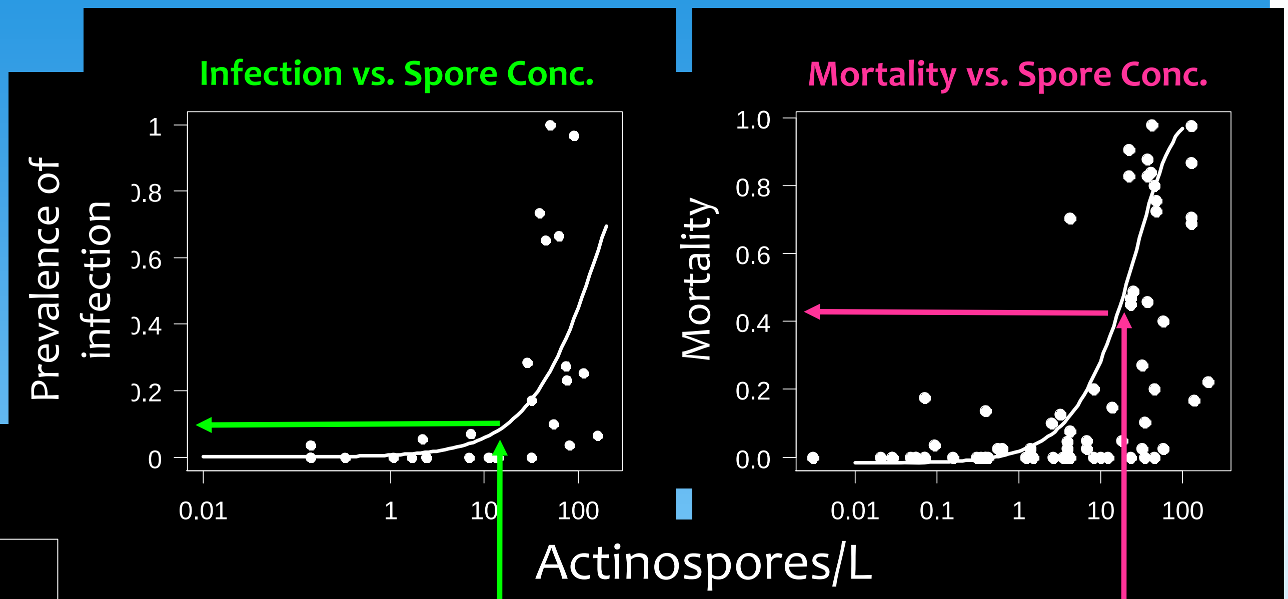
# Model Illustration

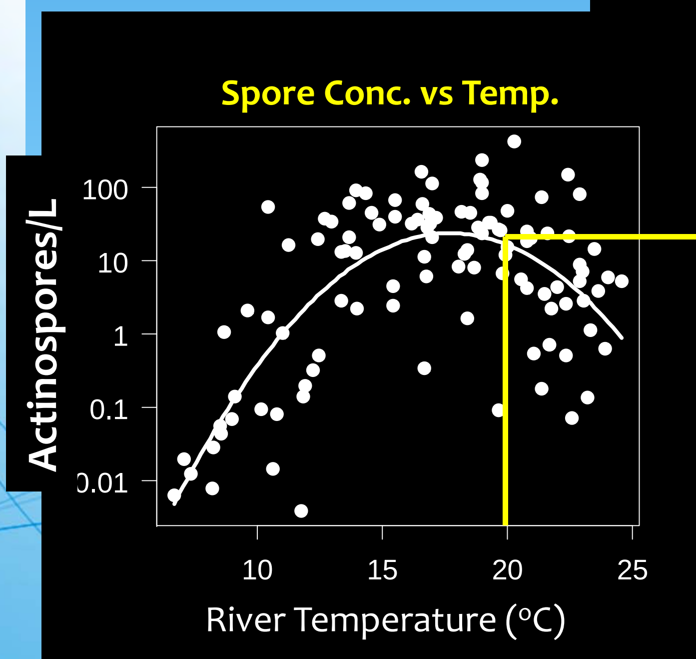
Temp → Spores → Infection → Mortality




Russ Perry USGS

# Linking River Conditions to Infection and Mortality




**River Temp = 20 °C & Spores/L = 16.5**

**Prev. of Infection = 9.3%**

**Mortality | Infection = 42.8%**

**Population Mortality = 0.093*0.428 = 0.04 = 4%**

R. Perry (USGS), Nick Som (USFWS), S. Hallett (OSU)

# Acknowledgements


* BOR for funding KRFHMP
* Fish Collection & Diagnostic Support - Field Crews
  * Karuk Tribe
  * Yurok Tribe
* CWT Data – IGH & Arcata FWO
  * Keith Pomeroy (IGH) & Steve Gough (AFWO)
* Fish Health Center staff
  * R0n Stone (histology) & Jennifer Jacobs (DNA extraction)
* Disease Modelers Russ Perry (USGS) & Nicholas Som (USFWS)

Annual Reports at

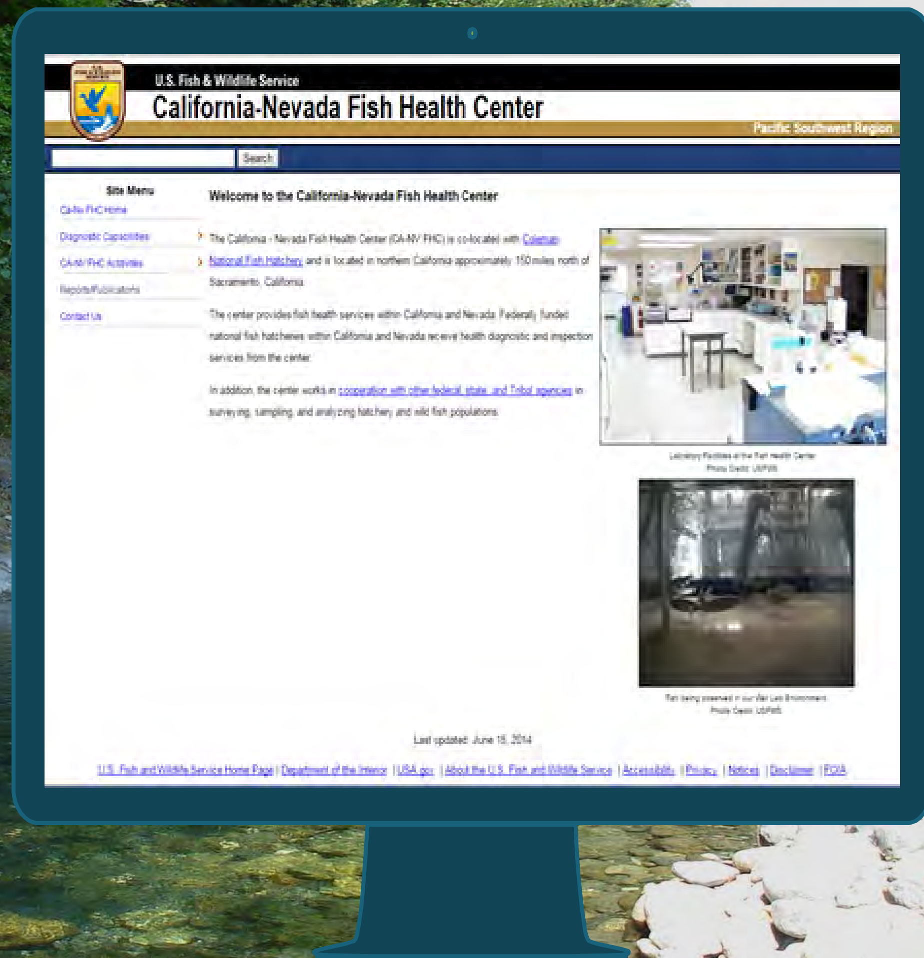
**http://www.fws.gov/canvfhc**

(Cntrl-F to search reports page)

You can contact me at

**kimberly_true@fws.gov**

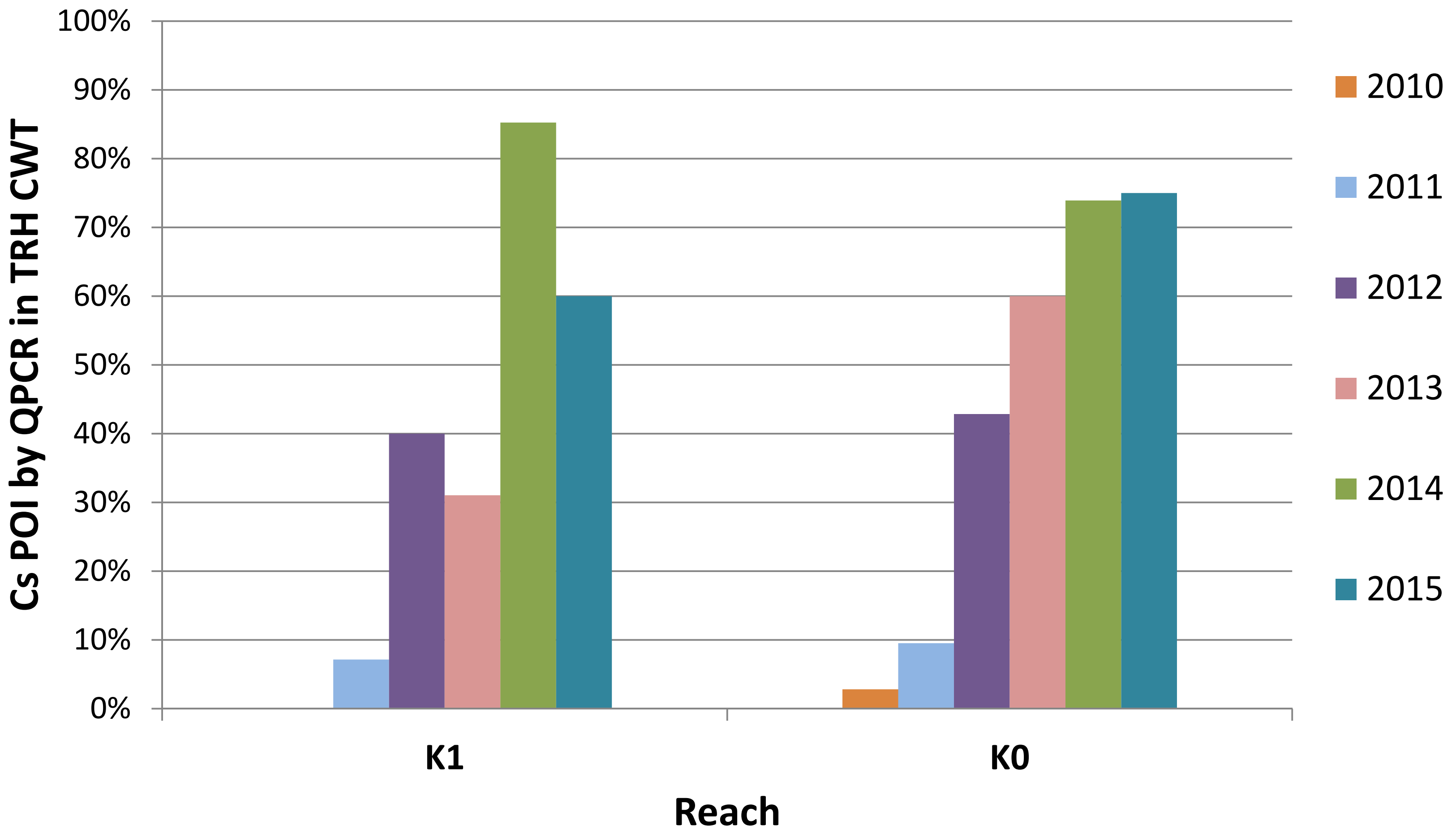
**Questions?**



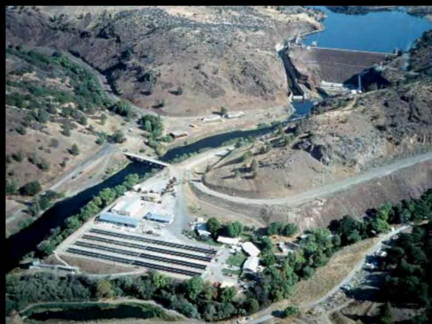

Happy
Birthday
Ethan
Shrooming w/Daddy!

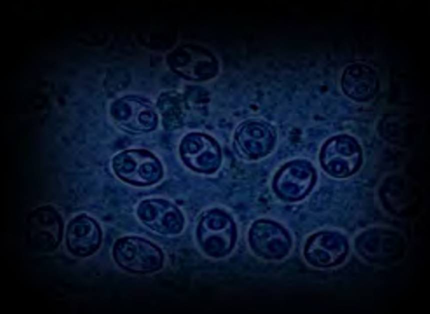
# Annual Comparison

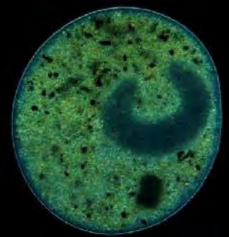
- TRH CWT 2010-2015 Cs POI by reach



# A Conceptual Plan to Remedy Major Fish Pathogens in the Klamath-Trinity Basin








Joshua Strange, Ph.D.

Stillwater Sciences


34th Annual Salmonid Restoration Federation Conference

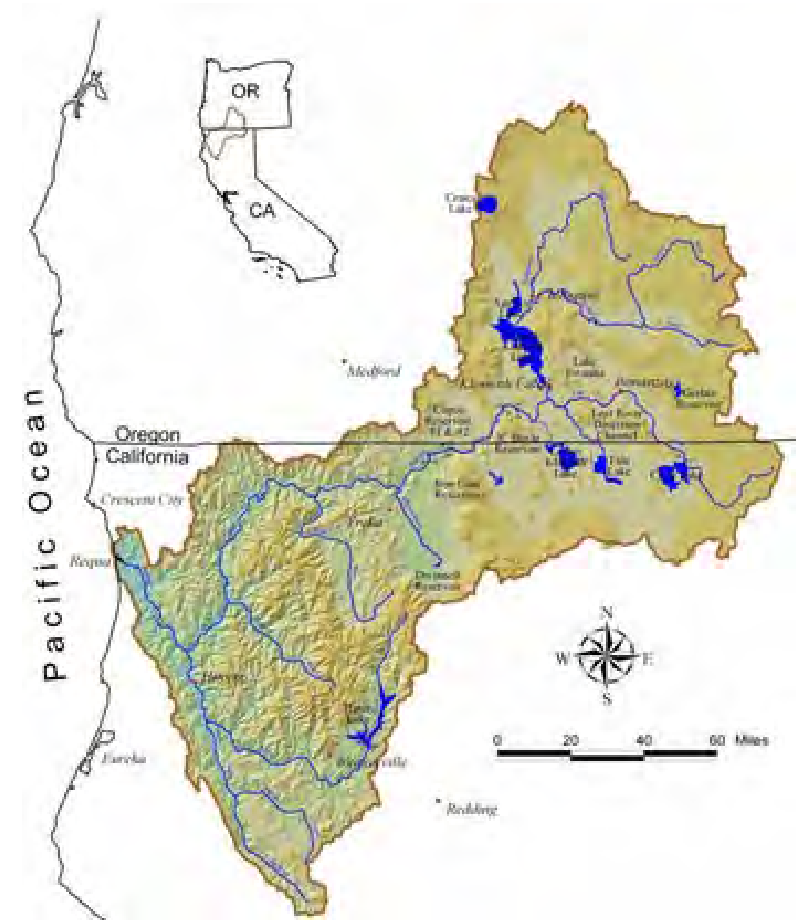
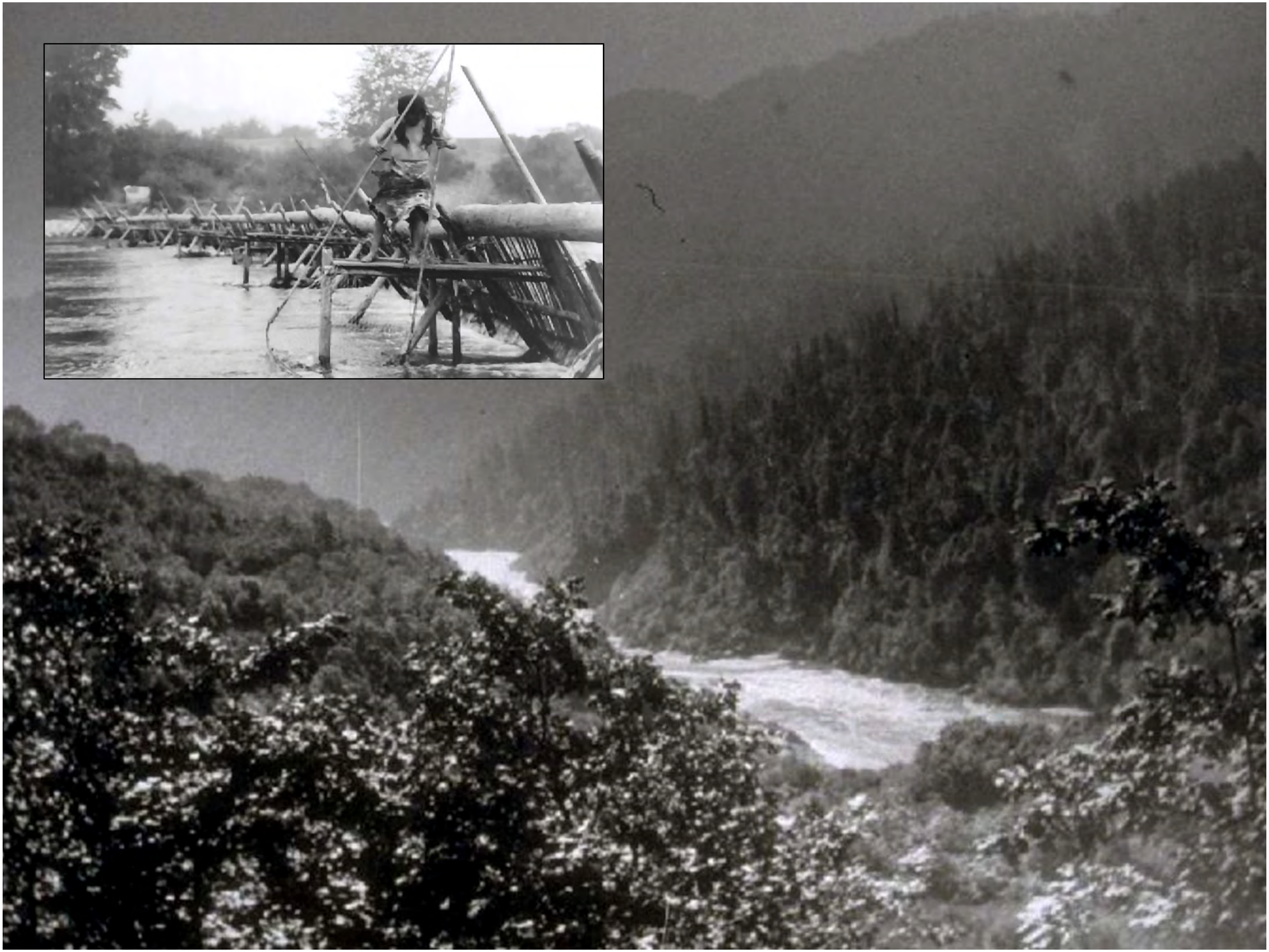
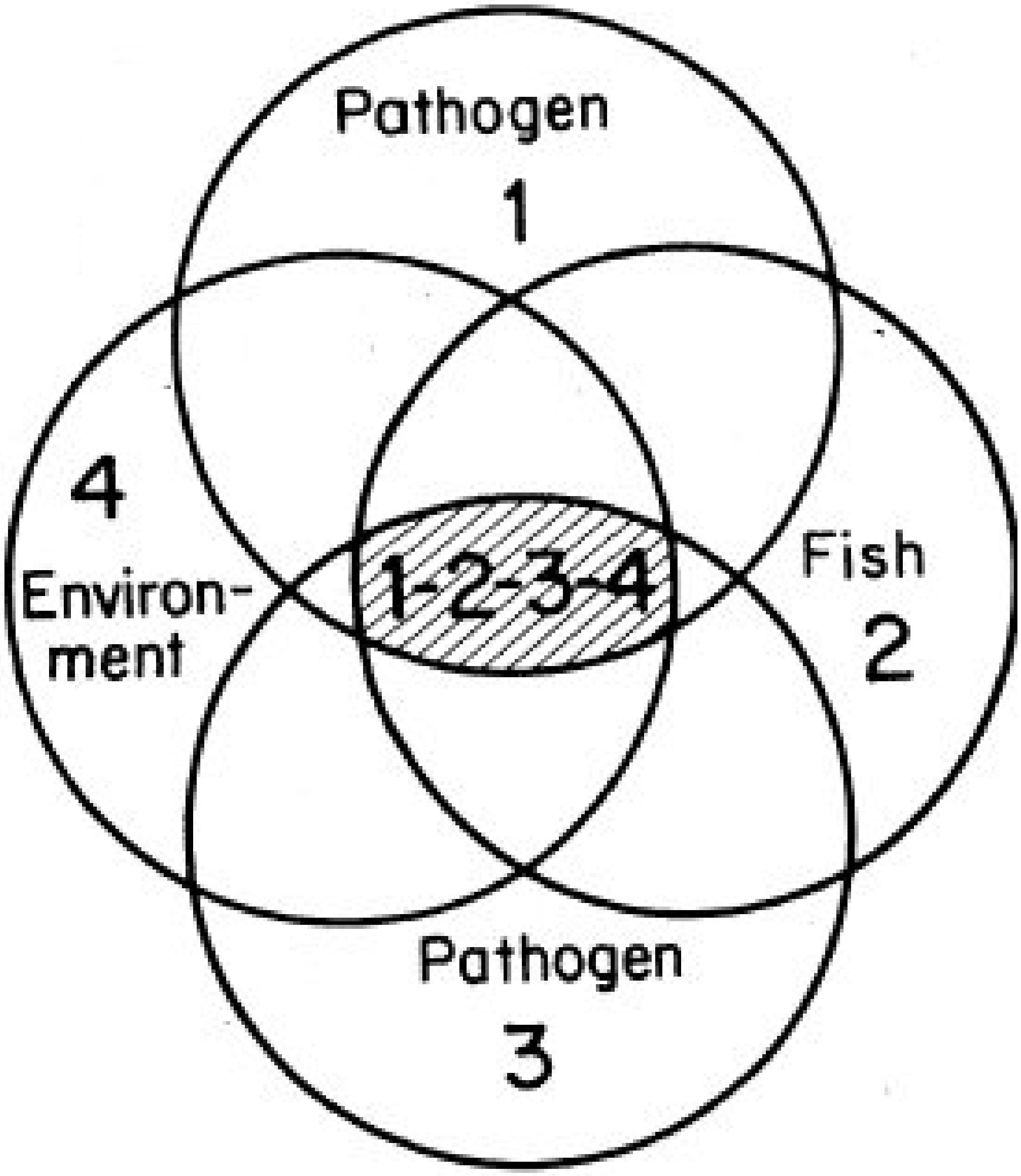
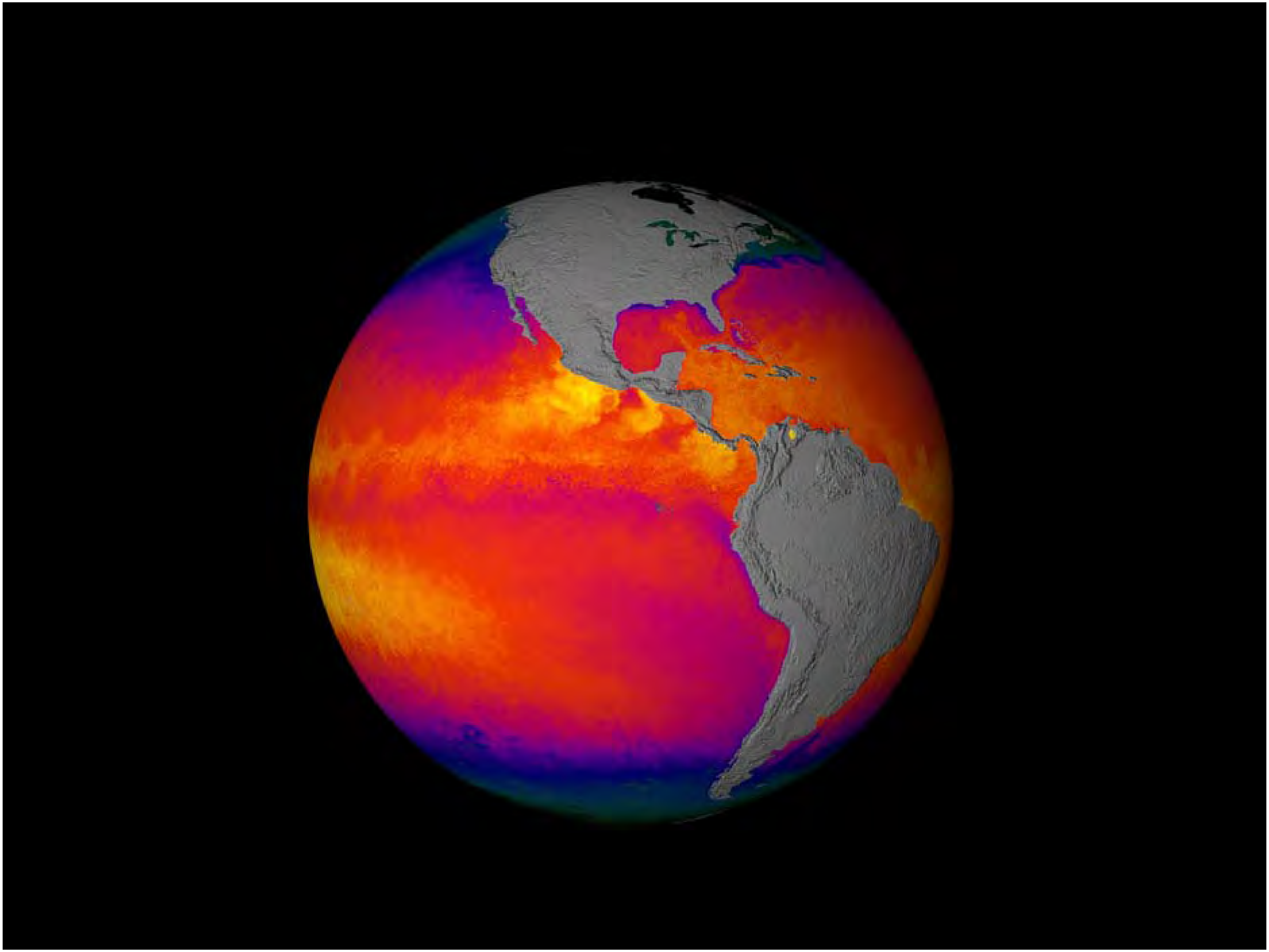

OR
CA
Medford
Pacific Ocean
Oregon
California
Crescent City
Requa
Eureka
Redding
N
W
E
S
0 20 40 60 Miles


Photo: Jamie Holt

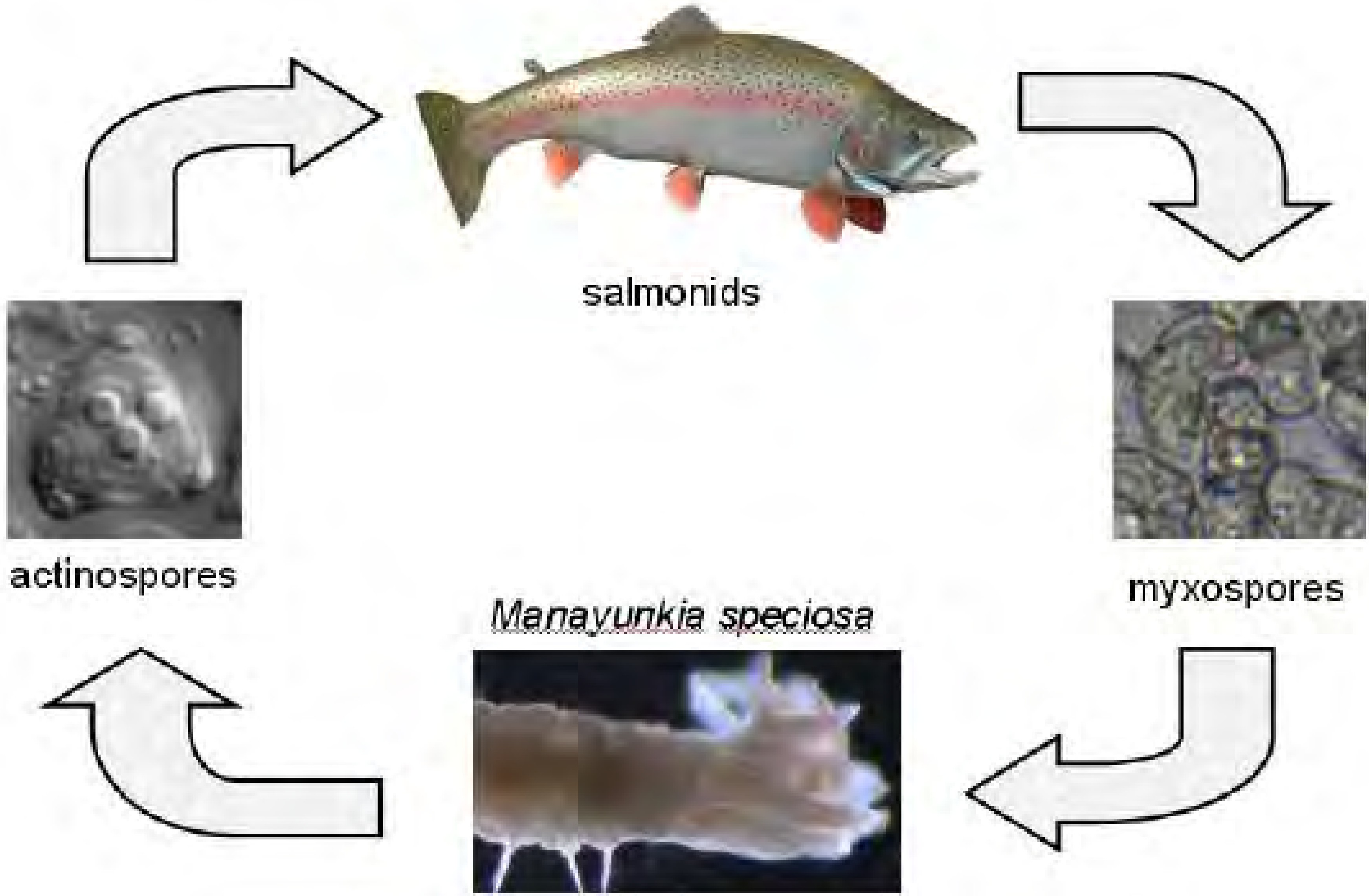


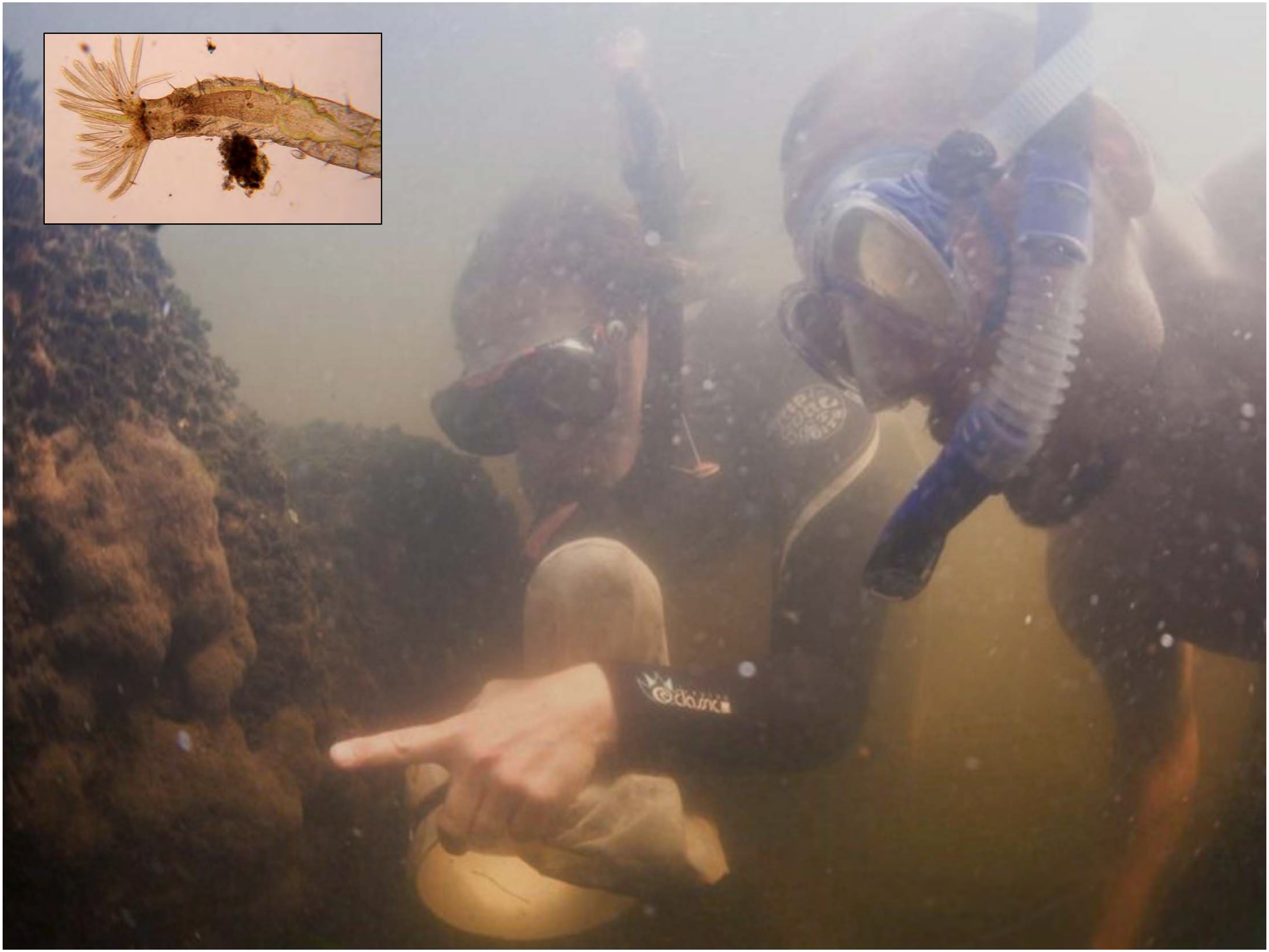

Pathogen
1
4
Environment
Fish
2
1-2-3-4
Pathogen
3



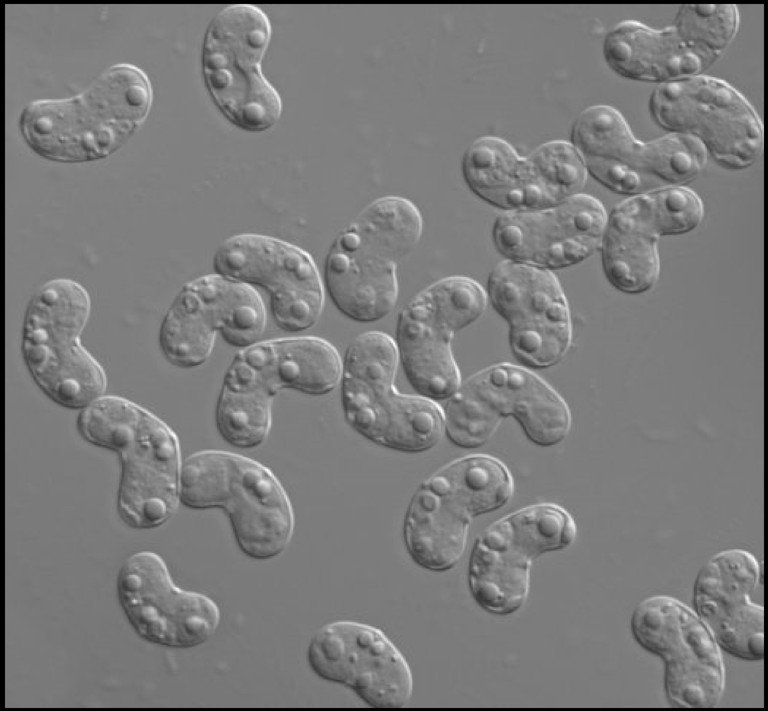

Juvenile Salmonids

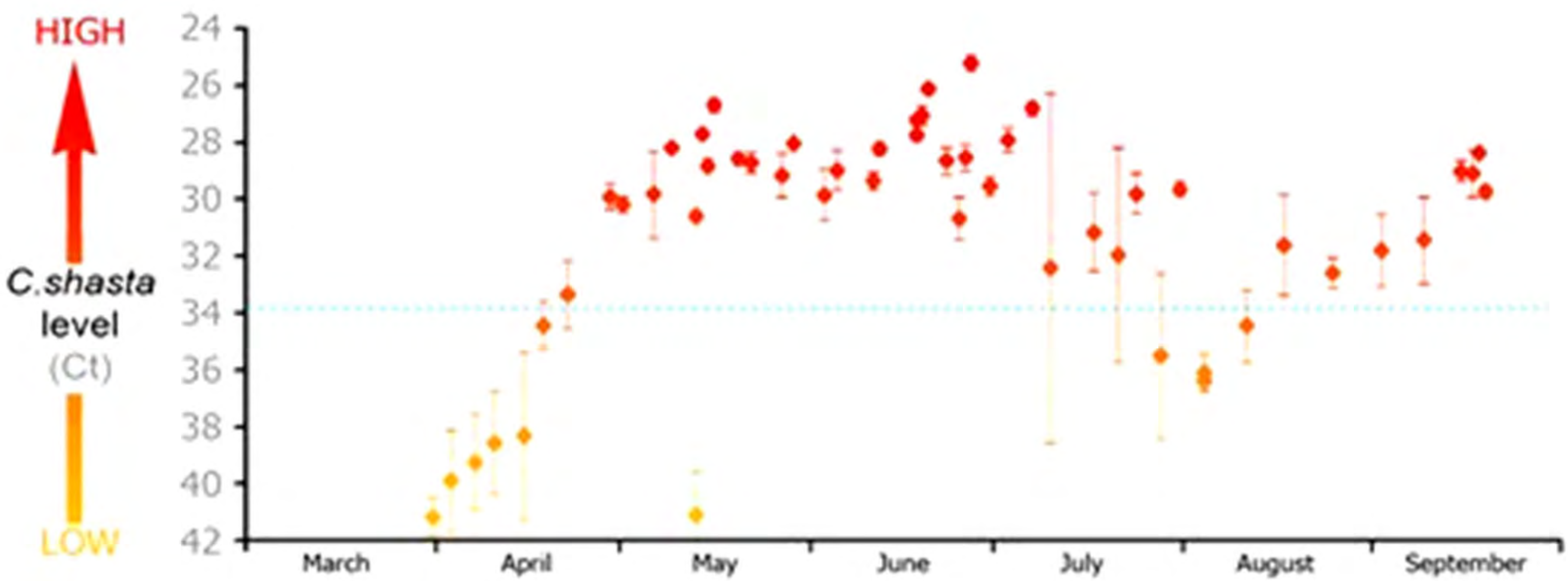
# Protozoan Myxosporidian Pathogens:
# *Ceratonova shatsa*
# *Parvicapsula minibicornis*


salmonids
actinospores
myxospores
Manayunkia speciosa

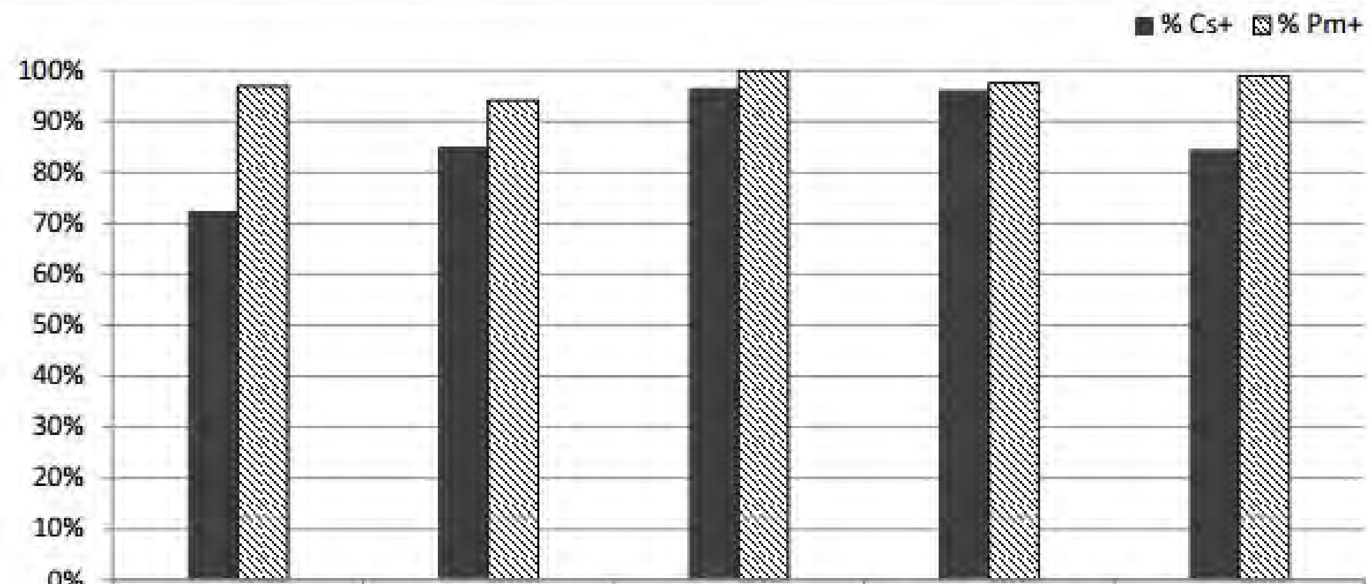



10
20
30
40
50
MILLIMETERS




HIGH
C.shasta
level
(Ct)
LOW
24
26
28
30
32
34
36
38
40
42
March
April
May
June
July
August
September

True, K., Voss, A., & Foott, J. Scott (2016). Myxosporean Parasite (*Ceratonova shasta* and *Parvicapsula minibicornis*) Prevalence of Infection in Klamath River Basin Juvenile Chinook Salmon, April - July 2015. U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, CA. http://www.fws.gov/canvfhc/reports.asp.




| | K4 | K3 | K2 | K1 | K0 |
|---|---|---|---|---|---|
| % Cs+ | 72% | 85% | 97% | 96% | 85% |
| % Pm+ | 97% | 94% | 100% | 98% | 99% |
| Cs n | 236 | 289 | 118 | 80 | 97 |
| Pm n | 196 | 289 | 118 | 80 | 97 |

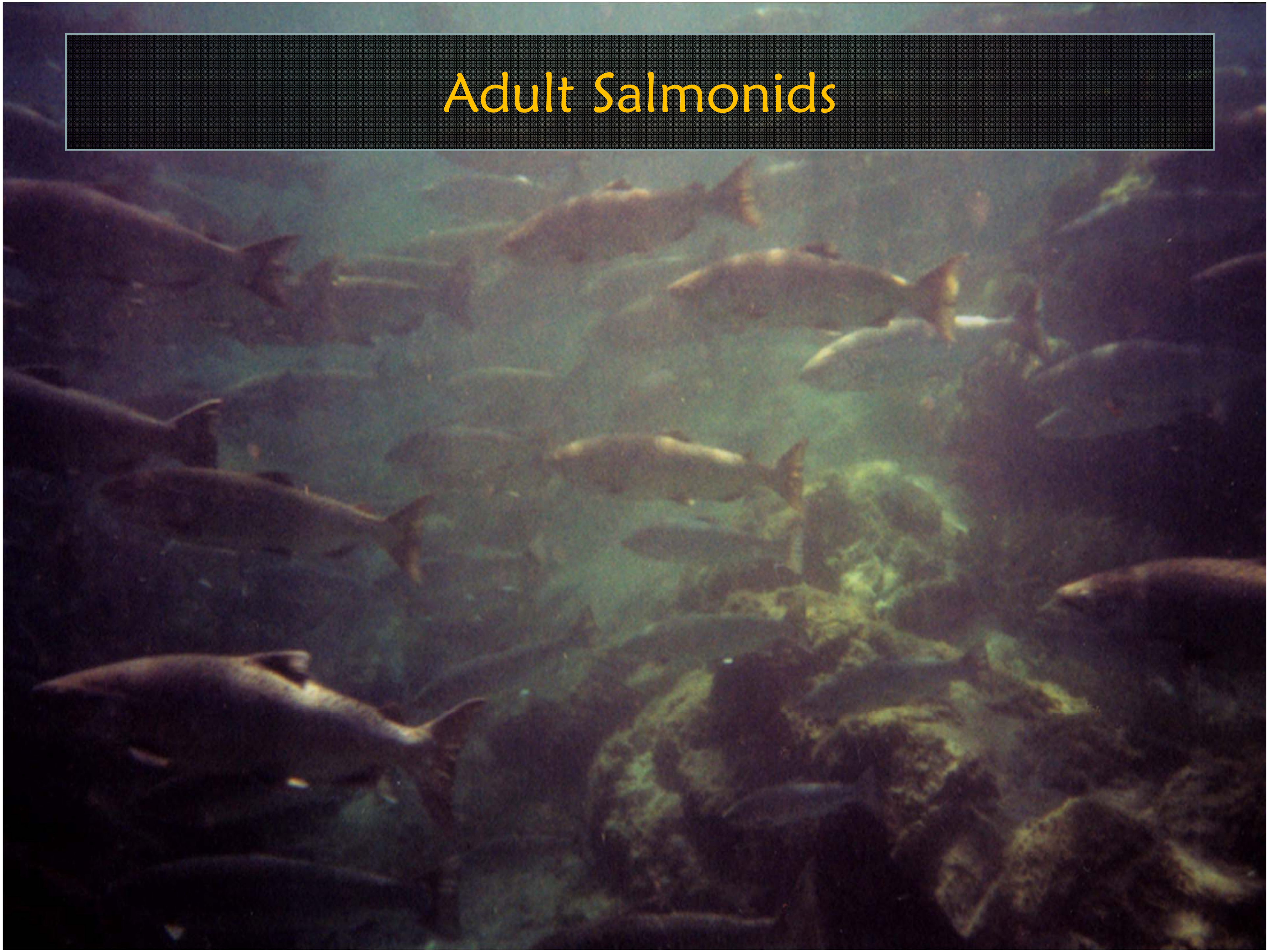
Figure 4. Prevalence of *Ceratonova shasta* (Cs+) and *Parvicapsula minibicornis* (Pm+) infection in juvenile Klamath River Chinook salmon by collection reach in 2015. Shasta River to Scott River (K4), Scott River to Salmon River (K3), Salmon River to Trinity River confluence (K2), Trinity River to upper Estuary (K1), and Klamath River Estuary (K0). Sample numbers collected (N) are displayed in the table below each column for both pathogens.

True, K., Voss, A., & Foott, J. Scott (2016). Myxosporean Parasite (*Ceratonova shasta* and *Parvicapsula minibicornis*) Prevalence of Infection in Klamath River Basin Juvenile Chinook Salmon, April - July 2015. U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, CA. http://www.fws.gov/canvfhc/reports.asp.

Table 2. Historic annual prevalence of *Ceratonova shasta* infection (% positive by assay) in all juvenile Chinook salmon collected from the main stem Klamath River between Iron Gate Dam and Trinity River confluence during May through July, 2006-2015.

| Year | Histology (% Positive) | QPCR (% Positive) |
|---|---|---|
| 2006 | 21 | 34 |
| 2007 | 21 | 31 |
| 2008 | 37 | 49 |
| 2009 | 54 | 45 |
| 2010 | 15 | 17 |
| 2011 | 2[1] | 17 |
| 2012 | 9[1] | 30 |
| 2013 | 16[1] | 46 |
| 2014 | 42[1] | 81 |
| 2015 | 62[1] | 91 |
| **Mean** | **28** | **44** |

[1] Histology limited to two reaches in 2011 (K4 and K1); and two reaches in 2012-2015 (K4 and K3).


Adult Salmonids


Flavobactor columnare
“columnaris”


September 2002
Fish Kill
67,000 adult chinook
Photo Mike Belchik

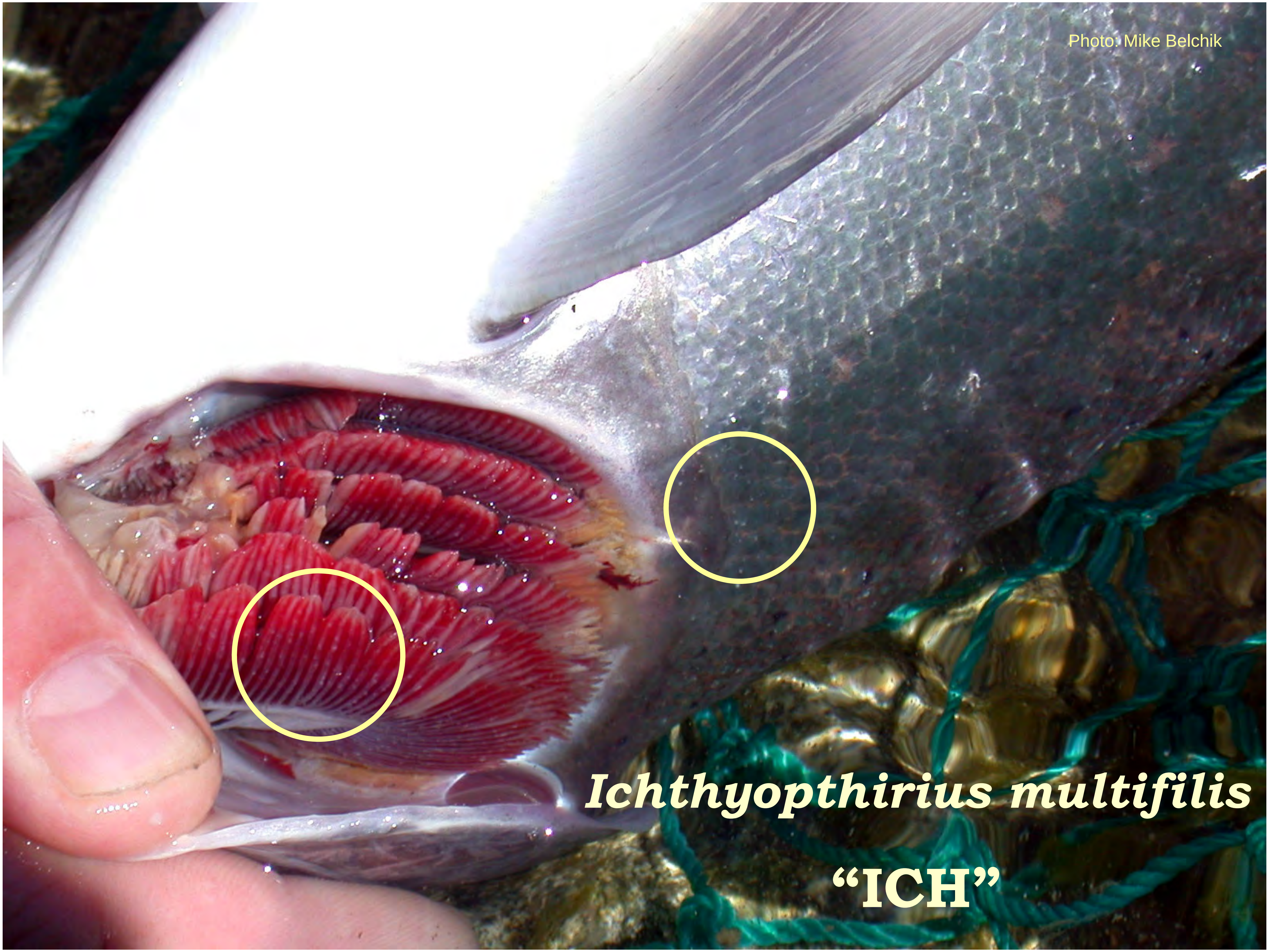
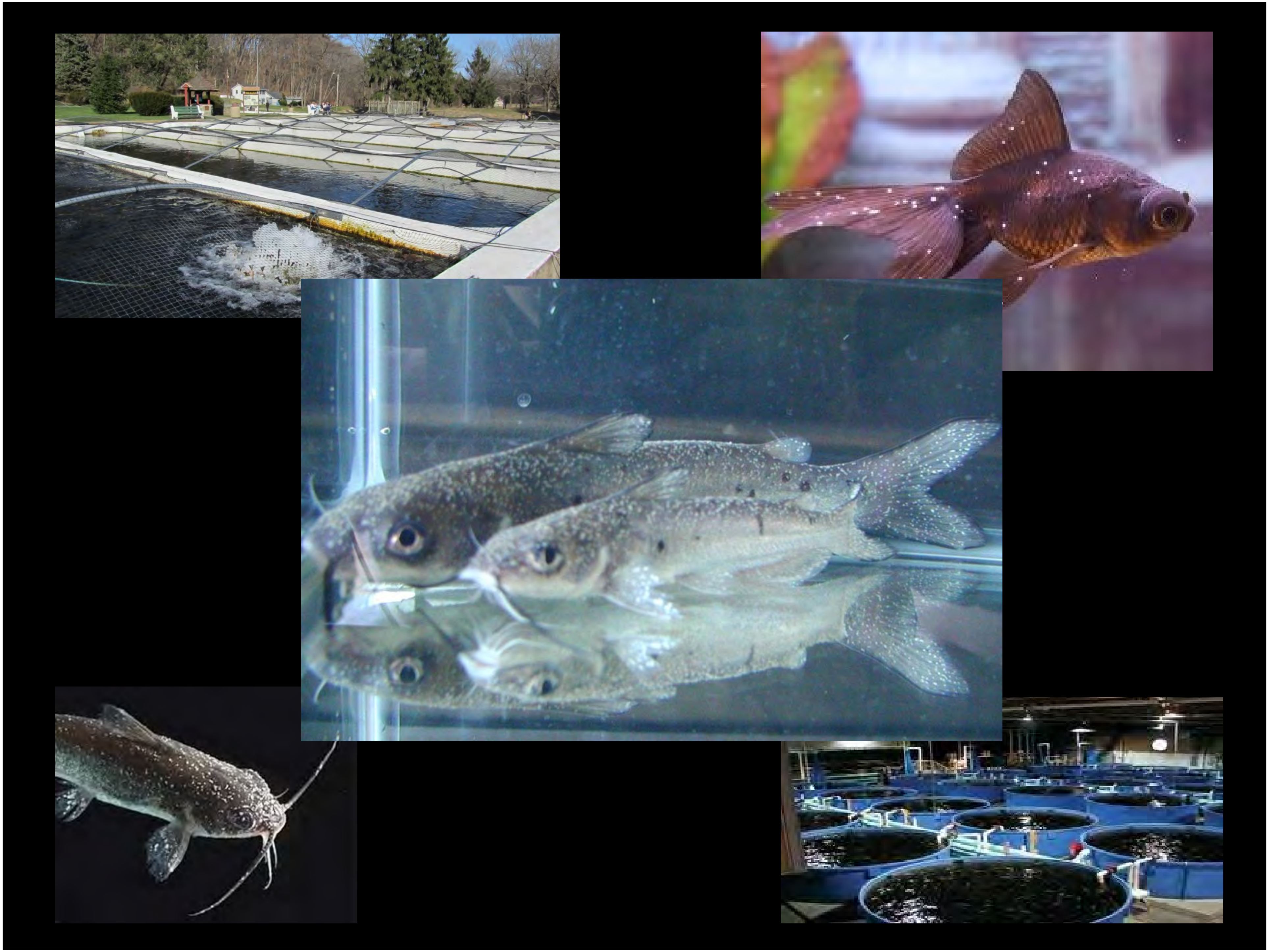
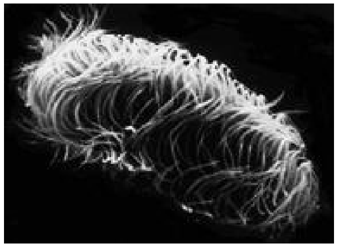
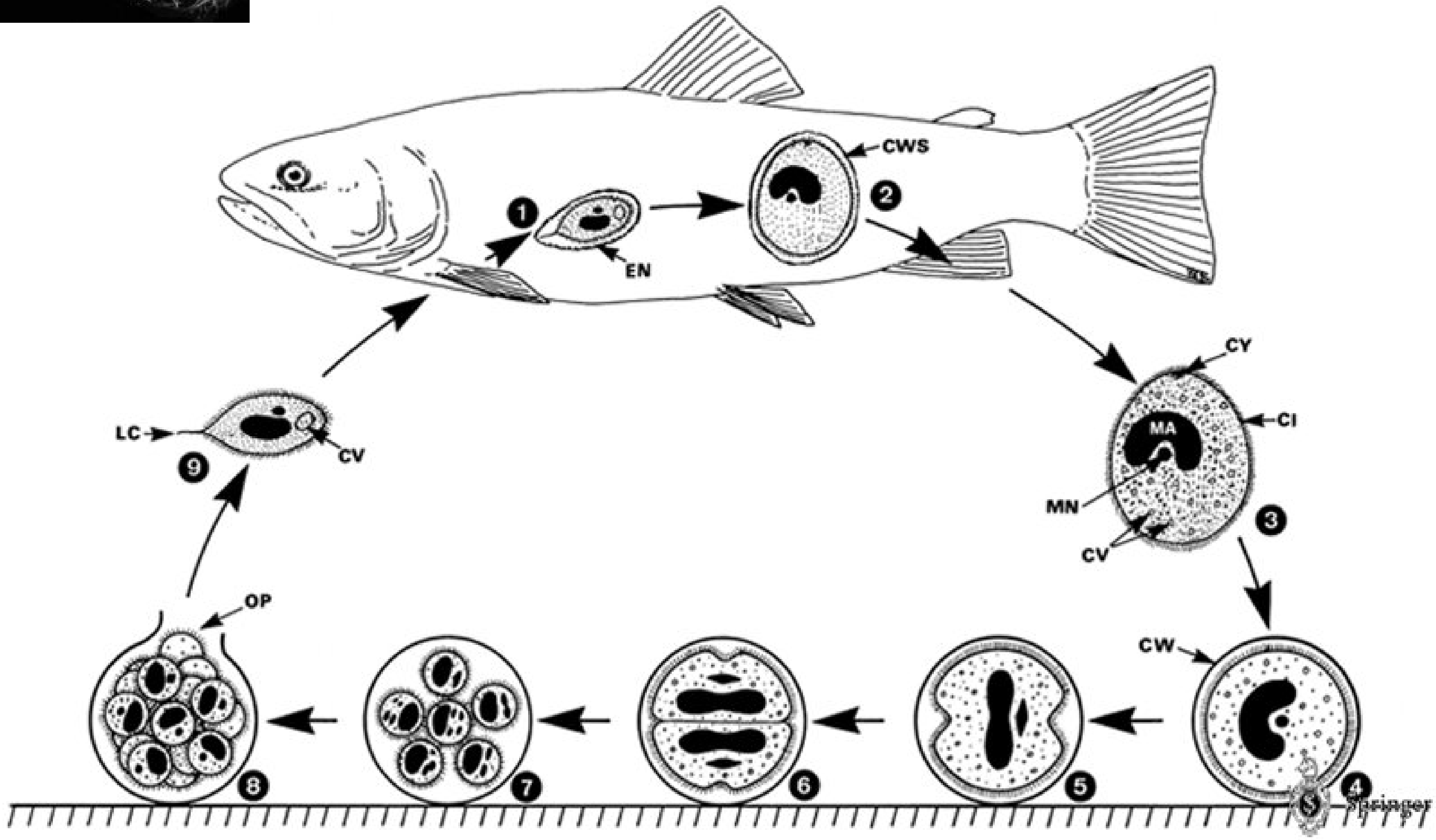


Photo: Mike Belchik
*Ichthyopthirius multifilis*
"ICH"





# *Ichthyopthirius multifilis*

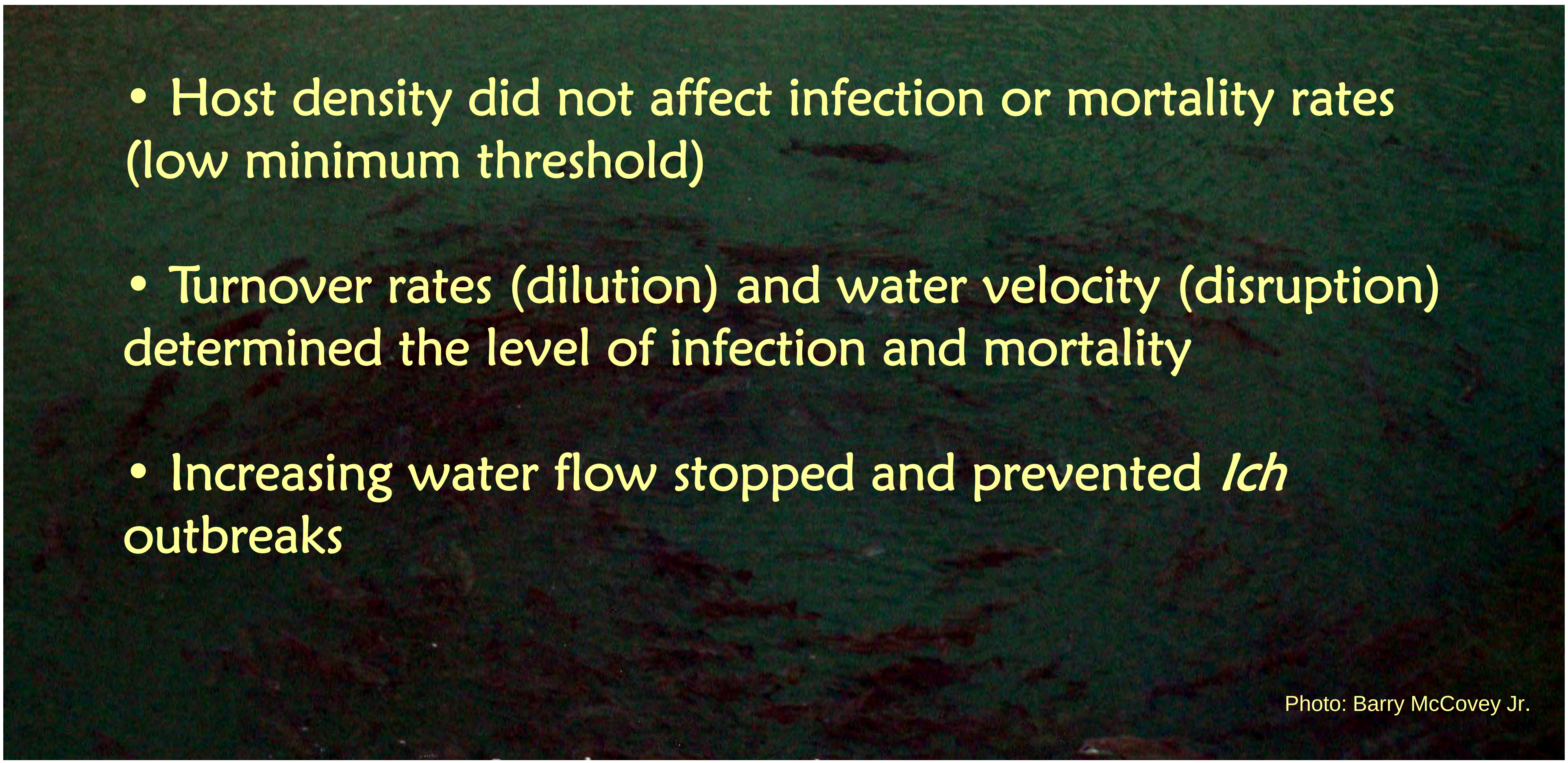


*Journal of Aquatic Animal Health* 12:209–219, 2000


# Flowing Water: An Effective Treatment for Ichthyophthiriasis

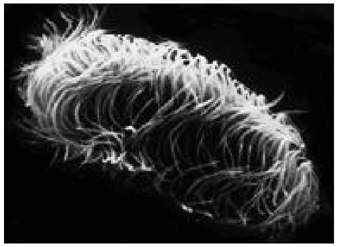
Leo R. Bodensteiner*

*Huxley College of Environmental Studies, Western Washington University, Bellingham, Washington 98225-9181, USA*

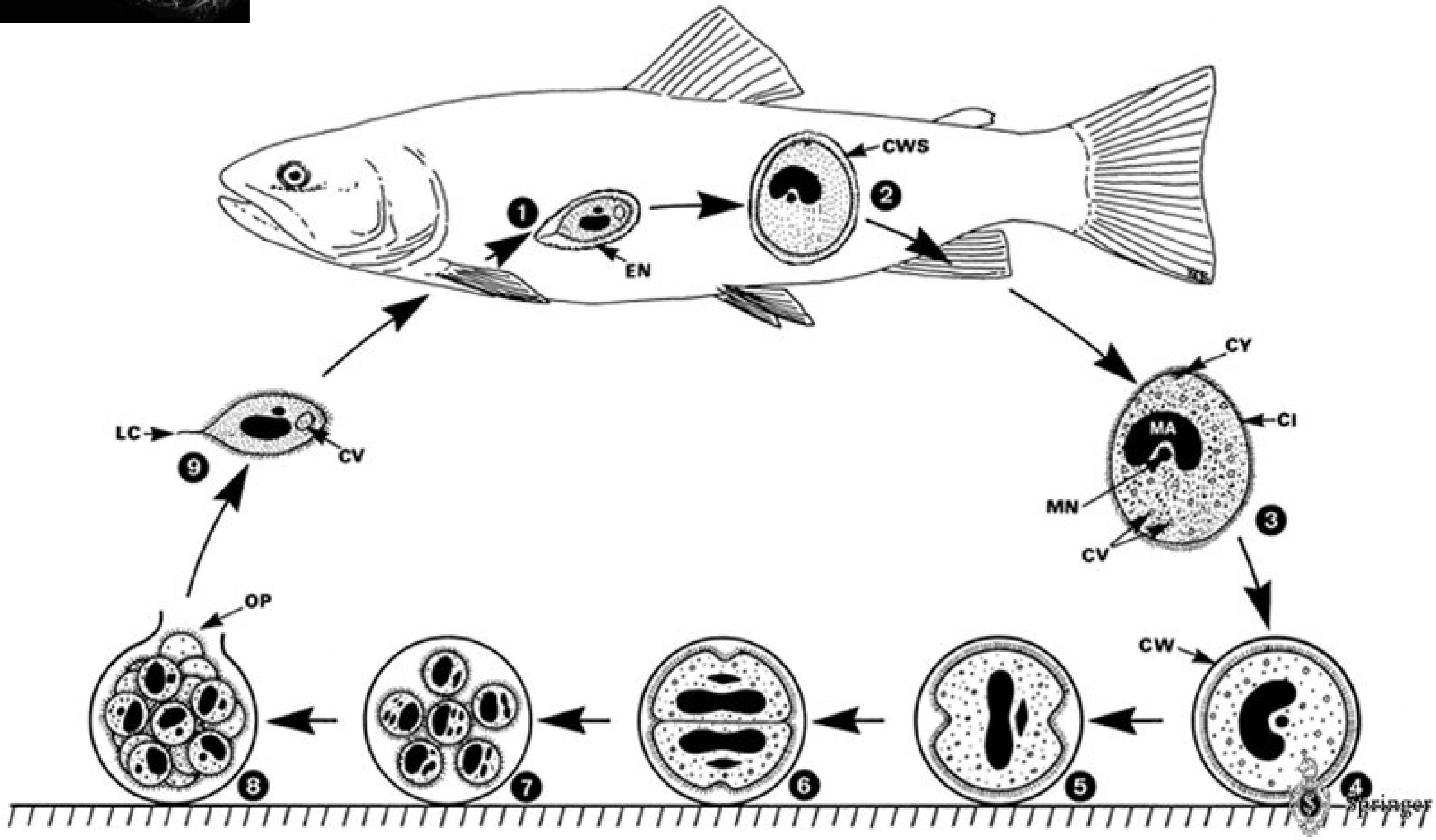


- Host density did not affect infection or mortality rates (low minimum threshold)
- Turnover rates (dilution) and water velocity (disruption) determined the level of infection and mortality
- Increasing water flow stopped and prevented *Ich* outbreaks

Photo: Barry McCovey Jr.



# *Ichthyopthirius multifilis*

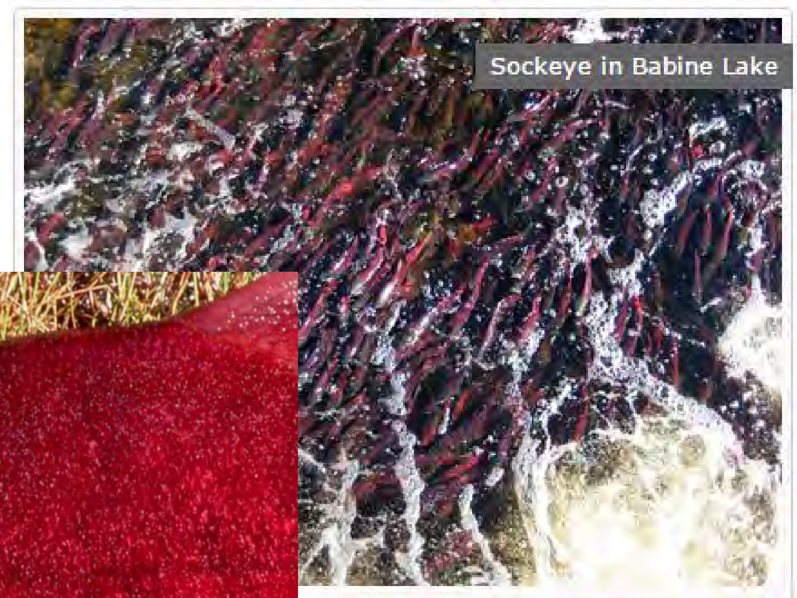


*Journal of Aquatic Animal Health* 10:143–151, 1998
American Fisheries Society 1998

# *Ichthyophthirius multifiliis* (Ich) Epizootics in Spawning Sockeye Salmon in British Columbia, Canada

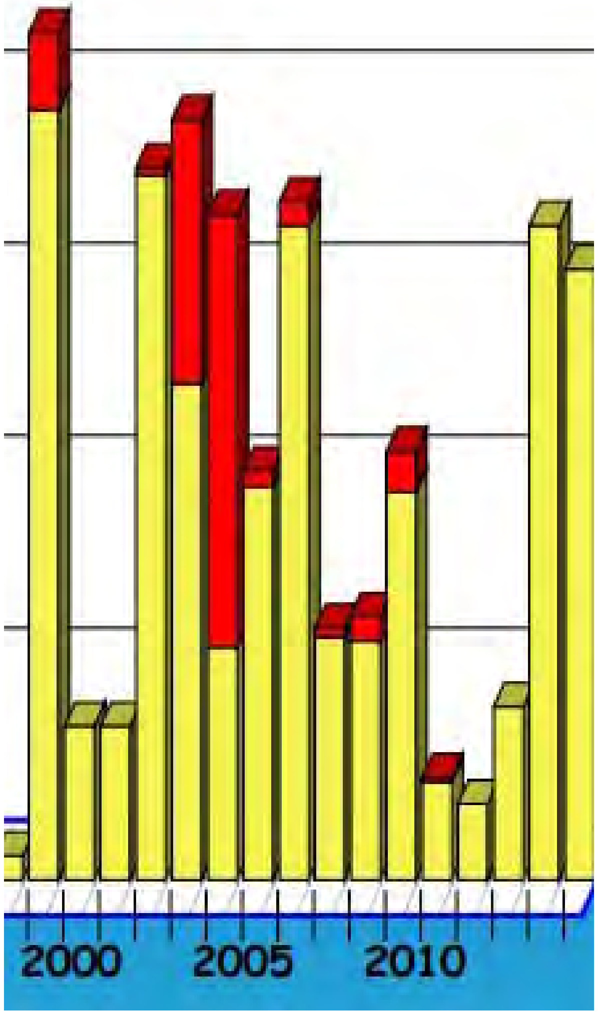
G. S. TRAXLER,* J. RICHARD, AND T. E. McDONALD

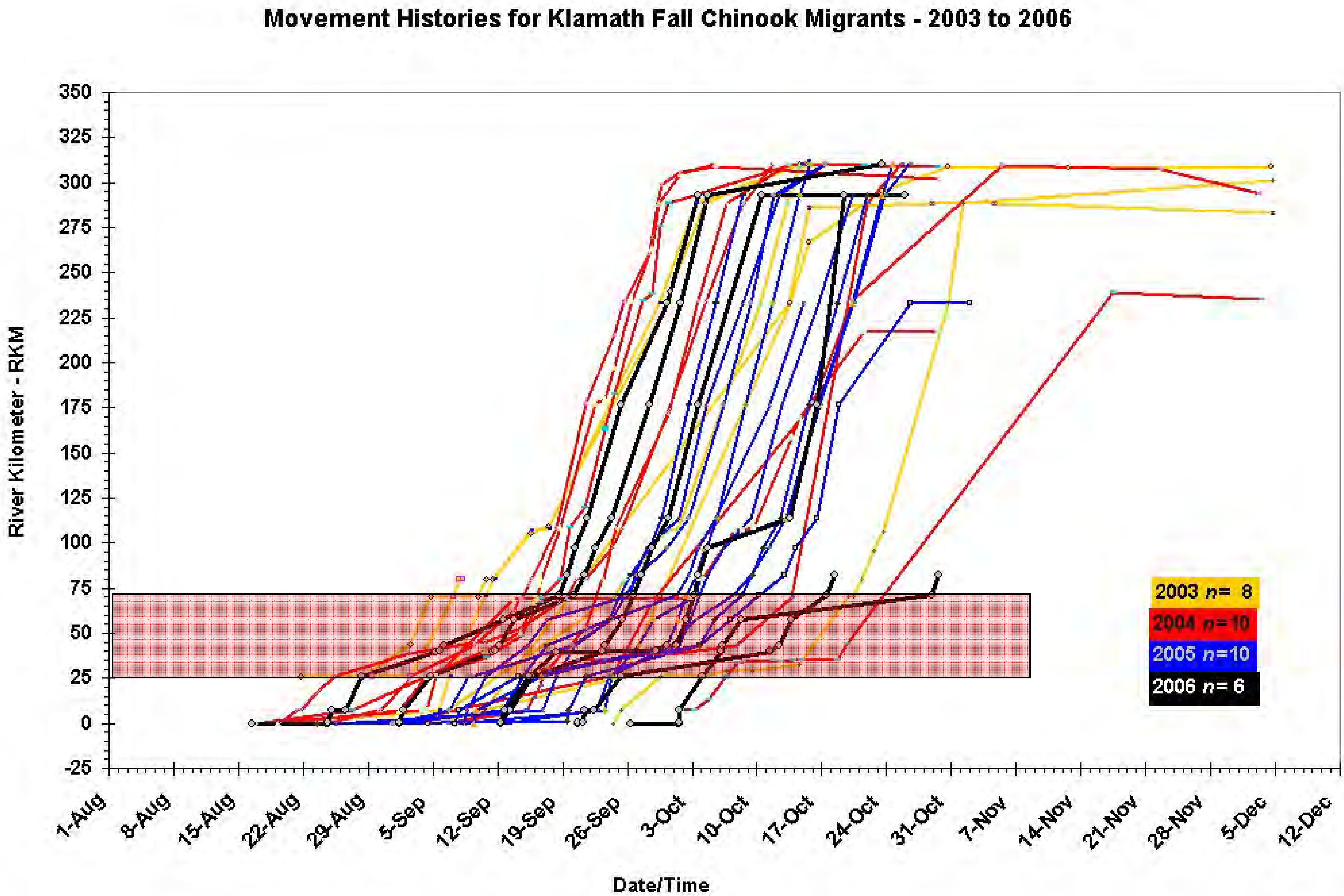
*Department of Fisheries and Oceans, Pacific Biological Station*
*Nanaimo, British Columbia V9R 5K6, Canada*




BUTTE CREEK
SPRING-RUN CHINOOK SALMON, ONCORYHNCHUS TSHAWYTSCHA
PRE-SPAWN MORTALITY EVALUATION

## Federal Government Intervenes in Butte Creek Salmon Disaster

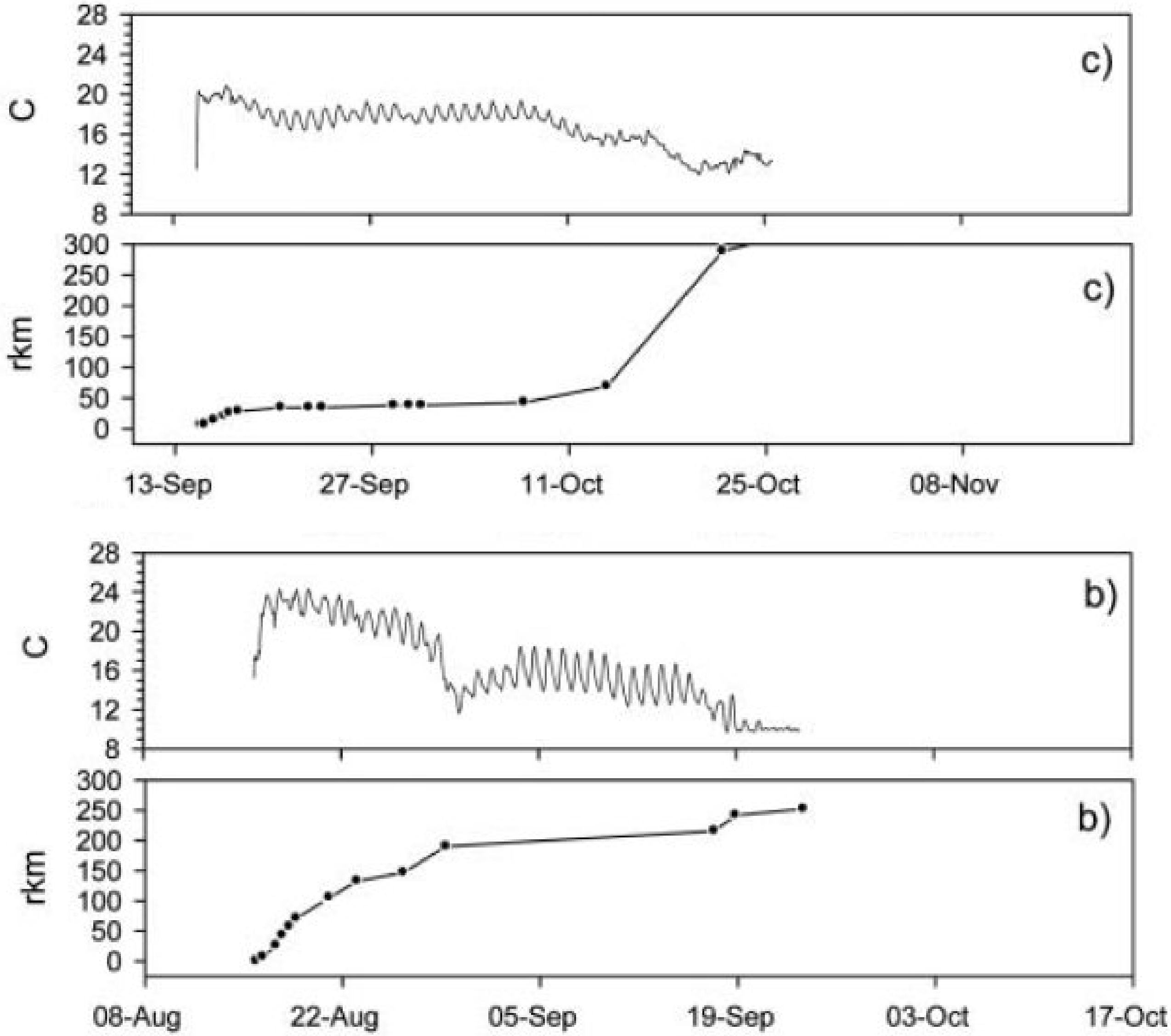


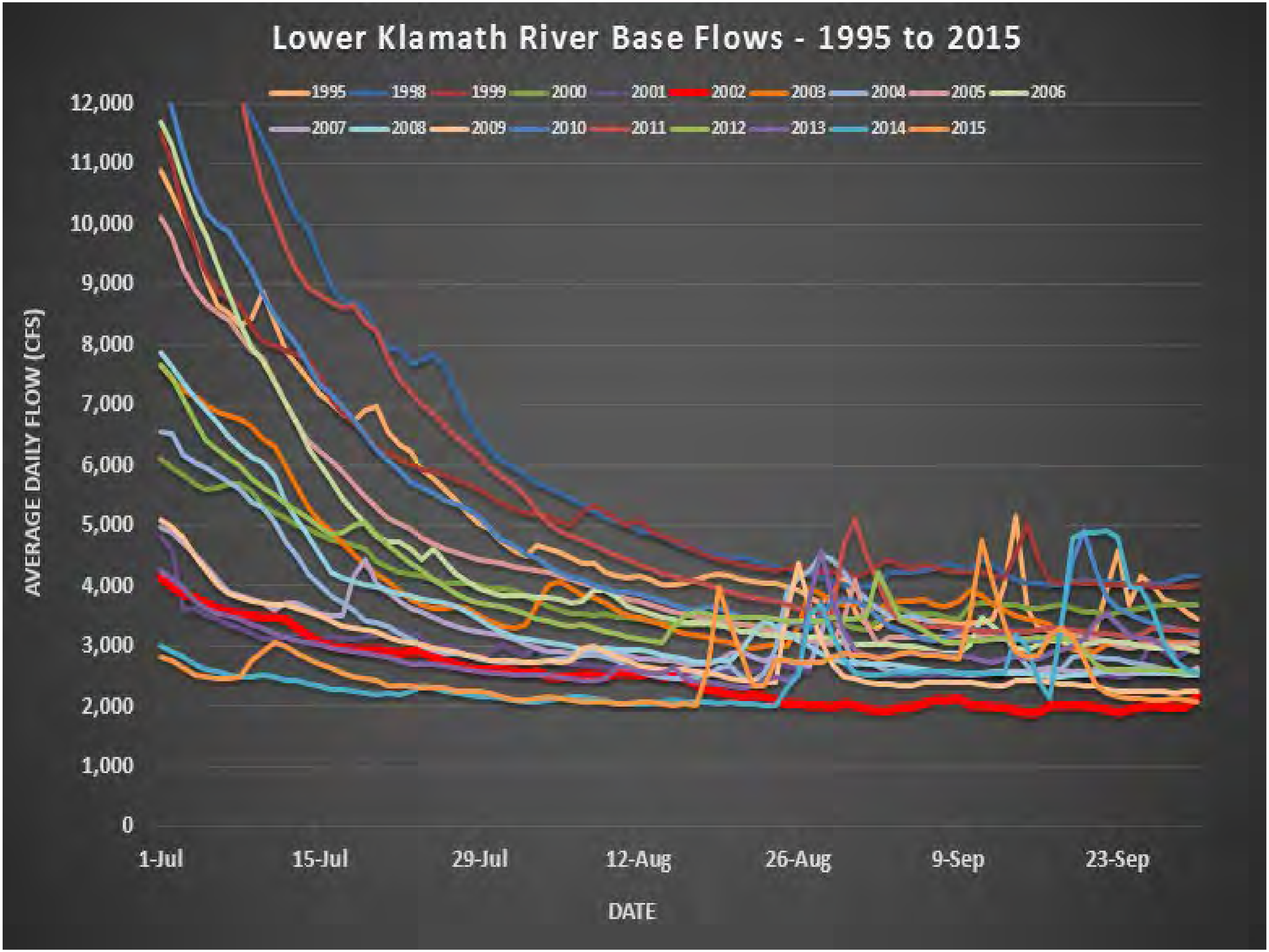


Movement Histories for Klamath Fall Chinook Migrants - 2003 to 2006
River Kilometer - RKM
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
-25
1-Aug
8-Aug
15-Aug
22-Aug
29-Aug
5-Sep
12-Sep
19-Sep
26-Sep
3-Oct
10-Oct
17-Oct
24-Oct
31-Oct
7-Nov
14-Nov
21-Nov
28-Nov
5-Dec
12-Dec
Date/Time
2003 n= 8
2004 n=10
2005 n=10
2006 n= 6

# Migration Strategies of Adult Chinook Salmon Runs in Response to Diverse Environmental Conditions in the Klamath River Basin

Joshua S. Strange*





Lower Klamath River Base Flows - 1995 to 2015
1995
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
AVERAGE DAILY FLOW (CFS)
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1-Jul
15-Jul
29-Jul
12-Aug
26-Aug
9-Sep
23-Sep
DATE


10 20 30 40 50
MILLIMETERS
Photo: Josh Strange


INCHES
CENTIMETERS

Mortality Threshold for Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in an Epidemiological Model of *Ceratomyxa shasta*

by
R. Adam Ray

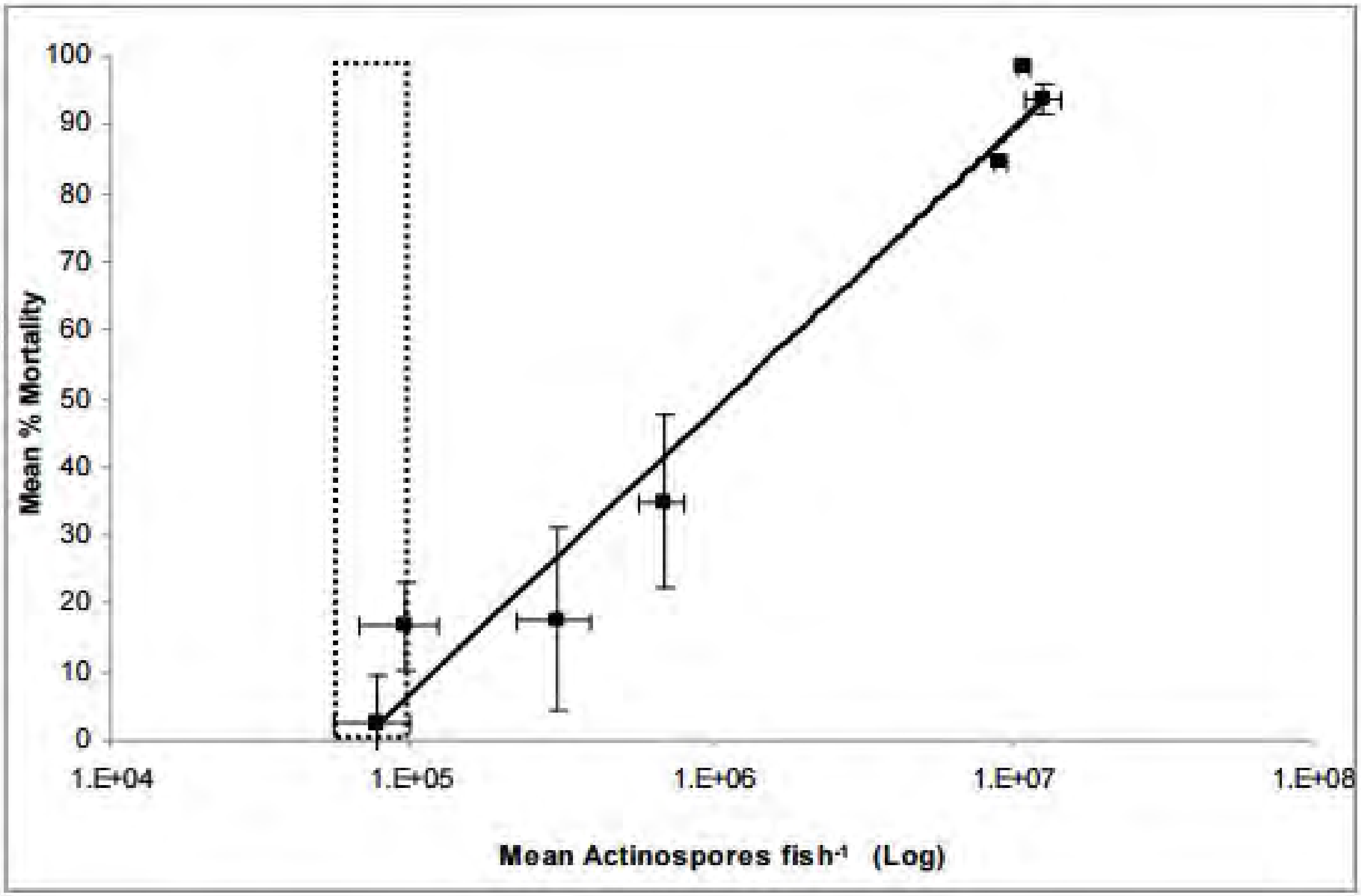



Photo: Thomas Dunklin


Photo: Josh Strange

Bartholow et al. 2004

DOI: 10.1007/s00267-004-0269-5

# ENVIRONMENTAL ASSESSMENT

## Predicting the Thermal Effects of Dam Removal on the Klamath River

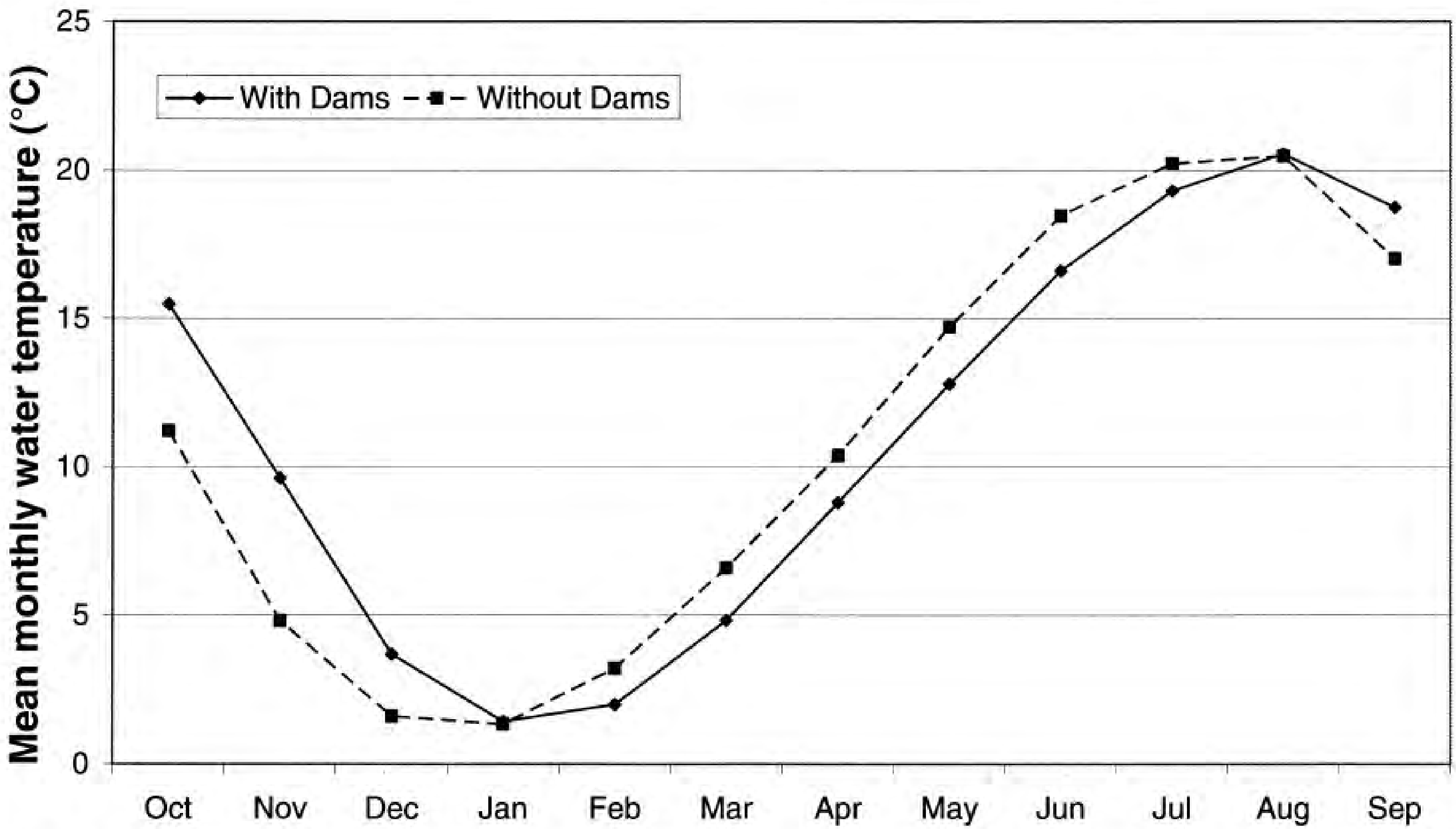
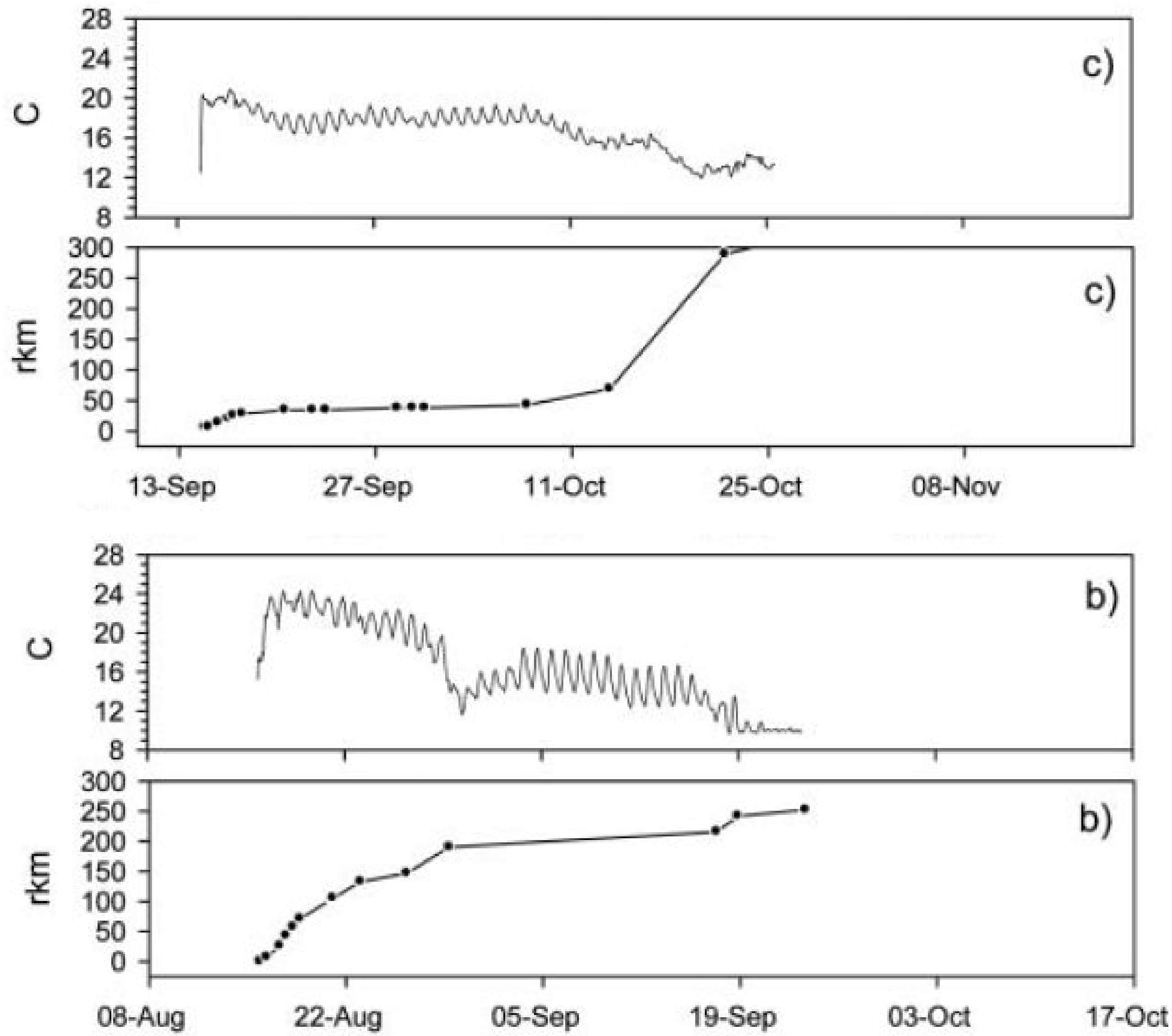



**Figure 4.** Comparison of predicted mean monthly water temperatures between the *With Dams* and *Without Dams* scenarios averaged over the 40-year period at the Iron Gate Dam site.

# Migration Strategies of Adult Chinook Salmon Runs in Response to Diverse Environmental Conditions in the Klamath River Basin

Joshua S. Strange*



# Klamath River dam-removal project will be world's biggest

Water trickles Aug. 21 over Copco 1 Dam on the Klamath River outside Hornbrook, Calif.

Jeff Barnard/AP

Enlarge


# Conceptual Plan Components

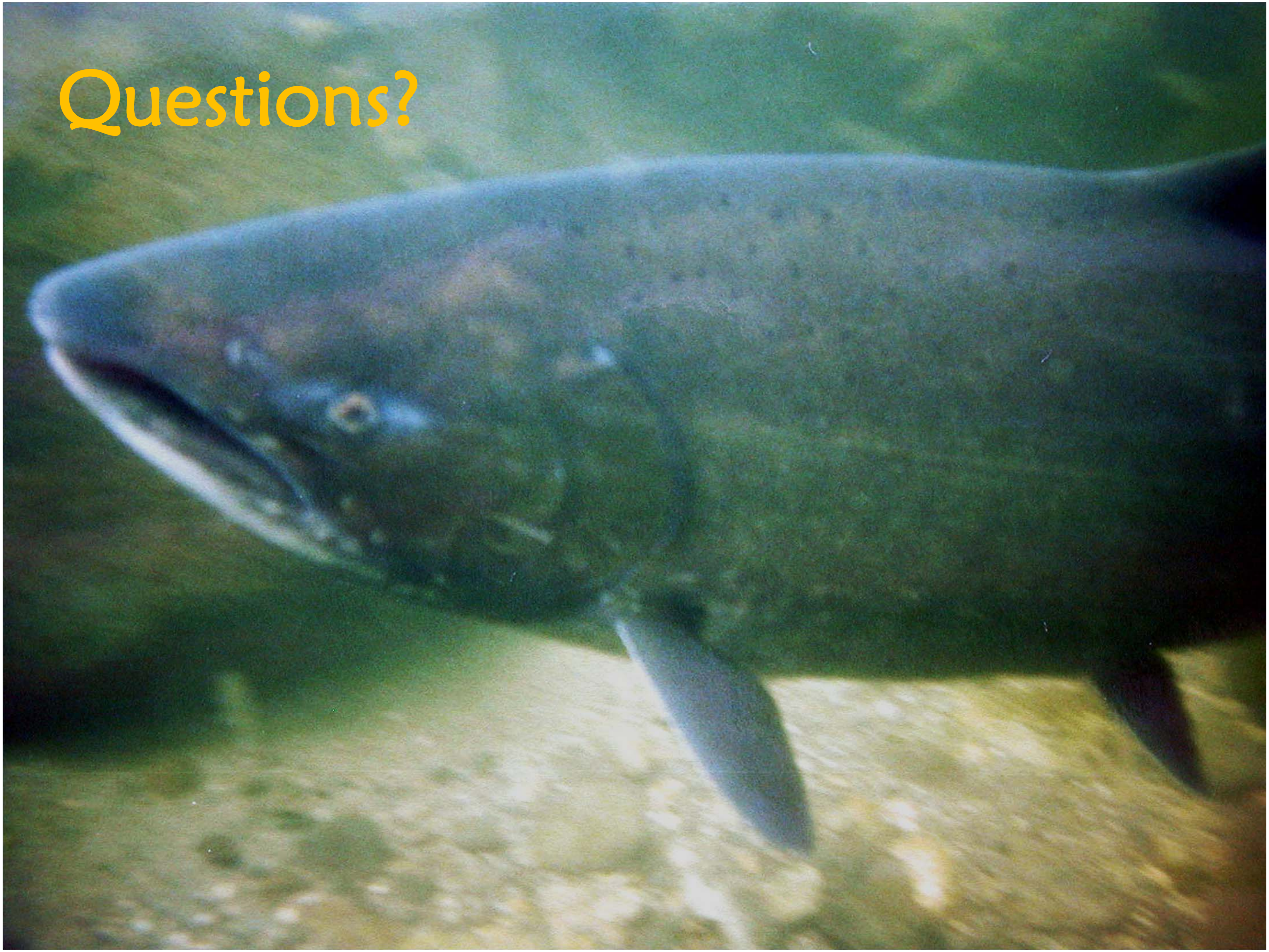
1. Implement removal of Klamath hydro dams
2. Implement phased closing of Iron Gate Hatchery
3. Augment summer/fall flows at Keno Dam with cold, clean water from ground water pumping, suitable storage, or reverse infiltration galleries/injection wells
4. Restore and engineer wetlands to treat return ag flow and water from UKL/Keno Reservoir

# Conceptual Plan Components

1. Implement removal of Klamath hydro dams
2. Implement phased closing of Iron Gate Hatchery
3. Augment summer/fall flows at Keno Dam with cold clean water from ground water pumping, suitable storage, or reserve infiltration galleries
4. Restore and engineer wetlands to treat return ag flow and water from UKL/Keno Reservoir
5. Continue targeted use of cold-water pulsed flows from Trinity Reservoir for adults but also juveniles
6. Protect cold-water water from Trinity Reservoir (Lewiston thermal solutions, lake level rules)

# Conceptual Plan Components

1. Implement removal of Klamath hydro dams
2. Implement phased closing of Iron Gate Hatchery
3. Augment summer/fall flows at Keno Dam with cold clean water from ground water pumping, suitable storage, or reserve infiltration galleries
4. Restore and engineer wetlands to treat return ag flow and water from UKL/Keno Reservoir
5. Strategic use of cold-water pulsed flows from Trinity Reservoir for adults and juveniles
6. Protect cold-water water from Trinity Reservoir (Lewiston thermal solutions, lake level rules)
7. Flow variability and winter pulses with freshets
8. Monitor effectiveness and adapt


Questions?

[redacted]