Exceptionally high mortality of adult female salmon: a large-scale pattern and a conservation concern

Scott Hinch

Pacific Salmon Ecology and Conservation Laboratory
University of British Columbia

scott.hinch@ubc.ca

https://www.pacificsalmonecologyconservationlab.ca

PACIFIC SALMON ECOLOGY & CONSERVATION LABORATORY

Upper Columbia Science Summit
January 21, 2026

Presentation based on a recent review paper

Canadian Science Publishing

INVITED REVIEW

Exceptionally high mortality of adult female salmon: a large-scale pattern and a conservation concern

Scott G. Hinch, Nolan N. Bett, Erika J. Eliason, Anthony P. Farrell, Steven J. Cooke, and David A. Patterson

Background: Sex ratios

- Sex ratios are fundamental to population demographics
- Skewed adult sex ratios are common in nature and occur across many taxa including salmonids
- Skew often caused by differential mortality between sexes
- Low number of females relative to males can negatively affect mating systems and population stability

Background: Sockeye salmon exhibit skewed sex ratios

- 1930s to early 1990s females dominated spawning grounds on all major populations of Fraser River sockeye (~ 90 populations)

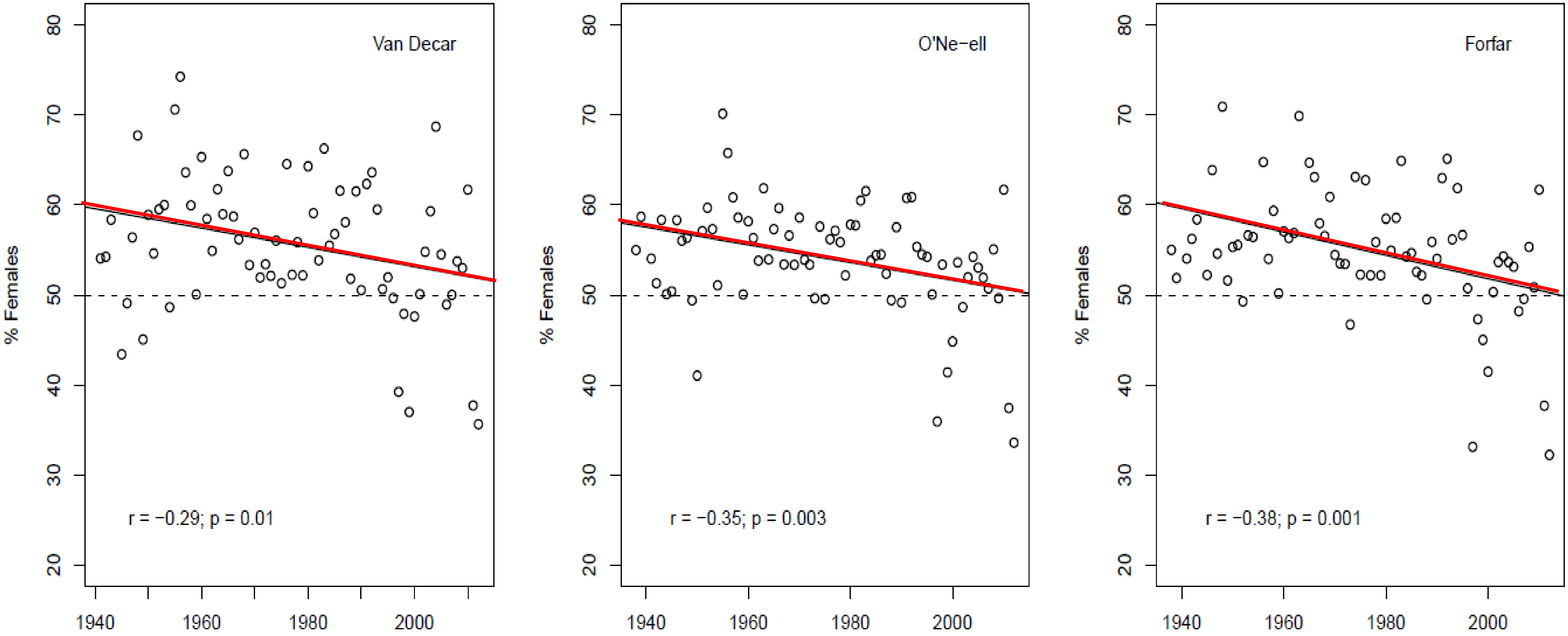
- Similar in other sockeye systems in Alaska and northern British Columbia

- An historical Fraser River study found 50:50 sex ratio in outmigrating smolts yet returning females dominated spawning grounds

- Skewed adult sex ratio caused during ocean rearing and/or spawning migration

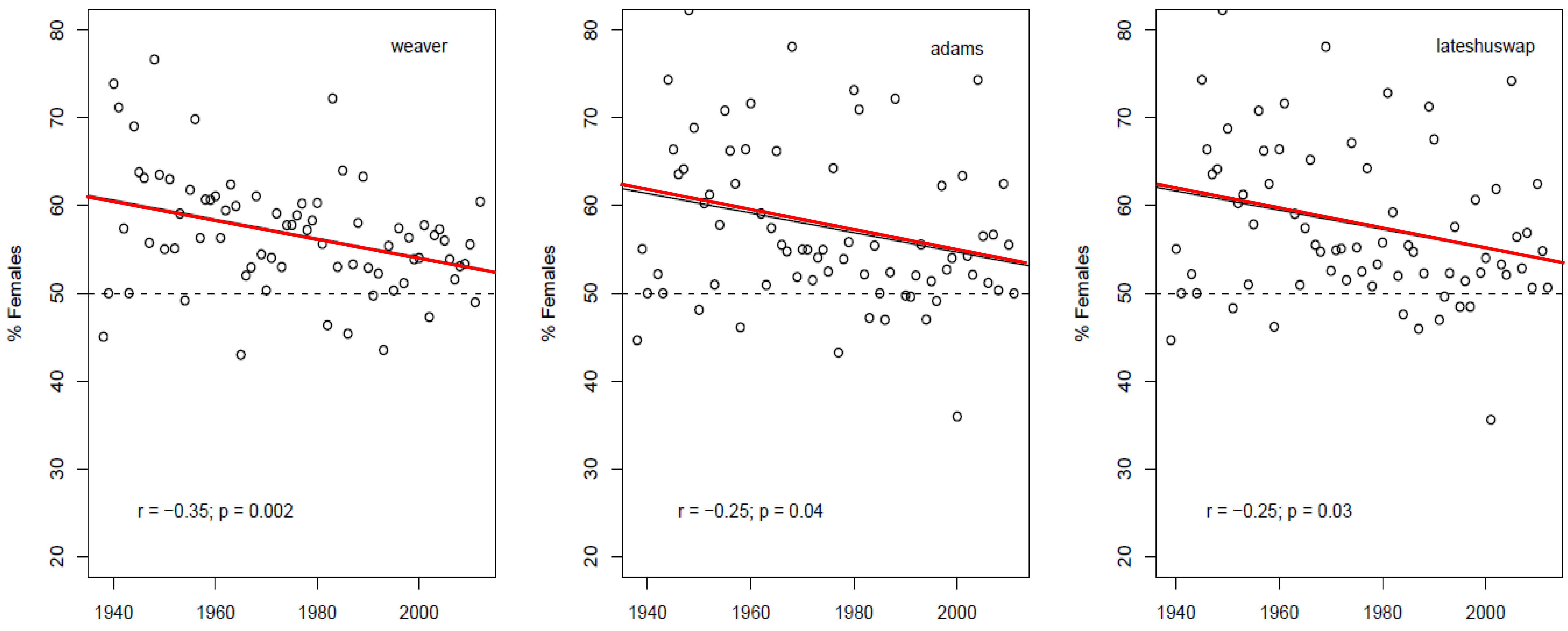
Declining proportion of females on spawning grounds

Three Early run populations (1940 - present)



Declining proportion of females on spawning grounds

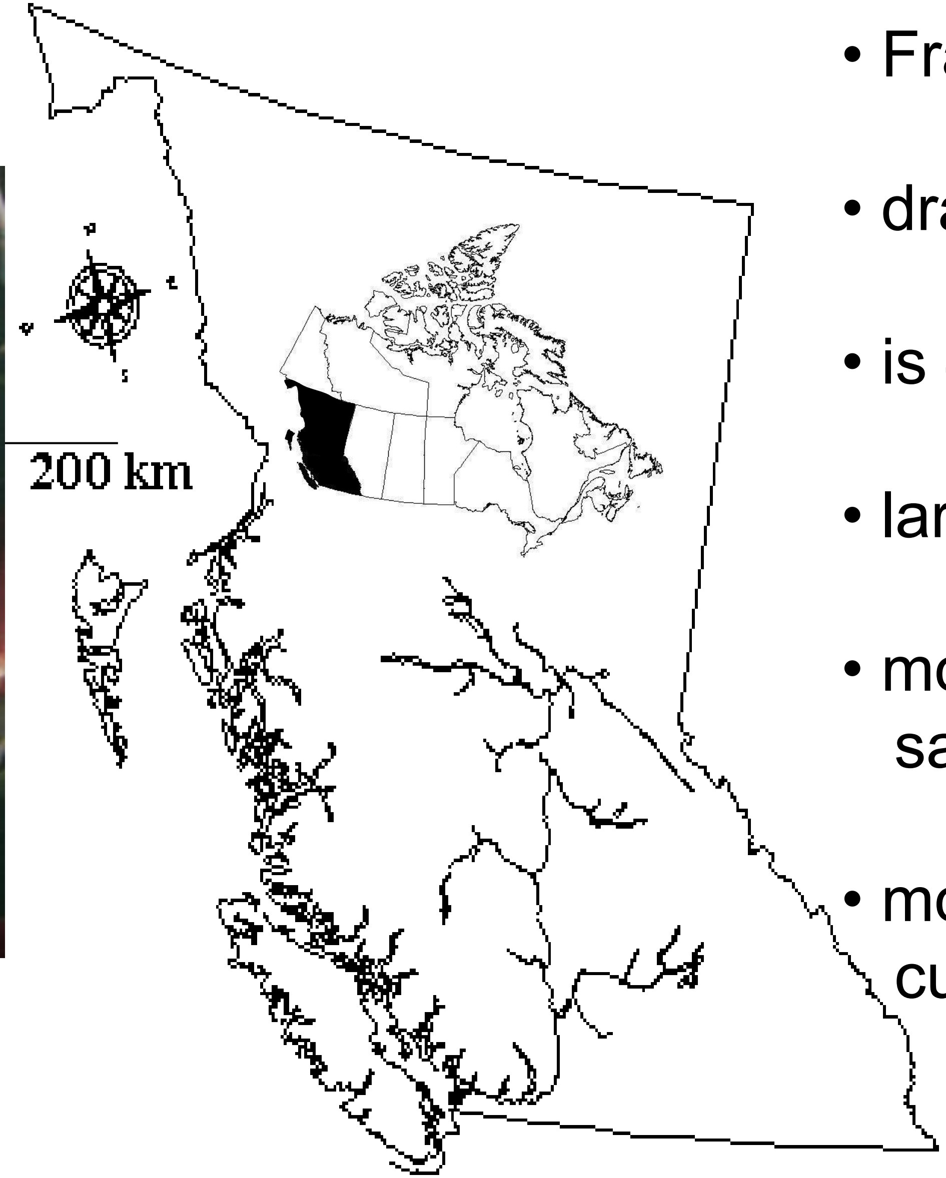
Three Late run populations (1940 - present)



Exploring differential mortality between males and females

- Significant changes to ocean rearing and upriver migration environments
- Are females now more likely to perish before getting to spawning grounds?
- Over the past 30 years, my group has conducted numerous studies examining migration mortality of adult sockeye salmon
- 22 published studies providing 52 ‘situations’ in lab and field where male and female mortality could be compared
- Variety of ‘situations’ (e.g. ‘treatments’) examined: captivity, biopsy sampling, high temperatures, turbulent or fast flows, exhaustive swimming, air exposure, release from fishing gear, and others…
- Most studies involved sockeye, but some involved coho and Chinook

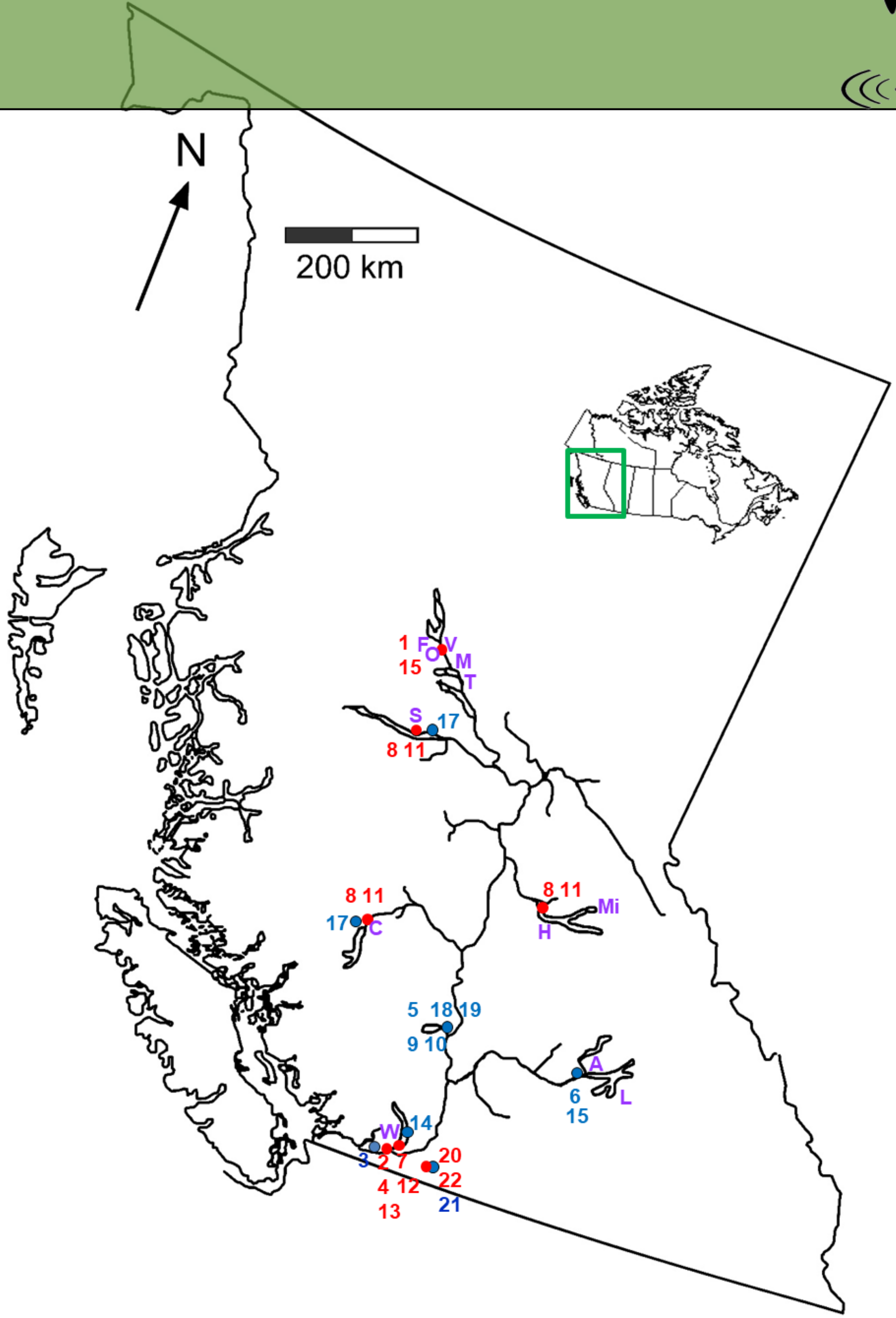
Fraser River and Sockeye Salmon



- Fraser River flows 1,375 km
- drains 1/3rd of British Columbia
- is 4th largest river in Canada
- largest producer of sockeye
- most commercially valuable salmon
- most important for First Nations culture

Fraser River Studies

- Telemetry tracking studies (n=10)
- Laboratory studies (n=12)
- Spawning ground sex ratio assessments (n=12)



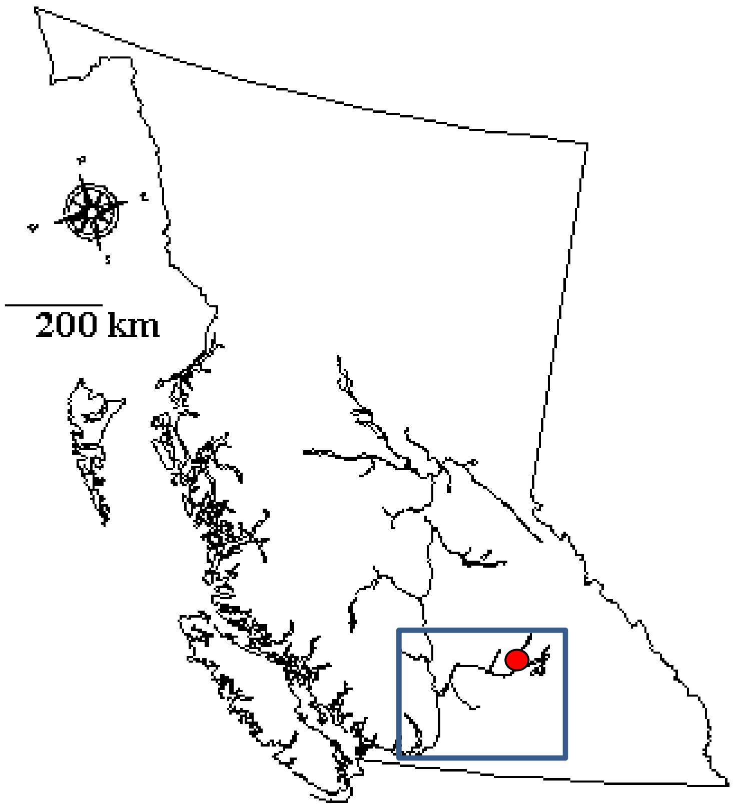
Bio-sampling and tagging

- Blood sample to examine range of plasma ions, stress and **reproductive hormones (sex determination)**

- Few examine fish sex as part of ocean or river tagging studies

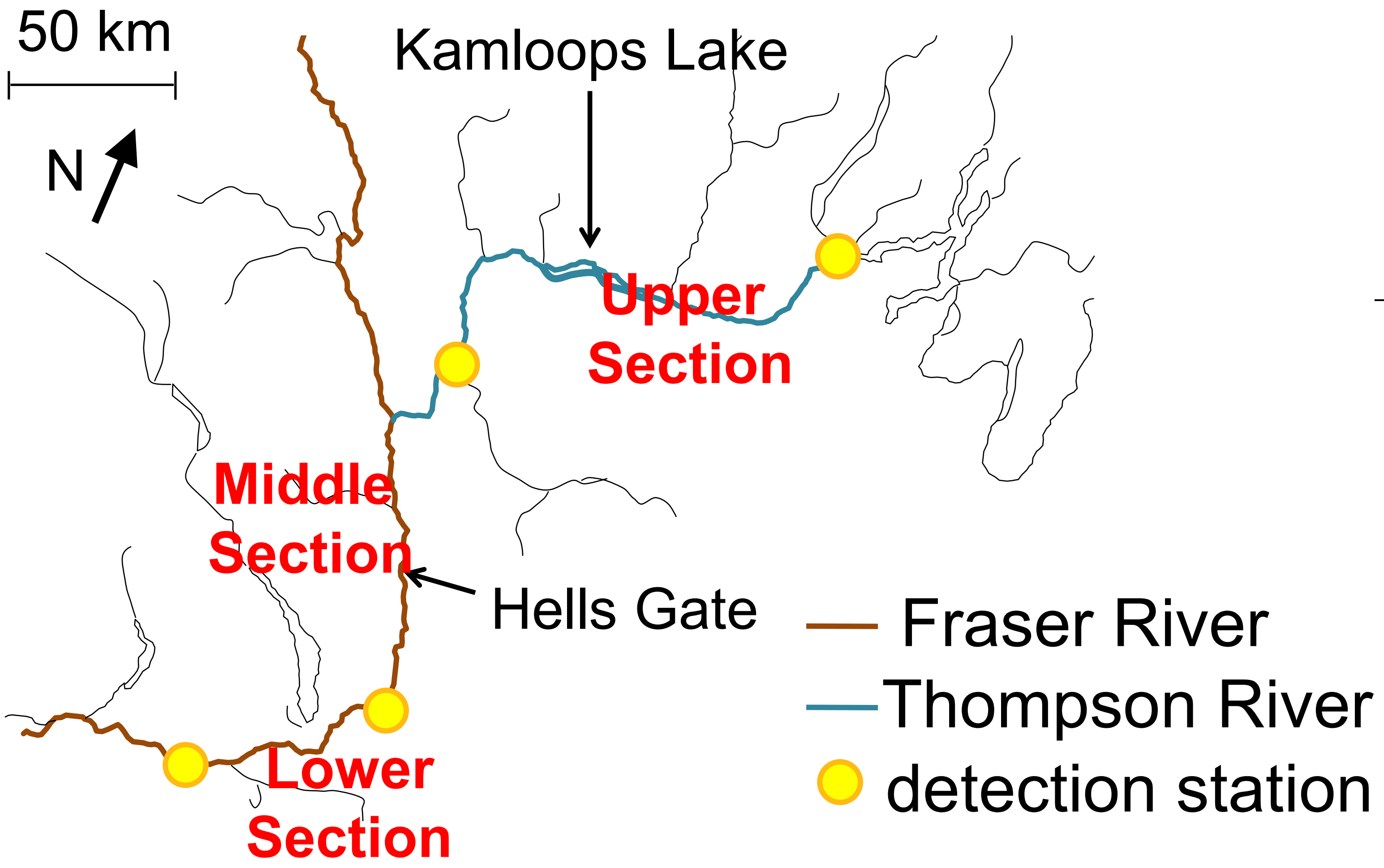
- Transmitter insertion down throat into stomach

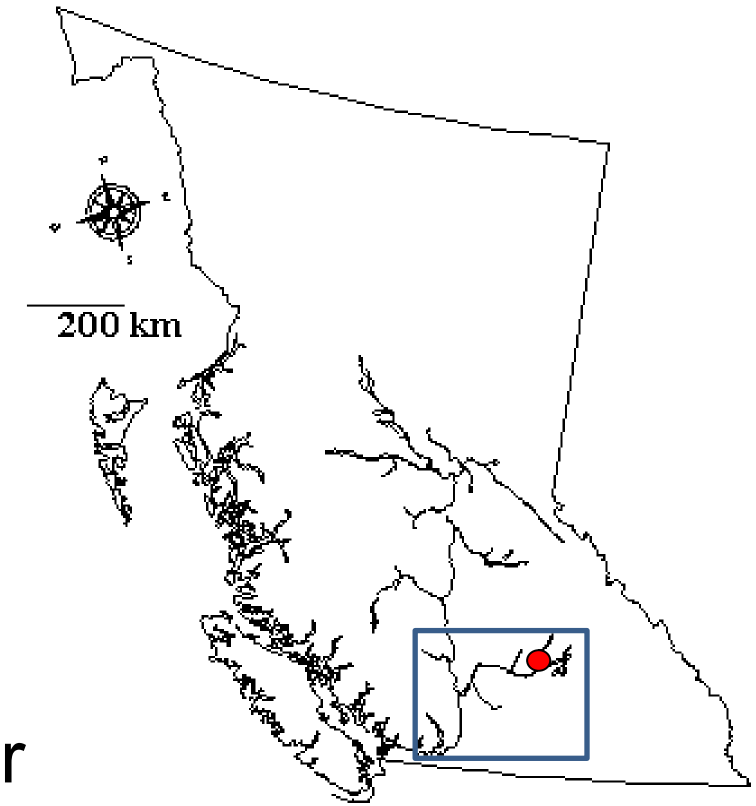
Telemetry Tracking Study: ocean to spawning grounds



Late Shuswap
population

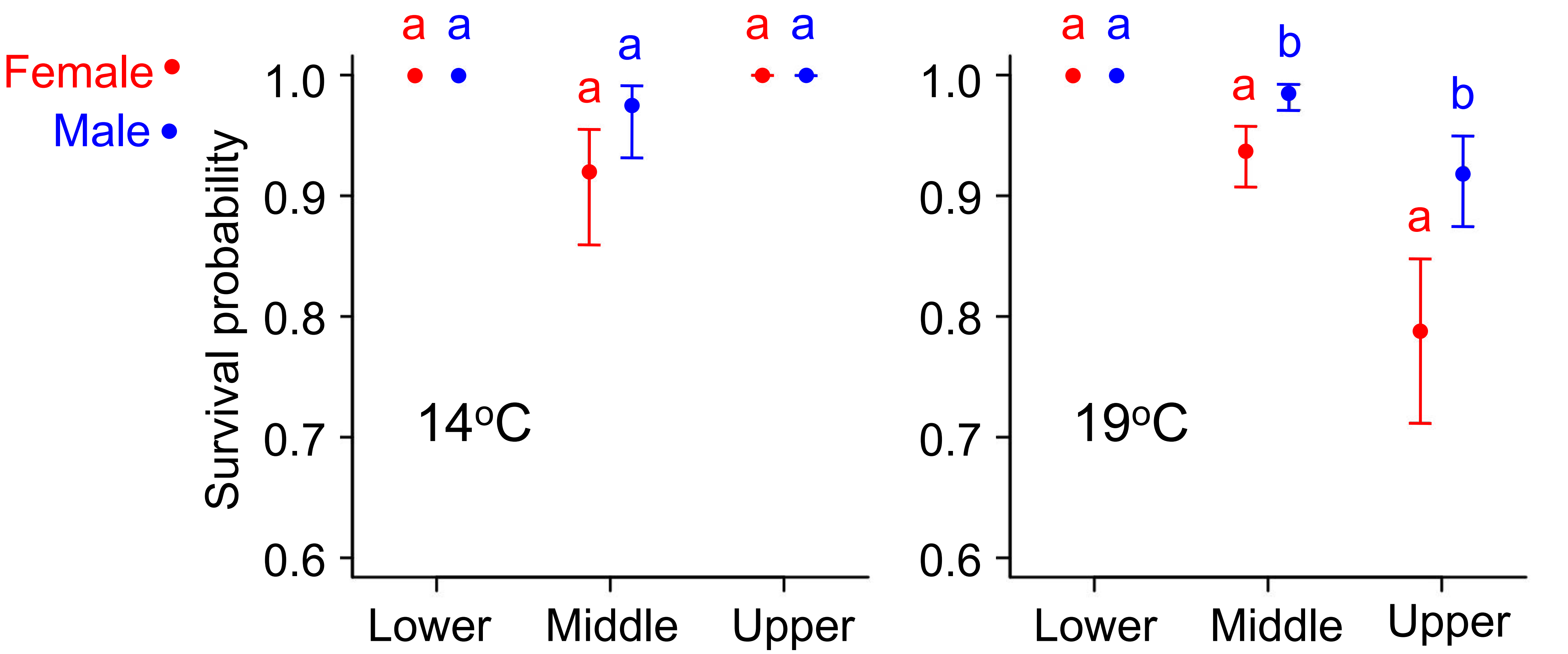
Telemetry Tracking Study: Ocean to Spawning Grounds





Late Shuswap population

Higher female mortality probability in warm water in upper river

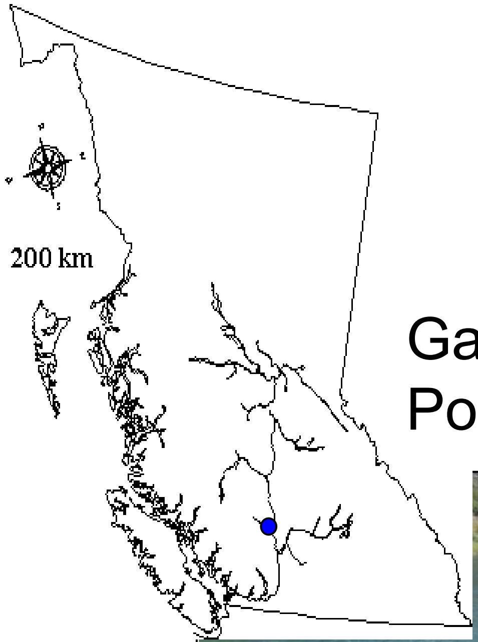


Overall Survival
female: 0.86±0.11 a
male: 0.95±0.07 a

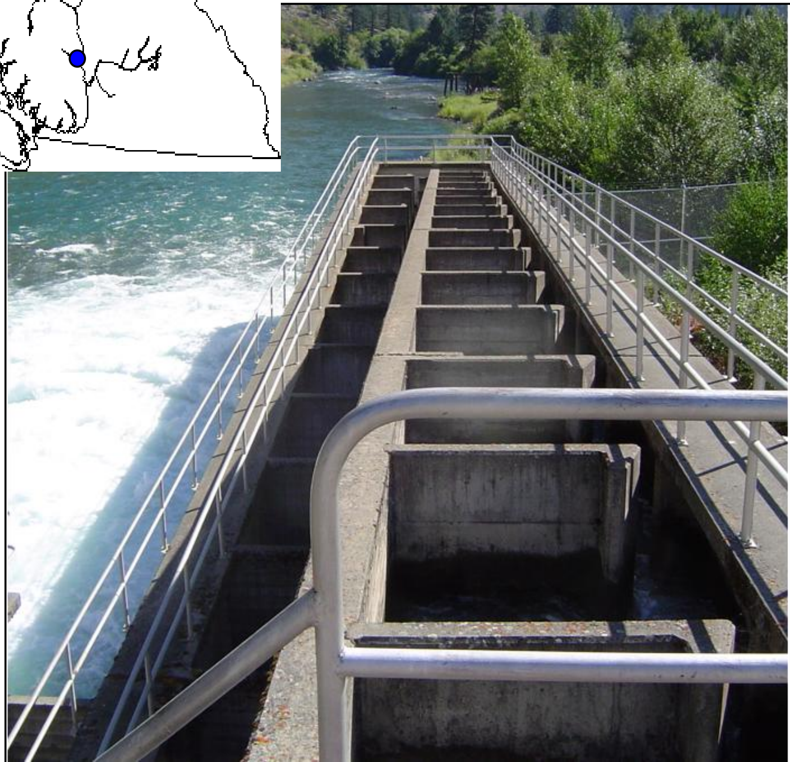
Overall Survival
female: 0.50±0.11 a
male: 0.79±0.09 b

Martins et al. 2012.
CJFAS 69: 330-342.

Telemetry Tracking Studies: Seton Fishway Passage



Gates Creek
Population



Seton Fishway Passage: Much higher latent mortality of females

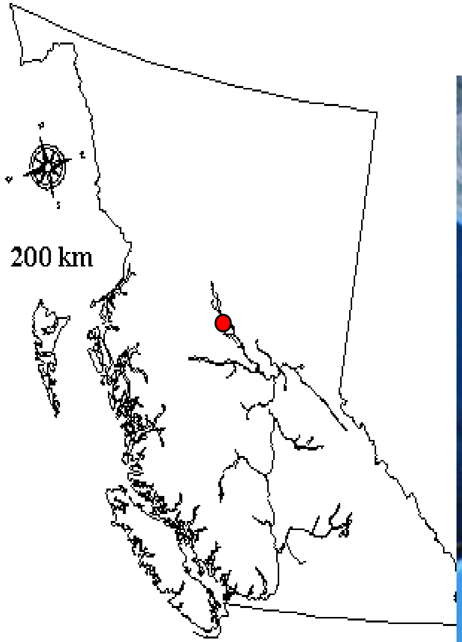
- sockeye captured near fishway, tagged, released downstream, tracked to upstream spawning area (**1 week further migration**)

Mortality to Spawning Grounds

- **2007** – female 60%, male 29% (Roscoe et al. 2011. River Res. Applic. 27: 693–705)
- **2012** – female 62%, male 29% (Burnett et al. 2013 Ecohydrology DOI: 10.1002/eco.1440)
- **2013** - female 56%, male 31% (Burnett et al. 2014 Physiol. Biochem. Zool 87(5):587-598)

Laboratory Gillnet 'Capture/Release' Experiments

- sockeye captured at start of 4 week migration
- held under natural thermal regime in lab
- entangled, air exposed, released from a gill net
- monitored till spawning date



Early Stuart
population

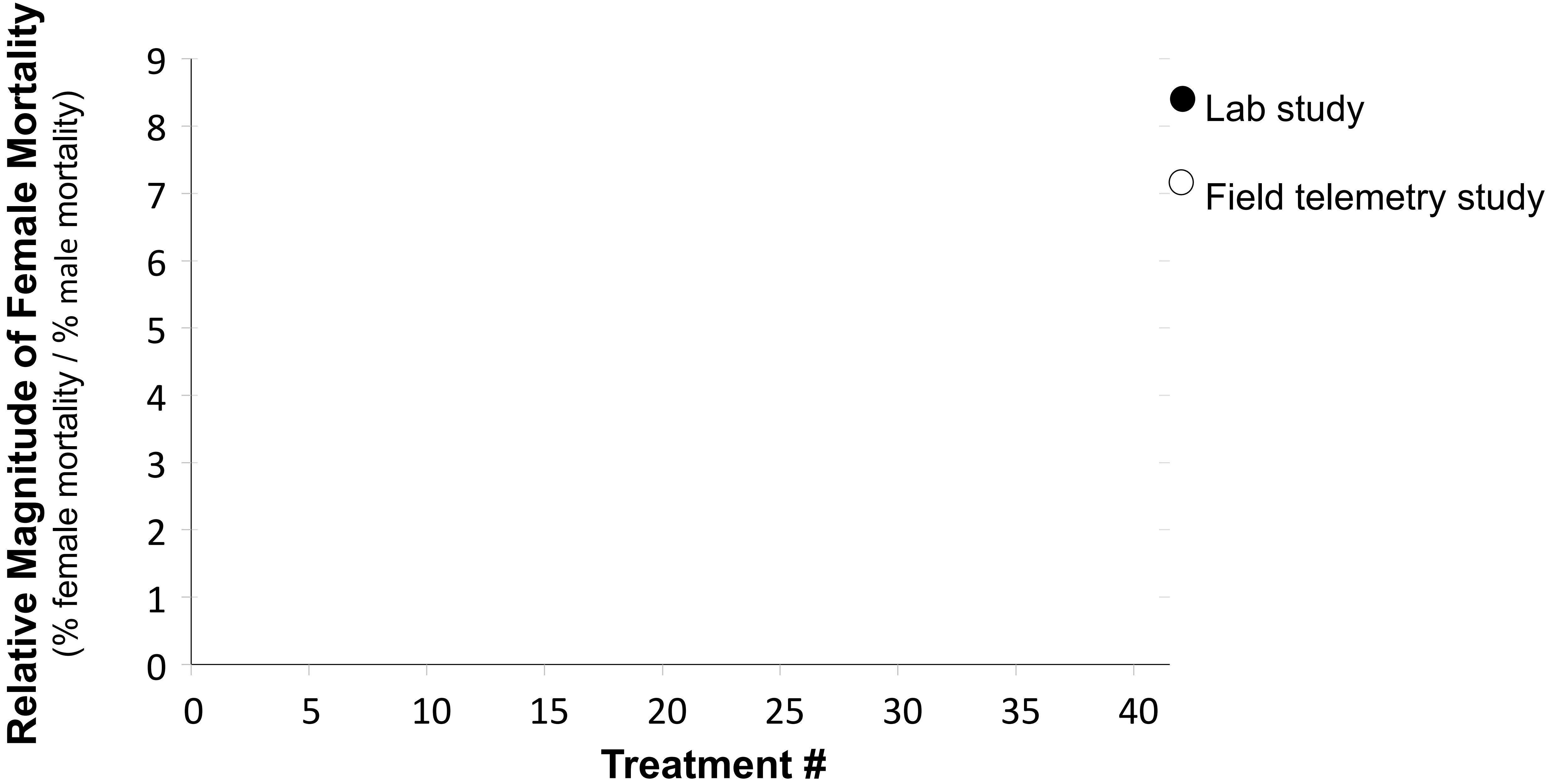
Much higher mortality of females: captivity and gear release

Mortality after 4 weeks

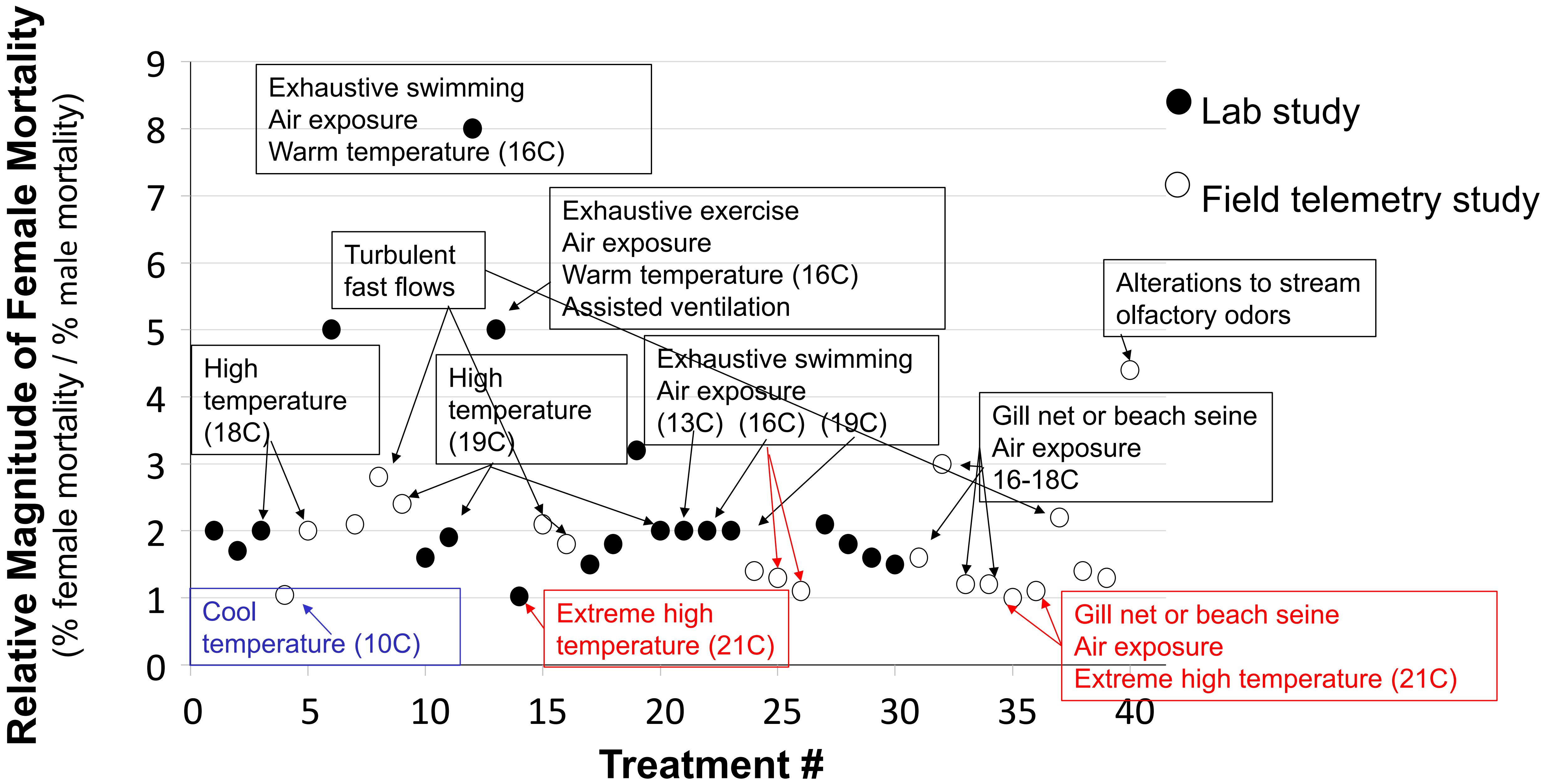
- Controls — female 23%, male 7%
- 20 sec entanglement — female 70%, male 44%
- 20 min entanglement — female 90%, male 75%

Teffer et al. 2017. Conservation Physiology 5:10.1093/conphys/cox017.

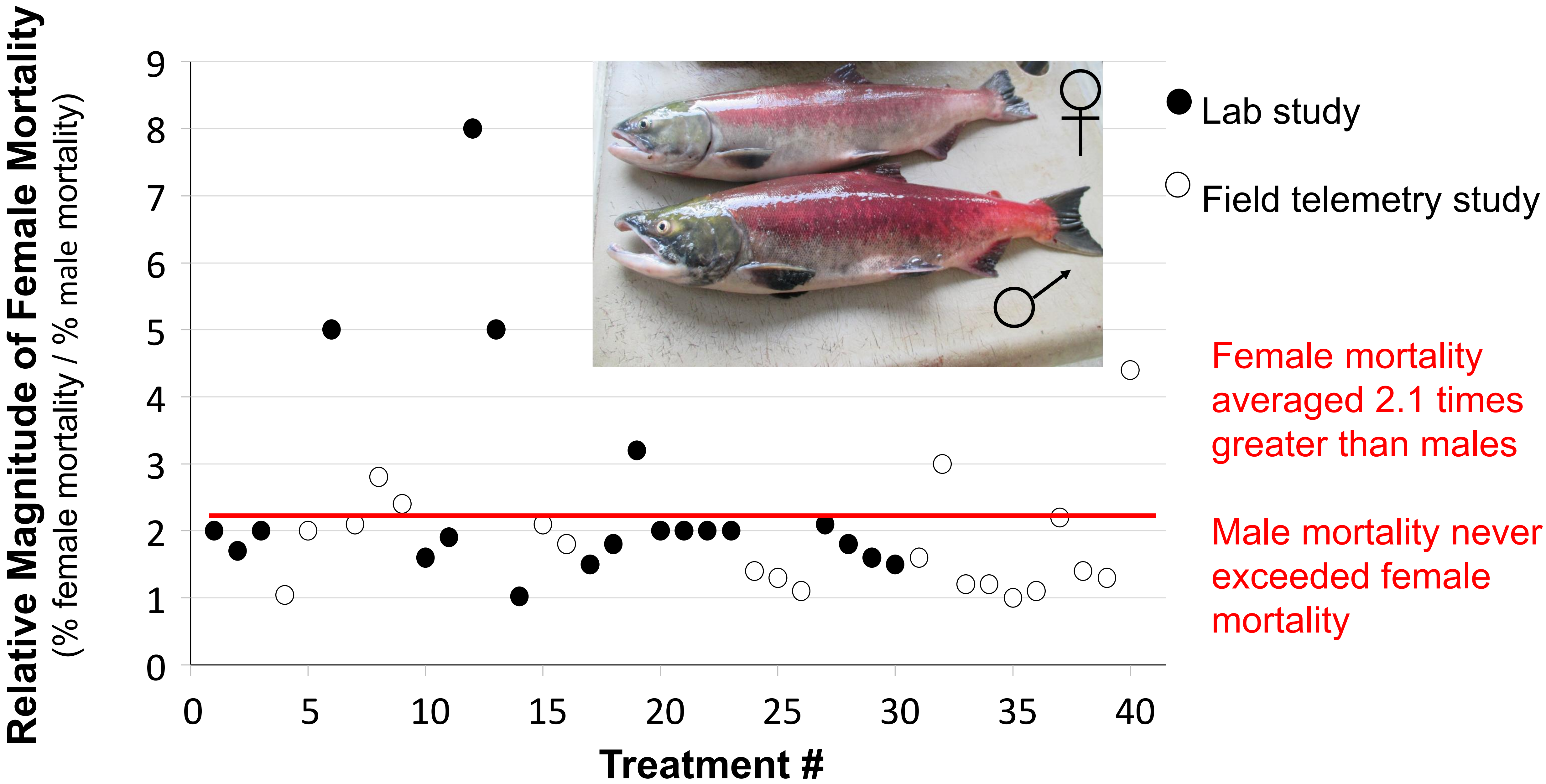
Summary of 19 Fraser sockeye studies involving 40 ‘treatments’



Summary of 19 Fraser sockeye studies involving 40 'treatments'



Summary of 19 Fraser sockeye studies involving 40 'treatments'



Female mortality averaged 2.1 times greater than males

Male mortality never exceeded female mortality

Why are females dying at higher rates?

Stress

Hinch et al. (2006) Behavioural Physiology of Fish Migrations: salmon as a model approach. pp. 239-295, Fish Physiology Volume 24: Behaviour and Physiology of Fish.

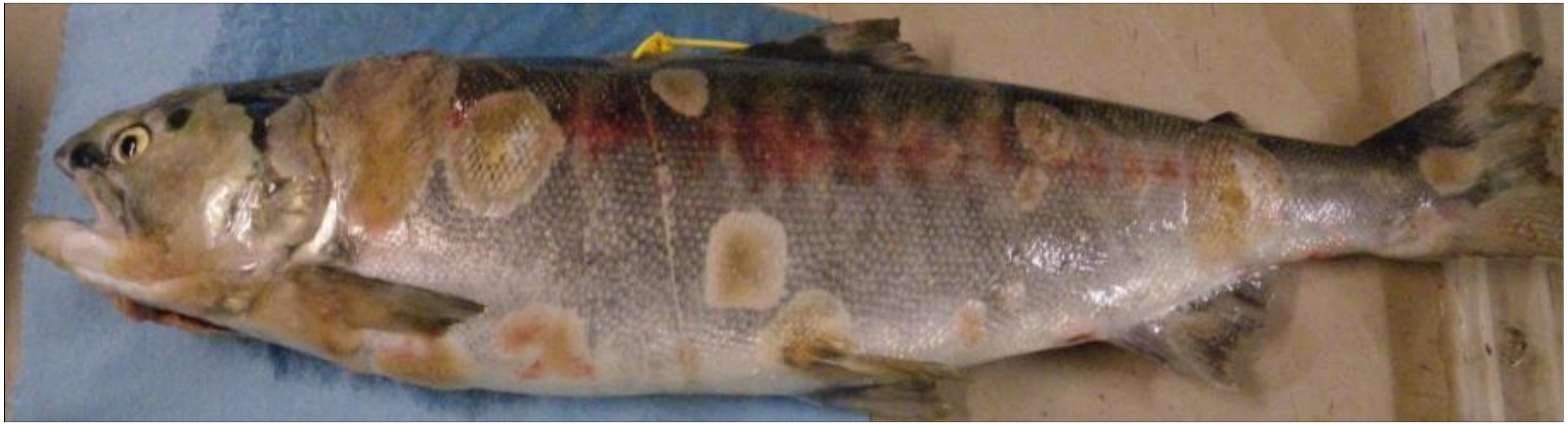
- females have much higher plasma cortisol
  -during migration, female cortisol levels rise 4X (males only 2X)
- possible impaired stress response
  -may not be able to mobilize energy or clear metabolic waste
- female chronic high levels same as passage at Hells Gate (< 1 day)

Why are females dying at higher rates?

Sick

- females develop more infections
  - high female cortisol levels can be immunosuppressive
  - senescence is occurring causing more immunosuppression
  - females appear to start freshwater migration with higher pathogen loads (bacteria and microparasites)

Teffer et al. 2018. Canadian Journal of Fisheries and Aquatic Sciences 75(11): 2069-2083.



Why are females dying at higher rates?

Energy exhaustion

Hinch, et al. (2006) Behavioural Physiology of Fish Migrations: salmon as a model approach. pp. 239-295, Fish Physiology Volume 24: Behaviour and Physiology of Fish.

- females deplete more reserve energy
  - gonad mass relative to body mass: female 15% vs male 2%

Why are females dying at higher rates?

‘Broken hearts’ and ‘greedy gonads’

- females have poorer cardiac performance
  - 20-25% lower metabolic scope and venous output
  - mature females have ~13% smaller hearts
  - females divert much more blood to gonads to maintain / grow eggs
  - ability to move oxygenated blood to vital organs and power swimming is reduced in females particularly later in the migration
- thus, more anaerobiosis in females which can lead to cardiovascular collapse (as well as acidosis issues from lactic acid accumulation)

Clark et al. 2011. JEB 214: 3074-3081
Eliason et al. 2013. Conservation Physiology 1:10.1093/conphys/cot008.

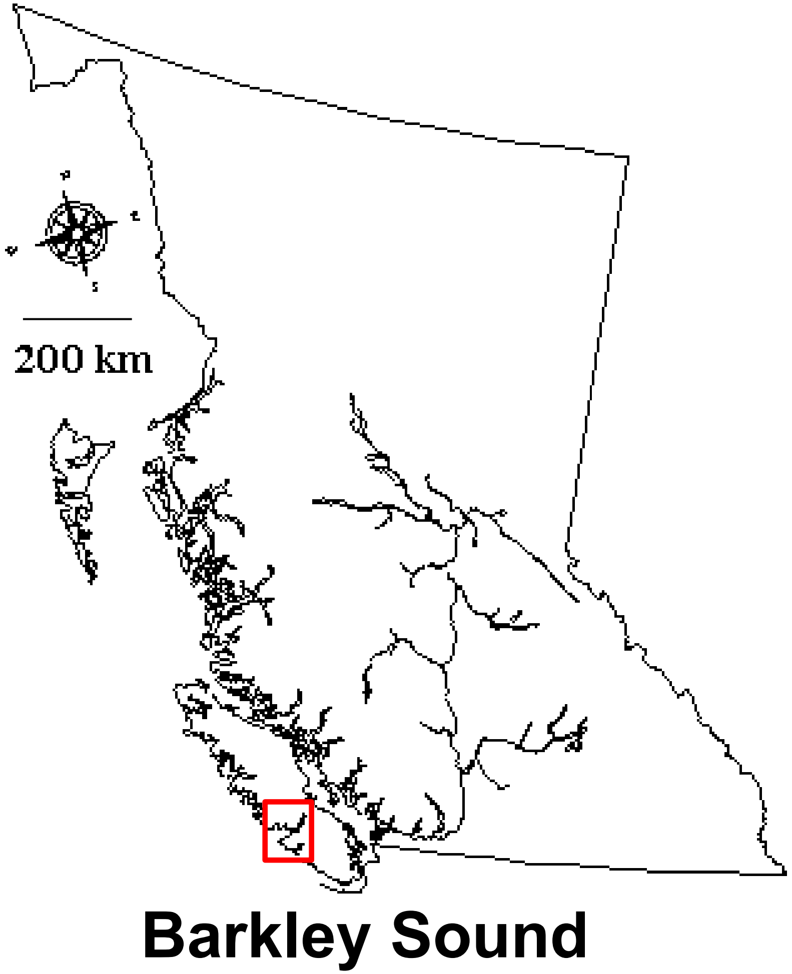
Summary of Findings

- female mortality averaged 2.1 times greater than males
- relative female mortality highest when conditions were most challenging
  e.g. combination of high temperatures and exhaustive swimming
- and highest towards end of river migration (maturing fish)
- relatively fewer females on several spawning grounds
- evidence for:
  -cardiac collapse
  -energy exhaustion
  -physiological stress
  -immune issues

What about ocean migrating fish?

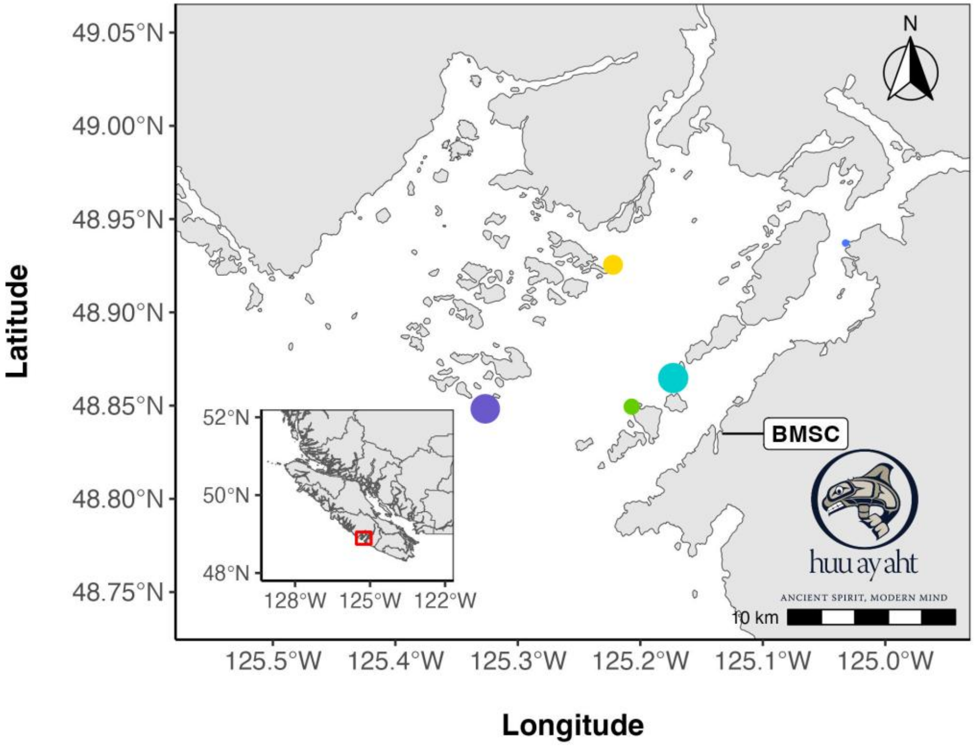
- Recently been examining effects of catch and release on ocean migrating salmon

Effects of catch and release on marine salmon

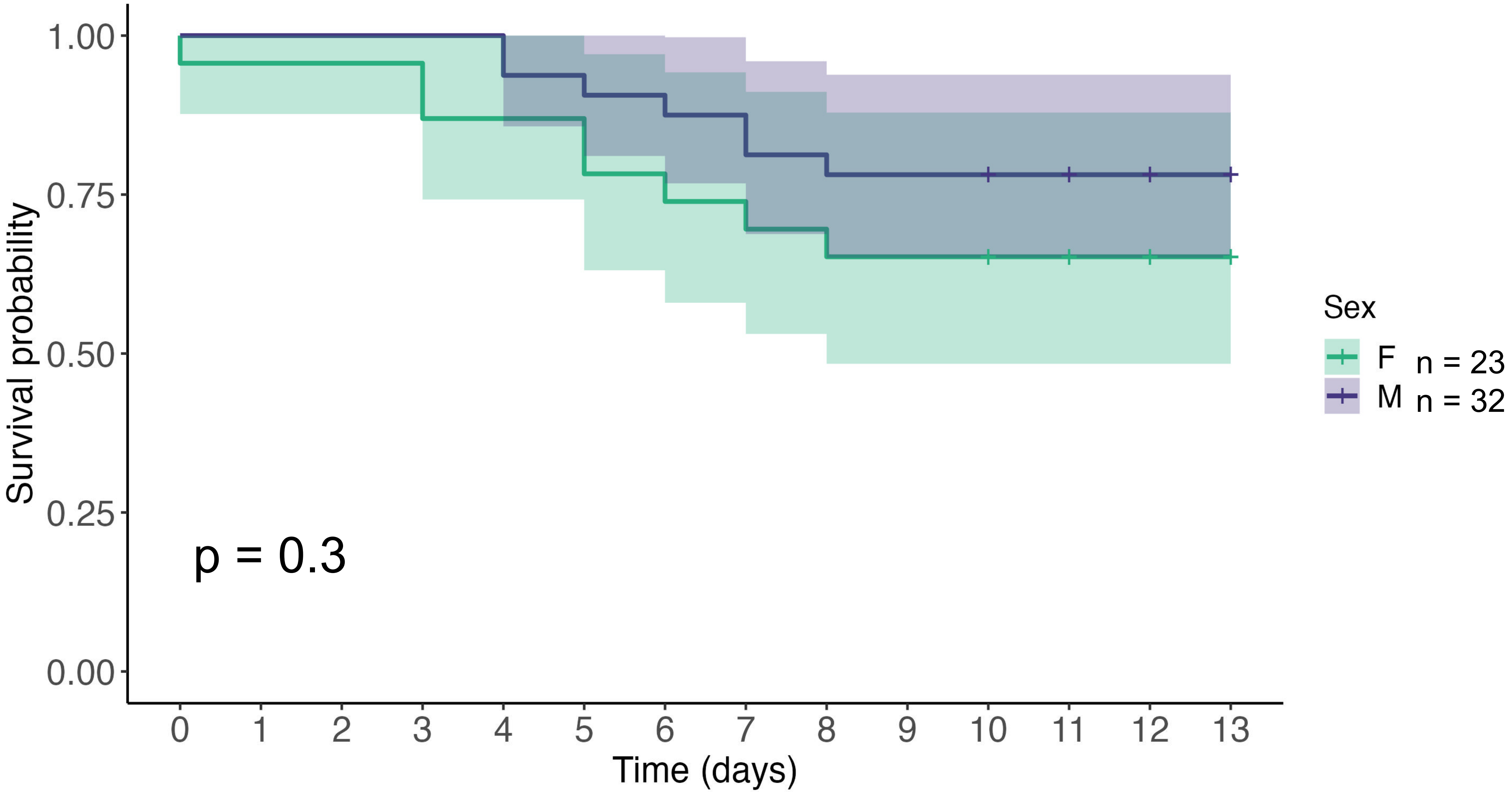


Laboratory holding of marine angled coho salmon

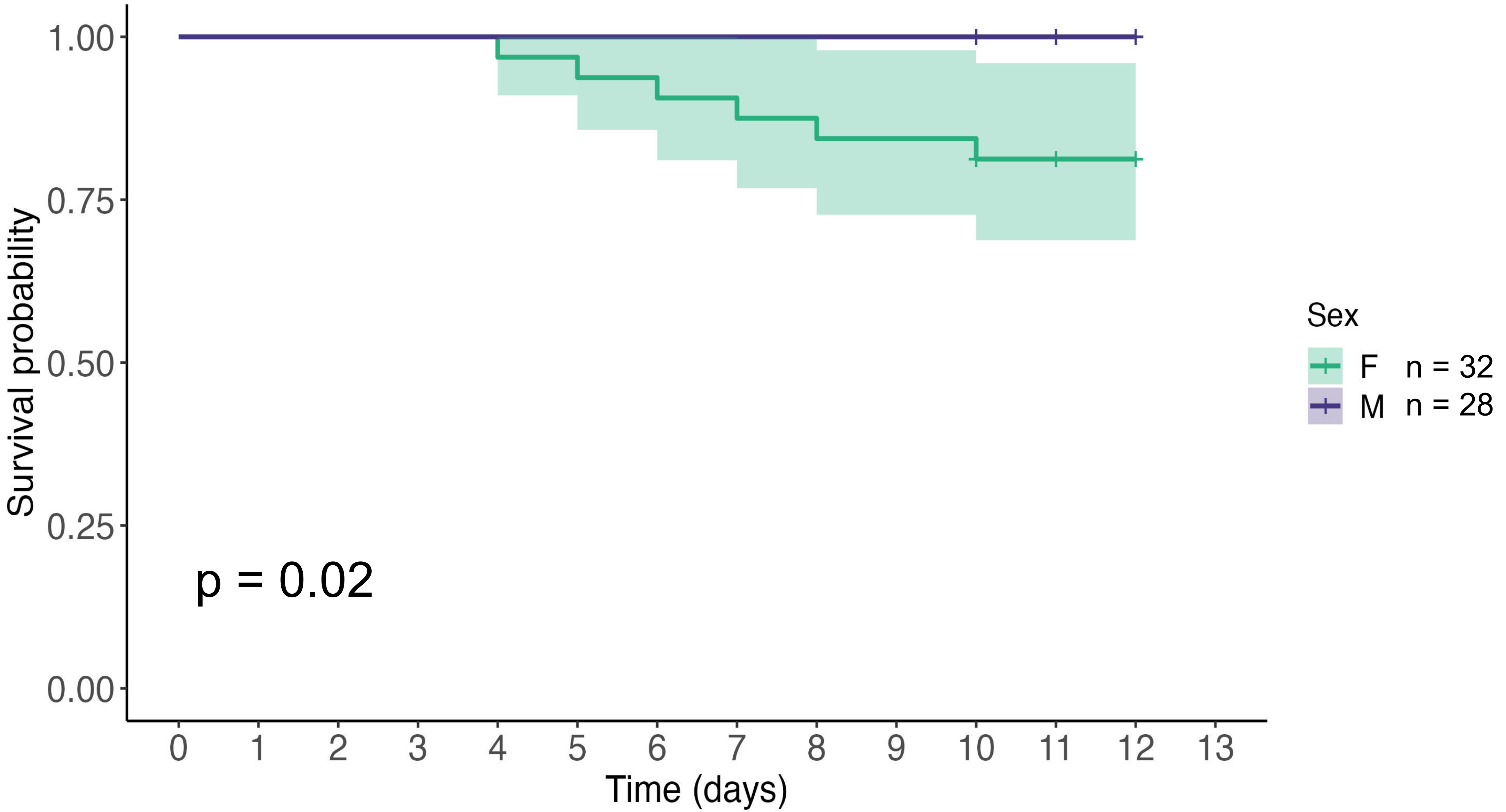
- Migrating fish captured in Barkley Sound using typical angling and landing approaches, held in 13 C marine water for 10-14 days, observed injury – disease – and survival



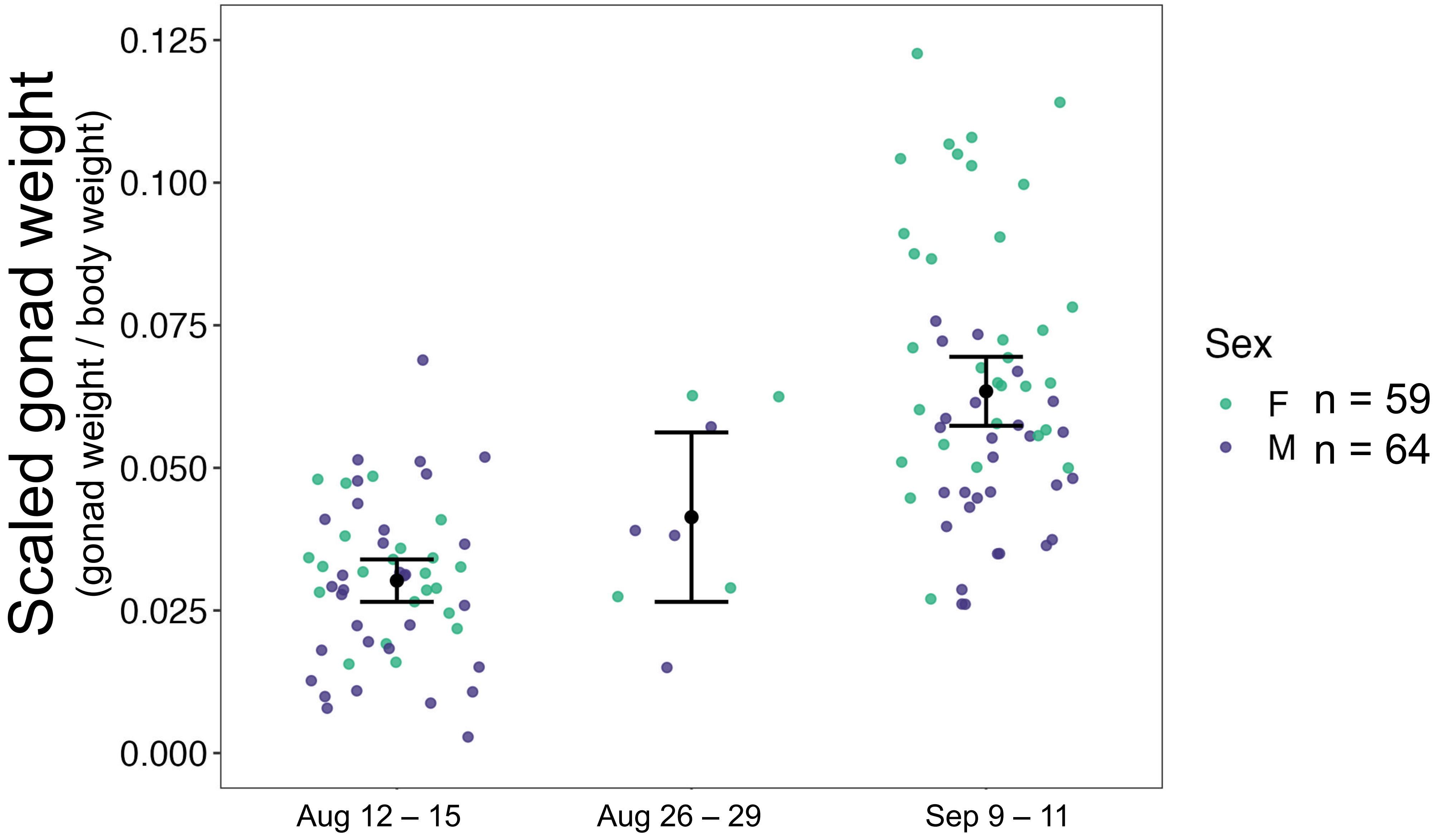
No differences between sexes (Aug 12-15, 2024)



Males survive better than females (Sept 9-11, 2024)



Relative reductions in female survival related to maturation?



Conservation and Management Implications

- high female mortality is concerning and is a 'warning'
- many of the populations that exhibit this are in decline
  - some designated as endangered
- Fraser River is warming (~ 2.0^{o}C, since 1950s)
- high female mortality will become more pronounced in coming years as ocean and riverine conditions continue to change

What do we do with this knowledge?

- reduce in-river fishing pressure in years or locations of high temperatures or high discharges

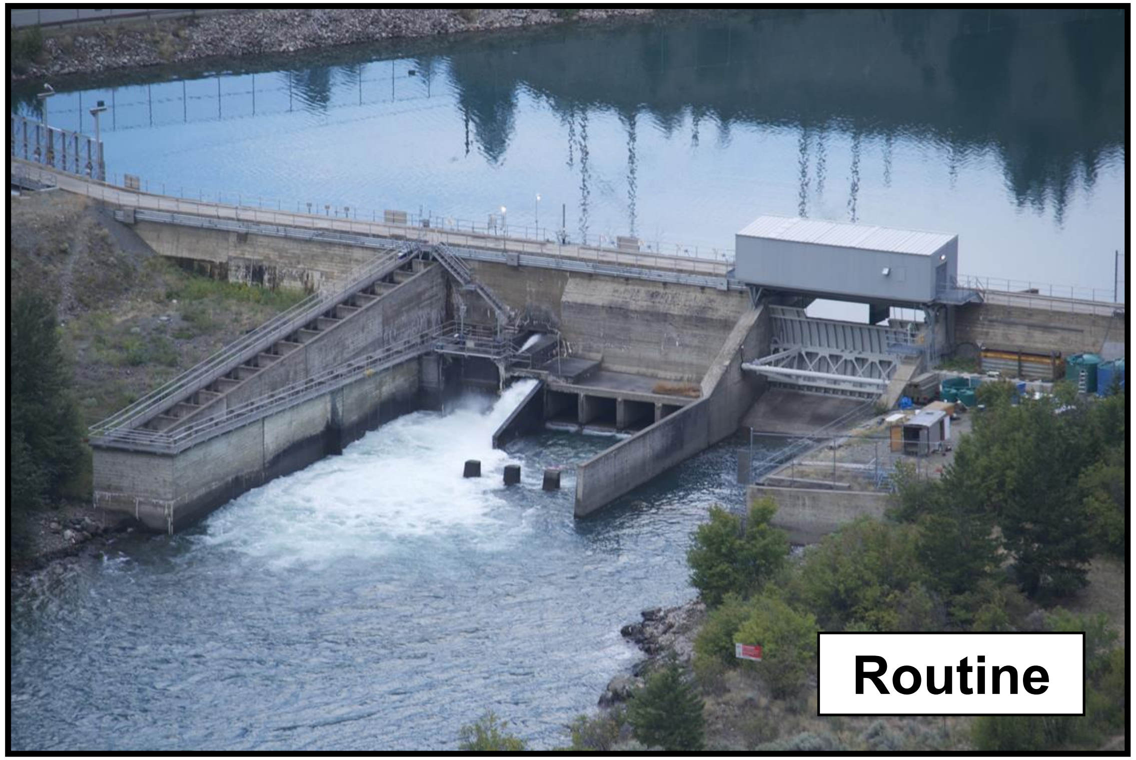
  - this is now happening

- don’t preferentially harvest migrating females

  - freshwater roe fisheries used to occur (chum and pink salmon)

- make migration routes more ‘female friendly’

Enhancing survival of females: example from Seton Dam Fishway



- alternative flow release improved rates of fishway passage and subsequent survival to spawning areas for both sexes
- but females benefitted the most (25% increase in females, 10% increase in males)
- alternative flow regime now operated by BC Hydro Bett et at. 2020. Hydrobiologia. doi:10.1007/s10750-020-04371-

Final Thoughts

• relatively high female migration mortality not commonly reported

• suspect this occurs commonly in all salmonids but rarely studied

Because

• migration studies don't typically assess sex until spawning periods

• historically, migration conditions were not always as 'stressful'

• extremely stressful conditions kills both sexes equally

• less extreme stressors create conditions for higher female mortality

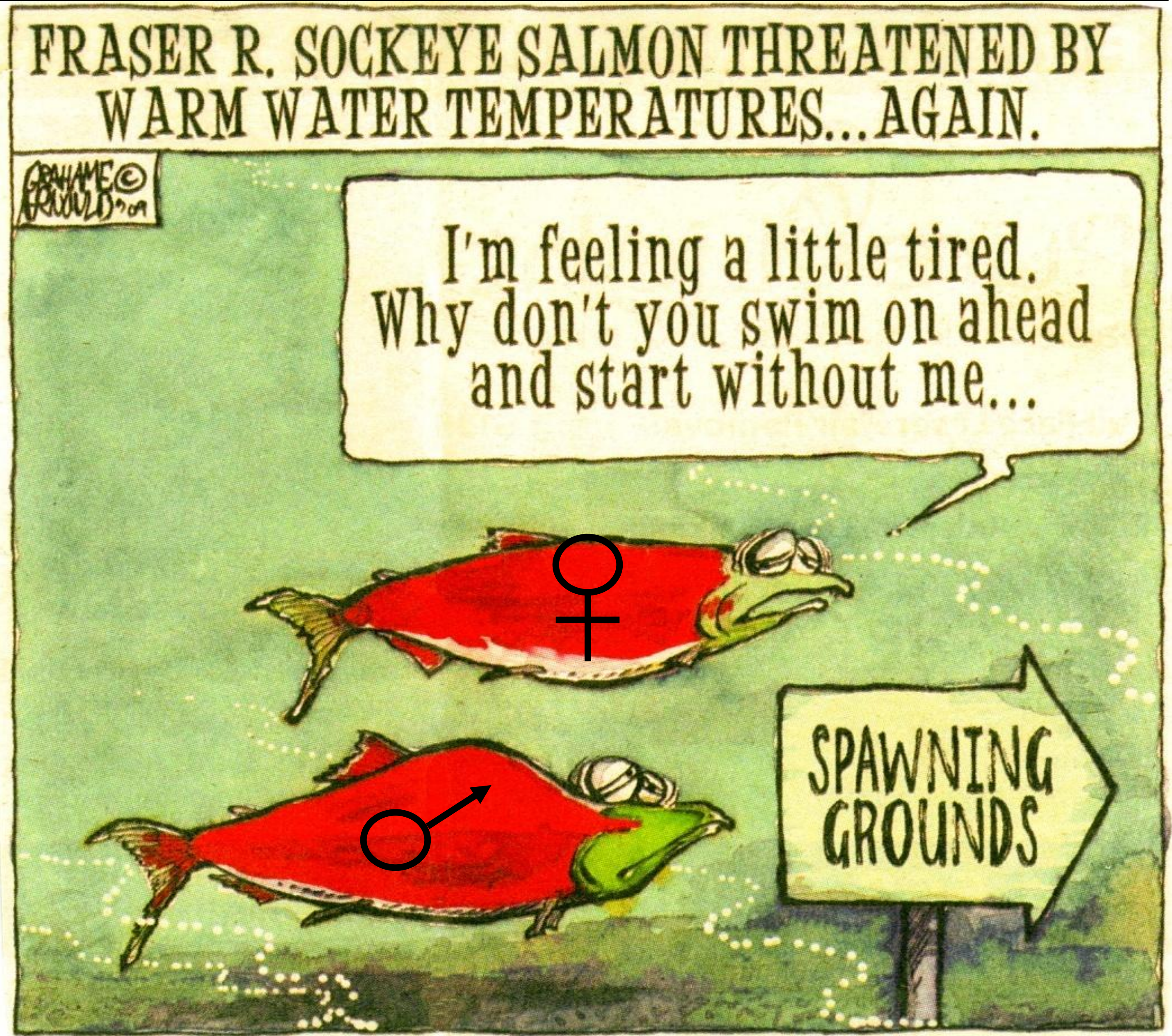
• some populations that did not exhibit declining female proportions have much higher thermal tolerance and energy saving adaptations

Thanks to those who collected data and generated ideas

- Glenn Crossin
- Ken Jeffries
- Marika Gale
- Kendra Robinson
- Tim Clark
- Kendra Robinson
- Pat Nadeau
- David Roscoe
- Lucas Pon
- Nich Burnett
- Eduardo Martins
- Amy Teffer
- Steve Healy
- Andrew Lotto
- Steve Johnston
- Quin Johnston
- Katie Zinn

Thanks to our funders and collaborators

Natural Sciences and Engineering Research Council of Canada
Genome British Columbia
Fisheries and Oceans Canada
Pacific Salmon Commission
Pacific Salmon Foundation
The University of British Columbia
Carleton University
LGL Limited
Kintama Limited
J.O. Thomas and Associates
Chehalis First Nations
Canadian Wildlife Federation
Watershed Watch Salmon Society
Ocean Tracking Network, Canada
BCSRIF
Sport Fishing Institute of BC



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