Kootenay Lake Advisory Team

November 27-28, 2019

Nelson, BC

Thank you to Funders and Contributors

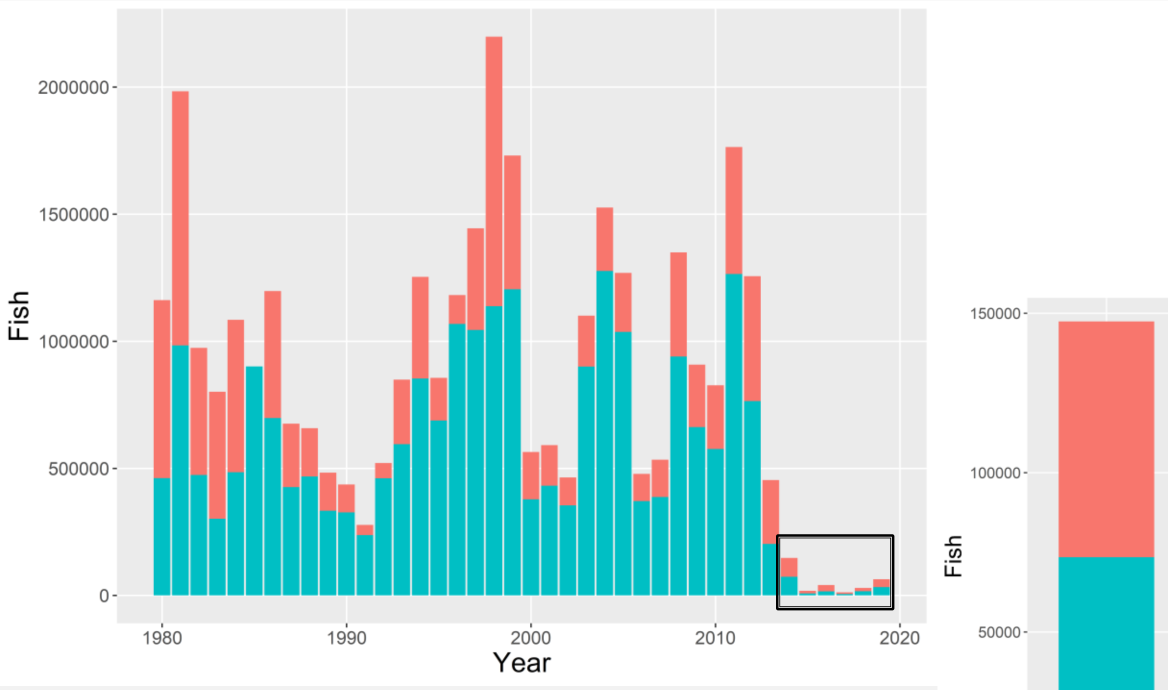
- Acknowledgments for funding – Nutrient program funding (including monitoring; FWCP, KTOI, BC Hydro, ENV, FLNR) Action plan implementation and enhanced monitoring (FFSBC, FLNR, FWCP, and HCTF)

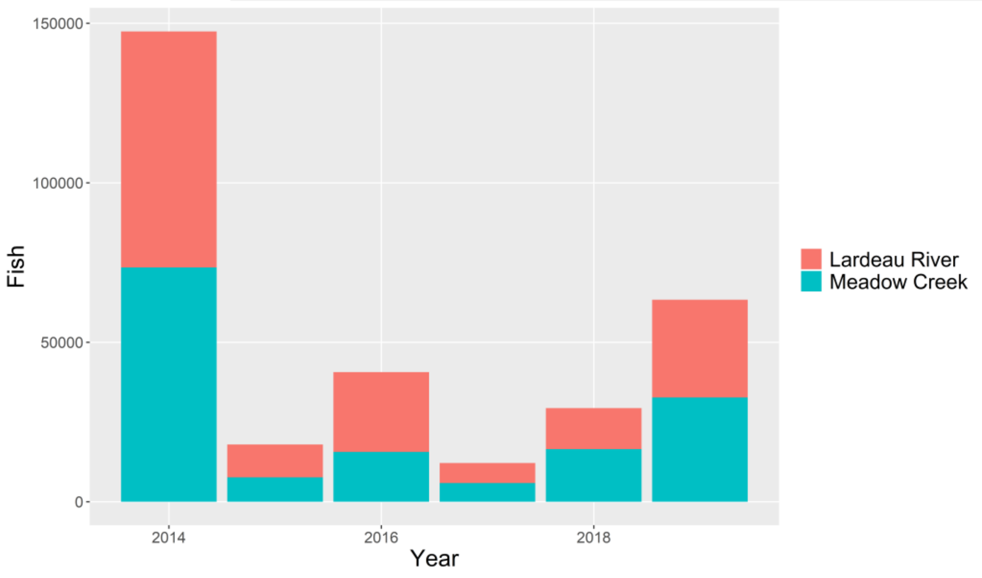
- Acknowledgments for contributors – too many to list…truly a collaborative, multi-faceted effort to recover Kootenay Lake. We thank all Advisory Team members, research technicians, FFSBC staff, nutrient program delivery team, external contractors delivering monitoring components…

Outline

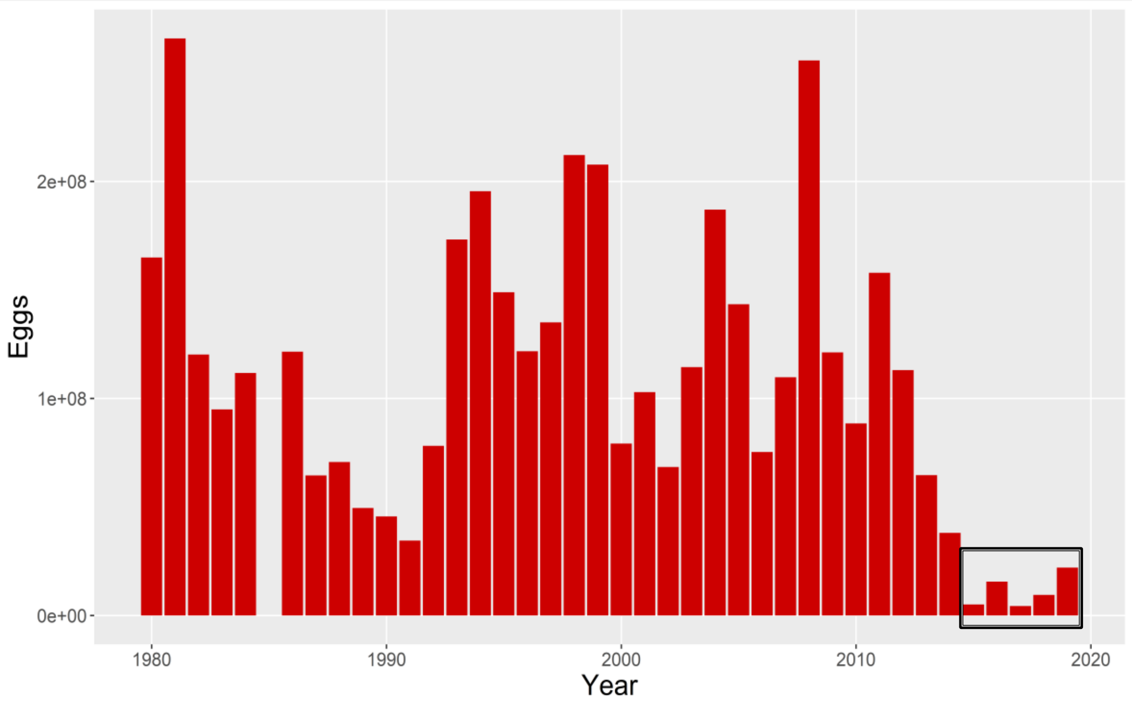
- Background/ Biological Response Update
- Review Actions, Triggers, and Implementation update from 2015-19 (what did we do?)
- Analysis/ ideas to help inform discussions around Key Questions

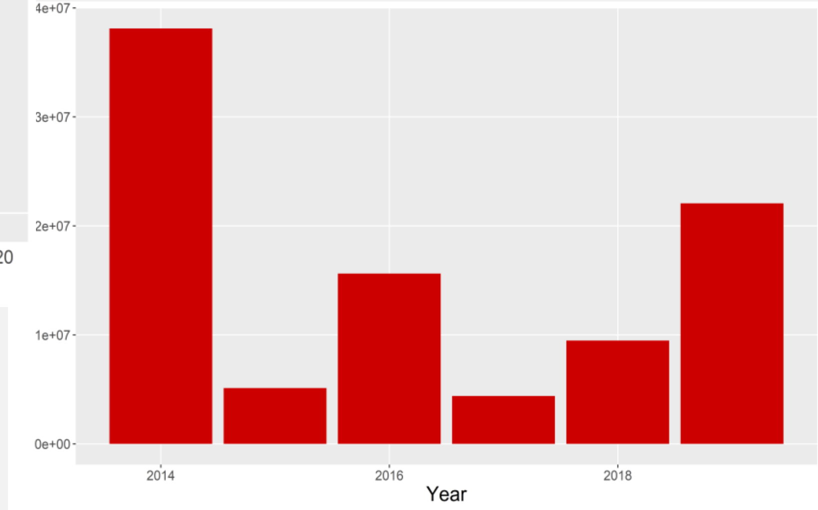
Kootenay Lake North Arm Kokanee Escapement



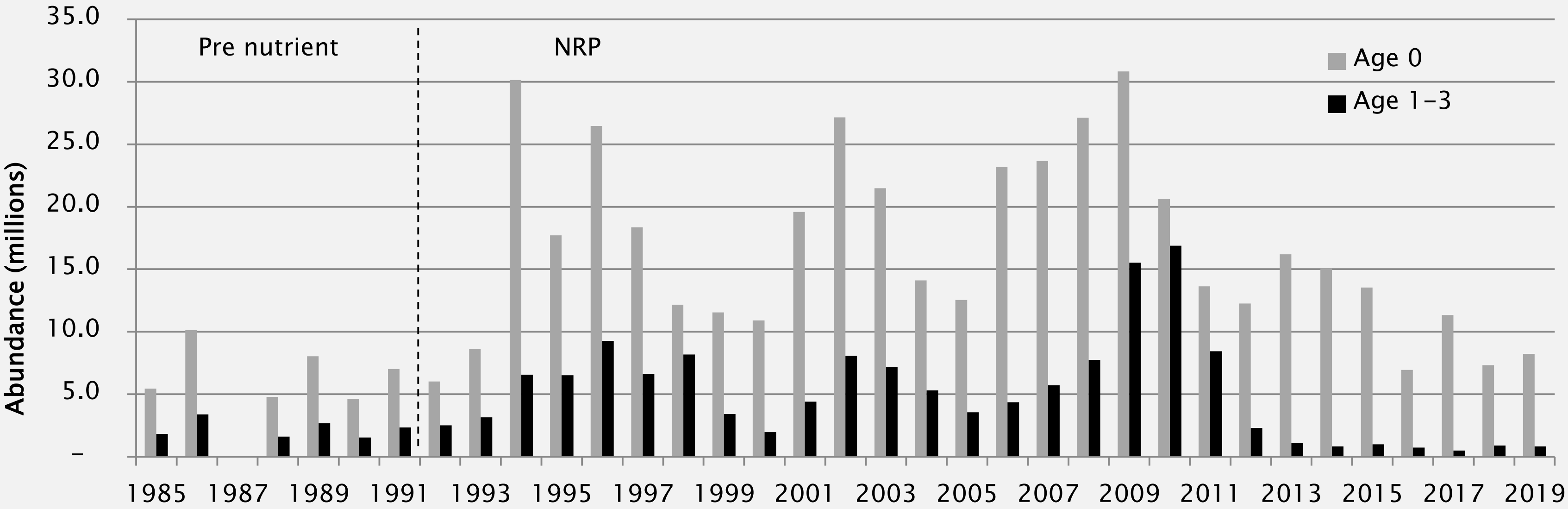


Kootenay Lake North Arm Kokanee Egg Deposition





Kootenay Kokanee In-Lake Abundance



Acoustic abundance trends for age 0 and age 1–3 kokanee from fall surveys of Kootenay Lake. 2019 data are preliminary.

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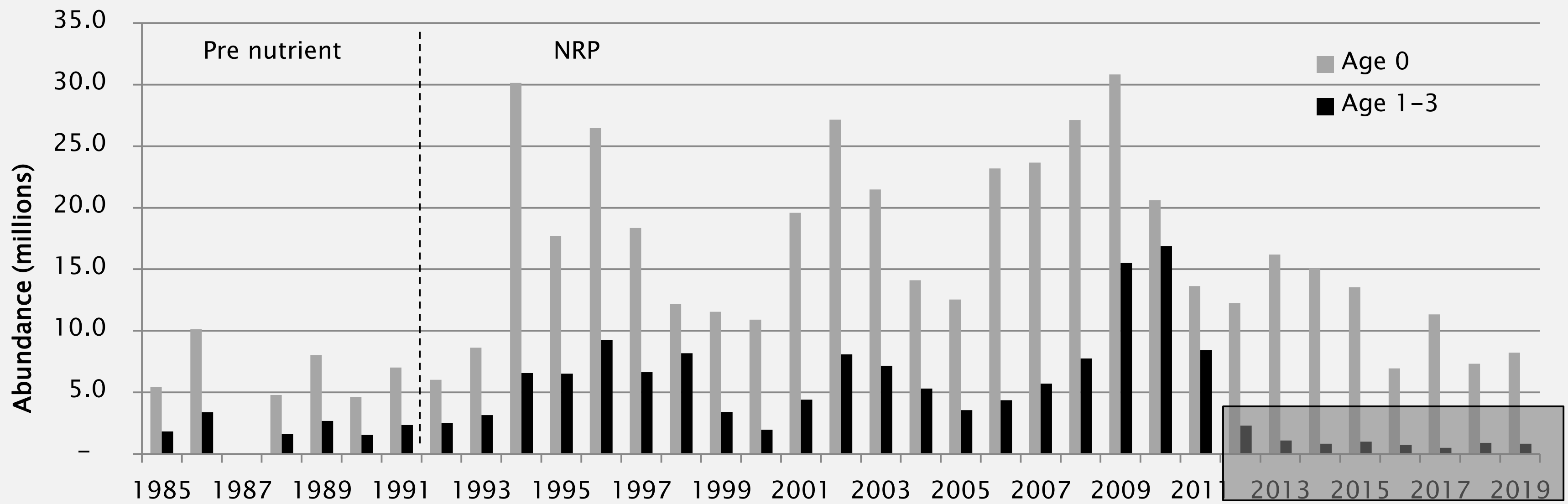

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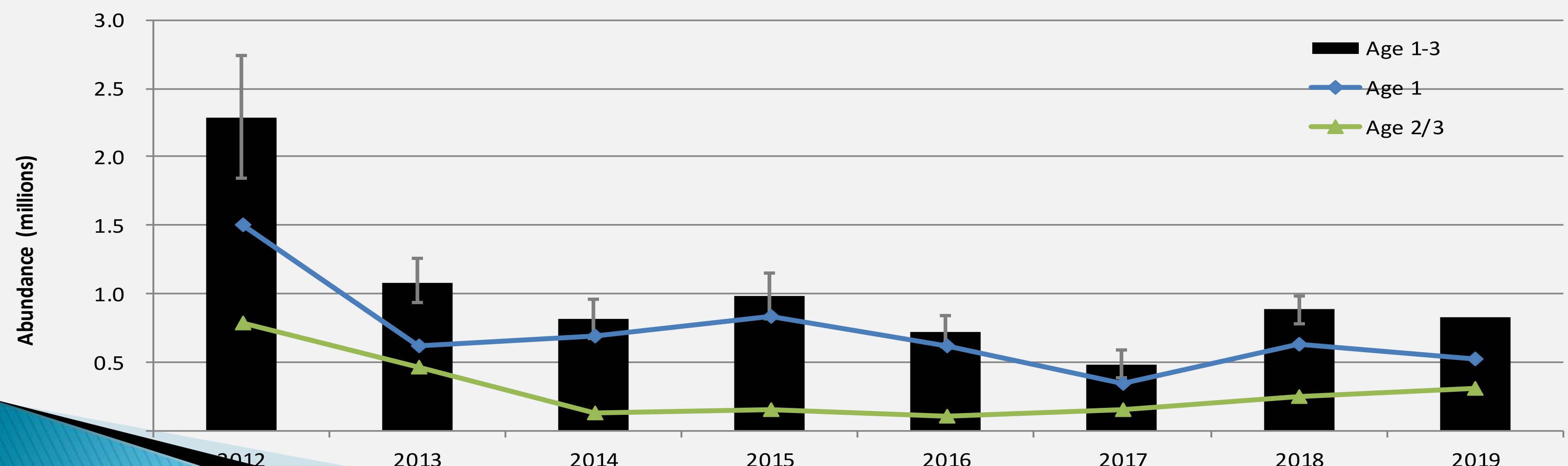
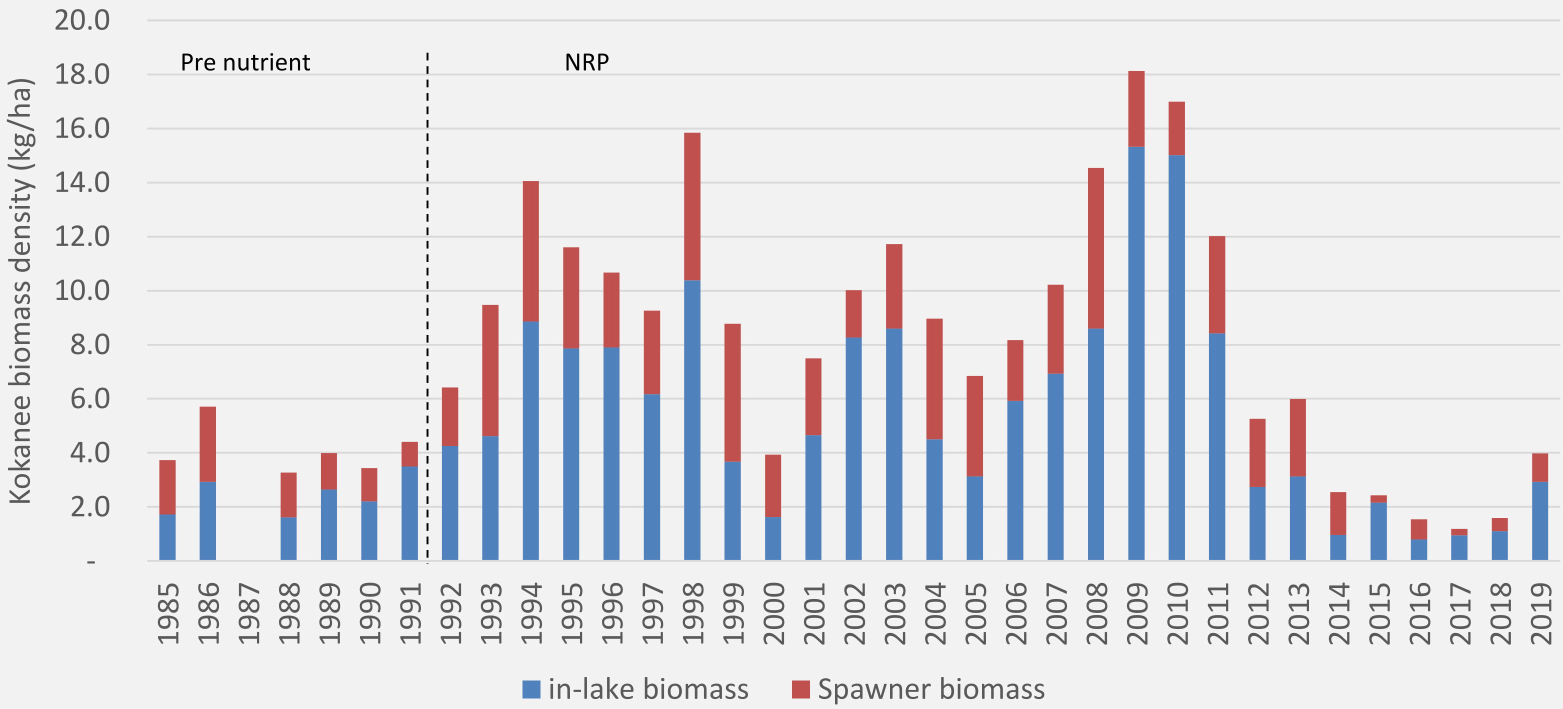
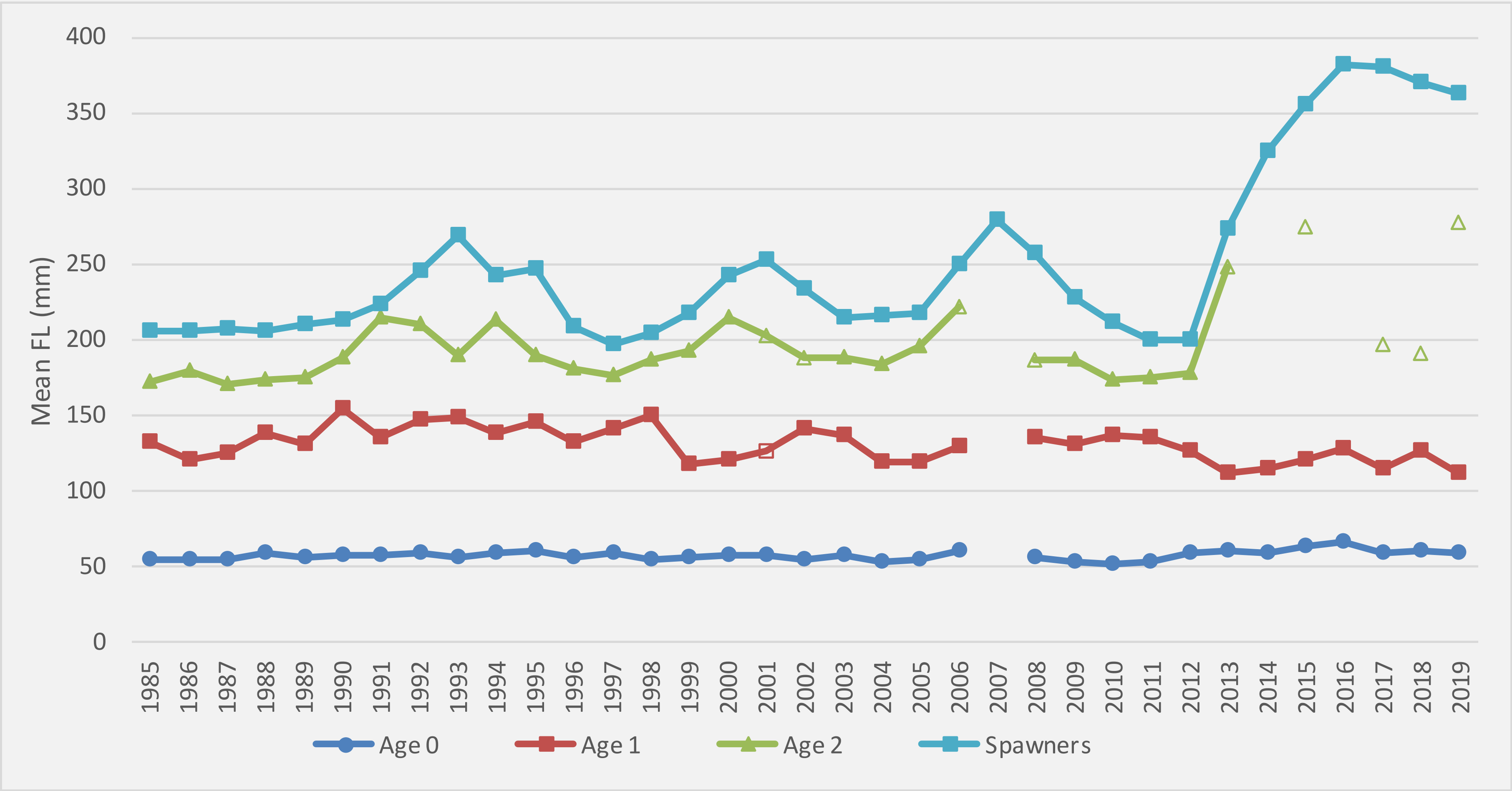


Acoustic abundance trends for age 1-3 kokanee from fall surveys of Kootenay Lake from 2012 to 2019. 2019 data are preliminary.

Kokanee fall biomass density – Kootenay lake.

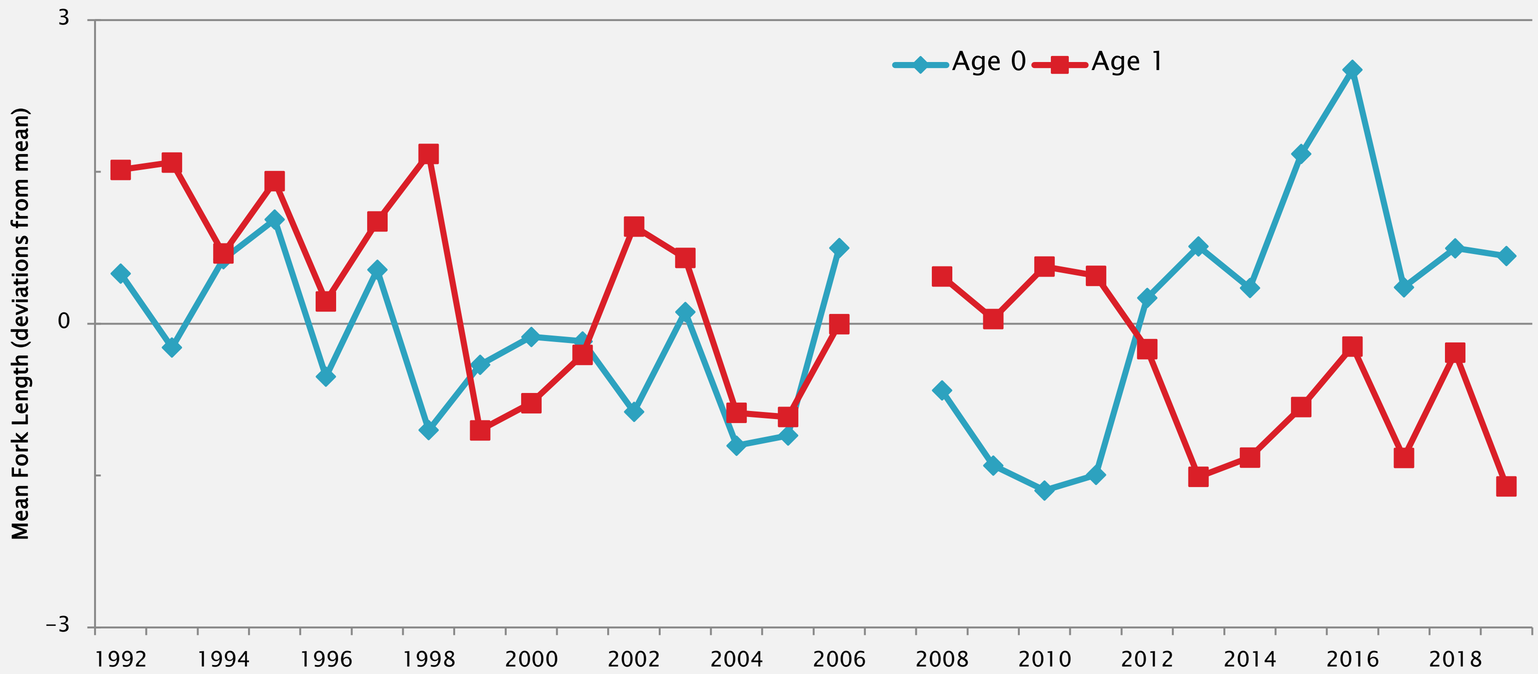


Kootenay Kokanee – Mean Length



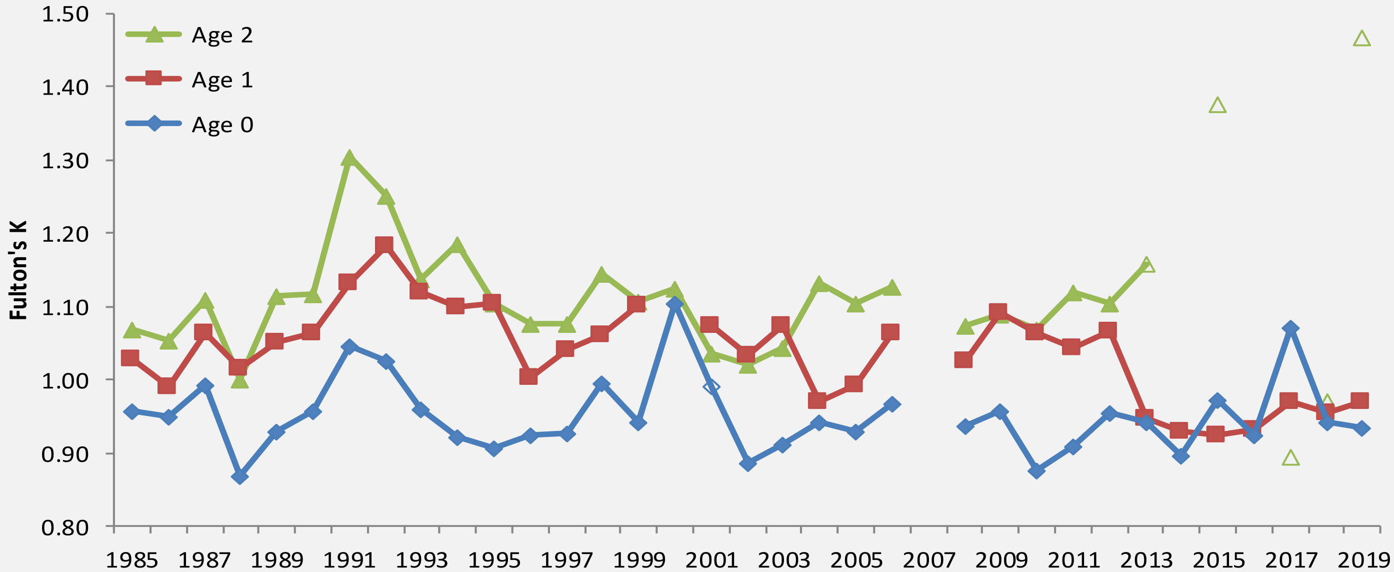
Mean fork length of trawl caught age 0-2 kokanee from fall trawl sampling in Kootenay Lake, and mean spawner fork length from Meadow Creek spawning channel. Fork lengths from trawl captured fish are corrected to an October 1st standard. Sample sizes less than 10 are identified by hollow points.

Kootenay Kokanee – Standardized Mean Length

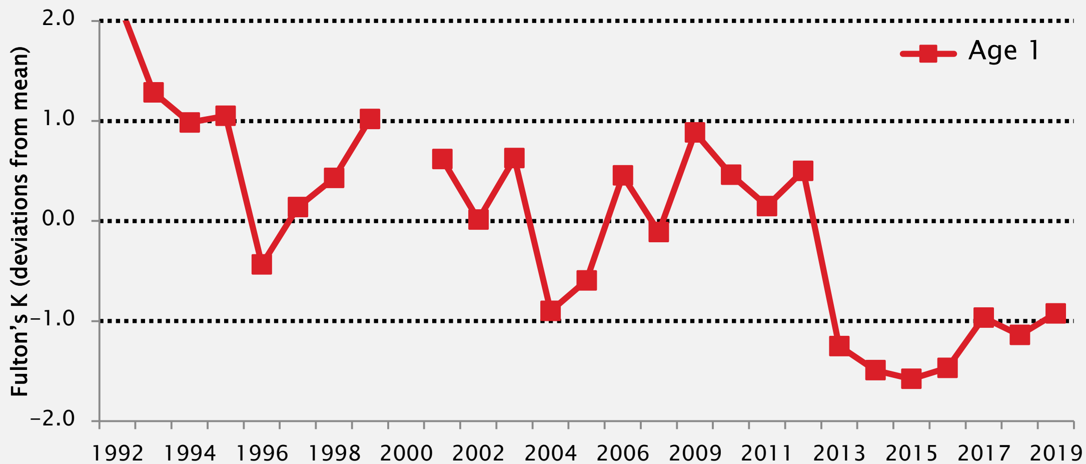


Trends in standardized mean lengths for age 0 and age 1 kokanee from fall trawling in Kootenay lake. * 2018 and 2019 ages are preliminary and estimated by FL.

Kootenay Kokanee – Fall Condition Factor



Fulton’s condition factor trends for fall trawl caught kokanee in Kootenay Lake during post fertilization years. Hollow points denote sample sizes <10.

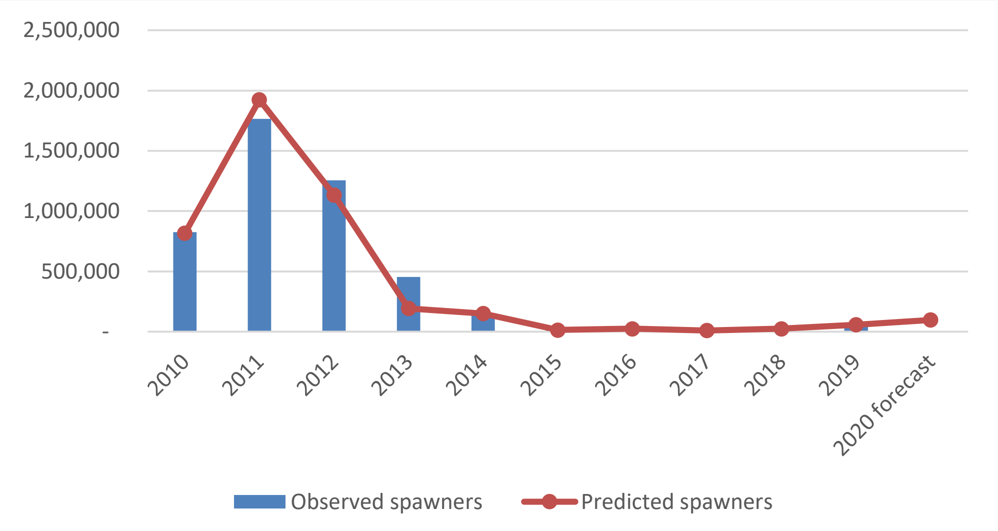


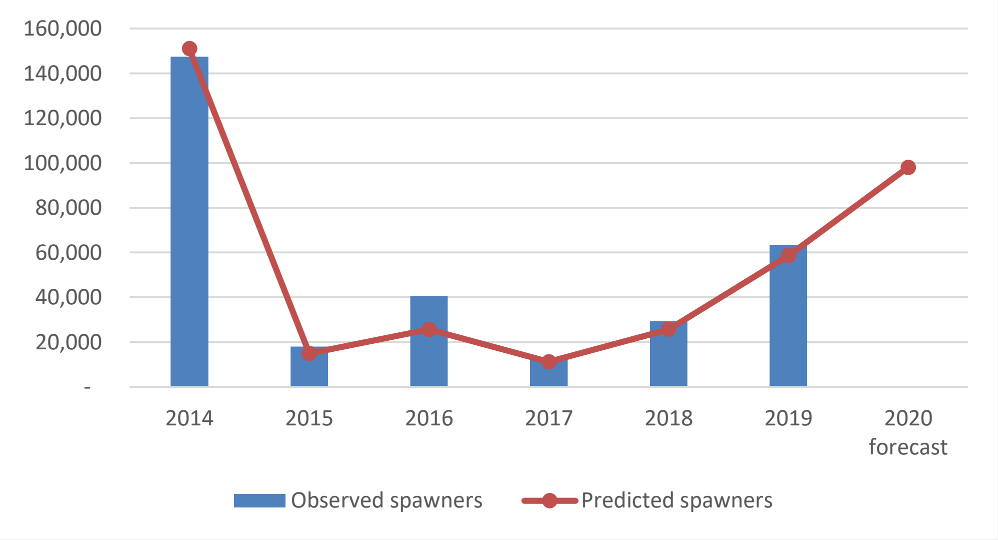
Trend in standardized condition (Fulton’s K) for fall trawl caught age 1 kokanee in Kootenay Lake during post fertilization years.

Kootenay Kokanee – Spawner Predictions

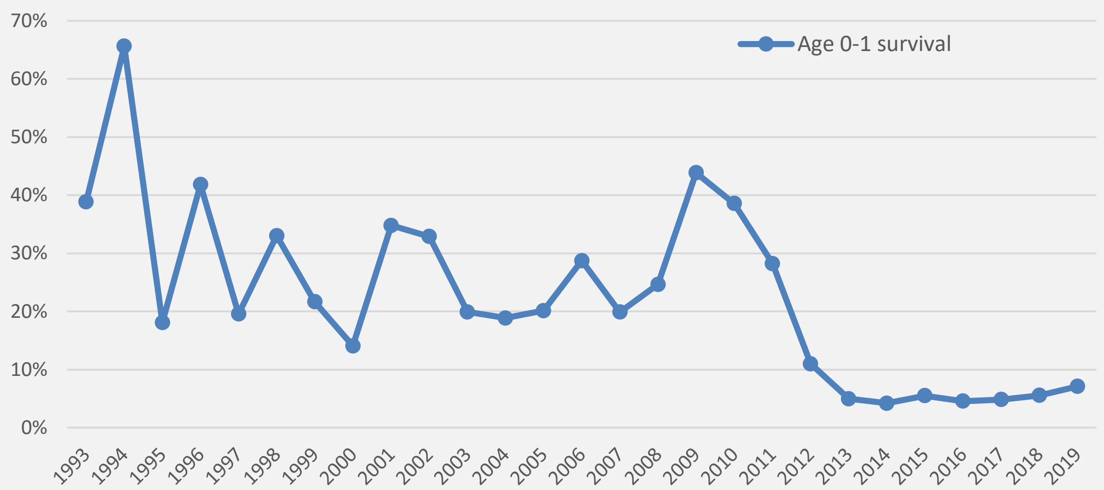
Table 1. Spawner counts and number of predicted spawners based on acoustic targets >-37 dB from year prior. Observed spawner number is meadow creek escapement + peak Lardeau count.

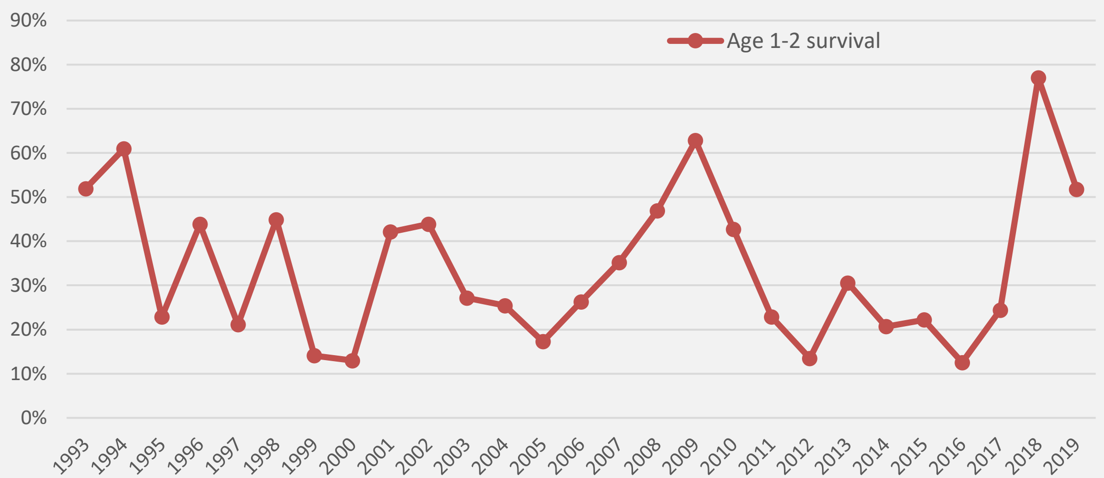
	Observed spawners	Predicted spawners	pred/obs R^2=0.97
2010	826,788	817,556	99%
2011	1,764,100	1,923,590	109%
2012	1,255,843	1,134,753	90%
2013	453,592	193,515	43%
2014	147,418	151,011	102%
2015	17,961	14,897	83%
2016	40,626	25,637	63%
2017	12,137	11,199	92%
2018	29,340	25,669	87%
2019	63,394	58,553	92%
2020 forecast		98,000	

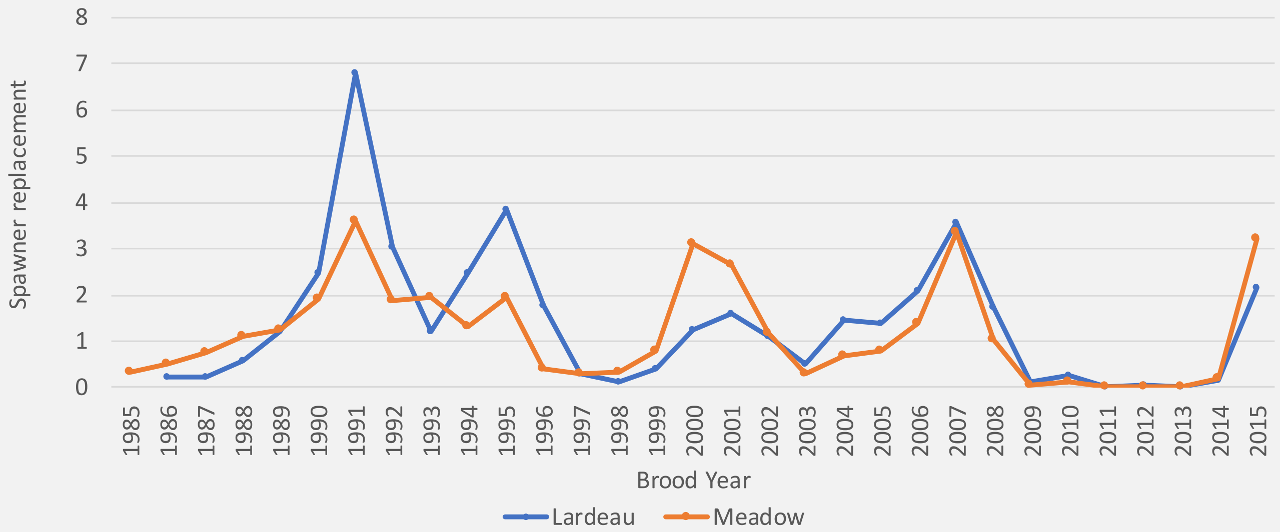


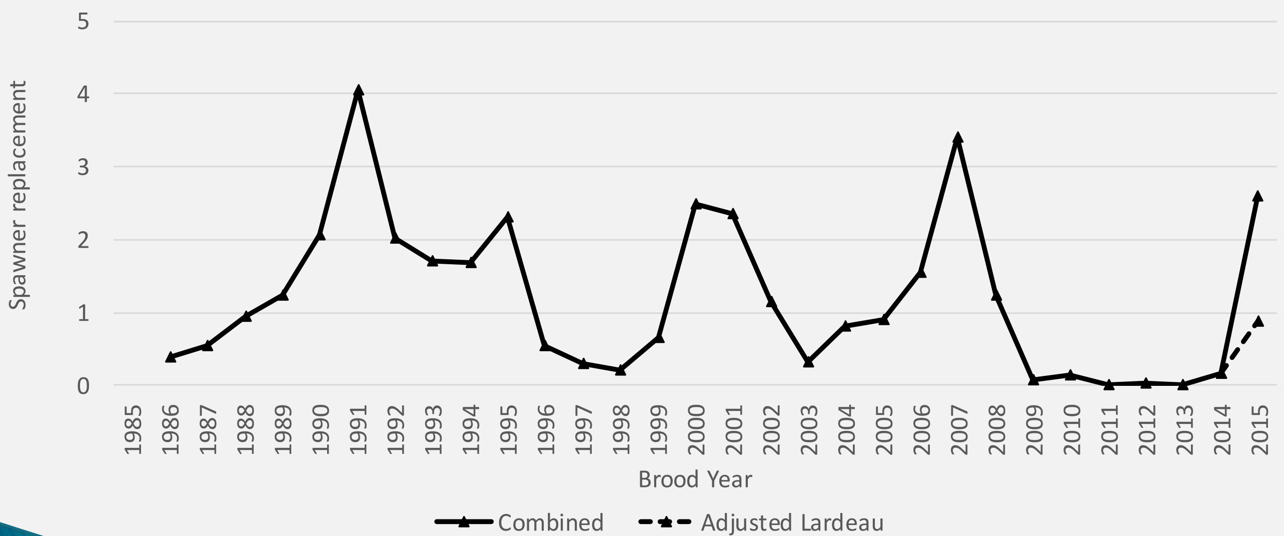


Kootenay Kokanee – In-Lake Survival









Spawner replacement trend demonstrates dramatic improvement for 2015 BY

Lardeau replaced at similar or higher rate from 2002-2014 BY's – If other methods (temp marks, genetics) are inconclusive, evaluation of replacement rate by tributary may provide insight into impact of egg plants going forward (Meadow = egg counts, Lardeau = no egg plants).

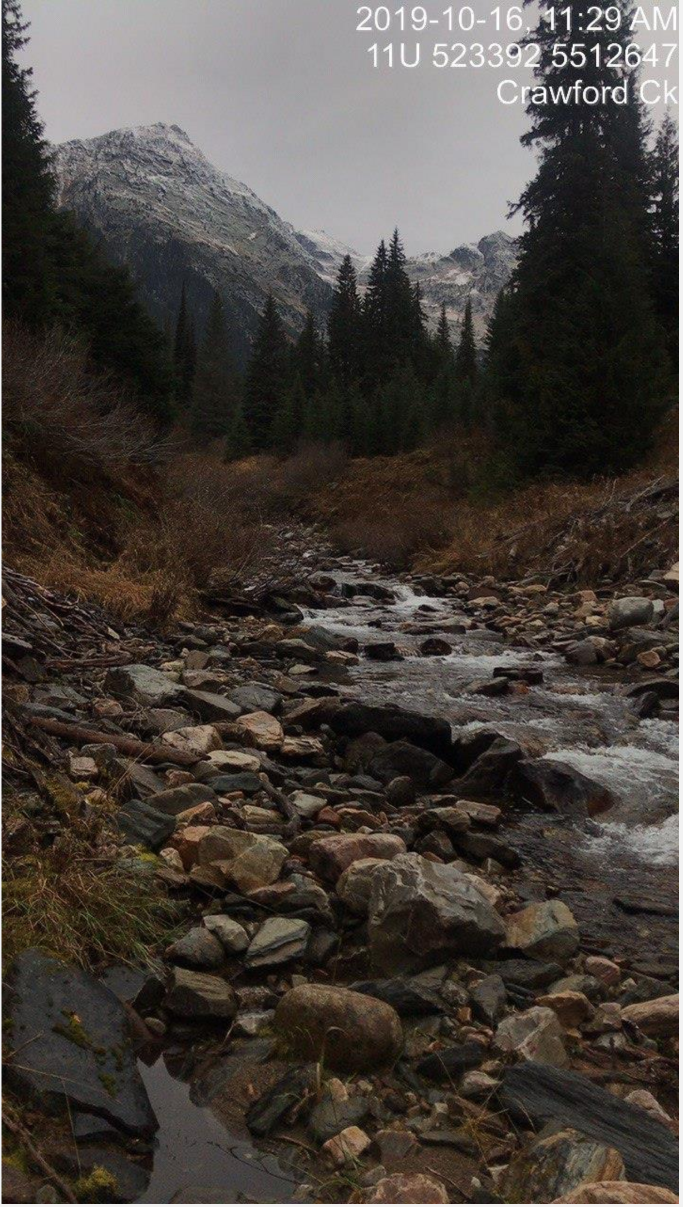
Possible that Lardeau count in 2015 may have been underestimated, adjusted Lardeau point in bottom panel illustrates more conservative replacement rate using adjusted count (45K vs 10K in Lardeau)

Kootenay Lake Bull Trout Redd Counts 2019

Stream Name	2019	
Upstream Flip Bucket Fish Count - Duncan Dam	na	five transfers with no counts
Hamill (including Clint)	na	cancelled due to weather conditions
Poplar	0	count incomplete due to high flows
Meadow Creek (including Mat)	38	
North Arm tributaries		
Crawford	91	upper/mid sections only; lower too high to count
Kaslo-mainstem	131	HCTF data
Kaslo-Keen Creek	33	HCTF data
Coffee	14	count delayed to allow flow to decline
Central tributaries (North Arm)	269	
Midge-mainstem & Kutetl	57	2 km missed
Midge-Seeman (incl. Wurttenberg)	47	
Midge-Conway	1	
Midge - Total	**105**	
Cultus	11	
South Arm tributaries	**116**	
TOTAL REDD COUNT	**423**	

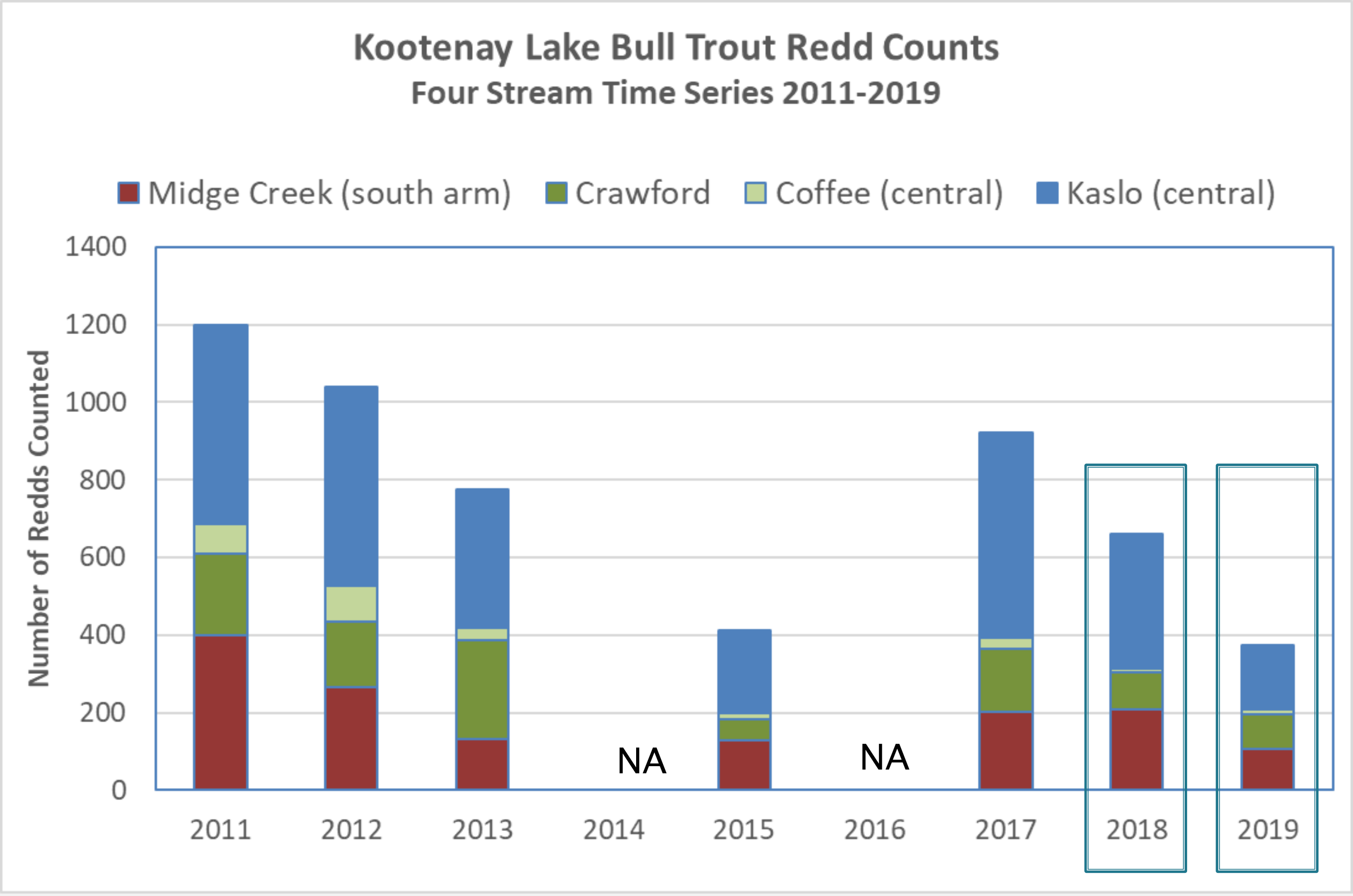
Data credits: FWCP, HCTF, Redfish Consulting Ltd. Masse Environmental Consultants, Mountain Water Research

Midge – 2 km missed due to logistics and weather conditions



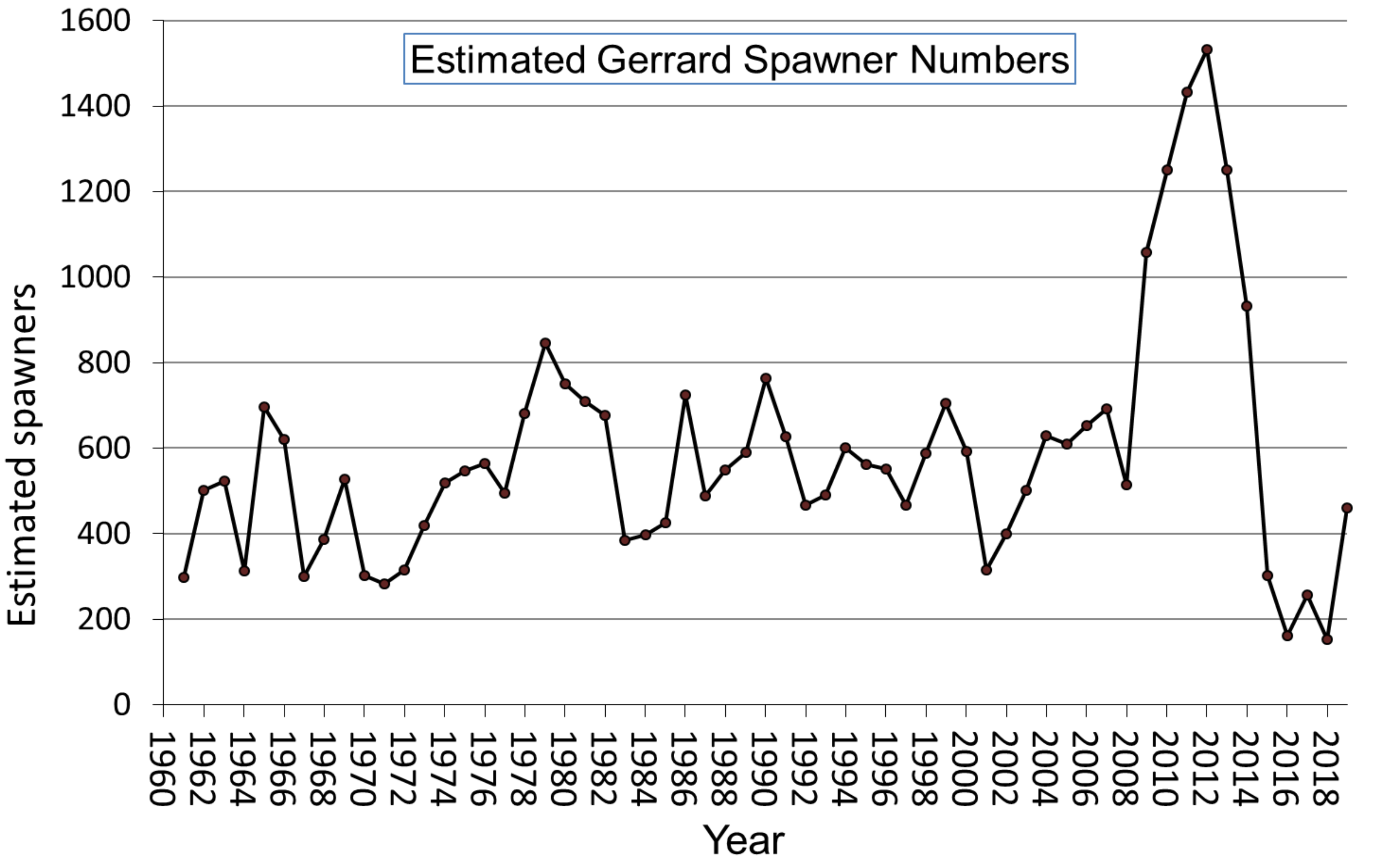
Crawford Creek Before/After

Jeremy Baxter photographs

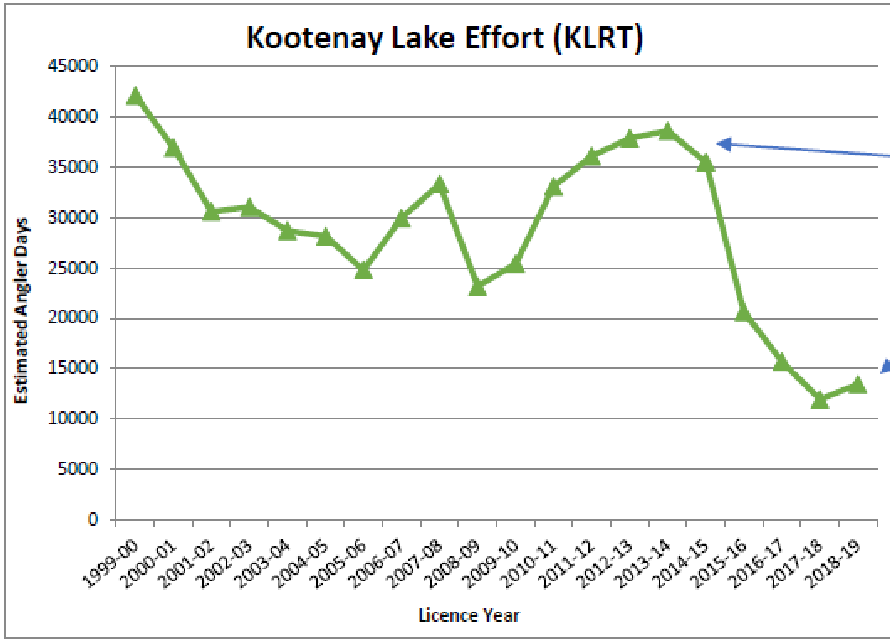


Kootenay Lake Bull Trout Redd Counts
Four Stream Time Series 2011-2019
Midge Creek (south arm)
Crawford
Coffee (central)
Kaslo (central)
Number of Redds Counted
1400
1200
1000
800
600
400
200
0
NA
NA
2011
2012
2013
2014
2015
2016
2017
2018
2019

Gerrard Spawner Abundance

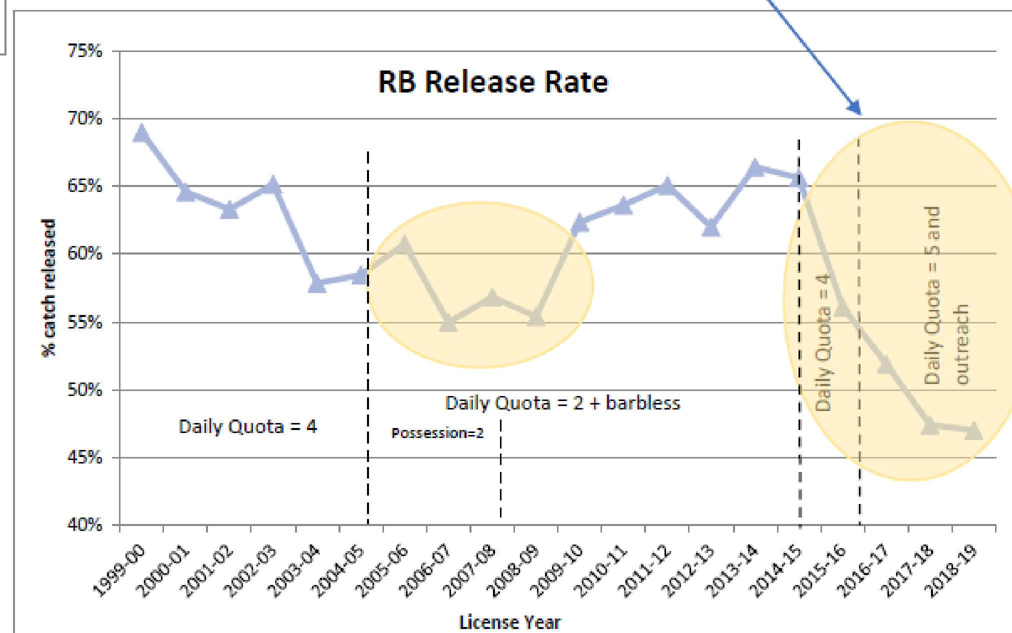


Fishery Trends– KLRT Creel



Effort Declines- 40,000 to 13,000 angler days

Recent outreach/daily quota increase= more harvest



Rainbow Trout Catch Trends (KLRT)

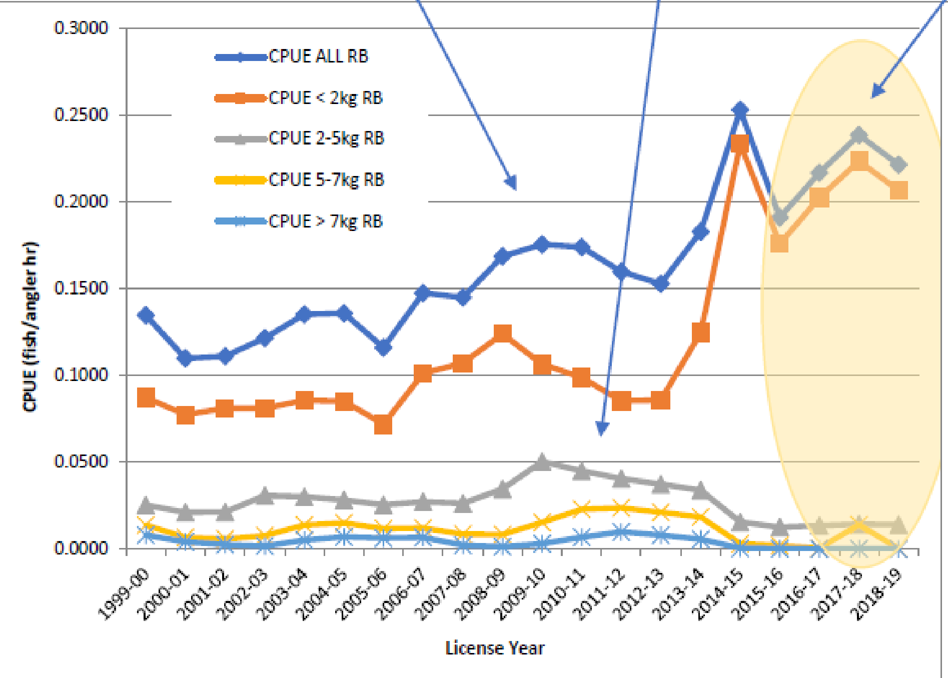
** Catch values could be inflated by ~50%-100%

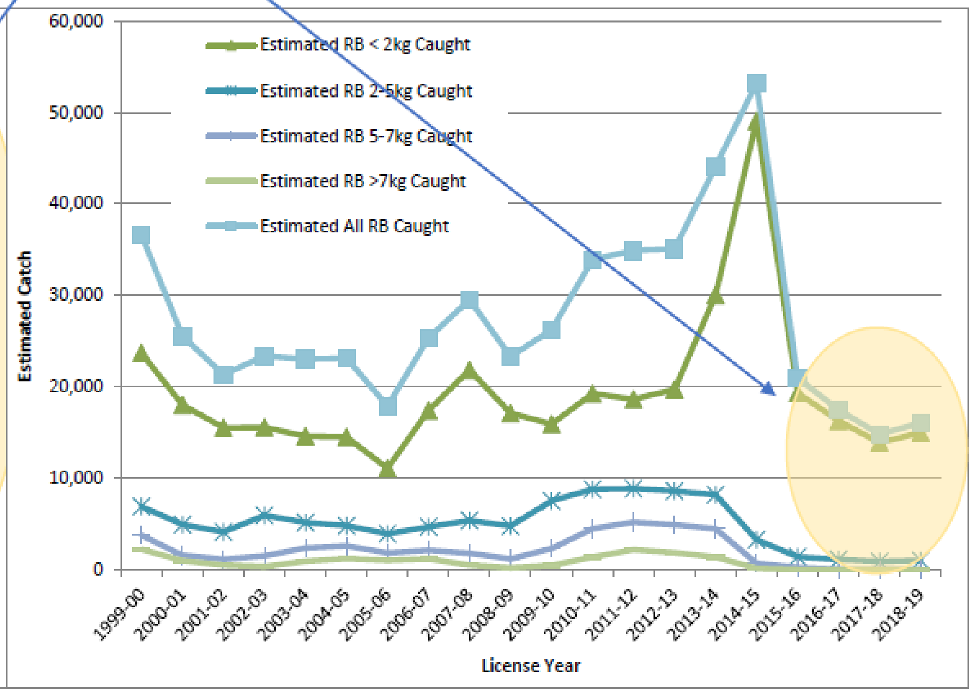
Large size classes now gone

Recent departure between CPUE and catch trends

General RB CPUE increase over time?

Catch now all small





Bull Trout Catch Trends (KLRT)

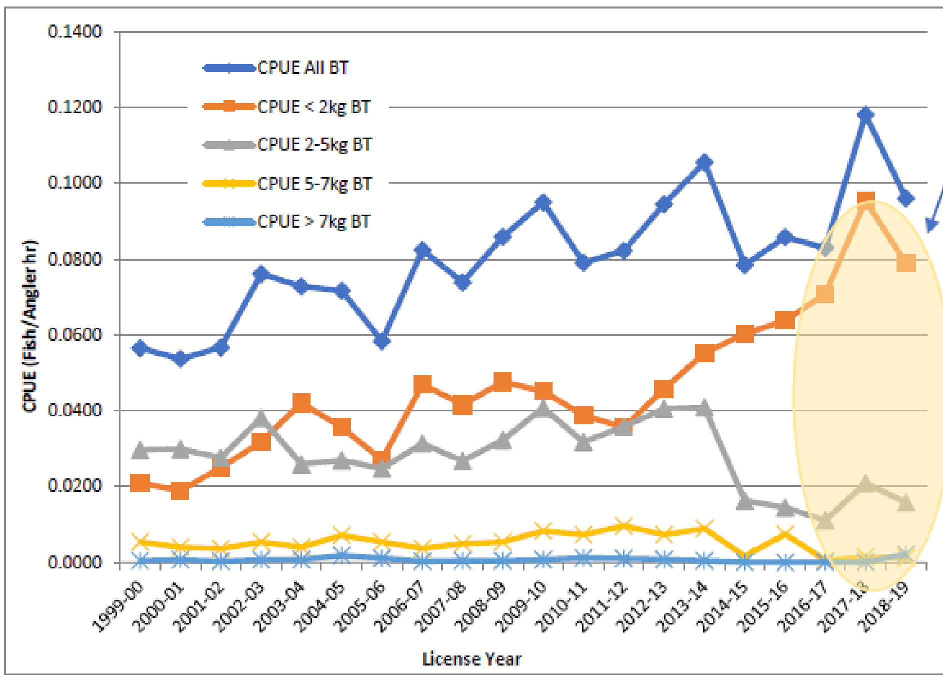
** Catch values could be inflated by ~50%– 100%

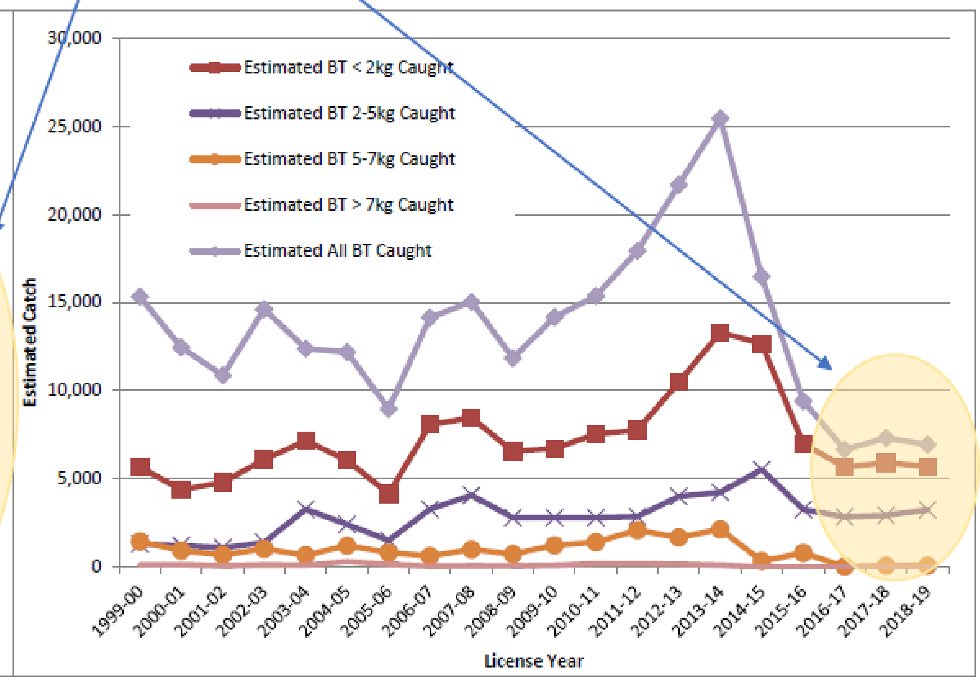
Large size classes now gone

Recent departure between CPUE and catch trends

General BT CPUE increase over time?

Catch now all small





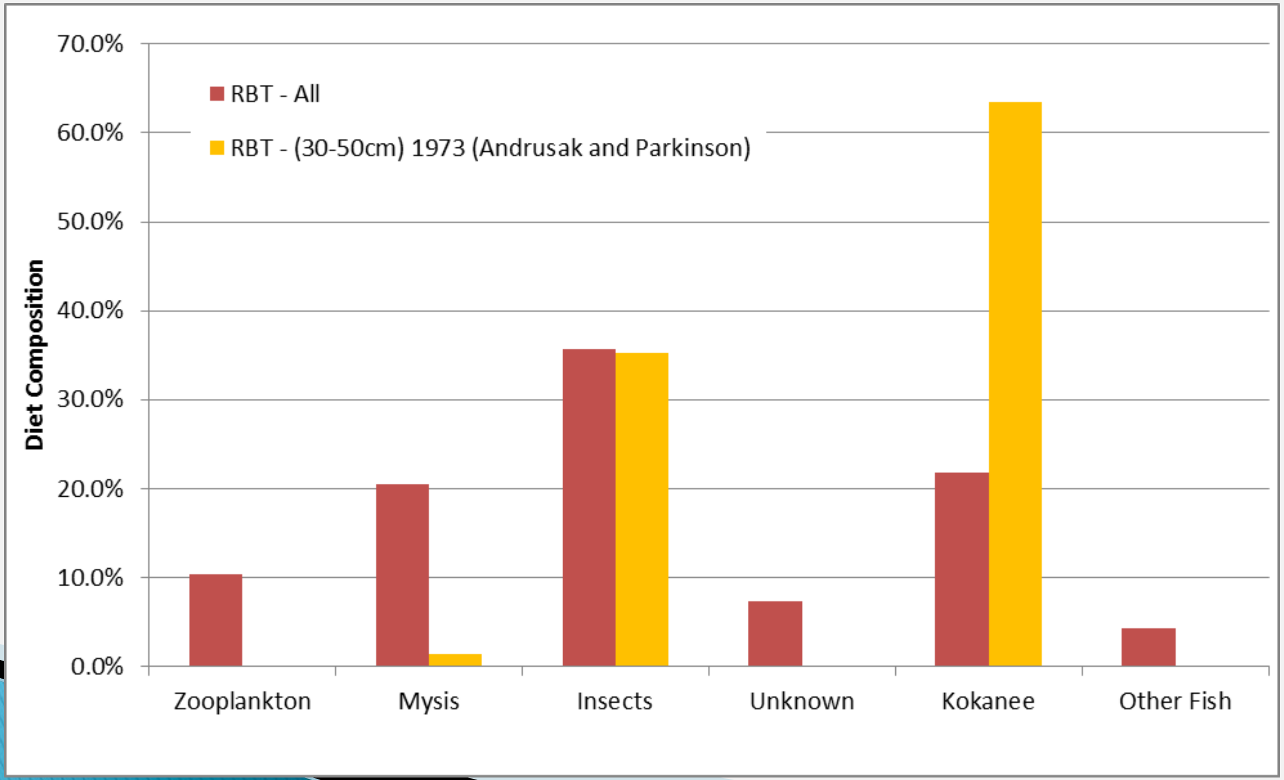
Piscivore Monitoring (2015-2019)

- Objective: To better inform recovery actions, contribute to predator reduction efforts

- Fish samples collected by angling guide, using standard large lake fishing methods
  - Total of 3390 angler hours expended (2015-2018)
  - Total of 738 RB and 287 BT harvested (2015-2018)
- Used data and samples collected by guide to analyse (2015-2018):
  - Age structure + diet composition
  - Maturation rate (% ripe) by ecotype
  - Fecundity
  - Age at entry to lake
  - Data used for bio-energetics modeling

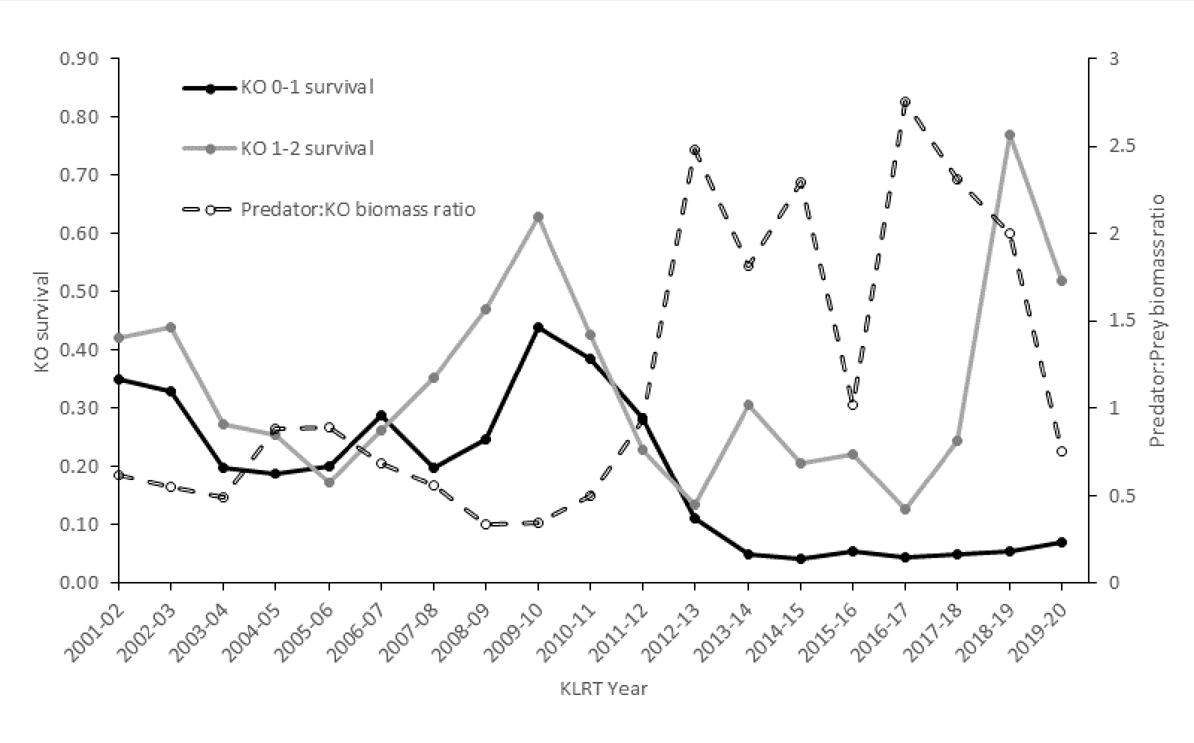
Piscivore Monitoring (2015-18)
Diet Composition

- One key thing to consider: RBT will take up kokanee production as they become more abundant…..
- Current shift to mysis and zooplankton to offset kokanee in diet
- Implications for kokanee recovery: even at static predator density in the future, RB kokanee consumption will likely increase concurrent with KO abundance increases –do we account for this in predictions?



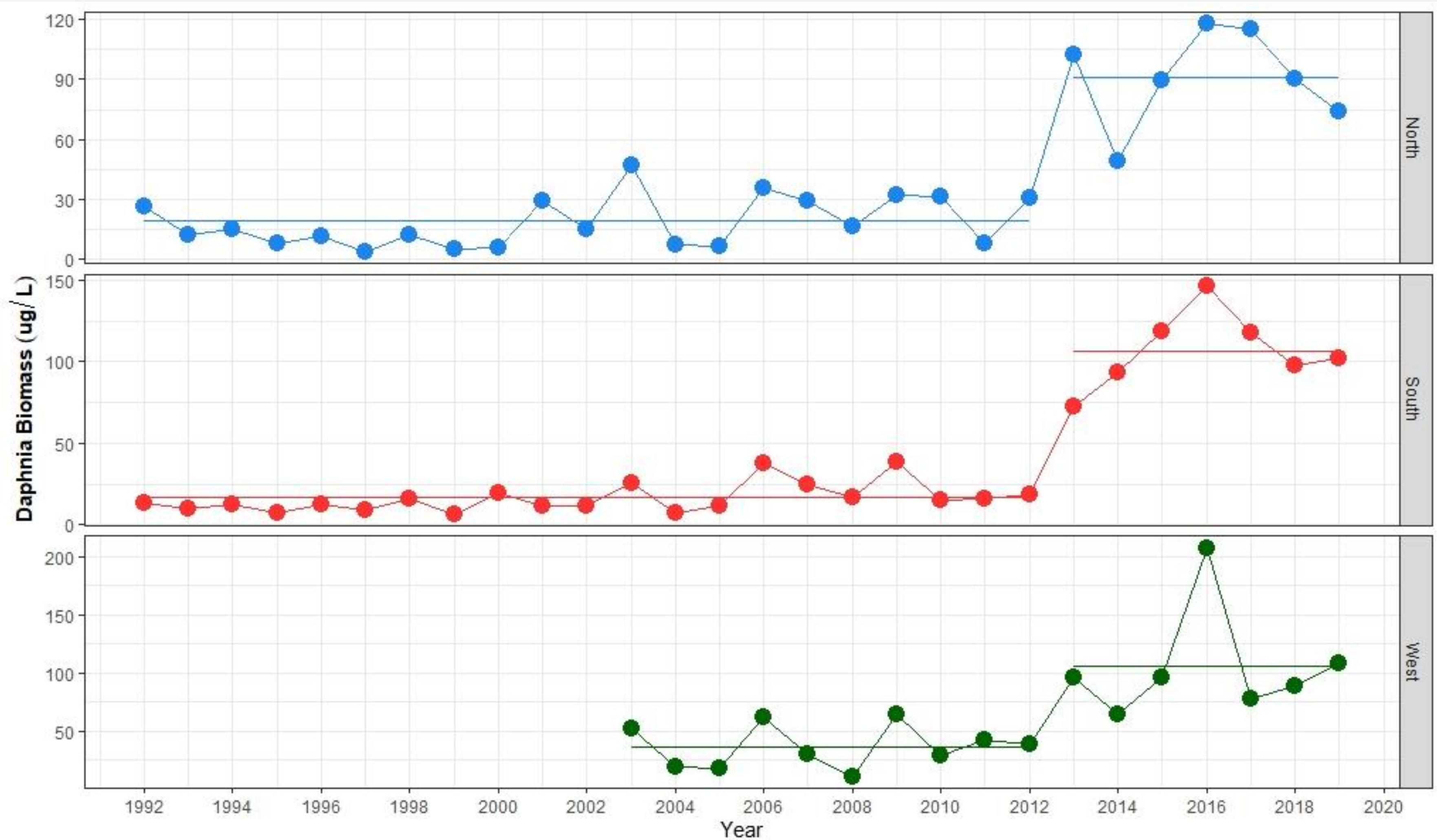
Kokanee trends and piscivore abundance

- KO survival tends to be inversely related to the Predator: KO biomass ratio – one way to visualize the current balance between predators and prey
- KO biomass from latest acoustic data, in lake + spawner biomass, adjusted to the proportion of the predator population that is within the gape limit of mean spawner size
- Predator biomass for pre-collapse years (<2014) from KLRT scaled to recently (Thorley 2019) updated 2011 estimate of Andrusak 2015, and post-collapse years based on an age-structured abundance estimate, using modified parameters of Thorley (2019), and Lardeau Age-1 counts. Growth curves developed from fishery-caught samples in pre-collapse literature and post-collapse 2015-2018 scientific samples.
- Collapse and post-collapse years all have ratios of >1 until 2019

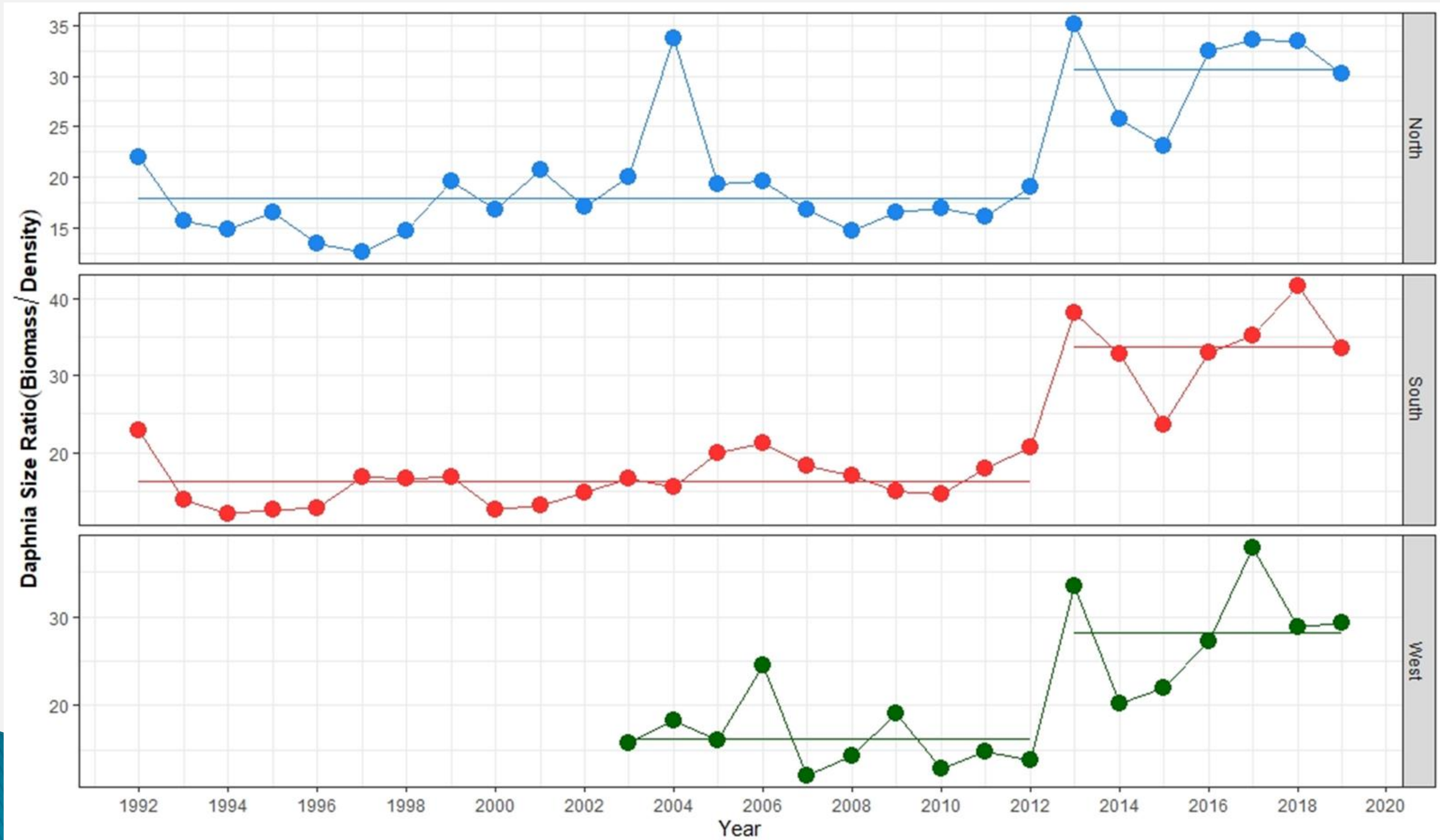


Kootenay Lake Predator Monitoring– Greg Andrusak

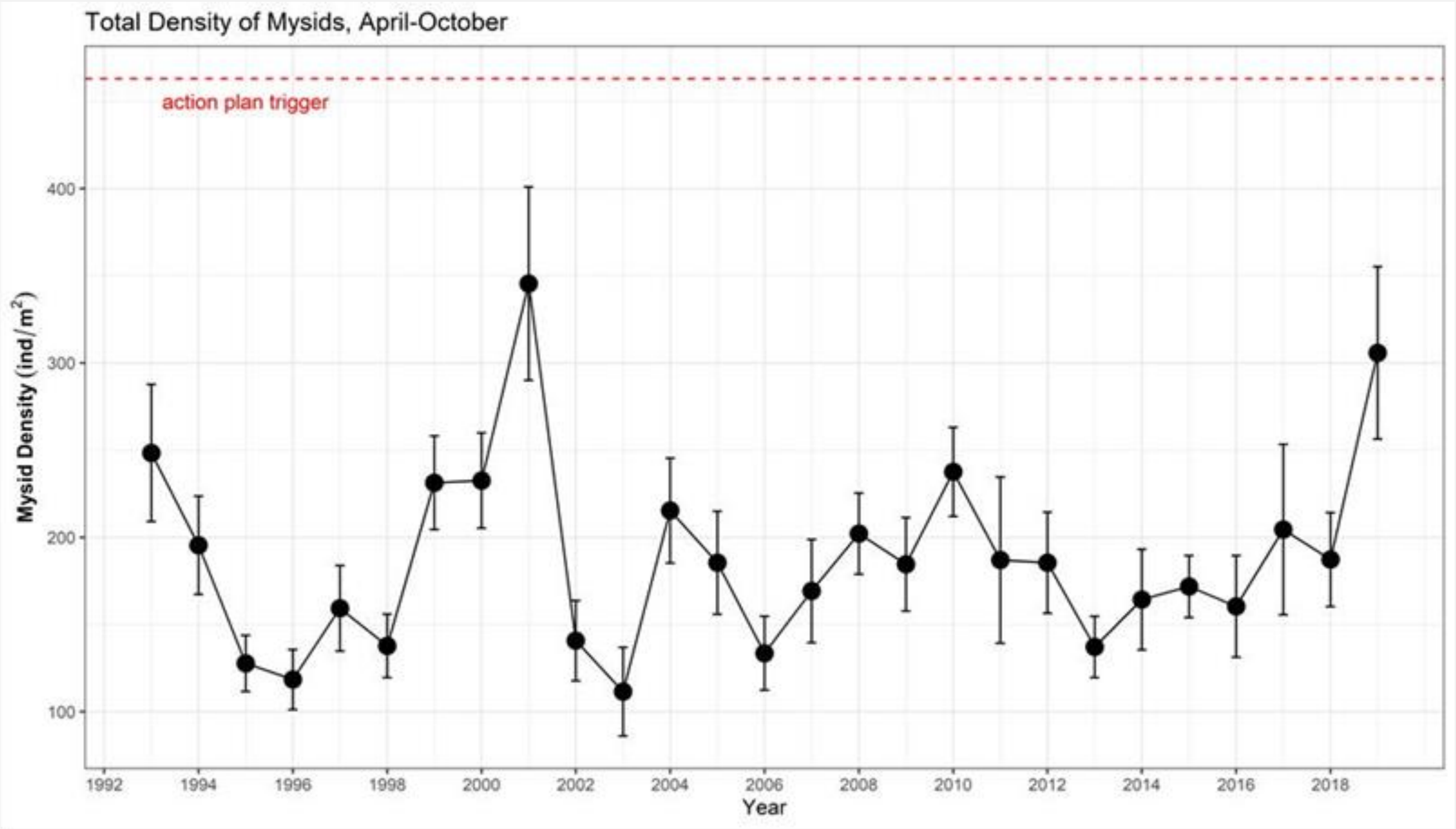
Kootenay Lake Results– Zooplankton: *Daphnia*– biomass by arm 1992–2019



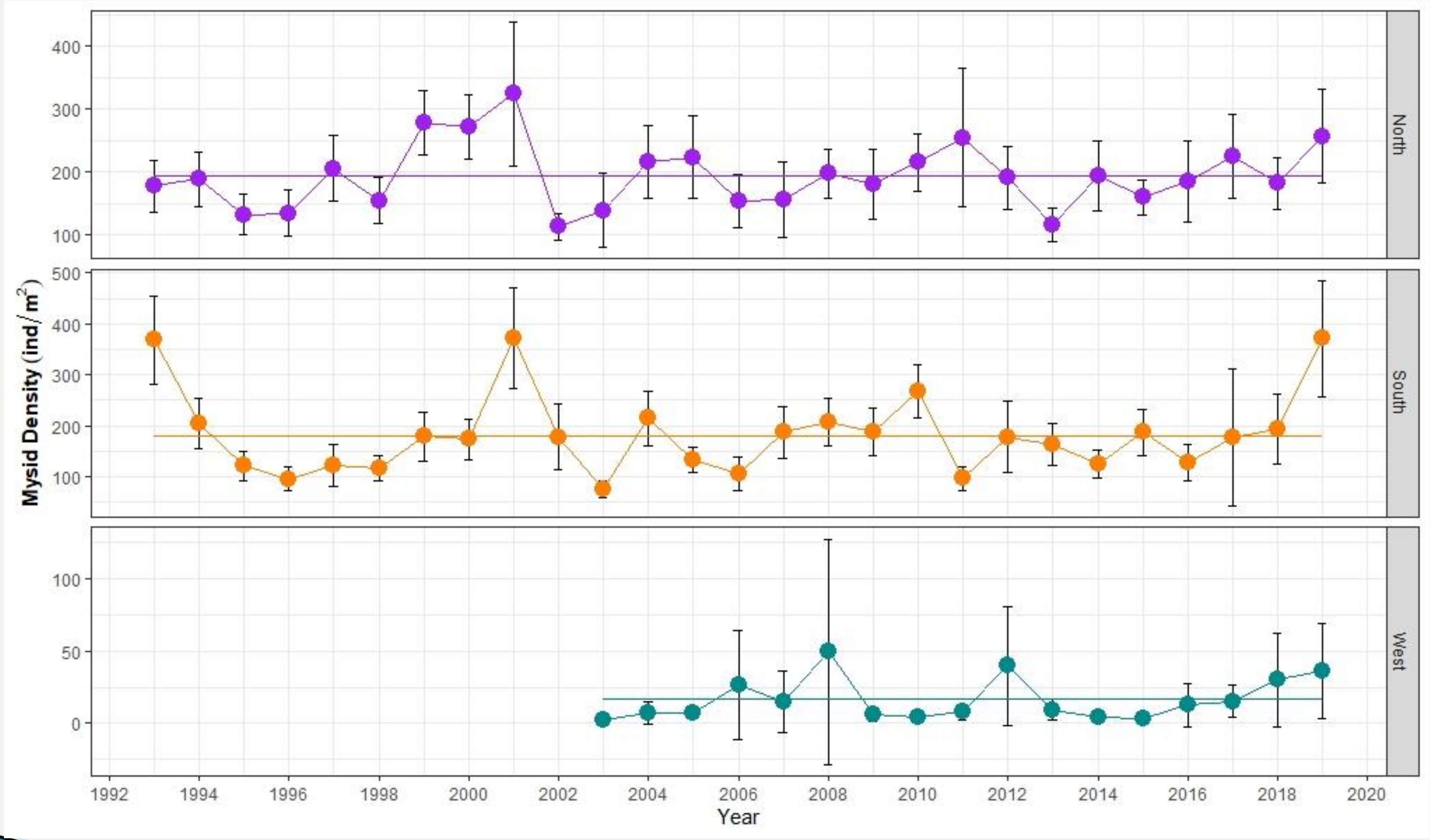
Kootenay Lake Results– Zooplankton: *Daphnia*– size 1992-2019



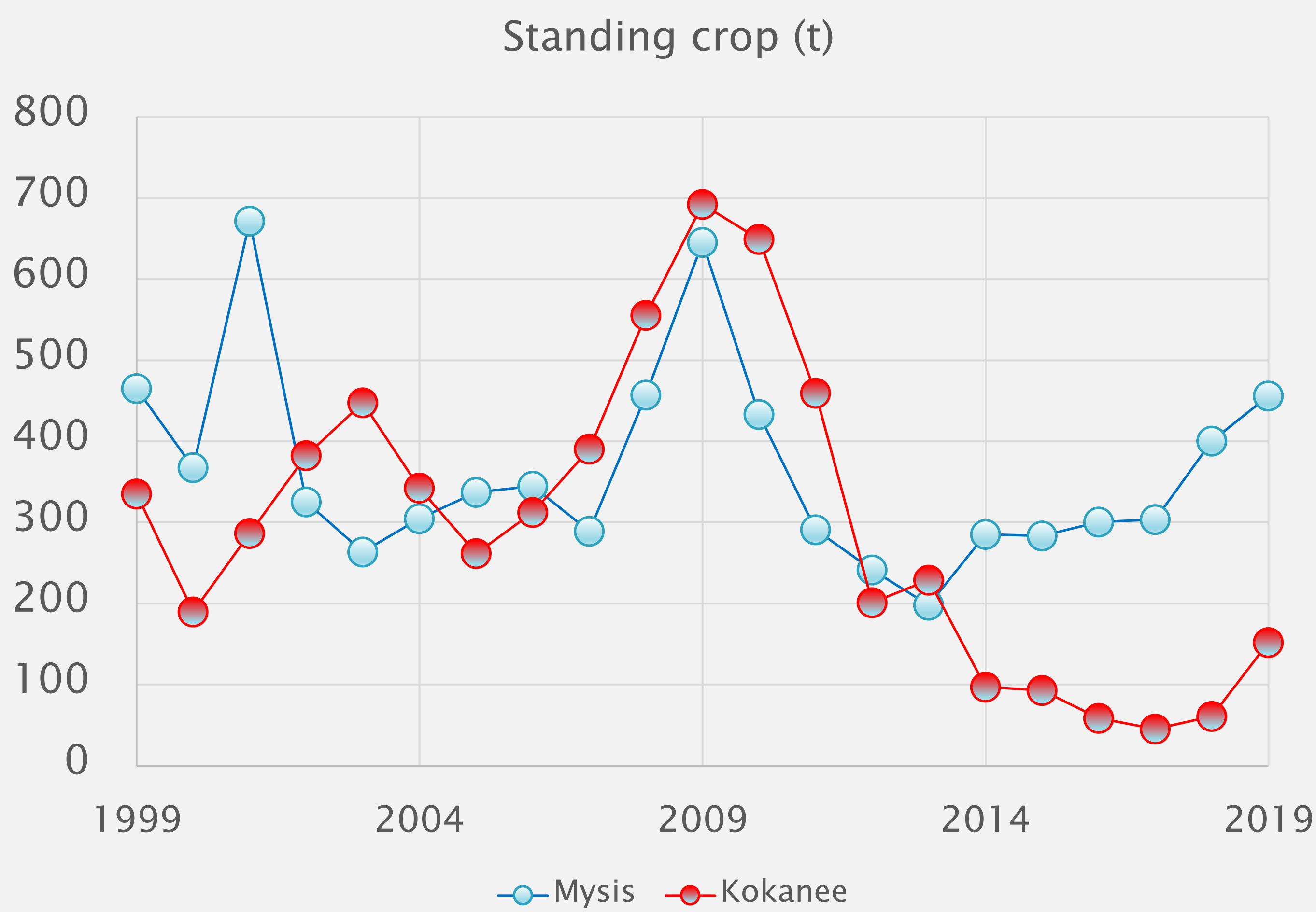
Kootenay Lake Results:
Mysids- whole lake density 1992-2019



Kootenay Lake Results:
Mysids- density by arm 1992-2019



Kootenay Lake Results:
Mysids & Kokanee – tonnes



Action Plan Implementation

Review

Action Update:
Kokanee Supplementation

- Action– stock 5 million eyed eggs in Meadow Creek
- Trigger – KO escapement<140,000 spawners; age 0–1survival <11%, <17.0 million fry, KLRT >2kg RB CUPE mod–high

- Stocking delivered in 2015–2019
    - **23,558,539** fry and eyed eggs total
    - Fry= 854,207
    - Eyed Eggs=22,704,332

Action Update:
Kokanee Supplementation

- Fry stocking

Source Location	Brood Yr	Release Yr	Site	Number	% Contr.
Norbury Creek	2015	2016	meadow	104,006	9%
Lussier	2015	2016	meadow	359,335	32%
Lussier	2015	2016	crawford	30,030	3%
Deka Lake	2015	2016	meadow	142,237	13%
Bridge Lake	2016	2017	crawford	79,599	1%
Hill Creek	2018	2019	meadow	109,000	4%
Hill Creek	2018	2019	crawford	30,000	1%

Action Update:
Kokanee Supplementation

- Egg stocking

- 2015

Source Location	Egg Number	Site	% contr.
Hill Creek	477,398	meadow	43%

- 2016

Source Location	Egg Number	Site	% contr.
Whatshan	603,164	meadow	9%
Fairmont (Columbia)	1,569,888	meadow	23%
Hill Creek	1,381,059	meadow	20%
Koocanusa (Lussier, Norbury, and Bull)	1,203,857	meadow	18%
Interior Brood Lakes	2,001,606	meadow	30%

- 2017

Source Location	Egg Number	Site	% contr.
Hill Creek	6,346,339	meadow	73%
Hill Creek	150,000	crawford	2%
Fairmont (Columbia)	1,238,740	meadow	14%
Whatshan	240,270	meadow	3%
Interior Brood Lakes	726,544	meadow	8%

Action Update:
Kokanee Supplementation

- 2018

Source Location	Egg Number	Site	% contr.
Hill Creek	3,447,154	meadow	79%
Hill Creek	100,000	crawford	2%
Whatshan	796,114	meadow	18%

- 2019

Source Location	Egg Number	Site	% contr.
Hill Creek	1,771,401	meadow	69%
Whatshan	650,798	meadow	25%

Thermal Mark Results

- 2015 brood year fed fry thermally marked
  - Meadow Creek 605,000 fry with certain thermal marks
  - > 50% of the fry from Meadow Creek in 2016
- Meadow spawners
  - 2018 (age 3), 2019 (age 4) 0 with thermal marks
  - Implies an implausible fry-to-adult survival of naturally spawned progeny > 11%
- Why
  - Stocked fry did not survive
  - Stocked fry did not imprint (survivors strayed)
  - marks hard to identify
  - combination
- No strong evidence to suggest a benefit of fed-fry over eyed eggs in supplementation actions
- More info may be available in future year from DNA (if checked)

Action Update:
Meadow Creek KO Incubation

- Action – upgrade of MC Hatchery to increase incubation capacity above 5 million
- Trigger – none
  - Complete – ~1 million eggs incubated in 2017 – Meadow Creek poor/last option for incubation (no alarms, egg quality issues, cold water pushes plants late)
  - Egg supply is more limiting than incubation space (only so many wild eggs available by source; collection/egg management also big time sink)

Action Update:

Kokanee Angling Closure

- Action – maintain kokanee daily quota=0
- Trigger – <140,000 spawners; age 0-1 <11%, KLRT >2kg RB CPUE mod-high
    - Implemented in 2015, continued

Nutrient Restoration Program

- Action – Continue current implementation program (max amounts of nutrients in the summer during optimal growing conditions)
- Trigger – none
    - Program delivered – dates range from April-September
    - Fall additions not strictly implemented (benefits to algae and zooplankton decrease as water temp and light decreases)

Action Update:
Mysis Removal

- Actions – evaluate feasibility, mysis removal
- Trigger – explore feasibility, removal if density/biomass > 463 ind/m^2 (2 SD > mean).

Mysid Suppression Feasibility

A Phased Approach for Kootenay Lake

Submitted to:
Jeff Burrows
Ministry of Forests, Lands, Natural Resource Operations and Rural Development
Province of British Columbia

Submitted by:
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and

Katrina Caley, MSc, AAg
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Ktunaxa Nation Council
(250) 489-2464

March 31, 2019

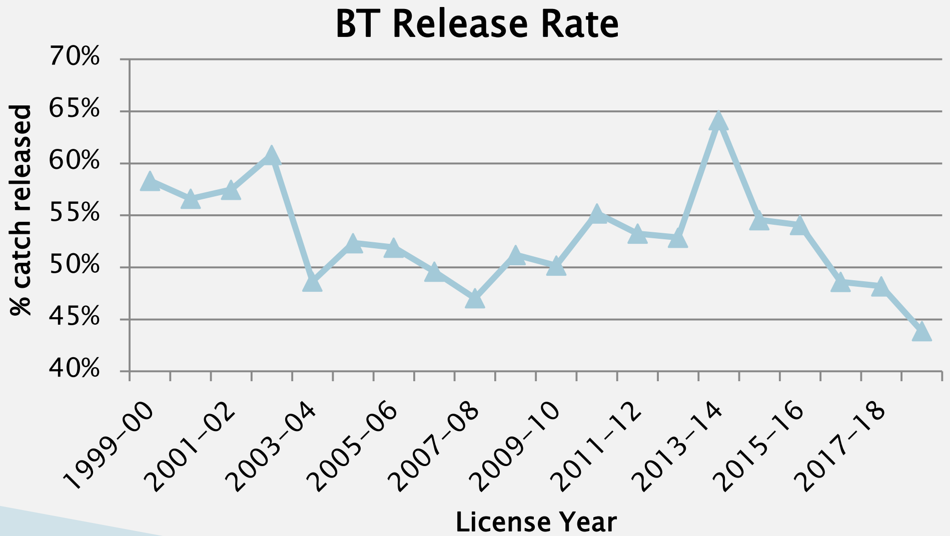
- **Mysid Suppression Feasibility**
- Incomplete draft

Action Update:
Predator Management– Rainbow Trout

- Action – Recreational Fishery Regulations
- Trigger – <140,000 spawners; age 0-1 <11%
  - Implemented RB daily quota increase (increased to 4/day in 2015 and then 5/d in 2018; still only 1>50cm)
  - KLRT RB harvest rate increased ~8% between 2015 and 2019 (regulations and outreach combined)
  - Effort declines resulted in a decrease in overall RB harvest (~9,000 to 5,000 in the same period)

Action Update:
Predator Management– Bull Trout

- Action – Recreational Fishery Regulations
- Trigger – Trigger – <140,000 spawners; age 0-1 <11%
- Kootenay Lake
  - Regional biologists recommended an increase to 2/d (only 1>50cm) in 2015, management decision not to proceed (stakeholder opposition)
  - In 2018 daily catch quota increase met with approval, 2/d (only 1>50cm) implemented
  - Release rate 44% in 2018-19



Action Update:
Predator Management– Bull Trout

- Action – Recreational Fishery Regulations
- Duncan River
  - Harvest opportunities: 2/d any size (October 5, 2018)
  - Creel survey: June 15– Sept 3, 2019
    - 603 fish caught, 274 harvested (45% retention)
    - No quantitative expansion method for remainder of year, but likely double the harvest (anecdotal evidence for good early spring and fall fishery)

- Action – Directed Reductions
- Duncan Dam
  - 2018 Directed removals
  - 55 from the tailrace
- Duncan River
  - Angling June 15– Sept 3, 2019
  - 104 harvested

Action Update:
Predator Management– Bull Trout

- Action: Directed Reductions

- Kaslo River
  - 2018 kelt fence
  - 257 caught, 171 removed
- Hamill Creek
  - 2018 kelt fence
  - 243 caught, 172 removed
- Kaslo River
  - 2019 kelt fence
  - 235 caught, 173 removed

Action Update:
Predator Conservation

- Gerrards
  - Action – reduce exploitation though regulations;
  - Trigger<50-100 spawners; ***action not triggered***
  - Hatchery Supplementation "Gene Banking"
  - Trigger – <50-100 spawners in two consecutive years; ***action not triggered***

- Bull Trout
  - Action – reduce exploitation though regulations;
  - Trigger – escapement < 50/500 spawners in Kaslo River and lake-wide index respectively; ***action not triggered***

Key Questions

Key Questions

- Should nutrient additions to KL be reduced or remain status quo while KO numbers are low?
- Given the 2020 kokanee escapement and egg supply estimates, should we collect and stock eggs?
- Would further piscivore reduction actions accelerate kokanee recovery?
- Should we consider monitoring/reducing pikeminnow populations?

Is fertilization necessary during collapsed state?

- FWCP Board requested this group to provide advice/recommendation on the benefits of continuing fertilization while KO collapsed.

"Should nutrient additions be reduced or remain status quo while kokanee numbers are low?"

FWCP
Fish & Wildlife
COMPENSATION PROGRAM

Columbia Region
601 – 18th Street
Castlegar, B.C. V1N 2N1
Crystal Klym, Columbia Region Manager
crystal.klym@bchydro.com
250-365-4591 fwcp.ca

October 8, 2019

Kootenay Lake Action Team

RE: FWCP Columbia Board requests a response from the Kootenay Lake Action Team regarding volume of nutrient additions

To whom it may concern;

On behalf of the Fish & Wildlife Compensation Program (FWCP) Columbia Region Board, I request a response from the Kootenay Lake Action Team regarding rationale for continued nutrient additions to Kootenay Lake at historic volumes despite low Kokanee spawner returns.

Over the past four years (2015-2018), Kootenay Lake Kokanee spawner returns have ranged from 12,000 to 40,500 which is a dramatic decline from previous spawner returns in Kootenay Lake. During the pre-nutrient restoration era (pre 1992), spawners ranged from 277,000 to 2 million kokanee (total of Meadow Creek Spawning Channel, Meadow Creek and the Lardeau River). The number of spawners ranged from 147,000 (2014 returns) to 2.2 million during the nutrient restoration program era (pre 2015). **Given this decline in spawner returns, should nutrient additions to Kootenay Lake be reduced or remain status quo while Kokanee numbers are low?**

In 2019, the Kootenay Lake Nutrient Restoration project budget totaled $1.1 million, representing approx. 17% of the overall Board approved project budget of $5.8 million. As the Kootenay Lake Action Team is likely aware, the FWCP Columbia Region Board has a several cost pressures when selecting projects for implementation each year. The Board always wants to ensure that FWCP funding contributions are being utilized in the most effective manner across priority conservation, enhancement and restoration projects that align with our Action Plans.

Please provide a response following the Action Team's fall 2019 meeting, which I understand is tentatively scheduled for late-November 2019.

Thank you and please contact me with any questions or to discuss this request further.

Warm regards,

Crystal Klym, P.Ag.
FWCP Columbia Region Manager
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From previous KLAT meetings

- Consensus to continue adding nutrients (primary discussion in Kelowna 2016 meeting), and given high priority as a continued action for KO recovery in Action Plan.

Key recommendations from KLFAT limnology experts:

a) Continue to ensure N:P ratios are optimized for nutrient balance and carbon transfer to zooplankton

b) Increase or decrease P and N loading to adapt to changing lake conditions, with the goal of always ensuring sufficient zooplankton are available to meet Kokanee demands

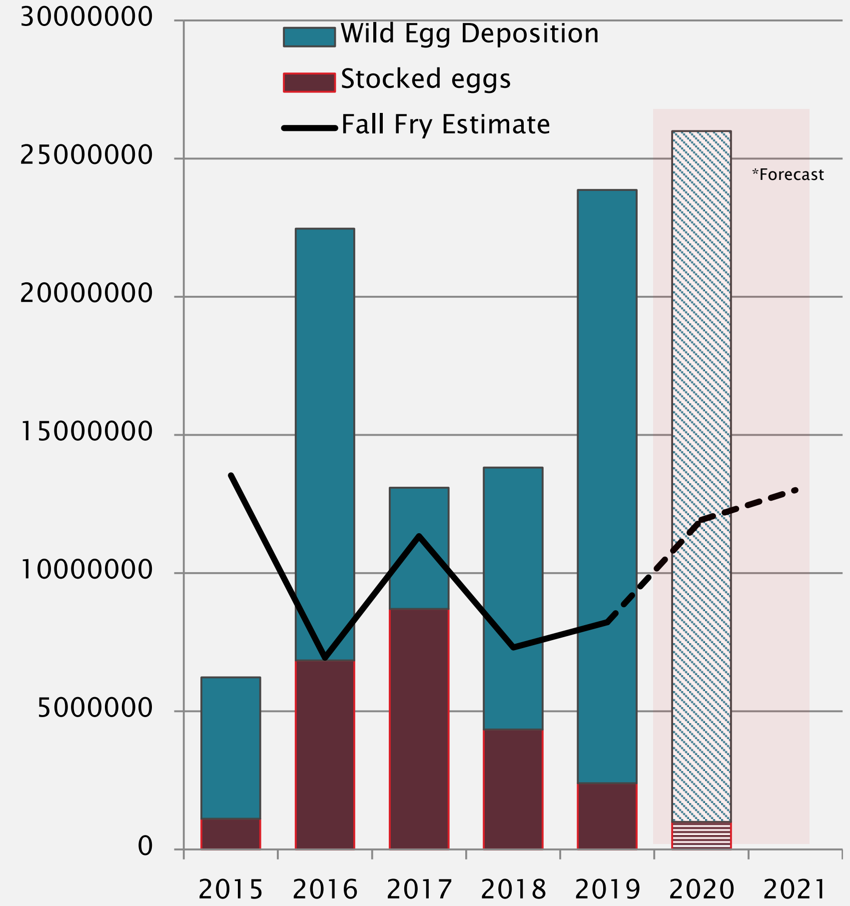
c) Continue to collaborate with colleagues to adaptively manage the nutrient addition program to changing lake conditions, and report annually on the nutrient addition program.

What is the scientific advice behind continuing nutrient additions?

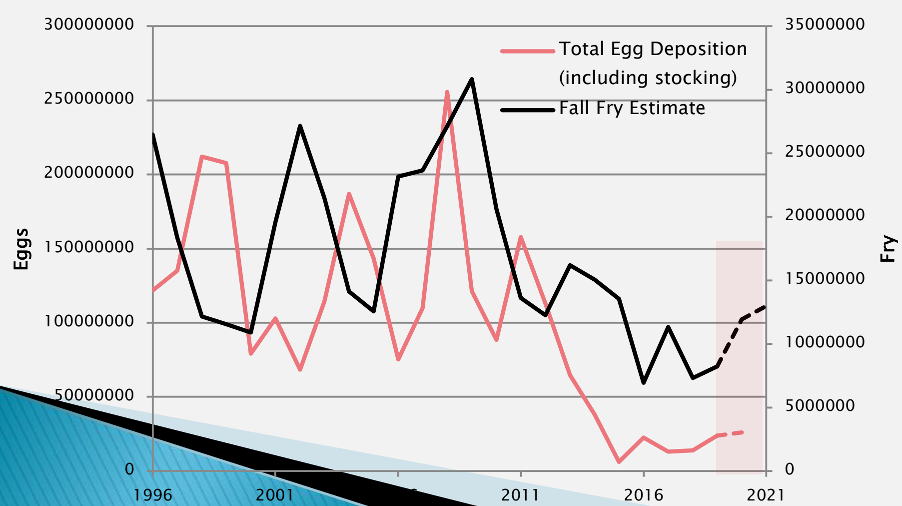
- Gives KO the best survival advantage possible (in-lake survival bottleneck)
- Good growing conditions for KO support foundation for recovery, i.e. larger size spawners and increase in fecundity
- May be especially important given evidence for altered foraging behaviour of collapsed KO population
  - Poor condition/size and survival to 1+ despite having excellent growing conditions
  - Implies surviving KO are behaviourally risk-averse to avoid predation
  - Higher food density may allow survival to be maximized under risk averse foraging strategy
- Allows maximizing growth/survival during recovery “breakout” (our monitoring would catch this phase too late)
- Current increasing Kokanee biomass ~ double that of 2018, improving abundance and supply (100K spawners and ~12 million fall fry forecast for 2020); food demand will increase through recovery

Is there benefit to 2020 egg collection and stocking?

- Previous stocking efforts maintained building blocks for recovery (fall fry 6–12 million)
- 10–66% of egg deposition from stocking
- Without stocking, fall fry likely to be ~11–12 million in the next two years
- 2020 stocked egg supply likely ~1 million (<5% of estimated wild deposition) sources – Kinbasket(?), Whatshan (800K), Hill Creek (200K)



*Forecast assumptions:
- egg to fall fry similar to previous 5 year mean (~50%)
- 2020 spawners 100K (50% F) and fecundity ~500



Should we continue to reduce piscivore populations?

- Bioenergetics modelling as a tool to evaluate past and future actions

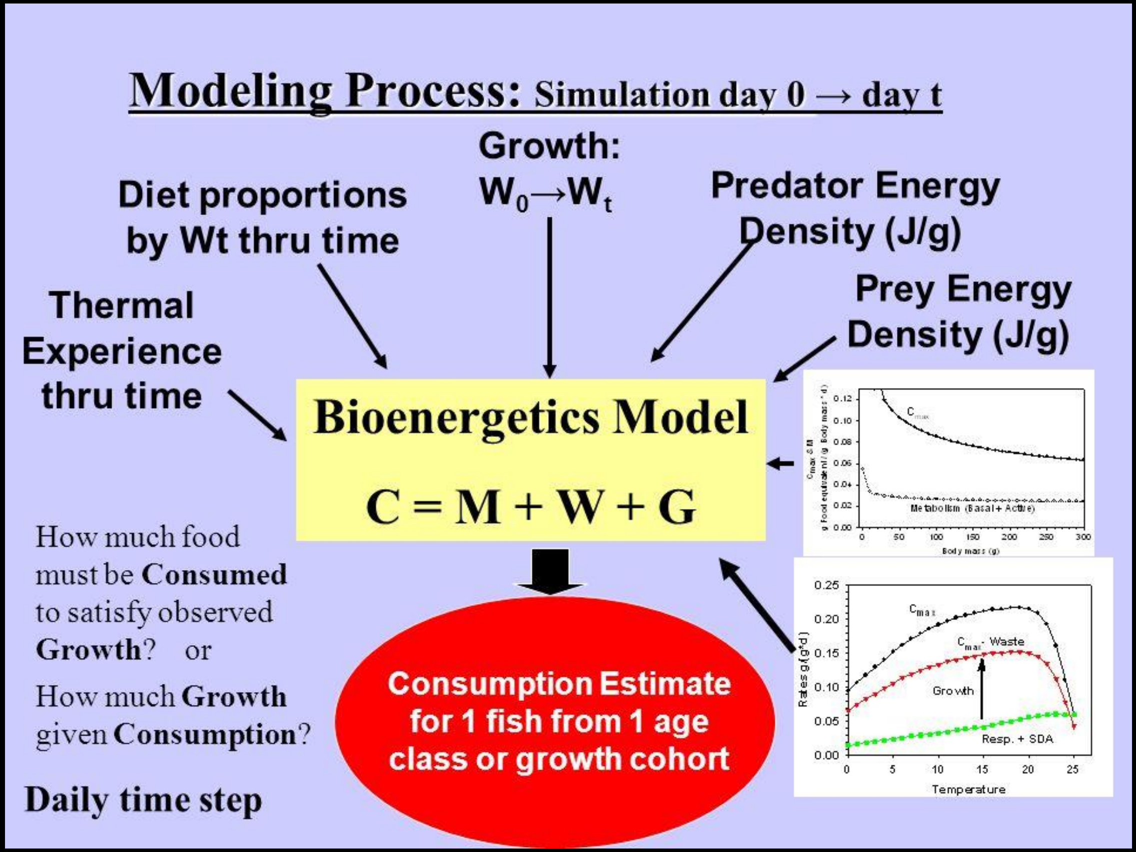
Bioenergetics model for Kootenay Lake

Rationale

- Earlier estimates of consumption were based on simple methods that didn't account for species-specific metabolic information or predator growth. Bioenergetics models can incorporate much more information.
- Bioenergetics models can be used to test multiple hypotheses and are useful tools for investigating predator-prey dynamics and informing management decisions
- Widespread use in western US reservoirs and work well for assessing predator-prey interactions of salmonids in pelagic foodwebs.
- Can help quantify the effect of past or future piscivore management actions.

How it works – Wisconsin bioenergetics model for predator consumption

- Model is information intensive.
- Calculates how much consumption required to satisfy growth from XXg to XXg
- Growth interval usually for an age class, referred to as a cohort
- Calculation is for an individual fish within the cohort



C = consumption
M = metabolism
W = waste
G = growth

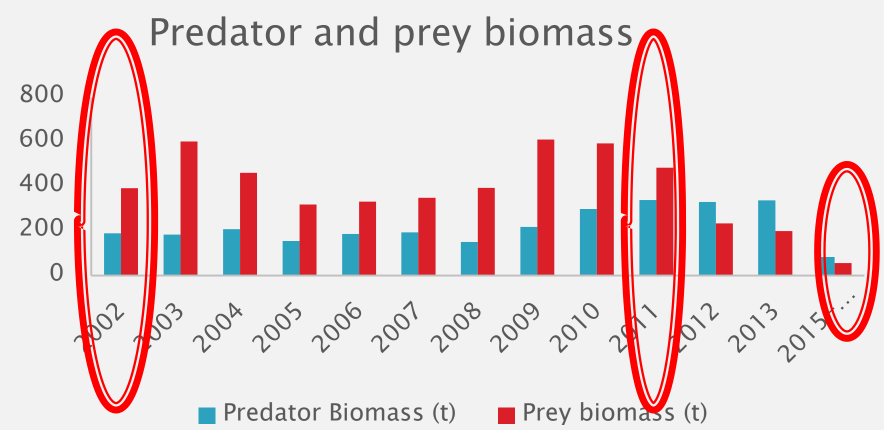
Slide Credit: Schoen and Beauchamp

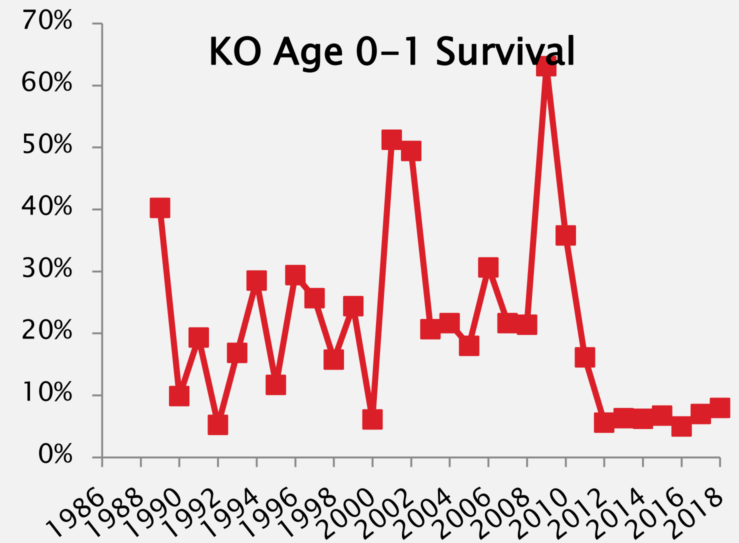
Consumption estimate for each fish – translating to population

- Model annual consumption for the entire cohort (age class) on a daily timestep for whole population by factoring in three values/parameters:
  - Population abundance on Day 1 (April 1)
  - Mortality
    - Fishing (seasonal)
    - Natural
  - Body weight loss from spawning
- Sum cumulative consumption for entire year for cohort
- Sum consumption for all cohorts to arrive at species estimate.
- Once consumption is estimated, it can be compared to estimates of prey supply

Developing the model for Kootenay Lake: Modeled years and species

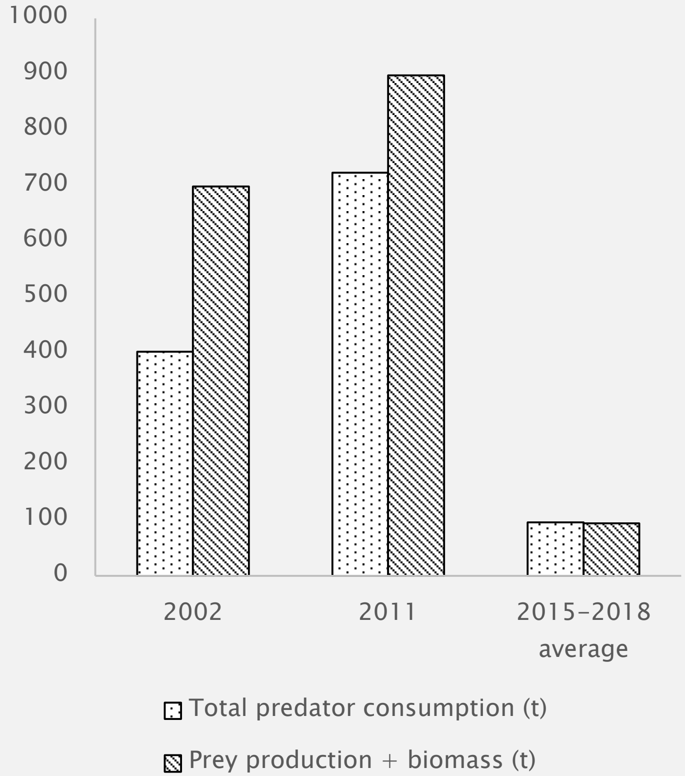
- 2002, 2011 and post-collapse period (2015+)
- Rainbow trout and Bull trout
- 2002 is probably a good representative year for pre-collapse stable-state
- 2011 is an excellent year to model – the “cusp” of collapse, and represents the first year where consumption should have begun to be unsustainable. i.e., predation inertia resulted in 2012 survival/biomass.
- 2011 also has excellent piscivore population data available to inform model (creel, exploitation study, rainbow/bull population estimate).
- “Collapse years” of 2012-2014 cannot be modeled as reliably due to drastically changing population parameters (Thorley and Andrusak 2017).
- 2015+ years rely on some assumptions of predator abundance (mort assumptions + Lardeau 1+ count), but generally good data collected on diet, growth, etc..





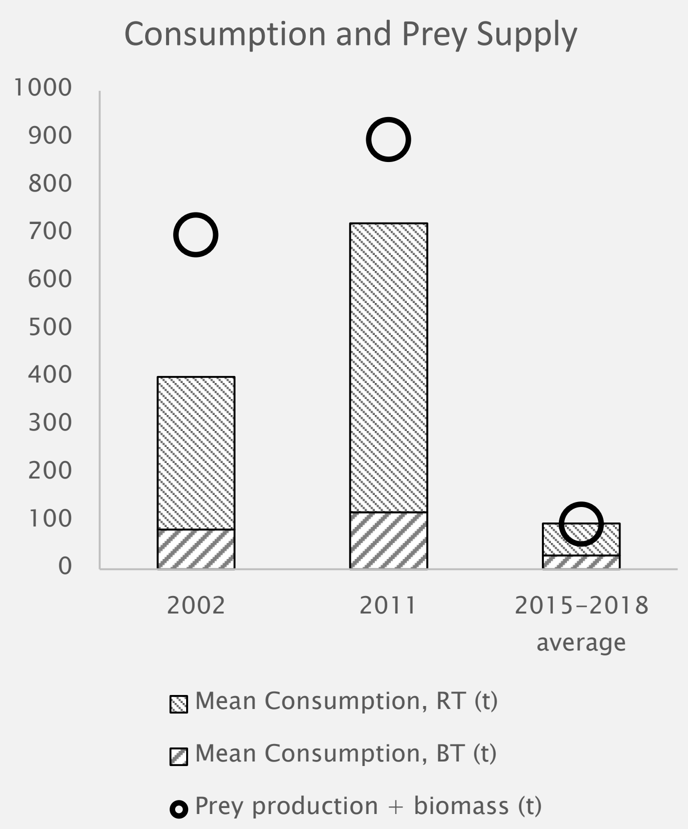
Results: Take home message 1 – support for initial collapse mechanism and sustained source of depensation in kokanee

- Initial collapse mechanism of predation is supported by bioenergetics model results. Predators consume >80% of supply in 2011 and post-collapse years, but <60% in pre-collapse state.
- 2011 consumption estimates greatly exceeded fall standing biomass and nearly exceeded annual biomass + production estimate (production estimated by method of Downing and Plante (1993), and added to standing biomass estimates *sensu* a similar study in Johnson and Martinez (2002))
- This would have resulted in little surplus biomass for 2012, as nearly ½ of the standing fall biomass estimate are spawners that have escaped predation, and likely explains the collapse of in-lake survival seen in 2011-2012.
- Results (consumption vs prey supply) for 2011 and 2015-2018 were similar to Lake Trout predation estimates of Kokanee interpreted to be unsustainable in Colorado Reservoirs by Johnson and Martinez (2000).
- The predator population had good initial food availability in 2011, but would have carried incredibly high predation inertia into the immediately subsequent collapse period.
- The post-collapse years modeled suggests that predation still outstrips prey supply.



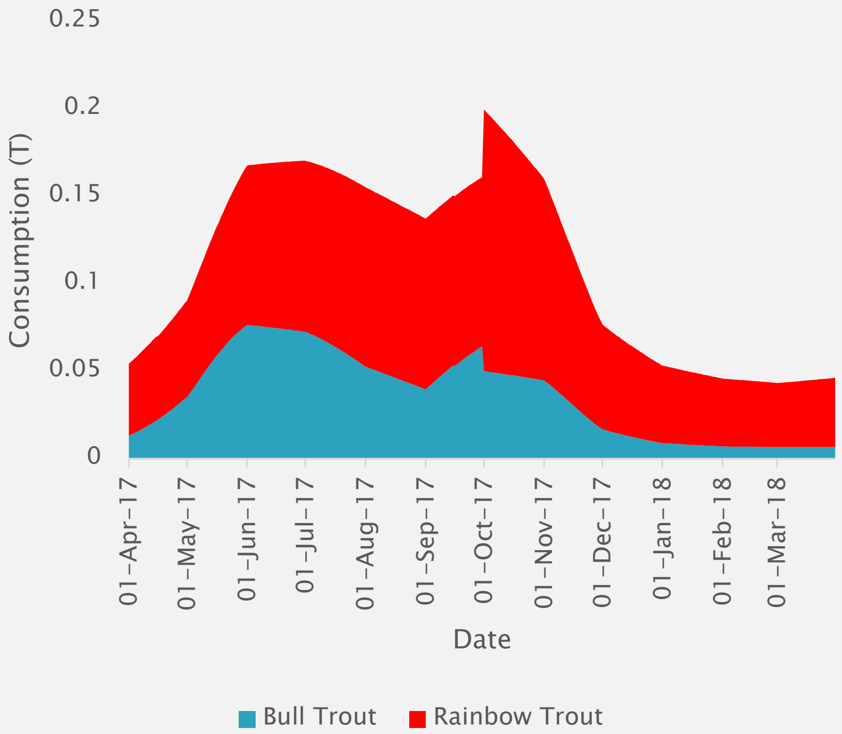
Take home message 2 – Rainbow were the main driver of collapse (with support from bull trout)

- Rainbow population level predation pressure is much higher than bull trout in pre-collapse state, and especially in 2011, when consumption was ~6X higher.
- Despite being less piscivorous, rainbow consumption is higher than bull trout consumption for the following reasons:
  - Mostly because in-lake abundance is estimated to be much higher for rainbow, in all years.
  - Rainbow trout have more expensive “machinery” and occupy warmer temperatures – their higher metabolism means their conversion of calories to growth is less efficient (this also explains why they are far more exciting to fight on a rod). In other words, Rainbows are less fuel efficient.
  - Rainbow von Bertalanffy parameters in the pre-collapse period were estimated to have higher growth (k).
- In post-collapse period, rainbow consumption still outpaces bull trout consumption, but the gap has narrowed to about 2X. This is reflective of the revised model inputs:
  - Rainbows switched to supplementary prey, BT did not, and rely exclusively on KO.
  - Gerrard growth has been estimated to be more severely curtailed than BT (more severe reduction in Linf in particular)



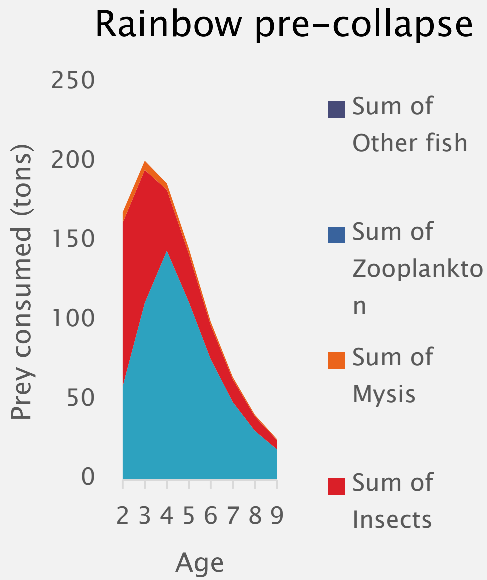
Take home message 3 – Winter is not the bottleneck

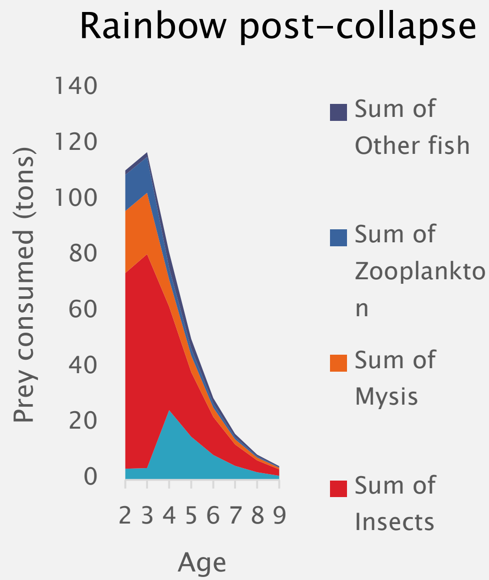
- Estimates of consumption are modeled on a daily timestep.
- In post-collapse period, warmer months are the sources of greatest consumption.
- Fall consumption is intense and continues into November.
- Winter months (Dec– Apr) have ~1/3 the total consumption of warmer months.

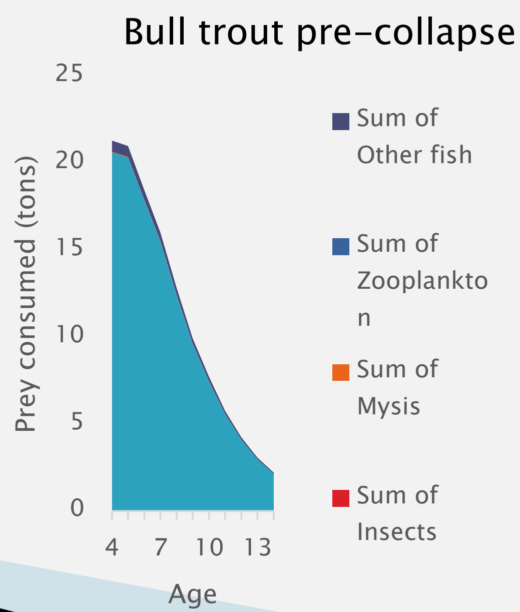


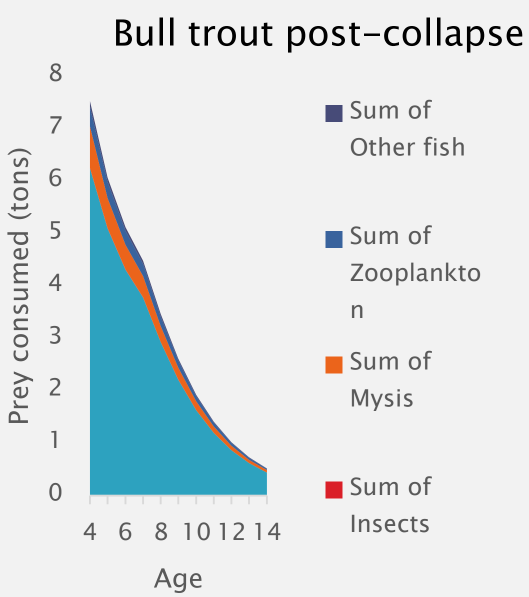
Take home message 4 – new recruits to piscivory drive kokanee consumption

- Even though young fish eat less per capita, they are assumed to be far more abundant, thus drive overall predation.
- Bull trout are highly piscivorous and dependent on KO regardless of age, in either pre or post collapse periods
- Management actions on older spawners will do little to reduce consumption
- Although removing spawner age classes is the biggest bang for the buck <u>individually</u>, they are not as abundant and thus management actions on them will always be less effective overall.
- If new recruits to piscivory could be reduced significantly, this would drive down consumption



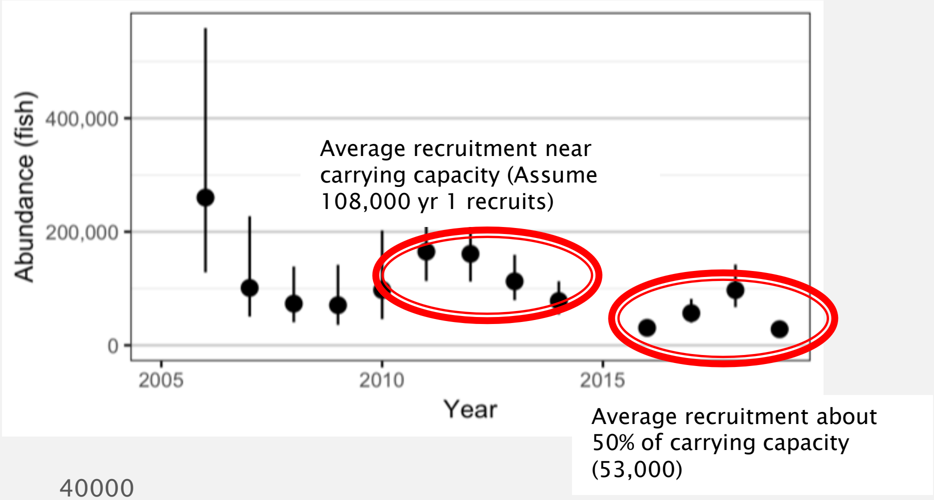


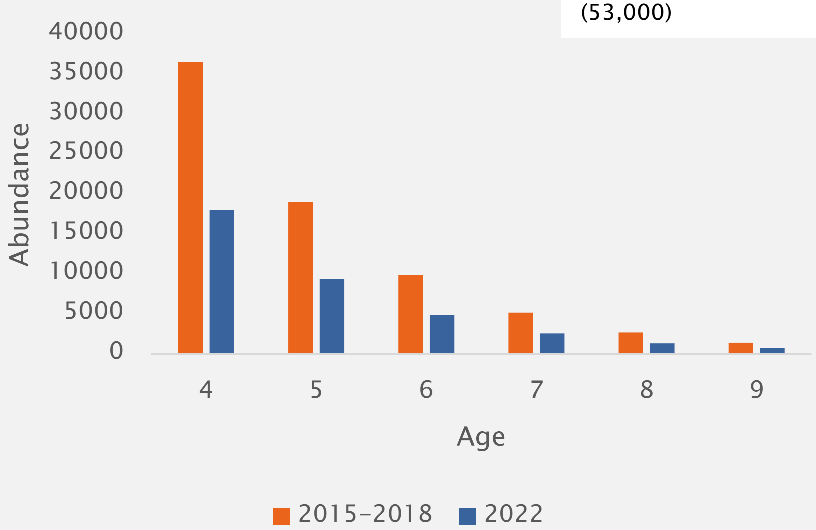




Take- home message 5: Recovery from 2019-2022?

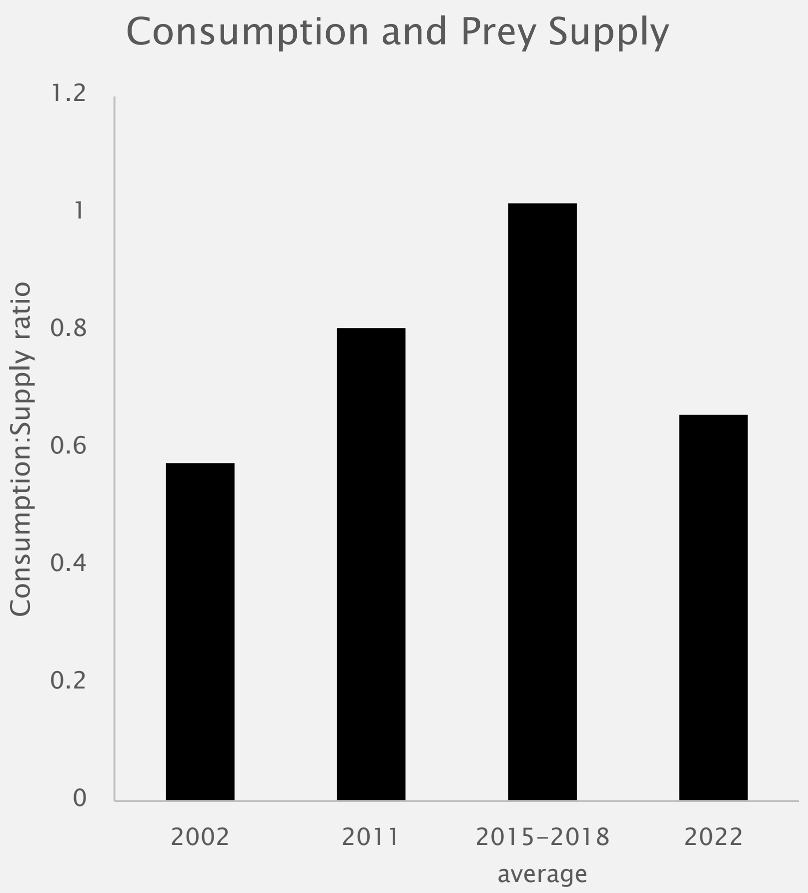
- Rainbow recruit to piscivory at ~ age 4
- Age 4 and older Rainbow consumption in 2015-2018 sources to 1+ recruits from the Lardeau in 2015 and earlier (left circle on graph), when supply of recruits was high.
- Lardeau age 1 counts declined to an average of ~50% of carrying capacity from 2016-2019
- If we assume density independence in rainbow mortality after the age 1+ count, then we can expect much less supply of rainbow recruiting to piscivory from 2019 onwards. Thus the adult population of age 4-8 may even out to ~50% of 2015-2018 abundance by 2022 (age structured abundance graph at right)
- This could result in a sustained relief in abundance of fish recruiting to piscivory over the next few years.
- Let's model it!





Forecasting recovery?

- Population estimates for Rainbow Trout from 2016-2019 recruitment were applied to model, using all the same inputs as the 2015-2018 model.
- Consumption declines by 34T, or 35% of overall consumption by 2022. This is a far larger effect than currently contemplated piscivore removal actions.
- Consumption is predicted to return to a sustainable ratio of supply (near 2002 levels), if supply remains at post-collapse levels.
- However, this is overly simplistic and not a guarantee of recovery. Both KO and predators will compensate. Rainbow are clearly not satiated by KO. If Rainbow Trout compensate with higher growth/KO diet proportions (upper modeled estimate) perhaps consumption would match increases in supply, preventing recovery. This cannot be modeled without strong assumptions.



Summary

- Bioenergetics model provides support for predation collapse mechanism and sustained depensation of KO. Predator consumption exceeded estimates of standing fall KO biomass in all years, but predators also consumed almost all the production in 2011 and in recent post-collapse years.
- Collapse was driven by Rainbows, not bull trout. Rainbow total consumption was ~6X higher than BT in initial collapse year. Rainbows outpace BT in post-collapse period, but the gap has likely narrowed greatly to ~2X the consumption.
- Population consumption is highest through warm temperature months – winter is not the bottleneck despite higher piscivory.

Summary (continued)

- Early age classes of predators recruited to piscivory exert the highest predation pressure. Management actions that target older, spawning age classes are unlikely to have large overall effects.
- The age-structured consumption estimates may give us clues of an upcoming recovery starting in ~2019-2022 due to declines in Lardeau 1+ output, though this is based on strong population assumptions and depends on the dynamic interaction of how predator and prey respond to predator declines.

Is recovery occurring right now?

Evidence for

- KO 1-2 survival has recovered for multiple years
- KO spawner abundance target/trigger for recovery actions will likely be met next year (hydroacoustics forecasts)
- KO recruits of spawner/spawner rebounded in 2019
- The estimated Predator/Prey biomass ratio for 2019 returned to near pre-collapse levels
- Predator abundance will likely continue to decline until at least 2022, as gerrard recruitment suffered, with low 1+ counts from 2015-2018. Bioenergetics model predicts a balanced supply/consumption ratio in 2022 if all else remains the same (predator growth and KO supply remain static).

Evidence against/uncertainty

- Gerrards and BT are not satiated. Growth of both and diet proportions of gerrards can increase almost instantaneously with prey supply.
- Age 1-2 KO survival likely rebounded because predators are now smaller (gape limited). If prey supply increases, growth of predators may increase, which in turn could <u>decrease</u> 1-2 survival again.
- Kokanee growth may decline due to density dependence, making them more vulnerable for a longer portion of their life due to being in the gape limit of predators longer
- Early indications are that gerrard spawner abundance/egg deposition is increasing, likely due to better in-lake growing conditions. This will likely result in rebounding abundance of new piscivore recruits in ~2023+
- There are no overt indications of BT recruitment effects, as a result of collapse or management actions
- KO 0-1 survival has not yet rebounded. This is our strongest indicator/trigger.

Quantifying piscivore management actions

- What has been the relative effect of prior management actions to remove piscivores on overall consumption?

- What further piscivore reduction actions may accelerate kokanee recovery?

  - Rainbow Trout
  - Bull Trout
  - If yes, what number and which method/size/age/stage?
  - Pikeminnow

Methodology

- Management actions can be expressed as an estimate # of piscivores, by age class
- Bioenergetics model results can be used to estimate the net effect of piscivore management on lake-wide consumption
- Compare actions, to inform recommendations.

Past and ongoing actions; Angler harvest change

Kootenay Lake – Angler outreach (ministry and others); Regulation Changes

- Effect of in-lake regulations changes and angler behaviour (increasing harvest rates)
- Effect of annual in-lake harvest rate increase between long-term pre-collapse (2000-2014; 39% RB, 46% BT) and recent post-collapse (2017-2019; 53% RB, 54% BT) period
- Adjusted downward by 50% to account for KLRT bias of over-reporting catch and harvest results in 264 BT and 1080 RT (annual average) that otherwise would have not been removed.

Duncan River

- Duncan fishery opening removed at least 274 BT; assume same age distribution as fences (i.e., pre-spawners), as size distribution is similar to fence data. Action does not affect rainbow.

Combined, we can expect that the 2019 effect of these actions resulted in 538 BT and 1080 RT that would have otherwise not been removed if not action had taken place.

Past and ongoing actions; Ministry Removals

- 2018-2019 Fences (includes 55 directed removals from Duncan in 2018 as well)
  - Average of 284 spawner age classes of BT removed per year
  - Action did not affect Rainbow

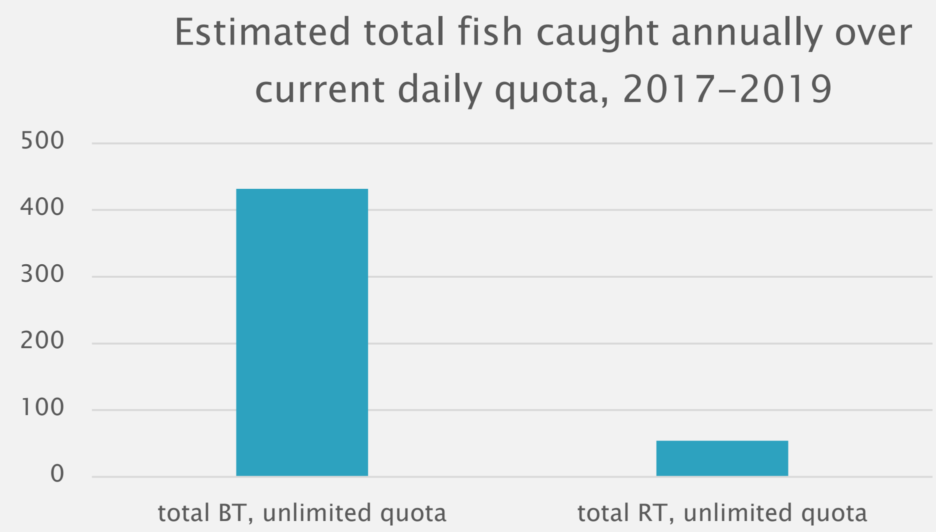
- Contracted removals
  - Includes the average (2015-2018) capture/retention of fish caught by Kerry Reed under contract with scientific collection permit, plus the Duncan Creel crew removal of 104 BT for 2019.
  - Combined, the annual effect of these two contracts is 185 RT and 176 BT removed.

Potential future actions with immediate benefit

- Further increase in quota
- Barbed hook
- Angling incentive

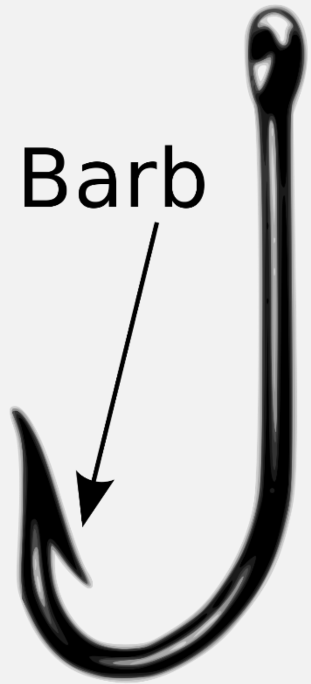
Are current in-lake quotas limiting?

- Used detailed data from guide catch 2015-2018 to determine if guides catch more / day than the current quotas (RB = 5/d, BT = 2/d)
- Guides with a "license to kill" catch more than quotas on average per day, but misleading (high rod effort ~42 hrs/d, high expertise)
- Adjusted daily guide catch to standardize with (bias adjusted) average daily angler catch from KLRT (adjust to average KLRT and 2011 creel effort distribution of rod hrs/d; CPUE differences)
- Analysis suggests that quotas could indeed be limiting for some BT harvest (~10-15% of total catch is 3rd + BT to the boat in the day per angler), but unlikely for RB (fig below)
  - But, not all anglers will keep to quota. In the 2011 creel only 23% of anglers kept bull trout to their quota (then, only 1)
  - Retention of 3rd+ BT can't be higher than current overall KLRT retention rate (54% in 2017-2019)
  - Effect of unlimited quota estimated to be 166 BT (average retention between two above values)



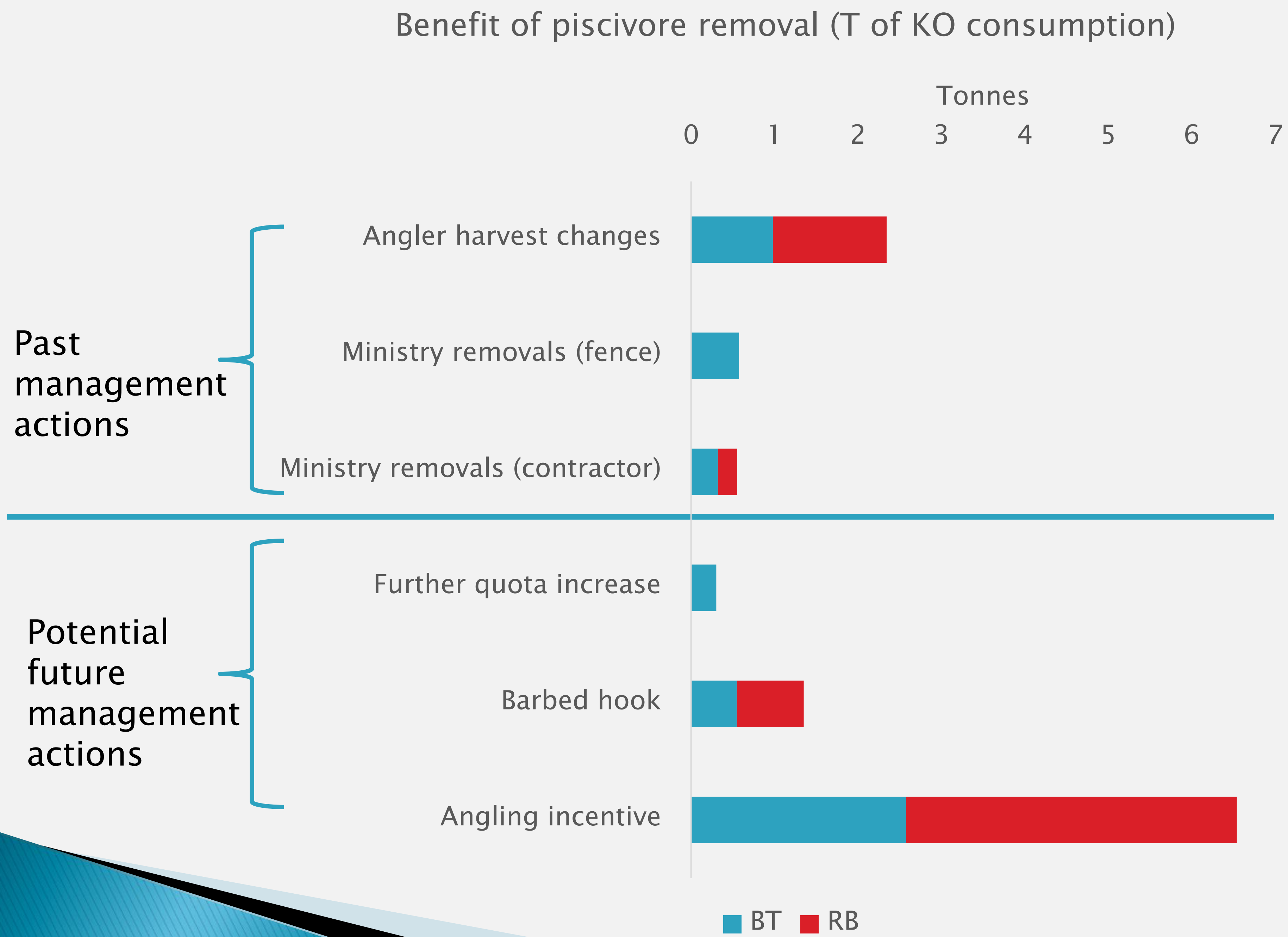
Barbed hooks

- Literature review suggests that barbed hooks result in higher capture efficiency (median reported ~15% based on Schaeffer and Hoffman 2002; Dubois and Dubielzig 2004; Meka 2004)
- Mortality effects of barbed hooks are widely variable/controversial in literature, but modern consensus seems to be that they may cause some low level of additional mortality (~2%)
- Applied to the recent (2017-2019) average, adjusted KLRT bias, we can expect 535 more BT and 1158 more RB to boats with barbed hooks.
- Assuming the same overall retention rate as the 2017-2019 average +2% additional mortality to overall catch, the estimated additional harvest will be 300 BT and 637 RB.



Angler incentive

- Assume that a strategy could be found to result in 90% retention
  - Assumed combined with quota lift for BT
- Assume that incentive is sufficient to attract a modest (10%) increase in effort.
- Assume no density dependence in angler catch
- Estimated effect of additional 1413 BT and 3141 RB harvested @ 2017-2019 catch rates.
- Estimates would be even higher if combined with barbed hook.

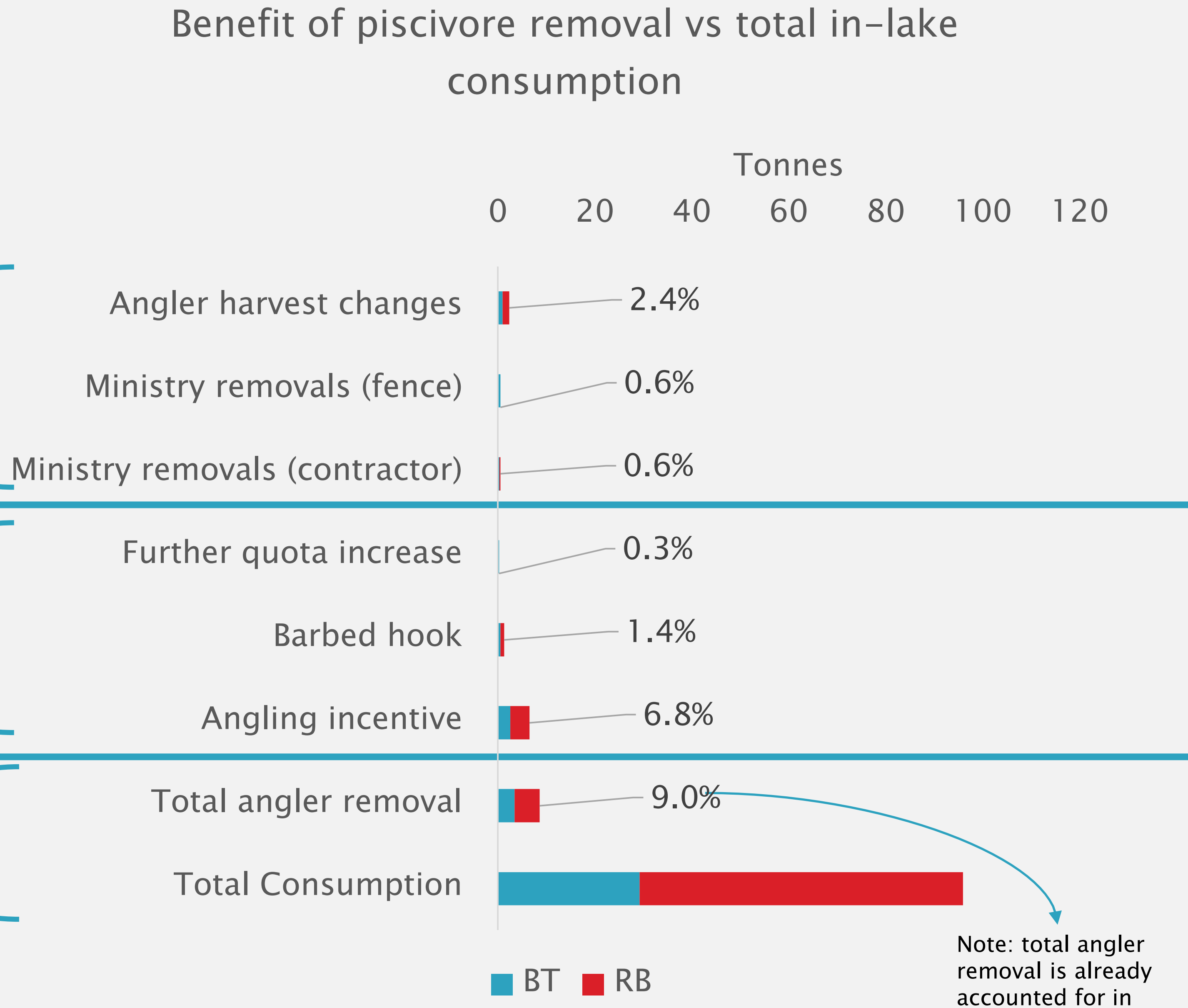


Benefit of piscivore removal (T of KO consumption)
Tonnes
0
1
2
3
4
5
6
7
Past management actions
Angler harvest changes
Ministry removals (fence)
Ministry removals (contractor)
Potential future management actions
Further quota increase
Barbed hook
Angling incentive
BT
RB

Past management actions

Potential future management actions

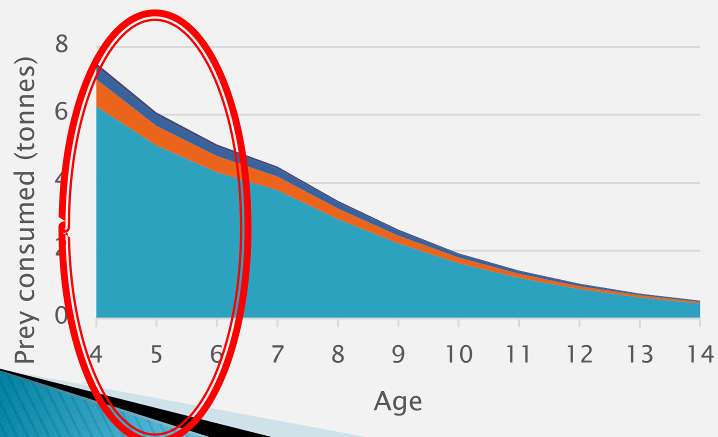
Current level of overall angler harvest and piscivore consumption

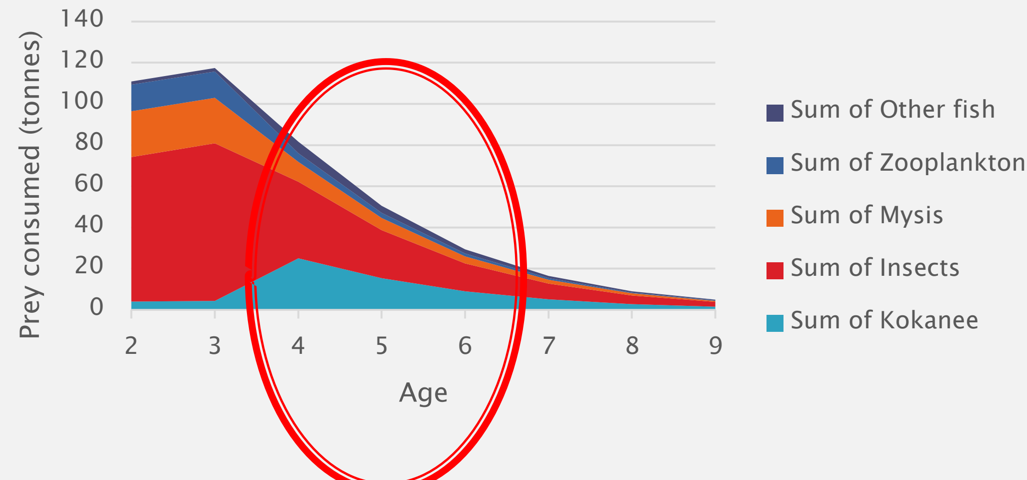


Note: total angler removal is already accounted for in total consumption estimate (assumption of 9–14% fishing mortality)

Actions on recruitment

- Stock productivity of BT and Gerrards is high (G. Andrusak studies), thus unless drastic, actions on in-lake piscivores are always limited by the effects of new recruits to piscivory (ages 4, 5 6), which are less catchable and account for the majority of consumption.
- Theoretically, another way to reduce piscivory is to drive recruitment down and wait 3-4 years.





Recruitment actions

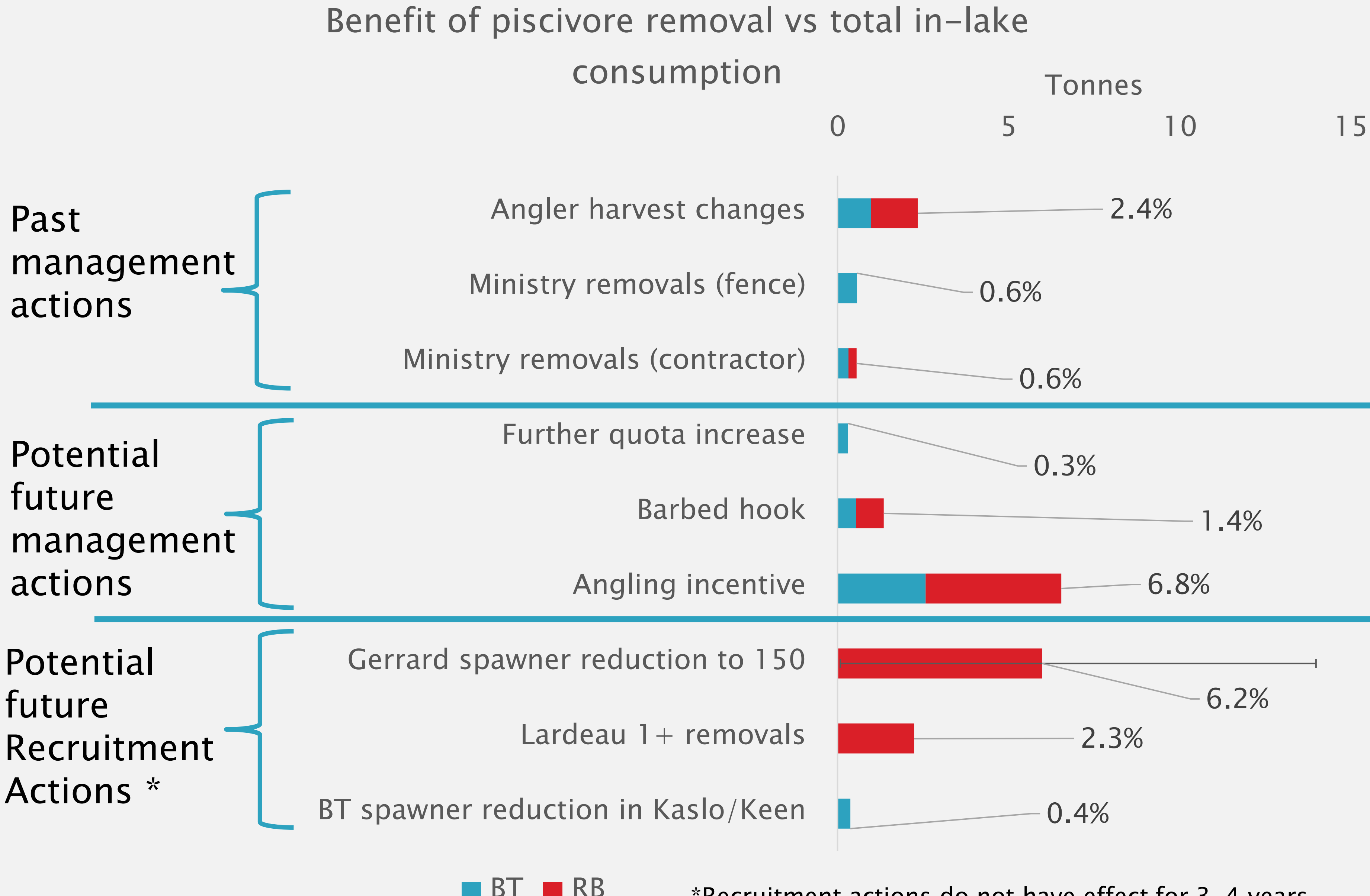
- Actions presented as 1-year implementation. Could occur for multiple, successive years for results to be cumulative, but would have diminishing returns each subsequent year due to natural and fishing mortality.

- Reduction in Gerrard spawners to 150 fish, or 75 females (50 above conservation threshold)
  - Requires forecast of spawners to determine effect. Assume 3 run size forecasts: 150, 400 (~LRP; 2019 run size) and >1000 (saturated) @ current post-collapse average of 1391g/spawner (~2000 egg/female).
  - 2024 overall piscivore effect of 0, 6.2% and 14.8% for spawner run sizes of 150, 400 and >1000, respectively

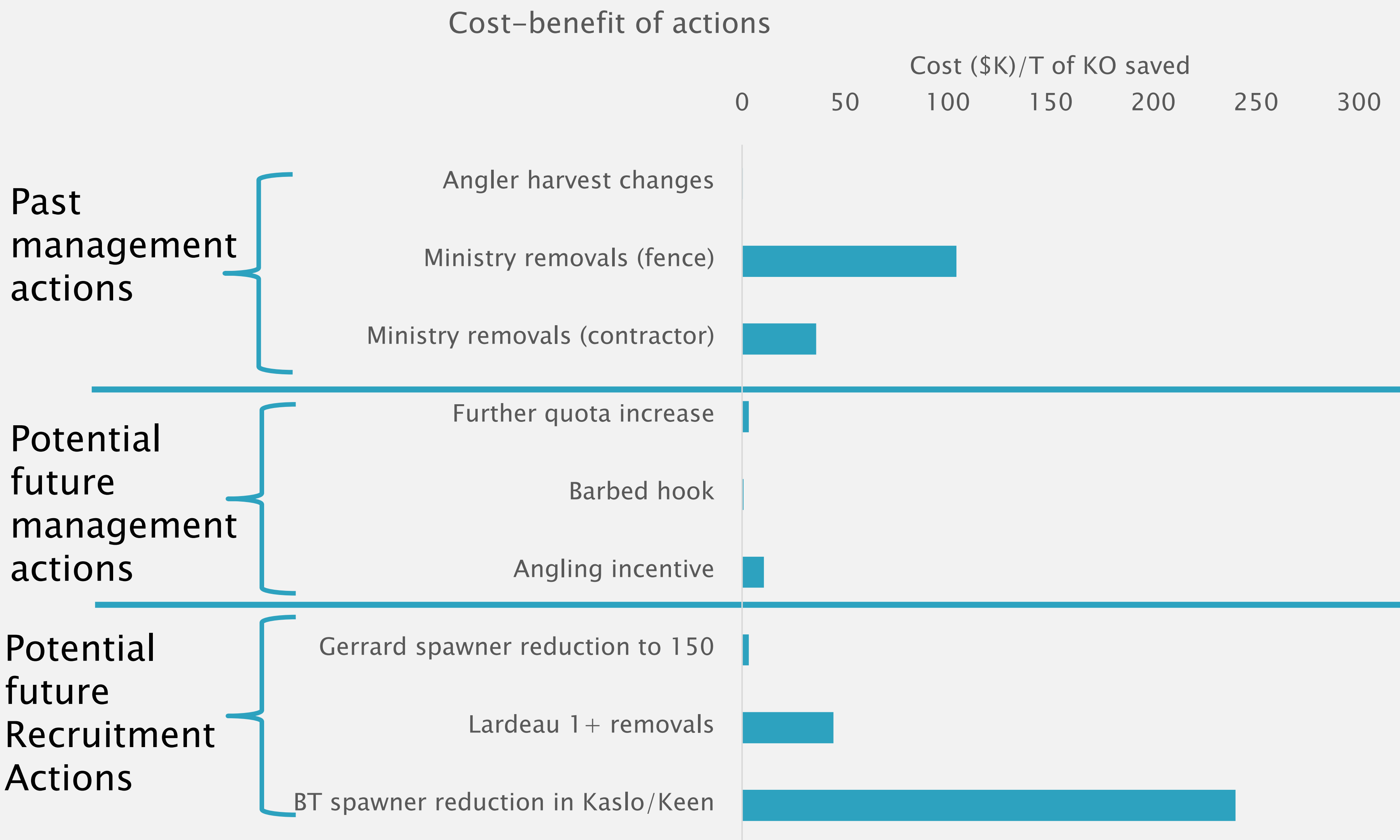
Recruitment actions (continued)

- Reduce juvenile Lardeau trout by capture through screw trap/efishing (10,000 age 1's)
  - Assume Lardeau is otherwise at carrying capacity (i.e., estimate is a max effect)
  - 2023 overall piscivore effect of 2%

- Reduce bull trout spawner abundance to result in 1.5 redds per km in 2 of the most abundant spawning streams (Keen – 10 spawners, or ~22 fish; Kaslo – 43 redds or ~95 spawners; ~50 above conservation genetics threshold)
  - Reduces to ~15-30% of Age-1 carrying capacity in the S-R relationship from Andrusak 2018
  - Max effect will be 6% reduction in lake-wide age-1 carrying capacity: estimate from S-R curves, applied to the age-4 year class abundance estimate 4-years hence, adjusted to Kaslo/Keen @ 20% juvenile rearing area for lake (data from various redd count reports of accessible trib length)
  - 2024 overall piscivore effect of 0.4%
  - Assumes carrying capacity is reached if action not implemented (i.e., estimate is a max effect)



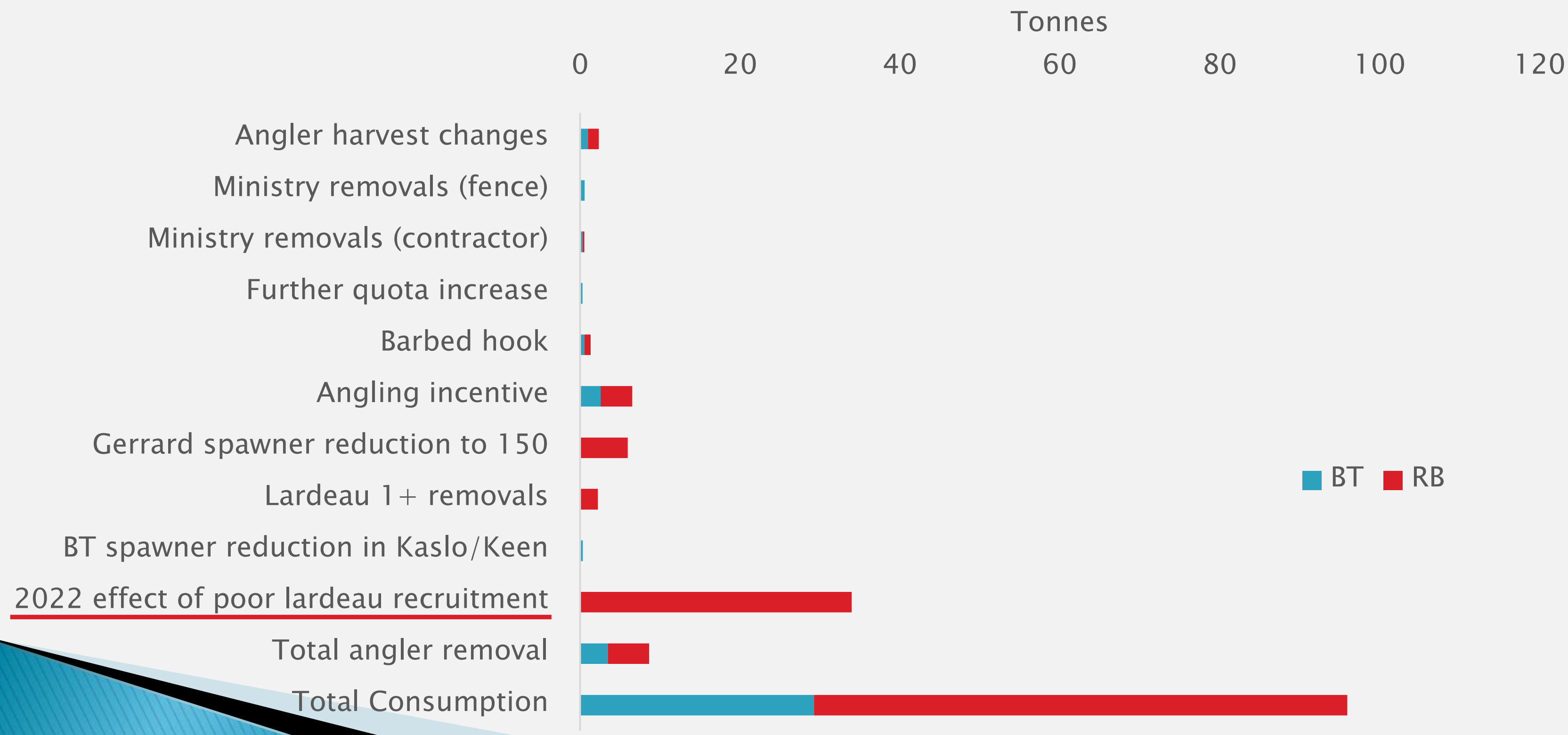
*Recruitment actions do not have effect for 3-4 years,
*Gerrard spawner reduction has error bars to depict the effect, relative to what the actual 2020 run size is.
* 1+ removals and BT spawner reduction assume carrying capacity (i.e., an estimate of max effect).



- Cost of each action estimated based on some assumptions of methodology or experience with recent actions.
- “Free” actions (reg changes, quotas) assigned 1000$

Natural experiment running in-lake now on recruitment

- 2022 model-estimated effect of reduced recruitment of Gerrards from 2016-2019, predicted to be 35% of overall consumption (from prior slides on bioenergetics model)
- This dwarfs any 1-year management action proposed.



Feasibility and risks of continuing prior management actions

1) Current quotas and Duncan fishery opening –medium benefit, $
   - likely >600 bull trout harvested annually (274 in two month creel)
   - Modeling shows small reduction in future kokanee biomass consumption
   - Potential for reduced recruitment and future catch rate in fishery (risk or benefit depending on future state)

2) BT Kelt fences– low benefit, $$$
   - Long-term removal of all older (spawner) age classes; diminishing returns as its already been done two years on the streams where logistically feasible.
   - Reduced recruitment and future catch rate in fishery (risk or benefit depending on future state)
   - Poor cost-benefit

3) Contracted removals –low benefit, $$
   - Low Risk – proportionally small increase in angler effort
   - Day rates high, relative to catch
   - Poor cost-benefit; however, is currently our primary source of information for piscivore monitoring
     - Age
     - Standardized effort
     - Size distribution
     - Biological samples (genetics, diet)

$ = 1-10K/t removed
$$ = 10-50K/t removed
$$$ = 50-500K/t removed

Feasibility and risks of immediate actions

1) Lake Quota increase – low benefit, $

- Limited reduction in kokanee biomass consumption
- Low risk given multiple age classes in harvest small numerical impact

2) Barbed hook – medium benefit, $

- Previous risks to implementation were around Gerrard conservation triggers in action plan (2016-2019 escapement 150-250 spawners)
- Given 2019 spawners and survival trend, likely low risk to increased landing rate in the fishery (small risk to overshoot conservation thresholds)

3) Angler incentive – high benefit, $$

- Risk of potential to overshoot piscivore conservation thresholds (2015-2018 spawner abundance was low even though in-lake abundance was high; spawning during crash appears to be driven by growth rather than survival); especially in combination with other fishery actions
- Depending on the need (i.e. is additional reduction necessary for kokanee recovery) potential to delay recovery in angler days; esp if recruitment affected
- Outside agency support required - Province can not deliver a reward program
- Subject to consultation and strong rationale to SDM

Feasibility and risks of recruitment actions

1) Bull trout Kaslo/Keen spawner reduction – low benefit, $$$

- Risks:
  - Similar to Lardeau spawner reduction, but only in one population of many (so lower risk overall).
- Feasibility
  - Requires removal from spawning grounds or upstream fence; some feasibility concerns. Likely high cost/low benefit.

2) Lardeau juvenile reduction – medium benefit, $$

- Risks:
  - Knowledge of basic biology somewhat lacking (emigration timing; early in-lake survival.
- Feasibility
  - Rotary Screw Trap, E fishing, Seining, all likely high effort/costs to return high numbers.

Feasibility and risks of recruitment actions

3) Lardeau spawner reduction – high benefit, $$

- Risks:
  - Risk of overshooting: Significant recruitment action comes close to conservation thresholds; high stock productivity is both a blessing and a curse.
    - Although reduction numbers proposed are above conservation triggers, the egg deposition (147,000) is well below the Limit Reference Point (Thorley et al. 2019) of 387,000 eggs due to small size/fecundity of spawners.
    - Uncertainty is dangerous at low numbers (S-R uncertainty [2016, 17 + 18 similar egg supply and 25-100% 1+ production] logistical challenges of achieving reduction goal).
  - Evolutionary risk: Small numbers carries higher risk of permanent, non-reversible genetic effects on the population
    - Large size phenotype is likely genes + kokanee. Many or most hypotheses around the evolution of large size center on selection pressure for large size at Gerrard, on spawners both male and female. To maintain that selection pressure, it requires competition and death of "surplus." Removal of spawners removes the selection pressure and would be a risk for the ecotype and for the trophy fishery
    - There has been no genetic risk analysis (inbreeding risk or selection risk is unknown and unaddressed)

Feasibility and risks of recruitment actions continued

3) Lardeau spawner reduction – high benefit, $$
Risks:

- Public opposition risk:
  - Public support likely very low – difficult or almost impossible messaging
  - High potential for protest and conflict
- Fishery risk (if recovery is imminent)
  - Reduction in spawners reduces number of potential trophy trout (if they survive spawning) next 4 – 8 years
  - Lower recruitment will translate to lower future catch rates – Reduces attractiveness of Kootenay Lake to trophy anglers (> 20,000 angler days) reduces participation, reduces economic benefits to region, prolongs fishery recovery.
- Feasibility
  - Difficult to hit exact target; needs sound design since risk of overshooting is high. Angling? Seining, gill-netting adults? Redd destruction? Every method of removal requires knowing the run size in advance.

Other actions –enhanced piscivore monitoring and modeling

- Is enhanced monitoring necessary to continue?
  - Not necessary for recovery, but may be essential for understanding recovery, esp. *during* recovery.
  - Eg. Periodic BT redd counts; lake-wide index
    - Necessary for action plan trigger
  - Eg. Angling guide- sci collection permit
    - Age structure + diet composition
    - Maturation rate (% ripe) by ecotype
    - Fecundity
    - Age at entry to lake
    - Data used for bio-energetics modeling
  - Others?

Pikeminnow

- Is pikeminnow consumption a significant source of mortality for Kokanee?
  - Evidence against
    - Diet data – only 1 of 115 pikeminnow had kokanee in stomachs (study by Aaron McGregor)
    - RB and BT consumption sufficient to account for KO depensation (bioenergetics)
    - Spring to fall fry survival is not the bottleneck (i.e., theorized to overlap during fry stream emigration)
  - Evidence for
    - Nothing quantitative
    - Anecdotal reports of Pikeminnow summer catch in pelagic zone
- Primary data gaps:
  - Summer piscivore diets
  - Comprehensive pikeminnow sampling
    - Pikeminnow in Aaron's study included:
      - Bycatch from summer sturgeon sampling @ Kootenay R confluence.
      - Guide-caught samples from June, 2016
      - Pikeminnow derby on Sept 2, 2017

Table 6. Total number of predator fish with kokanee present, and mean fork length of those predators. Mean fork length and corrected weight of kokanee was recorded; unable to estimate fork length of Kokanee in Pikeminnow. Mean number of Kokanee present for these predators was determined, Kootenay Lake (2016-2017).

Species	N	Mean Fork Length of Predator (cm)	Mean Fork Length of Kokanee (cm)	Mean Corrected Weight (g)	Mean Number of Kokanee Present
Rainbow Trout	28	43.0	10.8	15.3	1.5
Bull Trout	29	47.0	11.7	18.5	1.5
Pikeminnow	1	39.4	-	53.0	1.0

Diet Composition of Northern Pikeminnow (*Ptychocheilus oregonensis*) and Competition with Other Piscivorous Fish in Kootenay Lake, British Columbia

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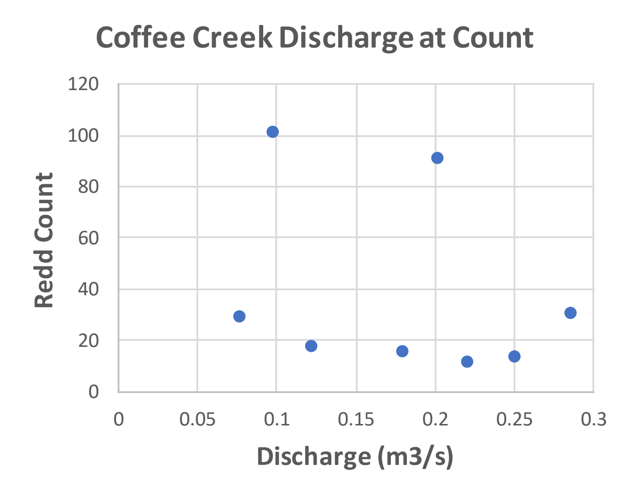
Considerations for Kootenay Lake Redd Count Time Series

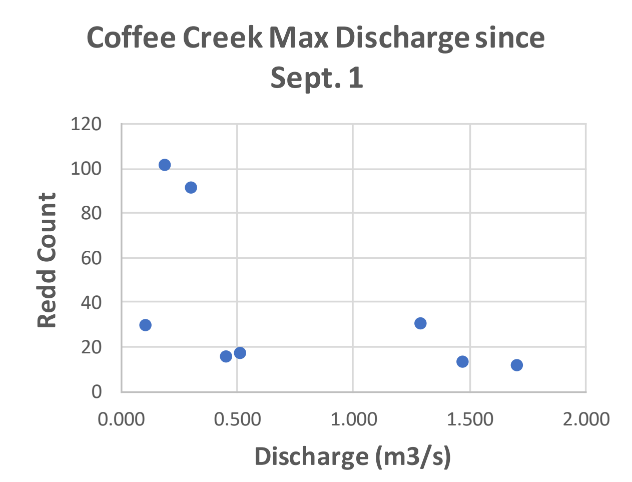
<u>3 Stream Discharge Variables:</u>

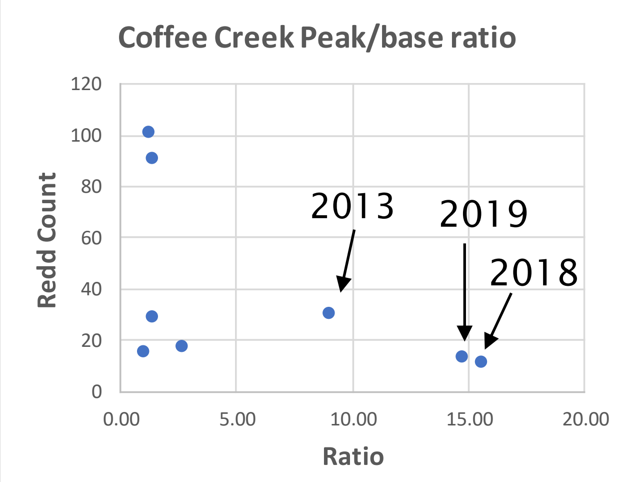
- Discharge on count date
- Max discharge since beginning of spawning (Sept.1)
- Peak flow/base flow ratio (Peak/Sept. 1 discharge)

Viewing conditions

Probability of redds being obscured prior to count







Note: Redfish hydrograph used as a surrogate for Coffee (adjacent drainage basin)