Predation of Northern Pikeminnow on Juvenile Chinook Salmon and Potential Impacts to Local Populations

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Abstract text here.

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# Introduction

The Upper Salmon River major population group (MPG) supports eight extant spring/summer Chinook salmon *Oncorhynchus tshawytscha* populations including Salmon River (above Redfish Lake), Valley Creek, Yankee Fork Salmon River, East Fork Salmon River, Salmon River (mainstem below Redfish), Pahsimeroi River, Lemhi River, and North Fork Salmon River (NOAA 2017). For the MPG to be considered viable, at least five of these eight populations should meet viability criteria set forth by McElhany et al. (2000) and ICTRT (2007), and is necessary for recovery of the Snake River Evolutionary Significant Unit (ESU). Populations within the ESU have substantial cultural value, support downriver mainstem Snake and Columbia River commercial and subsistence fisheries, and in year with sufficient abundance, support local fisheries that contribute to the local economies. All Upper Salmon River MPG populations have become depleted in recent decades. Declines in survival of juvenile Chinook salmon have been attributed to the removal of beavers from the landscape (fur trade), mining activities, simplification of rivers resulting from the construction of railroads and agriculture, water withdrawals, logging activities, urbanization, avian predation, proliferation of non-native species (e.g., non-native coastal rainbow trout *O. mykiss irideus* and brook trout *Salvelinus fontinalis*), warming streams and rivers, and modifications to downriver migration corridors (e.g., from hydropower projects). Moreover, the abundance of adult returns are further impacted by ocean and downriver harvests, altered ocean conditions, and changes to the spawning migration corridor. Each of these factors have contributed, to varying and unknown extents, to reduced adult escapement, the primary metric used to assess population viability. In response to the above human activities and reduced abundances, action agencies have invested substantial funds in recent years to rehabilitate tributary ecosystems in an attempt to improve juvenile survival and adult spawning conditions.

***Paragraph 2***

One potentially important, but perhaps under-appreciated source of mortality on Chinook salmon is predation on emigrating juveniles by piscivorious fishes, including both native and non-native species. As an example,…

* At this point, I’m thinking leave avian predation out of the equation, but instead include in Discussion
* and keep focus on the freshwater environment
* What is known about downriver (Columbia/Snake) piscivorous fish populations and potential predation on juvenile Chinook salmon?
  + literature review of northern pikeminnow, smallmouth bass, other? predation on juvenile Chinook salmon, particulary from the Snake and Columbia rivers
  + still stay away from avian predation

***Paragraph 3***

* Summary of findings from Axel et al. (2015) and early RT reports and papers (Ackerman et al. (2018), Porter et al. (2019), Porter et al. (2020)) in Deadwater Slough. Recent studies have demonstrated decreased movement and survival of juvenile salmonids emigrating through the Deadwater Slough. Axel et al. (2015) demonstrated decreased rates of emigration and survival for sockeye salmon *Oncorhynchus nerka* from Redfish Lake emigrating during the spring and recent winter telemetry studies have indicated decreased transition probabilities (approximately 10% less than nearby reaches) of juvenile Chinook salmon *Oncorhynchus tschawytscha* through Deadwater Slough during fall and winter months (Ackerman et al. (2018), Porter et al. (2019), Porter et al. (2020)).
* Axel et al. (2015) found increased mortality in a particular reach spanning location x to location y in the mainstem Salmon River on a study of juvenile (hatchery?) sockeye salmon released near Redfish Lake and actively migrating downriver.
  + in their case, these were actively migrating juveniles, and so transitional probabilities can likely be interpreted (almost) directly as survival
  + A previous study showed that the lowest transitional probabilities of Red Fish Lake Sockeye occurred in the Dead Water reach.
* Ackerman et al. (2018) and Porter et al. (2019), Porter et al. (2020) found reduced (apparent) survival in a reach spanning near the town of North Fork to just downstream of Deadwater Slough.
  + in these cases, there’s a chance that juvenile Chinook could exhibit concealment behavior prior to winter and so transition probability is interpreted as the probability of a fish surviving AND moving
* Anecdotally, locals (and others? maybe NOAA?) informed us that northern pikeminnow and perhaps other species are prevalent in Deadwater Slough.

Spring/summer Chinook salmon in the Upper Salmon MPG are stream-type and exhibit two distinct migration tactics, termed downstream rearing (DSR) and natal reach rearing (NRR) by (Copeland et al. 2014). The DSR migrants leave the natal spawning area as subyearlings during June through November and typically winter in downstream, mainstem habitats prior to emigration to the ocean the following spring as smolts. Alternatively, NRR migrants remain in their natal areas for approximately one year after emergence prior to emigration to the ocean as smolts. The diversity of emigration tactics provides for increases population resiliency due to changes in the freshwater rearing and migration environments and buffers against catastrophic events.

The Deadwater Slough is the result of human activities and resulted from an alluvial fan that formed at the bottom of Deadwater following a storm event and resulting failure of a mining dam on Dump Creek. Additionally, the Deadwater Slough occurs in a reach of the Salmon River believed to be an important overwinter rearing area for DSR emigrants attempting to exhibit concealment behavior to survive winter prior to emigration to the ocean the following spring. Deadwater Slough contains little to no hydrological or structure features (i.e., little fish cover) and fine sediment or mud substrate; all conditions making concealment behavior difficult and providing little refuge from predation. The Deadwater reach of the Salmon River is also important in that juvenile DSR and NRR emigrant from all eight extant populations must pass through the area during ocean migration.

In recent years, concerns arose that predation on juvenile Chinook salmon at or near the Deadwater Slough was not inconsequential to Chinook salmon populations in the Upper Salmon River MPG, impacting both DSR migrants in the fall and NRR emigrants during the following spring. We hypothesize that decreases in survival (or apparent survival) of juvenile Chinook salmon observed by Ackerman et al. (2018), and similar for sockeye salmon by Axel et al. (2015), are largely, or at least partially, due to increased densities of piscivorous predators in the Deadwater Slough area. =Beginning in 2019, we set out to evaluate potential piscivorous fish predator populations in the Deadwater Slough and evaluate their potential impacts to juvenile salmon emigrants, focusing on DSR and NRR Chinook salmon. Our objectives for the study were four-fold:

1. Estimate the abundance (or relative abundance) of potential predators in the Deadwater Slough during the peaks of fall (DSR) and spring (NRR) juvenile emigrations.
2. Document predation on juvenile Chinook salmon during the emigration periods using gastric lavage.
3. Using a bioenergetics approach, attempt to estimate the number of juvenile Chinook salmon consumed during defined emigration periods for DSR and NRR juveniles.
4. Estimate potential impacts to Chinook salmon adult returns based on the estimate of juvenile Chinook salmon consumed during the defined emigration periods.

# Methods

## Study Site

The Deadwater Slough is an approximately two kilometer (km) section of the mainstem Salmon River located rough 5.8 river kms downstream from North Fork, Idaho (publication quality map referenced here). The downstream end of the Deadwater Slough occurs at the confluence of Dump Creek and the Salmon River. Around 1897, a small mining diversion reservoir failed in the Dump Creek drainage, creating upslope instability, causing a large erosion event that deposited large amounts of sediment at the confluence of the Salmon River and Dump Creek (Emerson (1973)). The event created a large alluvial fan which backed up the Salmon River creating an approximately 25.3 acre (maybe convert to square meters or kilometers?) reservoir-like area that is unnaturally slow and deep (map reference or image here). The river in this section has slower water velocities, a deepened channel, and (anecdotally) warmer water temperatures which can favor piscivorous fishes (e.g., northern pikeminnow *Ptychocheilus oregonensis*, smallmouth bass *Micropterus dolomieu*).

## Abundance of Piscivorous Fishes (Objective 1)

**Data = C/M/R and Effort**

* Capture methods used - We initially attempted electrofishing, snorkeling, netting, others?, but eventually settled on angling as best method for mark-recapture.
* Mark-recapture - We kept the mark and recapture events close together in an attempt to use a closed population model
* What are the assumptions of a closed population model?
* How was sampling performed? What relevant information was captured for each fish? How/where were fish released? How was effort recorded to calculate CPUE?
* Description of sampling time frame:
  + Fall 2019: Goal was to estimate abundance during the peak of DSR emigration i.e., timing was done to coincide to be shortly after peak fall (DSR) emigration at the lower Lemhi River screw trap with the hopes of documenting predation. DSR are the more abundant juvenile emigration tactic.
  + Fall 2020: Intent was to repeat the above, but instead during peak NRR emigration, but effort canceled due to COVID-19. Instead, sampling was re-schedule to fall when social distancing, etc. could be put in place.
  + Spring 2021: Did a relative abundance effort during spring 2021. Had to reduce to a CPUE (single-week) effort due to funding constraints. However, goal was to 1) document presence during NRR outmigration and 2) estimate CPUE to provide a relative comparison to the fall efforts.

The Chapman-modified Lincoln-Peterson estimator is below, where is the number of fish marked and returned to the population, is the number of fish caught in the second/recapture event and is the number of marked fish in the second sample.

The Schnabel estimator is shown below, where the , and are indexed by the sampling occasion, . This estimator does not have an associate standard error, but 95% confidence intervals can be calculated.

## Predation Upon Juvenile Chinook Salmon i.e., Gastric Lavage (Objective 2)

**Data = Gastric Lavage Data**

The goal was to document predation upon juvenile Chinook salmon (or other targets), and ideally, estimate the proportion of their diet that consisted of juvenile Chinook salmon at the time of sampling?

* Which individuals was gastric lavage performed upon?
* How was gastric lavage performed?
* Intent was to quantify predation on juvenile Chinook salmon
  + or incidentally, juvenile steelhead or sockeye salmon

We collected stomach contents from most captured individuals using gastric lavage (Foster (1977)) and examined contents for the presence or absence of juvenile Chinook salmon and other incidentals (e.g., steelhead, sockeye salmon) juveniles and the proportion of stomach contents containing targets versus non-targets (e.g., macroinvertebrates). Stomach contents were stored in whirl-paks, preserved with 99% isopropyl alcohol, and analyzed one week later in a controlled environment. Each sample was uniquely identified to match up with the appropriate fish record, contents were identified down to its unique composition, total weight of all content was measured in grams, and total weight of fish content, if found, was measured in grams. Throughout the sampling period a proportion of the captured individuals were sacrificed after gastric lavage to validate that the gastric lavage was successful at flushing all or most of the stomach contents from the northern pikeminnow.

## Bioenergetics (Objective 3)

**Data = Temperature, Bioenergetics Inputs, Others?**

Pull material from technical report

## Impacts to Adult Returns (Objective 4)

**Data = SARs, Adult Escapements, Others?**

Pull material from technical report

1. After making some assumptions (e.g., on SARs) attempt to estimate how results from objective #3 could translate into impacts on adult returns (via a thought experiment or simulation approach)

# Results

## Abundance of Piscivorous Fishes (Objective 1)

* Total population estimates of Pike Minnow. Chart or table, but likely a chart.
* What is that equate to as a density? e.g., how many pikeminnow per 10 square meters? Is that a reasonable number?

## Predation Upon Juvenile Chinook Salmon i.e., Gastric Lavage (Objective 2)

* Gastric lavage sampling results. What percent of the diet is chinook salmon from each sampling event. Pie chart? Mike loves pie charts.

## Bioenergetics (Objective 3)

* Water Temperature measurements.
  + Hobo tidbit placed at site.
  + Calculated daily average water temperature for 365 days of the year.
* Water temperature plot for the 365 average.
* Bioenergetics results. Total mass consumed over a 365 day period. Plot of daily consumption with day of year on x and mass on y.

## Impacts to Adult Returns (Objective 4)

* SAR results. Maybe a plot of multiple scenarios depending on gastric lavage results? And pop estimates if they vary in time.

# Discussion

We estimated the population size of northern pikeminnow in the Deadwater Slough and during the fall emigration period to be greater than ***xx,xxx***. And although we did not attempt to estimate population size during the spring emigration period, the relative abundance measured as CPUE was comparable to that during the fall sampling periods (update statement later). That fall population size estimate translates to ***xxx*** northern pikeminnow per 100 m or ***xxx*** pikeminnow per 100 m2. For context, that is similar/more/less than estimates from the Columbia River where predation impacts have been demonstrated as substantial and bounty programs have been implemented to reduce northern pikeminnow abundance. Given that estimate of abundance and some assumptions, we estimated that northern pikeminnow potentially consume between ***xx,xxx*** and ***xx,xxx*** juvenile Chinook salmon during the *x* sampling periods resulting in a reduction of adult returns between ***xxx*** and ***x,xxx***. We suggest that modifications to the habitat due to human activities in the Deadwater Reach has resulted in favorable conditions for northern pikeminnow, including improving conditions for predation upon juvenile Chinook salmon, which has resulted in a consequential impact to ESA-listed Chinook salmon populations in the Upper Salmon River MPG.

## Mark-Recapture Model

Re-hash out our assumptions? What assumptions were most likely violated e.g., the closed population assumption? If we assumed an open population with varying immigration/emigration rates how might that affect our estimate? In the end, how good do we think our estimate is and is the bottom-line that we belive there still to be a shit-ton of pikeminnow even if our assumptions were violated?

## Gastric Lavage

Concerns with gastric lavage. We only observed juvenile Chinook salmon (and/or other fishes) in a very small number of stomach contents. However, we don’t necessarily believe that to mean that pikeminnow in Deadwater Slough rarely consume juvenile Chinook salmon. Are there other cases where gastric lavage failed to document predation? How soon after consumption do you need to take a sample? So instead, we made some assumptions about the proportion of a pikeminnows diet consisting of Chinook salmon.

## Bioenergetics

What assumptions did we make during the bioenergetics assessment? And how might violations of those assumptions change our estimate of the number of juvenile Chinook salmon consumed and resulting impacts to adult returns?

## Impacts to Adult Returns

Again, what assumptions did we make here and how might violations of those assumptions change our estimate of impacts to adult returns.

## Avian Predation

Although not formally assessed here, another potential source of predation upon juvenile salmon in the Deadwater Slough is from avian predators including great blue herons *Ardea herodias* and bald eagles *Haliaeetus leucocephalus*. The Deadwater Slough is recognized as an important bird watching and nesting area due to the riparian and backwater habitats created by the feature [(Deadwater Slough - Audubon Important Bird Areas)](https://www.audubon.org/important-bird-areas/deadwater-slough#). During the initial sampling event in 2019, a two-person crew equipped with a mobile passive integrated transponder (PIT) tag antenna walked the entire reach and surrounding and upstream areas scanning for PIT tags. During the informal survey, we did identify nine PIT tags on surfaces surrounding Deadwater Slough, many of which were near nests or in an upstream anastomizing reach where herons and eagles are prevalent. Investigating their tag histories in [PTAGIS](https://www.ptagis.org/), these tags were implanted into a combination of juvenile Chinook Salmon (3), Sockeye Salmon (3), and steelhead (3) suggesting avian predation does occur at and adjacent to the Deadwater Reach, although to an unknown degree. ***Follow up with a brief lit review on avian predation on juvenile Chinook salmon elsewhere***

## Management Implications

Discuss the potential for various management actions: \* Removing the Dump Creek alluvial fan and restoring flow. What would that look like? \* A local bounty program? What would that look like? Have they been successful elsewhere e.g., in the Columbia River?

* Deadwater is an opportunity to benefit multiple (6 or 7) local populations with a single management or restoration action.
* Also, this is an anthropogenically created dead water area, which could be a candidate for restoration (removing the impoundment). Is there anything in the literature that discusses habitat preferences for pike minnow? If we speed up velocities and add some cover potentially pike minnow predation success will be lowered. Will these fish just move elsewhere?

## Conclusions

* We have also presented a novel modeling framework for estimating predation on native, critically endangered anadromous species which can be applied to other areas of interest. John day? Others?
* The end.

# Acknowledgements

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### Colophon

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