Technical Memorandum

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To: UCUT Fish Committee

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Subject: Sockeye Salmon Rearing Capacity of Lake Roosevelt

Introduction

An assessment of limnological characteristics in Lake Roosevelt reservoir was used to determine potential rearing capacity for Sockeye Salmon (*Oncorhynchus nerka*) reintroduced to the blocked area of the upper Columbia River. Reservoir production or capacity has been calculated for anadromous species on a multitude of waterbodies for a variety of purposes. Some techniques rely on data derived from extant populations (e.g. adult stock-recruitment, juvenile abundance and size), while others depend solely on limnological data. Limnological-based techniques have been integral components of anadromous reintroduction feasibility assessments (e.g. Ackerman et al. 2002, Bocking and Gaboury 2003, Gaboury and Bocking 2004, Bussanich and Bocking 2006, BOR 2007a, BOR 2007b, Sorel 2017). Depending on the limnological data available to researchers, various models may be used for calculating the smolt capacity of reservoirs: Morphoedaphic Index (MEI; Ryder 1982), Euphotic Volume (EV; Koenings and Burkett 1987, Koenings and Kyle 1997), Zooplankton Biomass (ZB; Koenings and Kyle 1997), or Photosynthetic Rate (PR; Hume et al. 1996, Shortreed et al. 2000).

The Spokane Tribe of Indians (STI) Lake Roosevelt Fisheries Evaluation Program (LRFEP; BPA Project No. 1994-043-00) has been collecting limnological data for Lake Roosevelt since 1988. The 155-mile-long reservoir is annually surveyed across five reaches (Lower, Middle, and Upper mainstem Columbia, Spokane Arm and Sanpoil Arm) during the primary growing season. There were 11-12 sites sampled from 1997-2001 and five sites sampled from 2002-2006. Over time, LRFEP protocols have changed with advances in the field of limnology, in response to adaptive management, to meet various program objectives, and with resource availability. Based on the types and continuity of data available for Lake Roosevelt, Euphotic Volume was selected to model sockeye salmon smolt rearing capacity.

Euphotic volumes were calculated for three months (May, July, and October) to span the primary growing season and capture annual variability in the hydrologic operations of Lake Roosevelt. Data from 1997 – 2006 were used in this analysis due to the consistency in which they were collected, and as a means to capture inter-annual variability. Assumptions used in previous rearing capacity estimates within the Columbia Basin were applied to estimate smolt capacity for these months across the 10-year period.

Methods

Study Area

Lake Roosevelt is a mainstem Columbia River impoundment formed by Grand Coulee Dam (GCD) in 1941. Flood control operations at GCD annually reduce reservoir water elevation by up to 24 m (78.7 ft) between January and June to allow for the capture of peak spring flows, with peak drawdown usually occurring in late April to early May. Spring drawdown events decrease the volume of the reservoir by an average of 55% and its surface area by 45% annually (Beckman et al. 1985). Full pool elevation (393 m AMSL) is typically achieved by early July, coinciding with the Fourth of July weekend (Nigro et al. 1981). An additional drawdown of three meters occurs in August to facilitate anadromous fish migrations in downstream reaches of the Columbia River, subsequently refilling the reservoir by late September.

Temporal and spatial characteristics differ throughout Lake Roosevelt. Lotic waters predominate in the upper reaches, transitioning to more lentic waters in the lower reservoir near GCD. The reservoir's mainstem is within the oligotrophic range of Carlson's trophic state index (Carlson 1977; Carlson and Simpson 1996, Kain et al. 2017). The Spokane and Sanpoil rivers are major tributaries to Lake Roosevelt and appear to have more primary and secondary production than the mainstem (Lee et al. 2003; Knudson et al. 2014). Primary production in Lake Roosevelt is driven by pelagic photoautotrophy.

Euphotic Volume

The EV model uses a correlation between carbon production and rearing capacity (Hume et al. 1996). It has been used in other anadromous reintroduction feasibility evaluations in the Willamette, Yakima, and Fraser River watersheds (Bocking and Gaboury 2003, Gaboury and Bocking 2004, Bussanich and Bocking 2006, BOR 2007a, BOR 2007b, Sorel 2017). Euphotic volume for Lake Roosevelt was calculated as:

$$EV = EZD_t(m) \times SA_t\ (km^2)$$

Where: *EZD* = Euphotic Zone Depth at time *t*; and SA = Surface Area at time *t*

Euphotic zone depth is defined as the portion of the water column extending from the surface to the depth where one percent of ambient light penetrates (Schindler 1971). It approximates depths where nearly all primary production occurs in typical freshwater systems. Previous studies used measures of Secchi depth and a conversion factor to calculate EZD. The LRFEP directly measured EZD throughout the growing seasons of 1997 through 2006 using Kahl Scientific Instruments® Model 268WD305 underwater irradiameter. Data were consistently collected in the months of May, July, and October coinciding with early, middle, and late periods within the productive season. These months also approximately align with annual hydro-operations events: flood control maximum drawdown, full pool upon refill, and full pool following late-season drawdown.

Euphotic volumes were calculated for May, July, and October for all years from 1997 through 2006. Hydrologic data for each year were reviewed to determine the reservoir elevation and the associated reservoir surface areas for each of the months (DART 2018, Ferrari 2012). Reservoir-wide mean EZD for each month was multiplied by the corresponding surface area to determine the EV for each month and year. Euphotic volume for each month was then used to determine the potential Sockeye smolt capacity for Lake Roosevelt. Ten-year mean EV for each month also elucidated trends throughout the productive season.

Smolt Capacity

Three scenarios were considered in calculating potential Sockeye smolt capacity for Lake Roosevelt: low, moderate, and high. These scenarios are differentiated by the assumed number of smolts supported by an EV unit, which are then multiplied by the number of EV units in the reservoir. The Bureau of Reclamation used average smolt yield estimates from Lake Wenatchee as the number of smolts per EV unit in both Cle Elum Lake and Bumping Lake capacity estimates. Smolt yield estimates derived from Lake Wenatchee were similarly applied to Lake Roosevelt; where low = 6,780 smolts per EV unit, moderate = 8,531 smolts per EV unit, and high = 10,455 smolts per EV unit (BioAnalysts 2000, Murdoch and Petersen 2000, BOR 2007a, BOR 2007b).

Results

In general, EZD increased from May through October in most years. As expected, surface areas were lowest in May, and relatively equal during July and October when the reservoir is near full pool. Euphotic volumes increased throughout the growing season, following trends of EZD and SA, even from July to October after the late season drawdown and subsequent refill (10-year means of 3,515 and 4,647 EV units, respectively).

Table 1. 10-year means (1997 – 2006) of reservoir-wide Euphotic volume, by month.

	Euphotic Volume units
May	1,77
July	3,515
October	4,647

Potential smolt capacity for Lake Roosevelt varied with EV, being lowest in May and increasing through October. Within the 10-year survey period, the lowest mean potential capacity was found in May of 1997 with 4.7 million smolts under assumed low smolt yield (10-year mean for May with assumed low and high smolt yields = 12 million to 18.5 million; Table 2). The greatest mean potential capacity occurred in October of 2006 with 56.5 million smolts with an assumed high smolt yield (10-year mean for October with assumed low and high smolt yields = 31.5 million to 48.5 million; Table 2).

Table 2. 10-year mean potential smolt capacity for Lake Roosevelt, by month, under various assumed smolt yields.

	Assumed Smolt Yield		
	Low (6,780/EV Unit)	**Moderate (8,531/EV Unit)**	**High (10,455/EV Unit)**
May	12,046,000	15,157,000	18,576,000
July	23,833,000	29,988,000	36,751,000
October	31,506,000	39,643,000	48,584,000

Table 3. Comparison of euphotic volume sockeye smolt capacity estimates generated via reintroduction feasibility evaluations performed within the Columbia Basin (BOR 2007a, BOR 2007b). Values for Bumping and Cle Elum are adopted from Table 7 in BOR 2007a & BOR 2007b.

Reservoir	Reservoir Elevation Scenario	EZD (m)	Euphotic Volume Units	Estimated number of smolts produced at:		
				6,780 smolts/EV	**8,531 smolts/EV**	**10,455 smolts/EV**
Bumping	2yr Avg. Full Pool	23.9	135	915,300	1,151,685	1,411,425
	Low Pool	15.9	51.6	349,848	440,200	539,478
Cle Elum	2yr Avg. Full Pool	22.5	438.3	2,971,674	3,739,137	4,582,427
	Low Pool	18.9	190.8	1,293,624	1,627,715	1,994,814
Roosevelt	10yr Avg. Full Pool	12.4	4,647	31,506,221	39,643,004	48,583,707
	10yr Avg. Low Pool	6.6	1,777	12,046,173	15,157,213	18,575,626

Discussion

The euphotic volume model estimates a substantial capacity for rearing sockeye salmon in Lake Roosevelt, but the precise numbers (between 12 million and 48.5 million) may be overestimations. Koening and Kyle (1997) pioneered the technique in southeast Alaskan lakes. Conditions in these lake systems led to a positive correlation between EZD and photosynthetic rate. When Shortreed and others (2000) applied this technique to coastal and interior British Columbia lakes, they found a negative correlation which led to overestimations of sockeye capacity. The magnitude of this overestimation is difficult to quantify.

The EV model only considers availability of forage for sockeye. It does not holistically consider all potential limitations imposed by the reservoir, such as habitat quantity and quality, physicochemical stressors (e.g. dissolved-oxygen and temperature dynamics), lower trophic community assemblages and the subsequent transfer of carbon to higher trophic levels, potential for smolt entrainment, and other factors. It is also important to recognize that generalizations have been made in order to characterize 155-mile long Lake Roosevelt. In reality the reservoir has distinct reaches that vary in terms of nutrient cycling and trophic dynamics in response to reservoir operations. However, EV is an effective approximation of the relationship between productivity and smolt rearing potential, and, as such, may be one line of evidence for a system's ability to support reintroduction efforts.

Despite limitations of the EV model and unique characteristics of lake and reservoir systems, previous reintroduction efforts have used EV as fundamental information necessary to evaluate the feasibility of reintroducing anadromous species to unoccupied reservoirs. Rearing capacity estimates were components of a broader anadromous reintroduction feasibility assessments in the Yakima River subbasin (Ackerman et al. 2002, BOR 2007a, BOR 2007b) and the Frazer River watershed (Bocking and Gaboury 2003, Gaboury and Bocking 2004, Bussanich and Bocking 2006).

Employing additional methods for calculating sockeye smolt rearing capacity for Lake Roosevelt would be informative for reintroduction planning. However, substantial effort and resources would be required for these expanded techniques. In practice, increased effort in this regard may not be practical for planning purposes. Additional effort may be better expended post-reintroduction, monitoring zooplankton community dynamics and shifts in taxonomic composition; which may be more informative for managers.

Zooplankton are the primary heterotrophic carbon source in Lake Roosevelt, fundamental to growth and condition of fish because they play a pivotal role in the transfer of carbon between primary producers and higher trophic levels (Black 2003). Planktivores and age-0 fish preferentially consume *Daphnia* and other large-bodied zooplankton; *Daphnia* comprising the majority of Lake Roosevelt zooplankton biomass, 57% in 2015 (Kain et al. 2017). Koenings and Kyle (1997) found dramatic shifts in the zooplankton communities of lakes subject to stocking of juvenile *O. nerka*; including a 90% reduction in biomass and a transition towards taxa less available to pelagic fish species. Given the ecological consequences of such a potential shift in Lake Roosevelt, continuing to monitor zooplankton communities will be a crucial component to any reintroduction or artificial stocking programs.

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