Salmonid Egg-to-Fry Survival and Capture Methods

Bibliography

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Table of Contents

Background & Scope

Fish biologists at NMFS' California Central Valley Division are interested in the variety of methods used to examine the survival of fish eggs in a rivers where salmonids dig nests in gravel. They are also interested in how salmonid egg-to-fry survival is calculated. To that end, the NOAA Central Library conducted a literature search and present their findings in this bibliography.

Sources Reviewed

Along with a web search for relevant grey literature materials, the following databases were used to identify sources: ProQuests' Aquatic Science and Fisheries Abstracts and Earth-Atmospheric & Aquatic Science Database; Dimensions; Lens.org; Clarivate Analytics' Web of Science: Science Citation Index Expanded; Wiley Online Library; Science Direct; BioOne Complete; Google Scholar; and JSTOR. Only English language materials were considered.

References

Acara, A. H. (1977). *The Meadow Creek spawning channel*. (Fisheries and Marine Service Technical Report No. 744). Fisheries and Environment Canada Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/18320.pdf

This report describes two years' operation of a salmonid enhancement program in the Duncan-Lardeau River system which flows into the north end of Kootenay Lake, British Columbia. The object of the Meadow Creek spawning channel was to replace the spawning ground of kokanee lost due to the construction of the Duncan Dam. This longest spawning channel in the world was the first built for a freshwater fish in British Columbia. Its total length was 3,358 m and the width was 10 . 4 1 . 8 m, providing 34,923 m SUP-2 spawning area with an average grade of 0 . 25%. Screened gravel was laid to a depth of 23 cm (9 in). Different spawner and egg densities were compared to develop optimum operation and production criteria for the channel. Satisfactory survivals to the fry stage were obtained at 5 . 7 kokanee per m SUP-2 (2 . 8 female per m SUP-2) as 70 . 8 fry per m SUP-2 . The operation of the channel as well as the rate of survival, egg incubation, emergence timing, size of the fry, discharge and temperature were studied in different sections of the channel during 1967 and 1968 as the basis for evaluation of the channel. Before construction of the spawning, the mean fry survival from egg deposition in Meadow Creek was 5 . 87%. Survival increased to 15 . 75% after the channel became operational. Fry survival in the channel was 25 . 67% in 1968 and 8 . 5% in 1969, during the first two years of channel production. Uncontrolled water flows during spawning and fry migration caused these relatively low fry survival rates. The quality of fish appeared similiar to the Lardeau River fry and emergence occurred from mid-April to mid-June in a bimodal pattern. It was concluded, however, that fry production in 1967 and 1968 was greater than the production before loss of the natural spawning ground.

Al-Chokhachy, R., & Roper, B. B. (2010). Different approaches to habitat surveys can impact fisheries management and conservation decisions. *Fisheries,* 35(10), 476-488. https://doi.org/10.1577/1548-8446-35.10.476

We illustrate how the variability in data collected within and among habitat sampling protocols can profoundly affect the interpretation of habitat quality and quantity, along with the development of habitat-to-fish population metrics. We input data collected from two standardized survey techniques, as well as data collected using one standardized technique with multiple crews, into empirically-based relationships and found the variability in estimates of habitat data resulted in 1-50% differences in predictions of Chinook salmon (Oncorhynchus tshawytscha) egg-to-fry survival rates. Estimates of percent pool habitat collected via different protocols resulted in up to a 3.5-fold difference in juvenile trout abundance. We also found substantial differences in the geomorphic relationships between large woody debris (LWD) and the frequency of pools when using data collected by different protocols. We illustrate how the precision of estimates of LWD and pool frequency can substantially affect data-crosswalk opportunities between habitat data collected via different protocols. The effects of the variability in habitat assessments illustrated here highlights the importance of standardized, well-documented protocols, adequate training of field crews collecting habitat data, and the need to evaluate potential bias and error.

Amiro, P. G., & Jefferson, E. G. (1997). *Status of Atlantic salmon in salmon fishing area 22 and 23 for 1996, with emphasis on inner Bay of Fundy stocks.* Fisheries and Oceans Canada, Retrieved from https://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/1997/1997_026-eng.htm

Assessment of the status of Atlantic salmon(Salmo salar) stocks of Salmon Fishing Area (SFA) 22, the Bay of Fundy area of Nova Scotia and those of SFA 23 east of the Saint John River, known as inner Bay of Fundy, indicated that escapements of salmon to six of seven assessed rivers were less than conservation requirements. All harvest and hook-and-release fisheries have been closed since 1991. Stewiacke River parr densities remain low at 1.16 age-0+, 5.29 age-1+ and 1.92 age-2+ parr 10-2 m^2. Escapements to the Petitcodiac River remained low in 1996 and although age 0+ parr were found in three of four electrofishing sites in the vacinity where adult salmon were released in 1995, no age-1+ parr or older were observed. Observations and counts of salmon in Point Wolfe and Alma rivers were low in 1996. Escapements to the Big Salmon River were 16% of the conservation requirement in 1996. Mean density of age-0+ parr (fry) parr of five sites electrofished in 1996 in the Big Salmon River was 49.22 fry (m-2 * 100) and 10.68 age-1+ parr. Densities of fry and older parr were higher in Big Salmon River than other assessed rivers and higher than densities in six other inner Bay of Fundy rivers electrofished in 1996. Gaspereau River, a river containing two-sea-winter salmon atypical of inner Bay of Fundy and impacted by hydroelectric development, was 105% of the egg deposition requirement when hatchery returns were included and 27% of requirement without hatchery returns. Ineffective downstream fish passage of smolts in the Annapolis and Gaspereau rivers and episodic incidence of low marine survival for all Inner Bay of Fundy stocks are suggested as reasons for low returns in 1996 and since 1990. Prognosis and mitigation techniques were discussed and no fishery was recommended for 1997.

Amiro, P. G., & Jefferson, E. M. (1996). *Status of Atlantic salmon in salmon fishing areas 22 and 23 for 1995, with emphasis on inner Bay of Fundy stocks*.(Atlantic Fisheries Research Document 1996/0134). Fisheries and Oceans Canada Retrieved from https://www.dfo-mpo.gc.ca/csas-sccs/publications/resdocs-docrech/1996/1996_134-eng.htm

Assessment of the status of Atlantic salmon (Salmo salar) stocks of Salmon Fishing Area (SFA) 22, the Bay of Fundy area of Nova Scotia and those of SFA 23 east of the Saint John River, known as inner Bay of Fundy, indicated that escapements of salmon to five assessed rivers were less than conservation requirements. All harvest and hook-and-release fisheries have been closed since 1991. Aquaculture origin salmon were recorded at a monitoring fence in the Stewiacke River and because the native salmon population remained low in 1995, aquaculture escapees may have contributed 49.1% of the egg deposition in 1995. Stewiacke River parr densities remain low at 3.90 age-0+, 6.49 age-1+, and 1.67 age-2+ parr 10-2 m2. Escapements to the Petitcodiac River remained low in 1995 and although use of the fishway by salmon remains uncertain, wild parr were not detected in five spot check electrofishing sites. Observations and counts of salmon in Point Wolfe and Alma rivers were again low in 1995. Escapements to the Big Salmon River (BSR) were augmented by the second year with BSR-origin salmon grown in sea-cages and released into the river as mature adults. Mean density of age-0+ parr (fry) parr of five sites elecrofished in 1995 in the BSR was 21.8 fry 10-2 m2 and 6.44 age-1+ parr 10-2 m2. Densities of 42.78 and 31.58 fry 10-2 m2 at two sites in the BSR, proximate to 1994 releases of cage-reared adult salmon, were higher than the three other index sites. Gaspereau River, a river containing two-sea-winter salmon atypical of inner Bay of Fundy and highly impacted by hydroelectric development, was assessed in 1995. Only 39% of the egg deposition requirement for the area below Lanes' Mills not including Trout River was attained in 1995. Periodic episodic incidence of low marine survival is suggested as the reason for low returns to inner Bay of Fundy rivers in 1995 and since 1990.

Anderson, J. J., Beer, W. N., Israel, J. A., & Greene, S. (2022). Targeting river operations to the critical thermal window of fish incubation: Model and case study on Sacramento River winter-run Chinook salmon. *River Research and Applications,* 38(5), 895-905. https://doi.org/10.1002/rra.3965

Allocating reservoir flows to meet societal and ecosystem needs under increasing water demands and climatic variability presents challenges to resource managers. Often, rivers have been regulated to meet flow and temperature compliance points or mimic historical patterns. Because it is difficult to assess if this approach is efficient, process-based models are being used to design river operations. This paper describes a model for fish incubation survival based on the premise that mortality from thermal stress occurs over a critical window (CW) of embryo development. A model for the embryo CW based on metabolic studies of development is combined with density-dependent and background mortalities to describe salmonid survival from egg fertilization to fry detection downstream. The model is calibrated with a two-decade dataset of Sacramento River winter-run Chinook salmon egg-to-fry survival. The effects of temperature exposure over a range of CWs were explored. Based on statistical and biological support, two alternative CWs were identified for temperature control: the entire incubation period and a short duration window prior to hatching. Survival under different CW assumptions and temperature control operations were simulated with an internet-accessible form of the model. The analysis indicated that under years of limited cold-water resources, targeting water releases to the CW prior to hatching would yield the highest incubation survival.

Arntzen, E. V., Geist, D. R., Panther, J. L., & Dawley, E. M. (2007). *Total dissolved gas monitoring in chum salmon spawning gravels below Bonneville Dam.* Office of Scientific and Technical Information (OSTI), https://doi.org/10.2172/951872

At the request of the U.S. Army Corps of Engineers (Portland District), Pacific Northwest National Laboratory (PNNL) conducted research to determine whether total dissolved gas concentrations are elevated in chum salmon redds during spring spill operations at Bonneville Dam. The study involved monitoring the total dissolved gas levels at egg pocket depth and in the river at two chum salmon spawning locations downstream from Bonneville Dam. Dissolved atmospheric gas supersaturation generated by spill from Bonneville Dam may diminish survival of chum (Oncorhynchus keta) salmon when sac fry are still present in the gravel downstream from Bonneville Dam. However, no previous work has been conducted to determine whether total dissolved gas (TDG) levels are elevated during spring spill operations within incubation habitats. The guidance used by hydropower system managers to provide protection for pre-emergent chum salmon fry has been to limit TDG to 105% after allowing for depth compensation. A previous literature review completed in early 2006 shows that TDG levels as low as 103% have been documented to cause mortality in sac fry. Our study measured TDG in the incubation environment to evaluate whether these levels were exceeded during spring spill operations. Total dissolved gas levels were measured within chum salmon spawning areas near Ives Island and Multnomah Falls on the Columbia River. Water quality sensors screened at egg pocket depth and to the river were installed at both sites. At each location, we also measured dissolved oxygen, temperature, specific conductance, and water depth to assist with the interpretation of TDG results. Total dissolved gas was depth-compensated to determine when levels were high enough to potentially affect sac fry. This report provides detailed descriptions of the two study sites downstream of Bonneville Dam, as well as the equipment and procedures employed to monitor the TDG levels at the study sites. Results of the

monitoring at both sites are then presented in both text and graphics. The findings and recommendations for further research are discussed, followed by a listing of the references cited in the report.

Atkinson, G. (2004). *Relative abundance of juvenile Atlantic salmon (Salmo salar) and other fishes in rivers of southeastern New Brunswick from electrofishing surveys 1974 to 2003.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/463272/publication.html?wbdisable=true

In southeastern New Brunswick, from the Miramichi River to the Nova Scotia border, numerous short, shallow, low gradient streams provide limited areas of less-than-ideal spawning and rearing habitat for Atlantic salmon (Salmo salar). In 1974 a spot-check electrofishing survey of 22 rivers in the region produced catches of juvenile salmon in 14. Among these, the Kouchibouguac, Kouchibouguacis, Richibucto, Coal Branch, Buctouche and Cocagne rivers were considered to have the greatest production potential, and were sampled quantitatively in various subsequent years up to 2003. Fry densities generally were found to be well below Elson's (1967) 'normal' value of 29 per sq. m, except in the Kouchibouguac River where higher quality substrate probably contributes to higher abundance. Percent habitat saturation (PHS) values for the six largest rivers were consistently well below the reference level of 27%. In the Buctouche River, egg-to-fry survival was found to be low and appears to constrain juvenile production.

Bagdovitz, Taylor, W. W., Wagner, W. C., Nicolette, S. P., & Spangler, G. R. (1986). Pink salmon populations in the U.S. waters of Lake Superior, 1981-1984. *Journal of Great Lakes Research,* 12(1), 72-81. https://doi.org/10.1016/S0380-1330(86)71701-2

Pink salmon (Oncorhynchus gorbuscha) were introduced to Lake Superior in very small numbers at Thunder Bay, Ontario, Canada in 1956. Since that time, they have established themselves as permanent members of the Lake Superior ecosystem. Peak spawner densities were observed in the U.S. tributaries of Lake Superior in 1979 when many streams experienced runs of 10,000 fish or more. To better understand the population dynamics of pink salmon, population characteristics, fecundity and egg deposition of spawners, egg and larval survival, and fry outmigration were studied in several Michigan and Minnesota tributaries in 1980. Population estimates indicate a significant decline of pink salmon in the U.S. waters of Lake Superior since 1979. This decline appears to be related to instream fry survival, which is in turn related to the hydrological conditions of the streams in fall and winter. Approximately 90% of the adults mature as 2-year-olds while the remaining 10% mature as 3-year-olds.

Baglinière, J. L., Prévost, E., & Malsse, G. (1994). Comparison of population dynamics of Atlantic salmon (Salmo salar) and brown trout (Salmo trutta) in a small tributary of the River Scorff (Brittany, France). *Ecology of Freshwater Fish,* 3(1), 25-34. https://doi.org/10.1111/j.1600-0633.1994.tb00104.x

The population dynamics of Atlantic salmon (Salmo salar L.) and brown trout (Salmo trutta L.) were compared in a small tributary of the River Scorff (Brittany, France) from spawning time to the beginning of the third growing season. The spawning and fry emergence of the two species took place at approximately the same time. In the first autumn, the densityof 0+ juveniles and settling rate from the

egg stage were much higher in trout than in salmon. The emigration rate from 0+ population was much higher in trout than in salmon. The size of resident and migrating fish was always smaller in salmon than in trout, whatever the age. The low level of salmon production in the brook, compared with trout, was the result of low survival from egg to 0+ stage in autumn, combined with the small proportion of juveniles migrating after the first growing season. This was not compensated by a high number of migrants the next year. The role of physical habitat, inter-and intraspecific competition, predation and migration dependence on size and early sexual maturity is discussed. Indications are that small tributaries of the type studied are of great value for recruitment in trout but not very productive for juvenile salmon.

Bailey, J. E., Pella, J. J., & Taylor, S. G. (1976). Production of fry and adults of 1972 brood of pink salmon, Oncorhynchus gorbuscha, from gravel incubators and natural spawning at Auke Creek, Alaska. *Fishery Bulletin,* 74(4), 961-971. Retrieved from https://spo.nmfs.noaa.gov/content/production-fry-and-adults-1972-brood-pink-salmon-Oncorhynchus gorbuscha-gravel-incubators

Production of fry and adults of the 1972 brood of pink salmon, Oncorhynchus gorbuscha, at Auke Creek, Alaska, was compared between a gravel incubator hatchery and natural spawning. Natural production in the creek above the hatchery weir (estimated from hydraulic sampling) was 73,900 fry (SE: 32,800) from an estimated initial seeding of 934,065 eggs (SE: 42,811) for a survival rate of 0.079 (SE: 0.035). An estimated total of 579,000 unfed fry (SE: 25,296) were released from the hatchery for a comparable survival rate of 0.743 (SE: 0.047). Exactly 84,000 of the hatchery fry and 5,500 of the creek fry were released after being marked by clipping fins. All adults returning to the weir were examined for marks, and some additional marks were recovered from sport and commercial fishermen; 667 marked hatchery fish and 74 marked creek fish were recovered. Estimated survival of hatchery fry to returning adult was only 0.0079 (SE: 0.0003) equal to 0.59 (SE: 0.071) the corresponding estimate of 0.0135 (SE: 0.(016) for creek fry, which suggests that hatchery fry were inferior to creek fry in the marine environment; however, hatchery fry emigrated seaward 2 wk earlier than creek fry and may have encountered less favorable marine conditions. Survival from eggs to returning adult stage was 5.50 times (SE: 2.59) higher for hatchery fry than for creek fry because of much greater survival from egg to fry in the hatchery; the difference is not statistically significant. Hatchery fry were generally shorter but heavier than creek fry and emigrated seaward at a slightly earlier stage of development. No differences in size or time of return of adults could be traced to the incubation environment from which they came.

Bailey, J. E., Rice, S. D., Pella, J. J., & Taylor, S. G. (1980). Effects of seeding density of pink salmon, Oncorhynchus gorbuscha, eggs on water chemistry, fry characteristics, and fry survival in gravel incubators. *Fishery Bulletin,* 78(3), 649-658. Retrieved from https://spo.nmfs.noaa.gov/content/effects-seeding-density-pink-salmon-Oncorhynchus gorbuscha-eggs-water-chemistry-fry

We detennined the effects of seeding density of pink salmon eggs in gravel incubators on water chemistry and on size, stage ofdevelopment, and time ofemergence offry. Sixty days after fertilization, eyed eggs were placed in eight identical test incubators at five different densities (0 to 25,600 eggs per incubator). Test incubators had upwelling water (apparent velocity, 53 cm per hour); 0.015 mS ofgravel (size, 3-32 mm); and an average incubation temperature of 4.5° C (range, 3.5°_10.0° C). 'Ibtal ammonia (NHs + NH4 +) production and oxygen consumption rates per alevin generally increased throughout incubation. Maximum total ammonia production at any density was about 8 x 10-4 mg/h per alevin.

Maximum oxygen consumption was 0.028 mg/h per alevin. The rate of ammonia production and oxygen consumption per alevin increased with increased seeding density until the reduced oxygen concentration limited metabolism. Indications of stress-reduction in size of fry and early emergence- were evident only at the higher seeding densities, 12,800 and 25,600 eggs per 0.015 mS , and were either absent or unimportant at the lower seeding densities, 1,600 and 6,400 eggs per 0.015 mS • Un-ionized ammonia (NHs) concentrations did not reach lethal levels. The stress at higher seeding densities, 12,800 and 25,600 eggs per 0.015 mS , was probably caused by depletion of oxygen to concentrations below 6 mg/l. Sublethal ammonia concentrations and low dissolved oxygen concentrations were probably synergistic.

Bamberger, A. (2008). *Research into the early life history of Atlantic salmon with focus on practical implications for conservation and stock enhancement.* (Ph.D.), Kiel University, Retrieved from https://macau.uni-kiel.de/receive/diss_mods_00003453

The widespread decline of anadromous Atlantic salmon (Salmo salar L.) populations makes it imperative to research the underlying cause and to develop mitigation measures. One of the most vulnerable phases in the life-cycle of salmon is the fry stage in early spring. Survival rates of juveniles emerging from the gravel of riverbeds are related to the three-dimensional complexity of bottom morphology and hence the variety of microhabitats within the nursery area. However, anthropogenically increased sediment supply due to changes in agricultural land-use reduces complexity, especially the roughness of the streambed. This study used a series of controlled manipulative field experiments conducted in a purpose built raceway system, to provide quantitative data on the impact of sediment pollution on salmon production in freshwaters. The comparison of in-stream habitat with an increased sediment load and control (i.e. simulated natural) situations revealed that increased sedimentation drastically reduced the salmon fry carrying capacity of a stream. A modest increase in sand bed load (15%) in semi-natural streams reduced the fry density by 50% ten days after stocking with unfed fry. Emigration patterns of fry from sedimented habitat and control habitat were significantly different. Fry from both habitat types showed unusual active upstream migration which compensated for densities exceeding the carrying capacity. Riverine habitat was optimised on a reach scale to complement the raceway results and to provide a temporary mitigation measure. The in-stream habitat of a mill leat was manipulated to build the first Eco-Hatchery for salmon in the UK based, on results from the raceway and on an extensive literature review. The hatchery achieved high survival rates of salmon juveniles throughout their freshwater life stages. Furthermore, in-stream sediment traps were developed to offer effective protection for key fry nursery habitat from excess sand bed load. The data provided by the raceway system and the Eco-Hatchery inform riparian management plans. However, addressing sedimentation related issues in salmon rivers is a politically sensitive issue and will take time. Stocking with unfed fry is being used in the interim to temporarily enhance or restore populations. But stocking programmes based on conventional hatchery methodology as a response to declining stocks have frequently failed in both respects. A semi-natural incubator for salmon eggs, the Bamberger-box, was developed to address extremely low survival of newly stocked fry from conventional hatcheries. The new incubator mimics a natural salmon redd and aims in essence to produce wild fish in a hatchery environment. The results of five years field experiments using genetically different broodstock were encouraging. There was a significant increase in the average length and body mass of fry emerging from Bamberger-boxes and the mean eyed-egg-to-fry survival was 93% - greatly exceeding published data for egg-to-fry survival in the wild. Fry from Bamberger-boxes showed a significantly different and more natural rheotactic behaviour, and fewer fry had deformities when compared with fry incubated in conventional hatchery troughs. Seasonal and diurnal emergence patterns from Bamberger-boxes correlated with natural emergence

patterns. A potentially crucial advantage of this new semi-natural incubation system was to ensure larvae survival during environmental extremes when all juveniles incubated in conventional hatchery troughs did not survive. Large-scale commercial incubators based on the same principles as the Bamberger-Box were developed and proved equally effective in producing ecologically viable fry. Low costs of production and operation render the new incubators an economically viable alternative to traditional incubation systems. Exploratory research on the influence of hyporheic invertebrates abundance on fry size at emergence was carried out as a next step in continuously improving semi-natural incubation technology.

Bamberger, A. (2009). Semi-natural incubation techniques for Atlantic salmon, Salmo salar: Opportunities and limitations for restocking. *Aquaculture,* 293(3-4), 221-230. https://doi.org/10.1016/j.aquaculture.2009.03.040

Extremely high mortality rates of hatchery reared salmonid fry after stocking into a river made it imperative to have a fresh look at substrate incubation techniques as an alternative to a traditional technique which based on hatchery troughs. Four different types of semi-natural incubation units, analogous in utilizing a gravel matrix for incubation and a natural intra- and supra gravel water flow, but differing in size and shape, were developed. The new units required evaluation to establish efficiency of incubation, with existing hatchery troughs acting as control. Trials were carried out in a replicated design during five consecutive years using a range of genetically different Atlantic salmon (Salmo salar L.) broodstocks. Comparison at the fry stage showed the substrate incubation units produced significantly larger and heavier fry than the troughs. Semi-natural incubation resulted in a reduction in deformities by 420%. Mean eyed-embryo-to-fry (EETF) survival from semi-natural incubators (89.0 +/- 4.9%) matched EETF survival from hatchery troughs (94.3 +/- 3.3%) and greatly exceeded published data for egg-to-fry survival in the wild. During a period of unusual high water temperatures all fry died in hatchery troughs whereas fry survived seemingly unaffected in semi-natural incubators. Fry emergence from the semi-natural incubation units on a seasonal and diurnal time scale was similar to emergence patterns reported for wild populations. It was concluded that fry from the new semi-natural units are apt to have an increased survival rate when stocked in to a river. Low costs of production make the new incubators an economically viable alternative to traditional incubation systems. (C) 2009 Elsevier B.V. All rights reserved.

Bams, R. A. (1974). Gravel incubators: A second evaluation on pink salmon, Oncorhynchus gorbuscha, including adult returns. *Journal of the Fisheries Board of Canada,* 31(8), 1379-1385. https://doi.org/10.1139/f74-163

A hatchery method designed for mass production of unfed Pacific salmon fry and utilizing a gravel medium during most of the incubation period is being evaluated on successive cycles of a stock of pink salmon, Oncorhynchus gorbuscha, of the Tsolum River, B.C. Possible treatment effects are studied at emergent fry and returning adult stages in artificially and naturally propagated populations. Average growth rate and, hence, efficiency of yolk conversion were unimpeded in the hatchery environment, but fry emerged 11 days prematurely. Survival from green egg to emergent fry averaged 74.9% in the hatchery and 20.6% in the creek, for a gain ratio at emergence of 3.63. Recovery of selectively marked populations of hatchery and creek fish demonstrated almost identical survival rates from fry to adult stages and a final gain ratio of 3.46. Adult lengths and weights, fecundity, and timing of migrations were unaffected generally by the hatchery treatment.

Bams, R. A. (1979). *Evaluation of gravel incubators on the third cycle of Tsolum River pink salmon, 1972-74.* Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/20114.pdf

A new incubation method was designed for Pacific salmon (Oncorhynchus gorbuscha) that migrate to sea as fry, involving deep-gravel incubators. The method required evaluation to establish efficiency of incubation and survival potential of the fry, in comparison with a naturally produced population. This report covers the third consecutive test carried out from 1972 to 1974 on the even-year pink salmon population of the Tsolum River, B.C., Canada. Comparison with the natural population at the fry stage showed that the hatchery treatment was conducive to superior survival (93 versus 21%) and equal yolk-conversion efficiency. It did induce the fry to emerge at an average stage of development about 11 days earlier than that of the creek fry, at the prevailing water temperatures (about 6 C). This phenomenon is now believed to be associated with denial of opportunity to return to gravel. Further studies showed that, even though the hatchery treatment resulted in four times as many adults per unit of eggs, fry to adult survival was suppressed by about 6-8% in the hatchery fish. This difference in ocean survival may be associated with a delayed mortality of inferior stock, 'artificially' kept alive in the hatchery. Adults of hatchery origin were also up to 2% shorter and 5% less in weight, which may be related to the same delayed mortality supposition. Such subtle changes in characteristics could be of significant genetic importance and call for close attention in future operations.

Bams, R. A. (1985). Comparison of three instream incubation techniques for coho salmon. *North American Journal of Fisheries Management,* 5(2A), 159-172. https://doi.org/10.1577/1548-8659(1985)5<159:cotiit>2.0.co;2

As part of a strategy to rear salmonids semi-naturally, three instream incubation techniques were evaluated in 2 successive years in a diversion channel of the Big Qualicum River on Vancouver Island in British Columbia. Fertilized coho salmon (Oncorhynchus kisutch) eggs were (1) placed on screens above a single layer of gravel in fish- and light-tight boxes (shallow matrix), (2) interspersed with cleaned gravel in enclosed areas of existing riffles (deep matrix), and (3) interspersed with gravel in small screen cages (baskets) buried in the center of cleaned areas of the riffles. The shallow-matrix units were the least effective, mortality was extensive, and fry size, stage of development, and efficiency of yolk conversion were all relatively inferior. The basket technique was best in the second year, when mean survival was 68%, fry lengths were the largest, rate of development the fastest, and yolk conversion the most efficient. Performance of the deep-matrix boxes was intermediate in effectiveness. A recommended technique is described and compared with egg-planting techniques in general.

Ban, M., Itou, H., Nakashima, A., Sada, I., Toda, S., Kagaya, M., & Hirama, Y. (2022). The effects of temperature and salinity of hatchery water on early development of chum salmon (Oncorhynchus keta). *Aquaculture,* 549. https://doi.org/10.1016/j.aquaculture.2021.737738

Chum salmon Oncorhynchus keta is the most abundant and industrially important salmonid in Japan, of which Japanese hatcheries release about 1.8 x 10(9) fry annually. However, recent global warming and earthquake-induced crustal movement might have changed hatchery water environments. To sustainably maintain and operate hatcheries in Japan, we report the effects of rearing water temperature and salinity on the early development of chum salmon derived from the Chitose River. Effects are evaluated in terms of eyed-egg (Eer), hatching (Htr), and survival (Sur) rates, alevin body size,

and the quality of the egg envelope. Fertilized eggs were reared in groundwater (GW) at different temperatures (4, 7, 10, 13, 16 degrees C). Alevin reared at 4 degrees C were larger but had less yolk, while those reared at 16 degrees C were smaller but hatched precociously. A significant decrease in Htr and Sur was observed in the 4 degrees C treatment, which we regard to be because of the small amount of residual egg yolk at the time of hatching. Eggs were also fertilized in GW or different concentrations of brackish groundwater (BGW 0.5, 1.0, 2.1, 4.1, 8.3 psu), and continuously reared under the same salinity conditions at fertilization. Those BGW treatments at 1.0 and 2.1 psu had much lower Htr values than those reared in GW and salinities of 0.5 psu, despite their having a comparable Eer. Mortality in BGW treatments of 1.0 and 2.1 psu occurred during hatching, because of precocious hatching. No change in egg membrane proteins occurred after fertilization in 4.1 and 8.3 psu treatments, and embryos did not develop to an eyed-egg stage. These results suggest that constant temperatures of 4 and 16 degrees C, and salinities exceeding 1.0 psu during fertilization can prevent or interfere with the normal early development of chum salmon eggs and larvae in the Chitose River. To avoid the adverse effects of salination, fertilization with GW and hardening of the egg envelope effectively increase Sur dramatically, even after transfer to BGW.

Barlaup, B. T., & Moen, V. (2001). Planting of salmonid eggs for stock enhancement - a review of the most commonly used methods. *Nordic Journal of Freshwater Research,* 75, 7-19. Retrieved from http://hdl.handle.net/2077/48946

Successful planting of eggs has been reported from several studies which span a variety of planting techniques and salmonid species. The techniques used generally fall into two groups; 1) eggs incubated in boxes (e.g. Vibert-boxes) that are buried in the river bed or 2) eggs placed freely into a gravel structure, which to some degree imitates a natural redd. Poor results of egg planting have been ascribed to unnatural clustering of eggs, fungus infections, or accumulation of fine particles leading to reduced egg survival. Both newly fertilized eggs (green eggs) and eyed eggs have been used for planting. In contrast to green eggs, eyed eggs are robust and tolerate substantial handling. Eyed eggs also provide a much wider time span for disease control and for the planting of the eggs. These are weighty arguments for using eyed eggs instead of green eggs, although both developmental stages have shown to be viable alternatives. The main advantages of using egg planting over traditional use of hatchery-reared fish are that it is likely to result in fry more closely adapted to the local natural conditions, it reduces the risk of spreading disease, and it is more cost-effective.

Barnes, M. E., & Durben, D. J. (2008). Petri dish incubation of eyed eggs from rainbow trout and splake. *North American Journal of Aquaculture,* 70(4), 410-414. https://doi.org/10.1577/a07-057.1

Four experiments were conducted from 2004 to 2006 to evaluate different protocols for incubating eyed eggs of salmonids in petri dishes. In the first two experiments, which used eyed eggs from Erwin strain rainbow trout Oncorhynchus mykiss or splake (lake trout Salvelinus namaycush x brook trout S. fontinalis). dishes were loaded at either 10 or 20 eggs/dish and incubated at 10 degrees C. Water changes occurred every 3 or 7 d until complete hatch; for each species, one group of dishes received no water change. Survival to hatch was not affected by the number of eggs per dish or the frequency of water changes in either species. However, in experiments 1 and 2, hatch was significantly earlier in the dishes containing 20 eggs than in dishes containing 10 eggs, In the last two experiments, 15 eyed eggs from Shasta or McConaughy strain rainbow trout were incubated at either 10 degrees C or 12 degrees C; the water was changed every 3 d or not at all. Shasta strain eggs exhibited no significant difference in

survival or time to hatch between any of the treatments. For McConaughy strain eyed eggs, survival to hatch was significantly greater at 10 degrees C than at 12 degrees C, but water change treatment did not affect survival. No significant differences in time (d) to complete hatch were observed between temperature treatments or between water change regimes. To successfully mimic vertical-flow incubation of eyed salmonid eggs in petri dishes, we recommend a density of no more than 15 eggs/dish; no water change is needed at a temperature Of 10 degrees C. Daily removal of dead eggs and hatched fry is also required.

Barnes, M. E., Lott, J. P., Sayler, W. A., & Cordes, R. J. (1999). Practical observations on the use of eggs from electroshocked females during spawning of inland fall Chinook salmon. *North American Journal of Aquaculture,* 61(2), 162-166. https://doi.org/10.1577/1548-8454(1999)061<0162:Pootuo>2.0.Co;2

Eggs were obtained on three spawning dates in 1997 from female Chinook salmon Oncorhynchus tshawytscha that had either been caught by electrofishing or were passively captured with a fish ladder. The number of eggs per female and egg size were not significantly different between the broodfish captured by each method, Though not statistically significant, survivals to egg eye-up and to fry swim-up were consistently greater for eggs from the females captured at the fish ladder on each spawning date. Eggs collected from females that died after being electroshocked exhibited low rates of survival. Deleterious effects of handling ripe females during electrofishing were observed and probably contributed to the lower embryo survival rates on at least one occasion. If female broodfish must be captured by electrofishing methods, care should be taken to minimize any associated handling of the fish.

Barnes, M. E., Sayler, W. A., & Cordes, R. J. (2002). Formalin and hand-picking regimes during rearing in vertical-flow tray incubators. *North American Journal of Aquaculture,* 64(2), 129-135. https://doi.org/10.1577/1548-8454(2002)064<0129:Sortsf>2.0.Co;2

Sac fry of rainbow trout Oncorhynchus mykiss cultured in vertical-flow incubators were subjected to various combinations of physical (hand-picking) and chemical (formalin) antifungal treatments starting at either the eyed stage of egg development or at hatch and continuing until their removal from the incubator trays at fry swim-up. In all experiments, increases in the frequency of hand-picking, resulted in increased mortality. The elimination of hand-picking by the use of daily formalin treatments consistently produced the greatest fry survival. Attempts to determine the effect of no fungal control measures were unsuccessful because of excessive fungal growth, To achieve substantial labor reductions and maximize fry survival. we recommend daily formalin treatments of 1,667 mg/L for 15 min throughout the entire residence of salmonid eggs and sac fry in vertical-flow incubators. unless there are overriding human health or environmental concerns.

Barnes, M. E., Sayler, W. A., & Cordes, R. J. (2002). Survival of rainbow trout sac fry subjected to various formalin and hand-picking regimes during rearing in vertical-flow tray incubators. *North American Journal of Aquaculture,* 64(2), 129-135. Retrieved from https://www.tandfonline.com/doi/abs/10.1577/1548-8454%282002%29064%3C0129%3ASORTSF%3E2.0.CO%3B2

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Barnes, M. E., Sayler, W. A., & Cordes, R. J. (2005). Post-hatch hand-picking reduces salmonid fry survival in vertical-flow incubators. *Proceedings of the South Dakota Academy of Science,* 84, 71-76. Retrieved from https://www.sdaos.org/wp-content/uploads/pdfs/2005/71-76.pdf

Embryos of three salmonid species cultured in vertical-flow incubators were subjected to physical anti-fungal treatments (hand-picking) from complete hatch until fry swim-up. Removal of dead and crippled fry from incubation trays containing feral brown trout (Salmo trutta) or feral Chinook salmon (Oncorhynchus tshawytscha) resulted in significantly increased fry mortality. Survival of domesticated shasta strain rainbow trout (Oncorhynchus mykiss) fry from hatch to swim-up was also negatively affected by hand-picking, but no significant difference was observed in total mortality from egg eye-up to swim-up. Hand-picking after hatch is not recommended unless there are serious fish health concerns.

Beacham, T. D., & Murray, C. B. (1985). Effect of female size, egg size, and water temperature on developmental biology of chum salmon (Oncorhynchus keta) from the nitinat river, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences,* 42(11), 1755-1765. https://doi.org/10.1139/f85-220

We incubated eggs and alevins for five chum salmon (Oncorhynchus keta) families in each of three female size classes under controlled water temperatures of 4, 8, and 12 °C. Egg survival from fertilization to hatching was highest for eggs from small females and lowest for eggs from large females at all three incubation temperatures. Egg survival was highest at 8 °C, and at 4 °C survival rates were largely determined from fertilization to epiboly, but at 12 °C the lowest egg survival rates were recorded from eye pigmentation to hatching. There were marked differences in egg survival rates among families. Overall survival rates from egg fertilization to fry emergence were most divergent between the large and small female size class at 12 °C. Hatching time of the alevins and emergence time of the fry were similar among the three female size classes at each incubation temperature. Alevins hatching at 4 °C were the longest, but those hatching at 12 °C were the heaviest. Larger females produced alevins with both more yolk reserves and more body tissue at hatching than those from smaller females. The relation

between egg weight and subsequent alevin size was dependent upon incubation temperature. At emergence, the longest and heaviest fry were produced by the largest female size class.

Beacham, T. D., & Murray, C. B. (1986). Comparative developmental biology of chum salmon (Oncorhynchus keta) from the Fraser River, British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences,* 43(2), 252-262. https://doi.org/10.1139/f86-032

Eggs and alevins from 32 families of chum salmon (Oncorhynchus keta) from seven Fraser River stocks spawning at different times or in different tributaries were incubated in controlled water temperatures of 4, 8, and 12 °C. There were significant differences in egg and alevin survival among stocks and among families within stocks in the different incubation temperatures. Highest egg survival for a late-spawning Vedder River stock occurred at 4 °C, while egg survival from other stocks was highest at 8 °C. Late-spawning stocks had smaller eggs and earlier times of fry emergence than did early-spawning ones. There was no effect of spawning time on alevin hatching time. Alevins hatching at 8 °C were larger than those hatching at 4 or 12 °C, but there were no stock differences in alevin length or tissue weight. Stocks with greater egg sizes produced alevins of greater total weight. Fry emerging at 8 °C were larger than those emerging at 4 or 12 °C, and fry from early-spawning stocks were longer and had greater tissue weight than those from late-spawning ones. There were significant differences among families within stocks in size of alevins and fry, and family differences should be accounted for in studies of salmonid developmental biology.

Beacham, T. D., & Murray, C. B. (1986). Comparative developmental biology of pink salmon, Oncorhynchus gorbuscha, in southern British Columbia. *Journal of Fish Biology,* 28(2), 233-246. https://doi.org/10.1111/j.1095-8649.1986.tb05161.x

Eggs and alevins from 21 families of pink salmon, Oncorhynchus gorbuscha, from five odd-year broodline stocks spawning in southern British Columbia were incubated under controlled water temperatures of 4" C, 8" C and 12" C. There were significant dilTerences in egg survival among stocks and among families within stocks at all incubation temperatures, but the differences were greatest at 4" C. Alevin survival was at least 97% for each stock at each temperature. The most northern spawning stocks had higher egg survival at 4" C than did the others. Hatching time of the alevins and emergence time of the fry were similar for all five stocks. Alevins hatching at 8" C were longer than those hatching at 4" C or 12"C, but there were no stock differences in alevin length or tissue weight. Stocks with larger eggs produced alevins of greater total weight and more yolk. Emergent fry from Vancouver Island stocks had the greatest tissue weight at 12" C, but Fraser River fry were heaviest at 8" C. There were significant differences among families within stocks for alevin and fry size parameters, suggesting that family variation should be accounted for in studies of salmonid developmental biology.

Beacham, T. D., & Murray, C. B. (1987). Adaptive variation in body size, age, morphology, egg size, and developmental biology of chum salmon (Oncorhynchus keta) in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences,* 44(2), 244-261. https://doi.org/10.1139/f87-034

Chum salmon (Oncorhynchus keta) stocks in British Columbia spawning from August through January and in rivers of different size were surveyed for variation in sex ratios, age composition, meristic characters, morphology, and developmental biology. Males were more abundant than females at the

younger (2 and 3 yr of age) and older (5 and 6 yr of age) age-classes. Males had larger heads, thicker caudal peduncles, and larger dorsal fins than did females, but females had larger anal fins than did males. Stocks from large rivers had larger heads, thicker caudal peduncles, and larger fins than did those from small rivers. Chum salmon in an area characterized by a lower number of gillrakers also had a lower number of branchiostegal rays. At the same incubation temperature, alevin hatching time was similar for all stocks examined except those from the Queen Charlotte Islands, which was later than the other stocks. Early-spawning stocks had older fish, larger eggs, and later times of fry emergence than did late-spawning stocks. Late-spawning stocks had higher survival rates of embryos at 4 °C than did early-spawning ones. Stocks had different trends in alevin and fry length and weight with respect to incubation temperature. Northern stocks were more efficient than southern stocks at converting egg yolk to fry body weight at low incubation temperatures (4 °C). Selection has produced stocks adapted to the various environments that they encounter in their natal streams, allowing chum salmon to exploit a wide variety of spawning habitats in British Columbia.

Beacham, T. D., & Murray, C. B. (1989). Variation in developmental biology of sockeye salmon (Oncorhynchus nerka) and Chinook salmon (O. tshawytscha) in British Columbia. *Canadian Journal of Zoology-Revue Canadienne De Zoologie,* 67(9), 2081-2089. https://doi.org/10.1139/z89-297

Embryos and alevins of coastal-spawning and interior-spawning sockeye (Oncorhynchus nerka) and Chinook (O. tshawytscha) salmon stocks in British Columbia were incubated under controlled water temperatures of 2, 4, 8, 12, and 15 °C. At low incubation temperatures, interior-spawning stocks of both species had smaller eggs and higher embryo survival rates than did coastal-spawning stocks. Interior-spawning stocks had faster developmental rates to alevin hatching and fry emergence than did coastal-spawning stocks. Interior-spawning stocks had proportionately larger alevins or fry at 2 °C (for sockeye salmon) or 4 °C (for Chinook salmon) relative to their performance at 8 °C than did coastal-spawning stocks. Red-fleshed Chinook salmon had higher embryo survival rates at 15 °C than did white-fleshed Chinook salmon, as well as an indication of proportionately larger alevins or fry relative to the performance at lower incubation temperatures. Differences in developmental biology of interior- and coastal-spawning stocks may reflect adaptation to the thermal conditions experienced during development.

Beacham, T. D., & Murray, C. B. (1990). Temperature, egg size, and development of embryos and alevins of 5 species of Pacific salmon - a comparative-analysis. *Transactions of the American Fisheries Society,* 119(6), 927-945. https://doi.org/10.1577/1548-8659(1990)119<0927:Tesado>2.3.Co;2

We examined rate of development to alevin hatching and fry emergence, embryo and alevin survival, and alevin and fry size for five Pacific salmon species. There was little difference among values for hatching and emergence time predicted by a modified thermal sums model, power law model (log-inverse Belehradek), or quadratic model. Coho salmon Oncorhynchus kisutch had the fastest rates of development to hatching and emergence of the five species investigated; rankings for the other species depended upon temperature range. Coho salmon embryos had the highest survival rates at low incubation (1.5-degrees-C) temperatures. Embryos of pink salmon O. gorbuscha had the lowest survival at temperatures less than 4-degrees-C. For all five species, incubation temperature was the more important factor in determining alevin length, and egg size was the more important factor in determining alevin weight. Egg weight was a major determinant of fry weight at emergence. Rates of

development to hatching and emergence, and alevin and fry size, differed by species in response to changes in temperature. Coho salmon alevins and fry were proportionately larger at 4-degrees-C than at 8-degrees-C or 12-degrees-C, but alevins and fry of pink salmon and chum salmon O. keta were largest at 8-degrees-C. Variation in development characters of Pacific salmon reflected adaptations to each species' life history pattern.

Beacham, T. D., & Murray, C. B. (1993). Acceleration of maturity of pink salmon (Oncorhynchus gorbuscha) using photoperiod control. *Aquaculture,* 109(3-4), 315-325. https://doi.org/10.1016/0044-8486(93)90171-t

Fertilized pink salmon (Oncorhynchus gorbuscha) embryos were obtained in October 1989, raised in an elevated temperature to produce fry by January 1990, and then these fish were maintained under an accelerated photoperiod regime that resulted in mature males and females by April 1991, 6 months ahead of naturally-spawning populations. Virtually all males matured, but only 31% of the females. Fertility of the eggs of ten mature females ranged from 1% to 93%, and the eggs were about 50% of the weight of naturally-spawned pink salmon eggs, but survival of the embryos to fry emergence was comparable to that of embryos from naturally-spawned populations. Survival of the second generation juveniles from emergence to 40 days of rearing was 74%, with a mean weight of 0.64 g.

Beacham, T. D., & Starr, P. (1982). Population biology of chum salmon, Oncorhynchus keta, from the Fraser River, British Columbia. In *Fishery Bulletin* (Vol. 80, pp. 813-825). Retrieved from https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/1982/804/beacham.pdf

Population biology of Fraser River chum salmon, Oncorhynchusketa, was investigated. Mean age of chum salmon during the run declined from 3.98 years in October to 3.78years in December in the 1970s. Females were more abundant than males in 4-year-old chum salmon. but males were more abundant than females in 3- and 5-year-old chum salmon. Fecundity of females was 3,250 eggs/ female at a standard length of 58.0 cm and did not vary among years sampled. Fry tended to mi- grate downstream earlier when the previous winter had been warm than when it was cold. Egg- to-fry survival was correlated with rainfall, air temperature, and number of eggs deposited. Mean age of return of a brood year was positively correlated with its abundance. The return to escapement ratio for even-numbered brood years was inversely correlated with the abundance (catch plus escapement) of the previous brood year, which suggests that marine survival of chum salmon may be density-dependent. The return to escapement ratio for odd-numbered brood years was positively correlated with early downstream migration of chum salmon fry relative to pink salmon, O. gor- buscha, fry and with increased chum salmon spawningescapements relative to those of pink salmon.

Beall, E., Dumas, J., Claireaux, D., Barriere, L., & Marty, C. (1994). Dispersal patterns and survival of Atlantic salmon (Salmo salar l) juveniles in a nursery stream. *ICES Journal of Marine Science,* 51(1), 1-9. https://doi.org/10.1006/jmsc.1994.1001

The spatial and temporal patterns of dispersal and the survival of Atlantic salmon (Salmo salar L.) fry and parr were analysed over 1 year in a small stream of the Basque Country (south-west France). Dispersal just after emergence was studied with eight drift nets placed 10 to 800 m downstream from an artificial redd stocked with 15 000 eyed eggs. Subsequent distribution of parr was determined by

electrofishing in June, October, and February in representative sections of the stream including habitats 750 m upstream and 2400 m downstream from the redd. Early dispersal following emergence lasted 12 days for the majority (95%) of the fry population. Most fry (71%) settled within the first 200 m downstream from the redd, and 91% within the first 400 m. In June, parr were found 2400 m downstream and 750 m upstream, with 68% of the population established within 900 m downstream, and only 4% upstream. In October, there was a slight downstream shift of densities. In February, 56% of the parr were found within 900 m downstream and 11% upstream. Survival from egg planting to first dispersal in March was 51.9% and 11.3% over 1 year.

Beamer, E., Hayman, B., & Hinton, S. (2005). *Linking watershed conditions to egg-to-fry survival of Skagit Chinook salmon.* Skagit River System Cooperative, Retrieved from http://skagitcoop.org/wp-content/uploads/Appendix-B-Egg-to-Fry.pdf

Freshwater habitat conditions at the intragravel life stages of salmon (deposited egg to emerged fry) can be a constraint to salmon productivity and population levels (Thorne and Ames 1987, McNeil 1966, Seegrist and Gard 1972, Lisle and Lewis 1992). Survival of salmon eggs and embryos can be influenced by physical factors such as stream flooding, streambed scour and fill, and fine sediment deposition (Lisle and Lewis 1992, DeVries 1997). This report has been written to describe our basis for watershed restoration actions presented in the Skagit Chinook Recovery Plan that improve egg-to-fry survival for Chinook salmon. We present here the methods used to calculate the estimated change in egg-to-migrant-fry survival before and after watershed restoration. Biological factors such as spawner density also affect Chinook egg-to-fry survival through competition for limited spawning habitat (Vronskiy 1972, Davis and Unwin 1989). We do not consider the effect of these possible factors on Skagit Chinook salmon in this document.

Beauchamp, D. A. (1995). Riverine predation on sockeye salmon fry migrating to Lake Washington. *North American Journal of Fisheries Management,* 15(2), 358-365. https://doi.org/10.1577/1548-8675(1995)015<0358:rpossf>2.3.co;2

Recent declines in freshwater survival of juvenile sockeye salmon Oncorhynchus nerka in Lake Washington, Washington, prompted an examination of stage-specific mortalities. Previous investigations obscured the effects of winter flooding and postemergent predation on estimates of egg-to-fry survival. The purpose of this study was to explicitly estimate predation losses so that biotic and abiotic sources of mortality could be identified and quantified. During 1983–1985, the smolts of wild steelhead O. mykiss were the primary riverine predator of sockeye salmon fry migrating from the Cedar River into Lake Washington. Fry constituted 2–52% wet biornass of the smolts' diet, and averaged 13% of the diet from February through mid-May. Hatchery-reared steelhead smolts were stocked in the river during the latter half of the fry migration but showed no evidence of preying on fry. Fifty-four bioenergetics simulations were run to examine the effects of different rates of predator growth, temperature regimes, diet compositions, and wild steelhead smolt abundances on total number of fry lost to predation. The “normal” scenario indicated that wild steelhead smelts ate 6.8 million sockeye salmon fry in 1985, or about 15% of the estimated emergent fry production. Heaviest predation coincided with early and peak periods of the fry migration (February through mid-April). Aquatic insects and eggs from spawning large-scale suckers Catostomus macrocheilus made up most of the wild steelhead smolt diet during late April and May. Although winter flooding has been implicated as the

primary factor limiting sockeye salmon fry production in the Cedar River, this study demonstrated that riverine predation is also a significant source of fry mortality.

Becker, C. D., Fickeisen, D. H., & Montgomery, J. C. (1981). *Assessment of impacts from water level fluctuations on fish in the Hanford Reach, Columbia River.* Battelle Pacific Northwest Labs, https://doi.org/10.2172/6519612

Observations on the effects of water level fluctuations in the Hanford Reach of the Columbia River, Washington, were made in 1976 and 1977. The two years provided contrasting flow regimes: high water and fluctuations of greater magnitude prevailed in 1976; low water and higher temperatures prevailed in 1977. Situations where fish and other aquatic organisms were destroyed by changing water levels were observed and evaluated each year in three study areas: Hanford, F-Area, and White Bluffs sloughs. Losses primarily were due to stranding, entrapment (with or without complete dewatering), and predation. Juvenile fish were more susceptible to entrapment and stranding than were adult fish. Estimates of actual losses were biased and conservative because relatively few fish could be found after each decline of water level and dewatering. The most valued species of fish affected by water level fluctuations at Hanford were the anadromus fall Chinook salmon (Oncorhynchus tshawytscha) and the resident smallmouth bass (Micropterus dolomieui). Crucial periods for Chinook salmon occurred during winter when incubating eggs were in the gravel of the main channel, and before and during seaward migration in the spring when fry were abundant in shoreline zones. The crucial period for smallmouth bass was during spring and early summer when adults were spawning in warmed sloughs and shoreline zones. Chinook salmon and smallmouth bass fry were vulnerable to stranding and entrapment, and smallmouth bass nests were susceptible to exposure and temperature changes resulting from repeated water level fluctuations. Thus, flow manipulation may be crucial to their survival. The extent to which other species of riverine fish were affected by water level fluctuations depended upon their use of shoreline zones for spawning and rearing young.

Berejikian, B. (2004). *Research on captive broodstock programs for Pacific salmon; assessment of captive broodstock technologies, annual report 2002-2003.* Office of Scientific and Technical Information (OSTI), https://doi.org/10.2172/963079

The success of captive broodstock programs depends on high in-culture survival, appropriate development of the reproductive system, and the behavior and survival of cultured salmon after release, either as adults or juveniles. Continuing captive broodstock research designed to improve technology is being conducted to cover all major life history stages of Pacific salmon. Current velocity in rearing vessels had little if any effect on reproductive behavior of captively reared steelhead. However, males and females reared in high velocity vessels participated a greater number of spawning events than siblings reared in low velocity tanks. Observations of nesting females and associated males in a natural stream (Hamma Hamma River) were consistent with those observed in a controlled spawning channel. DNA pedigree analyses did not reveal significant differences in the numbers of fry produced by steelhead reared in high and low velocity vessels. To determine the critical period(s) for imprinting for sockeye salmon, juvenile salmon are being exposed to known odorants at key developmental stages. Subsequently they will be tested for development of long-term memories of these odorants. In 2002-2003, the efficacy of EOG analysis for assessing imprinting was demonstrated and will be applied in these and other behavioral and molecular tools inmore » the current work plan. Results of these experiments will be important to determine the critical periods for imprinting for the offspring of

captively-reared fish destined for release into natal rivers or lakes. By early August, the oocytes of all of Rapid River Hatchery Chinook salmon females returning from the ocean had advanced to the tertiary yolk globule stage; whereas, only some of the captively reared Lemhi River females sampled had advanced to this stage, and the degree of advancement was not dependent on rearing temperature. The mean spawning time of captive Lemhi River females was 3-4 weeks after that of the Rapid River fish. Captive Lemhi River females produced smaller and fewer eggs than the Rapid River females; however, relative fecundity was higher than that of the Rapid River fish. Female coho salmon that ceased or slowed oocyte development in the spring had lower body growth from the previous August onward compared with females that continued oocyte growth. This indicates that growth during the late summer and fall, one year prior to spawning, can determine the decision to mature the following spring. Therefore it is important to maintain the growth of broodstock during the summer/fall period to ensure the continuation of ovary development in the subsequent spring. A combined whole cell vaccine of Renogen with killed R. salmoninarum strain MT239 may be effective in reducing the occurrence of BKD during the period immediately after seawater transfer, but not in yearling seawater-adapted Chinook salmon. Control of BKD is likely to require an integrated disease management plan, utilizing three components, namely broodstock segregation, antibiotics, and vaccination. Vaccine results incorporated with antibiotic treatment will be used to work toward an integrated disease management plan to help to reduce the cycle of BKD transmission in the captive stocks to increase survival safely. Patterns of estimated survival in one Chinook salmon stock (Grovers Creek) were generally consistent with inbreeding depression: progeny of fish that were full siblings (approximate increment in F of 0.25) survived to return at much lower rates than did progeny of fish that were half siblings (F {approx} 0.125) or unrelated individuals (F {approx} 0). Growth at sea of Grovers Creek Hatchery stock study fish was lower than that of UWH stock fish. Among the inbreeding groups alone, no clear differences in growth were detectable. However, preliminary results suggest the general pattern of growth was opposite that expected if inbreeding depression reduced growth: the highest growth was in progeny of related parents.

Berejikian, B. A., Gable, J. T., & Vidergar, D. T. (2011). Effectiveness and trade-offs associated with hydraulic egg collections from natural salmon and steelhead redds for conservation hatchery programs. *Transactions of the American Fisheries Society,* 140(3), 549-556. https://doi.org/10.1080/00028487.2011.583540

Maintaining a large genetically effective number of breeders (N-b) in supplemented salmon populations is considered vital to their long-term sustainability, yet may be difficult to consistently achieve in practice, especially in conservation hatchery programs that require small numbers of eggs for captive rearing. We evaluated efforts to hydraulically collect eggs from naturally produced redds, as implemented by conservation hatchery programs for Endangered Species Act listed populations of Snake River Chinook salmon Oncorhynchus tshawytscha and Hood Canal steelhead O. mykiss; we then compared the estimated N-b represented in the hydraulically collected captive populations with the N-b obtained by the more conventional approach (i.e., adult collection and artificial spawning). Egg collection goals in the steelhead and Chinook salmon conservation hatchery programs were met in most cases and were never exceeded. The embryo viability and egg-to-fry survival consistently exceeded 90% and were no less than would be expected through artificial spawning. Demographic estimates suggested that a greater N-b in the captive population would be obtained by hydraulic redd sampling than by artificial spawning of captured adults to produce a specific, limited number of eggs. Hydraulic redd sampling allows sexual selection to occur naturally on the spawning grounds and does not require barrier weirs, handling of adults, or the removal of a female's entire fecundity from natural production.

The high rate of survival to emergence for hydraulically collected eggs (> 95%) suggests that eggs are not damaged by the collection process, but the fate of uncollected eggs that are disturbed during the process is unknown. Hydraulic redd sampling requires fairly frequent redd surveys to time collections at the proper stage of embryonic development, and access to some redds in remote areas can be difficult. Hydraulic sampling of eyed eggs appears to have largely accomplished the goals of these small- to moderately-sized conservation hatchery programs.

Berejikian, B. A., Tezak, E. P., & Endicott, R. (2002). *Research on captive broodstock programs for Pacific salmon, 2001-2002 annual report.* Office of Scientific and Technical Information (OSTI), https://doi.org/10.2172/961907

The efficacy of captive broodstock programs depends on high in-culture survival and the fitness of cultured salmon after release, either as adults or juveniles. Continuing captive broodstock research designed to improve technology is being conducted to cover all major life history stages of Pacific salmon. The following summarizes some of the work performed and results from the FY 2001 performance period: (1) The incidence of male maturation of age-1 Chinook salmon was significantly reduced by reducing growth in the first year of rearing. (2) Experimentally manipulated growth rates of captively-reared coho salmon had significant effects on female maturation rate, egg size, and fecundity, and the effects were stage-specific (i.e., pre-smolt vs. post-smolt). (3) A combination of Renogen and MT239 vaccination of yearling Chinook salmon given an acute R. salmoninarum challenge had a significantly longer survival time than the mock-vaccinated group. The survival time was marginally higher than was seen in acutely challenged fish vaccinated with either Renogen or MT239 alone and suggests that a combination vaccine of Renogen and MT239 may be useful as both a prophylactic and therapeutic agent against BKD. (4) Full-sib (inbred) groups of Chinook salmon have thus far exhibited lower ocean survival than half-sib and non-relatedmore » groups. Effects of inbreeding on fluctuating asymmetry did not follow expected patterns. (5) Sockeye salmon were exposed to specific odorants at either the alevin/emergent fry stage or the smolt stage to determine the relative importance of odorant exposure during key developmental periods and the importance of exposure duration. (6) Experimental studies to determine the effects of exercise conditioning on steelhead reproductive behavior and the effects of male body size on Chinook salmon fertilization success during natural spawning were completed.« less

Berejikian, B. A., Tezak, E. P., & Schroder, S. L. (2001). Reproductive behavior and breeding success of captively reared Chinook salmon. *North American Journal of Fisheries Management,* 21(1), 255-260. https://doi.org/10.1577/1548-8675(2001)021<0255:Rbabso>2.0.Co;2

Release of captively reared adults is one of several strategies currently being used to maintain imperiled populations of Chinook salmon Oncorhynchus tshawytscha in the Pacific Northwest. This study evaluated the breeding behavior and success of captively reared Chinook salmon released at maturity into a controlled-flow stream channel. Female egg deposition was 49.5%, which is much lower than that reported for wild populations, but egg-to-fry survival was 62.5%. Females abandoned 409,, of the nests they constructed, and males were often absent during the female's nest construction, The underlying causes of these presumed behavioral deficiencies might have limited the breeding success of the population. The efficacy of adult release strategies should be assessed within the context of other potential release options, keeping in mind the objectives of the individual program. Under current

culture practices, the reproductive success of captively reared Chinook salmon that are released as adults may be less than that of wild salmon.

Berejikian, B. A., Tezak, E. P., Schroder, S. L., Flagg, T. A., & Knudsen, C. M. (1999). Competitive differences between newly emerged offspring of captive-reared and wild coho salmon. *Transactions of the American Fisheries Society,* 128(5), 832-839. https://doi.org/10.1577/1548-8659(1999)128<0832:Cdbneo>2.0.Co;2

We investigated competition among newly emerged fry from captive-reared and wild female coho salmon Oncorhynchus kisutch by conducting dominance challenges and growth and survival experiments in laboratory stream channels. Newly emerged fry from captive-reared females won a significant majority (72.7%) of dyadic dominance challenges against fry from wild females. In a growth and survival experiment conducted from emergence to 30 d postemergence. fewer captive brood fry died of apparent starvation when food was limited than wild fry. further suggesting a competitive advantage for the captive brood fry. All fry used in the study were paternal half-sibs, so observed differences between captive brood and wild fry were attributed to the maternal parent. We hypothesize that fry coloration resulting from differences in egg color between wild and captive-reared females may have influenced the observed competitive asymmetries. If so, such differences might be ameliorated by changes in husbandry practices such as providing more natural diets.

Bernier-Bourgault, I., Guillemette, F., Vallee, C., & Magnan, P. (2005). A new incubator for the assessment of hatching and emergence success as well as the timing of emergence in salmonids. *North American Journal of Fisheries Management,* 25(1), 16-21. https://doi.org/10.1577/m03-152.1

We devised a new incubator to estimate hatching and emergence success as well as the timing,of emergence of brook trout Salvelinus fontinalis. The incubation basket is cylindrical and made of a polyvinyl chloride (PVC) grid that allows water to flow through from all directions. A fry trap is set on top of the incubation basket to catch the emergent larvae. A PVC coupler is fixed to the incubation basket and allows the fry trap to be easily removed and replaced so that one can sample larvae during emergence. In the field, the emergence success for incubators containing natural substrate ranged from 0% to 50%, compared with 0% to 77% for incubators that used Astroturf as a substrate. In the laboratory, the emergence success with Astroturf alone (75%) was comparable to that in the incubators that used Astroturf in the field (73%), suggesting that the incubator structure itself does not influence the survival of brook trout eggs. This incubator is easy to build and the materials needed for its construction are readily available. The collection of emergent larvae is easy and does not require additional equipment. Its advantages over other salmonid incubators are that it can resist adverse spring floods and freshets and it allows the assessment of emergence at various times in the field. This is important when determining the timing of emergence.

Biagi, C. A., Leggatt, R. A., Sakhrani, D., Wetklo, M., Vandersteen, W. E., Christensen, K. A., . . . Devlin, R. H. (2022). Timing of postfertilization pressure shock treatment for the production of mitotic gynogens in six salmonid species. *North American Journal of Aquaculture*. https://doi.org/10.1002/naaq.10266

Doubled haploid gynogens are individuals whose genetic material consists of two identical maternal chromosome sets and who lack paternal genetic contributions. These individuals can be useful in whole-genome sequence assembly to eliminate allelic variation in an individual that otherwise complicates the discrimination of SNPs and paralogs in regular diploids. This is particularly important in salmonid species, which have extensive remnants of an ancestral whole-genome duplication. Further, doubled haploid individuals are fully homozygous and can be used to generate clonal lines. Here, successful timing was determined for late pressure shocking for producing doubled haploid gynogens in five Oncorhynchus species (Chinook Salmon O. tshawytscha, Coho Salmon O. kisutch, Chum Salmon O. keta, Pink Salmon O. gorbuscha, and Sockeye Salmon O. nerka) and one Salvelinus species (domesticated Artic Char Salvelinus alpinus). For this study, sperm was treated with UV irradiation to inactivate the paternal nuclear DNA and used to fertilize eggs. The resulting zygotes were pressure shocked at various times following fertilization to form doubled haploid embryos via inhibition of the first cell division (mitotic gynogenesis). At an incubation temperature of 10.5°C, successful postfertilization pressure shock times for maximal survival of confirmed gynogens were 2.41–2.83 accumulated thermal units (ATUs) for Coho Salmon, 2.63–2.84 ATUs for Chum Salmon, 2.84–3.06 ATUs for Pink Salmon, 2.19 ATUs for Sockeye Salmon, and 2.63–3.06 ATUs for Chinook Salmon, whereas for Arctic Char a shock time of 2.29–2.54 ATUs at 4°C incubation was successful. Survival to fry stage ranged from less than 1% to 11.7%. Survivors were genotyped using microsatellite markers to assess nonpaternity and maternal homozygosity and were found to be 92.5% gynogens when averaged across all treatments and species. Mitotic gynogenetic individuals were produced in all six salmonid species and were used in subsequent studies to generate whole-genome sequences for Chinook, Coho, Chum, and Sockeye salmons.

Bilski, R., Shillam, J., Hunter, C., Saldate, M., & Rible, E. (2011). *Emigration of juvenile Chinook salmon (Oncorhynchus Tschawytscha) and steelhead (Oncorhynchus mykiss) in the lower mokelumne river, december 2009 through july 2010.* East Bay Municipal Utility District, Retrieved from https://www.ebmud.com/download_file/force/1903/568?emigration-of-juvenile-Chinook-salmon-dec-2009-july-2010.pdf

The emigration of juvenile Chinook salmon (Oncorhynchus tschawytscha) and steelhead (Oncorhynchus mykiss) on the lower Mokelumne River was monitored using two rotary screw traps (RST) and a bypass trap during the 2009/2010 season. The upstream rotary screw trap (VINO) was positioned just upstream of the Elliot Road bridge at river kilometer (Rkm) 87.4 and was operated from 30 November 2009 to 9 July 2010. The downstream rotary screw trap (GOLF) was located just below the Lower Sacramento Road Bridge at Rkm 61.8 and was operated from 14 December 2009 to 14 July 2010. The smolt bypass trap was located at Woodbridge Irrigation District Dam (Rkm 62.2) and was operated from 7 April 2010 to 16 July 2010.

Bisson, P. A., & Davis, G. E. (1976). Production of juvenile Chinook salmon, Oncorhynchus tshawytscha, in a heated model stream. *Fishery Bulletin,* 74(4), 763-774. Retrieved from https://spo.nmfs.noaa.gov/content/production-juvenile-Chinook-salmon-Oncorhynchus tshawytscha-heated-model-stream

Temperature was elevated approximately 4°C in a model stream, compared with an unheated but otherwise similar control stream. The streams were located outdoors and received identical amounts of exchange water from a nearby creek. Diel and seasonal temperature fluctuations were similar to those of area streams. Juvenile spring Chinook salmon, Oncorhynchus tshawytscha, were introduced into each stream either as eyed eggs or fry and allowed to remain for approximately 1 yr. Two consecutive year classes of juvenile salmon were studied. Their production was measured triweekly and related to changes in temperature, food availability, and other environmental factors. Ancillary experiments utilizing water from the model streams permitted measurement of differences in growth rate of salmon fed various rations. Salmon production in the control stream exceeded that in the heated stream. In 1972, total production in the control stream was twofold greater and, in 1973, it was approximately 30% greater than in the heated stream. Elevated temperature resulted in reduced growth rates of the fish especially as food became less abundant and at times also resulted in lower biomasses of food organisms, either because the temperature increase directly affected survival and growth of benthic invertebrates or because increased sedimentation associated with heavier growth of filamentous algae made riffle substrate less suitable for certain species. Beneficial effects of increased temperature appeared to include protection from infestation by a trematode parasite (Nanophyetus salmincola) and, possibly, increased tendencies of some invertebrates to enter the drift.

Blackbourn, D. J. (1992). Sea surface temperature and the subsequent freshwater survival rate of some salmon stocks: A surprising link between the climate of land and sea. In *Ninth Annual Pacific Climate (PACLIM) Workshop*: California Department of Water Resources, Interagency Ecological Studies Program. Retrieved from http://hdl.handle.net/1834/30336

Previous consideration of the relationship between climate and the survival rate of Pacific salmon eggs and fry has been confined to effects of large variation in the ambient freshwater environment; e.g., stream discharge, temperature, turbidity. This analysis shows sea surface temperatures during the last year of life of maturing adult salmon are also strongly associated with the subsequent survival rate of salmon eggs and fry is fresh water, presumably through development of the future eggs or sperm. In several stocks of three species of North American salmon, the association between the "marine" climate and egg survival is stronger than, or additive to, any estimated climatic association in fresh water. This apparent and surprising link between fresh water and the distant ocean has some interesting and complex implications for management of future salmon production.

Borok, S. L., & Jong, H. W. (1997). Evaluation of salmon and steelhead spawning habitat quality in the South Fork Trinity River Basin, 1997. In: California Department of Fish and Game. Retrieved from http://hdl.handle.net/1834/20631

Sediment sampling was used to evaluate Chinook salmon (Oncorhynchus tshawytscha) and steelhead (O. mykiss) spawning habitat quality in the South Fork Trinity River (SFTR) basin. Sediment samples were collected using a McNeil-type sampler and wet sieved through a series of Tyler screens (25.00 mm, 12.50 mm, 6.30 mm, 3.35 mm, 1.00 mm, and 0.85 mm). Fines (particles < 0.85 mm) were determined

after a l0-minute settling period in Imhoff cones. Thirteen stations were sampled in the SFTR basin: five stations were located in mainstem SFTR between rk 2.1 and 118.5, 2 stations each were located in EF of the SFTR, Grouse Creek, and Madden Creek, and one station each was located in Eltapom and Hayfork Creeks. Sample means for fines(particles < 0.85 mm) fer SFTR stations ranged between 14.4 and 19.4%; tributary station sample mean fines ranged between 3.4 and 19.4%. Decreased egg survival would be expected at 4 of 5 mainstem SFTR stations and at one station in EF of SFTR and Grouse Creek where fines content exceed 15%. Small gravel/sand content measured at all stations were high, and exceed levels associated with reduced sac fry emergence rates. Reduction of egg survival or sac fry emergence due to sedimentation in spawning gravels could lead to reduced juvenile production from the South Fork Trinity River. (PDF contains 18 pages.)

Bottom, D. L., Jones, K. K., Cornwell, T. J., Gray, A., & Simenstad, C. A. (2005). Patterns of Chinook salmon migration and residency in the Salmon River Estuary (Oregon). *Estuarine Coastal and Shelf Science,* 64(1), 79-93. https://doi.org/10.1016/j.ecss.2005.02.008

We examined variations in the juvenile life history of fall-spawning Chinook salmon, Oncorhynchus tshawytscha, for evidence of change in estuarine residency and migration patterns following the removal of dikes from 145 ha of former salt-marsh habitat in the Salmon River estuary (Oregon). Mark-recapture studies and abundance patterns in the estuary during 2000-2002 describe the following life-history types among Chinook salmon: (1) fry disperse throughout the estuary, and many move into restored tidal-marsh habitats in the early spring soon after emergence; (2) juveniles reside in freshwater for several months, enter the estuary in June or July, and remain for (a) a few weeks or (b) several months before entering the ocean; and (3) juveniles enter the ocean later in the fall after an extended period of rearing upriver and/or in the estuary. The absence of fry migrants in the estuary during spring and early summer in 1975-1977 - a period that precedes restoration of any of the diked marshes - and the extensive use of marsh habitats by fry and fingerlings April-July, 2000-2002 indicate that wetland restoration has increased estuarine rearing opportunities for juvenile Chinook salmon. Year-to-year patterns of estuarine rearing and abundance by juvenile salmon may be influenced by flood and drought conditions that affected adult spawner distribution and over-winter survival of salmon eggs. However, persistent changes in spawner distribution since 1975-1977, including the concentration of hatchery strays in the lower river, may account for the large proportion of fry that now disperse into the estuary soon after emergence in the spring. Although few of these earliest migrants survived to the river mouth, many fry and fingerlings from mid- and upper-basin spawning areas distributed throughout a greater portion of the estuary during the spring and summer and migrated to the ocean over a broader range of sizes and time periods than thirty years ago. The results suggest that wetland recovery has expanded life history variation in the Salmon River population by allowing greater expression of estuarine-resident behaviors. (c) 2005 Elsevier Ltd. All rights reserved.

Bowerman, T., Neilson, B. T., & Budy, P. (2014). Effects of fine sediment, hyporheic flow, and spawning site characteristics on survival and development of bull trout embryos. *Canadian Journal of Fisheries and Aquatic Sciences,* 71(7), 1059-1071. https://doi.org/10.1139/cjfas-2013-0372

Successful spawning is imperative for the persistence of salmonid populations, but relatively little research has been conducted to evaluate factors affecting early life-stage survival for bull trout (Salvelinus confluentus), a threatened char. We conducted a field experiment to assess the relationship between site-specific environmental factors and bull trout embryo survival and fry emergence timing.

Survival from egg to hatch was negatively related to percent fine sediment (<1 mm) in the redd and positively related to the strength of downwelling at spawning sites. Survival of eggs to fry emergence was also negatively related to fine sediment, and the best statistical models included additional variables that described the rate of downwelling and intragravel flow within the incubation environment. Fry emerged at an earlier stage in development from redds with high percentages of fine sediment. Increased hydraulic conductivity via redd construction and selection of spawning sites with strong downwelling appear to enhance hyporheic flow rates and bull trout egg survival, but early life-stage success may ultimately be limited by intrusion of fine sediment into the incubation environment.

Bradford, M. J. (1995). Comparative review of Pacific salmon survival rates. *Canadian Journal of Fisheries and Aquatic Sciences,* 52(6), 1327-1338. https://doi.org/10.1139/f95-129

I collated estimates of survival from the literature for naturally reproducing populations of the five major commercially harvested species of Pacific salmon (Oncorhynchus spp.) and compared the mean and variability of survival across species and life-history stages. The conclusion that survival rates can be described with a lognormal distribution was extended to include both the marine and freshwater stages. Average egg-fry survival of pink (O. gorbuscha), chum (O. keta), and sockeye (O. nerka) salmon was similar (average 7%) but was significantly lower than that of coho salmon (O. kisutch, 19%). The egg-smelt survival of Chinook (O. tshawytscha) was much higher than coho or sockeye that also rear in freshwater for similar periods (T compared with 1-2%). No direct estimates exist for the marine survival rate of naturally spawning Chinook stocks; however, from fecundity and freshwater survival data a species average of 1-2% was derived. Across all species freshwater contributes slightly more to total variation in egg-adult survival than does the ocean, and the schedule of mortality during the egg-adult interval depends on the natural history of each species.

Bratovich, P., Neal, M., Ransom, A., Bedore, P., & Bryan, M. (2020). *Chinook salmon early lifestage survival & Folsom Dam power bypass considerations.* Sacramento Water Forum, Retrieved from https://www.waterforum.org/wp-content/uploads/2020/09/Water-Forum-Water-Temp-Embryo-Survival-TM-9-23-20.pdf

The purpose of this Technical Memorandum (TM) is to provide biological information to help inform considerations regarding Folsom Dam power bypass operations to provide water temperature benefits for fall-run Chinook salmon spawning in the lower American River. More specifically, the objectives of this TM are to identify the differences in water temperature-related embryonic survival rates associated with differences in initial release water temperatures, and to provide an automated tool to estimate those differences. This TM also describes and compares alternative water temperature and Chinook salmon early lifestage survival relationships, which have previously been developed based upon field and laboratory studies.

Brinkman, S. F., Crockett, H. J., & Rogers, K. B. (2013). Upper thermal tolerance of mountain whitefish eggs and fry. *Transactions of the American Fisheries Society,* 142(3), 824-831. https://doi.org/10.1080/00028487.2013.765503

Some populations of Mountain Whitefish Prosopium williamsoni, a widely distributed native Rocky Mountain salmonid, have experienced catastrophic declines while other populations remain robust. To

assess the possibility that the declines have arisen from climate-related factors, several experiments were conducted to determine the upper thermal tolerances of embryos and fry and the effects of temperature on growth. Hatching of eggs was measured at 5.7, 6.4, 8.4, and 10.4 degrees C (three replicates each). Survival and growth of fry were measured for 33 d at 5.7, 8.2, 11.8, 16.5, 19.1, 22.2, and 25.2 degrees C (three replicates each). Mean hatching success was 96.7% (SD, 2.9) at 5.7 degrees C, 98.3% (2.9) at 6.4 degrees C, 90.0% (8.7) at 8.4 degrees C and 38.3% (10.4) at 10.4 degrees C. The ultimate upper incipient lethal temperature for fry was 23.6 degrees C (95% CI, 23.5-23.7 degrees C) after 7 d, which decreased with time to 22.6 degrees C (22.1-23.0 degrees C) after 33 d. The critical thermal maximum was 26.7 degrees C (SD, 0.8) for fry acclimated to 13.4 degrees C. The temperature for maximum growth was 13.8 degrees C (95% CI, 10.8-16.8 degrees C). Growth rates above and below the temperature for maximum growth decreased sharply to about 40% of the maximum at 5.7 degrees C and 22.2 degrees C. Based on these experimental data, the criteria for the protection of Mountain Whitefish fry are 21.6 degrees C for acute water temperature and 16.8 degrees C for chronic water temperature. The acute criterion for reproductionbased on the maximum temperature for successful incubationis 8.4 degrees C. The low upper thermal tolerance of Mountain Whitefish relative to those of other salmonids suggests that they will be very vulnerable to the increasing stream temperatures resulting from climate change. Received September 13, 2012; accepted January 8, 2013

Brown, H., Charrett, D. J., Strange, C. D., Aprahamian, M. W., & Jones, G. O. (1988). A study of salmonid egg and fry survival in the River Taff catchment. In: Welsh Water. Retrieved from http://hdl.handle.net/1834/25200

This report looks at previous findings that egg survival was related to the percentage of fine solids in the spawning gravels of the River Taff. Green salmonid eggs were planted out at 8 sites in the Taff catchment; and eyed salmonid eggs were planted out at 27 sites. Gravel cores were taken at 18 of these sites and an analysis of their composition was carried out, particular attention being given to the pecentage of particles less than 1mm. As well as its method, the report includes its own findings and recommendations, which includes other factors influencing egg survival such as the need for water quality improvements.

Burke, N. (2011). *Physical controls on salmon spawning habitat quality and embryo fitness: An integrated analysis.* (Ph.D.), University of Southampton, Retrieved from https://eprints.soton.ac.uk/341717/

The research focusses on the river Lugg – a cross-border catchment and major tributary of the river Wye, the most important Atlantic salmon river in England and Wales. The problem of declining Atlantic salmon populations in the catchment is addressed through investigating recruitment from egg fertilization to the emergent life stage and beyond using multiple field-based and laboratory techniques. The approach adopted is multidisciplinary and addresses the need for holistic approaches to habitat degradation which is increasingly recognised as systemic in nature; often with multiple stressors acting interactively. The initial premise of deleterious fine sediment infiltration into spawning gravels was addressed by a sediment fingerprinting study to ascertain the provenance of infiltrated redd sediment from a range of land-use types. In addition, nine artificial redd sites were constructed and assessed for fine sediment infiltration, intragravel dissolved oxygen levels, intragravel flow velocity and other hyporheic pore water characteristics, in relation to survival to emergence over two field seasons. A study examining the quality of emergent fry was also carried out using fitness tests and individual stress

levels. Additionally, a study on long-residence groundwater infiltration into the incubation environment was carried out. The main fine sediment contributor was derived from agricultural sources, particularly during wetter periods. The average contribution of fine sediment from agricultural sources was 60%. Survival ranged from 12% to 70% during the 2008 flood season and from 76% - 93% during the 2009 dry season. Fine sediment mass as a stand-alone index was only weakly correlated with survival but is thought to influence other factors; medium strength correlations of survival with dissolved oxygen, intragravel flow velocity and oxygen supply in particular were observed. Evidence of groundwater-surface water interactions were detected at two of three sites investigated and is proposed as an additional controlling mechanism for embryonic survival in the catchment. Sublethal fitness tests demonstrated variations between cohorts in the 2009 period despite a relatively small range of oxygen concentrations. The results highlight both temporal and spatial variations in spawning habitat quality, which influence not only survival to hatch but also posthatch fitness.

Burt, J. M., Hinch, S. G., & Patterson, D. A. (2012). Developmental temperature stress and parental identity shape offspring burst swimming performance in sockeye salmon (Oncorhynchus nerka). *Ecology of Freshwater Fish,* 21(2), 176-188. https://doi.org/10.1111/j.1600-0633.2011.00535.x

The persistent effects of embryonic temperature stress and individual parentage on fry swimming performance were examined in a cross-fertilisation experiment using sockeye salmon (Oncorhynchus nerka). A fixed-velocity test of burst swimming was used to assess the endurance capacity and behavioural performance of individual fry from 10 offspring families incubated at 12, 14 or 16 degrees C to hatch and then reared through yolk absorption and exogenous feeding stages in a common posthatch environment (average 6.9 degrees C). Fry burst swim time (BST) was influenced by an interaction between incubation temperature and family identity. Average BST was longer for fry from the 12 degrees C prehatch treatment compared to 14 and 16 degrees C, although differences were largely attributable to temperature effects on average fry size. Behavioural observations revealed that fish incubated at 16 degrees C performed more poorly, having a larger proportion of individuals that required stimulation to swim, fatigued more frequently or were classified as nonswimmers. Within all three incubation temperature treatments, mean BST varied significantly among offspring families, independent of fry mass and length. An interesting relationship was observed within the 16 degrees C treatment, whereby families with higher survivorship were characterised with lower mean BSTs. Collectively, these findings demonstrate that exposure to high temperatures in early sockeye salmon development can result in persistent, parentally mediated effects on fry performance. As such, these results provide important insight into how elevated temperature events during egg incubation may affect early life history selection processes and survival in stages beyond when the stressor is experienced.

Cass, A. (2001). *Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2001.* Canadian Science Advisory Secretariat, Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/256496.pdf

Forecasts are made for each of 18 individual sockeye stocks and four timing groups and for Fraser River pink salmon, all spawning populations combined. Adult returns of sockeye to the Fraser River on the 2001 cycle line are the highest of the four cycle lines averaging 15.9 million/ year (1980-97) compared to 9.3 million/year for the same period on the other three cycle lines combined. Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group. The forecast of

sockeye at the 50% level for all stocks combined is 12.9 million fish (420,000 Early Stuart, 202,000 Early Summer, 11.7 million Summer and 528,000 Late run). The total forecast at the 50% probability level is nearly two times the forecast at the 75% level (6.8 million). Quesnel, Late Stuart and Chilko sockeye are the three largest stocks anticipated in 2001. The 2001 pink forecast at the 50% probability level is 5.5 million fish or about half of the long-term odd-year return mean of 10.5 million/yr. Migratory conditions in the Fraser River for the early-timed sockeye runs (i.e. Early Stuart and Early Summer sockeye) in brood-year 1997 were poor as a result of high river discharge rates. The effect of stress on survival of the progeny from those fish that spawned in 1997 is not known. Except for low egg-to-fry survival of Early Stuart sockeye at one of two sites sampled, there is no evidence of anomalous freshwater conditions that signal low freshwater survival in the egg-to-fry stages where data exist (Early Stuart and Quesnel). There is, however, inadequate sampling throughout the watershed to reliably predict freshwater survival. The recent intense El Ninos were associated with poor marine survival of Fraser sockeye in ocean entry years 1993 and 1997 and over-forecasts in return years 1995 and 1997. Oceanographic and meteorological conditions in the northeast Pacific returned to near normal values in 1999 (2001 age-4 ocean entry year) and there is little evidence based on oceanographic conditions that adverse marine sockeye survival conditions prevailed in ocean-entry-year 1999 of age-4 sockeye returning in 2001. Fraser River pinks returning to spawn in 2001 entered the ocean as fry in 2000. Based on preliminary information on oceanographic condition that prevailed in 2000, there is no evidence to indicate adverse survival conditions.

Cass, A. (2002). *Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2003*.(Research Document 2002/116). Canadian Science Advisory Secretariat Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/270590.pdf

Sockeye production from the 2003 cycle line has been dominated by returns to Chilko Lake and Lower Adams River (Shuswap Lake). Average sockeye returns for all stocks on the cycle were 6.3 million sockeye/yr compared to an all-year average of 10.3 million fish/yr (1980-2000). At nearly equal proportions, Chilko and Late Shuswap sockeye together accounted for 61% of the total sockeye returns on the cycle since 1980. Forecasts are made for each of 18 individual sockeye stocks and four run timing groups (Table 1). Together the 18 sockeye stocks accounted for 96% of the estimated escapement to the Fraser River in brood year 1999. Escapement estimates for the remaining 4% are extrapolated based on mean recruits-per-spawner for combined stocks with escapement and recruitment data to forecast total returns for all spawning populations. Fraser pink salmon forecasts for all spawning populations combined are also provided. Pink returns in brood year 2001 were near record levels at 21 million fish. Average pink returns in odd-numbered year was 14 million (1981-2001). Pink escapement in 2001 was well beyond recent historical levels. Forecasts of returns are made using a variety of explanatory variables. For most stocks, forecasts are based on regression models that use spawning escapement to predict returning age-4 and age-5 sockeye in 2003. Additional explanatory variables are available for some stocks and include smolt and fry data. Model performance was evaluated in a retrospective analysis by comparing forecasts to estimated (observed) run sizes for years that estimates are available. The root-mean-square error criteria was used to select the best model from several candidate models. Forecasts are provided at various probability levels of achieving specified run sizes by stock and run-timing group. The forecast of sockeye at the 50% level for all stocks combined is 5.5 million fish (89,000 Early Stuart, 412,000 Early Summer, 3.4 million Summer and 1.6 million Late run). The Summer Run forecast accounts for 61% of the total forecast with Quesnel and Chilko stocks in nearly equal proportion at 1.1 and 1.3 million sockeye respectively. The remainder is almost entirely Late run sockeye with the Late Shuswap forecast of 1 million sockeye accounting for 60% of the Late run component. The Fraser

pink salmon forecast at the 50% level is 17 million fish. Forecasts are associated with high uncertainty. Although forecasts are presented as probability distributions, they are based on models that for most stocks assume average survival conditions. Improvements to pre-season abundance forecasts are unlikely without a better understanding of environmental factors affecting survival. Reliability of forecasts ultimately depend on understanding processes that affect survival in both freshwater and the marine environment. Migratory conditions in the Fraser River in 1999 were poor for many sockeye stocks as a result of high river discharge. The effect of stress on survival of the progeny from sockeye that spawned in 1999 is not known. Indicators of sockeye freshwater survival throughout the watershed for the brood were variable. Low egg-to-fry survival was evident for Early Stuart sockeye at one of three sites sampled as well as for Nadina sockeye.

Cassinelli, J. D., Meyer, K. A., Koenig, M. K., Vu, N. V., & Campbell, M. R. (2019). Performance of diploid and triploid westslope cutthroat trout fry stocked into Idaho alpine lakes. *North American Journal of Fisheries Management,* 39(1), 112-123. https://doi.org/10.1002/nafm.10254

Anglers value alpine lakes as providing a scenic, backcountry fishing experience that is seldom found in other fisheries. However, trout introduced into alpine lakes often pose a risk to native salmonids in downstream habitats by establishing source populations in headwater locations. Although the stocking of sterile triploid trout can reduce this risk, poststocking performance should be equivalent to that of diploid fish before fisheries managers and anglers consider triploid stocking to be ideal. In this study, three different mechanical pressure treatments were tested to create mixed-sex triploid Westslope Cutthroat Trout Oncorhynchus clarkii lewisi; at 65,500.19 kPa (9,500 psi) applied for 5 min at 300 Celsius-minutes after fertilization, triploid induction rates were 100%, and egg survival to eye-up was only 8% lower than that for diploids. Fry were stocked into 51 alpine lakes (25 with triploids and 26 with diploids), and fish were sampled 3 years later. Gill-net catch rates, growth, and condition did not differ between stocked diploid and triploid fish. General linear models revealed that test fish were larger and in better condition in lakes with fewer total fish (indicating a density-dependent influence on growth and condition) and were also in better condition in lower-elevation lakes containing a higher percentage of shallow habitat. Ploidy level was not included in the most plausible model for any of the response variables. Our results indicate that triploid Westslope Cutthroat Trout can easily be created by using pressure treatment of fertilized eggs and appear to be a suitable alternative to diploids in alpine lake stocking programs. Our study suggests that the use of triploid Westslope Cutthroat Trout in alpine lakes similar to those we studied would prevent hybridization with native salmonids in adjacent habitats without reducing the abundance, size, or condition of fish available to anglers in the lakes where they are stocked.

Chadwick, E. M. P. (1982). *Dynamics of an Atlantic salmon stock (Salmo salar) in a small Newfoundland river.* (Ph.D.), Memorial University of Newfoundland, Retrieved from https://research.library.mun.ca/4150/

Dynamics of an Atlantic salmon stock (Salmo salar L.) were studied in a small Newfoundland river, Western Arm Brook. The study examined dynamics of smolts, parr and adults. Smolt production was influenced by annual variation in year-class strength, smolt age, sex ratio and size. Year-class strength was significantly correlated with egg deposition. This was the first stock-recruitment relationship to be developed for Atlantic salmon. Supportive evidence was found on two other Newfoundland rivers, Indian and Little Codroy. On Little Codroy River, year-class strength of smolts was correlated ($P < 0.01$)

with potential egg deposition of adults counted as kelts. On Indian River, egg to fry survival was correlated ($P < 0.01$) with winter temperature and discharge. On Western Arm Brook, smolt age was significantly correlated ($P < 0.01$) with annual mean monthly air temperature. Evidence was presented for density-dependent influence on both smolt age and sex ratio. Size of smolts had the lowest annual variation of all biological characteristics. Fork length, weight, ovarian weight and especially annual instantaneous growth rates of smolt were significantly ($P < 0.01$) different between smolt ages. Ovarian weight of smolts was inversely correlated ($P = 0.01$) to sea age of adult salmon in 34 Newfoundland rivers. -- Biological characteristics of parr were significantly different between the four habit types: steadies, riffles, outflows and lakes. Parr from riffles were smaller and younger. Parr in outflows grew most during the summer season. However, parr did not remain within habitats and there was a net downstream movement. Downstream movement of parr was significantly correlated with the size of the smolt run in the same year. Mean production in lake and steady habitats was 0.07 g m^{-2} y^{-1}, and it was 2.23 g m^{-1} y^{-1} in riffles and outflows. Maximum production was estimated to be 5.47 g m^{-2} y^{-1}. Only 33% of smolts were produced in riffles and outflows; the remainder were produced in lakes and steadies which comprised 98.6% of habitat accessible to salmon. Production was correlated with standing stock and over 50% was contributed by the second and third age groups. -- This paper presented the first evidence that a commercial fishery selected larger and older 1SW salmon. 1SW salmon spend one year at sea before first spawning. Grilse taken in the local fishery of St. Barbe Bay were significantly ($P < 0.01$) greater in fork length, whole weight, condition and smolt age than grilse entering the river. Selection for older smolt ages was due to a significant correlation between size and smolt age. The fishery also selected a greater proportion of repeat spawners and almost all 2SW salmon. Consequently fish which spawned were smaller and younger than in unexploited populations. There was also a considerable loss of iteroparity as a result of exploitation. -- A model was proposed to describe Atlantic salmon stocks in exploited and unexploited states. The model was based on density-dependent growth in freshwater. At low stock densities, salmon parr grew faster and went to sea at younger smolt ages. Faster growth induced precocity in male parr and shifted the sex ratio of the smolt migration to be predominantly female. At carrying capacity, smolt ages increased and smolt production was stabilized due to overlapping of year-classes. The economic benefit of increased stream biomass was a stable yield to the fisheries. The model was compared to trends in the commercial fisheries which included a 40 yr cycle of abundance, and declines in sea age and smolt age. A significant correlation between stock abundance and smolt age corroborated the proposed biomass model.

Chadwick, E. M. P. (1982). Stock-recruitment relationship for Atlantic salmon (Salmo salar) in Newfoundland rivers. *Canadian Journal of Fisheries and Aquatic Sciences,* 39(11), 1496-1501. https://doi.org/10.1139/f82-201

A stock-recruitment relationship was developed for Atlantic salmon (Salmo salar) in Western Arm Brook, a small Newfoundland river. Supportive evidence was also found on Indian and Little Codroy, two other Newfoundland rivers. On Western Arm Brook, year-class strength of smolts was correlated ($P < 0.01$) with egg deposition. On Little Codroy River, smolt year-class strength was correlated ($P < 0.01$) with potential egg deposition of adults counted as kelt. On Indian River egg to fry survival was correlated ($P < 0.01$) with winter temperature and discharge. On the basis of these findings, the current recommended egg deposition of 2.4 eggs·m−2 of parr-rearing habitat was considered inadequate for Newfoundland rivers.

Chen, E. K., Som, N. A., Deibner-Hanson, J. D., Anderson, D. G., & Henderson, M. J. (2023). A life cycle model for evaluating estuary residency and recovery potential in Chinook salmon. *Fisheries Research,* 257, 106511. https://doi.org/10.1016/j.fishres.2022.106511

Understanding the spatial and temporal habitat use of a population is a necessary step for recovery planning. For Chinook salmon (Oncorhynchus tshawytscha), variation in their migration and habitat use complicate predicting how restoring habitats could impact total recruitment. To evaluate how juvenile life history variation affects a population's response to potential restoration, we developed a stage-structured model for a Chinook salmon population in a northern California river with a seasonally closed estuary. We modeled the timing of juvenile migration and estuarine use as a function of freshwater conditions and fish abundance. We used the model to evaluate the sensitivity of the population to different estuary and freshwater restoration scenarios that could affect population parameters at different life stages. The population's run size increased most in response to freshwater restoration that enhanced spawning productivity (egg and fry survival), followed by spawner capacity. In contrast, estuary restoration scenarios affected only a subset of Chinook salmon (average 15%), and as a result, did not have a large impact on the total recruitment of a cohort. Under current condition, estuary rearing fish were over six times less likely to survive than fish that migrate to the ocean in the spring or early summer before estuary closure. Because estuary residents experienced low survival in the estuary and in the ocean, improvements to both estuary survival and growth would be needed to increase their total survival. When life cycle monitoring data is available, life cycle models such as ours generate predictions at scales relevant to conservation and are an advantageous approach to managing and conserving anadromous salmon that use multiple habitats throughout their life cycle.

Chotkowski, M. A., Marsden, J. E., & Ellrott, B. J. (2002). An inexpensive modified emergent-fry trap for lake-spawning salmonids. *North American Journal of Fisheries Management,* 22(4), 1321-1324. https://doi.org/10.1577/1548-8675(2002)022<1321:AIMEFT>2.0.CO;2

Emergent-fry traps, designed for sampling salmonid fry, have been particularly valuable for evaluating the reproductive success of stocked lake trout Salvelinus namaycush in the Great Lakes. Traditional fry traps are constructed with a welded iron base and riveted walls and are therefore heavy and bulky as well as expensive. We describe an inexpensive new design with a semi-rigid base and soft, fabric walls that requires few specialized tools for construction. The soft design and light weight of the traps allow for easy stacking and transport. The weight can also be adjusted to suit sampling requirements. We deployed 15 rigid and 14 soft fry traps at two sites in Lake Champlain, Vermont and New York. Of the 286 fry collected, 187 were collected in rigid traps and 99 in soft traps. The numbers of fry collected per unit effort did not differ significantly between rigid and soft traps at either site. At one site, significantly greater numbers of soft traps than rigid traps contained fry (chi-square test, $P < 0.0005$). The new fry trap design provides a convenient, inexpensive method for determining locations of salmonid hatch and for estimating relative fry production.

Christiansen, R., Lie, O., & Torrissen, O. J. (1995). Growth and survival of Atlantic salmon, Salmo salar l., fed different dietary levels of astaxanthin. First-feeding fry. *Aquaculture Nutrition,* 1(3), 189-198. https://doi.org/10.1111/j.1365-2095.1995.tb00043.x

Atlantic salmon fry hatched from pigment-free eggs and from eggs containing the pigment astaxanthin were fed eleven casein/gelatine-based purified diets with varying levels of astaxanthin, ranging from 0

to 3 17 mg kg(-1), to determine the optimum dietary astaxanthin level for satisfactory growth and survival during the start-feeding period. The fish were fed the experimental diets for a period of 11 weeks. No difference in performance was found between the two types of fry originating from the pigment-free eggs and those containing pigment. However, the dietary astaxanthin concentration was found to have a significant effect on both the growth and the survival of fry. Fish fed diets with astaxanthin concentrations below 5.3 mg kg(-1) were found to have marginal growth. In addition, mortality was high in the groups fed diets with astaxanthin concentrations below 1.0 mg kg(-1). The specific growth rate (SGR) was also affected by the dietary treatment. The lipid content was higher and the moisture content was lower in the fish fed the diets containing astaxanthin concentrations above 5.3 mg kg(-1). The vitamin A and astaxanthin concentrations in whole-body samples of the fry were significantly affected by the dietary level of astaxanthin. A plateau level in whole-body vitamin A concentration was observed at dietary levels of approximately 80 mg astaxanthin kg(-1) and higher, while no maximum astaxanthin concentration in whole-body samples was observed within the dietary levels used. The results suggest the need for a minimum dietary astaxanthin concentration of 5.1 mg kg(-1) to achieve maximum growth and survival during the start-feeding period. The results indicate a low bioavailability of vitamin A palmitate and acetate and the results also suggest a provitamin A function for astaxanthin during the same period.

Coble, D. W. (1961). Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. *Transactions of the American Fisheries Society,* 90(4), 469-474. https://doi.org/10.1577/1548-8659(1961)90[469:iowead]2.0.co;2

A field study of spawning gravel conditions affecting the survival of steelhead trout (Salmo gairdneri Richardson) embryos was conducted in two small streams in the Alsea River Basin in Lincoln County, Oregon, from February to June 1959. Holes 10 inches deep, approximating natural redds, were dug in arbitrarily selected spawning locations. Plastic mesh sacks containing gravel and 100 fertilized trout eggs were placed in the upstream end of each hole. A stand-pipe was placed in the lower end of each excavation about 10 inches away from the eggs, and the hole was filled with gravel to the streambed level. Periodically, determinations were made of gravel permeability and of the apparent velocity and dissolved-oxygen content of the intra-gravel water. A month after calculated hatching times, the bags were removed from the stream-bed, and the fry contained in them were counted and preserved. The permeability of the spawning gravel fluctuated while embryos were in the gravel. During this period mean gravel permeabilities ranged from 80 to 400 meters per hour; apparent velocities from 5 to almost 110 centimeters per hour; and dissolved-oxygen concentrations from 2.6 to 9.25 milligrams per liter. Embryonic survival percentages ranged from 16 to 62. There was positive correlation between the apparent velocity of ground water and embryonic survivals, and between the dissolved-oxygen levels of the gravel water and survivals. Apparent velocities and dissolved-oxygen concentrations were closely related in the intra-gravel water, and effects of these factors could not be separated.

Coburn, A. S., & McDonald, J. (1972). *The trapping and marking of sockeye salmon fry (Oncorhynchus nerka) at Fulton River, Babine Lake B.C., (1966-1968)*.(Technical Report No. 348). Fisheries Research Board of Canada Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/28654.pdf

A comparative study of the distribution, growth, and survival of sockeye salmon fry resulting from the same parental stocks, but reared in natural and artificial conditions began in 1966 (McDonald 1969). Fry

produced from natural spawning in the Fulton River and in the adjacent artificial spawning channel (in 1966, channel fry were from planted eyed eggs) were marked distinctively, released, and later recovered in the lake nursery area and at the lake outlet at time of seaward migration (McDonald 1969; Scarsbrook and McDonald 1970). Recovery of the marked fish at the adult stage is being carried out in the commercial fishery and on the spawning grounds. This report describes the equipment and methods developed and used to collect and mark sockeye fry and the problems and procedures related to maintenance of marking quality.

Collins, J. J. (1975). An emergent fry trap for lake spawning salmonines and coregonines. *The Progressive Fish-Culturist,* 37(3), 140-142. https://doi.org/10.1577/1548-8659(1975)37[140:AEFTFL]2.0.CO;2

Kitchen sieves and trawls [3], traps [1], townets [2] and other devices have been used in pursuit of lacustrine fry. While these methods provided data on the distribution and density of flee-swimming fry, the trap described here samples a unit area of substrate, monitoring the location and duration of fry emergence. Unlike emergence traps used for salmonids in flowing streams [5,6] this design relies upon the vertical movement of emergent fry. Tait [8], observed this behavior in fry of lake trout (Salvelinus namaycush) and lake white-fish (Coregonus clupeaformis). The former surfaced to fill their swim bladders when yolk sac absorption was complete while the whitefish, with yolk sac intact, also surfaced upon hatching--an unexplained behavior. The trap was designed specifically to catch emerging kokanee salmon (Oncorhynchus nerka), splake (Salvelinus fontinalls x S. namaycush), and whitefish.

Cordone, A. J., Nicola, S. J., Baker, P. H., & Frantz, T. C. (1971). The kokanee salmon in Lake Tahoe. *California Fish and Game,* 57(1), 28-43. Retrieved from https://www.biodiversitylibrary.org/page/18627526

Large numbers of kokanee salmon (Oncorhynchus nerka) fry were stocked in Lake Tahoe from 1949 through 1955. Kokanee became established but the population remained at a low level until 1963 when a dramatic increase in the number of spawners was observed. A fishery finally developed in 1967. Major spawning concs occur in Taylor Creek and along the shores of McKinney Bay. In most years from 1960 through 1968 virtually the entire Taylor Creek run was composed of a single age group from certain strong year classes. Presence of strong year classes suggests high survival of naturally spawned fish. There is some evidence, however, of high egg retention. Lake Tahoe kokanee grow rapidly and a trend toward increasing growth rates since 1961 is suggested. Their length-weight relationship was log W = -3.26090 + 2.91063 log L. Their diet consisted mostly of cladocerans. They are widely distributed in the limnetic zone and strongly surface oriented, except during the summer and early fall when large schools form off Taylor Creek at depths from 50 to 120 ft. Under these conditions, fishing is feasible and an intensive deepline-troll fishery has developed. Efforts should be made to enlarge this fishery in space and time provided the average size of the kokanee does not decline below an acceptable level.

Cotter, D., O'Donovan, V., Drumm, A., Roche, N., Ling, E. N., & Wilkins, N. P. (2002). Comparison of freshwater and marine performances of all-female diploid and triploid Atlantic salmon (Salmo salar l.). *Aquaculture Research,* 33(1), 43-53. https://doi.org/10.1046/j.1355-557X.2001.00643.x

The performance of all-female diploid (AF2N) and triploid (AF3N) Atlantic salmon were compared in fresh water, under commercial production conditions in 1995 and 1996 year classes. The performance

of the 1996 year class was also assessed for 14 months in a commercial sea farm. Freshwater mortality was higher in the triploid groups. The majority of losses occurred in the early stages of egg development and during the first feeding period, when the incidence of non-feeding fry was consistently higher. In growth studies, although diploid fry were significantly heavier during first feeding there were no significant differences in weight between groups some 8 months after fertilization or in presmolt growth periods from February to April in 1996 and 1997. Smolting rates were high (range 93.5-95.3%) and the incidence of deformities was low (< 1%) in both groups. Marine survival was lower in the triploid group, largely as a consequence of higher losses sustained during a period of chronic stress, when triploid losses were 9% higher. Growth patterns were similar for the first 11 months in sea water. Although graded triploid salmon were heavier in January 1998 (AF3N 1.62 +/- 0.033 kg, AF2N 1.46 +/- 0.36 kg, P < 0.05), when the fish were harvested in May 1998 diploid salmon were significantly heavier than triploid salmon although there was no significant difference in weights after evisceration (AF3N 2.40 kg +/- 0.04 AF2N 2.49 kg +/- 0.03). The increase in weight of the diploids between winter and harvest reflects the growth spurt that occurs in maturing fish in the spring. Overall yields of triploid salmon in salt water were lower as a result of inferior survival.

Cowan, L. (1991). Physical characteristics and intragravel survival of chum salmon in developed and natural groundwater channels in Washington. In *Fisheries bioengineering symposium: American fisheries society symposium 10.* J. Colt & R. J. White (Eds.), (pp. 125-131): American Fisheries Society Retrieved from https://scholarworks.umass.edu/fishpassage_conference_proceedings/112/

Biological and physical evaluation of five groundwater-fed side channels (three artificially developed, two natural) on the East Fork Satsop River showed that recruitment of chum salmon spawners (Oncorhynchus keta) was positively correlated with streamflow discharge of channels. Straying was an important factor affecting initial colonization and seasonal densities of chum salmon spawners in the Satsop groundwater channels. Egg-to-fry survival ranged from 21 to 55%, substantially higher than the 6-31% range reported in other coastal streams. Correction of poor spawning conditions in a natural channel (Maple Glen) may more than double the egg-to-fry survival there. Female chum salmon spawner densities ranged from 0.07 to 0.24 female/m super(2), which was below optimum (0.5 female/m super(2)) for groundwater channels. It is postulated that increased adult escapements into the Satsop system would provide a fivefold increase in fry production per square meter without diminishing egg-to-fry survival rates in all channels, except Maple Glen. Total dissolved gas ranged from 100 to 104% saturation, although no detrimental effects were noted in fry of the Satsop channels.

Crisp, D. T. (1988). The effects of a sand layer upon swim-up success in UK salmonids. In: Ministry of Agriculture, Fisheries and Food,Northumbrian Water Authority,Natural Environmental Research Council. Retrieved from http://nora.nerc.ac.uk/id/eprint/504645

There are two main ways in which gravel composition and changes therein arising from siltation, can influence the survival of young salmonids. First, the composition of the gravel will affect its permeability and, hence, may influence the survival of eggs and alevins through its effect upon the rate of supply of oxygen and the rate of removal of metabolic products. Second, the composition of the gravel may affect the ease, or otherwise, of emergence at the time of swim-up and alevins may become trapped in the gravel and perish. This aspect is the main concern of the present report. Experiments were conducted to examine the effects upon fry emergence of a sand layer deposited on the gravel surface. The study

concludes that fry of brown trout and Atlantic salmon emerged through layers of sand up to 8 cm thick but the percentage emergence, even from the controls with no sand, was relatively low (5 - 68%). There was no firm evidence that the experimental treatments influenced percentage emergence, timing of emergence or weight of fry at the time of emergence.

Crooks, L. E. (2011). *Organic contaminants in salmonid spawning grounds: Occurrences and effects on the early life stages of salmonids.* (Ph.D.), University of Portsmouth, Retrieved from https://researchportal.port.ac.uk/portal/en/theses/organic-contaminants-in-salmonid-spawning-grounds(1b72081d-8873-4f43-a6a6-7388458ec67a).html

The factors regulating salmonid populations remain poorly understood, although contamination of the freshwater environment has been implicated as a causative factor. Depletion of stocks has become an increasing concern and it is believed that the early life stages are potentially the most vulnerable. Reduction in salmonid stocks has been reportedly linked to water quality and this current study has shown that freshwater pollution can affect the survival and development of salmonids. Environmental concentrations measured in this study varied greatly and high levels of sediment-bound contaminants were found, especially polycyclic aromatic hydrocarbons. Concentrations of waterborne contaminants were similar to levels previously measured, with some high level peaks in triazine metabolites. Field studies, as previous literature has suggested, found a higher mortality in river sites of greater sediment and nutrient loading and in sites with a greater proportion of fine sediment (<63µm). The River Avon was found to have a higher concentration of fine sediment and mortality of implanted eggs in this site was significantly higher than in the Rivers Wylye and Nadder. Although mortality of eggs implanted in river field sites was generally high, few morphometrics and biochemical effects were observed. Laboratory studies examined the toxicity of environmentally relevant levels of water-borne and sediment-bound contaminants on the brown trout (Salmo trutta) but found few acute effects and no specific trends were observed. The results did reveal a higher frequency of yolk sac oedemas for contaminant-exposed alevins in the laboratory trials compared to the control groups. In general survival was high for both the eyed egg and alevin stages when exposed to the water-borne contaminants. However, survival was greatly reduced when the water-borne contaminant exposures were carried out from the fertilisation stage compared to the eyed stage. Generally, sedimentbound contaminants had a greater effect on survival at the egg stage and mortalities were found to be reduced at the fry stage. Additionally, the results from the comet assays revealed that exposure to sediment-bound organochlorine pesticides and polycyclic aromatic hydrocarbons did induce significant acute effects in the form of DNA damage when compared to the control. Such results could indicate that certain pollutants may be problematic for the species at later stages of their development and on into adulthood. In general the findings of this research proved largely inconclusive in terms of specific impacts of contaminants on the early developmental stages of Atlantic salmon and brown trout. The results of these studies did show that the presence of common pollutants within the freshwater environment can have impacts on the survival and development of salmonids. These impacts may have serious implications throughout the lifecycle and could impact heavily on recruitment and survival at both the juvenile and adult life stages, potentially leading to a reduction of wild populations.

Crozier, W. W., & Kennedy, G. J. A. (1995). The relationship between a summer fry (0+) abundance index, derived from semi-quantitative electrofishing, and egg deposition of Atlantic salmon, in the River Bush, Northern Ireland. *Journal of Fish Biology,* 47(6), 1055-1062. https://doi.org/10.1111/j.1095-8649.1995.tb06029.x

Atlantic salmon survival in the R. Bush (N. Ireland) from egg to summer 0+ was inversely density-dependent on egg deposition (P<0.05). A stock-recruitment relationship derived from egg deposition and summer 0+ abundance index data was compared to that derived from adult and smelt counts based on total trapping. Fitted Ricker curves indicated maximum recruitment at around 2.35 million eggs and 2.46 million eggs for 0+ index and smelt count methods, respectively. Salmon 0+ abundance index data from semiquantitative electrofishing could be obtained with relatively little effort, and used to derive whole-river stock-recruitment relationships on rivers where only: adult count or some other estimator of parental stock is available. The derivation and expression of spawning targets from stock/recruitment relationships is discussed with reference to the R. Bush data.

Cunjak, R. A., Linnansaari, T., & Caissie, D. (2013). The complex interaction of ecology and hydrology in a small catchment: A salmon's perspective. *Hydrological Processes,* 27(5), 741-749. https://doi.org/10.1002/hyp.9640

For the past 22years, we have monitored hydro-meteorological conditions and fish population dynamics in Catamaran Brook, a 52km2 catchment in the Miramichi River system of New Brunswick, Canada. Given the long-term nature of the multidisciplinary dataset, we are able to provide an overview of the complex interaction between streamflow and fish population dynamics drawing on previously published material as well as new data analyses. For autumn-spawning fishes like the Atlantic salmon, access to headwater reaches was directly related to streamflow during late October (when they ascend spawning tributaries), as well as the propensity of beaver dams in the stream (also a function of streamflow). Winter streamflow was positively correlated with egg survival, except when rain-on-snow conditions induced severe ice break-up events that likely caused the highest mortalities on record for salmon and other fishes. Juvenile recruitment was significantly influenced by density-dependent processes of growth and competition but further mediated by density-independent factors like winter flow. In spring, fry emergence was largely temperature-driven, although peaks in fry drift were sometimes synchronized with secondary discharge peaks and temperature. Tributaries like Catamaran Brook provide thermal refugia for coolwater fishes like salmon and trout during the summer when wide, shallow main-stem Atlantic rivers experience low discharge and high water temperatures that induce physiological and behavioural stress (i.e. >23 degrees C). These phenomena are discussed in detail, especially in terms of how they may be compromised by future changes in hydrologic conditions resulting from predicted climate change scenarios. Copyright (c) 2012 John Wiley & Sons, Ltd.

Cunjak, R. A., & Therrien, J. (1998). Inter-stage survival of wild juvenile Atlantic salmon, Salmo salar l. *Fisheries Management and Ecology,* 5(3), 209-223. https://doi.org/10.1046/j.1365-2400.1998.00094.x

A biological model was developed to calculate annual survival between life stages of juvenile Atlantic salmon, Salmo salar L., in Catamaran Brook, a small stream basin (52 km2) in the Miramichi River catchment in New Brunswick, Canada. Seven years' data (1990–1996) were used in the model. Input variables included: daily fish counts and measurements of parr (3–4 age classes), smolts, and adult

salmon at a fish-counting fence near the stream mouth; biennial quantification of all habitat types along the watercourse; fish density estimated by electric fishing at 30 sites; and estimates of young-of-the-year emigration via stream drift. Continuous recording of stream discharge provided data to assist in interpretation of survival estimates. Annual survival for juvenile salmon in their first 3 years of life in the stream averaged between 31% and 34%. The greatest annual variation (CV = 0.699) occurred at the egg to 0+ (summer) stage with a low of 9.2% survival recorded for a winter with an atypical midwinter flood event; parr and pre-smolt survival were similarly affected. Survival from egg deposition (after correction for losses caused by predation and retention/non-fertilization) to smolt emigration was between 0.16% and 0.52%, which is low relative to estimates from many other studies. Survival of smolts to returning 1-sea-winter adults (grilse) averaged 8.5%. Potential errors in the computation of the model are discussed, e.g. inaccurate counts of spawning adults during high autumn stream flow. A possible explanation for the low egg to smolt survival was the environmental conditions experienced during various winters. Mean egg survival was 1.3 times higher (39.3%) and egg to smolt survival increased to 1.03% when the two winters characterized by extremely low discharge or midwinter freshets were excluded from the calculation. Density-dependent factors related to a beaver dam, which limited spawning distribution, may also have contributed to poor survival and increased fry emigration in one year. Environmental factors, particularly winter conditions, in streams such as Catamaran Brook may act as bottlenecks to natural production of Atlantic salmon.

Darling, J. E., Pajak, P., & Wunderlich, M. P. (1984). *Lower Flathead system fisheries study, 1984 annual report.* Confederated Salish & Kootenai Tribes of the Flathead Reservation, Montana, https://doi.org/10.2172/911850

This study was undertaken to assess the effects of Kerr Dam operations on the fisheries of the Lower Flathead System. Supported by Bonneville Power Administration funding, and conducted by the Confederated Salish and Kootenai Tribes, the study began in December of 1982 and is scheduled for completion in December of 1987. This report covers the 1983-84 field season and includes the status of target fish species populations in the Flathead River and tributaries, and initial work in South Bay of Flathead Lake. Additionally it addresses how Kerr operations may effect the reproduction of salmonids and northern pike. Combined trout population estimates for rainbow, brown, brook, and bull trout, averaged 13 fish/km of the lower Flathead River. The number of bull trout and cutthroat trout captured was so low that estimation of their individual populations was not possible. An interim closure to trout harvest on the lower Flathead River was recommended and approved by the Tribal Council until study results can be further analyzed and management options reviewed. Population estimates for northern pike ranged from six/kilometer in poorer habitat, to one hundred three/km in the best habitat in the main Flathead River. Seven pike were radio tagged and their movements monitored.more » Movements of over 89 km were recorded. One fish left the Flathead River and moved down the Clark Fork to the Plains area. Fish weirs were constructed on the Jocko River and Mission Creek to assess spawning runs of trout from the main river. Thirty-two adult rainbow passed the Jocko weir and twenty-eight passed the Mission weir during the spring spawning season. Twenty adult brown trout were captured at the Jocko weir and five at Mission weir in the fall. The Jocko weir suffered minor damage due to bed load movement during high flows of spring runoff. The structure of trout populations in the lower Flathead River points to spawning and recruitment problems caused by hydroelectric operations and sedimentation. Among the consequences of the present operational regime are constant, rapid changes in river discharge during spawning and Incubation seasons of trout species present in the lower river. Hamilton and Buell (1976) reported that similar fluctuation might exceed tolerance limits of adults and inhibit spawning behavior, dewater redds, strand fry, and displace juveniles to habitats less suitable for

survival. Similar problems are felt to exist on the lower river. Constant fluctuations over backwater vegetation have been linked to major problems in successful northern pike spawning and recruitment by preventing access to spawning sites, and dewatering eggs and attached fry. Phase I of the South Bay investigation was completed this year resulting in a detailed study program for the next three years. Dominant habitat types were mapped, and physical habitat and biological monitoring methods were evaluated and selected. Permanent habitat transects, water quality stations, fish sampling, gillnetting, seining, and trapping sites were established.« less

Davis, S. F., & Unwin, M. J. (1989). Fresh-water life-history of Chinook salmon (Oncorhynchus tshawytscha) in the Rangitata River catchment, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* 23(3), 311-319. https://doi.org/10.1080/00288330.1989.9516367

Migration and residence of Chinook salmon in the Rangitata River and 1 of its tributaries (Deep Stream) were investigated during 1983–85, and compared with findings from similar studies undertaken in the nearby Rakaia River catchment during 1972–84. The estimated spawning population (±95% confidence interval) in Deep Stream was 748 ± 161 in 1983, and 1071 ± 147 in 1984. The seasonal timing of adult and juvenile movements in and out of Deep Stream was similar to that in Glenariffe Stream, a Rakaia River tributary, as was the development of a population of resident juveniles in spring and early summer. Juvenile salmon biomass in Deep Stream from October to March averaged 0.31 ± 0.14 g m-2. During peak fry migration, juvenile Chinook salmon were found throughout the Rangitata mainstem, although only in the upper reaches was there evidence of extended freshwater rearing. Juvenile salmon migration from Deep Stream appears to be less influenced by competition for rearing habitat than in Glenariffe Stream, suggesting that differences may exist between the egg to fry survival and/or rearing capacity in the 2 streams.

Debes, P. V. (2013). Genetically based effects of domesticated-wild outbreeding in Atlantic salmon. In (Vol. Ph.D.): Dalhousie University. Retrieved from http://hdl.handle.net/10222/37484

Rapid advances in the aquaculture industry pose an environmental challenge that is generated by outbreeding between escaped domesticated and wild individuals. Given that escapees genetically differ from wild individuals because of domestication and possibly by ancestry, periodic domesticated-wild outbreeding has the potential to influence fitness-related traits in wild populations. In Atlantic salmon (Salmo salar), the understanding of mechanisms and direction of domesticated influences are especially important because of the conservation concerns associated with many wild populations, notably in the southern parts of their North Atlantic range. My thesis investigates domestication-induced, genetically based changes during the parr stage by assessing growth, parr maturity and survival under predation for three salmon strains differing in their history of domestication, as examined in two semi-natural environments (predator present, absent). Growth and size-at-age increased with increasing generations of domestication, yet male parr maturation probability declined. Survival under gape-limited predation increased with domestication-conveyed increases in size and growth rate. Domesticated but not wild individuals exhibited stress-resistant growth in the presence of a predator. To assess mechanism and magnitudes of trait changes resulting from domesticated-wild outbreeding, a domesticated strain was crossed with a wild population (up to third-generation hybrids) and outbreeding effects were studied for different life stages, several controlled environmental laboratory conditions, and traits. Life stages included the developmental periods between egg and fry, and between immature and adult post smolts. Traits assessed included survival, yolk conversion efficiency, size-at-age, maturation probability,

growth rate, mRNA transcript levels and their environmental plasticity. For many traits, both additive and non-additive genetic components in the between-population genetic architecture were revealed by cross means analyses. Furthermore, maternal outbreeding effects on early life stages were present. Altogether the results indicate that constant outbreeding effects of escapees on wild populations will increase present growth rates during all life stages and decrease early maturation probabilities for male parr and post-smolts, but by unpredictable magnitudes across hybrid generations. Maternally controlled co-adapted traits might be disrupted in hybrid mothers. Further, mixed-origin individuals might be temporarily at an advantage relative to wild individuals because of size and growth advantages and these might accelerate a wild genotypes displacement.

Decker-Hess, J., & McMullin, S. L. (1983). *Impacts of water level fluctuations on kokanee reproduction in Flathead Lake: Annual progress report 1983.* Montana Department of Fish, Wildlife and Parks https://doi.org/10.2172/901139

Koktneesalmon (Oncorhynchus nerka), the land-locked form of sockeye salmon, were originally introduced to Flathead Lake in 1916. My 1933, kokanee had become established in the lake and provided a popular summer trolling fishery as well as a fall snagging fishery in shoreline areas. Presently, Flathead Lake supports the second highest fishing pressure of any lake or reservoir in Montana (Montana Department of Fish and Game 1976). During 1981-82, the lake provided 168,792 man-days of fishing pressure. Ninety-two percent of the estimated 536,870 fish caught in Flathead Lake in 1981-82 were kokanee salmon. Kokanee also provided forage for bull trout seasonally and year round for lake trout. Kokanee rear to maturity in Flathead Lake, then return to various total grounds to spawn. Spawning occurred in lake outlet streams, springs, larger rivers and lake shoreline areas in suitable but often limited habitat. Shoreline spawning in Flathead Lake was first documented in the mid-1930's. Spawning kokanee were seized from shoreline areas in 1933 and 21,000 cans were processed and packed for distribution to the needy. Stefanich (1953 and 1954) later documented extensive but an unquantified amount of spawning along the shoreline as well as runs in Whitefish River and McDonald Creek in the 1950's.more » A creel census conducted in 1962-63 determined 11 to 13 percent of the kokanee caught annually were taken during the spawning period (Robbins 1966). During a 1981-82 creel census, less than one percent of the fishermen on Flathead Lake were snagging kokanee (Graham and Fredenberg 1982). The operation of Kerr Dam, located below Flathead Lake on the Flathead River, has altered seasonal fluctuations of Flathead Lake. Lake levels presently remain high during kokanee spawning in November and decline during the incubation and emergence periods. Groundwater plays an important role in embryo and fry survival in redds of shoreline areas exposed by lake drawdown. Stefanich (1954) and Domrose (1968) found live eggs and fry only in shoreline spawning areas wetted by groundwater seeps. Impacts of the operation of Kerr Dam on lakeshore spawning have not been quantified. Recent studies have revealed that operation of Hungry Horse Dam severely impacted successful kokanee spawning and incubation in the Flathead River above Flathead Lake (Graham et al. 1980, McMullin and Graham 1981, Fraley and Graham 1982 and Fraley and McMullin 1983). Flows from Hungry Horse Dam to enhance kokanee reproduction in the river system have been voluntarily met by the Bureau of Reclamation since 1981. In lakeshore spawning areas in other Pacific Northwest systems, spawning habitat for kokanee and sockeye salmon was characterized by seepage or groundwater flow where suitable substrate composition existed (Foerster 1968). Spawning primarily occurred in shallower depths (<6 m) where gravels were cleaned by wave action (Hassemer and Rieman 1979 and 1980, Stober et al. 1979a). Seasonal drawdown of reservoirs can adversely affect survival of incubating kokanee eggs and fry spawned in shallow shoreline areas. Jeppon (1955 and 1960) and Whitt (1957) estimated 10-75 percent kokanee egg loss in shoreline areas of Pend Oreille Lake, Idaho after regulation

of the upper three meters occurred in 1952. After 20 years of operation, Bowler (1979) found Pend Oreille shoreline spawning to occur in fewer areas with generally lower numbers of adults. In studies on Priest Lake, Idaho, Bjornn (1957) attributed frozen eggs and stranded fry to winter fluctuations of the upper three meters of the lake. Eggs and fry frozen during winter drawdown accounted for a 90 percent loss to shoreline spawning kokanee in Donner Lake, California (Kimsey 1951). Stober et al. (1979a) determined irrigation drawdown of Banks Lake, Washington reduced shoreline survival during five of the seven years the system was studied. The goal of this phase of the study was to evaluate and document effects of the operation of Kerr Dam on kokanee shoreline reproduction in Flathead Lake. Specific objectives to meet this goal a e: (1) Delineate the extent of successful shoreline spawning in Flathead Lake both on-shore (to an approximate depth of 6.1 m below full pool elevation) and off-shore (approximately 6.1-21.3 m below full pool elevation). (2) Quantify and qualify influence of groundwater on reproductive success of on-shore spawners. The effects of groundwater on spawning and incubation on off-shore spawners will also be studied. Rates of groundwater discharge and groundwater chemistry will be established in spawning and non-spawning areas. Those data will be compared and contrasted in an attempt to delineate parameters affecting spawning site selection and embryo success. (3) Determine the relative contributions of major spawning areas to the total kokanee population.« less

Decker-Hess, J., & Parks, K. (1984). *Impacts of water level fluctuations on kokanee reproduction in Flathead Lake, 1984 annual report.* Montana Department of Fish, Wildlife and Parks, https://doi.org/10.2172/901140

This study was initiated in the fall of 1981 to delineate the extent of successful shoreline spawning of kokanee salmon in Flathead Lake and determine the impacts of the historic and present operations of Kerr and Hungry Horse dams. An investigation of the quantity and quality of groundwater and other factors affecting kokanee reproductive success in Flathead Lake began in the spring of 1982. A total of 719 redds were counted in 17 shoreline areas of Flathead Lake in1983 compared to 592 in 1981 and 1,029 in 1982. Shoreline spawning contributed three percent to the total kokanee spawning in the Flathead drainage in 1983. Fifty-nine percent of the redds were located above 2883 ft, the operational minimum pool. The majority of those redds were constructed between 2885 and 2889 ft. In areas above minimum pool, intergravel dissolved oxygen concentrations were adequate for embryo survival and exhibited a decrease with depth. Limited data indicated apparent velocity may be the key in determining redd distribution. Seventy-five percent of the redds located below minimum pool were constructed in a zone between 2869 and 2883 ft. In individual areas, apparent velocity measurements and intergravel dissolved oxygen concentrations were related to redd density. The variationmore » in intergravel dissolved oxygen concentrations in the Yellow Bay spawning area was partially explained by lake stage fluctuation. As lake stage declined, groundwater apparent velocity increased which increased intergravel dissolved oxygen concentrations. Mean survival to the eyed stage in the three areas below minimum pool was 43 percent. Prior to exposure by lake drawdown, mean survival to the eyed stage in spawning areas above minimum pool was 87 percent. This indicated habitat most conducive to successful embryo survival was in gravels above 2883 ft. prior to significant exposure. Survival in redds exposed to either extended periods of drawdown or to temperatures less than -10% was significantly reduced to a mean of 20-30 percent. Survival in individual spawning areas exposed by lake drawdown varied from 0 to 65 percent. Groundwater reaction to lake stage explained some of the variation in individual spawning area survival. Three types of groundwater reaction to lake stage were identified. Increased survival in exposed redds resulted from two of the three types. A significant statistical relationship was determined between embryo survival and the number of days exposed by lake drawdown. The operation of Kerr Dam in 1983-84 was characterized by an early decline in lake stage, a longer period near minimum pool

and a later and more rapid filling compared to the operation seen in 1981-82 and 1982-83. Based on the survival relationship observed in natural redds exposed by drawdown in 1983-84, complete mortality from exposure would have occurred to all redds constructed above 2884.7 ftor 90 percent of all redds constructed above minimum pool. Emergence traps placed over redds below minimum pool in Gravel, Blue, and Yellow bays captured fry in Gravel and Blue bays only. Duration of fry emergence in1984 was three weeks longer than in 1982 or 1983, but was not related to the date of initial redd construction. Survival to fry emergence in Gravel Bay was calculated to be 28.9 percent of egg deposition or 57,484 fry. Survival to fry emergence above and below the zone of greatest redd density was 33.6 and 245 percent, respectively, indicating a relationship between survival and spawner site selection. After analysis of the historic operation of Kerr Dam, it is believed that the dam has, and is continuing to have, a significant impact on successful shoreline spawning of kokanee salmon in Flathead Lake. Based on the evidence that prolonged exposure of salmonid embryo by dewatering causes significant mortality, the number of days the lake was held below various foot increments (2884 ft to 2888 ft) during the incubation period was investigated. The annual change in the number of days the lake was held below 2885 ft was further investigated because 80-90 percent of he redds constructed in spawning areas above minimum pool during this study were above this level. The operation since 1977 was found to be the least conducive to successful shoreline spawning since the earliest operation of the dam. A significant relationship was established between female kokanee length, which is a measure of year class strength, and the number of days that lake levels were held below 2885 feet from 1966-1983. This relationship indicated that kokanee year class strength in Flathead Lake has been affected by the operations of Kerr Dam. The addition of lake level data improved the correlation in the Flathead River gauge height model, indicating kokanee year class strength has been affected by the operations of both Kerr and Hungry Horse dams.

Delaval, A., Solås, M. R., Skoglund, H., & Salvanes, A. G. V. (2021). Does vaterite otolith deformation affect post-release survival and predation susceptibility of hatchery-reared juvenile Atlantic salmon? *Frontiers in Veterinary Science,* 8, 709850. https://doi.org/10.3389/fvets.2021.709850

Sagittal otoliths are calcareous structures in the inner ear of fishes involved in hearing and balance. They are usually composed of aragonite; however, aragonite can be replaced by vaterite, a deformity which is more common in hatchery-reared than in wild fish. Vaterite growth may impair hearing and balance and affect important fitness-related behaviours such as predator avoidance. Captive rearing techniques that prevent hearing loss may have the potential to improve fish welfare and the success of restocking programmes. The aim of this study was to test the effect of structural tank enrichment on vaterite development in the otoliths of hatchery-reared juvenile Atlantic salmon Salmo salar, and to assess the effects of vaterite on immediate predation mortality and long-term survival after release into the wild. Fry were reared in a structurally enriched or in a conventional rearing environment and given otolith marks using alizarin during the egg stage to distinguish between the treatment groups. Otoliths were scrutinised for the presence and coverage of vaterite at 6, 13, and 16 weeks after start feeding, and the growth traits were measured for enriched and control fry when housed in tanks. In a subsequent field experiment, juveniles were released in the Rasdalen river (western Norway), and otoliths of enriched reared and control reared fry were scrutinised from samples collected immediately prior to release, from predator (trout Salmo trutta) stomachs 48 h after release and from recaptures from the river 2-3 months after release. Vaterite otoliths occurred as early as 6 weeks after start feeding in hatchery-reared S. salar. Vaterite occurrence and coverage increased with fish length. Enriched rearing had no direct effect on vaterite formation, but enriched reared fry grew slower than control fry. After release into the wild, fewer salmon fry with vaterite otoliths had been eaten by

predators, and a higher proportion of fry with vaterite otoliths than those lacking vaterite were recaptured in the river 2-3 months after release. Contrary to expectations, this suggests that vaterite does not increase predation mortality nor reduce survival rates in the wild during the early life stages.

Dill, L. M., & Northcote, T. G. (1970). Effects of some environmental factors on survival, condition, and timing of emergence of chum salmon fry (Oncorhynchus keta). *Journal of the Fisheries Board of Canada,* 27(1), 196-201. https://doi.org/10.1139/f70-026

In an experiment in incubation channels at Robertson Creek, B.C., survival of chum salmon from planting of eggs to emergence of fry was higher in large gravel (2–4 inches, 5.1–10.2 cm) than in small gravel (0.4–1.5 inches, 1.0–3.8 cm). Neither condition coefficient nor timing of emergence was affected by gravel size. There were no significant effects of egg burial depth (8 and 12 inches, 20.3 and 30.5 cm) or density (50 and 100 per treatment) on condition coefficient, or timing of emergence.

Duffy, T. A., Iwanowicz, L. R., & McCormick, S. D. (2014). Comparative responses to endocrine disrupting compounds in early life stages of Atlantic salmon, Salmo salar. *Aquatic Toxicology,* 152, 1-10. https://doi.org/10.1016/j.aquatox.2014.03.015

Atlantic salmon (Salmo solar) are endangered anadromous fish that may be exposed to feminizing endocrine disrupting compounds (EDCs) during early development, potentially altering physiological capacities, survival and fitness. To assess differential life stage sensitivity to common EDCs, we carried out short-term (4 day) exposures using three doses each of 17 alpha-ethinylestradiol (EE2), 17 beta-estradiol (E2), and nonylphenol (NP) on four early life stages; embryos, yolk-sac larvae, feeding fry and 1 year old smolts. Differential response was compared using vitellogenin (Vtg, a precursor egg protein) gene transcription. Smolts were also examined for impacts on plasma Vtg, cortisol, thyroid hormones (T-4/T-3) and hepatosomatic index (HSI). Compound-related mortality was not observed in any life stage, but Vtg mRNA was elevated in a dose-dependent manner in yolk-sac larvae, fry and smolts but not in embryos. The estrogens EE2 and E2 were consistently stronger inducers of Vtg than NP. Embryos responded significantly to the highest concentration of EE2 only, while older life stages responded to the highest doses of all three compounds, as well as intermediate doses of EE2 and E2. Maximal transcription was greater for fry among the three earliest life stages, suggesting fry may be the most responsive life stage in early development. Smolt plasma Vtg was also significantly increased, and this response was observed at lower doses of each compound than was detected by gene transcription suggesting plasma Vtg is a more sensitive indicator at this life stage. HSI was increased at the highest doses of EE2 and E2, and plasma T-3 was decreased at the highest dose of EE2. Our results indicate that all life stages are potentially sensitive to endocrine disruption by estrogenic compounds and that physiological responses were altered over a short window of exposure, indicating the potential for these compounds to impact fish in the wild. (C) 2014 Elsevier B.V. All rights reserved.

Dumas, J., & Marty, S. (2006). A new method to evaluate egg-to-fry survival in salmonids, trials with Atlantic salmon. *Journal of Fish Biology,* 68(1), 284-304. https://doi.org/10.1111/j.0022-1112.2006.00907.x

A new method to estimate the survival of salmonids from egg fertilization to fry emergence is described. Fine mesh screen cylindrical capsules, 12 cm(3) in volume, filled with batches of 10 eggs of Atlantic

salmon Salmo salar were implanted in the substratum using small removable guiding tubes inserted with a metal spike. The method was compared with two other commonly used techniques, capping redds with fry-traps and fine mesh screen incubation-emergence boxes buried into the gravel. Egg-to-fry survival was recorded for the three methods run in parallel in artificial redds created on three sites of the Nivelle River watershed (south-west of France), two in the stream and one in an experimental spawning channel. In the channel, survival to the eyed stage and to hatching in capsules and incubation-emergence boxes was also compared. The implant of capsules proved easier and faster to use than other methods, the structure of the surrounding substratum was less disturbed and the capsules were less vulnerable to spates. This technique provided survival values largely free of the bias induced by other methods and intermediate between that of incubators and of traps. (c) 2006 The Fisheries Society of the British Isles.

Egglishaw, H. J., & Shackley, P. E. (1973). An experiment on faster growth of salmon Salmo salar (l.) in a scottish stream. *Journal of Fish Biology,* 5(2), 197-204. https://doi.org/10.1111/j.1095-8649.1973.tb04448.x

The experiment was made in an attempt to modify the usual relationship in which young trout grow faster than young salmon in streams in which they occur together. A stretch of a trout stream was stocked with advanced salmon eggs, which produced fry earlier than the trout eggs laid naturally. The salmon grew faster than the trout and were longer than the trout at the end of the growing season. The mean length of 77.7 mm attained by the salmon is the largest known size reached by salmon in their first year when feeding on natural food supplies in streams in Scotland. Survival rate from egg planting to production of salmon of this mean length was high.

Egglishaw, H. J., & Shackley, P. E. (1980). Survival and growth of salmon, Salmo salar-(l), planted in a scottish stream. *Journal of Fish Biology,* 16(5), 565-584. https://doi.org/10.1111/j.1095-8649.1980.tb03734.x

Salmon eggs and unfed fry were planted in reaches (total length 2.8 km, mean width 4 m) of a Scottish stream between 1971 and 1977 and their subsequent progress was studied by sampling 16 sections (areas 38-126 m2) of the stream. Brown trout are the only fish which spawn in the stream, waterfalls and a dam near its mouth preventing adult salmon and sea-trout passing upstream. There were no restraints on the downstream movement of fish except in 1977, when a fry trap was operated. In 1971 and 1974 boxes each containing 300 eggs were buried in groups of 3-6. In other years fry were evenly distributed at 3.6-29.3 m-2. At the end of the first growing season, salmon occurred at decreasing population densities for a distance of 600 m below the planting, but after two growing seasons there was little remaining indication of their pattern of dispersion when planted. Rates of survival between planting and the end of the growing season were 94-3 1Yo. Survival when eggs were planted (1 I. 1448%) was not affected by the numbers planted together at one point (900-1 800) or the distance apart of groups of boxes (10-85 m). When fry were planted the instantaneous mortality rate (M) of the O+ salmon during their first growing season was related to the initial stocking density (Dp) by the formula M= 0.00637 + 0.00444 log,, Dp.. Twenty-two to 88% of O+ salmon present at the end of the growing season were still surviving in the stream as I+ fish one year later. In 1973-1976 only a small number of 2+ salmon occurred, the majority having migrated between the end of the second growing season and the following spring. There were more 2+ salmon in 1977 and 1978 resulting from higher stocking densities in 1975 and 1976 and slower growth. Trout of several age classes were present but

their population densities were never high (~0.6 m-2). Salmon reached a greater size than trout by the end of the first growing season. Their mean weight (W,,, g) at this time was inversely related to their population density (Do- No. m-2) and the biomass (B,, g m-2) of I+ salmon present, giving the relationship log,, W, =O6584-O.0558 Do-0.0352B,. The mean weight of I+ salmon tended to be highest in sections where the O+ salmon had reached a relatively large size the previous year. When a reach of the stream was planted twice (I I and 30 May 1977) with salmon fry (total 13.9 m-2) at the same stage of development, M during the first growing season was 0.0099 per day. This was less than that of fry in a control (M= 00107) where the stocking density was lower (6.8 m-2) and also less than in previous years when single planting rates of approximately 14 m-* were used (M=0.0115). The double planting resulted in a wide range of lengths ofO+ salmon in September and the highest biomass values encountered during all experiments.

Ellen Marsden, J., Ellrott, B. J., Claramunt, R. M., Jonas, J. L., & Fitzsimons, J. D. (2005). A comparison of lake trout spawning, fry emergence, and habitat use in lakes Michigan, Huron, and Champlain. *Journal of Great Lakes Research,* 31(4), 492-508. https://doi.org/10.1016/S0380-1330(05)70279-3

Restoration of self-sustaining populations of lake trout is underway in all of the Great Lakes and Lake Champlain, but restoration has only been achieved in Lake Superior and in Parry Sound, Lake Huron. We evaluated progress toward restoration by comparing spawning habitat availability, spawner abundance, egg and fry density, and egg survival in Parry Sound in Lake Huron, in Lake Michigan, and in Lake Champlain in 2000–2003. Divers surveyed and assessed abundance of spawners at 5 to 15 sites in each lake. Spawning adults were sampled using standardized gill nets, eggs were sampled using egg bags, and fry were sampled using emergent fry traps and egg bags left on spawning reefs overwinter. Spawning habitat was abundant in each lake. Adult lake trout abundance was low in Lake Michigan and Parry Sound, and very high at one site in Lake Champlain. Egg deposition was lowest in Lake Michigan (0.4–154.5 eggs•m−2, median = 1.7), intermediate in Parry Sound (39–1,027 eggs•m−2, median = 278), and highest in Lake Champlain (0.001–9,623 eggs•m−2, median = 652). Fry collections in fry traps followed the same trend: no fry in Lake Michigan, 0.005–0.06 fry•trap−1 day−1 in Parry Sound, and 0.08–3.6 fry•trap−1 in Lake Champlain. Egg survival to hatch in overwinter egg bags was similar in Lake Michigan (7.6%) and Parry Sound (2.3–8.9%) in 2001–02, and varied in Lake Champlain (0.4–1.1% in 2001–02, and 1.8–18.2 in 2002–03). Lake trout restoration appears unlikely in northern Lake Michigan at current adult densities, and failure of restoration in Lake Champlain suggests that there are sources of high mortality that occur after fry emergence.

Elliott, J. M., & Elliott, J. A. (2010). Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic charr Salvelinus alpinus: Predicting the effects of climate change. *Journal of Fish Biology,* 77(8), 1793-1817. https://doi.org/10.1111/j.1095-8649.2010.02762.x

Atlantic salmon Salmo salar, brown trout Salmo trutta (including the anadromous form, sea trout) and Arctic charr Salvelinus alpinus (including anadromous fish) provide important commercial and sports fisheries in Western Europe. As water temperature increases as a result of climate change, quantitative information on the thermal requirements of these three species is essential so that potential problems can be anticipated by those responsible for the conservation and sustainable management of the fisheries and the maintenance of biodiversity in freshwater ecosystems. Part I compares the temperature limits for survival, feeding and growth. Salmo salar has the highest temperature tolerance,

followed by S. trutta and finally S. alpinus. For all three species, the temperature tolerance for alevins is slightly lower than that for parr and smolts, and the eggs have the lowest tolerance; this being the most vulnerable life stage to any temperature increase, especially for eggs of S. alpinus in shallow water. There was little evidence to support local thermal adaptation, except in very cold rivers (mean annual temperature < 6 center dot 5 degrees C). Part II illustrates the importance of developing predictive models, using data from a long-term study (1967-2000) of a juvenile anadromous S. trutta population. Individual-based models predicted the emergence period for the fry. Mean values over 34 years revealed a large variation in the timing of emergence with c. 2 months between extreme values. The emergence time correlated significantly with the North Atlantic Oscillation Index, indicating that interannual variations in emergence were linked to more general changes in climate. Mean stream temperatures increased significantly in winter and spring at a rate of 0 center dot 37 degrees C per decade, but not in summer and autumn, and led to an increase in the mean mass of pre-smolts. A growth model for S. trutta was validated by growth data from the long-term study and predicted growth under possible future conditions. Small increases (< 2 center dot 5 degrees C) in winter and spring would be beneficial for growth with 1 year-old smolts being more common. Water temperatures would have to increase by c. 4 degrees C in winter and spring, and 3 degrees C in summer and autumn before they had a marked negative effect on trout growth.

Eskelinen, P. (1989). Effects of different diets on egg-production and egg quality of Atlantic salmon (Salmo salar l). *Aquaculture,* 79(1-4), 275-281. https://doi.org/10.1016/0044-8486(89)90468-7

Four-year-old Atlantic salmon broodstock were fed different feeds. These included five dry and five semimoist feeds and smelt (Osmerus eperlanus) as a fresh feed. The feeds differed according to their moisture, amount and composition of lipids and contents of alpha-tocopherol and ascorbic acid. The fish were stripped and fertilized individually and eggs of six females from each feeding group were incubated separately. Survival rates to eyeing, hatching and start-feeding were determined. The best growth of the broodstock fish was obtained when fat-supplemented semimoist feed was given. The gonadosomatic index did not differ using semimoist and fresh feeds, and was slightly reduced using dry feeds. The relative fecundity was highest with the semimoist feeds and lowest with the dry feeds. The diameter of swollen eggs varied little between the groups. Survival before the eyed stage ranged from 75.9% to 97.5% and from fertilization to the end of start-feeding from 61.2% to 92.7%. For most of the measured parameters, variations within the groups were conspicuous. In this study, a high alpha-tocopherol content in the feed did not increase survival of eggs and fry, but a high vitamin C content seemed to have such an effect.

Essington, T. E., Quinn, T. P., & Ewert, V. E. (2000). Intra- and inter-specific competition and the reproductive success of sympatric Pacific salmon. *Canadian Journal of Fisheries and Aquatic Sciences,* 57(1), 205-213. https://doi.org/10.1139/cjfas-57-1-205

Individual female Pacific salmon fight for breeding space with conspecific and heterospecific females. We evaluated the consequences of this competition on the reproductive success of sockeye (Oncorhynchus nerka), chum (Oncorhynchus keta), and pink salmon (Oncorhynchus gorbuscha) in the Weaver Creek spawning channel, British Columbia. We hypothesized that differences in body size, relative abundance, and spawning date would influence the magnitude of interspecific interactions. Reproductive success (survival rate of eggs to emigrating fry) of the most abundant species, sockeye, was strongly and inversely correlated with conspecific abundance but not with the abundance of the

other, less abundant species. Chum reproductive success was inversely correlated with sockeye abundance but not with the abundance of the scarce and smaller pink. Surprisingly, pink reproductive success was not correlated with sockeye abundance and only marginally correlated with chum abundance despite the fact that pink are smaller and spawn earlier than sockeye. Thus, intra- and inter-specific competition can substantially affect salmon reproductive success, but the magnitude of the competitive effects may depend on relative abundance, size, spawning date, and microhabitat preferences.

Fischer, G. J., Hartleb, C., Holmes, K., Hansum, C., & Tintle, N. (2022). Lake herring (Coregonus artedi) aquaculture best-practices: Randomized experiments from eggs to juvenile. *North American Journal of Aquaculture*. https://doi.org/10.1002/naaq.10267

Lake Herring (also known as Cisco) Coregonus artedi, a cold-water salmonid found in the Great Lakes is of interest to multiple agencies for restoration and conservation purposes due to their important ecological role. Further information on rearing and restocking of Cisco are needed, especially understanding the biological culture needs of eggs, larvae, and fingerling Cisco. To address this gap in the literature and provide needed fish culture information, we performed three early preliminary studies in 2010 with Lake Herring: fertilization (wet versus dry fertilization), egg survival (pre-water hardening versus post-water hardening iodine treatment), and fry development with three different larval feed treatments commercially available at this time. Dry fertilization methodology (68%) had a significantly better eye-up percentages when compared to wet fertilization (34%). Additionally, our testing revealed higher survival rates when iodophor treatment was used on fertilized eggs post-water hardening (54%) in comparison to before water hardening (43%). Although mean survival rates across the three diet treatments were not statistically significant, larval Lake Herring fed artemia replacement diets outperformed the other diets with Inve-Proton diet ranking best. These early preliminary studies substantially increased understanding of the optimum culturing parameters of Lake Herring in preparation for widespread production of this important species and provide propagation recommendations for conservation stocking programs.

Fitzgerald, G. J., & Caza, N. (1993). Parental investment in an anadromous population of threespine sticklebacks - an experimental-study. *Evolutionary Ecology,* 7(3), 279-286. https://doi.org/10.1007/bf01237745

Two previously published field studies of threespine sticklebacks conducted to test predictions of parental investment (PI) theory yielded different conclusions about how males invest in their young. Males of a freshwater population invested more in older/larger broods whereas environmental factors played no role in PI decisions. In contrast, males of an anadromous population adjusted levels of PI in response to environmental factors rather than brood characteristics. The current laboratory study attempts to determine possible reasons for the discrepancy between these two studies. We addressed the following questions. Do males invest more in larger/older broods? Do environmental factors affect levels of parental investment? Males were more aggressive (a measure of PI) in defending eggs than empty nests and free-swimming fry. However, aggression was similar for different-aged eggs and different-aged fry. Moreover, when we manipulated brood sizes (fry), males did not change their level of investment. Males increased their level of aggressive defence in response to a rise in water level, indicating that they can adjust their level of investment in response to changes in environmental conditions that affect brood survival.

Flagg, T. A. (1988). *Cle Elum Lake sockeye salmon restoration feasibility study, 1986-1988 progress report.* Office of Scientific and Technical Information (OSTI), https://doi.org/10.2172/6675268

In 1986, a multi-year project to evaluate the biological feasibility of reestablishing anadromous sockeye salmon (Oncorhynchus nerka) runs to Cle Elum Lake in the Yakima River Basin was established between the Bonneville Power Administration (BPA) and the National Marine Fisheries Service (NMFS). This program involves the capture, spawning, and rearing of disease-free donor stock in 1987 and 1988 and assessment of juvenile outmigration and survival from Cle Elum Lake in 1989 and 1990. Work in 1987--1988 involved collection of adult sockeye salmon from the Lake Wenatchee run and incubation and rearing of progeny as donor stock. In July 1987, 263 adults were captured at the Dryden fishway on the Wenatchee River and transferred to net-pens in Lake Wenatchee. Adults were held approximately 90 days and spawned, and the eggs were transferred to a quarantine hatchery. Pre-spawning survival was 95.1%, and all spawners were certified as being free of Infectious Hematopoietic Necrosis (IHN) and other replicating viruses. Egg viability averaged about 40%; however, eyed egg to hatch survival was over 99%. Juveniles are being reared in quarantine, and survival to date is about 92%. The NMFS currently has over 131,000 fry (0.7 g average weight) in culture. Fry have been certifiedmore » twice (at 0.12 g and 0.25 g average weight) as being free of IHN and other replicating viruses. Viral certification will continue throughout rearing. 13 refs., 4 figs., 3 tabs.« less

Flanagan, J. J. (2003). *The impacts of fine sediments and variable flow regimes on the habitat and survival of Atlantic salmon (Salmo salar) eggs.* (Master of Science), University of New Brunswick, Retrieved from https://unb.ca/research/institutes/cri/_resources/pdfs/Flanagan%20MSc%20Thesis.pdf

This thesis evaluated a newly modified incubation basket design and applied this method to study the impacts of two human-made disturbances on survival and habitat of incubating Atlantic salmon (Salmo salar) eggs. In Catamaran Brook (Miramichi) the effects of fine sediments (<2mm) from forestry activities were investigated, and in rivers within the Tobique River Basin the effects of variable flow regimes from hydroelectric dams were assessed. Using baskets buried in situ, the overall mean survival to the eyed stage in Catamaran Brook from 1994-1997 was 80% (range 65-98%) and from 1998-2000 was 95% (range 83-100%). Emergence survival was generally much more variable and ranged from 2 to 83% from 1994-1997 and 47 to 85% in 1998-2000. The percent fines measured in 1998- 99 and 1999-00 was <13%, which suggested fine sediment amounts in Catamaran Brook were minimal compared to the literature and did not negatively affect egg survival. In the Tobique River Basin from 1997-2000, rivers regulated by hydroelectric dams in the headwater reaches showed lower mean survivals to the eyed and hatch stages than in an unregulated, control river. The regulated rivers also experienced more discharge and temperature variability during the winter, an advancement of embryo development (degree-days), and a higher incidence of scour of the streambed, which are all believed to have negatively affected survival.

Fowler, L. G. (1972). Growth and mortality of fingerling Chinook salmon as affected by egg size. *Progressive Fish-Culturist,* 37(2), 66-69. https://doi.org/10.1577/1548-8640(1972)34[66:Gamofc]2.0.Co;2

3 experiments have been carried out to ascertain the effect of egg size on the growth and mortality of fingerling Chinook salmon: (1) 4 females were paired one with large eggs with one with small. Each pair was fertilised with semen from the same male. (2) 10 females were similarly paired and fertilised and (3)

20 females were sorted into 5 groups of differing egg size and each group fertilised by the same male. The fry produced in each experiment were reared for 11, 12 and 4 wk respectively. All experiments confirmed that fish hatched from large eggs were large initially and maintained their size superiority during the early stages of rearing. However eggs, fry and fingerlings from large eggs-usually produced by older females-sustained higher mortality rates. Elimination of large-egg producing fish would result in the development of a str with higher hatchery survival but maximal growth may not be attained.

Fraley, J. J., Gaub, M. A., & Cavigli, J. R. (1986). Emergence trap and holding bottle for the capture of salmonid fry in streams. *North American Journal of Fisheries Management,* 6(1), 119-121. https://doi.org/10.1577/1548-8659(1986)6<119:etahbf>2.0.co;2

A 0.12-m 2 fry emergence trap was constructed of rigid steel strip, plumber's tape, and nylon netting. A holding bottle was fashioned from a polyethylene screw cap bottle and plastic funnel. The trap was inexpensive, durable, and effective in a wide range of current velocities. The method proved effective in estimating egg-to-fry survival rates for kokanee (Oncorhynchus nerka) in various sediment mixtures. Egg-to-fry survival varied from 0 to 52%, and was negatively correlated to percent fines ($r = 0.91$; $P < 0.01$). The emergence period indicated by the trap catches in McDonald Creek agreed closely with the period indicated by drift-net sampling. Fry mortality in the holding bottle was almost nil if the trap was checked at least once a week.

Franssen, J., Blais, C., Lapointe, M., Berube, F., Bergeron, N., & Magnan, P. (2012). Asphyxiation and entombment mechanisms in fines rich spawning substrates: Experimental evidence with brook trout (Salvelinus fontinalis) embryos. *Canadian Journal of Fisheries and Aquatic Sciences,* 69(3), 587-599. https://doi.org/10.1139/f2011-168

We investigated the distinct physical controls causing entombment and asphyxiation, the key mechanisms influencing salmonid egg-to-emergence (EtE) survival. Entombment occurs when sediment blocks the interstitial pathways (macropores) that larvae use to emerge from the streambed, while asphyxiation is related to low oxygen flux, which is a function of interstitial flow velocity. EtE survival has been related to substrate composition and flow velocity. However, in streambed sediments these variables are correlated, and few studies have examined the sensitivity of EtE survival to changes in velocity and oxygen flux at fixed substrate composition. EtE survival has not yet been directly related to the size and density of macropores. We incubated brook trout (Salvelinus fontinalis) embryos in artificial redds with different sediment compositions and hydraulic gradients to examine independently the effects of substrate composition, macropore geometry, and flow velocity on EtE survival, emergence timing, and fry condition. In situ measurements of macropore size were obtained using a computed tomography scanner. Despite high oxygen concentrations, we observed that entombment or blockage effects caused high embryo mortality in fines-rich substrates with few large macropores, and triggered early emergence of rare survivors. These outcomes could not be mitigated by increased flow velocity and oxygen flux to the egg pocket.

Fukushima, M., & Smoker, W. W. (1997). Determinants of stream life, spawning efficiency, and spawning habitat in pink salmon in the Auke Lake system, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences,* 54(1), 96-104. https://doi.org/10.1139/f96-258

Variation in stream life, spawning efficiency, and spawning habitat among adult pink salmon (Oncorhynchus gorbuscha) in the Auke Lake system, southeastern Alaska, was best explained by stream discharge, stream temperature, and a combination of stream temperature and discharge. We estimated these attributes of female pink salmon spawners in samples of daily cohorts tagged as they entered fresh water and used generalized linear models to analyze variation in the attributes with respect to environmental factors. Spawners varied in stream life (5-11 days), spawning efficiency (30-70% of females in daily entry cohorts retained less than 500 eggs at death), and spawning habitat (30-70% spawned in the lake outlet stream rather than the lake inlet stream). Observed variation of habitat (proportionately more use of the cooler inlet stream early in the spawning season when stream temperatures are warm and development is rapid) would contribute to synchronicity of fry emigration, which is known to be positively correlated with subsequent survival in Auke Lake pink salmon.

Gallinat, M. P., Bumgarner, J. D., & Ross, L. A. (2022). Efficacy of a short-term captive broodstock program compared with hatchery-origin spring Chinook salmon derived from the same population. *North American Journal of Aquaculture*. https://doi.org/10.1002/naaq.10259

We examined the efficacy of a one-generation (five brood years: 1997-2001) captive broodstock program for spring Chinook Salmon Oncorhynchus tshawytscha by comparing survival rates of captive broodstock progeny (CBP; F-2) with that of hatchery-origin fish (HOR) from a conservation hatchery supplementation program in which both groups were derived from the Tucannon River (Washington State) population for the 2000-2006 brood years. Survival rates compared were egg to fry, fry to smolt, egg to smolt, total (ages 3-5) and adult (ages 4+) smolt-to-adult-return (SAR) survival, and total (ages 3-5) and adult (ages 4+) progeny-to-parent (P:P) ratio. Total escapement and adult P:P ratios were also examined to determine if observed demographic benefits to the population continued after the captive broodstock program ended. The CBP group had lower within-hatchery survival than the HOR group, with significant differences in survival at the egg-to-fry and egg-to-smolt stages due to poor egg viability. Mean untransformed total and adult SARs for the CBP were half those of the HOR group; however, SARs did not differ significantly. The CBP also had significantly lower total and adult P:P ratios than the HOR group and were below replacement for six of the seven brood years. While the captive broodstock provided additional fish for release that would not have been available otherwise, overall the CBP performed poorly and below expectations compared with the HOR group, both within the hatchery and after release. The captive broodstock program provided a short-term demographic boost, most notable in the 2008-2010 return years, but the benefit did not carry over after the program ended.

Garling, D. L., & Masterson, M. (1985). Survival of Lake Michigan Chinook salmon eggs and fry incubated at 3 temperatures. *Progressive Fish-Culturist,* 47(1), 63-66. https://doi.org/10.1577/1548-8640(1985)47<63:Solmcs>2.0.Co;2

One of the primary environmental factors affecting the growth and survival of salmonids is temperatue. All salmonids have a species specific optimum temperature range in which growth and survival can be maximized. Outside this range growth and survival will decrease.

Geist, D. R., Abernethy, C. S., Hand, K. D., Cullinan, V. I., Chandler, J. A., & Groves, P. A. (2006). Survival, development, and growth of fall Chinook salmon embryos, alevins, and fry exposed to variable thermal and dissolved oxygen regimes. *Transactions of the American Fisheries Society,* 135(6), 1462-1477. https://doi.org/10.1577/t05-294.1

Some fall Chinook salmon Oncorhynchus tshawytscha initiate spawning in the Snake River downstream of Hells Canyon Dam at temperatures that exceed 13 degrees C and at intergravel dissolved oxygen concentrations that are less than 8 mg O-2/L. Although water temperature declines and dissolved oxygen increases soon after spawning, the initial temperature and dissolved oxygen levels do not meet the water quality standards established by the states of Oregon and Idaho for salmonid spawning. Our objective was to determine whether temperatures from 13 degrees C to 17 degrees C and dissolved oxygen levels from 4 to more than 8 mg O-2/ L during the first 40 d of incubation followed by declining temperature and rising dissolved oxygen affected survival, development, and growth of Snake River fall Chinook salmon embryos, alevins, and fry. During the first 40 d of incubation, temperatures were experimentally adjusted downward approximately 0.2 degrees C/d and oxygen was increased in increments of 2 mg O-2/L to mimic the thermal and oxygen regime of the Snake River where these fish spawn. At 40 d postfertilization, embryos were moved to a common exposure regime that followed the thermal and dissolved oxygen profile of the Snake River through emergence. Mortality of fall Chinook salmon embryos increased markedly at initial incubation temperatures of 17 degrees C or more, and a rapid decline in survival occurred between 16.5 degrees C and 17 degrees C; there were no significant differences in survival at temperatures up to 16.5 degrees C. Initial dissolved oxygen levels as low as 4 mg O-2/L over a range of initial temperatures from 15 degrees C to 16.5 degrees C did not affect embryo survival to emergence. There were no significant differences in alevin and fry size at hatch and emergence across the range of initial temperature exposures. The number of days from fertilization to eyed egg, hatch, and emergence was highly related to temperature and dissolved oxygen; fish required from 6 to 10 d longer to reach hatch at 4 Mg O-2/L than at saturation and up to 24 d longer to reach emergence. In contrast, within each dissolved oxygen treatment, fish required about 20 d longer to reach hatch at 13 degrees C than at 16.5 degrees C (no data were available for 17 degrees C) and up to 41 d longer to reach emergence. Overall, this study indicates that exposure to water temperatures up to 16.5 degrees C will not have deleterious effects on survival or growth from egg to emergence if temperatures decline at a rate of 0.2 degrees C/d or more after spawning. Although fall Chinook salmon survived low initial dissolved oxygen levels, the delay in emergence could have significant long-term effects on their survival. Thus, an exemption to the state water quality standards for temperature-but not oxygen-may be warranted for the portions of the Snake River where fall Chinook salmon spawn.

Geist, J. (2016). *Importance and restoration of stream bed substrates in european catchments.* Paper presented at the 11th International Symposium on Ecohydraulics, Melbourne, AUSTRALIA. Retrieved from https://asnevents.s3.amazonaws.com/Abstrakt-FullPaper/26138/Geistfinal.pdf

The stream bed is an important habitat for many species and is crucial for ecosystem functioning. This paper addresses the factors that determine stream bed functioning, the methodological approaches used to characterize the quality of this habitat, and the options to restore it. Using the examples of endangered European freshwater mussel and fish species, the crucial substrate-dependent physicochemical variables that determine the recruitment success in those species are illustrated. Models integrating texture and substrate penetration resistance allow characterization of the exchange between open and interstitial water, which in turn determines the redox potential in the stream bed and biological responses such as egg-to-fry survival in salmonid fishes. The use of bioindicator tools such

as the "egg sandwich" can be useful in pre-assessment of restoration success and in deciding priority areas for restoration. As evident from case studies in Germany, increased amounts of fine sediment in streams often result from changes in catchment management and cannot be sufficiently addressed by in-stream measures. A comparison of frequently used techniques of stream substrate restoration in Europe reveals that one of the most heavily used techniques, the loosening of substrate with an excavator, was least sustainable, additionally resulting in the strongest adverse effects on downstream habitats compared to all other techniques. This example illustrates that restoration of stream substrates primarily needs to address catchment management measures such as erosion control, and restoration of environmental water flow regimes that determine sedimentation and colmation patterns.

Gendaszek, A. S., Burton, K., Magirl, C. S., & Konrad, C. P. (2018). Streambed scour of salmon spawning habitat in a regulated river influenced by management of peak discharge. *Freshwater Biology,* 63(8), 917-927. https://doi.org/10.1111/fwb.12987

In the Pacific Northwest of the United States, salmon eggs incubating within streambed gravels are susceptible to scour during floods. The threat to egg-to-fry survival by streambed scour is mitigated, in part, by the adaptation of salmon to bury their eggs below the typical depth of scour. In regulated rivers globally, we suggest that water managers consider the effect of dam operations on scour and its impacts on species dependent on benthic habitats. We instrumented salmon-spawning habitat with accelerometer scour monitors (ASMs) at 73 locations in 11 reaches of the Cedar River in western Washington State of the United States from Autumn 2013 through the Spring of 2014. The timing of scour was related to the discharge measured at a nearby gage and compared to previously published ASM data at 26 locations in two reaches of the Cedar River collected between Autumn 2010 and Spring 2011. Thirteen percent of the recovered ASMs recorded scour during a peak-discharge event in March 2014 (2-to 3-year recurrence interval) compared to 71% of the recovered ASMs during a higher peak-discharge event in January 2011 (10-year recurrence interval). Of the 23 locations where ASMs recorded scour during the2011 and 2014 deployments, 35% had scour when the discharge was 87.3m(3)/s (3,082ft(3)/s) (2-year recurrence interval discharge) with 13% recording scour at or below the 62.3m(3)/s (2,200ft(3)/s) operational threshold for peak-discharge management during the incubation of salmon eggs. Scour to the depth of salmon egg pockets was limited during peak discharges with frequent (1.25-year or less) recurrence intervals, which managers can regulate through dam operations on the Cedar River. Pairing novel measurements of the timing of streambed scour with discharge data allows the development of peak-discharge management strategies that protect salmon eggs incubating within streambed gravels during floods.

Gibson, R. J. (2010). Regulation of the fitness of altantic salmon (Salmo salar) by intra-specific competition amongst the juveniles. In *Freshwater Forum* (Vol. 5, pp. 54-72). Retrieved from https://aquadocs.org/handle/1834/22163

Factors affecting the fitness of juvenile salmon are discussed. Although fitness from the genetic point of view is defined as the relative capacity of carriers of a given genotype to transmit their genes to the gene pool of the following generations, growth and survival of individuals are also components of fitness, and are influenced by responses to competition, which is the major topic of this article including implications for management. In order to better understand the relationships of density-dependent survival in Newfoundland, egg depositions were manipulated experimentally in the Freshwater River. Figures demonstrate the relationship between stock (number of eggs per 100 m2 of river) and

recruitment (number of smolts per l00 m2 of Atlantic salmon, and also the percentage survival from egg to smolt stage related to potential egg depositions.

Gillson, J. P., Maxwell, D. L., Gregory, S. D., Posen, P. E., Riley, W. D., Picken, J. L., & Assunção, M. G. L. (2020). Can aspects of the discharge regime associated with juvenile Atlantic salmon (Salmo salar l.) and trout (S. trutta l.) densities be identified using historical monitoring data from five uk rivers? *Fisheries Management and Ecology,* 27(6), 567-579. https://doi.org/10.1111/fme.12456

Understanding salmonid discharge requirements can help inform management to conserve wild populations in a changing climate. This study developed Bayesian hierarchical mixed-effects models relating 0+ Atlantic salmon (Salmo salar L.) and trout (Salmo trutta L.) densities to different aspects of river discharge. Associations between these densities and nine hydrological variables representing the magnitude, frequency and duration of discharge events were evaluated using historical monitoring data from 36 sites on five rivers in England and Wales. All hydrological variables had weak associations with 0+ salmonid densities. More frequent high discharges between spawning and emergence were positively and negatively associated with 0+ salmon and trout densities, respectively. High discharges might increase spawning site availability for salmon and decrease egg-to-fry survival for trout. However, overall, only equivocal evidence was found regarding which discharge aspects affect juvenile salmonid densities. Therefore, a strategic review of juvenile salmonid monitoring programmes integrating environmental data collection is recommended.

Gray, R. W., & Cameron, J. D. (1987). A deep-substrate streamside incubation box for Atlantic salmon eggs. *Progressive Fish-Culturist,* 49(2), 124-129. https://doi.org/10.1577/1548-8640(1987)49<124:Adsibf>2.0.Co;2

The design, site selection, m•d operational features of a portable streamside incubation box for Atlantic salmon (Salmo salad eggs are described. The incubation box was located inside a field laboratory and was evaluated from 1978 to 1980. Performance of the box was then field tested in 1981. Incubation capacity of the box, estimated from this study, was 93,000 salmon eggs at a loading density of 9,000 eggs/m 2 of Astroturf; eight layers of Astroturf were used, and flow rate was 1.0 L/min per 1,000 eggs. Mean survival rate from green eggs to fry emergence was 77.2%. Fry emergence occurred from early May to mid June and was partially controlled by manipulating the amount of light allowed to enter the box.

Green, D., Vidergar, D., Baker, D., Gable, J., Heindel, J., & Kline, P. (2007). Emergence survival for progeny of captive-reared Chinook salmon allowed to spawn naturally. *Proceedings of 58th Annual Northwest Fish Culture Conference*, 16. Retrieved from https://www.rmpc.org/files/nwfcc/nwfcc_2007_proceedings.pdf

Captive rearing strategies are often used by conservation hatcheries to strengthen native fish stocks while minimizing the effects of domestication. Captive rearing involves collecting eggs or young fish from their natal waters, raising them at a hatchery until they reach maturity, then releasing the fish to spawn naturally. Facilities that use captive rearing strategies invest considerable time and effort to raise fish to maturity with the goal that released fish will spawn naturally with the same success as their

natural counterparts. However, once mature fish are released, monitoring is rarely performed to identify whether fish spawn successfully and if resulting gametes are viable. We conducted weekly spawning ground surveys post release to identify redds produced by captive-reared and natural Chinook salmon in two tributaries of the upper Salmon River, Idaho. By monitoring water temperature units we identified when eggs had developmentally reached the eyed stage and used hydraulic sampling gear to collect approximately 70 eyed from each redd. Eyed eggs were placed in modified egg transport tubes and inserted back into the redds at the depth the eggs were collected. By continuing to monitor water temperature units we estimated the time of emergence and extracted the egg capsules to enumerate live fry. In 2006, a total of 13 redds produced by captive-reared Chinook salmon and five redds produced by natural Chinook salmon were sampled. Survival to eye for captive-reared fish averaged 85% and ranged from 44 to 97%. Survival to eye for natural fish averaged 90% and ranged from 84 to 96%. Survival to emergence for captive-reared fish averaged 56% and ranged from 00 to 93%. Survival to emergence for natural fish averaged 39% and ranged from 00 to 85%. We plan to repeat our survival estimates during the 2007 and 2008 spawning seasons. Although still preliminary, the results indicate that our methods may provide a reliable way to estimate emergence survival for captive-reared naturally spawned Chinook salmon.

Gretsch, D. (1989). *Annual report: Terror Lake hydroelectric project 1988 salmon egg and fry survival, escapement magnitude and spawner distribution*.(Regional Information Report No. AK89-29). Alaska Department of Fish and Game Division of Commercial Fisheries, Westward Region Retrieved from http://sf.adfg.state.ak.us/fedaidpdfs/rir.4k.1989.29.pdf

The pre-emergent fry indices on the Terror River and Kizhuyak River were generally fair to good. High waters during the fall of 1987 resulted in scouring in both river systems. However spring climatic conditions were mild and an average to lower than average pink salmon return is expected in 1989. The peak indexed pink salmon escapement in 1988 was 124,000 in the Terror River and 39,000 in the Kizhuyak River. The peak indexed chum salmon escapements in 1988 were 15,000 in the Terror River and 27,000 in the Kizhuyak River. These are at or near peak indexed escapements for these rivers since this study began.

Gunn, J. M., & Keller, W. (1984). In situmanipulation of water chemistry using crushed limestone and observed effects on fish. *Fisheries,* 9(1), 19-24. https://doi.org/10.1577/1548-8446(1984)009<0019:Ismowc>2.0.Co;2

In acidic lakes near Sudbury, Ontario, limestone additions were used to create favorable microenvironments for early life stages of salmonids. Under acutely toxic conditions (eg. pH 4.6, total Al > 400 µg/L), substrate baskets, containing as little as 15 kg of crushed limestone, neutralized interstitial water, permitting high survival of incubating eggs and fry. Such small-scale, site-specific neutralization reduced mortality and/or increased growth of fry under a variety of ambient chemical conditions. Flow-through filter tanks and stream bed additions were used to neutralize flowing water. Effects on fish were similar to those with the substrate baskets. Both treatment procedures produced significant changes in water chemistry, including elevations in pH, alkalinity, conductivity, and Ca. A 345 tonne stream bed addition was largely ineffective at controlling springtime pH depressions but produced substantial annual increases (70–145%; 6000–9000 kg as CaCO3) in the downstream discharge of alkalinity. Neutralization was primarily used to provide on-site controls to assess acidification effects, but our findings also suggest that small-scale treatments such as limestone covered spawning sites could

be of remedial value in acidic systems. The detrimental effects of precipitating Al during neutralization deserve further attention.

Gunnes, K. (1979). Survival and development of Atlantic salmon eggs and fry at 3 different temperatures. *Aquaculture,* 16(3), 211-218. https://doi.org/10.1016/0044-8486(79)90109-1

Groups of Atlantic salmon (Salmo salar) eggs were incubated at 12, 10 and 8° C. At 12° C mortality was high and fry averaged little more than half the weight of those hatched at 10 or 8° C. Development of alevins to the 'swim-up' stage was also abnormal at 12° C. The results suggest that 10° C is optimal for incubating Atlantic salmon eggs. For the period between hatching and swim-up, the most favourable temperature varies according to the temperature used during incubation. Mortality rate during the first 6 weeks of feeding was correlated with mortality during earlier development. Total numbers of day-degrees required by the eggs and fry to reach the eyed, hatching, and swim-up stages of development were significantly less at 12° C than at 10 or 8° C. However, total day-degrees required to reach an average weight of 0.5 or 0.6 g were almost the same regardless of temperature during hatching.

Guyette, M. Q. (2012). *Responses of Atlantic salmon stream communities to marine-derived nutrients.* (Ph.D.), University of Maine, Retrieved from https://digitalcommons.library.umaine.edu/cgi/viewcontent.cgi?article=4760&context=etd

This research examined responses of Atlantic salmon (Salmo salar) stream communities to experimental simulation of marine-derived nutrient input. Prior to construction of dams beginning in the early 1800s, Atlantic salmon and other anadromous species migrated from the ocean to spawn in Maine's extensive rivers and streams. Spawning fish transported marine-derived nutrients to these systems as carcasses, eggs, and waste products. These contributions may have influenced productivity in otherwise nutrient limited systems, bolstering growth and survival of young Atlantic salmon and other anadromous species and influencing other components of the stream communities.

Hall, J. E., Greene, C. M., Stefankiv, O., Anderson, J. H., Timpane-Padgham, B., Beechie, T. J., & Pess, G. R. (2018). Large river habitat complexity and productivity of Puget Sound Chinook salmon. *Plos One,* 13(11). https://doi.org/10.1371/journal.pone.0205127

While numerous studies have shown that floodplain habitat complexity can be important to fish ecology, few quantify how watershed-scale complexity influences productivity. This scale mismatch complicates population conservation and recovery strategies that evaluate recovery at regional or multi-basin scales. We used outputs from a habitat status and trends monitoring program for ten of Puget Sound's large river systems to examine whether juvenile Chinook salmon productivity relates to watershed-scale habitat complexity. We derived habitat complexity metrics that quantified wood jam densities, side and braid to main channel ratios, and node densities from a remote sensing census of Puget Sound's large river systems. Principal component analysis revealed that 91% of variance in these metrics could be explained by two principal components. These metrics revealed gradients in habitat complexity across Puget Sound which were sensitive to changes in complexity as a result of restoration actions in one watershed. Mixed effects models revealed that the second principle component term (PC2) describing habitat complexity was positively related to log transformed subyearling Chinook per spawner productivity rates from 6-18 cohorts per watershed. Total subyearling productivity

(subyearlings per spawner) and fry productivity (subyearling fry per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed peak flow recurrence interval, suggestive of reduced survival due to egg destruction during floods. Total subyearling productivity (subyearlings per spawner) and parr productivity (subyearling parr per spawner) rates were best described by models that included a positive effect of habitat complexity (PC2) and negative relationships with log transformed spawner density, suggestive of density dependent limits on juvenile rearing habitat. We also found that coefficient of variation for log transformed subyearling productivity and subyearling fry productivity rates declined with increasing habitat complexity, supporting the idea that habitat complexity buffers populations from annual variation in environmental conditions. Therefore, we conclude that our watershed-scale census-based approach provided habitat complexity metrics that explained some of the variability in productivity of subyearling juveniles among Chinook salmon populations. Furthermore, this approach may provide a useful means to track and evaluate aggregate effects of habitat changes on the productivity of Endangered Species Act (ESA) listed Chinook salmon populations over time.

Hamda, N. T., Martin, B., Poletto, J. B., Cocherell, D. E., Fangue, N. A., Van Eenennaam, J., . . . Danner, E. (2019). Applying a simplified energy-budget model to explore the effects of temperature and food availability on the life history of green sturgeon (Acipenser medirostris). *Ecological Modelling,* 395, 1-10. https://doi.org/10.1016/j.ecolmodel.2019.01.005

In highly regulated systems, like large dammed rivers, conservation legislation requires that systems are managed, in part, to avoid adverse impacts on endangered species. However, multiple endangered species can occur in the same system, and management actions that benefit one species may be detrimental to another species. The current water management strategies in the Sacramento River basin are an example of this conflict. Cold-water releases from Shasta Reservoir during the summer and fall months are aimed at protecting Sacramento River winter-run Chinook (SRWRC) salmon by providing suitable incubation temperatures for their eggs. However, the effects of these regulated water temperature releases on another threatened species, green sturgeon, are less well understood. In this study, we applied a simplified dynamic energy budget (DEB) model (aka DEBkiss) to explore the effect of food limitation and water temperature on the growth rates of green sturgeon. This model captures these effects and able to predict the growth of green sturgeon at different food levels and temperature conditions. We then linked the DEB model with a physically-based water temperature model. We applied the DEB- water temperature linked model for green sturgeon along with a temperature-dependent egg to fry survival model for SRWRC salmon to quantify the consequences of managing water temperatures to improve salmon eggs survival on the growth rate of green sturgeon. We found that mean temperature-dependent egg-to-fry survival of salmon increased across a modeled environmental gradient from critically dry to wet water year types, while the fractional growth rate of juvenile green sturgeon showed the opposite trend, and decreased as water years transitioned from dry to wet conditions. We also found a non-linear negative correlation between temperature dependent mean growth rate of green sturgeon and mean temperature-dependent egg-to-fry survival of salmon, which indicated there is a river temperature related trade-off between early growth rate of green sturgeon and embryonic stage survival of salmon. However, the relatively small gains in the growth rate of green sturgeon achieved in years when temperature criteria for SRWRC salmon eggs were not met came at the cost of large reduction in temperature-dependent egg-to-fry survival of salmon. Thus, we concluded the current Sacramento River water-temperature management for the eggs of the endangered SRWRC salmon eggs have a relatively small impact on the growth rate of green sturgeon.

Hamoutene, D., Perez-Casanova, J., Burt, K., Lush, L., Caines, J., Collier, C., & Hinks, R. (2017). Early life traits of farm and wild Atlantic salmon Salmo salar and first generation hybrids in the south coast of Newfoundland. *Journal of Fish Biology,* 90(6), 2271-2288. https://doi.org/10.1111/jfb.13304

This study examined fertilization rates, survival and early life-trait differences of pure farm, wild and first generation (F1) hybrid origin embryos after crossing farm and wild Atlantic salmon Salmo salar. Results show that despite a trend towards higher in vitro fertilization success for wild females, differences in fertilization success in river water are not significantly different among crosses. In a hatchery environment, wild females' progeny (pure wild and hybrids with wild maternal parent) hatched 7-11 days earlier than pure farm crosses and hybrids with farm maternal parents. In addition, pure wild progeny had higher total lengths (LT) at hatch than pure farm crosses and hybrids. Directions in trait differences need to be tested in a river environment, but results clearly show the maternal influence on early stages beyond egg-size differences. Differences in LT were no longer significant at 70 days post hatch (shortly after the onset of exogenous feeding) showing the need to investigate later developmental stages to better assess somatic growth disparities due to genetic differences. Higher mortality rates of the most likely hybrids (farm female x wild male hybrids) at egg and fry stages and their delayed hatch suggest that these F1 hybrids might be less likely to survive the early larval stages than wild stocks. (C) 2017 Her Majesty the Queen in Right of Canada

Hanrahan, T., Geist, D., & Arntzen, C. (2004). *Effects of hyporheic exchange flows on egg pocket water temperature in Snake River fall Chinook salmon spawning areas, 2002-2003 final report.* Bonneville Power Administration, https://doi.org/10.2172/962131

The development of the Snake River hydroelectric system has affected fall Chinook salmon smolts by shifting their migration timing to a period (mid- to late-summer) when downstream reservoir conditions are unfavorable for survival. Subsequent to the Snake River Chinook salmon fall-run Evolutionary Significant Unit being listed as Threatened under the Endangered Species Act, recovery planning has included changes in hydrosystem operations (e.g., summer flow augmentation) to improve water temperature and flow conditions during the juvenile Chinook salmon summer migration period. In light of the limited water supplies from the Dworshak reservoir for summer flow augmentation, and the associated uncertainties regarding benefits to migrating fall Chinook salmon smolts, additional approaches for improved smolt survival need to be evaluated. This report describes research conducted by the Pacific Northwest National Laboratory (PNNL) that evaluated relationships among river discharge, hyporheic zone characteristics, and egg pocket water temperature in Snake River fall Chinook salmon spawning areas. This was a pilot-scale study to evaluate these relationships under existing operations of Hells Canyon Dam (i.e., without any prescribed manipulations of river discharge) during the 2002-2003 water year. The project was initiated in the context of examining the potential for improving juvenile Snake River fall Chinook salmon survival more » by modifying the discharge operations of Hells Canyon Dam. The potential for improved survival would be gained by increasing the rate at which early life history events proceed (i.e., incubation and emergence), thereby allowing smolts to migrate through downstream reservoirs during early- to mid-summer when river conditions are more favorable for survival. PNNL implemented this research project at index sites throughout 160 km of the Hells Canyon Reach (HCR) of the Snake River. The HCR extends from Hells Canyon Dam (river kilometer [rkm] 399) downstream to the upper end of Lower Granite Reservoir near rkm 240. We randomly selected 14 fall Chinook salmon spawning locations as study sites, which represents 25% of the most used spawning areas throughout the HCR. Interactions between river water and pore water within the riverbed (i.e.,

hyporheic zone) at each site were quantified through the use of self-contained temperature and water level data loggers suspended inside of piezometers. Surrounding the piezometer cluster at each site were 3 artificial egg pockets. In mid-November 2002, early-eyed stage fall Chinook salmon eggs were placed inside of perforated polyvinyl chloride (PVC) tubes, along with a temperature data logger, and buried within the egg pockets. Fall Chinook salmon eggs were also incubated in the laboratory for the purpose of developing growth curves that could be used as indicators of emergence timing. The effects of discharge on vertical hydrologic exchange between the river and riverbed were inferred from measured temperature gradients between the river and riverbed, and the application of a numerical model. The hydrologic regime during the 2002-2003 sampling period exhibited one of the lowest, most stable daily discharge patterns of any of the previous 12 water years. The vertical hydraulic gradients (VHG) between the river and the riverbed suggested the potential for predominantly small magnitude vertical exchange. The VHG also showed little relationship to changes in river discharge at most sites. Despite the relatively small vertical hydraulic gradients at most sites, results from the numerical modeling of riverbed pore water velocity and hyporheic zone temperatures suggested that there was significant vertical hydrologic exchange during all time periods. The combined results of temperature monitoring and numerical modeling indicate that only 2 of 14 sites were significantly affected by short-term (hourly to daily) large magnitude changes in discharge. Although the two sites exhibited acute flux reversals between river water and hyporheic water resulting from short-term l rge magnitude changes in discharge, these flux reversals had minimal effect on emergence timing estimates. Indeed, the emergence timing estimates at all sites were largely unaffected by the changes in river stage resulting from hydropower operations at Hells Canyon Dam. Our results indicate that the range of emergence timing estimates due to differences among the eggs from different females can be as large as or larger than the emergence timing estimates due to site differences (i.e., bed temperatures among sites). We conclude that during the 2002-2003 fall Chinook salmon incubation period, hydropower operations of Hells Canyon Dam had an insignificant effect on fry emergence timing at the study sites. « less

Hanrahan, T. P., Geist, D. R., Arntzen, E. V., & Abernethy, C. S. (2004). *Effects of hyporheic exchange flows on egg pocket water temperature in Snake River fall Chinook salmon spawning areas.* Bonneville Power Administration, https://doi.org/10.2172/15020949

The development of the Snake River hydroelectric system has affected fall Chinook salmon smolts by shifting their migration timing to a period when downstream reservoir conditions are unfavorable for survival. Subsequent to the Snake River Chinook salmon fall-run Evolutionary Significant Unit being listed as Threatened under the Endangered Species Act, recovery planning has included changes in hydrosystem operations to improve water temperature and flow conditions during the juvenile Chinook salmon summer migration period. In light of the limited water supplies from the Dworshak reservoir for summer flow augmentation, and the associated uncertainties regarding benefits to migrating fall Chinook salmon smolts, additional approaches for improved smolt survival need to be evaluated. This report describes research conducted by PNNL that evaluated relationships among river discharge, hyporheic zone characteristics, and egg pocket water temperature in Snake River fall Chinook salmon spawning areas. The potential for improved survival would be gained by increasing the rate at which early life history events proceed (i.e., incubation and emergence), thereby allowing smolts to migrate through downstream reservoirs during early- to mid-summer when river conditions are more favorable for survival. PNNL implemented this research project throughout 160 km of the Hells Canyon Reach (HCR) of the Snake River.more » The hydrologic regime during the 2002?2003 sampling period exhibited one of the lowest, most stable daily discharge patterns of any of the previous 12 water years. The vertical hydraulic gradients (VHG) between the river and the riverbed suggested the potential for

predominantly small magnitude vertical exchange. The VHG also showed little relationship to changes in river discharge at most sites. Despite the relatively small vertical hydraulic gradients at most sites, the results from the numerical modeling of riverbed pore water velocity and hyporheic zone temperatures suggested that there was significant vertical hydrologic exchange during all time periods. The combined results of temperature monitoring and numerical modeling indicate that only two sites were significantly affected by short-term (hourly to daily) large magnitude changes in discharge. Although the two sites exhibited acute flux reversals between river water and hyporheic water resulting from short-term large magnitude changes in discharge, these flux reversals had minimal effect on emergence timing estimates. Indeed, the emergence timing estimates at all sites was largely unaffected by the changes in river stage resulting from hydropower operations at Hells Canyon Dam. Our results indicate that the range of emergence timing estimates due to differences among the eggs from different females can be as large as or larger than the emergence timing estimates due to site differences (i.e., bed temperatures within and among sites). We conclude that during the 2002-2003 fall Chinook salmon incubation period, hydropower operations of Hells Canyon Dam had an insignificant effect on fry emergence timing at the study sites. It appears that short-term (i.e., hourly to daily) manipulations of discharge from the Hells Canyon Complex during the incubation period would not substantially alter egg pocket incubation temperatures, and thus would not affect fry emergence timing at the study sites. However, the use of hydropower operational manipulations at the Hells Canyon Complex to accelerate egg incubation and fry emergence should not be ruled out on the basis of only one water year's worth of study. Further investigation of the incubation environment of Snake River fall Chinook salmon is warranted based on the complexity of hyporheic zone characteristics and the variability of surface/subsurface interactions among dry, normal, and wet water years.« less

Harig, A. L., & Fausch, K. D. (2002). Minimum habitat requirements for establishing translocated cutthroat trout populations. *Ecological Applications,* 12(2), 535-551. https://doi.org/10.1890/1051-0761(2002)012[0535:mhrfet]2.0.co;2

Translocation is an important management strategy in conservation programs for endangered or threatened species, including native cutthroat trout (Oncorhynchus clarki) in the western United States. Most subspecies of cutthroat trout have declined to <5% of their historical range, and both historical and translocated populations now persist in small isolated fragments of habitat. Success rates for translocations of fishes are generally <50%, and habitat quality or quantity are frequently cited as the cause of failure. Therefore, we conducted field surveys of stream-scale habitat and measured basin-scale habitat using a Geographic Information System for 27 streams where two subspecies of cutthroat trout were translocated in Colorado and New Mexico, to identify specific habitat attributes that contribute to the success of translocations. We used polytomous logistic regression to develop models that predict three categories of cutthroat trout translocation success (high, low, absent) from habitat attributes at two spatial scales. Models based on stream-scale habitat attributes indicated that cold summer water temperature, narrow stream width, and lack of deep pools limited translocations of cutthroat trout. Cold summer temperatures are known to delay spawning and prolong egg incubation, which reduces the growth of fry and likely limits their overwinter survival. Furthermore, small streams with few deep pools may lack the space necessary to permit overwinter survival of a sufficient number of individuals to sustain a population. Models based on basin-scale habitat were not as effective as stream-scale habitat models for distinguishing among translocation sites with high, low, or absent population status but indicated that a minimum watershed area of 14.7 km2 was useful as a coarse filter for separating sites with high numbers of cutthroat trout from those with low or absent status. Watersheds larger than this are expected to encompass low-elevation habitat that provides warmer

summer temperatures and to have relatively wide stream channels of sufficient length to provide an adequate number of deep pools. These results indicate that the appropriate scale of habitat measurement for predicting cutthroat trout translocation success in fragmented watersheds is at the patch rather than landscape scale, which is similar to results for other salmonids and vertebrate taxa in general.

Harris, J. E. (2010). *Migration and spawning of anadromous shads in the Roanoke River, North Carolina.* (Ph.D.), North Carolina State University, Ann Arbor. Retrieved from http://www.lib.ncsu.edu/resolver/1840.16/5655

Anadromous alosines are ecologically, commercially, and recreationally valuable fishes. Some populations of alosines are at historically low levels, as a result of overfishing, pollution and habitat change, including the presence of dams, which block access to historic spawning sites upstream and alter spawning habitat downstream. To aid in the restoration of alosine stocks, I evaluated several methods for spawning habitat identification and characterization and evaluated trap and transport as a method to give American shad Alosa sapidissima access to additional spawning habitat above dams in the Roanoke River, North Carolina and Virginia. The Roanoke River has four anadromous alosines: American shad, hickory shad A. mediocris, blueback herring A. aestivalis, and alewife A. pseudoharengus. For all four alosines, spawning sites river-wide were most efficiently identified using plankton tows, which collect eggs of all species. Spawning habitat selection for hickory shad and river herring (blueback herring and alewife) could be evaluated using spawning pads, which collected their eggs in clumped distributions. American shad eggs were not successfully sampled by spawning pads and spawning habitats could be best examined by visual observations of spawning splashes. Unlike the other alosines in this study, little is known about spawning habitat for hickory shad. Hickory shad eggs were collected at water temperatures from 10 to 23°C, and peaked from 11 to 14°C. Spawning generally occurred in water velocities ≥ 0.1 m/sec, over substrates free from silt. A habitat suitability model for hickory shad was developed using a Bayesian belief network. Bayesian belief networks are a relatively new method for modeling habitat suitability for fishes, but could prove very useful in the future, especially for species such as American shad which have been the focus of more study and are in need of restoration. I evaluated movement patterns and spawning of sonic-tagged adult American shad transported to habitats above dams on the Roanoke River. Most transported fish spent relatively little time in the riverine habitat considered suitable for spawning, and no eggs were collected by plankton sampling. American shad appeared to move more effectively through a smaller, as compared to a larger, reservoir, but fish released directly into riverine habitat spent the longest amount of time in suitable spawning habitat. Although the mortality associated with moving downstream through a dam turbine was generally low, few adults completed the passage, and many were observed just upstream from a dam late in the season, suggesting that structures to increase downstream passage may be beneficial. I used data on behavior and outmigration of American shad adults and fry released above and below dams on the Roanoke River to develop a deterministic, density-dependent, stage-based matrix model to predict possible population-level effects of transporting American shad to upper basin habitats. The American shad population in the Roanoke River appears small compared to assumed values of carrying capacity in the lower river and would appear to benefit from transport only under optimal conditions of young survival and effective fecundity. The matrix model predicted that under present conditions, improvements to survival rates of young or adults would likely lead to greater improvements in the stock size of American shad in the Roanoke River.

Heard, W. R. (1978). Probable case of streambed overseeding 1967 pink salmon, Oncorhynchus gorbuscha, spawners and survival of their progeny in Sashin Creek, southeastern Alaska. *Fishery Bulletin,* 76(3), 569-582. Retrieved from https://spo.nmfs.noaa.gov/content/probable-case-streambed-overseeding-1967-pink-salmon-Oncorhynchus gorbuscha-spawners-and

The 1967 escapement of38,067 pink salmon, Oncorhynchus gorbuscha, to Sashin Creek, southeastern Alaska, was the largest since 1942. Studies on distribution and density of spawners and freshwater survival of their progeny indicated that deposition of excessive numbers of eggs caused a severe compensatory mortality ofalevins during winter. Spawner density was 1.7, 1.6, and 1.2 females/m2 in upper, middle, and lower study areas respectively. The greater density ofspawners in the upper area in the odd-numbered years may be determined by genetic factors like timing of escapements and by greater marine survival offry from the upper area. Based on the previously consistent relation between timing ofadult entry and resulting freshwater survival, 1967 spawners should have produced 8 million fry rather than the 3 million that were produced. Mortality of eggs and alevins was high during spawning, low between spawning and hatching, and high between hatching and emergence. Between 1 December 1967 and 25 March 1968, 11.1 million eggs or alevins, 10.7 million of which were alive on 1 December, disappeared within the streambed. Initial mortality of these progeny probably occurred in the early alevin stage from oxygen privation, whereas disappearance was probably related to rapid decomposition and invertebrate scavenging. A "snowball effect" is postulated whereby alevins that die shortly after hatching place increasing demands on available oxygen, causing accelerated mortality. A review of historical patterns of fry production in Sashin Creek indicates that streambed overseeding occurred in 1967.

Heggberget, T. G. (1988). Timing of spawning in Norwegian Atlantic salmon (Salmo salar). *Canadian Journal of Fisheries and Aquatic Sciences,* 45(5), 845-849. https://doi.org/10.1139/f88-102

A hypothesis that thermal regime regulates the timing of spawning in Atlantic salmon (Salmo salar) was analysed by correlating time of commencement and peak of spawning in 16 Norwegian streams with temperature, latitude, and stream flow. Only temperature during incubation of the eggs proved to have any statistically significant effect. Since the duration of egg incubation is known to depend on temperature regime (i.e. on degree-days), a similar linking of spawning time to stream temperature allows spawning to occur at a time which will result in hatching of eggs at a specific and presumably optimal time for survival of fry.

Hilland, R. T. (1977). *The effect of density, substrate, water quality and egg-take procedures on pink salmon (Oncorhynchus gorbuscha) production from the Atnarko River incubation boxes.* Fisheries and Oceans Canada, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/18330.pdf

Pink salmon (Oncorhynchus gorbuscha) eggs, taken from Atnarko River stock were planted in upwelling gravel incubators at the Atnarko River Pilot Incubation Box site. A number of treatments were tested to determine the effect of water quality, substrate type, loading density and egg treatment prior to planting on survival rate, emergence timing and fry quality. Results indicated that overall survival was 49% to the fry stage; however, variability in fertilization rates made comparison of the various treatments difficult. Treatments utilizing filtered water, crushed rock and eggs planted within 2 hours of

fertilization or when eyed, at an approximate density of 132,000 eggs/m SUP-3 , appeared to be the most satisfactory in terms of egg-to-fry survival, timing of fry emergence and fry quality.

Hillson, T. D. (2009). *Reintroduction of lower Columbia River chum salmon into Duncan Creek: Annual report 2003-2004.* Bonneville Power Administration, https://doi.org/10.2172/901056

Currently, two methods of reintroduction are being simultaneously evaluated at Duncan Creek. Recolonization is occurring by introducing adult chum salmon from the Lower Gorge (LG) population into Duncan Creek and allowing them to naturally reproduce. The supplementation strategy required adults to be collected and artificially spawned, incubated, reared, and released at the mouth of Duncan Creek. All eggs from the artificial crossings at Washougal Hatchery were incubated and the fry reared to release size at the hatchery. The Duncan Creek chum salmon project was very successful in 2003-04, providing knowledge and experience that will improve program execution in future years. The gear used to collect adult brood stock was changed from tangle nets to beach seines. This increased efficiency and the speed at which adults could be processed in the field, and most likely reduced stress on the adults handled. Certain weaknesses exposed in past seasons still exist and new ones were exposed (e.g. inadequate incubation and rearing space at Washougal Hatchery for any large salvage operation and having to move the rearing troughs outside the raceway in 2004). Egg-to-fry survival rates of 64% and 58% showed that the channels are functioning at the upper end of what can be expected from them. Possibly the most important event this season was the ability to strontium mark and release all naturally-produced fry from the spawning channels. Channel and floodplain modifications reduced the likelihood that floods will damage the channels and negatively impact survival rates.

Holtby, L. B., & Healey, M. C. (1986). Selection for adult size in female coho salmon (oncorhynchus-kisutch). *Canadian Journal of Fisheries and Aquatic Sciences,* 43(10), 1946-1959. https://doi.org/10.1139/f86-240

Several recent studies have presented evidence that large size confers a selective advantage to female Pacific salmon. Nevertheless, a wide range of female sizes is normally present in any spawning population. Two possible explanations exist for the observed range in female size. First, average female size might be determined by an optimizing process with variation around the optimum size due to individual differences in success at obtaining food. Second, various sizes of females might coexist as a mixed evolutionary stable strategy. Under the first explanation, females of sizes other than the optimum would display lower fitness whereas, under the second explanation, females of all sizes would be equally fit. We investigated factors affecting survival of eggs, fry, and smolts of coho salmon (Oncorhynchus kisutch) in Carnation Creek on Vancouver Island with a view to determining the relative fitness of different sized females. Egg-to-fry mortality was best explained by a model that included only the effects of stream bed scour and gravel quality. Including an effect of female size, expressed through depth of egg burying, worsened the model's predictive capability. We could find no evidence that the eggs of large females consistently survived better during incubation than those of small females. In fact, we observed three instances in which it appeared that the eggs of small females survived better. In Carnation Creek, large 1- and 2-yr-old smolts did not consistently survive better in the marine environment than small smolts. Thus, we were unable to demonstrate that the reproductive success of large females was consistently higher than that of small females, contrary to the hypothesis that female size is the result of an optimizing process. In Carnation Creek the observed range of female sizes probably represents an evolutionary stable strategy in which all sizes have equal fitness. We propose a

model that predicts female size and variance in size based on the conflicting selective effects of gravel quality, scour, and competition for nest sites.

Houde, A. L. S., Black, C. A., Wilson, C. C., Pitcher, T. E., & Neff, B. D. (2015). Genetic and maternal effects on juvenile survival and fitness-related traits in three populations of Atlantic salmon. *Canadian Journal of Fisheries and Aquatic Sciences,* 72(5), 751-758. https://doi.org/10.1139/cjfas-2014-0472

Although studies addressing natural selection have primarily focused on additive genetic effects because of their direct relationship with responses to selection, nonadditive genetic and maternal effects can also significantly influence phenotypes. We partitioned the phenotypic variance of survival and fitness-related traits in juvenile Atlantic salmon (Salmo salar) from three allopatric populations (LaHave, Sebago, and Saint-Jean) into additive genetic, nonadditive genetic, and maternal environmental effects using a full-factorial breeding design. We also modelled the potential increase in offspring performance if nonrandom mating (e.g., mate choice) is considered instead of random mating. The three populations exhibited significant differences in trait values as well as the genetic architecture of the traits. Nevertheless, nonadditive genetic and maternal environmental effects tended to be larger than the additive genetic effects. There was also a shift from maternal environmental to genetic effects during development in two of the populations. That is, maternal environmental effects were larger at early (egg and alevin) life stages, whereas nonadditive effects were larger at the later (fry) life stage. The amount of additive genetic effects was small, suggesting the traits will respond slowly to selection. We discuss how different maternal environmental effects across years may influence the genetic architecture of offspring traits.

Hourston, W. R., & MacKinnon, D. (1957). Use of an artificial spawning channel by salmon. *Transactions of the American Fisheries Society,* 86(1), 220-230. https://doi.org/10.1577/1548-8659(1956)86[220:uoaasc]2.0.co;2

Investigation of effect of a proposed hydro-electric development on the salmon spawning grounds in Jones Creek, British Columbia in 1949 indicated spawning areas would be so affected that only a small portion of existing runs could be maintained. Methods for preserving the run were suggested and one selected that involved the construction of an artificial spawning channel capable of supporting the existing runs with provision for controlling the flow in the channel and by-passing surplus flows. Behavior studies of pink salmon (Oncorbynchus gorbuscha) and chum salmon (O. keta) spawning in the channel were made in 1955 and the survival from egg to fry was determined in 1956 when there was survival of 37 percent of the 428,000 pink salmon eggs calculated to have been available for deposition and 30 percent of the 251,000 chum salmon eggs calculated to have been available for deposition.

Howell, B. E., Stewart, E. M. C., Frasca, V. R., Wilson, C. C., & Raby, G. D. (2022). Capture of spawning brook trout by electrofishing does not impair embryo survival. *North American Journal of Fisheries Management,* 42(1), 228-235. https://doi.org/10.1002/nafm.10735

Electrofishing is widely used to capture fish in freshwater systems. Fisheries assessment and fish culture activities that occur during spawning do so in the absence of a meaningful base of evidence about the potential effects of electrofishing on fish reproduction. In this laboratory experiment, we assessed

whether electrofishing adult Brook Trout Salvelinus fontinalis affected the survival of their embryos. We used two genetically distinct strains of Brook Trout (domestic and wild-origin strains) to do so. Both strains and sexes of fish were exposed to pulsed-DC electrofishing techniques in a fully factorial design (i.e., male shocked, female shocked, both parents shocked, or neither parent shocked [control]), after which their incubating offspring were monitored for survival to the eyed egg, alevin, and fry stages. We did not detect any effects of our electrofishing treatment or interactions with the sex or strain of the fish exposed to electrofishing, suggesting that electrofishing did not negatively impact gamete viability. Our results support the use of responsible electrofishing to collect spawning salmonids for the purpose of gamete collection for hatchery rearing.

Hume, J. M. B., & Parkinson, E. A. (1988). Effects of size at and time of release on the survival and growth of steelhead fry stocked in streams. *North American Journal of Fisheries Management,* 8(1), 50-57. https://doi.org/10.1577/1548-8675(1988)008<0050:eosaat>2.3.co;2

Survival and growth from age-0 fry to age-1 + parr was estimated for steelhead Salmo gairdneri stocked in two British Columbia streams at different times (May 26–October 15) and different sizes (0.2–6.0 g). Fry were released into separate sections of the two streams. Monthly mortality rates, which ranged from 15.4 to 9.6%/month, were inversely related to size at stocking and time of release. We were unable to separate the effects of size and release time because these factors were highly correlated. Daily instantaneous growth rates of early stocked, small fry (> 0.009) were much higher than those of later-stocked, larger fry (<0.002) but there were only minor differences in mean weights of age-1 + parr among release groups. In determining the best strategy for releasing fry, factors other than survival must also be considered. Costs of raising fish to larger sizes must be balanced against the costs of collecting eggs and the availability of brood stock.

Hunter, G. A., Donaldson, E. M., Goetz, F. W., & Edgell, P. R. (1982). Production of all-female and sterile coho salmon, and experimental-evidence for male heterogamety. *Transactions of the American Fisheries Society,* 111(3), 367-372. https://doi.org/10.1577/1548-8659(1982)111<367:Poaasc>2.0.Co;2

In May 1977, groups of coho salmon Oncorhynchus kisutch were immersed in 17fl-estradiol or 17a-methyltestosterone in the eyed-egg and alevin stages. Treatments were continued during the early fry stage via administration of a diet containing the steroids. The estradiol groups and the control were spawned in December 1979. The estradiol groups contained 96-100% females compared with 54% female fish in the control. The methyltestosterone groups were comprised primarily of sterile fish. The ova from 23 females in each of the estradiol groups and 22 control females were fertilized with normal milt and offspring were reared to 9 months of age, at which time male: female ratios were determined. There was no significant difference in survival between treated and control families. Half of the families from estradiol-treated fish had a 3:1 male: female ratio, indicating male heterogamety. The two methyltestosterone-treated groups continued to grow during the 1-year period following the spawning of the control group.

Hunter, J. G. (1959). Survival and production of pink and chum salmon in a coastal stream. *Journal of the Fisheries Board of Canada,* 16(6), 835-886. https://doi.org/10.1139/f59-061

A study of the propagation of pink and chum salmon in the central coastal region of British Columbia was made for the years 1947 to 1956.Timing, distribution and movement of the adults and fry are discussed. The effects of temperature, stream discharge, sex ratio and population density were considered in relation to survival of egg to fry. Within the limits observed, temperature, stream discharge and sex ratio were not affecting the population perceptibly, but population density was an important factor. The density of spawners in preceding years also affected the survival in subsequent years.Predation was an important factor in keeping the fry output low: the number of fry consumed was approximately 500,000 during each migration.Ocean survival, including the effect of fishing mortality, ranged from 5.2% down to 0.7% for pink salmon, and from 2.6% to 0.85% for chum salmon. Ocean survival for pink salmon before fishing mortality occurred ranged from 10.8% down to 1.0%.Combination of freshwater and ocean survival rates indicate that a variation up to 190 times the lowest rate recorded is possible.

Hyatt, K. D., Mathias, K. L., McQueen, D. J., Mercer, B., Milligan, P., & Rankin, D. P. (2005). Evaluation of hatchery versus wild sockeye salmon fry growth and survival in two British Columbia lakes. *North American Journal of Fisheries Management,* 25(3), 745-762. https://doi.org/10.1577/m03-230.1

We evaluated the relative success of sockeye salmon hatchery fry stocking in two British Columbia-Alaska transboundary lakes (1,622-ha Tatsamenie Lake and 492-ha Tahltan Lake). Fry stocking began in the late 1980s and is still under way. During the study period, survival patterns in the two lakes were different. At Tatsamenie Lake, wild egg-to-fry survival was higher than hatchery egg-to-fry survival (11.3% versus 4.3%) and wild egg-to-smolt survival was higher than hatchery egg-to-smolt survival (5.8% versus 2.5%). We found no relationship between fry survival and stocking date, spawner abundance, or food availability in Tatsamenie Lake, but we did find a significant positive relationship between early-spring fry length and egg-to-fry survival. Also, we found that in net-pen experiments, larger fry survived better. From this, we concluded that hatchery fry stocked into Tatsamenie Lake may suffer from size-mediated mortality and that net-pen supplemental feeding could be used to overcome this problem. However, because eggs used for hatchery production come from the lake, fry stocking can only be justified when hatchery fry survival exceeds wild fry survival. At Tatsamenie Lake, this goal has not yet been attained. At Tahltan Lake, wild egg-to-fry survival was lower than hatchery egg-to-fry survival (1.5% versus 6.3%) and wild egg-to-smolt survival was lower than hatchery egg-to-smolt survival (3.6% versus 12.8%). Hatchery fry release date and food availability both failed to explain these differences in fry and smolt survival at Tahltan Lake. However, there was a strong negative relationship between total female escapement and wild egg-to-smolt survival. This supported the results of an earlier investigation, which suggested that Tahltan Lake was spawning-site limited. We concluded that at Tahltan Lake, hatchery fry stocking increased smolt numbers, is biologically justified, and should be continued.

Hyatt, K. D., McQueen, D. J., Ogden, A. D., Benson, R., & Wright, H. (2021). Age-structured interactions among reintroduced sockeye salmon, resident kokanee, invasive mysids, and their zooplankton prey in skaha Lake, British Columbia. *North American Journal of Fisheries Management,* 41(5), 1246-1273. https://doi.org/10.1002/nafm.10635

In 2004, after an 85+ year absence, Sockeye Salmon Oncorhynchus nerka were reintroduced into Skaha Lake, British Columbia. Prior to this, the lake's planktivore community was dominated by kokanee (lacustrine Sockeye Salmon) and an invasive freshwater shrimp Mysis diluviana, and British Columbia fisheries managers were concerned that reintroduced Sockeye Salmon fry might reduce the abundance of zooplankton prey and negatively affect the abundance and size of kokanee available for the recreational fishery. We looked for possible adverse effects by introducing contrasting densities (0-2,309 fish/ha) of marked, hatchery-origin Sockeye Salmon fry to Skaha Lake over 12 years (2005-2017). During each year, we monitored state change indicators of lake flushing, water temperature, nutrients, phytoplankton, microzooplankton, M. diluviana, kokanee, and Sockeye Salmon. Zooplankton consumption by Sockeye Salmon, kokanee, and M. diluviana was estimated via bioenergetics models. We found that (1) average densities of pelagic fish gradually increased above premanipulation densities and (2) survival (egg to winter) of kokanee fry was variable but positively associated with increased abundances of Sockeye Salmon fry. Average survival of age-0 to age-3+ kokanee in Skaha Lake exhibited no significant trends. We also found that (3) growth rates for age-0 Sockeye Salmon fry and kokanee were stable during 2005-2013, despite moderate increases in fish abundance, but declined in 2017. This decline was associated with record-high biomasses of kokanee and M. diluviana, record rates of zooplankton loss from predation and lake flushing, and reduced zooplankton production. We found that (4) bioenergetics data showed that, on average, 1.8% of annual zooplankton prey consumption was attributable to hatchery-origin Sockeye Salmon fry, 2.8% to Lake Whitefish Coregonus clupeaformis, 13.9% to older kokanee, and 79.6% of the zooplankton was consumed by M. diluviana. We concluded that during 2005-2015 consumption by planktivores never exceeded production by zooplankton, but in 2017, when lake flushing rates were exceptionally high, consumption by planktivores exceeded lake-carrying capacity for pelagic fish. Sockeye Salmon fry played virtually no part in these events.

Iida, M., Imai, S., & Katayama, S. (2017). Effect of riverbed conditions on survival of planted eyed eggs in chum salmon Oncorhynchus keta. *Fisheries Science,* 83(2), 291-300. https://doi.org/10.1007/s12562-016-1052-2

Wild stocks of chum salmon Oncorhynchus keta are supplemented by hatchery fry enhancement programs in northern Honshu, Japan. To maintain these programs, there is a need to reduce expenses and labor. Eyed egg planting is more cost effective than hatchery production of fry. Therefore, we evaluated the effect of environmental conditions on survival of chum salmon eyed eggs planted using Whitlock-Vibert boxes. We measured the percent cumulative weight of fine sediments, Fredle index (FI) as a measure of permeability, vertical hydraulic gradient, water depth (WD), and flow velocity at planting locations. Egg-to-fry survival averaged 92.7% (range: 57.2-100%) in 2013 (N = 19) and 71.5% (range: 6.4-100%) in 2014 (N = 23). Survival was significantly positively correlated with FI and flow velocity, negatively associated with percent cumulative weight of fine sediments and WD. Vertical hydraulic gradient had no effect on survival. Our results suggest that a higher FI (i.e., low amount of fine material and larger particle size), higher flow velocity, and shallower WD reduce the mortality of planted chum salmon eyed eggs. This is likely a result of increased permeability in the substrate and restriction of fine sediment intrusion into the incubation zone.

Supplement to the pre-season return forecasts for Fraser River sockeye salmon in 2014. (2014). Canadian Science Advisory Secretariat, Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/363655.pdf

Since most Fraser Sockeye Salmon return as four year old fish after spending two winters in freshwater and two winters in the marine environment, the majority of Sockeye returning in 2014 will be recruits from eggs spawned by adults in 2010 (i.e. the 2010 brood year). Predicting Fraser Sockeye returns in 2014 is a particular challenge, given the exceptional escapements observed for a number of stocks in the 2010 brood year (including Scotch, Seymour, Chilko, Harrison, Late Shuswap, and Portage). These record high brood year escapements require that forecast models be extrapolated beyond the observed stock-recruitment data range, creating additional uncertainty in forecasts for 2014. However, juvenile (fry and smolt) data for various key stocks in the 2010 brood year (Shuswap and Chilko) provide evidence of density-dependent compensation (lower freshwater survival) due to these record high spawner abundances. The juvenile data, therefore, support model forms that predict overcompensation at high spawner abundances. To provide further context for the 2014 Fraser Sockeye forecasts, additional information on the condition of Fraser Sockeye throughout their various life-history stages is reported in the current document. The Shuswap, Chilko, and Harrison stocks are evaluated, given their unprecedented high escapements in 2010. Quesnel is also included, due to poor survival observed for this stock in recent years, which diverges from the improvements in survival observed for most other Fraser Sockeye stocks between the 2006 and 2009 brood years (2010 to 2013 return years). Fish and environmental conditions are examined for the adults spawners in 2010 (all stocks), fry in 2011 (Shuswap and Quesnel lakes only), outmigrating smolts in 2012 (Shuswap and Chilko), Fraser River downstream smolt migration at Mission (all stocks), and subsequent Strait of Georgia and Johnstone Strait juvenile migrations (all stocks). In addition, the stock composition in the 2010 escapements, and 2012 smolt downstream migration and juvenile ocean surveys, and 2014 return forecasts are compared to evaluate proportional changes through time. This information will be used to supplement DFO's official Fraser River Sockeye Salmon forecasts. This Science Response Report results from a Regional Science Response Process held January 2014 to summarize data on fish condition and/or survival (including adults escapement in 2010 and their juvenile offspring). This Science Response is intended to provide context for the official DFO Fraser Sockeye forecasts in 2014.

Jarrams, P. (1979). Egg, fry and smolt production from salmon, Salmo salar l. and sea trout Salmo trutta l. Reared entirely in fresh water. *Journal of Fish Biology,* 15(5), 607-611. https://doi.org/10.1111/j.1095-8649.1979.tb03651.x

For five years hatchery reared salmon and sea trout which had spent their entire lives in hatchery tanks were stripped each Autumn to investigate the survival of the resulting offspring.

Jensen, D. W., Steel, E. A., Fullerton, A. H., & Pess, G. R. (2009). Impact of fine sediment on egg-to-fry survival of Pacific salmon: A meta-analysis of published studies. *Reviews in Fisheries Science,* 17(3), 348-359. https://doi.org/10.1080/10641260902716954

Egg-to-fry survival of salmonids is tempered by habitat degradation, including increased sediment in streams. To best manage multiple salmon species and prioritize scarce habitat restoration funds for the benefit of fish recovery, many studies have described and predicted the relationship between fine sediment deposited in spawning gravels and salmonid egg-to-fry survival. In this article, we used

published studies, agency reports, and university theses (N = 14) to create predictive relationships between percent fine sediment and egg-to-fry survival of Chinook (Oncorhynchus tshawytscha), coho (O. kisutch) and chum (O. keta) salmon, and steelhead trout (O. mykiss). In our analysis, coho survival tended to decline more rapidly per unit sediment increase and chum survival least rapidly. Threshold effects were observed, with survival dropping rapidly when percent fines less than 0.85 mm was greater than 10%. For other size classes of fines, a threshold was primarily observed only for eyed egg survival when fines exceeded 25-30%. Our predictive models combine both field and laboratory data and take into account a variety of conditions; they include estimates of uncertainty in the impact of sediment on egg-to-fry survival. These models can be used to forecast effects of watershed management practices on salmonids and to make comparisons between predicted salmonid survival rates under alternative management strategies for conditions where fine sediment is the limiting factor for survival.

Jeric, R. J., Modde, T., & Godfrey, J. M. (1995). Evaluation of a method for measuring intragravel dissolved oxygen concentrations and survival to emergence in shore-spawned salmonids. *North American Journal of Fisheries Management,* 15(1), 185-192. https://doi.org/10.1577/1548-8675(1995)015<0185:eoamfm>2.3.co;2

We describe an incubation basket and a modified intragravel water sampling device used to quantify salmonid survival to emergence relative to dissolved oxygen (DO) concentrations in deep lacustrine habitats. Incubation baskets containing viable eggs from kokanees Oncorhynchus nerka and a shale substrate were set by divers in 2–20-m-deep spawning habitat in Flaming Gorge Reservoir, Utah–Wyoming. Water drawn into a syringe from an intragravel pipe buried near each incubation basket was used to determine intragravel DO concentrations throughout the incubation period. A trap on each incubation basket captured emergent fry in a holding bag. The bags were exchanged weekly to determine survival to emergence and time of emergence. Water in control baskets without eggs did not have significantly greater DO concentrations than adjacent water.

Johnson, C. L., Roni, P., & Pess, G. R. (2012). Parental effect as a primary factor limiting egg-to-fry survival of spring Chinook salmon in the upper Yakima River basin. *Transactions of the American Fisheries Society,* 141(5), 1295-1309. https://doi.org/10.1080/00028487.2012.690815

Few field estimates of egg-to-fry survival of Chinook salmon Oncorhynchus tshawytscha exist, although it is one of the major factors thought to limit freshwater production and recovery of Chinook salmon populations. This is likely due to the challenges of estimating survival at this life stage, which is further complicated by the variety of methods that have been employed. Our study objectives were to (1) develop a method by which spring Chinook salmon egg-to-fry survival could be estimated at a large spatial scale, and (2) investigate the primary factors affecting survival in the natural environment. We conducted a field experiment using 81 artificial redds to test our proposed method for evaluating egg-to-fry survival at a basin scale and to evaluate the effects of parentage (adult mating), river reach, and fine sediment infiltration on survival in the upper Yakima River basin, Washington. Egg-to-fry survival and preemergent Chinook salmon fry developmental stage were significantly different among matings, but were not detectably different among reaches. Fine sediment accumulation in egg boxes from artificial redds was largely below published threshold levels, explained less than 6% of the variation in survival, and was not correlated with developmental stage. In contrast, survival of individual matings in the natural environment and those same matings incubated under controlled hatchery conditions were highly correlated. Our study suggests that in years of low scour and potentially ideal incubation

conditions, parental effects play an important role in determining in situ egg-to-fry survival, and that extensive replication and tracking of gamete viability is needed to separate parental effects from environmental factors affecting survival. We provide standardized methods for collecting egg-to-fry survival data and outline a number of potential biases that should be addressed in future research.

Johnson, J. H. (2003). Egg-to-fry survival of two strains of Atlantic salmon (salmo salar) in stream incubators under laboratory conditions. *Journal of Freshwater Ecology,* 18(3), 499-500. https://doi.org/10.1080/02705060.2003.9663987

Egg-to-fry survival of two strains of Atlantic salmon (Salmo salar) was evaluated under laboratory conditions in two commercial stream egg incubators. The survival was also examined based on egg developmental stage (i.e., green eggs, eyed eggs, advanced eggs). There was no significant difference in survival of eggs in the Jordan-Scotty and Whitlock-Vibert incubators. However, the survival of Sebago strain Atlantic salmon eggs was significantly higher than that of Penobscot stream eggs, and survival increased with advanced egg developmental stage.

Johnson, J. H. (2004). Comparative survival and growth of Atlantic salmon from egg stocking and fry releases. *North American Journal of Fisheries Management,* 24(4), 1409-1412. https://doi.org/10.1577/1548-8675(2004)24<1409:Csagoa>2.0.Co;2

First summer survival and subsequent growth of Atlantic salmon Salina salar planted as eggs and fry in a tributary of Cayuga Lake, New York, were examined for 3 years. Atlantic salmon were planted in December 1999-2001 in 20 Whitlock-Vibert (W-V) egg incubators, each containing 300 eyed eggs. The following May, 500 fin-clipped Atlantic salmon fry were released in the same stream section. In autumn, a back-pack electroshocker was used to capture fry to assess survival and growth. Mean survival was significantly greater for fry (27.9%) than eggs (0.8%). In autumn, mean length was significantly greater for Atlantic salmon released as fry (90.1 mm) than those planted as eggs (76.2 mm), probably owing to accelerated growth in the hatchery caused by warmer water temperatures (i.e., hatchery, 9.4degreesC; stream, 5.1degreesC). Releasing Atlantic salmon fry in May was nearly I I times more costly in terms of hatchery effort than was releasing eggs in December. Although the survival of Atlantic salmon eggs in W-V incubators was low, when considering production costs, the use of egg plantings may warrant consideration under certain restoration or enhancement situations.

Kapuscinski, A. R. D., & Lannan, J. E. (1983). On density of chum salmon (Oncorhynchus keta) eggs in shallow matrix substrate incubators. *Canadian Journal of Fisheries and Aquatic Sciences,* 40(2), 185-191. https://doi.org/10.1139/f83-028

Eyed chum salmon (Oncorhynchus keta) eggs were loaded at seven equidistant densities ranging from 10 760 to 75 350 eggs/m2 of gravel into Netarts-type shallow matrix substrate incubators. Egg density did not affect fry survival but altered emergence timing which influenced fry quality. Fry emergence was most premature in the 32 290 and 43 060 eggs/m2 treatments. Early migrants had higher development index values, more variable lipid contents, and lower water contents than peak and late migrants. Results are discussed in relation to economic and biological optimization of hatchery incubation.

Kennedy, C. J. A., & Strange, C. D. (1981). Comparative survival from salmon (Salmo salar l.) stocking with eyed and green ova in an upland stream. *Aquaculture Research,* 12(2), 43-48. https://doi.org/10.1111/j.1365-2109.1981.tb00008.x

The survival rates of salmon stocked as eyed ova and green eggs in an upland trout stream were compared by electrofishing a number of sites during their first summer and at the end of their first complete year. The results were compared with the survival rates in the naturally spawning trout population. It was found that the survival rates from eyed ova were considerably better than that from green eggs and the results were discussed in the context of environmental effects and territorial competition in emerging fry.

Kerns, O. E., & Donaldson, J. R. (1968). Behavior and distribution of spawning sockeye salmon on island beaches in Iliamna Lake, Alaska, 1965. *Journal of the Fisheries Board of Canada,* 25(3), 485-494. https://doi.org/10.1139/f68-042

In 1965, spawning was studied on the island beaches of the eastern part of Iliamna Lake from a 5.5-m tower mounted on a 9.1-m boat and with the use of scuba. Over 3 million sockeye salmon, Oncorhynchus nerka (Walbaum), utilized nearly 130 ha of the beaches surveyed during the period August 8–21. The total spawning population and utilized area of shoreline of all the islands in the lake were greater since each area was surveyed only once and possible multiple waves of spawners were not taken into account, and not all of the island shoreline was surveyed by the above methods. The salmon generally spawned in dense groups, over immovable rock, in exposed areas with no upwelling ground water, and with little display of territorial defense. Density ranged from less than 0.1 fish to more than 5 fish per 0.84 m 2 (1 yard 2). The latter density prevailed on reefs and outside points of the islands. Seventy-three per cent of spawning took place over bottom with irregular rocks from 102 to 305 mm (4–12 inches) in diam, and over 90% at depths from 2 to 6 m (6–20 ft) on bottom with slopes from 15 to 25°. Commonly, in a group of fish, one or more of the females were seen with their vents down in rock interstices, emitting eggs, while the males in close proximity were observed releasing milt. Eggs on the beaches are probably aerated by wind-generated lake currents and seiches. Of 3553 eggs collected from several island beaches, 6.8% were infertile.Several features of the spawning behavior and environment are favorable to the survival of eggs and fry. The bottom is not scoured. Most eggs are deposited between immovable rocks and are thus not disturbed by subsequent spawners. Fry emerging from the beaches have immediate access to the large food supply in the lake. Some hazards are predation on eggs by fishes, freezing, and ultraviolet radiation of eggs in shallow water, and smothering of eggs in areas with a high density of eggs or algal growth.

Khan, F., Johnson, G. E., Royer, I. M., Hughes, J. S., Fischer, E. S., Trott, D. M., & Ploskey, G. R. (2012). *Hydroacoustic evaluation of juvenile salmonid passage and distribution at Lookout Point Dam, 2010.* Pacific Northwest National Laboratory, https://doi.org/10.2172/1042548

Pacific Northwest National Laboratory evaluated juvenile salmonid passage and distribution at Lookout Point Dam (LOP) on the Middle Fork Willamette River for the U.S. Army Corps of Engineers, Portland District (USACE), to provide data to support decisions on long-term measures to enhance downstream passage at LOP and others dams in USACE's Willamette Valley Project. This study was conducted in response to the listing of Upper Willamette River Spring Chinook salmon (Oncorhynchus tshawytscha) and Upper Willamette River steelhead (O. mykiss) as threatened under the Endangered Species Act. We

conducted a hydroacoustic evaluation of juvenile salmonid passage and distribution at LOP during February 2010 through January 2011. Findings from this 1 year of study should be applied carefully because annual variation can be expected due to variability in adult salmon escapement, egg-to-fry and fry-to-smolt survival rates, reservoir rearing and predation, dam operations, and weather. Fish passage rates for smolt-size fish (> {approx}90 mm and < 300 mm) were highest during December-January and lowest in mid-summer through early fall. Passage peaks were also evident in early spring, early summer, and late fall. During the entire study period, an estimated total of 142,463 fish {+-} 4,444 (95% confidence interval) smolt-size fish passed through turbine penstock intakes. Of this total, 84% passed during December-January. Run timing for small-size fish ({approx}65-90 mm) peaked (702 fish) on December 18. Diel periodicity of smolt-size fish showing crepuscular peaks was evident in fish passage into turbine penstock intakes. Relatively few fish passed into the Regulating Outlets (ROs) when they were open in summer (2 fish/d) and winter (8 fish/d). Overall, when the ROs were open, RO efficiency (RO passage divided by total project passage) was 0.004. In linear regression analyses, daily fish passage (turbines and ROs combined) for smolt-size fish was significantly related to project discharge (P<0.001). This relationship was positive, but there was no relationship between total project passage and forebay elevation (P=0.48) or forebay elevation delta, i.e., day-to-day change in forebay elevation (P=0.16). In multiple regression analyses, a relatively parsimonious model was selected that predicted the observed data well. The multiple regression model indicates a positive trend between expected daily fish passage and each of the three variables in the model-Julian day, log(discharge), and log(abs(forebay delta)); i.e., as any of the environmental variables increase, expected daily fish passage increases. For vertical distribution of fish at the face of the dam, fish were surface-oriented with 62%-80% occurring above 10 m deep. The highest percentage of fish (30%-60%) was found between 5-10-m-deep. During spring and summer, mean target strengths for the analysis periods ranged from -44.2 to -42.1 dB. These values are indicative of yearling-sized juvenile salmon. In contrast, mean target strengths in fall and winter were about -49.0 dB, which are representative of subyearling-sized fish. The high-resolution spatial and temporal data reported herein provide detailed information about vertical, horizontal, diel, daily, and seasonal fish passage rates and distributions at LOP from March 2010 through January 2011. This information will support management decisions on design and development of surface passage and collection devices to help restore Chinook salmon populations in the Middle Fork Willamette River watershed above LOP.

Kiyohara, K. (2017). *Evaluation of juvenile salmon production in 2016 from the Cedar River and Bear Creek*. (FPA 17-01). Washington Department of Fish and Wildlife Retrieved from https://wdfw.wa.gov/sites/default/files/publications/01901/wdfw01901.pdf

This report describes the emigration of five salmonid species from two tributaries in the Lake Washington watershed: Cedar River and Bear Creek. Cedar River flows into the southern end of Lake Washington; Bear Creek flows into the Sammamish River, which flows into the north end of Lake Washington (Figure 1). In each watershed, the abundance of juvenile migrants is the measure of freshwater production upstream from the trapping location. In 1992, the Washington Department of Fish and Wildlife (WDFW) initiated an evaluation of sockeye fry migrants in the Cedar River to investigate the causes of low adult sockeye returns. In 1999, the Cedar River juvenile monitoring study was expanded in scope in order to include juvenile migrant Chinook salmon. This new scope extended the trapping season to a six month period and, as a consequence, also allowed estimation of coho production, and assessment of steelhead and cutthroat trout movement. In 1997, WDFW initiated an evaluation of sockeye fry migrants in the Sammamish watershed. In 1997 and 1998, a juvenile trap was operated in the Sammamish River during the downstream sockeye migration. In 1999, this monitoring

study was moved to Bear Creek in order to simultaneously evaluate Chinook and sockeye production. Since 1999, the Bear Creek juvenile monitoring study has also provided estimates of coho production and described ancillary data on movement patterns of steelhead and cutthroat trout. The primary study goal of this program in 2016 was to estimate the number of juvenile sockeye fry, and natural-origin Chinook and coho migrating from the Cedar River and Bear Creek into Lake Washington. This estimate was used to calculate survival of the 2015 brood from egg deposition to lake/river entry and to describe the migration timing of each species. Cutthroat and steelhead movements were assessed through catch totals but no abundance estimates were made. Biological data representing each population are also summarized.

Knudsen, C. M., Schroder, S. L., Busack, C., Johnston, M. V., Pearsons, T. N., & Strom, C. R. (2008). Comparison of female reproductive traits and progeny of first-generation hatchery and wild upper Yakima River spring Chinook salmon. *Transactions of the American Fisheries Society,* 137(5), 1433-1445. https://doi.org/10.1577/t06-160.1

Hatchery and wild female spring Chinook salmon Oncorhynchus tshawytscha front the upper Yakima River were compared to determine whether their reproductive traits had diverged after a single generation of artificial propagation. Fecundity, relative fecundity, individual egg mass, and total gamete mass were all significantly correlated with body length, while reproductive effort (gonadosomatic index) was not. Regressions of trait versus body length often differed significantly among brood years. Hatchery spring Chinook salmon were significantly smaller than wild females over the four brood years examined. After brood year and body length (when necessary) were accounted for, wild females had an average of 8.8% more total gamete mass, 0.8% more individual egg mass, 7.7% greater fecundity, and 0.8% greater reproductive effort than hatchery females. Relative fecundity (the number of eggs per centimeter of body length) was on average 1.3% greater in hatchery females. We also compared body size at yolk absorption and egg-to-fry survival of the progeny from hatchery-by-hatchery and wild-by-wild matings. After differences in egg size were accounted for, hatchery fry were on average 1.0% heavier than wild fry. Egg-to-fry survival rates varied among years, with no consistent difference between hatchery and wild try. The relationships between reproductive traits and body length were not significantly altered by a single generation of hatchery exposure. However, because hatchery females had smaller body sizes, the distributions of linked traits, such as total gamete mass and fecundity, differed by as much as 0.6 SD, probably resulting in sonic fitness loss. Our data support the idea that a single generation of state-of-the-art conservation hatchery propagation can produce fish with reproductive traits similar to those of wild fish, given comparable body size.

Knudsen, E. E., Symmes, E. W., & Margraf, E. J. (2003). Searching for a life history approach to salmon escapement management. In *Nutrients in salmonid ecosystems: Sustaining production and biodiversity.* American Fisheries Society https://doi.org/10.47886/9781888569445.ch19

A number of Pacific salmon populations have already been lost and many others throughout the range are in various states of decline. Recent research has documented that Pacific salmon carcasses serve as a key delivery vector of marine-derived nutrients into the freshwater portions of their ecosystems. This nutrient supply plays a critical biological feedback role in salmon sustainability by supporting juvenile salmon production. We first demonstrate how nutrient feedback potential to juvenile production may be unaccounted for in spawner-recruit models of populations under long-term exploitation. We then present a heuristic, life history-based, spreadsheet survival model that incorporates salmon carcass-

driven nutrient feedback to the freshwater components of the salmon ecosystem. The productivity of a hypothetical coho salmon population was simulated using rates from the literature for survival from spawner to egg, egg to fry, fry to smolt, and smolt to adult. The effects of climate variation and nutrient feedback on survival were incorporated, as were density-dependent effects of the numbers of spawners and fry on freshwater survival of eggs and juveniles. The unexploited equilibrium population was subjected to 100 years of 20, 40, 60, and 80% harvest. Each harvest scenario greater than 20% brought the population to a reduced steady state, regardless of generous compensatory survival at low population sizes. Increasing harvest reduced the positive effects of nutrient contributions to population growth. Salmon researchers should further explore this modeling approach for establishing escapement goals. Given the importance of nutrient feedback, managers should strive for generous escapements that support nutrient rebuilding, as well as egg deposition, to ensure strong future salmon production.

Kocik, J. F., Taylor, W. W., & Wagner, W. C. (1991). Abundance, size, and recruitment of pink salmon (Oncorhynchus gorbuscha) in selected Michigan tributaries of the upper Great Lakes, 1984-1988. *Journal of Great Lakes Research,* 17(2), 203-213. https://doi.org/10.1016/s0380-1330(91)71357-9

The abundance and size of pink salmon spawners and fry were studied in selected Michigan tributaries of Lakes Huron, Michigan, and Superior from 1984 to 1988. Pink salmon populations in Lake Superior have declined since the early 1980s. In Lake Huron, populations began increasing in 1983 and have leveled off at relatively high numbers. Lake Michigan populations have increased. Male spawners were significantly longer than females in all lakes. Lake Michigan fish were significantly longer than Lake Huron and Lake Superior fish, but no significant difference was observed between the latter two groups. Male spawners averaged 482 mm (1,045 g) in Lake Michigan, 418 mm (574 g) in Lake Huron, and 410 mm (567 g) in Lake Superior. Females averaged 449 mm (840 g) in Lake Michigan, 389 mm (450 g) in Lake Huron, and 388 mm (466 g) in Lake Superior. No significant length differences were observed in outmigrating fry from tributaries of the three lakes. Fry from individual tributaries averaged 31.94 mm (0.138 g) in Lake Huron, 32.64 mm (0.132 g) in Lake Michigan, and 31.96 mm (0.117 g) in Lake Superior. Fry recruitment was variable among years and dependent upon spawner abundance and over-winter flow conditions. Survival estimates from egg deposition to fry outmigration were poor (0.15% to 0.45%), which demonstrates the importance of riverine environments to Great Lakes pink salmon abundance.

Koenings, J. P., & Kyle, G. B. (1997). Consequences to juvenile sockeye salmon and the zooplankton community resulting from intense predation. *Alaska Fishery Research Bulletin,* 4(2), 120-135. Retrieved from https://www.adfg.Alaska.gov/fedaidpdfs/AFRB.04.2.120-135.pdf

Stocking of juvenile sockeye salmon Oncorhynchus nerka into nonanadromous lakes at levels comparable with juvenile densities in anadromous lakes supporting natural sockeye salmon populations effected up to a 90% reduction in zooplankton biomass. The zooplankton communities subsequently became resistant to predation as the vulnerable Daphnia, Diaptomus, and ovigerous Cyclops were virtually eliminated and the more agile (nonovigerous) Cyclops and smaller Bosmina persevered and became predominant. Relying on a standing crop of zooplankton that was severely depressed by intense grazing the previous season, juvenile sockeye salmon experienced at least a 3-fold reduction in numbers and biomass between fry and smolt stages from the previous year. Our experimental results confirmed our empirical findings that, in rearing-limited lakes, smolt biomass production becomes a function of zooplankton biomass. Once restructured by excessive predation, some zooplankton communities were

unresponsive or slow to respond to either reduced grazing pressure and/or to subsequent nutrient treatment. This delayed recovery of overgrazed zooplankton populations reduced growth and survival (rearing efficiency) for ensuing cohorts. In response, Frazer Lake sockeye salmon populations fell far below replacement, the dominant-year run segment collapsed, and the amplitude of high versus low return per spawner ratios increased. In contrast, less damaged zooplankter populations responded to nutrient treatments, leading to a 3-fold increase in fry-to-smolt survival and a 6- to 20-fold increase in smolt biomass. The degree to which juvenile sockeye salmon foraging decreases biomass levels and changes the species composition of the zooplankton community ultimately determines the duration of zooplankton recovery and lowered sockeye salmon production.

Krueger, D. M., Rutherford, E. S., & Mason, D. M. (2013). Modeling the influence of parr predation by walleyes and brown trout on the long-term population dynamics of Chinook salmon in Lake Michigan: A stage matrix approach. *Transactions of the American Fisheries Society,* 142(4), 1101-1113. https://doi.org/10.1080/00028487.2013.797496

Predation events during ontogeny may have long-term consequences for fish population abundance and variability. We used a stage-based matrix model to evaluate Walleye Sander vitreus and Brown Trout Salmo trutta predation on Chinook Salmon Oncorhynchus tshawytscha parr of the Muskegon River stock and the relative influence of parr predation on the long-term population dynamics and recruitment of Chinook Salmon in Lake Michigan. The model predicted the number of Chinook Salmon individuals in each stage (fry, smolts, and lake age 0 [recruits] through lake age 4) and forecasted population trajectories based on demographic data (e.g., survival, growth, and fecundity). The relative influence of parr predation was compared with influences of environmental stochasticity in the egg stage and Alewife Alosa pseudoharengus abundance (prey for lake-stage salmon) on Chinook Salmon fecundity, recruitment, and population growth. To simulate environmental stochasticity and the influence of Alewife abundance, we varied Chinook Salmon stage-specific survival rates, growth rates, maturity schedule, and carrying capacity. Relative to a baseline recruitment scenario, removal of stocked Brown Trout resulted in a significant increase in parr survival and long-term Chinook Salmon abundance. Walleye predation on parr had little apparent influence on Chinook Salmon population dynamics. Predation on parr during out-migration was positively correlated with variation in Chinook Salmon population stability and was negatively correlated with population growth, suggesting that Brown Trout have a significant negative effect on Chinook Salmon recruitment and long-term population stability. The negative effects of variation in egg survival rates and Alewife abundance on Chinook Salmon recruitment and population growth rates were similar to the negative effects from parr predation scenarios. Our study suggests that management decisions to promote Great Lakes Chinook Salmon populations may require evaluation of trout stocking practices in nursery habitats. Received October 9, 2012; accepted April 15, 2013

Lacroix, G. L. (1985). Survival of eggs and alevins of Atlantic salmon (Salmo salar) in relation to the chemistry of interstitial water in redds in some acidic streams of Atlantic Canada. *Canadian Journal of Fisheries and Aquatic Sciences,* 42(2), 292-299. https://doi.org/10.1139/f85-037

Eggs of Atlantic salmon (Salmo salar) were incubated in spawning areas of five streams of mean pH 4.6–6.5. Hatching success (36.6–88.7%) for eggs planted after fertilization in the natural substrate of four acidic streams was highly correlated with the pH (4.5–5.0) of interstitial water, and the LL50 was about pH 4.7. Dissolved oxygen concentrations (>6.0 mg·L−1) in the interstitial water in these streams were

probably not limiting to embryos before hatching. In a near-neutral stream (pH 6.5), the comparatively lower hatching success (5.6–77.0%) was significantly correlated with minimum dissolved oxygen concentration (1.4–9.2 mg·L−1) in the interstitial water, and the mean survival of embryos was very low (16.2%) at oxygen concentrations <6.0 mg·L−1. Conditions in the substrate where eggs were incubated until hatching were representative of those in natural salmon redds. In one of the acidic streams (pH 4.8), dissolved oxygen concentrations in the interstitial water were low (2.0–7.6 mg·L−1) after the hatch, and the emergence of salmon fry from natural redds was minimal, which indicated a low survival of alevins. Estimates of critical pH levels for salmon embryos differ between the laboratory and field approach and are probably site specific because survival in acid waters is determined by acidity, related chemical factors, and changes in water quality within the redd environment.

Lacroix, G. L. (1989). Ecological and physiological responses of Atlantic salmon in acidic organic rivers of Nova Scotia, Canada. *Water, Air, and Soil Pollution,* 46(1-4), 375-386. https://doi.org/10.1007/bf00192871

Ecological and toxicological data from field studies on acidic rivers of Nova Scotia were examined to review the effects of low pH on Atlantic salmon (Salmo salar) populations in waters rich in organic acids where noexchangeable forms of Al dominate at all times. There were no survival of salmon past the dry stage at pH <4.7, and survival rates for salmon from egg to smolt only increased at pH >4.9. Annual production of juvenile salmon and potential yield of smolts were lower at pH 4.7 to 5.4 than at pH 5.6 to 6.3 because of reduced densities attributable to the high mortality of fry at pH ≤5.0. However, acidity episodes to pH <4.7 also resulted in mortality of parr, reducing densities and often completely eliminating year-classes. The physiological responses of juvenile salmon to chronic acid conditions and to acute acidity typical of episodic events were also reviewed in relation to toxicity. Decreased in plasma Na and Cl were well correlated with ambient pH, but not with exchangeable Al concentrations in rivers. These plasma electrolytes provided reliable indicators of the thresholds for sublethal effects on ionoregulatory mechanisms. There was no morphological evidence of damage or lesions in gill epithelia, indicating that accumulation of Al in the gills of parr was not a significant factor in the lethal effects observed in acidic rivers. High organic matter content in the water apparently protected gills from adverse Al effects. Toxicity was considered to result from the effect of low ambient pH on branchial ionoregulatory mechanisms.

Ladago, B. J., Marsden, J. E., & Evans, A. N. (2016). Early feeding by lake trout fry. *Transactions of the American Fisheries Society,* 145(1), 1-6. https://doi.org/10.1080/00028487.2015.1073622

The restoration of Lake Trout Salvelinus namaycush in the Great Lakes and Lake Champlain has been challenging due to the bottlenecks in recruitment that occur mostly during early life stages. Among possible sources of fry mortality (e.g., predation, starvation, and disease), the least is known about the diet and starvation risk of pre-emergent fry. The first feedings by fry are generally assumed to be delayed until close to the absorption of the yolk sac and the emergence of the fry. The stomach contents of 374 wild-caught Lake Trout fry from Lake Champlain were examined from hatching to the exogenous feeding stage to identify the earliest occurrence of feeding relative to yolk sac absorption and to describe the diet. Within 2 weeks of hatching, 19% of fry had food in their stomachs. At 4?6 weeks and after yolk sac absorption, 98% of fry began feeding. Diet was primarily comprised of Bosmina as well as calanoid and cyclopoid copepods, and fry contained up to 215 items per stomach. Our finding that fry began feeding within 2 weeks of hatching (prior to yolk sac absorption) is relevant to current concerns

that Lake Trout fry mortality in the Great Lakes is caused by thiamine deficiency syndrome: wild Lake Trout fry may be able to mitigate thiamine deficiency with early feeding on thiamine-rich zooplankton.

Leaniz, C. G. d., Fraser, N., & Huntingford, F. (1993). Dispersal of Atlantic salmon fry from a natural redd: Evidence for undergravel movements? *Canadian Journal of Zoology,* 71(7), 1454-1457. https://doi.org/10.1139/z93-201

In this paper we describe a modified version of a box trap used for bank-to-bank trapping during a study of dispersal of Atlantic salmon fry (Salmo salar L.). Two such traps were positioned 2?m upstream and downstream of a single isolated natural redd and a third was placed 20?m downstream. All fry captured in each trap were marked and released beyond the trap. Of the fish caught in the second downstream trap, 64% were unmarked. The seasonal patterns of trapping for marked and unmarked fish were identical, but the unmarked fish were significantly smaller than their marked peers. We argue that these unmarked captures represent fish that evaded capture in the first downstream trap, either by dispersing from the redd deep within the gravel or by leaving the water column and burrowing into the gravel on encountering the trap. Implications for the interpretation of trapping data on newly emerged salmonids are discussed.

Leatherland, J. F., & Sonstegard, R. A. (1987). Comparative fecundity and egg survival in 2 stocks of goitred coho salmon (Oncorhynchus kisutch Walbaum) from Lake Erie. *Canadian Journal of Zoology-Revue Canadienne De Zoologie,* 65(11), 2780-2785. https://doi.org/10.1139/z87-419

The reproductive success of two stocks of Lake Erie coho salmon (Oncorhynchus kisutch Walbaum) was examined in an attempt to determine if the low embryonic survival of one of the stocks could be related to the epizootic of thyroid hyperplasia exhibited by that stock. In one stock (derived from Lake Michigan and introduced annually into Trout Run, Fairview, Pennsylvania, by the Pennsylvania Fish Commission) the mortality of the embryos and yolk sac fry was significantly higher and the weight of yolk sac fry and parr was smaller than in a second self-reproducing stock which spawns in Young and Fishers creeks, Ontario. The gonadosomatic indices and number of eggs per unit weight of female were larger in the Pennsylvania stock, although carcass weights, weights of unfertilized eggs, and number of eggs per female were similar in the two stocks; secondary sexual characteristics were poorly exhibited in both stocks. There were no differences in plasma thyroid hormone levels or the degree of thyroid hyperplasia in the two stocks, suggesting that the low survival of the embryos and poor growth of the yolk sac fry in the Pennsylvania stock cannot be attributed directly to thyroid dysfunction, as had been proposed previously. Plasma thyroid hormone levels fell from relatively high levels in sexually immature salmon collected in summer to near zero levels in the pre-ovulatory to post-ovulatory salmon collected in the fall. Moreover, there was a significant decrease in plasma triiodo-L-thyronine (T3) levels in males during the period between early October and early December. No such decline was seen in females, which had low plasma T3 levels by the first (early October) fall collection.

Lehnert, S. J., Heath, J. W., & Heath, D. D. (2013). Ecological and genetic risks arising from reproductive interactions between wild and farmed Chinook salmon. *Canadian Journal of Fisheries and Aquatic Sciences,* 70(12), 1691-1698. https://doi.org/10.1139/cjfas-2013-0181

Escapes from aquaculture sites may threaten wild populations through ecological risks such as reproductive interference and genetic risks through successful hybridization. Mating studies examining wild-farmed interactions should quantify fertilization and reproductive success separately through genotyping of eggs and fry, respectively, to estimate ecological and genetic risks. We examined fertilization and reproductive success (fry survival to 158 and 201 days) of farmed (XY and XX males) and wild Chinook salmon (Oncorhynchus tshawytscha) males in competitive seminatural spawning channels with farmed females. XY and XX farmed males did not differ in fertilization and reproductive success. Farmed and wild males exhibited no difference in fertilization success; however, farmed males experienced significantly lower reproductive success relative to wild owing to differences in egg-to-fry survival because of competition with wild-sired offspring. Therefore, farmed males pose ecological risk to wild populations by removing reproductive opportunities from wild males, potentially reducing wild salmon productivity. However, low survival of farm-sired offspring will reduce further opportunities for interbreeding between wild and farm-raised fish. Nevertheless, research is needed to further quantify these genetic impacts.

Leon, K. A., & Bonney, W. A. (1979). Atlantic salmon embryos and fry: Effects of various incubation and rearing methods on hatchery survival and growth. *The Progressive Fish-Culturist,* 41(1), 20-25. https://doi.org/10.1577/1548-8659(1979)41[20:aseaf]2.0.co;2

Significantly heavier fry of Atlantic salmon (Salmo salar) and greatly reduced mortality apparently resulted from the use of matrix substrates during egg incubation and alevin development. Salmon fry produced by this method fed readily and did not have the constricted yolk sacs that commonly occur when conventional rearing methods are used.

Leppi, J. C., Rinella, D. J., Wilson, R. R., & Loya, W. M. (2014). Linking climate change projections for an Alaskan watershed to future coho salmon production. *Global Change Biology,* 20(6), 1808-1820. https://doi.org/10.1111/gcb.12492

Climate change is predicted to dramatically change hydrologic processes across Alaska, but estimates of how these impacts will influence specific watersheds and aquatic species are lacking. Here, we linked climate, hydrology, and habitat models within a coho salmon (Oncorhynchus kisutch) population model to assess how projected climate change could affect survival at each freshwater life stage and, in turn, production of coho salmon smolts in three subwatersheds of the Chuitna (Chuit) River watershed, Alaska. Based on future climate scenarios and projections from a three-dimensional hydrology model, we simulated coho smolt production over a 20-year span at the end of the century (2080-2100). The direction (i.e., positive vs. negative) and magnitude of changes in smolt production varied substantially by climate scenario and subwatershed. Projected smolt production decreased in all three subwatersheds under the minimum air temperature and maximum precipitation scenario due to elevated peak flows and a resulting 98% reduction in egg-to-fry survival. In contrast, the maximum air temperature and minimum precipitation scenario led to an increase in smolt production in all three subwatersheds through an increase in fry survival. Other climate change scenarios led to mixed responses, with projected smolt production increasing and decreasing in different subwatersheds. Our

analysis highlights the complexity inherent in predicting climate-change-related impacts to salmon populations and demonstrates that population effects may depend on interactions between the relative magnitude of hydrologic and thermal changes and their interactions with features of the local habitat.

Lim, P. G., & Barrett, D. T. (1982). *A review of pink salmon (Oncorhynchus gorbuscha) transplants to Robertson Creek (1959-1964).* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/454858/publication.html

An artificial spawning channel was built on Robertson Creek in 1959. One of the primary objectives of the channel was to establish a commercial-sized run of pink salmon (Oncorhynchus gorbuscha) in the upper Somass River and to increase the numbers of coho (O. kisutch) and Chinook (O. tshawytscha) salmon. Massive pink salmon egg transplants from various B.C. sources ensued with variable, but overall poor results. Egg to fry survival was extremely high, ranging from 86 to 95 percent, but adult returns, good one year, were dismally poor in others during the period 1961 to 1967. The project was consequently abandoned and by 1971 local people were aware that the expensive facility was sitting idle. Eventually the Department of Fisheries and Forestry (now Fisheries and Oceans) converted the site to an enormously successful Chinook, coho, and steelhead trout (Salmo gairdneri) hatchery which is operating at high production levels today. This paper reviews the data gathered form 1960 to 1967 on the pink egg transplant experiments at Robertson Creek.

Maeland, A., Waagbo, R., Sandnes, K., & Hjeltnes, B. (1998). Biotin in practical fish-meal based diet for Atlantic salmon Salmo salar l. Fry. *Aquaculture Nutrition,* 4(4), 241-247. https://doi.org/10.1046/j.1365-2095.1998.00076.x

Groups of Atlantic salmon fry (0.19 g initial weight) were fed a fish-meal based starter diet with different supplements of biotin (0, 0.5, 1.0 and 1.5 mg biotin kg(-1)) in triplicate tanks for 18 weeks. The basal diet contained 0.3 mg total biotin kg(-1). The experimental design included a negative control diet made by replacing 10% of the fish-meal with spray-dried raw hen's egg white. Throughout the experimental period the fish grew to about 5 g and there were no significant differences in growth and mortality among the groups of fish fed the fish-meal diets. At the end of the experiment there were no significant differences in biotin level in the liver, while whole-body biotin concentrations correlated significantly with the dietary biotin concentrations. No significant increase in pyruvate carboxylase (PC) activity was found in livers from fish given different dietary levels of biotin. The control diet with egg white resulted in severe growth reduction and increased mortality compared with the other dietary groups. The concentrations of biotin in liver and whole body were decreased in fish fed egg white. Increased levels of glycogen and reduced PC activity in the liver were observed in this group after 18 weeks. Histology of the gills showed no differences in appearance when fish were fed fish-meal based diets while the addition of egg white resulted in hypertrophy and hyperplasia of the gill tissue and extensive fusions of the secondary gill lamellae. The results show that there is no need for supplemental biotin in practical fish-meal based diets for Atlantic salmon fry to achieve optimal growth, survival and maximal liver PC activity.

Malecha, P. W. (2002). *Survival and development of pink salmon (Oncorhynchus gorbuscha) embryos and fry as related to egg size and quantitative genetic variation.* (MS), University of Alaska Fairbanks, Retrieved from http://hdl.handle.net/11122/6349

The effect of egg weight on survival and development of pink salmon (Oncorhynchus gorbuscha) embryos, alevins, and fry was analyzed; in addition, embryo survival was investigated in relation to additive genetic variation. Embryonic survival to eyeing, development time to hatch, yolk weight, somatic tissue weight, yolk use rate, somatic tissue growth rate, and the survival of first-feeding fry was recorded relative to egg weight. The analyses demonstrated significant egg weight effects on development time to hatch, yolk weight, somatic tissue weight, yolk use rate, and somatic tissue growth rate on alevins. Weight and length of post-emergent fry (17 weeks post-ponding) were also significantly affected by initial egg weight. However, egg weight did not affect survival of eyed eggs or fry. Differential family-specific survival of eyed eggs indicated the presence of significant additive genetic variation.

Mantua, N., Tohver, I., & Hamlet, A. (2010). Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change,* 102(1-2), 187-223. https://doi.org/10.1007/s10584-010-9845-2

This study evaluates the sensitivity of Washington State's freshwater habitat of Pacific Salmon (Oncorhynchus spp.) to climate change. Our analysis focuses on summertime stream temperatures, seasonal low flows, and changes in peak and base flows because these physical factors are likely to be key pressure points for many of Washington's salmon populations. Weekly summertime water temperatures and extreme daily high and low streamflows are evaluated under multimodel composites for A1B and B1 greenhouse gas emissions scenarios. Simulations predict rising water temperatures will thermally stress salmon throughout Washington's watersheds, becoming increasingly severe later in the twenty-first century. Streamflow simulations predict that basins strongly influenced by transient runoff (a mix of direct runoff from cool-season rainfall and springtime snowmelt) are most sensitive to climate change. By the 2080s, hydrologic simulations predict a complete loss of Washington's snowmelt dominant basins, and only about ten transient basins remaining in the north Cascades. Historically transient runoff watersheds will shift towards rainfall dominant behavior, undergoing more severe summer low flow periods and more frequent days with intense winter flooding. While cool-season stream temperature changes and impacts on salmon are not assessed in this study, it is possible that climate-induced warming in winter and spring will benefit parts of the freshwater life-cycle of some salmon populations enough to increase their reproductive success (or overall fitness). However, the combined effects of warming summertime stream temperatures and altered streamflows will likely reduce the reproductive success for many Washington salmon populations, with impacts varying for different life history-types and watershed-types. Diminishing streamflows and higher stream temperatures in summer will be stressful for stream-type salmon populations that have freshwater rearing periods in summer. Increased winter flooding in transient runoff watersheds will likely reduce the egg-to-fry survival rates for ocean-type and stream-type salmon.

Marsden, J. E., & Marcy-Quay, B. (2021). A generalized model for correcting bias due to permeability using emergent fry traps in mesocosm experiments. *Fisheries Research,* 233, 105769. https://doi.org/10.1016/j.fishres.2020.105769

Relative abundance, or CPUE, is a commonly used metric for fisheries conservation and management. Interpreting CPUE data requires understanding the probability that a fish will be caught (catchability) by a particular type of gear and factors that affect catchability. Escape is often not considered in catchability studies, and there is little to no mention of this phenomenon in fisheries textbooks. However, most passive sampling gear, particularly traps, is 'permeable', so the number of organisms actually collected will fluctuate based on probability of escapement. Because high or variable escape rates have the potential to bias measures of abundance, the use of passive traps requires recognition and assessment of permeability. To better understand these dynamics, and particularly how they apply to salmonid emergent fry traps, we conducted a series of mesocosm experiments with early-life stage lake trout (Salvelinus namaycush). We assessed entry and exit rates by fitting daily capture data to a hierarchical state-space model. We also evaluated a trap modification and the effect of thiamine deficiency on capture rates; thiamine-deficient fish can be lethargic and unlikely to enter traps, so deficiency in the wild may be underestimated. Results revealed distinct temporal trends, with low initial entry rates that rose around the third week after hatch and remained constant thereafter. Thiamine deficiency decreased entry rates but appeared to have no effect on exit rates. Conversely, a minor trap design change had an unexpectedly large effect on exit rates. We developed a generalizable model for estimating abundance using passive traps based on soak time and entry/exit rates, as well as specific rate estimates for lake trout in emergent fry traps. Such corrections should be performed whenever feasible, as abundance estimates may otherwise be biased by exit-related equilibrium.

Martin, R. M., Heard, W. R., & Wertheimer, A. C. (1981). Short-term rearing of pink salmon (Oncorhynchus gorbuscha) fry - effect on survival and biomass of returning adults. *Canadian Journal of Fisheries and Aquatic Sciences,* 38(5), 554-558. https://doi.org/10.1139/f81-079

Survival of pink salmon (Onchorynchus gorbuscha) fry could theoretically be improved if they were reared to a larger size before being released into the estuary. Three lots of 1975-brood pink salmon fry, reared from eggs in a hatchery, were cultured in floating estuarine raceways for 30, 60, and 90 d before being released into the Little Port Walter estuary on Baranof Island, southeastern Alaska. An unfed control lot was released after emergence. Four groups of 15 000 fry each were differentially fin marked. Total marine survival for the four lots was computed from recoveries of marked adults in the Little Port Walter vicinity in 1977. Survival from release to return was lowest for the control lot (3.1%); increased for fry reared for 30 and 60 d (4.6 and 5.2%, respectively); and decreased for fry cultured for 90 d (4.3%). Mortalities in lots cultured for 60 and 90 d significantly reduced the numbers of fry released in these groups. Mortalities were associated with the marine diatoms Chaetoceros spp. Mean length and weight of returning adults declined with increased fry-rearing time. Compared with the control lot, adults from fry cultured for 30 d had 39% more biomass; adults from fry cultured for 60 d had the same biomass; and adults from fry cultured for 90 d had 45% less biomass. Culturing fry for 30 d in the raceways significantly increased the number and biomass of returning adults.

McDonald, J., & Hume, J. M. (1984). Babine lake sockeye salmon (Oncorhynchus nerka) enhancement program - testing some major assumptions. *Canadian Journal of Fisheries and Aquatic Sciences,* 41(1), 70-92. https://doi.org/10.1139/f84-007

The objective of the Babine Lake sockeye salmon (Oncorhynchus nerka) enhancement project was to increase fry outputs (and thus, smolt outputs and adult returns) by expanding and improving available spawning beds through the use of artificial spawning channels and related water flow control facilities. The project proceeded on four basic assumptions: (1) the artificial spawning channels would prove an effective means of producing sockeye fry, (2) the fry produced would be as viable as those produced from natural spawning beds, (3) the lake nursery area had the capacity to support larger juvenile populations, and (4) increased smolt outputs would result in increased adult returns. A before and after study has allowed these assumptions to be tested. Egg-to-fry survival in the channels was close to 40%, as expected. Comparisons of wild and channel-produced fry did not reveal any substantial difference in their distribution, growth, and survival in the lake. Increases in the abundance of fry were followed by corresponding increases in the abundance of underyearlings in the lake and seaward migrating smolts. No significant change in the average size of the juveniles or their survival in the lake could be detected when population size increased. While the assumptions regarding juvenile production were found to be generally valid, adult returns did not meet expectations. This was due largely to the lack of response to increased smolt outputs from even-numbered brood years. Some options for future management are offered.

McDonald, J. G. (1969). Distribution, growth, and survival of sockeye fry (Oncorhynchus nerka) produced in natural and artificial stream environments. *Journal of the Fisheries Board of Canada,* 26(2), 229-267. https://doi.org/10.1139/f69-027

A comparative study was made at Babine Lake, British Columbia, of the distribution, growth, and survival of sockeye salmon fry resulting from the same parental stock but reared in natural and artificial streams. Fry produced from natural spawning in the Fulton River and from eyed eggs planted in an adjacent artificial spawning channel were marked distinctively, released, and later recovered in the lake nursery area and at the lake outlet at time of seaward migration. Both groups dispersed rapidly and widely into the main lake basin and apparently mixed extensively with sockeye produced from other main lake tributaries. Lake distribution of marked fish, and the underyearling population as a whole, was not uniform nor static and the fish were concentrated in different lake areas at different times of their first growing season. River and channel fry were comparable in mean length at time of release but subsequently channel fish were smaller. Their smaller size appeared to result from late lake entry and a slower rate of growth for a short period thereafter. Over most of the growing period (June 25–October 25) rates of growth in length were similar (instantaneous daily rates of 0.00687 and 0.00737). No significant difference in survival rates of the two groups could be detected for the first 5 months of lake residence. Production of age I seaward migrants was less for river fish than for channel fish but no significance was attached to the small difference observed. These findings are discussed with respect to a fish-cultural scheme which is aimed at increasing adult production by making fuller use of the lake's capacity to rear young sockeye.

McGurk, M. D. (1999). Size dependence of natural mortality rate of sockeye salmon and kokanee in freshwater. *North American Journal of Fisheries Management,* 19(2), 376-396. https://doi.org/10.1577/1548-8675(1999)019<0376:sdonmr>2.0.co;2

Little is known of the relationship between instantaneous natural mortality rate, M (year−1), and body weight, W (g), for the lake-resident life stages of sockeye salmon Oncorhynchus nerka and kokanee (lacustrine sockeye salmon), despite the importance of the M–W relationship for modeling fishery management options. This study provided estimates of the two parameters of the allometric relationship M = 1.38W−0.19 based on nonlinear regression of sockeye salmon egg–fry and egg–smolt survivals on fry and smolt weights reported in the literature. The values of both parameters were low compared with values reported from data sets that included marine iteroparous fish species and larval fish but were similar to values calculated from production–biomass ratios of lake fish populations. The difference suggests that nonpredation mortality plays a minor role in the population dynamics of juvenile sockeye salmon due to their relatively large size at emergence. The M–W relationship provided reasonable predictions of M for juvenile kokanee, based on M calculated from literature reports of kokanee density at age. Predictions of M also appeared reasonable when extrapolated to adult kokanee body weights, based on a comparison with M predicted by four previously published models of adult fish M. The M–W relationship has three potential applications to fishery management: (i) modeling of O. nerka population dynamics; (ii) back-calculating density of age-0 kokanee from density of age-2 kokanee; and (iii) estimating fishing mortality rate of exploited age-classes of kokanee by subtracting predicted M from total mortality rate.

McKinnell, S. M., Wood, C. C., Rutherford, D. T., Hyatt, K. D., & Welch, D. W. (2001). The demise of Owikeno Lake sockeye salmon. *North American Journal of Fisheries Management,* 21(4), 774-791. https://doi.org/10.1577/1548-8675(2001)021<0774:Tdools>2.0.Co;2

A persistent period of low abundance in what was once the second largest fishery for sockeye salmon Oncorhynchus nerka in British Columbia has kept the Rivers Inlet fishery closed since 1996. Initial speculation about the cause of the decline focused on factors such as reduced egg-to-fry survival, declining quantity and quality of spawning habitat, and reduced fry-to-smolt survival in Owikeno Lake (the only nursery lake in Rivers Inlet). We developed an index of juvenile sockeye salmon abundance by combining direct estimates of abundance from trawl surveys with indirect estimates of abundance inferred from density-dependent growth of juvenile sockeye salmon. Juvenile growth data were available as either direct samples of presmolt weight or as measurements of freshwater growth from the scales of returning adults. Collectively, these data do not indicate a Ion-term decline in juvenile sockeye salmon abundance since the 1950s. Throughout the 1970s and 1980s and even more recently (1991 and 1994 brood years), the juvenile abundance index exceeded the long-term mean. If freshwater abundance war either untrended or increasing, the most likely cause of the population decline would have been lower survival after the fry stage, which would have been noticeable in the 1970s and especially from 1992 to 1998. Poor marine survival is the most parsimonious explanation for the declining fry-to-adult survival in Owikeno Lake, particularly in light of coincident declines in sockeye salmon returns per spawner at Long Lake (a nearby pristine watershed) and declines in adult sockeye salmon abundance in other populations to the north of Rivers Inlet.

McMenemy, J. R. (1995). Survival of Atlantic salmon fry stocked at low density in the West River, Vermont. *North American Journal of Fisheries Management,* 15(2), 366-374. https://doi.org/10.1577/1548-8675(1995)015<0366:soasfs>2.3.co;2

Fry of Atlantic salmon Salmo salar stocked at low density (32/100 m2; ±0.7, SE) in the West River, Vermont, produced underyearling and yearling parr densities of 13.5 ± 0.8/ 100 m2 and 5.9 ± 0.5/100 m2, respectively. Survival of fry stocked at low density to underyearling and yearling part- was 42 ± 2.5% and 19 ± 1.3%, respectively. Density of underyearling part produced from fry stocked at low density was not significantly different from the 10.6 ± 1.5 parr produced from fry stocking at high density (mean, 117 ± 16.5/100 m2). However, the 4.0 ± 0.8 yearling part-/100 m2 produced was significantly lower at high stocking density. Survival to underyearling and yearling parr at high stocking density was 11.6 ± 2.0% and 4.6 ± 1.0%, respectively, both significantly lower than survival rates at low stocking density. Thus, low-density stocking produced equal or greater densities of parr with much higher survival rates. Estimated smolt production from low-density fry stocking (with the assumption of a part—to-smolt overwinter survival rate of 65%) was about 4.0 smolts/100 m2; this is equivalent to a fry-to-smolt survival rate of 13%. Results from stocking fed and unfed fry were similar, except fed fry were more likely to produce yearling smolts. Managers of restoration and enhancement programs with limited broodstock, eggs, or incubation space should be able to produce more smolts by stocking fry at lower densities over wider areas without affecting per-unit-area smolt production.

McMichael, G. A., Rakowski, C. L., James, B. B., & Lukas, J. A. (2005). Estimated fall Chinook salmon survival to emergence in dewatered redds in a shallow side channel of the Columbia River. *North American Journal of Fisheries Management,* 25(3), 876-884. https://doi.org/10.1577/m04-168.1

Fall Chinook salmon Oncorhynchus tshawytscha often spawn in the tailraces of large hydroelectric dams on the Columbia River. Redds built in shallow habitats downstream of these dams may be periodically dewatered as a result of load-following operations and subsequent changes in water surface elevation before the fry emerge. To determine whether fall Chinook salmon redds in a shallow area subjected to periodic dewatering downstream of Wanapum Dam on the Columbia River produced live fry, we installed seven redd caps and monitored emergence. Large numbers of live fry were captured from the redds between March 9 and May 18, 2003. Estimated survival from egg to fry for these redds, which were dewatered approximately 3.1% of the time during the posthatch intragravel rearing period, ranged from 16.9% to 66.6% and averaged 29.2% (assuming 4,272 viable eggs/redd). The peak emergence date ranged from April I to April 29 (average, about April 14). Peak emergence dates corresponded well with predicted emergence dates based on 1,000 accumulated temperature units. For fall Chinook salmon emerging from individual redds the mean fork length for each redd ranged from 38.3 to 41.2 mm. and lengths of fish emerging from individual redds increased throughout the emergence period.

Mighell, J. L. (1981). Culture of Atlantic salmon, Salmo salar, in Puget Sound. *Marine Fisheries Review,* 43(2), 1-8. Retrieved from https://spo.nmfs.noaa.gov/content/culture-Atlantic-salmon-Salmo salar-puget-sound

Atlantic salmon, Salmo salar , stocks are extremely low in New England streams. A pilot study conducted in Puget Sound, Wash., showed that Atlantic salmon brood stock could be reared successfully by combining special techniques of fry rearing and saltwater pen culture as used for Pacific salmon. Fingerlings smolted at 13-15 months of age and first adult spawning occurred at 4 years of age. Smolt

size varied in different groups from an average weight of 19.6-200 g (0.70-7.0 ounces). The 1971 and 1974 brood Atlantic salmon spawned for the first time at 4 years of age, when they were averaging about 4.0 kg (8.8 pounds) and 4.2 kg (9.4 pounds), respectively. Survival of the 1971 and 1974 broods in salt water from smolt to mature adult was 90.3 and 81.1%, respectively. The egg survival through hatching was 82.7 and 71.4%, respectively.

Milks, D. J., Varney, M., & Schuck, M. L. (2009). Lyons Ferry hatchery evaluation fall Chinook salmon annual report: 2006. In: Washington Department of Fish and Wildlife. Retrieved from https://wdfw.wa.gov/publications/00664/wdfw00664.pdf

This report summarizes activities by the Washington Department of Fish and Wildlife's (WDFW) Lower Snake River Hatchery Evaluation Program for the period 16 April 2006 through 15 April 2007. We have also included the Statistical Analysis of 2006 Lower Granite Dam Fall Chinook Run Reconstruction report funded by the Pacific Salmon Commission's Southern boundary Restoration and Enhancement Fund in order to make it more widely available. In 2006, WDFW collected 3,679 fish at Lyons Ferry Hatchery (LFH) and Lower Granite Dam (LGR) for broodstock, monitoring and evaluation of our hatchery releases, and to estimate the run size to LGR. This was the fourth year that natural origin fish were integrated into our broodstock. Of the total number of fish contributing to production, 81.1% were Lyons Ferry hatchery origin, 12.2% were natural origin, 5.1% were out-of-basin stray hatchery fish based on scale readings, and 1.6% were of unknown origin. A total of 2,819,004 green eggs were taken at Lyons Ferry Hatchery, well below the full production goals listed in the 2005-2007 United States v. Oregon Management Agreement. Survival from green to eye-up was 96.8% with an estimated 1.1% additional loss to ponding. WDFW released brood year 2005 (BY05) sub-yearlings directly from LFH (202,211 fish), two releases (200,820 and 211,508 fish) into the Snake River near Couse Creek Boat Launch (Rkm 253.7), and two releases (200,432 and 208,733 fish) directly into the Grande Ronde River near the mouth of Cougar Creek. The first Couse Creek release was part of an ongoing direct vs. acclimated study (released from the Captain John acclimation site). An accidental fry (BY05) release of 71,000 fry at 181 fpp occurred on 4 April at LFH. The LFH also released 503,160 yearling fall Chinook (BY05) into the Snake River on site from 2-6 April 2007. Releases of fish into the Snake Basin from 2000 through 2007 are provided. We surveyed the Tucannon River by foot, covering 91% of the historical spawning area of fall Chinook. We estimated 449 fall Chinook and 11 summer Chinook escaped to the Tucannon River, producing an estimated 153 redds. The return to the Tucannon River was estimated to be 45% inbasin hatchery fish, 14% out-of-basin hatchery fish, 30% natural origin fish, 9% unknown origin fish (hatchery or wild), and 2% summer Chinook. Smolt-to-adult return estimates for broodyears 1999 through 2005 are presented for fish released by WDFW. Yearlings continue to provide a survival advantage over subyearlings although it is highly variable year to year. We present data showing a survival advantage of onstation subyearlings when compared to direct releases into the Snake River near Couse Creek and the Grande Ronde River. We adjusted harvest estimates of CWT tagged fish by fishery, sample detection type, and tag loss to fully reflect total take of non-tagged, non-clipped, as well as adipose clipped, and CWT tagged fall Chinook. Analysis was done solely on recoveries of fall Chinook released by WDFW and does not include recoveries of LSRCP fish from the Nez Perce Tribe (NPT), fish released from NPT Hatchery, or fish released from Idaho Power Company programs. Of the WDFW releases, we estimate that 2,844 fall Chinook were taken in fisheries downstream of the Snake River in 2006. By location, fishers in the Columbia River harvested 38% of the total number harvested and fishers in British Columbia harvested 37%. By fishery, the British Columbia Troll fishery intercepted 28% of all fish harvested. This is the first time we have attempted to expand the CWT data in this manner and although it is preliminary, it shows the importance of doing so to fully reflect and understand the harvest component for mitigation.

Outside of the Snake River basin, 25 of Washington's fall Chinook were intercepted at hatcheries or racks and 40 were recovered on spawning grounds. We estimate that 4,827 LFH/Snake River hatchery origin fall Chinook released by WDFW returned to the Snake River.

Moffett, I. J. J., Allen, M., Flanagan, C., Crozier, W. W., & Kennedy, G. J. A. (2006). Fecundity, egg size and early hatchery survival for wild Atlantic salmon, from the River Bush. *Fisheries Management and Ecology,* 13(2), 73-79. https://doi.org/10.1111/j.1365-2400.2006.00478.x

A total of I IS wild Atlantic salmon, Sabno salar L., females were stripped at the River Bush Salmon Station. The total number of eggs (fecundity) and egg diameters were compared for three age groups of adults. Adult length explained the majority of the variation in fecundity whilst freshwater age explained the majority of the variation in egg diameter. Parallel regression analysis for the total number of eggs on fish length relation for 3 years (2000-2002) showed significant temporal variation among years. Larger eggs from 2.1 + adults produced longer and heavier swim-up fry than smaller eggs from 1. 1 + adults. There was also the suggestion that the survival of eggs from 1. 1 + adults was lower than eggs from 2.1 + adults to the swim-up stage.

Mulcahy, D., & Bauersfeld, K. (1983). Effect of loading density of sockeye salmon, Oncorhynchus nerka (Walbaum), eggs in incubation boxes on mortality caused by infectious haematopoietic necrosis. *Journal of fish diseases,* 6(2), 189-193. https://doi.org/10.1111/j.1365-2761.1983.tb00066.x

Eggs were taken from a spawning population of sockeye salmon, O. nerka , with an infectious haematopoietic necrosis virus (IHNV) infection rate of 100% and loaded in incubation boxes at high (900,000), medium (650,000) and low (350,000) densities (eggs per box). Virus titration in fry samples was determined by the plaquing method. Density did not affect survival from egg to fry but did effect level of titre. Within 10-20 days of transferral of emergent fry to laboratory holding tanks, viral epizootics broke out among the fry from the medium and high density incubation boxes. Samples of dead fry yielded high IHN viral titres. No virus was isolated from fry of low density boxes, indicating that egg and alevin density was an important factor in determining mortality by IHNV.

Murray, C. B., & Beacham, T. D. (1986). Effect of incubation density and substrate on the development of chum salmon eggs and alevins. *Progressive Fish-Culturist,* 48(4), 242-249. https://doi.org/10.1577/1548-8640(1986)48<242:Eoidas>2.0.Co;2

Eggs from four families of chum salmon (Oncorhynchus keta) were incubated without gravel substrate at low and high densities until hatching. The alevins then were incubated at high or low density with or without substrate until emergence. Embryo survival rates were significantly different among families but not between incubation densities. Alevins incubated at low density with substrate had higher survival rates than those at low density without substrate and better survival than both high-density groups. Yolk-sac abnormalities and coagulated yolk in alevins and fry were least frequent among chum salmon incubated at low density with substrate; the alevins at low density had greater tissue weights at hatching than those incubated at high density. Fry emerging from low-density incubation with substrate were longer and heavier than those in all other groups. Egg and alevin densities and substrate quantity can be manipulated in standard hatching trays to enhance the survival, size, and quality of chum salmon fry.

Murray, C. B., & Beacham, T. D. (1986). Effect of varying temperature regimes on the development of pink salmon (Oncorhynchus gorbuscha) eggs and alevins. *Canadian Journal of Zoology-Revue Canadienne De Zoologie,* 64(3), 670-676. https://doi.org/10.1139/z86-099

Eggs and alevins from six odd-year, brood-line stocks of pink salmon (Oncorhynchus gorbuscha) spawning in southern British Columbia were incubated under varying temperature regimes and subjected to rapid temperature changes at specific developmental stages. Increasing or decreasing temperature regimes had no significant effect on egg and alevin survival. The inclusion of 2 or 4 °C in the temperature regime reduced egg survival. Rapid temperature changes from 12 to 1 °C late in development reduced alevin survival when compared with transfers from 8 to 1 °C. Hatching and emergence time varied inversely with mean incubation temperature. Decreasing temperature regimes produced longer and heavier alevins and fry than increasing temperature regimes. Low mean incubation temperatures from fertilization to fry emergence resulted in longer and heavier alevins and fry than those at higher mean temperature. Transfers from 8 or 12 °C to 1 °C early in development had a greater effect on alevin length and weight than transfers late in development. Temperature regimes can be manipulated to enhance survival, control development time, and increase alevin and fry size.

Nadeau, P. S., Hinch, S. G., Pon, L. B., & Patterson, D. A. (2009). Persistent parental effects on the survival and size, but not burst swimming performance of juvenile sockeye salmon Oncorhynchus nerka. *Journal of Fish Biology,* 75(3), 538-551. https://doi.org/10.1111/j.1095-8649.2009.02302.x

Sockeye salmon Oncorhynchus nerka were used as a model in an artificial fertilization experiment to investigate the relationships between individual adult O. nerka and their offspring. Survival, size and burst swimming ability were assessed in fry of known parentage (adult spawners from the Weaver Creek population, British Columbia, Canada). Maternal identity significantly affected the survival rate of eggs at hatch time, though this effect did not extend to fry life stages. The results were also suggestive of a paternal effect on both egg and fry survival, though this could not be separated from the experimental block design. After 4 months of exogenous feeding, fry mass remained under significant maternal influence, though fork length did not, despite having a high correlation with mass. Burst swimming performance was highly variable among individuals, and was not significantly influenced by maternal identity or individual fry size. Collectively, the findings presented here suggest that maternal, and possibly paternal, effects can be integral components of population dynamics in the early life stages of O. nerka. A good understanding of these factors will be essential for scientists and fisheries managers in developing a more holistic view of population-level spawning success and fry survival.

Nagtegaal, D. A., & Carter, E. W. (2000). *A preliminary report on juvenile Chinook production in the Cowichan River, 1999.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/465678/publication.html

In 1991, Fisheries and Oceans Canada, Pacific Biological Station began a study of juvenile Chinook salmon (Onchorhychus tshawytscha) productivity in the Cowichan River. The 1999 study is concerned primarily with the enumeration and out-migration timing of naturally-reared Chinookjuveniles. The estimated production of naturally-reared Chinook juveniles from the 1998 brood year was 173,225 (95% CL: 85,159 - 193,718. The release of juvenile Chinook from the Cowichan River hatchery tatalled 2,543,109. Of these, 2,142,563 hatchery-reared Chinook were released above the trapping site. Egg to

fry survival fro naturally-reared Chinook was estimated to be 2.2% (95% CL: 1.08% - 2.47%). Trapping results maintain that most hatchery-reared Chinook migrate to the Cowichan estuary within one week of release. Interaction between naturally-reared and hatchery-reared Chinook juveniles is therefore believed to be limited.

Nagtegaal, D. A., Carter, E. W., Hop-Wo, N. K., & Jones, K. E. (2003). *Juvenile Chinook production in the Cowichan River, 2000.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/468097/publication.html

In 1991, Fisheries and Oceans Canada (DFO), Pacific Biological Station began a study of juvenile Chinook salmon (Oncorhynchus tshawytscha) productivity in the Cowichan River. The 2000 study is concerned primarily with the enumeration and out-migration timing of naturally-reared Chinook juveniles. The estimated production of naturally-reared Chinook juveniles from the 1999 brood year was 673,726 (range: 546,060 - 915,723). The release of juvenile Chinook from the Cowichan River hatchery totaled 2,580,655. Of these, 2,050,028 hatchery-reared Chinook were released above the trapping site. Egg to fry survival for naturally-reared Chinook was estimated to be 6.54% (range: 5.30% - 8.89%). Trapping results maintain that most hatchery-reared Chinook migrate to the Cowichan estuary within one week of release. Interaction between naturally-reared and hatchery-reared Chinook juveniles is therefore believed to be limited.

Nagtegaal, D. A., Carter, E. W., Hop Wo, N. K., & Jones, K. E. (2004). *Juvenile Chinook production in the Cowichan River, 2001.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/468178/publication.html

In 1991, Fisheries and Oceans Canada (DFO), Pacific Biological Station began a study of juvenile Chinook salmon (Oncorhynchus tshawytscha) productivity in the Cowichan River. The 2001 study is concerned primarily with the enumeration and out-migration timing of naturally-reared Chinook juveniles. The estimated production of naturally-reared Chinook juveniles from the 2000 brood year was 664,715 (range: 385,911 - 757,678). The release of juvenile Chinook from the Cowichan River Hatchery totaled 2,409,720. Of these, 1,971,251 hatchery-reared Chinook were released above the trapping site. Egg to fry survival for naturally-reared Chinook was estimated to be 5.58% (range: 3.24% - 6.36%). Trapping results maintain that most hatchery-reared Chinook migrate to the Cowichan estuary within one week of release. Interaction between naturally-reared and hatchery-reared Chinook juveniles is therefore believed to be limited in freshwater.

Nagtegaal, D. A., Carter, E. W., Hop Wo, N. K., & Jones, K. E. (2004). *Juvenile Chinook production in the Cowichan River, 2002.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/468345/publication.html

In 1991, Fisheries and Oceans Canada (DFO) began a study of juvenile Chinook salmon (Oncorhynchus tshawytscha) productivity in the Cowichan River. The 2002 study is concerned primarily with the enumeration and out-migration timing of naturally-reared Chinook juveniles. The estimated production of naturally-reared Chinook juveniles from the 2001 brood year was 895, 180. The release of juvenile Chinook from the Cowichan River Hatchery totalled 3,228,287. Of these, 2,572, 674 hatchery-reared Chinook were released above the trapping site. Egg to fry survival for naturally-reared Chinook was

estimated to be 12.73%. Trapping results maintain that most hatchery-reared Chinook migrate to the Cowichan estuary within one week of release. Interaction between naturally-reared and hatchery-reared Chinook juveniles is therefore believed to be limited in freshwater.

Neave, F. (1953). Principles affecting the size of pink and chum salmon populations in British Columbia. *Journal of the Fisheries Board of Canada,* 9a(9), 450-491. https://doi.org/10.1139/f52-023

In pink salmon (Oncorhynchus gorbuscha) the survival during the freshwater phases of the life-cycle has been found to vary from about 1 to 24 per cent of available eggs. Natural survival during marine existence is considered to average about 5 per cent. In the central region of the British Columbia coast the annual catch averages about 60 per cent of the adult fish. Populations maturing in "even" and "odd" years vary in size independently. Fluctuations in level of stock originate mainly in fresh water.Population levels and changes are determined by the combined effects of three types of mortality: (a) mortality which becomes relatively heavier as populations increase in density (compensatory); (b) mortality which becomes relatively heavier as populations decrease in density (depensatory); (c) mortality which is independent of density (extrapensatory). Compensatory mortality is especially identified with the, period of spawning and incubation. Depensatory mortality is considered to occur mainly during the period of fry migration and to be due to predation. Extrapensatory mortality may occur at any stage; it is most variable during the period between entrance of the adults into fresh water and emergence of the free-swimming fry.Populations of chum salmon (O. keta) are controlled by similar influences. Effects are modified by higher egg-production and a less rigid life-span than in the pink salmon.

Nebeker, A. V., Andros, J. D., McCrady, J. K., & Stevens, D. G. (1978). Survival of steelhead trout (Salmo gairdneri) eggs, embryos, and fry in air-supersaturated water. *Journal of the Fisheries Research Board of Canada,* 35(2), 261-264. https://doi.org/10.1139/f78-043

Egg, embryo, fry, and swim-up stages of steelhead trout (Salmo gairdneri) were exposed to water at total gas saturation levels ranging from 130 to 115%. Eggs, embryos, and newly hatched fry were not affected at 126.7%, but at about day 16 posthatch when the fish began swimming up deaths occurred rapidly, and at the end of the test post button-up mortality ranged from 99% at 126.7% saturation to 45% at 115.3% saturation. Bubbles in the mouth, gill cavity, and yolk sac caused flotation and severe respiratory difficulties. Rupture of yolk-sac membranes also caused death. No differences were noted in survival between fish exposed from egg to fry, and those exposed only from swim-up to fry stage. In summary, there were differences in susceptibility among steelhead life stages to air-supersaturated water; eggs, embryos, and pre-swim-up larvae were more resistant than swim-up and later fry stages.

Negus, M. T. (1999). Survival traits of naturalized, hatchery, and hybrid strains of anadromous rainbow trout during egg and fry stages. *North American Journal of Fisheries Management,* 19(4), 930-941. https://doi.org/10.1577/1548-8675(1999)019<0930:stonha>2.0.co;2

Two strains of anadromous rainbow trout Oncorhynchus mykiss, naturalized steelhead and “kamloops” (not the pure Kamloops strain from British Columbia, hence not capitalized) currently inhabit the Minnesota waters of Lake Superior and may have the potential to hybridize. This could compromise the genetic integrity of the naturalized steelhead population. Both strains are supplemented by annual stocking, despite the fact that the steelhead population reproduces naturally. Egg viability and fry

behavior experiments were undertaken to evaluate the potential for hybridization and to provide information for future management of the two strains. The kamloops eggs were slightly smaller, but sizes overlapped substantially with steelhead egg sizes. Mortalilty of kamloops eggs from spawning to hatching was greater than steelhead eggs. Steelhead fry exhibited a greater fright response (wariness) than kamloops fry when startled by movement over their tanks. Hybrid egg survival and wariness traits were intermediate to those of the pure strains, but more closely resembled those of the maternal strain. These traits appeared to be heritable. Reevaluation of steelhead and kamloops management will be necessary in the future, taking into account the popularity of the kamloops fishery and the potential for degradation or elimination of the naturalized steelhead strain.

Nislow, K. H., Einum, S., & Folt, C. L. (2004). Testing predictions of the critical period for survival concept using experiments with stocked Atlantic salmon. *Journal of Fish Biology,* 65, 188-200. https://doi.org/10.1111/j.0022-1112.2004.00561.x

Two separate field experiments were performed in the U.S.A. and Norway with stocked Atlantic salmon Salmo salar. In the Norwegian experiment, the offspring of early-spawning fish which had larger eggs and emerged a few days before offspring of later spawning fish had consistently higher survival rates. In the U.S.A. experiment, stream sections with higher proportions of favourable foraging locations during the critical period (the transition from dependence on maternally-derived yolk reserves to independent feeding) had lower loss rates of fish stocked as unfed fry. These results provide support for the critical period concept (CPC) in Atlantic salmon, underscores the utility of a manipulative approach to achieve further advances in knowledge of Atlantic salmon ecology and provide additional guidance to management and restoration. A mechanistic, conceptual model for density dependence is presented to identify important knowledge gaps that remain to further evaluate the importance of the CPC for Atlantic salmon population regulation. (C) 2004 The Fisheries Society of the British Isles.

Olofsson, H., & Mosegaard, H. (1999). Larger eggs in resident brown trout living in sympatry with anadromous brown trout. *Ecology of Freshwater Fish,* 8(2), 59-64. https://doi.org/10.1111/j.1600-0633.1999.tb00054.x

Freshwater resident brown trout (Salmo trutta L.) in the stream Jorlandaan (southwestern Sweden) had larger eggs (range of actual mean egg wet weights, 65.9–108.5 mg) than both sympatric migratory trout (76.8–84.2 mg) and trout from five other Swedish streams with allopatric resident (23.7–80.1 mg) or migratory populations (44.5–121.9 mg), after accounting for differences in body size. In Jörlandaån, some resident females even had a larger absolute mean egg weight than any of the migratory females found in the stream. Resident trout had low absolute fecundity, and our data suggest that resident females in Jörlandån produce large eggs at the expense of their fecundity. The extremely large relative egg size in resident Jörlandaån females suggests that the production of large offspring enhances fitness, possibly through increased fry survival.

Palm, D. (2007). *Restoration of streams used for timber floating.* (Ph.D.), Swedish University of Agricultural Sciences, Retrieved from https://pub.epsilon.slu.se/1649/

The construction of floatways during the 19th and 20th century profoundly changed the habitat conditions for fish and other aquatic organisms in lotic environments. Increased mortality during early

life stages, reduced habitat quality and availability probably had large negative consequences for populations of salmonids. As timber floating ended during the 1970's, restoration programs were initiated that aimed to reverse the damage caused by floatway activities and to increase the production of salmonids. We predicted that restoration would have positive effects on egg to fry survival, fry displacement, over-wintering and population density of juvenile brown trout and on fish species diversity. To test these predictions, I conducted studies in restored (treatment) and unrestored (control) reaches in tributaries to the rivers Ume-, Vindel, Pite- and Kalixalven in northern Sweden. Egg-to-fry survival was approximately six times higher in restored (10.3%) compared to unrestored (1.7%) gravel beds. Displacement of newly emerged fry was reduced from 10.1% to 2.3% and first summer recruitment increased approximately three fold (from 0.2‰ to 0.6‰) following habitat restoration. Trout density increased significantly (>360%) in restored stream reaches whereas no change was evident in unrestored control reaches during a period of eleven years. Tracking of PIT-tagged individuals revealed that brown trout managed to over-winter within a restored stream. Minimum habitat suitability index explained a large portion (66.8 %) of the variation in the proportion of individuals that over wintered within different stream reaches. Although more fish species were caught in restored reaches, restoration did not result in significantly higher fish species diversity. These results show that restoration of streams utilized for timber floating can be an efficient method to enhance and conserve populations of trout and salmon. However, success of restoration relies on good knowledge about other species occurring in the system and their ecology. For instance, using wrong substrate sizes during restoration of spawning habitat can result in increased rates of egg predation by benthic predators. As brown trout utilize a variety of different environments during their lifecycle, including streams, lakes and sea, maximal response to habitat restoration will not be achieved as long as other factors, i.e. migration barriers and over exploitation, also constrain populations.

Pauwels, S. J., & Haines, T. A. (1994). Survival, hatching, and emergence success of Atlantic salmon eggs planted in three maine streams. *North American Journal of Fisheries Management,* 14(1), 125-130. https://doi.org/10.1577/1548-8675(1994)014<0125:shaeso>2.3.co;2

We devised and tested a method to evaluate survival of embryos of Atlantic salmon Salmo salar from fertilization through hatching and emergence from the streambed. This method entailed placing freshly fertilized eggs in nylon net bags filled with gravel and burying the bags in simulated redds within a streambed. Two net bags were used; an inner bag of 1 -cm (stretch) mesh allowed alevins to escape after hatching, and an outer bag of 0.3-cm (stretch) mesh prevented alevins from escaping the redd. Multiple redds were placed in each of three streams and removed periodically during the incubation period to assess survival. At the estimated time of emergence, outer bags from the remaining redds were opened and covered with traps to catch emerging fry. These were checked twice weekly until emergence ended. Survival to hatching ranged from 7 to 61% (mean = 30.7%, N = 12 redd samples) and was consistently higher in one of the streams. Survival to emergence ranged from 2 to 12% (mean = 7%, N = 5). Although survival to hatching, based on the known number of eggs implanted, was lower than previously reported, survival to emergence with our method agreed with published results. A large proportion of the planted eggs died and disintegrated during incubation and were not recovered. If survival to hatching is calculated on the basis of only the total of live and dead eggs and alevins recovered (not incorporating disintegrated eggs), the values range from 10 to 88% (mean = 46.8%, N = 12) and agree well with literature values. Death and disintegration of eggs may be greater than previously reported, and this loss may have caused some studies to overestimate survival.

Pepper, V. A. (1984). *Deep-substrate incubators : A field guide for Atlantic salmon enhancement.* Fisheries Research Board of Canada, Ottawa. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/14252.pdf

This field guide describes procedures for operating an Atlantic salmon (Salmo salar) enhancement project in which incubation of eggs is required to assure a juvenile ,salmon supply for stocking purposes. Much of this manual describes activities and information gathering relating to the egg incubation aspects of an enhancement project. Use of the deep-substrate incubator is advocated as an effective means to secure swim-up fry. Procedures described in this manual include: brood stock collection, holding, stripping and fertilization of eggs, incubator design, preparation, loading and operation; and fry enumeration and evaluation of developmental index. The need for detailed records of project activities is stressed throughout the manual. Methods are given to calculate the number of eggs planted in the incubator, the number of fry produced, egg to fry survival, indicators of incubator performance efficiency, and stage of fry development. Although operating procedures are described as simply as possible to encourage use of the manual by individuals with no formal training in biology, statistical and biological discussions are also presented in greater complexity to encourage critical appraisal and refinement of salmon enhancement methodologies by scientists and technicians.

Peress, J. (1998). *River dart salmon spawning target and compliance assessment.* Environment Agency, Bristol, UK, Retrieved from http://ea-lit.freshwaterlife.org/fedora/repository/ealit:804/OBJ/19001490.pdf

This paper presents the Environment Agency methodology used to set up the spawning target for the River Dart and to assess its compliance. It also provides details of what data are collected, and how. The methodology relies on the Environment Agency transportation process from the River Bush to the River Dart, based on habitat classification by stream order and altitude range, and on river specific information such as: the accessible stream area for salmon; percentage of spawners assumed within each combination of altitude range and stream order, i.e. spawners distribution within the river catchment; percentage of grilse of the River Dart salmon population; percentage of females; fecundity. The methodology is also based on national means, such as: juvenile density, with proportion of fry and parr; and marine survival. After assessing these data, the transportation process uses a specific spreadsheet, presented in Table 1, to calculate the total egg target for the River Dart.

Phillips, R. W., & Koski, K. V. (1969). A fry trap method for estimating salmonid survival from egg deposition to fry emergence. *Journal of the Fisheries Board of Canada,* 26(1), 133-141. https://doi.org/10.1139/f69-012

The method involves a trap of nylon netting placed over an individual redd with the trap's edges buried 15–20 cm in the gravel just outside the periphery of the redd. It has been used successfully on more than 70 coho salmon (Oncorhynchus kisutch) redds over the past 5 years, with as many as 2061 fry being captured from a single redd. The trap is relatively stable because it is flexible and conforms to the surface of the streambed, causing debris to float or roll over the surface. It can be used on individual redds; thus, emergent survival for separate parental combinations can be estimated. Field tests showed the efficiency of the trap approached 100%. Installation and presence of the trap had no significant effect on intragravel dissolved oxygen and gravel permeability. Mortality of fry in the traps averaged less than 1.5% when fry were removed at least three times a week. We concluded that the trap provides a

more accurate estimate of survival from egg deposition through fry emergence than four other methods.

Pittman, K. (1996). Rearing halibut in Norway: Present practices and challenges. *Marine and Freshwater Research,* 47(2), 243-249. https://doi.org/10.1071/mf9960243

Atlantic halibut (Hippoglossus hippoglossus L.) has been identified as the species that can best complement the salmon farming industry in Norway. From an experimental fry production of only 2 in 1985 to a production of Over 350000 in 1994 and commercial sales of 69 t in 1995, the advances have accumulated through close cooperation between research and industry. Current practices involve holding the broodstock on natural or controlled photoperiod, stripping and disinfecting eggs before incubation in darkness, controlling larval placement in the water column, and first-feeding on natural zooplankton in green water. Many of the original practices are being examined with a critical eye, such as use of salt during removal of bottom water and the necessity of maintaining the larvae in darkness beyond 150 degree-days. Early temperature regimes play a role in viability, and experimental evidence points to changing temperature optima with size and to effects of light and photoperiod on growth, behaviour and survival in most stages. Challenges include identification of the period in which pigmentation is affected by exogenous nutrients, control and synchronization of metamorphosis, early identification and separation of the fast-growing females in the populations, and prevention of the early maturation in males. These and other biological and environmental requirements of the developing halibut must be better understood to achieve predictable production routines.

Porter, T. R. (1973). Fry emergence trap and holding box. *Progressive Fish-Culturist,* 35(2), 104-106. https://doi.org/10.1577/1548-8659(1973)35[104:Fetahb]2.0.Co;2

2 devices designed and used to capture and retain emerging fry of stream spawning salmonids are described. The design of Phillips and Koski is modified by the use of a metal frame and by the addition of a holding box which keeps the fry alive. Field tests were carried out in Blue Jay Creek, Manitoulin Island, Ontario. The device described is effective in studying survival to emergence of fish eggs deposited under different environmental conditions. The number of eggs deposited is estimated knowing the fecundity of the species and the length or weight of the female which deposited the eggs in the redd being tested. The emergence trap and holding box are used to study patterns of fry emergence.

Raddum, G. G., & Fjellheim, A. (1995). Artificial deposition of eggs of Atlantic salmon (Salmo salar l.) in a regulated Norwegian river: Hatching, dispersal and growth of the fry. *Regulated Rivers: Research & Management,* 10(2-4), 169-180. https://doi.org/10.1002/rrr.3450100212

Fertilized eggs of Atlantic salmon (Salmo salar) were artificially deposited in the regulated River Ekso, western Norway. This was done by placing 320–2400 eggs in perforated platic baskets, together with small stones and gravel, buried in the river. To evaluate development of the eggs, some baskets were removed and examined with respect to fertilization and mortality at the eye-roe stage. After swim-up of alevins, all baskets were examined for the number of dead eggs. The hatching of eggs was between 55 and 98% in the baskets. There was no correlation between the egg number in the basket and survival. The alevins were restricted to their hatching area for the first month; after the first season they migrated 50 m upstream and 175 m downstream of their birthplace. One year later they occupied the

whole area (375 m) between the two weir basins. Mortality was 80% in the first season and 87% in the second (regarded as normal and high, respectively). High mortality was probably due to acid episodes, independent of regulation. Growth was fast and salmon became smolt at age 2+, explained by favourable temperature and low fish density. Competition between salmon and native brown trout (Salmo trutta) seemed to be low as they occupied different habitats.

Radtke, G. (2008). A simple trap for the capture new-emergent salmonid fry in streams. *Archives of Polish Fisheries,* 16(1). Retrieved from https://www.fal.infish.com.pl/index.php/FisheriesAndAquaticLife/article/view/235

A simple trap was built for capturing salmonid fry emerging from natural spawning redds in streams. The trap is shaped like a cap with a vertical PVC tube. Since the trap is not attached permanently to the substrate, settled debris can be cleaned out regularly, and the trap can be deployed in streams with large amounts of drifting organic material. Its simple construction means that it is easy to use. Based on the comparison of the effectiveness of two types of traps on artificial redds, the catch efficiency of the newly constructed trap was determined to be 37%.

Radtke, G. (2013). Effects of substrate composition and water temperature on the emergence success of lacustrine brown trout Salmo trutta m. Lacustris l. Fry from natural redds. *Folia Zoologica,* 62(4), 247-256. https://doi.org/10.25225/fozo.v62.i4.a1.2013

The emergence of lake-migratory brown trout Salmo trutta m. lacustris L. fry from natural redds was observed in a small lake outlet stream. A total of 1104 emerging fry were captured in traps in nine of the 12 investigated redds during three seasons. In 2005, all the fry emerged during the daytime, but in 2007 and 2009 they emerged mostly at night. Furthermore, the timing of emergence was earlier than expected from temperature models. The fry left the redds at a water temperature range of 6.2–15.0 °C, and the emergence pattern was correlated with the moon phase. The number of fry captured was strongly affected by the percentage of fine particles < 1 mm and the 8–16 mm particle content, and was positively correlated with the geometric mean of substrate particle size (Dg) and the index of permeability: the fredle index (fi). The estimated survival rate between egg deposition and fry emergence ranged from 0.0 to 59.8 % in individual redds. Additionally, the greatest number of fry and the highest survival rate were observed in redds that had the high water velocity and shortest duration of intragravel period.

Rasmussen, G. H., & Pedersen, S. (2017). Sea trout (Salmo trutta l.) in denmark. In *Brown trout.* (pp. 483-521) https://doi.org/10.1002/9781119268352.ch19

Denmark (43,000 km2) is a lowland moraine area and formed by the last glacial period. Mean summer water temperatures in rivers and streams are about 15–20C°, and during winter a little above 0C°. Because of raining during the whole year, most of them never dry out completely during even long-lasting high summer temperatures. After the latest glaciation, the streams were colonized by migrating sea trout and new spawning populations established. Originally, there were no natural obstacles to migration between fresh and salt water. The original number of independent river systems with wild brown trout was 876 with an estimated annually smolt production of about 2.64 million. This number of river systems was reduced in the 1960s, when only 176 systems contained spawning wild brown trout.

As a result of the termination of pollution, removal of barriers, changed watercourse maintenance and restoration of habitats, the present number of wild smolt produced from about 371 river systems in 2014 is estimated at about 1.1 million smolts. Wild brown trout production is supplemented by releases of wild F1 fish: fry, half-yearlings, yearlings (these three age classes contribute with 116,000 smolts) and 1.534 million stocked F1 smolts. The total number of smolt (wild and stocked F1: fry, parr and smolt) annually from Danish rivers to marine areas is today about 2.74 million smolt. Legal size in freshwater is 30 cm for local brown trout and in fresh- and saltwater 40 cm for sea trout, and closed season 15 November to 15 January. In some local and/or protected areas there are increased legal size and closed seasons. Brown trout is the most important salmonid for anglers in fresh and saltwater. Spawners from saltwater enter freshwater from spring until spawning in November to January. The oldest migrate first and youngest (after ½ year in saltwater) in autumn. Spent fish leave freshwater in November to June. Fry emerge from gravel mid-April to mid-May, and growth rate and mortality is regulated by density of parr and water temperature. Most sea trout spawn every year after reaching maturity. In some rivers draining into the North Sea and northern part of the Kattegat, immature sea trout migrate from salt water to freshwater during winter, especially during cold winters, in order to optimize the osmoregulation and survival. Smolts migrate from fresh to saltwater during the period March to May as one, two, three, four and five year-old smolt with two and three year smolts dominating, and with sizes from about 10 to 30 cm. 25% are males and 75% females. Recent results show that parr also migrate out from the streams outside the smolt run period, but the fate of these are not known; do they contribute to the sea trout in saltwater or to the local freshwater trout in the main stem of the rivers? A summary of smolt production from many rivers and geographical areas is presented. The parr in freshwater eat mostly invertebrates, but bigger local brown trout also consume different freshwater fish species. Post-smolts in the sea feed on different invertebrates until the first winter, and older and larger sea trout mostly on different fish species. Information on growth, survival, and migration routes of sea trout in saltwater and yield in fresh and saltwater are mostly based on externally-tagged stocked smolts, but also to a minor degree on results from tagging wild smolt and wild sea trout. Survival from egg to smolt is about 0.5%. From a catch model it is estimated that one wild smolt contributes about 190 g caught sea trout with a mean weight of about 1.65 kg, and that nine wild smolt equals one caught sea trout. This means an annual brown trout fishery of about 520 tons.

Recsetar, M. S., & Bonar, S. A. (2013). Survival of apache trout eggs and alevins under static and fluctuating temperature regimes. *Transactions of the American Fisheries Society,* 142(2), 373-379. https://doi.org/10.1080/00028487.2012.741551

Increased stream temperatures due to global climate change, livestock grazing, removal of riparian cover, reduction of stream flow, and urbanization will have important implications for fishes worldwide. Information exists that describes the effects of elevated water temperatures on fish eggs, but less information is available on the effects of fluctuating water temperatures on egg survival, especially those of threatened and endangered species. We tested the posthatch survival of eyed eggs and alevins of Apache Trout Oncorhynchus gilae apache, a threatened salmonid, in static temperatures of 15, 18, 21, 24, and 27 degrees C, and also in treatments with diel fluctuations of +/- 3 degrees C around those temperatures. The LT50 for posthatch survival of Apache Trout eyed eggs and alevins was 17.1 degrees C for static temperatures treatments and 17.9 degrees C for the midpoints of +/- 3 degrees C fluctuating temperature treatments. There was no significant difference in survival between static temperatures and fluctuating temperatures that shared the same mean temperature, yet there was a slight difference in LT50s. Upper thermal tolerance of Apache Trout eyed eggs and alevins is much lower than that of fry to adult life stages (2223 degrees C). Information on thermal tolerance of early life stages (eyed egg and

alevin) will be valuable to those restoring streams or investigating thermal tolerances of imperiled fishes. Received December 1, 2011; accepted October 12, 2012

Reisenbichler, R. R., & McIntyre, J. D. (1977). Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, Salmo gairdneri. *Journal of the Fisheries Research Board of Canada,* 34(1), 123-128. https://doi.org/10.1139/f77-015

Relative growth and survival of offspring from matings of hatchery and wild Deschutes River (Oregon) summer steelhead trout, Salmo gairdneri, were measured to determine if hatchery fish differ genetically from wild fish in traits that can affect the stock–recruitment relationship of wild populations. Sections of four natural streams and a hatchery pond were each stocked with genetically marked (lactate dehydrogenase genotypes) eyed eggs or unfed swim-up fry from each of three matings: hatchery × hatchery (HH), hatchery × wild (HW), and wild × wild (WW). In streams, WW fish had the highest survival and HW fish the highest growth rates when significant differences were found; in the hatchery pond, HH fish had the highest survival and growth rates. The hatchery fish were genetically different from wild fish and when they interbreed with wild fish may reduce the number of smolts produced. Hatchery procedures can be modified to reduce the genetic differences between hatchery and wild fish.

Reiser, D. W., Olson, A., & Binkley, K. (1998). Sediment deposition within fry emergence traps: A confounding factor in estimating survival to emergence. *North American Journal of Fisheries Management,* 18(3), 713-719. https://doi.org/10.1577/1548-8675(1998)018<0713:SDWFET>2.0.CO;2

We provide evidence that the effects of sediment infiltration and deposition within fry emergence traps can lead to a potential negative bias when estimating survival to emergence (STE) of salmonid fry. Fry emergence traps were placed over 12 redds of brown trout Salmo trutta located in sections of three streams in the upper Clark Fork River system in Montana. The redds were capped in March 1989 and monitored through June 1989. During this period, sediment deposition became noticeable inside 8 of the 12 traps. During the final removal of the traps, substrate core samples were collected from a location inside and outside of each emergence trap. Substrate size gradation analysis indicated that concentrations of fine sediments (≤0.84 mm in diameter) were significantly higher in samples collected inside the traps than outside. These results suggested that the local sediment transport capacity was reduced within the emergence traps, resulting in increased deposition of fines. An understanding of the hydrology, ambient sediment concentrations, and sediment transport capabilities of river systems is important when considering the use of fry emergence traps. Without consideration for this potential confounding factor, STE estimates that involve the use of fry emergence traps may underestimate actual STE values.

Reiser, D. W., & White, R. G. (1988). Effects of two sediment size-classes on survival of steelhead and Chinook salmon eggs. *North American Journal of Fisheries Management,* 8(4), 432-437. https://doi.org/10.1577/1548-8675(1988)008<0432:eotssc>2.3.co;2

We compared, in the laboratory, egg survival, and alevin and fry size of steelhead Oncorhyncus mykiss (formerly Salmo gairdneri) and Chinook salmon O. tshawytscha after incubations in 16 mixtures of two distinct size-classes of sediment. Fine sediments were less than 0.84 mm in diameter, and coarse

sediments were 0.84–4.6 mm in diameter. We incubated recently fertilized and eyed steelhead eggs and Chinook salmon eggs in Whitlock–Vibert boxes placed in controlled-flow channels. Egg survival in both sediment types was inversely related to the percentage of sediments within the incubation gravel; the poorest survival occurred in fine sediments. Percentage egg survival was positively related to intragravel water velocities, which ranged from 36 to 1,550 cm/h. No definitive relationship was found between sediment size and concentration, and alevin and fry quality. Overall, our results indicated that different sizes and mixtures of sediment can affect egg survival differently. The results confirmed that it is the smaller sediments (<0.84 mm) that are the most detrimental to incubating eggs.

Roni, P., Johnson, C., De Boer, T., Pess, G., Dittman, A., & Sear, D. (2016). Interannual variability in the effects of physical habitat and parentage on Chinook salmon egg-to-fry survival. *Canadian Journal of Fisheries and Aquatic Sciences,* 73(7), 1047-1059. https://doi.org/10.1139/cjfas-2015-0372

Mortality during incubation is believed to be a major factor limiting the recovery of many salmon populations, though direct field measurements of egg-to-fry survival are rare or small in scale. To determine the effects of physical habitat (river reach, fine sediment intrusion, scour), parentage (mating, source of gametes) on Chinook salmon (Oncorhynchus tshawytscha) egg-to-fry survival and developmental stage at emergence across a basin, we constructed 324 artificial redds in nine reaches over 4 years in the Yakima River Basin, Washington, USA. Mean egg-to-fry survival ranged from 49% to 69% annually from 2009 to 2012 brood years. Survival was significantly different among reaches in 2010, but not in 2009, 2011, or 2012, while mating was a significant factor in all years but 2010. In contrast, developmental stage differed significantly among reaches and matings in all 4 years. Percentage of fines, days-in-gravel, and median particle size explained only small (<10%) additional amount of variation in survival or developmental stages. Our results suggest that parentage and reach within a basin are major factors influencing egg-to-fry survival, but their relative influence varies annually, presumably depending on the magnitude of high flows and scour during incubation.

Rubin, J. F. (1995). Estimating the success of natural spawning of salmonids in streams. *Journal of Fish Biology,* 46(4), 603-622. https://doi.org/10.1111/j.1095-8649.1995.tb01100.x

A new method is described to estimate the survival of salmonids in streams from fertilization of the eggs to the emergence of the fry. The method is compared to other techniques generally used to estimate the egg-to-fry survival: fry traps, excavation of redds, construction of artificial redds and laboratory experiments. Especially designed boxes filled with substratum and freshly fertilized eggs are buried in the stream bed. Survival is determined at three different embryological development stages: eyed stage, hatching and emergence. Boxes are planted inside the stream bed using a special injector, so that substratum alterations are minimal around the boxes. This method was tested successfully in two different studies, one in Switzerland on the brown trout, the other one in Sweden on the sea trout.

Saegrov, H., Hindar, K., Kalas, S., & Lura, H. (1997). Escaped farmed Atlantic salmon replace the original salmon stock in the River Vosso, western Norway. *ICES Journal of Marine Science,* 54(6), 1166-1172. https://doi.org/10.1016/s1054-3139(97)80023-9

Eggs and alevins were collected from 36 redds in the River Vosso in late March 1996, The redds had been made by 20 individual female Atlantic salmon and 12 female brown trout. Species-specific allozyme variation was used to distinguish trout from salmon and egg size and pigment analyses were used to distinguish farmed from wild salmon females. Nine (45%) of the 20 female salmon spawners in the sample were of confirmed farmed origin, because their offspring contained synthetic astaxanthin which is an additive to commercial fish feed. Most of the remaining female salmon were also likely to have been farmed escapees because only about half of the actual farmed spawners can be identified by their astaxanthin content due to intake of carotenoids from natural food sources. The estimated peak spawning for both confirmed and putative farmed females was 32 d earlier than peak spawning of wild females. Egg survival was high and similar to previous estimates for wild and farmed salmon in the River Vosso. Based on the astaxanthin content in sampled eggs and the time of peak spawning it is concluded that most Atlantic salmon fry that hatched in the River Vosso in 1996 were produced by escaped farmed females. The frequency of redds made by farmed females was in accordance with their estimated representation (81%) in the population of spawners during autumn 1995. (C) 1997 International Council for the Exploration of the Sea.

Saltveit, S. J., & Brabrand, A. (2013). Incubation, hatching and survival of eggs of Atlantic salmon (Salmo salar) in spawning redds influenced by groundwater. *Limnologica,* 43(5), 325-331. https://doi.org/10.1016/j.limno.2013.05.009

Many west coastal and northern Norwegian rivers run through deep, confined valleys with permeable layers of glacial and alluvial deposits. Groundwater flows through these permeable layers and enter lakes and rivers as underwater seepage and springs. Groundwater inflow to inland Norwegian rivers may constitute 40-100% of total water discharge during low flow periods in late summer and winter. Juvenile salmonids may take advantage of groundwater upwellings and actively seek out such patches. In regulated rivers groundwater influx may create refuges during low flow or hydropeaking episodes. The importance of groundwater for salmon redd site selection and egg survival is also clear, although less known and documented in regulated rivers. Eggs of Atlantic salmon (Salmo salar) are deposited in redds in river bed gravels lacking fine sediments and with high oxygen levels. Egg development is therefore dependent on the interaction of a number of environmental factors such as groundwater influx, oxygen and temperature. Atlantic salmon in the regulated River Suldalslagen, Western Norway, spawn relatively late compared to other Norwegian rivers, with a peak in early January. Newly emerged fry are found from the end of May to the beginning of June, i.e. "swim up" one month earlier than expected using models for egg and alevin development and river water temperatures. The most plausible explanation is that groundwater has a higher and more stable temperature than surface river water. In field experiments, fertilized salmon eggs were placed in boxes close to natural spawning redds in the river bed at sites influenced and those not influenced by groundwater. A difference of up to 40 days in 50% hatching was found, and "swim up" occurred at the end of May in boxes influenced by groundwater. Preliminary studies have revealed that groundwater also plays an important role in survival of salmon eggs in the River Suldalslagen when dewatered in winter. Eggs placed in boxes in groundwater seepage areas during winter in the dewatered river bed survived even when covered by ice and snow. The survival from fertilization until 30 April, one month before hatching, was 91%, the same survival as found for eggs placed in boxes in the wetted river bed. However, mortality from fertilization to hatching

was higher compared to the eggs placed in wetted river bed, 57 and 91% respectively. Groundwater creates a horizontal and vertical mosaic of temperatures in spawning redd areas leading to potentially greater variation in spawning sites, time of hatching and "swim up". This is likely to increase egg survival during low flow periods in regulated rivers. In conclusion, the interaction between groundwater and surface river water should therefore be considered when managing fish populations in regulated rivers. (C) 2013 Elsevier GmbH. All rights reserved.

San Joaquin River Restoration Program. (2015). *Egg survival and emergence in reaches 1a and 1b of the San Joaquin river: Final 2015 monitoring and analysis plan.* Retrieved from https://www.restoresjr.net/?wpfb_dl=1240

The goal of this study is to evaluate the survival to emergence, as well as the overall condition at and timing of emergence for alevins from naturally placed fall-run Chinook salmon redds in the San Joaquin River as an element of the tasks identified by the Spawning and Incubation Small Interdisciplinary Group (SIG) as important for describing the overall suitability of spawning gravel from Friant Dam to Skaggs Bridge.

Schroder, S. L., Knudsen, C. M., Pearsons, T. N., Kassler, T. W., Young, S. F., Busack, C. A., & Fast, D. E. (2008). Breeding success of wild and first-generation hatchery female spring Chinook salmon spawning in an artificial stream. *Transactions of the American Fisheries Society,* 137(5), 1475-1489. https://doi.org/10.1577/t07-123.1

First-generation hatchery and wild spring Chinook salmon Oncorhynchus tshawytscha from the upper Yakima River, Washington, were placed into an artificial stream and allowed to spawn. Seven independent test groups were placed into the stream from 2001 through 2005. No differences were detected in the egg deposition rates of wild and hatchery females. Pedigree assignments based on microsatellite DNA, however, showed that the eggs deposited by wild females survived to the fry stage at a 5.6% higher rate than those spawned by hatchery females. Subtle differences between hatchery and wild females in redd abandonment, egg burial, and redd location choice may have been responsible for the difference observed. Body size did not affect the ability of females to spawn or the survival of their deposited eggs. How long a female lived was positively related to her breeding success, but female origin did not affect longevity. The density of females spawning in portions of the stream affected both egg deposition and egg-to-fry survival. No difference, however, was found in the overall distribution patterns of the two types of females. Other studies that have examined the effects of a single generation of hatchery culture on upper Yakima River Chinook salmon have disclosed similar low-level effects on adult and juvenile traits. The cumulative effect of such differences will need to be considered when hatcheries are used to restore depressed populations of Chinook salmon.

Schroder, S. L., Pearsons, T. N., & Knudsen, C. M. (2005). *Comparing the reproductive success of Yakima River hatchery- and wild-origin spring Chinook: Yakima/Klickitat fisheries project monitoring and evaluation, 2004-2005 annual report.* Bonneville Power Administration, https://doi.org/10.2172/887233

A growing body of literature suggests that adult salmon produced by artificial culture are not as reproductively successful as wild fish when they spawn under natural conditions. Behavioral,

morphological, and physiological divergences have been observed between hatchery and wild fish. These disparities are the likely proximate causes of the differences seen in the reproductive success of hatchery and wild salmonids. Two evolutionary paradigms have been proposed to explain why salmonids cultured in hatcheries are genetically and phenotypically different from wild cohorts. The first proposes that natural selection has been significantly relaxed in hatcheries. Consequently, fish that normally would have perished because of the possession of unsuitable traits are able to survive. If these traits have a genetic basis, they may become established in a hatchery population and cause its productivity to be less than expected if the fish are once again exposed to natural selection pressures. The second theorizes that environmental and social conditions in hatcheries are less variable than in the natural environment and that these conditions will remain relatively constant from one generation to the next. In this circumstance, selection for genetic traits that adapt fish to artificial culture will become prevalent in the population. Such traits may be mal-adaptive under natural conditions. Many of the studies that have compared the reproductive success (RS) of hatchery and wild fish, however, have used non-local hatchery fish that have experienced multiple generations of hatchery culture. Few efforts have been made where both the hatchery and wild fish have originated from the same population. When such studies have been performed differences in the competency of the fish to produce offspring have not been detected or are not as great as those expressed when non-local hatchery fish have been used. The hatchery spring Chinook produced by the Yakima Fisheries Project originated from wild fish returning to the upper Yakima River. When they return as adults, almost all of them will spawn naturally in the Yakima River. The offspring they produce are expected to augment the Yakima spring Chinook population. Whether such an increase will occur or how great it may be depends on two factors, the ability of hatchery fish to reproduce under natural conditions and the capacity of their offspring to survive to maturity. One of the objectives of the Yakima Fisheries Project is to determine whether the hatchery-origin adults produced by the project have experienced any reduction in their ability to reproduce under natural conditions. To accomplish that objective an observation stream was built in 2000 on the grounds of the Cle Elum Supplementation and Research Facility. Beginning in 2001 hatchery and wild spring Chinook from the upper Yakima River stock have been introduced into the stream and allowed to reproduce. Microsatellite DNA is used to establish the genetic relationships between the adults placed into the stream and fry that are produced by each population. Six populations consisting of mixtures of wild and hatchery fish have been placed into the stream. Pedigree assessments have been completed on five of them. These assessments have shown that the reproductive success in males is often twice as variable as that experienced by females. In the five populations so far examined; wild males (age 4 and 5) produced the most offspring. The success of comparable hatchery males relative to wild males ranged from 37% to 113%. Hatchery and wild males maturing as 3-yr-olds (jacks) and as 1- and 0-yr-olds (precocious males) were also used in the study populations. They were not as successful at producing offspring as the larger hatchery and wild males. During 2001 and 2002 two populations of hatchery and wild fish were placed into the observation stream each year. Each one occupied about half of the structure. In these populations wild females exhibited a superior capacity to deposit eggs. In addition, their eggs survived to the fry stage at h gher rates. This survival advantage ranged from 1.9 to 11.7%. In 2003 the entire observation stream was made available to a single population of fish in an effort to reduce intrasexual competition among the females for redd locations. In this year, hatchery females were better at depositing eggs (12.5%) and their buried eggs also achieved a higher egg-to-fry survival rate (3.4%). This suggests that at low population levels hatchery females were as competent as wild fish in burying eggs and in producing fry. Although variation in the reproductive success of females was lower than that seen in males it could be quite variable. For example, coefficient of variation values calculated on female RS ranged from 34 to 77% in the populations we examined. Numerous factors may affect RS in females.

Schwartz, E. A. (2007). *Evaluate selective fishing in the Willapa River, a Pacific northwest estuary*. Washington Department of Fish and Wildlife Retrieved from https://wdfw.wa.gov/sites/default/files/publications/00858/wdfw00858.pdf

Selective fishing is defined as the ability of a fishing operation to avoid non-target species and stocks, or when encountered, to capture and release them in a manner that minimizes mortality. Commercial and sport gears were tested in an estuary environment to selectively harvest adult hatchery coho (Oncorhynchus kisutch) and release natural coho and fall Chinook salmon (O. tshawytscha) bycatch. Experienced commercial fishers fished tangle nets (8.9 cm (3.5") mesh size, multifilament net) and gill nets (14.6 cm (5.75") mesh size, monofilament net) suitable for a coho fishery. To minimize mortality as much as possible, fishers also used careful handling techniques, a revival box, a shorter net, and shorter soak times. During the same time period, experienced sport fishers fished using barbless hooks and herring. Live fish were tagged and released for recovery in sport fisheries, commercial fisheries, at hatchery racks, and during spawning ground surveys. Overall, although the tangle net performed better for evaluations such as condition at capture for both coho and Chinook and immediate survival for Chinook, there was no difference detected in post-release survival between fish caught in tangle nets and gill nets for either species; this latter result could be due to a lack of statistical power. Sample sizes for coho were much larger, (430 and 580 for tangle and gill net, respectively) than for Chinook (158 and 182 tagged releases for tangle and gill net, respectively). Because many fish needed to be revived, a successful commercial selective fishery in this setting is expected to require a high ratio of marked hatchery to wild fish. A reproductive success study to evaluate the progeny of fish captured in fishing gears showed a significant difference between tangle net and gill net captured adults. The eyed egg to fry and fry abnormality rates were highest for tangle net captured fish. However, this imparted a 5.5% survival advantage, which from a biological perspective seems negligible. Too few fish were captured in sport gear for analysis. A modified purse seine was used as a control. Because the purse seine could not fish in the same locations as the commercial and sport gears and too few fish were captured for survival estimation, this gear is not useful as a control for the Willapa system. However, all coho and Chinook captured in this manner were in excellent condition and consequently, this gear should be further analyzed as a live capture selective harvest method.

Scrivener, J. C. (1988). Two devices to assess incubation survival and emergence of salmonid fry in an estuary streambed. *North American Journal of Fisheries Management,* 8(2), 248-258. https://doi.org/10.1577/1548-8675(1988)008<0248:tdtais>2.3.co;2

Survival of eggs of chum salmon Oncorhynchus keta was determined at Carnation Creek, British Columbia, with two devices that were designed to help assess factors influencing incubation and to cause minimum disturbance of natural stream gravels. Three variations of the incubation technique were assessed with perforated plastic cylinders (incubation capsules). Survival rates of 0–47% were obtained when (1) water exchange through the capsules was adequate, (2) egg density was limited to 30 eggs/capsule, (3) eggs were distributed throughout the capsules, and (4) eggs were planted within 1 h of fertilization. Variation in survival was partially attributed to differences among stations in salinity, substrate composition, and dissolved oxygen concentrations. The technique was simple and inexpensive, so many replicates could be used. A capped and inverted plastic pipe (intragravel fry releaser) was developed to introduce alevins into the streambed. From 0 to 69% of them emerged. No differences in timing and pattern of emergence were observed between wild and experimental fry. Results compared favorably with other techniques that had been designed to assess instream survival of salmonid eggs, but those techniques required extensive gravel disturbance during installation.

Semple, J. R., Zamora, P. J., & Rutherford, R. J. (1995). *Effects of dredging on egg to fry emergence survival, timing, and juvenile Atlantic salmon abundance, Debert River, Nova Scotia*.(Canadian technical report of fisheries and aquatic sciences No. 2023). Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/site/eng/422157/publication.html

Fry emergence success and timing from artificial Atlantic salmon Salmo salar redds in one dredged and two adjacent undredged areas were determined from 1981-85. Supporting information was collected to explain some of the observed differences between fry emergence and juvenile salmon abundance in undredged and dredged areas. This information included counts of natural salmon redds, determination of gravel permeability and sand concentrations in artificial redds, and streambed degradation/aggradation.

Shanley, C. S., & Albert, D. M. (2014). Climate change sensitivity index for Pacific salmon habitat in southeast Alaska. *Plos One,* 9(8). https://doi.org/10.1371/journal.pone.0104799

Global climate change may become one of the most pressing challenges to Pacific Salmon conservation and management for southeast Alaska in the 21 st Century. Predicted hydrologic change associated with climate change will likely challenge the ability of specific stocks to adapt to new flow regimes and resulting shifts in spawning and rearing habitats. Current research suggests egg-to-fry survival may be one of the most important freshwater limiting factors in Pacific Salmon's northern range due to more frequent flooding events predicted to scour eggs from mobile spawning substrates. A watershed-scale hydroclimatic sensitivity index was developed to map this hypothesis with an historical stream gauge station dataset and monthly multiple regression-based discharge models. The relative change from present to future watershed conditions predicted for the spawning and incubation period (September to March) was quantified using an ensemble global climate model average (ECHAM5, HadCM3, and CGCM3.1) and three global greenhouse gas emission scenarios (B1, A1B, and A2) projected to the year 2080. The models showed the region's diverse physiography and climatology resulted in a relatively predictable pattern of change: northern mainland and steeper, snow-fed mountainous watersheds exhibited the greatest increases in discharge, an earlier spring melt, and a transition into rain-fed hydrologic patterns. Predicted streamflow increases for all watersheds ranged from approximately 1-fold to 3-fold for the spawning and incubation period, with increased peak flows in the spring and fall. The hydroclimatic sensitivity index was then combined with an index of currently mapped salmon habitat and species diversity to develop a research and conservation priority matrix, highlighting potentially vulnerable to resilient high-value watersheds. The resulting matrix and observed trends are put forth as a framework to prioritize long-term monitoring plans, mitigation experiments, and finer-scale climate impact and adaptation studies.

Shepard, B. B., Clancey, P., Nelson, M. L., Kruse, C. G., Al-Chokhachy, R., Drinan, D., . . . Zale, A. V. (2021). Evaluation of remote site incubators to incubate wild- and hatchery-origin westslope cutthroat trout embryos. *North American Journal of Fisheries Management,* 41(3), 844-855. https://doi.org/10.1002/nafm.10588

Fish managers must weigh trade-offs among cost, speed, efficiency, and ecological adaptation when deciding how to translocate native salmonids to either establish or genetically augment populations. Remote site incubators (RSIs) appear to be a reasonable strategy, but large-scale evaluations of this method have been limited. We used 129 RSIs to incubate >35,700 eyed embryos of Westslope Cutthroat

Trout Oncorhynchus clarkii lewisi at eight sites within the upper 30 km of the Cherry Creek basin (Madison River, Montana) from 2007 to 2010, after using piscicides to remove all fish. We obtained gametes from 258 parental-pair crosses (164 females and 258 males) from four wild populations and two hatchery broods. All embryos were incubated to the eyed stage in two hatcheries prior to placing them in RSIs. Green-to-eyed egg survivals were higher for progeny of wild-spawned adults (median, 91.0%; 95% CI, 88.7–93.7%) than for progeny of hatchery-spawned adults (median, 81.7%; 95% CI, 74.9–88.4%), and this difference was highly significant ($P < 0.01$). Over 26,500 fry were counted leaving RSIs. Median embryo-to-fry survival was 75.6% (95% CI, 72.2–79.0%). Fry exited individual RSIs from 8 to 45 d after embryo translocation. Fry survivals differed among years and sites, and year was more important than site in explaining variation in survival. The success of RSI fry introductions was confirmed by annual monitoring of fish abundance, which indicated that abundances of Westslope Cutthroat Trout 5 to 9 years after RSI introductions were equal to or higher than abundances of nonnative salmonids prior to their removal using piscicides.

Shippentower, G. E. (2007). *Development of a progeny marker for steelhead.* Oregon State University, https://doi.org/10.2172/962408

This study was undertaken to determine if strontium chloride could be used to create a trans-generational otolith mark in steelhead (Oncorhynchus mykiss). I completed two strontium injection trials and a survey of juvenile steelhead from various steelhead hatcheries. The two trials measured Sr:Ca ratios in otoliths in response to injections and the survey measured the natural variation in Sr:Ca ratios in otoliths of juvenile hatchery steelhead in response to the natural variation. In 2003, adult female Wallowa River, Oregon O. mykiss, were captured at the hatchery and evenly divided between a control group and two treatment groups. These females received an intraperitoneal injection of 1cc/500 g of body weight of a physiologically isotonic solution (0.9% saline) containing concentrations of 0 (control), 1000, or 5000 parts per million (ppm) of strontium chloride hexahydrate (SrCl{sub 2}* 6H{sub 2}O). Females were housed in a single outdoor tank until spawned artificially, and a distinct external tag identified each female within each treatment group. In 2004, female steelhead were captured throughout the duration of the adult returns to the Umatilla River basin and injected with 0, 1000, 5000, or 20,000-ppm strontium. In both trials, progeny of fish treated with strontium had significantly higher Sr:Ca ratiosmore » in the primordial region of their otoliths as measured using an electron wavelength dispersive microprobe. There was no difference in fertilization rates of eggs and survival rates of fry among treatment groups. Progeny from treated mothers were on average larger than progeny of untreated mothers. The Sr:Ca ratios in otoliths collected from various populations of steelhead were greater than the control values measured in both injections studies. This study suggests that the marking technique works and the utility for such a technique could be used for empirical observations in determining the relative fitness of progeny of adult hatchery origin fish that spawn naturally. The variation in Sr:Ca ratios found among steelhead hatcheries suggests that care must be taken if the technique is employed where fish from more than one hatchery could potentially be involved.

Silver, S. J., Warren, C. E., & Doudoroff, P. (1963). Dissolved oxygen requirements of developing steelhead trout and Chinook salmon embryos at different water velocities. *Transactions of the American Fisheries Society,* 92(4), 327-343. https://doi.org/10.1577/1548-8659(1963)92[327:dorods]2.0.co;2

Embryos of steelhead trout, Salmo gairdneri gairdneri Richardson, and Chinook salmon, Oncorhynchus tshawytscha (Walbaum), were reared from fertilization of the eggs to hatching at different constant oxygen concentrations and water velocities. For this purpose, an apparatus was developed that makes it possible to control oxygen concentration independently of water velocity, which was maintained at levels ranging from 6 to 1,350 centimeters per hour. Measurements of the embryos and hatched fry indicate that water velocities must be high enough not only to transport enough oxygen to the redd for supplying the total requirement of all embryos, but also to deliver sufficient oxygen to the surface of the chorion enveloping the individual embryo. Steelhead embryos held at 9.5° C. and Chinook salmon embryos held at 11° C. all died at an oxygen concentration of 1.6 mg/1. Survival of large percentages of embryos reared at concentration as low as 2.5 mg/1 was apparently made possible by reduction of respiration rates and consequent reduction of growth and development rates. Sac fry from embryos reared at low and intermediate oxygen concentrations were smaller and weaker than sac fry from embryos reared at high concentrations. Although weak sac fry may survive under laboratory conditions, they cannot be expected to do so in nature. The size of steelhead trout and Chinook salmon fry at hatching probably was dependent on water velocity even at velocities as high as 740 and 1,350 cm/hr, respectively, and on oxygen concentration even at concentrations near saturation levels. Mean size differences among embryos reared under different conditions at the higher velocity and oxygen-concentration levels were not great, particularly in the case of the steelhead trout.

Smith, H. A., & Slaney, P. A. (1980). *Age, growth, survival and habitat of anadromous dolly varden (Salvelinus malma) in the Keogh River, British Columbia*.(Fisheries Technical Circular No. 76). Vancouver: Ministry of Environment, Province of British Columbia Retrieved from https://www.for.gov.bc.ca/hfd/library/fisheries/FMR76.pdf

Life history and population characteristics of anadromous Dolly Varden char in the Keogh River on northern Vancouver Island were studied from 1975 to 1978. Dolly Varden migrating from the ocean in 1977 averaged 280 mm (150 mm to 470 mm) and ranged from two to nine years old. In total, 1800 fish entered the river from July until October, of which 50% were female. Adults averaged 340 mm and comprised 40% of the run. Sixty percent of the run were 'sub-adults' that averaged 220 mm after returning from their first ocean migration to overwinter mainly in lakes. Eighty-three percent of adult females were mature enough to spawn, but only 21% of the younger sub-adults were mature. Rate of ovary development accelerated from August to October. Average fecundity for migrants in 1977 was 1642 eggs per female ranging from 101 to 5321 as a function of fish length. Freshwater production of juvenile Dolly Varden occurred in tributaries as well as in the mainstem river. Rate of growth in freshwater was slow; fry required, on average, three years to attain smolt stage at an average length of 139 mm. Greatest densities of Dolly Varden were found in higher velocity habitats. Fry (age 0+) were 54% in riffles, 40% in run types and 6% in flat and pool types. Parr (age 1+ to 3+) were 64% in riffles, 22% in run types and 14% in flat and pool types. Migration to the ocean occurred between March and June. Adults moved from the lakes to the river and entered the ocean first, overlapping with the later parr and smolt migrations. Adults remained in the ocean approx 157 days when they gained an average of 181 g and 45 mm. Smolts remained in the ocean approx 107 days and gained an average of 98 g and 74 mm before returning as sub-adults. Inter-river m1x1ng of anadromous Dolly Varden populations, similar to

that recorded in S.E. Alaska, was not considered significant at this latitude, but further tagging studies are needed. Estimated survival from egg to smolt, fry to smolt, and from smolt to sub-adult was 0.4%, approx 12% and 44%, respectively. Overwinter survival of sub-adults was approx 56%, although it is possible some fish remained in freshwater. During the winter in freshwater, sub-adults and adults lost considerable weight. Sport fishing for anadromous Dolly Varden occurred mainly in late summer and autumn in the estuary and tidal zone of the river, and to a lesser extent in the mainstem during the latter months of the winter steelhead fishery. In 1977 an estimated 7.5% of the total adult and sub-adult run· was harvested in the summer, and 2.5% during the winter fishery. Further research needs and management implications are discussed.

Sneep, J., & Evans, M. (2022). *BRGMON-1 lower bridge river aquatic monitoring: Chinook salmon emergence timing and life history review.* St'at'imc Eco-Resources and BC Hydro, Retrieved from https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/corporate/environment-sustainability/water-use-planning/lower-mainland/brgmon-01-Chinook-life-history-review-2022-02-15.pdf

The Chinook population in the Lower Bridge River (LBR) has been monitored as a part of a multiyear fish and aquatic monitoring program that was initiated in 1996 and has continued every year since (known as BRGMON-1 Lower Bridge River Aquatic Monitoring). The program monitors the effects of a flow release from Terzaghi Dam on salmon and steelhead production, as well as other indicators of ecosystem health (e.g., water temperature, water chemistry, periphyton accrual and diversity, benthic invertebrate abundance and diversity). The monitoring has spanned a period of years prior to the continuous flow release as well as three different flow trials (see more information about the flow trials in Section 1.2, below), which featured different flow magnitudes and hydrograph shapes. The results from this program have characterized life history components for the freshwater life stages of Chinook in the LBR and documented trends in recruitment and juvenile abundance. Information about Chinook salmon spawner escapements and distribution has been collected under a separate program called BRGMON-3 Lower Bridge River Adult Salmon and Steelhead Enumeration. Since the first flow trial, Chinook juvenile abundance declined in the LBR and has remained consistent across the flow trials (refer to the most recent BRGMON-1 report for more details; Sneep et al. 2019). Since approx. 2005, which was five years following the start of the declines in Chinook juvenile numbers, the adult escapements also dropped and have remained low. A tremendous amount of data and information have been collected about the effects of the flow release on fish production and ecosystem health in the LBR over 24 years of monitoring. However, some uncertainty remains about the specific effects of the flow release on Chinook recruitment, survival and habitat use in the LBR, largely because some of these effects were not foreseen when the study approach and methodologies were initially conceived. This review is intended to summarize existing data to document what has been learned and provide information for making informed decisions for addressing this uncertainty going forward.

Solas, M. R., Skoglund, H., & Salvanes, A. G. V. (2019). Can structural enrichment reduce predation mortality and increase recaptures of hatchery-reared Atlantic salmon Salmo salar l. Fry released into the wild? *Journal of Fish Biology,* 95(2), 575-588. https://doi.org/10.1111/jfb.14004

Captive-reared fish often have poor survival in the wild and may fail to boost threatened populations. Enrichment during the nursery period can in some circumstances generate a broader behavioural repertoire than conventional hatchery production. Yet, we do not know if enrichment promotes survival

after release into the wild. We conducted a field experiment during three field seasons using age 0+ year Atlantic salmon Salmo salar to investigate if enrichment during rearing, in the form of structural complexity (shelters), reduced immediate (within 2 days after release) predation mortality by piscine predators (brown trout Salmo trutta) and if such rearing environments improved long-term (2-3 months after release) post-release survival. In addition, we investigated if predation mortality of released fry was size-selective. S. salar fry were reared in a structurally enriched environment or in a conventional rearing environment and given otolith marks using alizarin during the egg stage to distinguish between enriched and conventionally-reared fry. The outcome from the field experiments showed that structural enrichment did not consistently reduce immediate predation mortality and it did not improve, or had a negative effect on, the recapture rate of fry from the river 2-3 months after release. The data also showed that enriched rearing tended to reduce growth. Additionally, we found that S. trutta predators fed on small individuals of the released fry. Overall, the data suggest that structural enrichment alone is not sufficient to improve long-term survival of hatchery-reared fish after release and that other factors might affect post-release survival.

Sparkman, M. D., Park, R., Osborn, L., Holt, S., & Wilzbach, M. A. (2016). *Lower Redwood Creek juvenile salmonid (smolt) abundance project, study year 2015: A report to the Fisheries Restoration Grants Program (project no. P1210322)*. California Department of Fish and Wildlife Retrieved from https://cuca.humboldt.edu/sites/default/files/cuca/reports/ulredwoodcreek2015.pdf

Juvenile anadromous salmonid trapping was conducted for the 12th consecutive year in 2015 in lower Redwood Creek (RC), Humboldt County, California during the spring/summer emigration period (March – August). Trapping in 2015 was initiated earlier than previous study years to account for the earlier migration and subsequent production from adult Chinook Salmon returns in September and October, 2014. The purpose of the study was to describe juvenile salmonid out-migration and estimate smolt population abundances for wild 0+ Chinook Salmon, 1+ Chinook Salmon, 1+ Coho Salmon, 1+ Steelhead Trout, 2+ Steelhead Trout, and Coastal Cutthroat Trout using mark/recapture methods. The long term goal is to monitor the status and trends of outmigrating juvenile salmonid smolts in RC in relation to watershed conditions and restoration activities in the basin, provide data for Viable Salmonid Population Analysis, and to make RC a Life Cycle Monitoring station by combining sonar counts of adults with smolt abundance estimates. A rotary screw trap and fyke net/pipe trap collectively operated 132 out of 138 days/nights possible, and captured 175,966 0+ Chinook Salmon (ocean type), 10 1+ Chinook Salmon (stream type), 39,779 0+ Steelhead Trout, 8,535 1+ Steelhead Trout, 1,596 2+ Steelhead Trout, 211 juvenile Coastal Cutthroat Trout, 1 0+ pink Salmon, 100 0+ Coho Salmon, and 496 1+ Coho Salmon to total 226,694 juvenile salmonids. Eight adult Coastal Cutthroat Trout were also captured, and for the first time of record one Eulachon and four Staghorn Sculpins were captured. Average weekly trapping efficiencies were 50% for 0+ Chinook Salmon, 50% for 1+ Chinook Salmon, 14% for 1+ Steelhead Trout, 12% for 2+ Steelhead Trout, 29% for Coastal Cutthroat Trout, 28% for 0+ Coho Salmon, and 38% for 1+ Coho Salmon. The 0+ Chinook Salmon population abundance in 2015 equaled 295,664 individuals (95% CI = 284,021 – 307,308), and was 1.3 times greater than the previous 11 year average. Based upon a much higher abundance determined in mid/upper RC (N = 575,353) in 2015, we suspect high flows in March and early April caused considerable mortality to an estimated 260,000 fry that migrated downstream prior to these fry stressor flows. 1+ Chinook Salmon abundance equaled 17 individuals (95% CI = 8 – 25), and was 99% less than abundance in 2014. 1+ Chinook Salmon abundances in a given year were positively related to 0+ Chinook Salmon abundances the previous year ($p < 0.05$). Low abundances over the current 12 year period indicate 1+ Chinook Salmon are relatively rare in RC. Population abundances (with 95% confidence intervals) in 2015 equaled 56,020 (49,180 – 62,860) for 1+

Steelhead Trout, 18,155 (13,912 – 22,397) for 2+ Steelhead Trout, 303 (191 – 416) for 0+ Coho Salmon, 1,923 (1,542 – 2,304) for 1+ Coho Salmon, and 825 (561 – 1,089) for juvenile Coastal Cutthroat Trout. Although abundance of 1+ Coho Salmon smolts in 2015 was the highest of record, abundances across all years were consistently low. The abundances of 1+ Steelhead Trout, 2+ Steelhead Trout, juvenile Coastal Cutthroat Trout, and 1+ Coho Salmon were greater than average, and indicate that drought conditions during the summer of 2014 did not drastically reduce survival. The correlation of time (study year) on yearly population abundances was not significant for 0+ Chinook Salmon, 1+ Chinook Salmon, 0+ Coho Salmon, 1+ Coho Salmon, 1+ Steelhead Trout, and 2+ Steelhead Trout ($p > 0.05$). Juvenile Coastal Cutthroat Trout showed a positive increase in abundance over study years ($p < 0.05$). The average size (FL, Wt) of 0+ Chinook Salmon and 0+ Coho Salmon over study years was negatively related to population abundances ($p < 0.05$), indicating density-dependent effects. The two most important months for migration in 2015 were May/June for 0+ Chinook Salmon, 1+ Steelhead Trout, and juvenile Coastal Cutthroat Trout, and April/May for 1+ Chinook Salmon, 0+ Coho Salmon, 1+ Coho Salmon, and 2+ Steelhead Trout. 0+ Chinook Salmon, 1+ Steelhead Trout, 2+ Steelhead Trout, juvenile Coastal Cutthroat Trout, and 0+ Coho Salmon showed increased migration earlier in the migration period, which may indicate a response to drought conditions. Considerably more 1+ Steelhead Trout emigrated downstream than 2+ Steelhead Trout each study year, suggesting stream habitat conditions are limiting the abundance of the older age class, or favoring a change in the life history to a younger smolt age.

Srivastava, R. K. (1990). *Measures of egg quality and hatchery performance of Arctic charr (Salvelinus alpinus l.) and Atlantic salmon (Salmo salar l.).* (MS), Memorial University of Newfoundland, Retrieved from http://research.library.mun.ca/id/eprint/4144

The present study examined how morphological, biological and biochemical characteristics of eggs correlated with overall performance (survival, growth) of eggs and alevins of Arctic charr (Salvelinus alpinus) and Atlantic salmon (Salmo salar). In addition, the effect of time of stripping on biochemical composition of laboratory-reared charr eggs was studied, and the biological, morphological and biochemical egg quality criteria of cultured and wild Atlantic salmon (anadromous) were compared and evaluated. Fertilization and hatching success, growth and survival of developing embryos, alevins and fry were recorded as biological measures of egg quality. These measures were compared to levels of protein, lipid, carbohydrate, moisture, ash, total and free amino acids as potential biochemical indicators, and to egg size, yolk-sac volume at hatching, alevin size at hatching and age at hatching as potential morphological indicators of egg quality. -- For Arctic charr, eggs collected in the middle of the spawning period had the highest protein, lipid, carbohydrate and energy content, which were associated with higher fertilization and hatching success, and growth and survival of embryos, alevins and fry, than that of eggs collected early or late in the spawning period. Eggs collected from wild Atlantic salmon had higher protein, lipid, carbohydrate and energy content and concomitantly higher fertilization and hatching success, faster development and greater growth and survival of embryos, alevins and fry than those collected from cultured stock. The total amino acid pool, and the protein, lipid, carbohydrate and energy content of eggs, alevins and fry decreased simultaneously during embryonic development of both Arctic charr and Atlantic salmon because they were utilized in metabolic processes. -- Egg diameter and alevin length were positively correlated with egg weight and alevin weight, respectively. There was no correlation between egg weight and alevin weight or egg diameter and alevin length at hatching for either Arctic charr or Atlantic salmon. -- The amino acids, serine, valine, tryptophan, lysine, isoleucine and threonine were important for growth and survival of embryos, alevins and fry of Arctic charr. However, alanine, aspartic acid, histidine, isoleucine, leucine, lysine, phenylalanine, proline, serine, threonine, tyrosine and valine were important for growth and survival of embryos, alevins and fry of

Atlantic salmon. -- It is suggested that energy level and/or amino acid content of eggs could be used as a condition index for the future development, growth and survival of embryos and alevins of salmonids.

Stanley, J. G., & Trial, J. G. (1994). Habitat suitability index models: Nonmigratory freshwater life stages of Atlantic salmon. In: National Biological Service, U.S. Department of the Interior. Retrieved from https://pubs.er.usgs.gov/publication/bsr3

A Habitat Suitability Index model was developed by evaluating individual suitability indices of 17 environmental variables that have been shown to affect productivity or survival of nonmigratory freshwater life history stages of Atlantic salmon (Salmo salar L.). These stages included egg, embryo, fry, and parr but not smolt. During summer base flows, the most suitable habitats had temperatures of 16-19 deg C, oxygen percent saturation exceeding 60%, and pH between 5.5 and 6.8. The most suitable current velocity was 1030 cm/s for fry and 10-40 cm/s for parr. The most suitable depth was 10-40 cm for fry and 20-50 cm for parr. The Habitat Suitability Index model is useful for evaluating stream habitat for production and survival of juvenile Atlantic salmon when these variables cannot practically be measured directly.

Stark, E. J., Atkinson, E. J., & Kozfkay, C. C. (2014). Captive rearing for Chinook salmon (Oncorhynchus tshawytscha) and Atlantic salmon (Salmo salar): The Idaho and Maine experiences. *Reviews in Fish Biology and Fisheries,* 24(3), 849-880. https://doi.org/10.1007/s11160-014-9346-x

Captive rearing is a conservation strategy where juveniles are collected from the natural environment, reared to maturity in a hatchery environment, and then released back into the natural environment at maturity for volitional spawning. This strategy has been used to produce adult outplants for stock enhancement where natural escapement is poor or capture of adults is difficult. In both Idaho (Chinook salmon, Oncorhynchustshawytscha) and Maine (Atlantic salmon, Salmo salar), captive rearing programs have been initiated as an experimental strategy to prevent cohort collapse and conserve genetic integrity of select depressed populations. In this paper, we provide an overview of these programs and describe some of the methods used to evaluate the effectiveness of this approach. Behaviors such as habitat selection, courting, and spawn timing were monitored. Data collected for both programs indicate that the captive fish display similar behaviors as their wild conspecifics in terms of habitat selection and spawning, although there were some differences in spawn timing. Evaluations of egg and fry production also indicate that captive-reared adults are successfully spawning and producing offspring. Each program is still waiting on final evaluations of reproductive success through genetic analyses of returning adults, but results so far indicate that this could be an additional captive propagation strategy for depressed populations.

Stark, E. J., Vidergar, D. T., Kozfkay, C. C., & Kline, P. A. (2018). Egg viability and egg-to-fry survival of captive-reared Chinook salmon released to spawn naturally. *Transactions of the American Fisheries Society,* 147(1), 128-138. https://doi.org/10.1002/tafs.10020

Conservation hatchery strategies for anadromous salmonids are designed to boost depressed wild populations while conserving genetic resources. Captive rearing is an approach in which eggs or juveniles are collected from wild fish, taken into a hatchery and reared to maturation, and then released to spawn. In this study, we quantified spawn timing and redd production for captive-reared and wild

Chinook Salmon Oncorhynchus tshawytscha and measured survival of eggs to the eyed stage of development (egg viability) and from egg to fry. The study objective was to determine whether there was a difference in egg viability and egg-to-fry survival between captive-reared and wild Chinook Salmon that spawned in the wild. During 2007-2009, 90 redds were sampled in the East Fork Salmon River, Idaho; 45 of captive-origin salmon and 45 of wild origin. Egg viability was significantly lower for captive-reared fish (75.0%) than for their wild counterparts (95.6%). The overall mean egg-to-fry survival for captive-reared fish was quite high (80.4%), and although it was significantly lower than that for wild fish (84.0%), biologically this survival difference was not large. While others have estimated the egg-to-fry survival of production hatchery Chinook Salmon in the wild, it had not previously been estimated for captive-reared fish released to spawn. Through the use of novel techniques such as hydraulic pumping and egg capsules, we were able to successfully estimate egg viability and egg-to-fry survival of captive-reared and wild Chinook Salmon spawning in the wild. Although egg viability and egg-to-fry survival of captive-reared fish was lower than for their wild counterparts, both survival rates may be sufficient to provide a demographic benefit to the receiving wild population.

Sternecker, K., Denic, M., & Geist, J. (2014). Timing matters: Species-specific interactions between spawning time, substrate quality, and recruitment success in three salmonid species. *Ecology and Evolution,* 4(13), 2749-2758. https://doi.org/10.1002/ece3.1128

Substratum quality and oxygen supply to the interstitial zone are crucial for the reproductive success of salmonid fishes. At present, degradation of spawning grounds due to fine sediment deposition and colmation are recognized as main factors for reproductive failure. In addition, changes in water temperatures due to climate change, damming, and cooling water inlets are predicted to reduce hatching success. We tested the hypothesis that the biological effects of habitat degradation depend strongly on the species-specific spawning seasons and life-history strategies (e. g., fall-vs. spring-spawners, migratory vs. resident species) and assessed temperature as an important species-specific factor for hatching success within river substratum. We studied the species-specific differences in their responses to such disturbances using egg-to-fry survival of Danube Salmon (Hucho hucho), resident brown trout (Salmo trutta fario), and migratory brown trout (Salmo trutta lacustris) as biological endpoint. The egg incubation and hatching success of the salmonids and their dependence on temperature and stream substratum quality were compared. Hatching rates of Danube salmon were lower than of brown trout, probably due to higher oxygen demands and increased interstitial respiration in spring. Increases in maximum water temperature reduced hatching rates of resident and migratory brown trout (both fall-spawners) but were positively correlated with hatching rates of Danube salmon (a spring-spawner). Significantly longer incubation periods of resident and migratory brown trout coincided with relatively low stream substratum quality at the end of the egg incubation. Danube salmon seem to avoid low oxygen concentrations in the hyporheic zone by faster egg development favored by higher water temperatures. Consequently, the prediction of effects of temperature changes and altered stream substratum properties on gravel-spawning fishes and biological communities should consider the observed species-specific variances in life-history strategies to increase conservation success.

Sternecker, K., & Geist, J. (2010). The effects of stream substratum composition on the emergence of salmonid fry. *Ecology of Freshwater Fish,* 19(4), 537-544. https://doi.org/10.1111/j.1600-0633.2010.00432.x

Salmonid fishes are target species for the conservation of freshwater habitats, but their natural reproduction is often insufficient. The emergence of fry is a crucial phase in the life cycle of salmonids and the stream substratum is the key habitat which regulates the emergence success. In this study, brown trout (Salmo trutta) and Danube salmon (Hucho hucho) eggs were exposed to different sediment textures and the emergence and the postemergence survival and growth were observed under constant water chemical conditions in the laboratory. In both species, textural effects on emergence rate, chronology of emergence, survival rate after emergence and growth after emergence were detected. Fine-textured substratum (5-8 mm) formed a physical barrier to the posthatch migration of salmonids from the interstitial zone to the open water. The time period between the first and the last emerged fish was shorter in treatments with fine texture compared with coarse substratum. The survival rate was higher in treatments of coarser sediment. The effects of different textures on the growth of fry after emergence differed between brown trout and Danube salmon, which can be explained by different life history strategies. These results suggest that physical characteristics of substratum texture can have strong effects on salmonid emergence, and ultimately on the persistence of salmonid populations. They also suggest that biodiversity conservation in stream ecosystems can greatly benefit from an inclusion of the physical characteristics of the stream bed into catchment-based management plans.

Stewart, D. B., Carmichael, T. J., Sawatzky, C. D., Mochnacz, N. J., & Reist, J. D. (2007). *Fish life history and habitat use in the Northwest Territories: Round whitefish (Prosopium cylindraceum).* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.618783/publication.html

Round whitefish occur throughout the Northwest Territories, where populations can follow lacustrine, adfluvial, fluvial, or anadromous life histories. Differences in habitat use by these populations and in the seasonal requirements of eggs, fry, juveniles, and adults are summarized. The round whitefish prefers lake, river and larger stream (&gt10 m width) habitats, eats mostly aquatic invertebrates, and spawns in the fall in either river or lake habitats. It is common in cold, clear water (0 to 18 degree C) above 37 m depth, but sometimes uses turbidity for cover. To support the assessment, avoidance and mitigation of environmental impacts in the Mackenzie River Valley, the potential impacts of development activities and climate change on survival of the species are reviewed. The species' small size, dietary preferences, limited seasonal movements and use of lakes or rivers for spawning may limit its vulnerability to habitat degradation, habitat fragmentation, harvesting, and climate change. However, its eggs are sensitive to elevated or unstable temperatures during incubation. It is absent from lakes with a pH of less than 5.5. And, the introduction of warm-water predators such as smallmouth bass (Micropterus dolomieu), yellow perch (Perca flavescens), and rainbow smelt (Osmerus mordax) can cause populations to decline.

Stober, Q. J., & Hamalainen, A. H. (1980). *Cedar River sockeye salmon production, 1980.* Fisheries Research Institute, Retrieved from http://hdl.handle.net/1773/3952

The 1979 Cedar River escapement of sockeye salmon (Oncorhynchus nerka) was estimated at 185,300 spawners that were the progeny of the 1975 brood year that had been impacted by the maximum flood on record. River discharge during the 1979 spawning seasons was regulated along the critical year flow

curve, due to extant drought conditions. National egg survival was probably reduced by a moderate flood in mid-December. Fry estimated to have entered Lake Washington totalled 13,900,000. The egg-to-fry survival rate for the entire run was 4.0%. The infection rate due to hematopoetic necrosis viral disease declined to low level after all fry emigrated from the enchancement facilities. The 1976 and 1978 brood years were comparable, but 1978 escapement was doubled. Egg-to-fry survival was 8.1, 4.5, and 4.0 for the 1976, 1978, and 1979 brood years, respectively. The number of pre-emergent fry has increased with enhancement production.

Stober, Q. J., Quinnell, S., Cowman, C. F., Wilcock, J., & Tyler, R. W. (1979). Irrigation drawdown and kokanee salmon egg to fry survival in Banks Lake. In: Fisheries Research Institute. Retrieved from http://hdl.handle.net/1773/3923

The effect of lake level drawdown on the 1979 kokanee fry emergence in Banks Lake was determined by monitoring the catch of 90 emergence traps placed on six transects ranging in depth from 0.6 to 13.6 m (2 to 45 ft) on the prime spawning area. An additional 12 traps monitored the emergence from a lesser spawning area at Million Dollar Mile. The lake drawdown reached 4.2 in (13.9 ft) below full pool before emergence began and thus killed the eggs and alevins in 90% of the primary spawning gravel, which occurs between 1.5 and 4.6 m (4.9 and 15 ft). The principal emergence occurred from secondary spawning gravel from 4.6 to 6.7 in (15 to 22 ft) below full pool. The deeper area was extensively spawned in 1978, because of increased competition for spawning sites which forced the use of less desirable gravel at greater depth. The estimated emergence of kokanee fry from the prime spawning site was 26,162 (Za = ±11,152) based on a trap efficiency of 100%. The estimated kokanee fry emergence indicated below optimum survival, which may result in a poor kokanee fishery in 1982. An estimated 1,706,967 lake whitefish fry emerged from the prime spawning area during April and were not affected by drawdown. The relationships between the depth range of the kokanee spawning area, time of spawning, egg incubation, and fry emergence and the spring reservoir drawdown for 1977, 1978, and 1979 were analyzed graphically. Drawdown limits which allow fry emergence to occur were developed for small spawner populations restricted to the primary depths and a large population including the secondary spawning area. The rule curves are used to determine a water management strategy for kokanee fry survival as well as to estimate the loss when the curves are exceeded. KEY WORDS: kokanee salmon, lak

Stober, Q. J., & Tyler, R. W. (1982). Rule curves for irrigation drawdown and kokanee salmon (Oncorhynchus nerka) egg to fry survival. *Fisheries Research,* 1(3), 195-218. https://doi.org/10.1016/0165-7836(81)90025-4

The survival of kokanee salmon (Oncorhynchus nerka) eggs and pre-emergent fry in the shoreline spawning areas of Banks Lake, Washington State, U.S.A., is reduced by annual drawdown of the reservoir. Kokanee salmon spawn exclusively along steep talus shorelines during the months of October and November. No suitable spawning streams enter the lake and nearly all water is pumped into this irrigation reservoir from lake Roosevelt on the Columbia River. Preferred spawning depths range from 1.5–4.6 m; however, when large populations were present, spawning was observed to 13.7 m. Fry emergence was estimated at depth intervals from conical trap catches deployed in an array over a major spawning area in the reservoir. Emergence occurred from late March to early June; however, the timing of maximum emergence shifted from 28 April to 10 May during three consecutive years due to changes in the thermal regimes during incubation. The relationships between the depth range of spawning area,

timing of spawning, egg incubation and fry emergence, and the spring reservoir drawdown for 1977, 1978 and 1979 were analyzed graphically. Rule curves defining rate and magnitude of reservoir drawdown to achieve 75% fry emergence were developed. These rule curves can be used to determine a water management strategy for natural kokanee salmon production or to estimate the loss when exceeded.

Sunde, J., Tamario, C., Tibblin, P., Larsson, P., & Forsman, A. (2018). Variation in salinity tolerance between and within anadromous subpopulations of pike (Esox lucius). *Scientific Reports,* 8. https://doi.org/10.1038/s41598-017-18413-8

Environmental heterogeneity is a key determinant of genetic and phenotypic diversity. Stable and homogenous environments tends to result in evolution of specialism and local adaptations, while temporally unpredictable environments may maintain a diversity of specialists, promote generalist strategies, or favour diversified bet hedging strategies. We compared salinity tolerance between two anadromous subpopulations of pike (Esox Lucius) that utilize freshwater spawning sites with different salinity regimes. Eggs from each population were artificially fertilized and incubated in a salinity gradient (0, 3, 5, 7, and 9 psu) using a split-brood design. Effects on embryonic development, hatching success, survival of larvae, and fry body length were compared between populations and families. The population naturally spawning in the stable freshwater habitat showed signs of specialization for freshwater spawning. The population exposed to fluctuating selective pressure in a spawning area with occasional brackish water intrusions tolerated higher salinities and displayed considerable variation in reaction norms. Genetic differences and plasticity of salinity tolerance may enable populations to cope with changes in salinity regimes associated with future climate change. That geographically adjacent subpopulations can constitute separate units with different genetic characteristics must be considered in management and conservation efforts to avoid potentially negative effects of genetic admixture on population fitness and persistence.

Swartzman, G. L. (1991). Equilibrium abundance of salmon stocks in a life cycle model with interacting hatchery and natural substocks. *Natural Resource Modeling,* 5(1), 1-18. https://doi.org/10.1111/j.1939-7445.1991.tb00229.x

This paper develops the equilibrium solutions for an age-structured life cycle model where spawning stock is split between natural and hatchery spawners. Mixing is allowed between the stocks through natural stock take by the hatchery and release of eggs or fry by the hatchery when its capacity is exceeded. The natural stock is assumed to have density-dependent egg-smolt survival while the hatchery stock has linear survival. The model can be applied to any hatchery reared fish stock but is most appropriate for salmon, where hatchery and naturally spawned fish mix completely later in life. Questions about the mix between the hatchery and natural stocks can be addressed by computing the fraction of naturally and hatchery derived stock among the natural and hatchery spawners as well as among the total adult run. Columbia River Chinook stock are used as an example for which equilibria and mixing fractions are computed. A Monte Carlo sensitivity study on model parameters showed that the natural stock survival from smoltification to age 1 and the natural basin smolt carrying capacity are most important in controlling the equilibrium age-1 naturally spawned stock. Changing hatchery capacity over two orders of magnitude showed a 50 percent change in the fraction of naturally derived fish in the natural spawning stock, while the relative size of natural and hatchery stocks changed over two orders of magnitude. The model can serve as a tool for quickly assessing the effects of spawning

habitat modification and hatchery supplementation practices on long-term stock mixing and stock abundance.

Sweeten, T., McLean, W. E., & Jensen, J. O. T. (2003). *Suspended sediment in the little qualicum watershed 1986-2001*.(Canadian technical report of fisheries and aquatic sciences No. 2446). Fisheries and Oceans Canada Retrieved from https://publications.gc.ca/site/eng/463123/publication.html

The Little Qualicum River spawning channel operated by the Department of Fisheries and Oceans is sensitive to suspended sediment. Accumulation of fines in the spawning beds eventually degrades gravel quality and only routine cleaning will maintain egg survival. Increased suspended sediment is also detrimental to juvenile salmon that rear in the channel. Egg-to-fry measurements were used to assess the impact on eggs deposited in the gravel and a model developed by Newcombe and Jensen (1996) to assess the impact on juvenile salmonids.

Syrjanen, J. T., Ruokonen, T. J., Ketola, T., & Valkeajarvi, P. (2015). The relationship between stocking eggs in boreal spawning rivers and the abundance of brown trout parr. *ICES Journal of Marine Science,* 72(5), 1389-1398. https://doi.org/10.1093/icesjms/fsv017

Stocking with eggs has been widely used as a management measure to support degraded salmonid stocks. In Finland, Atlantic salmon and both seamigrating and lake-migrating brown trout are stocked as eggs, alevins, fry, parr, and smolt, whereas trout are also stocked as mature fish. The aim of this stocking is to improve catches and to support collapsed spawning stocks. We assessed the success of stocking with brown trout eggs in a study of 17 Finnish boreal forest rivers, of which 9 were subject to egg stocking. All rivers contained some naturally spawning trout. In 16 rivers, including non-stocking years and unstocked rivers, egg stocking did not increase the total (wild and stocked) density of 0-year-old parr. However, those rivers with higher existing trout densities in non-stocking years seemed to benefit most from stocking, suggesting some role of river-specific extrinsic factors affecting egg-to-parr survival. In one river monitored for 14 years, only a weak correlation was found between the total density of 0-year-old parr and the number of eggs stocked. However, in nine parr samples from five rivers, the mean proportion of parr derived from stocked eggs was 40%. The mean survival to first autumn parr of egg-stocked and wild individuals was 1.0 and 3.3%, respectively. Probable reasons for the detected low to moderate impact of egg-stocking are (i) large variation in total parr density between years and rivers, (ii) small number of stocked eggs, (iii) placing egg boxes and egg pockets in unsuitable microhabitats, and (iv) unsuitable emergence time of egg-stocked individuals, or other extrinsic factors creating extra mortality. We recommend field and laboratory experiments to improve and standardize stocking methods, and monitoring the connection of wild spawning stocks and parr recruitment. Finally, we encourage fishery authorities to create clear management goals for threatened wild salmonid stocks.

Taylor, S. G. (1980). Marine survival of pink salmon fry from early and late spawners. *Transactions of the American Fisheries Society,* 109(1), 79-82. https://doi.org/10.1577/1548-8659(1980)109<79:Msopsf>2.0.Co;2

Pink salmon, Oncorhynchus gorbuscha, eggs were collected from early-run and late-run spawners at Auke Creek, Alaska, and reared separately in a hatchery in deep-gravel incubators. Both groups of fry

were marked the day after emergence, then released, unfed, to complete downstream migration. Early hatchery fry migrated downstream about 35 days ahead of late hatchery fry and about 55 days ahead of fry naturally hatched in Auke Creek. Hatchery fry developed faster than wild fry because hatchery water was warmer than Auke Creek water during egg incubation. Early hatchery fry had an averagd ocean life of 515 days and a marine survival of 0.17%; late hatchery fry had an average ocean life of 513 days and a marine survival of 1.46%. Low water temperatures experienced by early fry when they entered the estuary probably slowed their growth and made them more vulnerable to predators.

Taylor, S. G. (1984). Quality of pink salmon (Oncorhynchus gorbuscha) fry incubated from eggs in river gravel or plastic substrates. *Aquaculture,* 42(3-4), 359-365. https://doi.org/10.1016/0044-8486(84)90114-5

Pink salmon (Oncorhynchus gorbuscha) eggs were incubated to the emergent-fry stage in separate incubators containing either river gravel or one of four plastic substrates (2.5-cm saddles, 2.5-cm rings, 3.7-cm rings, and a 1 : 1 mixture of 2.5-cm and 3.7-cm rings). Length, weight, stage of development, and survival from egg to emergent fry were similar for fry from all incubators, regardless of substrate. Significantly more fry emerged prematurely (i.e., had open ventral slits) from incubators with plastic substrates (10%) than from incubators with gravel substrates (3%); however, fully developed fry emerged an average of 3 days later from plastic substrates than from gravel substrates.

Teuscher, D. (1995). *Snake River sockeye salmon habitat and limnological research: 1994 annual report.* Bonneville Power Administration, https://doi.org/10.2172/119928

Snake River sockeye salmon were listed as endangered in 1991. Since then, the Shoshone-Bannock Tribes (SBT) have been involved in a multi-agency recovery effort. The purpose of this document is to report activities completed in the rearing environments of the Sawtooth Valley Lakes, central Idaho. SBT objectives for 1995 included: continuing population monitoring and spawning habitat surveys; estimating smolt carrying capacity of the lakes, and supervising limnology and barrier modification studies. Hydroacoustic estimates of O. nerka densities in the Sawtooth Valley lakes ranged from 32 to 339 fish/ha. Densities were greatest in Stanley followed by Redfish (217 fish/ha), Pettit (95 fish/ha), and Alturas. Except for Alturas, population abundance estimates were similar to 1993 results. In Alturas Lake, O. nerka abundance declined by approximately 90%. In 1994, about 142,000 kokanee fry recruited to Redfish Lake from Fishhook Creek. O. nerka fry recruitment to Stanley and Alturas lakes wa s 19,000 and 2,000 fry, respectively. Egg to fry survival was 11%, 13%, and 7% in Fishhook, Alturas and Stanley Lake Creeks. Kokanee spawning in Fishhook Creek was slightly lower than 1993 estimates but similar to the mean escapement since 1991. About 9,200 kokanee entered the creek in 1994 compared to 10,800 inmore » 1993. Escapement for Stanley Lake Creek was only 200, a 68% reduction from 1993. Conversely, O. nerka spawning densities increased to 3,200 in Alturas Lake Creek, up from 200 the previous year.

Teuscher, D. M., Taki, D., & Ariwite, K. (1996). *Snake River sockeye salmon habitat and limnological research: Annual report 1995.* Bonneville Power Administration, https://doi.org/10.2172/405698

Critical habitat for endangered Snake River sockeye salmon includes five rearing lakes located in the Sawtooth Valley of central Idaho. Most of the lakes contain either introduced or endemic kokanee populations. Snake River sockeye occur naturally in Redfish Lake, and are being stocked in Redfish and Pettit Lakes. Because kokanee compete with sockeye for limited food resources, understanding population characteristics of both species such as spawn timing, egg-to-fry survival, distribution and abundance are important components of sockeye recovery. This chapter describes some of those characteristics. In 1995, hydroacoustic estimates of O. nerka densities in the Sawtooth Valley Lakes ranged from 57 to 465 fish/ha. Densities were greatest in Pettit followed by Redfish (167), Alturas (95), and Stanley Lakes. O. nerka numbers increased from 1994 values in Pettit and Alturas Lakes, but declined in Redfish and Stanley. Despite a decline in total lake abundance, O. nerka biomass estimates in Redfish Lake increased. Approximately 144,000 kokanee fry recruited to Redfish Lake from Fishhook Creek. O. nerka fry recruitment to Stanley and Alturas lake was 5,000 and 30,000 fry, respectively. Egg-to-fry survival was 14% in Fishhook and 7% in Stanley Lake Creek. In Fishhook Creek, kokanee spawning escapement was estimated using stream surveys more » and a weir. Escapement estimates were 4,860 from weir counts, and 7,000 from stream surveys. As part of the kokanee reduction program, 385 of the spawning female kokanee were culled. Escapement for Stanley Lake Creek was only 60 fish, a ten fold decrease from 1994. In Alturas Lake, kokanee spawners dropped by 50% to 1,600. « less

Thomas, A. E. (1975). Effect of egg concentration in an incubation channel on survival of Chinook salmon fry. *Transactions of the American Fisheries Society,* 104(2), 335-337. https://doi.org/10.1577/1548-8659(1975)104<335:Eoecia>2.0.Co;2

Eyed eggs of Chinook salmon (Oncorhynchus tshawytscha) were planted in the Abernathy (Washington) incubation channel at concentrations of 7,180, 10,764, and 14,349 eggs/m 2 of gravel. Numbers of eggs planted were 200,000, 240,000, and 200,800, and survivals to the downstream migrant stage were 78.5, 85.0, and 79.1%, respectively; the differences were not statistically significant. The concentration of 14,349 eggs/m 2 is near the capacity of the channel. This stocking rate is 10 times that commonly recommended for artificial spawning channels. Egg concentration was apparently limited only by the physical capacity of the gravel.

Thomas, A. E. (1975). Effect of egg development at planting on Chinook salmon survival. *Progressive Fish-Culturist,* 37(4), 231-233. https://doi.org/10.1577/1548-8659(1975)37[231:Eoedap]2.0.Co;2

Salmon and trout eggs are planted in natural spawning gravel or in artificial incubation channels to introduce or supplement fish populations. The eggs are normally planted at one of three stages of development: (1) unwaterhardened, (2) waterhardened, or (3) eyed. Experimentation at the Abernathy incubation channel near Longview, Washington, indicated that the stage of egg development at planting might be an important factor in the number of fry produced [3]. Plants of eyed eggs of both fall Chinook salmon (Oncorhynchus tshawytscha) and chum salmon (O. keta) in the Abernathy channel have resulted in better survivals than did plants of green eggs. However, these tests were made during different seasons of operation and under varying environmental conditions. The installation of a sedimentation system to control excess egg mortality in upper reaches of the channel [2, 3] and the division of the

channel into three equal segments by the addition of two additional fry traps enabled multiple experiments during the same season. This report presents results of tests in which eggs in the three stages of development were planted in the same seasons and under more nearly uniform conditions.

Tipping, J. M., & Gilhuly, G. J. (1996). Survival of electroanesthetized adult steelhead and eggs of fall Chinook salmon. *North American Journal of Fisheries Management,* 16(2), 469-472. https://doi.org/10.1577/1548-8675(1996)016<0469:soeasa>2.3.co;2

We evaluated the effects of the Coffelt system 91 electroanesthesia unit on survival of adult steelhead Oncorhynchus mykiss and the egg-to-fry stages of fall Chinook salmon O. tshawytscha. Adult steelhead were anesthetized at one of several voltages with the complex pulse pattern from the system 91 or with carbon dioxide gas. Fish were then tagged, transported, and released. Tags were recovered at two hatcheries and by recreational anglers. An average of 39% of electroshocked fish and 46% of fish anesthetized with carbon dioxide were recovered. However, tags from both groups were returned at similar rates by recreational anglers. Recovery rate differences appeared to be reduced at 50 and 80 V. Egg-to-fry mortality for progeny of electroanesthetized fall Chinook salmon averaged 7%, compared with 12% for control groups. We conclude that if low levels of fish damage are acceptable, electroanesthesia may be a viable alternative to other anesthetics.

Triton Environmental Consultants Ltd. (2004). *2001 fry emergence.* Nechako Fisheries Conservation Program, Retrieved from https://www.neef.ca/uploads/library/6770_Triton2004_NFCP%20FryEmergence2001.pdf

The Nechako Fisheries Conservation Program (NFCP) has conducted a Chinook salmon (Oncorhynchus tshawytscha) fry emergence trapping project in the upper Nechako River since 1990 to monitor the incubation environment in the river. During the 2001 trapping program emergence peaked in mid to late April, as in previous years. Accumulated thermal units (ATUs) at the time of 50% emergence (April 21) was 893, below the 10 year average of 914 (range of 840 to 1,004) The index of fry emergence for 2001 was 1,235,554, the highest since 1997, and the second highest overall. The number of female spawners estimated above the trapping site was the highest on record (n = 336). This translated into an index of emergence success of 63.7% when the estimated egg deposition above the trapping site the previous fall was taken into account. Emergent success was lower than in the four previous years but above the average for 1991-1996 (47%). The data from 2001 strengthened the positive correlation between the index and the number of spawners in the river above the trap site (Spearman rho = 0.83), which confirmed that the index was a reliable estimate of fry abundance. Emergent fry in 2001 were of similar average length (37.6 mm), weight (0.38 g), and development index (KD; 1.9) to those of previous years. Mark recapture estimates provided an index of 2,138,766 ± 1,268,786. The data from 2001 fell within the range of mark recapture indices developed over the period of the project and added strength to the relationship of the mark recapture and emergence indexes (Spearman rho = 0.80). Species other than Chinook made up 2.1% of the total number of fish sampled in the four IPTs. The most common species was sockeye salmon (Oncorhynchus nerka) followed by longnose dace (Rhinichthys cataractae), largescale sucker (Catostomus macrocheilus), redside shiner (Richardsonius balteatus) and leopard dace (Rhinichthys falcatus). Overall, the results from the 2001 fry emergence trapping program are as would be expected: a high index of fry emergence resulting from the largest estimate of spawners upstream of the trapping site on record, a normal progression of emergence, and typical morphological

characteristics of emergent fry. The 2001 index of fry emergence indicates that the quality of the incubation environment in the upper Nechako River appears to be stable.

Tschaplinski, P. J. (2020). The effects of forest harvesting, fishing, climate variation, and ocean conditions on salmonid populations of Carnation Creek, Vancouver Island, British Columbia. In *Sustainable fisheries management.* (pp. 297-327): CRC Press https://doi.org/10.1201/9780429104411-23

The Carnation Creek Fisheries-Forestry Interaction Project, initiated in 1970, is the longest, continuous study of the effects of forestry practices on biological and physical watershed processes in North America. This case study was initially designed to investigate the effects of different streamside forest-harvest treatments on stream channels, aquatic habitats, and fish. The salmonid populations of Carnation Creek have been monitored through 5 pre-logging, 6 during-logging, and 14 post-logging years as one component of this multidisciplinary study. Forest harvesting has had complex and often variable effects upon Carnation Creek fish species and life stages. Chum salmon Oncorhynchus keta have shown the sharpest decline. After logging, numbers of adults returning to the stream fell to about one third of the pre-logging average. This decline is due partly to reductions in egg-to-fry survival resulting from decreased quality of spawning and egg-incubation habitats in the lowermost stream reach. Reductions in summer rearing habitat appear to explain the roughly 50% post-logging decline in abundance of coho salmon O. kisutch fry inhabiting the stream. However, the fewer coho fry have produced >1.5-times more smolts after logging due to improved overwinter survival, which is in turn correlated with increased winter water temperatures and summer growth. Increased smolt abundance has not caused more adults to return. Coho returning to the system have declined after logging by 31%, due at least partly to both depressed marine survivals resulting from earlier timing of spring smolt migrations and ocean climate shifts. The production of salmonids from coastal streams clearly depends upon processes occurring both within watersheds and the marine environment. We cannot control natural shifts in marine ecosystems and climate. Therefore, to sustain our salmonid resources, we must always apply our best forest-harvest practices to ensure that adverse effects of natural variations are not compounded with those of inappropriate land use.

Ulgenes, Y., & Torrissen, O. J. (1989). Accumulation of aluminum on Atlantic salmon eggs during the incubation period. *Aquacultural Engineering,* 8(6), 369-380. https://doi.org/10.1016/0144-8609(89)90031-9

Groups of rainbow trout Onchorhyncus mykiss eggs were incubated in duplicate trays with PVC screens and the original aluminum screens. During the incubation period, aluminum bound to sediments was deposited on the eggs and in the whole hatching system.The pH of the inlet water to the hatching system with PVC screen was experimentally lowered by adding sulphuric acid. Buffering of the outlet water was observed at pH lower than 5, and at pH 4·5 and lower, an increased aluminum concentration in the outlet water was recorded.These experiments show that aluminum accumulated on eggs and in the hatching system during periods with neutral water represents a serious threat to the survival of eggs and fry of salmonids if pH drops below 5·0, even for a few hours. In sensitive lakes and rivers, pH drops below 5·0 are common during heavy rain or during the snow melting period.

Van den Berghe, E. P. (1984). *Natural selection and reproductive success of female coho salmon (Oncorhynchus kitsutch) : A study in female competition.* (MSc), Simon Fraser University, Retrieved from https://summit.sfu.ca/item/6045

This thesis looks at how reproductive behavior and life history traits evolve under female-female competition, in the coho salmon (Oncorhynchus kisutch). Previous studies of reproductive success in female fishes have ignored the contribution of behavior to reproductive success, and thus to natural selection. Reproductive success of individual females was studied for two years in a wild population in Washington State, from the first spawning in November until fry emergence in April. Mature adults were tagged and followed until death. The position, depth, completion date, and eventual fate of each nest was known for most females in the population. Territory quality was quantified by examining survival of eggs to fry. The age and growth patterns are known from analyses of adult scales. My data are supplemented with additional sources on fecundity, and on post-emergent freshwater, ocean, and fishing mortalities. Nest depth was strongly correlated with female body size (r=.778, P<.OOl), as was female breeding life (r=.65, P<.001) which ranged from 3 to 22 days. Females spent almost all of their breeding life guarding their territory to prevent other females from re-using it and thereby digging up the eggs. Variance in nest survival was due to competitive differences in guarding time, fighting ability, and nest depth among females of different body sizes. A total of 24% of all nests in the stream were lost.

Venditti, D. A., Willard, C., Looney, C., Kline, P., & Hassemer, P. (2002). *Captive rearing program for Salmon River Chinook salmon, 2000 annual report.* Bonneville Power Administration, https://doi.org/10.2172/910568

During 2000, the Idaho Department of Fish and Game (IDFG) continued to develop techniques to rear Chinook salmon Oncorhynchus tshawytscha to sexual maturity in captivity and to monitor their reproductive performance under natural conditions. Eyed-eggs were collected to establish captive cohorts from three study streams and included 503 eyed-eggs from East Fork Salmon River (EFSR), 250 from the Yankee Fork Salmon River, and 304 from the West Fork Yankee Fork Salmon River (WFYF). After collection, the eyed-eggs were immediately transferred to the Eagle Fish Hatchery, where they were incubated and reared by family group. Juveniles collected the previous summer were PIT and elastomer tagged and vaccinated against vibrio Vibrio spp. and bacterial kidney disease before the majority (approximately 75%) were transferred to the National Marine Fisheries Service, Manchester Marine Experimental Station for saltwater rearing through sexual maturity. Smolt transfers included 158 individuals from the Lemhi River (LEM), 193 from the WFYF, and 372 from the EFSR. Maturing fish transfers from the Manchester facility to the Eagle Fish Hatchery included 77 individuals from the LEM, 45 from the WFYF, and 11 from the EFSR. Two mature females from the WFYF were spawned in captivity with four males in 2000. Only onemore » of the females produced viable eggs (N = 1,266), which were placed in in-stream incubators by personnel from the Shoshone-Bannock Tribe. Mature adults (N = 70) from the Lemhi River were released into Big Springs Creek to evaluate their reproductive performance. After release, fish distributed themselves throughout the study section and displayed a progression of habitat associations and behavior consistent with progressing maturation and the onset of spawning. Fifteen of the 17 suspected redds spawned by captive-reared parents in Big Springs Creek were hydraulically sampled to assess survival to the eyed stage of development. Eyed-eggs were collected from 13 of these, and survival ranged from 0% to 96%, although there was evidence that some eggs had died after reaching the eyed stage. Six redds were capped in an attempt to document fry emergence, but none were collected. A final hydraulic sampling of the capped redds yielded nothing from five of the

six, but 75 dead eggs and one dead fry were found in the sixth. Smothering by fine sediment is the suspected cause of the observed mortality between the eyed stage and fry emergence.

Vincenzi, S., Crivelli, A. J., Jesenšek, D., & De Leo, G. A. (2010). The management of small, isolated salmonid populations: Do we have to fix it if it ain't broken? *Animal Conservation,* 13(1), 21-23. https://doi.org/10.1111/j.1469-1795.2009.00292.x

In their recent paper, Sato H Gharrett et al., 1999; McGinnity et al., 2003; Tallmon et al., 2004), but claimed the close geographical proximity, similar habitat and small genetic differences among remnant populations might considerably reduce this risk. In a recent review, Edmands (2007) stated that concerns over outbreeding should be taken seriously, as the effects of outbreeding can be, in some cases, as damaging as severe inbreeding. Here, we raise concerns about mixing of populations as a strategy to increase genetic variation, and we bring evidence of likely outbreeding depression observed in the rehabilitation project of the endangered freshwater salmonid marble trout Salmo marmoratus, started in Slovenia in 1993 (Crivelli et al., 2000). Since the beginning of the rehabilitation project, four marble trout populations went extinct due to landlsides (Predelica) and severe flood events (Gorska, Sventarska and Zakojska). The seven remnant populations of marble trout living in Slovenian streams are genetically distant (FST=0.66, Fumagalli et al., 2002), present a very low effective population size (for the Huda Grapa population a total population size ranging from 29 to 60 individuals was estimated between 2000 and 2007) and very low genetic variability estimated at 14 microsatellite loci (for Huda Grapa Ho=0.046, Fumagalli et al., 2002). In order to expand the genetic variability of marble trout living in the watershed, a new population (Gatsnik) was created in 1998 in a previously fishless stream by mixing the progeny of marble trout from two remnant populations from isolated streams with similar habitat (Trebuscica and Lipovesck). After two generations, the population of Gatsnik presented the typical features associated with maladaptation and outbreeding depression, that is lower annual survival rate (0.39 0.02 for trout born in the stream, higher than 0.55 for other marble trout populations living in the study area, Vincenzi et al., 2008), reproductive underperformance at the F2 generation and unusual morphological abnormalities (Fig. 1). Moreover, preliminary results from a egg-to-fry experiment performed in the fish farm for the F1 generation of Gatsnik showed 80.4% of mortality from fertilization to hatching (35.6 29.2% for the remnant populations) (D. Jesensek, pers. comm.). The translocation experiment in Gatsnik is still ongoing and may provide unequivocal evidence of outbreeding effects in 3–4 years. Nevertheless, despite the striking contrast of salmonid species in lifehistory traits may hinder generalizations, what we observed in the marble trout population of Gatsnik urges now further considerations on the opportunity of mixing populations of salmonids to increase their genetic variability. As recently reviewed by Willi et al. (2006), small populations are predicted to have low potential to adapt to environmental changes, as genetic variation and potential response to selection should be positively related to population size. Moreover, individuals in small populations may have lower fitness and be inbred, which may decrease an adaptive response to unpredictable environmental changes. Apart from the obvious cases of overexploitation, pollution and human-induced fragmentation, the small population size and low heterozygosity frequently observed in endemic

Vitale, A., Bailey, D., & Peters, R. L. (2003). *Implementation of fisheries enhancement opportunities on the Coeur d'Alene Reservation: Progress report 1996-1998.* Coeur d'Alene Tribe Fish, Water, and Wildlife Program, Bonneville Power Administration, https://doi.org/10.2172/963013

As part of an ongoing project to restore fisheries resources in tributaries located on the Coeur d'Alene Indian Reservation, this report details the activities of the Coeur d'Alene Tribe's Fisheries Program for FY 1997 and 1998. This report (1) analyses the effect introduced species and water quality have on the abundance of native trout in Coeur d'Alene Lake and selected target tributaries; (2) details results from an ongoing mark-recapture study on predatory game fish; (3) characterizes spawning habitats in target tributaries and evaluates the effects of fine sediment on substrate composition and estimated emergence success; and (4) provides population estimates for westslope cutthroat trout in target tributaries. Low dissolved oxygen values in the hypolimnion of Coeur d'Alene Lake continue to be a cause for concern with regard to available fisheries habitat. Four sample sites in 1997 and eight sample sites in 1998 had measured levels of dissolved oxygen below what is considered optimum (6.0 mg/L) for cutthroat trout. As well, two sample points located north of the Coeur d'Alene River showed hypolimnetic dissolved oxygen deficits. This could lead to a more serious problem associated with the high concentration of heavy metals bound up in the sediment north of the Coeur d'Alene River. Most likely these oxygen deficits are a result of allochthonous input of organic matter and subsequent decomposition. Sediment loading from tributaries continues to be a problem in the lake. The build up of sediments at the mouths of all incoming tributaries results in the modification of existing wetlands and provides ideal habitat for predators of cutthroat trout, such as northern pike and largemouth bass. Furthermore, increased sediment deposition provides additional substrate for colonization by aquatic macrophytes, which serve as forage and habitat for other non-native species. There was no significant difference in the relative abundance of fishes in Coeur d'Alene Lake from 1997 to 1998. Four out of the six most commonly sampled species are non-native. Northern pikeminnow and largescale suckers are the only native species among the six most commonly sampled. Northern pikeminnow comprise 8-9% of the electroshocking catch and 18-20% of the gillnet catch. Largescale suckers comprise 24-28% of the electroshocking catch and 9-21% of the gillnet catch. Cutthroat trout and mountain whitefish, on the other hand, comprise less than 1% of the catch when using electroshocking methods and about 1.4% of the gillnet catch. Since 1994, the Coeur d'Alene Tribe Fish, Water and Wildlife Program has conducted an extensive mark-recapture study (Peters et al. 1999). To date, 636 fish have been tagged and 23 fish have been recaptured. We are finding that northern pike have a tendency to migrate from the original sampling site, while largemouth bass appear very territorial, rarely moving from the site where they were tagged. Both species are most commonly associated with shallow, near-shore habitats, where the potential for encountering seasonal migrations of cutthroat trout is maximized. Low-order tributaries provide the most important spawning habitat for cutthroat trout on the Reservation. The mapped distribution of potentially suitable spawning gravel was patchy and did not vary considerably within reaches or between watersheds. Furthermore, the quantity of spawning gravel was low, averaging just 4.1% of measured stream area. The lack of a strong association between spawning gravel abundance and several reach characteristics (gradient, proportion of gravel and pea gravel) corroborates the findings of other authors who suggest that local hydrologic features influence spawning gravel availability. Although the distribution of spawning substrate was patchy within the target watersheds, there is probably adequate habitat to support resident and adfluvial spawners because of currently depressed numbers. Spawning gravels in target tributaries of the Reservation contained proportions of fine sediments comparable to those in egg pockets of salmonid redds in the Rocky Mountain region. At 23 of 29 sample sites, low levels of fine sediment led to high predictions of overall embryo survival (mean = 28.4%). The estimates of fry production potential at sample sites ranged widely (0.0 to 31.2 fry/100 square meters) due, primarily, to the quantity of suitable gravels present. Only in the mainstem

of Lake Creek were the proportions of both small and coarse fines considered above the levels for these particle sizes (10% and 30%, respectively) shown to adversely affect salmonid emergence success. Of the 6 sites where high levels of small or coarse fines were recorded, only the sites located in the mainstem of Lake Creek showed supporting evidence for low recruitment.

Walker, C. E., & Lister, D. B. (1971). Results for three generations from transfers of pink salmon (Oncorhynchus gorbuscha) spawn to the qualicum river in 1963 and 1964. *Journal of the Fisheries Board of Canada,* 28(5), 647-654. https://doi.org/10.1139/f71-096

Transfers of pink salmon (Oncorhynchus gorbuscha) eggs were made to the Qualicum River in two years, utilizing 5.79 million eggs from Cheakamus River stock in 1963 and 6.85 million eggs from Bear River stock in 1964. Adult returns to the Qualicum River were 100 spawners in 1965, 1967, and 1969; 11,940 in 1966; 3000 in 1968; and 300 in 1970. Differences between the odd- and even-year plants were noted in times of egg-take (equivalent to time of spawning of donor stock), incubation, and fry emigration, lengths of emigrating fry, possibility of losses through predation by herring on estuarine fry, and direction of orientation to the recipient (Qualicum River) stream. Pronounced differences between donor stock in rate of return are thought to be primarily related to differences in spawning times and stream temperature. The decrease in numbers of adults in the even-year generation may have been due to lower freshwater survival during incubation as a result of suspected superimposition of chum salmon on the earlier deposited pink salmon eggs; the loss was estimated to be in the order of 46%.

Wang, I. A., Leder, E. H., Smoker, W. W., & Gharrett, A. J. (2006). Timing of development during epiboly in embryos of second-generation crosses and backcrosses between odd- and even-broodyear pink salmon, Oncorhynchus gorbuscha. *Environmental Biology of Fishes,* 75(3), 325-332. https://doi.org/10.1007/s10641-006-0015-3

Odd- and even-year-spawning pink salmon (Oncorhynchus gorbuscha) are genetically isolated; their broodlines differ even in the same natal stream. Hybrids between broodlines exhibit outbreeding depression in survival. Variation in the time to completion of epiboly in embryos appears to be adaptive in both broodlines. We compared stage of development at a time near the completion of epiboly in families of second-generation offspring from crosses between odd- and even-year broodlines with development stages of within-broodyear controls and of backcrossed families. We observed embryos derived from matings of mature fish that were the results of fertilizations made 2 years earlier of eggs from females from the even brood year with semen from males from the even broodyear and with cryopreserved semen from males of the odd broodyear. The resulting fry had been released to the Pacific Ocean and recovered at maturity. Second generation embryos were produced by factorial matings of these mature fish involving (1) female and male controls, (2) female and male hybrids, and (3) both backcrosses. Analysis of variation of development time detected no effect of outbreeding, i.e., differences between controls and second generation hybrids ($p > 0.05$), but did detect variation between individual female parents ($p < 0.03$). Neither epistatic nor additive outbreeding depression could be detected in the rate of early embryonic development of pink salmon. However, effects on development rate attributable to female parents indicate that either a maternal effect or early additive genetic effects occurred before the expression of the paternal genome in embryos.

Ward, B. R., & Slaney, P. A. (1993). Egg-to-smolt survival and fry-to-smolt density dependence of Keogh River steelhead trout. In *Production of juvenile Atlantic salmon Salmo salar, in natural waters.* R. J. Gibson & R. E. Cutting (Eds.), (pp. 209-217): National Research Council Canada Retrieved from https://www.worldcat.org/title/43475806

The population dynamics of steelhead trout (Oncorhynchus mykiss) in a coastal stream on Vancouver Island, B.C., Canada, have been studied since 1976. Estimates of numbers of spawners, fecundity, potential egg deposition (n = 12 yrs), fry abundance (n = 7 yrs) and parr abundance (n = 2 yrs) provided information on survivorship when combined with smolt counts from brood years. The relationship between eggs and fry (1-month post-emergence) was linear with the exception of 1976, when flows during spring were exceptionally high. Mean egg-to-fry survival was 6.5% (min., 1.8%; max., 11.5%). Mean fry-to-smolt survival was 12.9% (min. 3.3%, max. 21.9%). We conclude that variation in smolt number and size, and thereby in adult returns, is mainly determined at the fry-to-1 + parr stage and thus the production of steelhead trout smolts is highly density dependent.

Weaver, T. M., & Fraley, J. J. (1993). A method to measure emergence success of westslope cutthroat trout fry from varying substrate compositions in a natural stream channel. *North American Journal of Fisheries Management,* 13(4), 817-822. https://doi.org/10.1577/1548-8675(1993)013<0817:AMTMES>2.3.CO;2

This study developed a field method to examine emergence success of fry of westslope cutthroat trout Oncorhynchus clarki lewisi in relation to varying levels of fine substrate materials in a natural stream environment. We attempted to simulate natural incubation conditions in a stream by constructing cells with particle sizes and egg pockets characteristic of natural westslope cutthroat trout redds. We found a significant inverse relationship ($r^2 = 0.72$, $P < 0.005$, $N = 17$) between fry emergence success, as measured by fry emergence traps, and the percentage of substrate materials less than 6.35 mm in diameter. Mean fry emergence success was 76, 55, 39, 34, 26, and 4%, respectively, in cells containing 0, 10, 20, 30, 40, and 50% substrate materials less than 6.35 mm. There were no significant differences in length or weight of fry emerging from the six gravel mixtures. Using the methods and results presented in this study, as well as previous laboratory results, resource managers could develop substrate quality guidelines for westslope cutthroat trout reproduction in streams affected by land management practices.

Weeber, M. A., Giannico, G. R., & Jacobs, S. E. (2010). Effects of redd superimposition by introduced kokanee on the spawning success of native bull trout. *North American Journal of Fisheries Management,* 30(1), 47-54. https://doi.org/10.1577/m08-038.1

Intra- and interspecific competition for spawning space is a commonly observed interaction in salmonids that can result in progeny loss. This study examined the impacts of redd superimposition by kokanee Oncorhynchus nerka on the reproductive success of bull trout Salvelinus confluentus in the Deschutes River basin, Oregon. The activities of high-density spawning groups of kokanee were hypothesized to place the eggs and alevins of bull trout at risk of displacement and damage wherever the spawning habitats of these two species overlap. Bull trout egg pocket depths and kokanee scouring depths were measured. Fry emergence from redds, a proxy for bull trout reproductive success in the presence of kokanee, was compared between superimposed and undisturbed redds by using fry emergence traps. Our results indicate that groups of spawning kokanee did not scour the stream bed deeply enough to

reach bull trout eggs. Data on bull trout fry emergence revealed that kokanee redd superimposition did not affect bull trout egg-to-fry survival rates.

Wertheimer, A. C., & Martin, R. M. (1981). Viability of gametes from adult anadromous coho salmon ripened in an estuarine pen. *Progressive Fish-Culturist,* 43(1), 40-42. https://doi.org/10.1577/1548-8659(1981)43[40:Vogfaa]2.0.Co;2

Because the final maturation of the gametes of Pacific salmon (Oncorhynchus spp.) is usually completed in fresh water, salmon hatcheries are typically designed to hold returning adult salmon in fresh water until they are reproductively mature. In remote coastal areas and at estuarine sites where hatchery-reared salmon are released, construction of freshwater holding facilities can be prohibited by high costs or lack of sufficient fresh water. If returning adults could reach reproductive maturity in nearby marine waters, freshwater holding facilities would not be necessary. The objective of the present study was to determine whether returning adult coho salmon (O. kisutch) could successfully be ripened in an estuarine pen. The effects of holding the fish were determined by evaluation survival of adult fish to reproductive maturity, survival of eggs taken from these fish to the eyed-egg stage of development, and survival of eyed eggs to the emergent-fry stage.

West, C. J. (1978). *A review of the Babine Lake development project 1961-1977.* Fisheries and Oceans Canada, Retrieved from https://publications.gc.ca/site/eng/9.891951/publication.html

In 1962, the Babine Lake Development Project was initiated to provide additional sockeye salmon fry (Oncorhynchus nerka), in order to fully utilize the rearing capacity of the Babine main lake basin. Two spawning channels were constructed at Fulton River and one at Pinkut Creek, with partial river-flow control facilities at each location. Production expectations of Fulton Channel No. 1 have been exceeded. The major producer of sockeye fry is Fulton Channel No. 2. Low egg-to-fry survivals have been experienced in the original Pinkut Creek spawning channel, due to technical difficulties. This channel has recently been rebuilt on improved specifications. Density-dependent factors have prevented increased fry production in Fulton River and in Pinkut Creek. Benefits of partial flow control are derived from the insurance of maintained spawnings and incubation flows and tempered spring freshets. The viability of spawning channel fry is comparable to that of natural fry, and increased fry outputs are followed by increased numbers of smolts. When large numbers of fry are produced, however, the smolt output has been found to be less than anticipated. Reasons for this loss are discussed.

White, L. E. (1980). Evaluation of a new planting device for salmon eggs. *Progressive Fish-Culturist,* 42(3), 177-180. https://doi.org/10.1577/1548-8659(1980)42[177:Eoanpd]2.0.Co;2

In 1977 and 1978, a new planting device for salmon eggs was tested and compared with the conventional shovel method of planting eggs. Both methods were tested in natural stream beds with eyed eggs ofsockeye salmon (Oncorhynchus nerka). The egg-planting device was 3.5 times faster to operate than the shovel method and was less cumbersome. Both methods immediately and significantly reduced fine intragravel material. Survival of eyed eggs to the fry stage was 11.0% for the conventional method and 50.8% for the new egg-planting device. Fry emergence from the conventional plots was earlier and lasted longer than from plots where the egg-planting device was used. The conventional shovel method produced fry that were heavier at emergence than those produced by using the device.

Wickett, W. P. (1958). Review of certain environmental factors affecting the production of pink and chum salmon. *Journal of the Fisheries Board of Canada,* 15(5), 1103-1126. https://doi.org/10.1139/f58-058

The relation between stock and numbers of spawners is obscured by annual environmental changes. Stream discharge at the time the spawners are migrating upstream, at the time when the eggs are in the early stage of incubation, and extreme discharge during the period eggs and alevins are in the gravel can impose an 8-fold variation in the stock resulting from a given number of spawners in one area. Ocean conditions soon after the fry enter the sea have been observed to increase or decrease survival by a factor of 3. The density of spawners that produces the greatest numbers of fry is related to the average permeability of the stream bottom. Preliminary data indicate that more spawners could be used to advantage in most areas of the coast.

Winship, A. J., O'Farrell, M. R., & Mohr, M. S. (2014). Fishery and hatchery effects on an endangered salmon population with low productivity. *Transactions of the American Fisheries Society,* 143(4), 957-971. https://doi.org/10.1080/00028487.2014.892532

We estimated the natural spawner-fry stock-recruitment relationship and juvenile survival rates for Sacramento River winter Chinook Salmon Oncorhynchus tshawytscha in California and used these estimates to examine the expected numbers of spawners and fishing mortality under different fishing mortality rates and levels of hatchery supplementation. A stochastic, age-structured population dynamics model was fit to fry and female spawner abundance data for the years 1996-2010. Estimated survival rates of fry through the end of the first year in the ocean were generally <0.5%. Estimated survival rates of hatchery-origin fish from egg to the end of the first year in the ocean were on average about four times greater than the estimated maximum rate for natural-origin fish. The hatchery program was estimated to increase the number of spawners returning to natural spawning areas and thereby increase the fishing mortality rate that could be sustained. Assessing the past or future net effect of the hatchery on the size of the natural population would require quantifying any potential reduction in the productivity of the natural population as a result of reduced fitness of hatchery-origin fish spawning in natural spawning areas.

Wipf, M. M., & Barnes, M. E. (2012). Parental male effects on landlocked fall Chinook salmon progeny survival. *North American Journal of Aquaculture,* 74(4), 443-448. https://doi.org/10.1080/15222055.2012.681105

The Lake Oahe, South Dakota, population of landlocked fall-run Chinook salmon Oncorhynchus tshawytscha is maintained entirely by hatchery propagation and exhibits relatively poor egg survival during hatchery incubation. This study was undertaken to determine the influence of male gametes on embryo survival. Eggs from an individual female were subdivided and subsequently fertilized with milt from four discrete males. This was repeated with three additional females using the milt from the same four males. This entire procedure was then replicated three times, using four new females and four new males each time, for a total of 16 males and 16 females. The eggs from each unique cross were then incubated discretely. There was no significant effect of spawning males on subsequent embryo survival to the eyed stage of egg development. Swim-up fry length and weight were also not significantly affected by male parentage. In contrast, there was a significant maternal effect on eyed egg survival, and swim-up fry length and weight, which varied significantly among progeny from individual females.

These results suggest that the relatively poor survival exhibited by Lake Oahe landlocked fall Chinook salmon eggs during hatchery incubation is largely a function of initial egg quality from spawning females.

Wissmar, R. C. (2004). *Realities of fish habitat improvements in a developed river.* Paper presented at the 4th World Fisheries Congress, Vancouver, CANADA. Retrieved from https://fisheries.org/bookstore/all-titles/afs-symposia/54049p/

This paper assesses the effectiveness of three created sockeye spawning channels within an intensively managed reach, the Elliott reach of the lower Cedar River near Seattle, Washington. Fish spawning responses and economic benefits and costs were used to examine the effectiveness of new channels areas. The mean female density (1.1 +/- 0.34 female m(2)) for the channels was higher than spawning records for densities (0.23 +/- 0.60 females m(-2)) of surveyed reaches of the main channel of Cedar River. In contrast, fry survival rates (range 1.3-7.0%) in spawning channels were lower than in the river (mean 9.5 +/- 2.5%). High spawning densities in channels, during low-flow and poor cover conditions, contributed to repeated spawning and potential superimposition of eggs and density-dependent egg mortality. Although benefit and cost ratios (range 2.7-13.5) suggest economically effective spawning channels, more complete economic estimates will require better accounting of fixed (e.g., construction) and variable (e.g., salaries and maintenance) expenditures and revised assumptions for determining benefit values of annual fish returns and harvests (commercial and recreational). Recommendations for future spawning channels include improving design specifications for excavating channels, creating habitat characteristics preferred by spawning salmon, implementing long-term monitoring programs, and using available landscape models to prioritize locations of new channels.

Withler, R. E., Clarke, W. C., Riddell, B. E., & Kreiberg, H. (1987). Genetic-variation in fresh-water survival and growth of Chinook salmon (Oncorhynchus tshawytscha). *Aquaculture,* 64(2), 85-96. https://doi.org/10.1016/0044-8486(87)90344-9

Five pairs of paternal half-sib families were obtained from each of six stocks of Chinook salmon (Oncorhynchus tshawytscha) in British Columbia. Life history patterns and size and age at maturity varied among the parental fish used from each stock. The freshwater survival and growth of progeny were monitored under controlled hatchery conditions.

Survival of uneyed eggs, alevins, fry, smolts, and cumulative survival to 125–140 days after ponding differed among stocks and among families within stocks. The overall heritabilities (sire component) of survival at all four developmental stages were less than 0.05. Alevin weight, smolt weight, and growth rate differed among stocks and among families within stocks. The heritability (sire component) of smolt weight ranged from 0.0±0.59 to 0.88±0.72 among stocks, with an overall value of 0.0. The success of selection for smolt weight might be stock-dependent.

Wood, A. T. (2018). *The effects of oxygen variability during early development on the physiology of Atlantic salmon (Salmo salar).* (Ph.D.), University of Tasmania, Retrieved from https://eprints.utas.edu.au/28675/

Variable oxygen availability can challenge the performance and survival of anadromous salmon species from early development in freshwater redds to adult life in the open ocean. Salmon are also a highly

valued aquaculture species, and may face similar hypoxic or hyperoxic challenges in hatcheries and sea cage rearing. This thesis investigates the physiological responses of Atlantic salmon (Salmo salar) early life stages to oxygen variability (hypoxia and hyperoxia) that is typically experienced in natural and aquaculture systems. In particular, the thesis focuses on how oxygen variability during incubation affects developmental trajectories that may cause long-term impacts. Salmon incubating in natural under-gravel redds and aquaculture incubation systems can experience oxygen levels from < 20% to 180% dissolved oxygen (DO; % air saturation). While hypoxia is known to compromise the growth and development of salmon and stimulate physiological processes to improve oxygen uptake rate (Ṁ\(_2\)) or reduce metabolism, it is unclear whether hyperoxia alleviates respiratory stress and leads to improved performance. Across two experiments, we investigated how various hypoxia and hyperoxia levels affected growth, aerobic metabolism and hypoxia tolerance of salmon from fertilisation until yolk-sac absorption. Rearing in hyperoxia had no effect on Ṁ\(_2\) or O\(_{2crit}\), and a negligible effect on growth. On the other hand, salmon incubated in moderate (50% DO) or cyclical hypoxia (100-25% DO daily) grew and developed slower associated with reduced Ṁ\(_2\) and critical oxygen level (O\(_{2crit}\)) prior to the eyed-egg stage. Severe hypoxia (~27% DO) caused nearcomplete mortality and deformities. Thus, during development, salmon appear most sensitive to hypoxia prior to hatching and respond to oxygen limitation by reducing their oxygen demand. There was no evidence to suggest that embryos or alevins compensated for hypoxia via mechanisms to increase oxygen supply. Hypoxia exposure during incubation can permanently affect physiology by altering the developmental trajectory, thereby impacting later life performance. Hypoxia imposes limitations on the aerobic metabolic scope that may be compensated for by physiological modifications that increase the maximum attainable Ṁ\(_2\). We tested how moderate or cyclical hypoxia from fertilisation until the fry stage affected subsequent aerobic performance, hypoxia tolerance and haematology of juveniles reared in normoxia. In addition, aerobic performance was measured following a re-acclimation period of up to 44 days in hypoxia. Hypoxia exposure during incubation had no effect on aerobic performance, hypoxia tolerance or haematology, even following re-acclimation to hypoxia. Overall, acute hypoxia (<13 h) reduced aerobic scope, however acclimation to hypoxia (up to 44 days) increased blood-oxygen carrying capacity and reduced the limitation that acute hypoxia had on aerobic scope. The results of this thesis demonstrate that the effects of oxygen limitation on salmon during hypoxia incubation are most severe between fertilisation and hatching. However, hypoxia incubation did not appear to impact the developmental trajectory of salmon, as there was negligible impact on later life aerobic performance and hypoxia acclimation capacity. I conclude that there may be negligible evolutionary advantages to anadromous salmon modifying their long-term physiological phenotype based on the oxygen levels encountered during incubation in natural redds. However, the considerable hypoxia acclimation capacity of Atlantic salmon can alleviate the limitation that hypoxia has on aerobic performance later in life.

Wood, C. C., & Foote, C. J. (1990). Genetic-differences in the early development and growth of sympatric sockeye-salmon and kokanee (Oncorhynchus nerka), and their hybrids. *Canadian Journal of Fisheries and Aquatic Sciences,* 47(11), 2250-2260. https://doi.org/10.1139/f90-250

Anadromous (sockeye salmon) and nonanadromous (kokanee) Oncorhynchus nerka spawn sympatrically yet appear genetically distinct in a number of rivers in British Columbia. To investigate whether genetic differences are maintained by selection against -hybrid" progeny, we raised pure and reciprocal crosses of Shuswap River sockeye and kokanee under controlled hatchery conditions. Sockeye eggs were larger and survived slightly better than kokanee eggs, regardless of male type, both to the eyed egg stage and as young fry. We observed no differences in survival among cross types during the remainder of the 460

d study. Rate of yolk absorption was similar in pure sockeye and pure kokanee alevins, but significantly faster in alevins sired by sockeye than those sired by kokanee. This indicates a male genetic effect which compensates for the difference in egg size. Hybrid alevins developed differently because egg size is mismatched with the male genotype. Growth rates of fry were significantly more variable within pure kokanee families than within pure sockeye families Hybrid crosses survived as well as pure crosses under the study conditions. However, any progeny resulting from hybrid crosses in nature may sustain higher mortality than those from pure crosses.

Yaripour, S., Kekalainen, J., Hyvarinen, P., Kaunisto, S., Piironen, J., Vainikka, A., . . . Kortet, R. (2020). Does enriched rearing during early life affect sperm quality or skin colouration in the adult brown trout? *Aquaculture,* 529. https://doi.org/10.1016/j.aquaculture.2020.735648

Enriched rearing has been demonstrated to shape the phenotype of hatchery-reared salmonids and improve their post-release survival in the wild, thus having an important applied value in conservation. However, it is unclear if rearing conditions or survival selection during the early life stages induce long-term fitness effects on adult phenotypes. Using a paired full-sib set-up, we investigated the influence of the environmental enrichment at the egg and fry stages on the milt quality and skin colouration of the adult brown trout (Salmo trutta L.). Overall, males had a higher number of skin spots than females. Notably, the total numbers of spots and black spots were significantly lower in fish raised in an enriched environment than in their full siblings reared in a conventional hatchery environment. However, neither sperm motility nor sperm swimming behaviour differed between full sib males reared in different environments. Our results suggest that rearing method may shape the colouration of brown trout, either by ecological carry-over effects or by selective survival during the rearing process. This, in turn, indicates that ecological conditions at early life can have long-prevailing phenotypically plastic or microevolutionary effects on the adult traits of fish. These effects should be taken into consideration to better understand the ecological role of rearing methodology in salmonid conservation.

Zeigler, M. P., Brinkman, S. F., Caldwell, C. A., Todd, A. S., Recsetar, M. S., & Bonar, S. A. (2013). Upper thermal tolerances of Rio Grande cutthroat trout under constant and fluctuating temperatures. *Transactions of the American Fisheries Society,* 142(5), 1395-1405. https://doi.org/10.1080/00028487.2013.811104

The Rio Grande Cutthroat Trout Oncorhynchus clarkii virginalis is the southernmost subspecies of Cutthroat Trout, and as with the other subspecies, stream temperature regulates growth, reproductive success, distribution, and survival. An understanding of the upper thermal tolerance of Rio Grande Cutthroat Trout is important for developing water temperature standards and for assessing suitable habitat for reintroduction and management. Hatch success of Rio Grande Cutthroat Trout eggs was determined under static temperatures. The thermal requirements of fry and juveniles were also assessed under static and fluctuating temperature regimes using the acclimated chronic exposure method. Egg hatch success was 46–70% from 6°C to 16°C but declined significantly at 18°C and 20°C. Maximum growth of fry that were fed to satiation occurred at 15.3°C. The 30-d ultimate upper incipient lethal temperature (UUILT) was 22.6°C for fry and 21.7°C for juveniles. Survival during fluctuating temperature experiments was dependent upon the daily maximum temperature and the daily fluctuation. The upper thermal limits for Rio Grande Cutthroat Trout were lower than those of Rainbow Trout O. mykiss but similar to those of other Cutthroat Trout subspecies. The low UUILT of Rio Grande Cutthroat Trout relative to some salmonids may increase the risk of deleterious effects brought about by

a changing climate, habitat alteration, and sympatric nonnative salmonids, which are known to outcompete Cutthroat Trout at temperatures above the species' optimal range. Daily mean water temperatures near the Rio Grande Cutthroat Trout's optimal growth temperature of 15°C would be suitable for reintroduction of this subspecies. Depending on the daily temperature fluctuation, daily maximum temperatures within reintroduction streams and current habitat should remain at or below 25°C to ensure long-term persistence of a Rio Grande Cutthroat Trout population. This information will aid in establishing water quality standards to protect habitat where the subspecies currently occurs.