The Cohen Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River

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TECHNICAL REPORT 3

Evaluating the Status of Fraser River Sockeye Salmon and Role of Freshwater Ecology in their Decline

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Preface

Fraser River sockeye salmon are vitally important for Canadians. Aboriginal and non-Aboriginal communities depend on sockeye for their food, social, and ceremonial purposes; recreational pursuits; and livelihood needs. They are key components of freshwater and marine aquatic ecosystems. Events over the past century have shown that the Fraser sockeye resource is fragile and vulnerable to human impacts such as rock slides, industrial activities, climatic change, fisheries policies and fishing. Fraser sockeye are also subject to natural environmental variations and population cycles that strongly influence survival and production.

In 2009, the decline of sockeye salmon stocks in the Fraser River in British Columbia led to the closure of the fishery for the third consecutive year, despite favourable pre-season estimates of the number of sockeye salmon expected to return to the river. The 2009 return marked a steady decline that could be traced back two decades. In November 2009, the Governor General in Council appointed Justice Bruce Cohen as a Commissioner under Part I of the *Inquiries Act* to investigate this decline of sockeye salmon in the Fraser River. Although the two-decade decline in Fraser sockeye stocks has been steady and profound, in 2010 Fraser sockeye experienced an extraordinary rebound, demonstrating their capacity to produce at historic levels. The extreme year-to-year variability in Fraser sockeye returns bears directly on the scientific work of the Commission.

The scientific research work of the inquiry will inform the Commissioner of the role of relevant fisheries and ecosystem factors in the Fraser sockeye decline. Twelve scientific projects were undertaken, including:

Project	
1	Diseases and parasites
2	Effects of contaminants on Fraser River sockeye salmon
3	Fraser River freshwater ecology and status of sockeye Conservation Units
4	Marine ecology
5	Impacts of salmon farms on Fraser River sockeye salmon
6	Data synthesis and cumulative impact analysis
7	Fraser River sockeye fisheries harvesting and fisheries management
8	Effects of predators on Fraser River sockeye salmon
9	Effects of climate change on Fraser River sockeye salmon
10	Fraser River sockeye production dynamics
11	Fraser River sockeye salmon – status of DFO science and management
12	Sockeye habitat analysis in the Lower Fraser River and the Strait of Georgia

Experts were engaged to undertake the projects and to analyse the contribution of their topic area to the decline in Fraser sockeye production. The researchers' draft reports were peer-reviewed and were finalized in early 2011. Reviewer comments are appended to the present report, one of the reports in the Cohen Commission Technical Report Series.

Executive Summary

Although changes in marine conditions often play a key role in driving salmon population dynamics, freshwater habitats are also important in how sockeye salmon express their resilience. Watershed processes provide a high level of variability in conditions, which helps salmon express diverse life history tactics, metapopulation structure, and genetic / phenotypic diversity. In Bristol Bay, Alaska the diversity of sockeye salmon has been related to maintaining fish population stability across the region and found to benefit ecosystems (by stabilizing inputs to terrestrial nutrient supplies and food webs), and human communities (by stabilizing catch and reducing the number of fisheries closures).

Fraser River sockeye salmon and its component stocks demonstrate considerable life history diversity. Stocks vary migration according to four adult run timing groups, demonstrate 4 year cycles of abundance, and spend different lengths of time in freshwater / at sea. The abundance of Fraser River sockeye salmon is also dominated by a few large stocks, which co-migrate with many smaller stocks which are often less resilient to environmental stressors. Given this structure in abundance, it is often difficult to maximize both harvest and population diversity. Weak stocks that are the target of conservation are often harvested and become threatened when they co-migrate with the strong stocks that are the target of the fishery. Thus, despite their inherent resilience this co-migration illustrates how sockeye salmon are vulnerable.

This report is focused on evaluating changes in freshwater ecology and its role in recent sockeye salmon declines for the Cohen Commission. This work includes examining the status of sockeye salmon populations and habitats, as well as the impacts of human activities on freshwater habitats (i.e., logging, hydroelectricity, urbanization, agriculture, and mining). Changes in freshwater ecology due to natural and human forces are hypothesized as having three pathways of effects. These pathways include effects on the: (1) quantity and quality of spawning habitats; (2) productivity of nursery lakes for rearing; and/or (3) habitat conditions associated with migration of smolts / adults.

To assess the current status of Fraser River sockeye salmon populations, we have been charged with three tasks: (1) summarizing existing delineations of population diversity into Conservation Units (CUs); (2) evaluating Fisheries and Oceans Canada’s (DFO) methods for assessing conservation

status; and (3) determining the status of Fraser River sockeye salmon CUs. Delineations of Conservation Units were necessary to quantify habitat conditions, analyze landscape level disturbances, and evaluate the relationship between changes in freshwater ecology and changes in productivity. Strategy 1 of the Wild Salmon Policy includes a framework for delineating salmon populations according to three major axes: ecology, life history, and molecular genetics. Using DFO's delineations, we identified 36 Conservation Units (30 lake and 6 river type CUs) within the Fraser River basin. We use four criteria to evaluate alternative methods for assessing conservation status of these CUs: (1) ecological criteria and indicators; (2) approach for setting benchmarks; (3) data needs and availability; and (4) overall feasibility of implementation. No method is ideal across these criteria; DFO's method and two alternatives have different strengths and weaknesses. An alternative to DFO's method was used to summarize conservation status for 25 of 36 CUs; others were not assessed due to insufficient data. Based on the results of the best available assessments, we found that 17 of 36 Conservation Units have a poor population status and are distributed across all timing groups (Early Stuart – Stuart, Takla / Trembleur; Early Summer – Nahatlatch, Anderson, Francois, Taseko, Bowron, Shuswap Complex; Summer – Stuart, Takla / Trembleur; Late – Cultus, Harrison u/s, Lillooet, Seton, Kamloops; River – Widgeon). The status of 11 CUs is unknown.

The majority of Fraser River sockeye salmon populations rear in large lakes for their first year of life. Given our review of available data, measures of freshwater habitat condition are generally not available across many CUs even though Strategy 2 of the Wild Salmon Policy is charged with developing relevant habitat indicators. Given this gap, we developed direct and surrogate landscape level indicators of the quantity and quality of migration, spawning, and rearing habitats for each sockeye salmon lake-type CU using: (1) mapped habitat features we extracted or derived from readily available GIS data, and (2) lake productivity datasets provided to us by DFO. These indicators included: total spawn extent (m), ratio of lake influence to total spawning extent, nursery lake area (ha), nursery lake productivity (estimated smolts / ha), migration distance (km), average summer air temperature across adult migration (ºC), and average spring air temperature at the nursery lake (ºC). Data were not available to describe basic habitat conditions for the river-type CUs.

Given a general lack of information that could be used to reliably define dynamic changes in condition across sockeye salmon spawning, rearing, and migratory habitats we defined habitat "status" as a combination of the: (1) intrinsic habitat vulnerability and (2) intensity of human stressors on those habitats. We used three independent and static indicators to define intrinsic habitat vulnerability for each sockeye salmon freshwater life-stage. These independent indicators are: (1) migration distance; (2) total area of nursery lakes; and (3) ratio of lake influence to total spawning extent. The placement of an individual CU across these dimensions was used to illustrate its vulnerability to watershed disturbances relative to other CUs in the Fraser River basin. The CUs with the greatest relative habitat vulnerability include (i.e., have long migration distances, a low ratio of lake influence to total spawning extent, and a small to moderate nursery lake area): Early Stuart – Stuart, Takla / Trembleur; Early Summer – Bowron, Fraser; and Summer – Mckinley.

To understand the intensity of human stressors on habitats and assess the potential role of freshwater stressors in recent declines of sockeye salmon we compiled and analyzed the best available data describing six categories of human activities which have the potential to affect sockeye salmon: forestry (e.g., forest harvesting activities, Mountain Pine Beetle disturbance, and log storage), mining, hydroelectricity (large scale and run of river power projects), urbanization upstream of Hope, agriculture, and water use. Next, we developed a spatial layer that represented "zones of influence" on core habitats for migration, spawning, and rearing across each Conservation Unit using DFO's sockeye salmon habitat data (e.g., nursery lakes, spawning locations, monitoring sites, and escapement data). We then intersected the stressor layers with our "zones of influence" layer to summarize the intensity of human stresses on each Conservation Unit.

To assess the intensity, spatial distribution, and temporal patterns of forestry related stressors, we examined the level of forest harvesting over time, density of roads and road-stream crossings, and accumulated level of disturbance due to Mountain Pine Beetle (MPB) across sockeye salmon watersheds. We also examined the best available site specific information to qualitatively assess the impacts of log storage in the lower Fraser River. Our findings indicate that the level of forest harvesting within the last 15 years is less than 10% of the area of sockeye salmon watersheds. Drainage areas upstream of lake inlet spawning, tributary spawning, and nursery lakes tend to be more heavily disturbed than the riparian zones adjacent to spawning downstream of lakes or along migration corridors. There is considerable variation in road development across Conservation Units, which tends to be concentrated in areas adjacent to spawning zones downstream of lakes and along migration corridors. The level of MPB disturbance has increased dramatically since 2003, with the level of disturbance being most dramatic in interior Fraser CUs as opposed to coastal CUs whose watersheds are largely absent of ponderosa and lodgepole pine. The intensity of Mountain Pine Beetle disturbance has been very high; up to 90% of the area in some sockeye salmon watersheds. Variation in the intensity of log storage appears to be larger across reaches than across seasons or years within reaches of the lower Fraser River. Based on past studies, the historic intensity of log storage has not appeared to have significant on juvenile salmon.

To assess the effects of mining, we examined the spatial distribution, number, and types of mines occupying sockeye salmon watersheds in the Fraser River basin (e.g., placer mining, gravel mining, industrial mineral production, metal mining, oil and gas production, coal mining, and exploration related to these production activities). The occurrence of mining activity in the watersheds of spawning streams varies substantially across sockeye salmon CUs. Placer mining is the dominant mining activity and appears to have the highest potential to reduce early freshwater survival. However, the data suggest the impacts of mining on sockeye salmon are likely small and difficult to detect because the contrasts among stocks and strength of the effect relative to other factors is low.

To assess the effects of hydroelectricity, we reviewed scientific studies describing the effects of the Bridge/Seton River power project and Alcan's Kemano Project, as well as the spatial distribution of small scale hydroelectric operations across sockeye salmon watersheds. The Bridge/Seton River power project can affect migrations of smolts and adults on the Seton Rivers, but adverse effects have been largely mitigated by changes in flow diversions and operations of the powerhouse. Likewise, the Kemano Project affects water temperature on the lower Nechako River, but a temperature compliance program has been implemented to ensure that water temperatures remain suitable for adult passage. Our findings indicate that the history of interaction between IPPs and sockeye salmon is very short and limited in number and spatial extent.

To assess the effects of urbanization upstream of Urban environments have a relatively small footprint within watersheds and riparian zones that influence sockeye salmon, though urban footprints have the most intense interaction with sockeye salmon migration corridors. The extent of urban development along migration corridors is further illustrated by the human population data which shows a similar pattern of concentration.

To assess the effects of agricultural activities (beyond impacts on water quality), we reviewed the spatial distribution of agricultural lands. Compared to other land uses, agriculture has a relatively small footprint within watersheds and riparian zones that influence sockeye salmon spawning and rearing habitats. Agriculture does, however, have a greater interaction with migration corridors.

To assess the effects of water use, we calculated the total allocation of water, density of water allocation restrictions, and distribution of water licenses across uses for all sockeye salmon water sheds. Not surprisingly, high water demand is associated with the greatest concentrations of people across the Fraser River basin. Migration corridors appear to have the greatest allocation of water through licensing and the greatest density of water allocation restrictions, largely allocated to the agricultural sector. The CUs of the Lower Mainland have the highest water allocations.

Given a lack of experimental design in the way population, habitat, and stressor data have been collected, our ability to test for cause and effect relationships between the freshwater environment and Fraser sockeye salmon declines was limited. As a result, we were only able to use a limited set of quantitative techniques and data summaries to assess the role of freshwater influences.

We used three analytical approaches to gain insights into possible hypotheses about the role of freshwater influences on Conservation Units. First, we developed a series of cumulative stressor tables which: (1) aligned the hypothesized stressors to the relevant habitat types and Conservation Units, (2) scored the relative intensity of and trend in disturbance, and (3) summarized the cumulative level of stress on a Conservation Unit. Second, we plotted the measures of cumulative stress against the indicators of habitat vulnerability to generate bivariate plots for each habitat type and Conservation Unit (i.e., a summary of habitat status). Lastly, we developed a "dashboard" summary of the all data available to describe population status, habitat vulnerability, and freshwater stressors specific to each lake Conservation Units across the Fraser River basin.

We undertook three additional analyses to assess whether freshwater habitat conditions have contributed to the recent declines in Fraser River sockeye salmon. First, we summarized key findings from recent research examining alternative hypotheses for the declines in Fraser sockeye salmon. This understanding was important for prioritizing our analytical efforts and developing testable hypotheses that are consistent with these other studies. Second, we analyzed the habitat and stressor data to test whether they could explain declines in productivity. Lastly, for those habitat and stressor variables for which we had time series data (i.e., forest harvesting, Mountain Pine Beetle disturbance, summer air temperatures across adult migration, and spring air temperatures at nursery lakes) we examined correlations with total salmon and juvenile productivity indices.

Due to our inability to rigorously test for cause effect relationships on survival at key life stages we used a "weight of evidence" to reach a conclusion about significance of the role of freshwater influences, drawing upon the data and analyses conducted through this effort. Using this approach we believe that recent declines in Fraser River sockeye salmon are unlikely to be the result of changes in the freshwater environment. An important piece of evidence in reaching this conclusion is that juvenile survival has remained relatively stable across CUs where data are available, even though there is substantial variation in stressor intensity across CUs.

Despite our belief that recent declines are not likely to be directly linked to deterioration in habitat conditions, the protection of freshwater habitats remains important to the conservation of Fraser River sockeye salmon because they contribute to their overall diversity and resilience. Given this context, our recommendations include:

(1) **To improve our understanding about survival at critical freshwater life stages**, scientists need better estimates of juvenile abundance, overwinter survival, and mortality during smolt outmigration.
(2) **To improve our understanding about population status across Conservation Units,** scientists need more information about the abundance and distribution of small lake and all river CUs.
(3) **To improve our understanding about habitat status across Conservation Units,** scientists need information on habitats monitored in a consistent manner on a regular basis across a larger number of rivers and nursery lakes.
(4) **To improve our understanding about the population level effects of stressors on freshwater habitats,** scientists need more precise estimates of the biological consequences of disturbance as a function of increasing stress.
(5) **To improve transparency in the science and related decision making** scientists, managers, and the public need information that is more accessible and collected in a way that is more integrated across federal and provincial agencies.

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1.0 Context for assessing freshwater ecology of Fraser River sockeye salmon

Sockeye salmon are an icon in British Columbia and an important species for human, marine, freshwater, and terrestrial communities. For human communities they are a cultural cornerstone providing food, social, and ceremonial values to First Nations, while contributing $2.5 to $250 million annually[1] in financial benefits to commercial fisheries depending on abundance of returns on the Fraser (Nelson 2006). For freshwater and terrestrial communities they provide a means of transferring marine nutrients to watersheds that support the production of salmon, other fish, riparian forests, and wildlife (Naiman et. al 2002; Gende et al. 2002; Nelitz et al. 2006).

Sockeye salmon's complex life history and physiology allows them to thrive in vastly different conditions in marine and freshwater environments, and traverse the large distances in between. For centuries sockeye salmon across the north Pacific have had highly variable, but sustained abundance, while responding to changes in these environments (e.g., Gresh et al. 2000; Finney et al. 2000). The ability of sockeye salmon to thrive across such a large range in environmental conditions and stressors has led to their recognition as an inherently resilient species (Hilborn et al. 2003; Healey 2009). Seven attributes contribute to their resilience: multiple, independent reproducing populations, high reproductive capacity, metapopulation structure, high genetic diversity, phenotypic plasticity, variable life history tactics, and opportunistic use of habitat (Healey 2009).

Although changes in marine conditions often play a key role in driving salmon population dynamics, freshwater habitats also play an important role in how sockeye salmon express their resilience at the population level (Hilborn et al. 2003). Watershed processes provide a high level of variability in environmental conditions (e.g., climate, vegetation, stream conditions), which help salmon express diverse life history tactics, metapopulation structure, and genetic / phenotypic diversity that are evident among populations (Bisson et al. 2009). For instance, sockeye salmon populations will vary their life history tactics and physiology in response to differences in migration distances to natal streams, water temperatures on spawning grounds, or rearing conditions in nursery lakes (reviewed by Burgner 1991). In Bristol Bay, Alaska the diversity of sockeye salmon has been related to maintaining fish population stability across the region (Schindler et al. 2010). By analyzing 50 years

[1] Also see Fisheries and Oceans Canada. Commercial salmon landings in British Columbia 1951-1995. Available from: http://www.pac.dfo-mpo.gc.ca/stats/comm/summ-somm/smon/chart-tab/index-eng.htm

of data, variability in sockeye salmon abundance was found to be 2.2 times lower than if the population were defined by the simplest and most dominant life history strategy. Thus, population diversity was found to benefit both ecosystems (by stabilizing inputs to terrestrial nutrient supplies and food webs), and human communities (by stabilizing catch and reducing the number of fisheries closures). This “portfolio effect” has been considered analogous to a financial investment strategy (Schindler et al. 2010), in which the stability of a portfolio (Bristol Bay regional stock complex) is enhanced by the diversity of its assets (river stocks and their individual spawning populations).

Fraser River sockeye salmon and its component stocks demonstrate considerable life history diversity. For instance, stocks vary migration according to four adult run timing groups (early Stuart, early summer, summer, and late), demonstrate 4 year cycles of abundance, and spend different lengths of time in freshwater / at sea. Despite this underlying diversity, the abundance of Fraser sockeye salmon is dominated by a few large stocks (e.g., Quesnel, Adams, and Chilko River runs), which co-migrate with many smaller stocks which are often less resilient to environmental stressors. Given this structure in abundance, it is often difficult to maximize both harvest and population diversity. Weak stocks that are the target of conservation are often harvested when they co-migrate with the strong stocks that are the target of the fishery. As a result, weak stocks can become endangered (see Cultus Lake stock, COSEWIC 2003). Such differences in abundance have also led to a disparity in our level of understanding about different Fraser sockeye salmon stocks and individual populations. We tend to have the best information on the biggest and most economically important stocks.

Despite their inherent resilience, the co-migration of strong and weak stocks on the Fraser illustrates how sockeye salmon can be vulnerable. Since the late 1980s Fraser sockeye salmon have demonstrated dramatic declines in productivity (adult recruits produced per spawner, see Figure 1). In 2009 these declines were punctuated by a return of 1.5 million fish, well below the median pre-season forecast of 10.6 million (DFO 2009) and below the level of productivity at which the population can replace itself in the long term. Complicating our understanding of recent trends, in 2010 Fraser returns totalled approximately 28.6 million fish, well above the median pre-season forecast of 11.4 million (DFO 2010) and representing the highest number of returns on the Fraser since 1913[2]. Both 2009 and 2010 returns were within the statistical distributions of forecasted returns but at opposite ends of these distributions (i.e., < 0.10 probability of being at/or below 1.5 million in 2009; ~ 0.90 probability of being at/or below 28.6 million in 2010).

This report is focused on evaluating changes in freshwater ecology and its role in recent sockeye salmon declines for the Cohen Commission. This specific work includes examining the status of sockeye salmon populations and habitats, as well as the impacts of human activities on freshwater habitats (i.e., logging, hydroelectricity, urbanization, agriculture, and mining). Fisheries and Oceans Canada's 36 Conservation Units form the basis for delineating and assessing the status of sockeye salmon sub-populations in the Fraser River basin (Holtby and Ciruna 2007). Changes in habitats due to natural and human forces are hypothesized as having three potential pathways of effects (mirroring the organization of Section 4.6 in Peterman et al. 2010). These pathways include effects on the: (1) quantity and quality of spawning habitats; (2) productivity of nursery lakes for rearing juveniles; and/or (3) habitat conditions associated with smolt outmigration / adult migration[3]. An integrative consideration of these pathways is valuable because variation in natural conditions (e.g., Burgner 1991; Quinn 2005; Bisson et al. 2009) and human-mediated disturbances (e.g., Meehan 1990; Miller et al. 1997) can interact to affect habitats and ultimately the survival and productivity of salmon.

This work leverages and builds upon a recent and preliminary review of factors that might explain both the low 2009 returns and longer term declines in Fraser River sockeye salmon roughly over the last two decades (Peterman et al. 2010). The evidence in support of nine explanations was examined, which included a consideration of changes in freshwater habitat conditions. For each explanation, researchers attempted to relate changes in the causal mechanism to changes in productivity for 18 sockeye salmon populations. The report did not reach a definitive conclusion, though three key findings are relevant to this evaluation. First, analyses of the indicators of sockeye salmon productivity suggest that recent declines are likely due to mortality in the **post-juvenile stage** or that a non-lethal stressor in the freshwater environment is causing mortality during a later life stage (see Section 3.1.2 in Peterman et al. 2010). Given the timing and location of juvenile sampling for these

[2] Note that pre-season forecasts of abundance are always associated with an estimate of the cumulative probability that the actual number returning will be at or below the forecasted value. In 2009 and 2010, the reported forecasts were associated with a 50% cumulative probability that the actual number would be at or below the forecast level.
[3] Note Hinch and Martins (2011) are evaluating potential changes in freshwater habitat conditions during adult migration.

analyses (i.e., after several months in the lake or at the onset of smolt outmigration), it is possible that the source of mortality could be occurring during smolt outmigration in the freshwater environment. Next, the direction of recent trends and magnitude of declines in productivity varied across stocks. Most of the 18 stocks showed declines (all but Harrison and Shuswap), and the magnitude of decline was greater for those stocks that had the largest distances from the ocean to their nursery lake (see Selbie et al. in Appendix C of Peterman et al. 2010). Differences in the magnitude of decline across stocks was not likely explained by differences in enroute and prespawn mortality during adult migration. Looking across all potential factors, the authors concluded it was unlikely that a single mechanism could explain declines in productivity across stocks. Based on the evidence it seems most likely that changes in the physical and biological conditions in the Strait of Georgia have led to an increase in mortality during marine life stages. Specific mortality agents include lack of food, freshwater and marine pathogens, harmful algal blooms, and other factors. Given the level of rigour and thoroughness of Peterman et al. (2010), we believe that our conclusions need to be compared with their findings, and if contradictory, need to be supported by a defensible scientific rationale.

The statement of work for this project (see Appendix 1) asked us to examine and evaluate four topics each of which form a focal objective for our work:

(1) the population and habitat status of 36 sockeye salmon Conservation Units (CUs) within the Fraser;
(2) Fraser River sockeye salmon ecology and survival in freshwater environments;
(3) industrial and urban activities in the Fraser River and their potential effects; and
(4) the impacts of surface water and groundwater diversions on Fraser River sockeye salmon.

To address these objectives, the remaining discussion is divided into five sections:

<u>Section 2.0 Current status of Fraser River sockeye salmon</u> sets the context for understanding the role and influence of human stressors in the freshwater environment by describing the current status of populations and habitats across all sockeye salmon Conservation Units in the Fraser River basin (addressing Objective 1).

Section 3.0 Freshwater stressors affecting Fraser River sockeye salmon describes the potential mechanisms of impact and results from our examination of the evidence about the potential role of each stressor in contributing to recent sockeye salmon declines (addressing Objectives 3 and 4).

Section 4.0 Freshwater influences on Fraser River sockeye salmon analyzes the findings from Sections 2.0 and 3.0 to assess the significance of these issues (addressing Objective 2). We use qualitative and quantitative analyses to explain the trends and status within each and across all Conservation Units (to the extent possible). Due to limitations in data and time availability, we focused our analyses on understanding landscape level changes in habitat conditions and human stressors as opposed to the detailed cause-effect relationships influencing each Conservation Unit.

Section 5.0 State of the science provides a brief summary of the state of knowledge and data available to describe populations, habitats, and freshwaters stressors in the Fraser River basin.

Section 6.0 Recommendations summarizes the main findings of this work and the implications for Fraser sockeye salmon.

Figure 2 presents a conceptual model showing how human and natural factors can mitigate the effects of potential stressors on freshwater habitats, and places this report in context with the work of other experts working for the Cohen Commission. Section 2.2 of this report develops various indicators to describe the pink box in Figure 2 (i.e., indicators of habitat quantity and quality, which affects the vulnerability of watersheds to natural and human disturbances). We acknowledge that contaminants (MacDonald et al. 2011), diseases and parasites (Kent 2011), habitat conditions in the lower Fraser River and Strait of Georgia (Johannes et al. 2011), and changes to in-river conditions leading to en route loss and pre-spawn mortality (Hinch and Martins 2011) might be acting independently, cumulatively, or synergistically with the stressors considered herein. Consequently, this report provides only a partial understanding of the influence of freshwater habitat conditions on productivity of Fraser River sockeye salmon. A separate research project has been tasked with investigating the full range of environmental conditions and stressors across both freshwater and marine life stages to assess the cumulative and synergistic effect of environmental conditions and human stressors on Fraser River sockeye salmon (see Marmorek et al. 2011).

2.0 Current status of Fraser River sockeye salmon

2.1 Populations

2.1.1 Background on assessing status

We have been charged with three tasks related to evaluating the current status of Fraser River sockeye salmon populations:

(1) Summarize existing delineations of population diversity;
(2) Evaluate DFO's methods for evaluating sockeye salmon conservation status; and
(3) Determine status of Fraser River sockeye salmon CUs.

Our first task is to summarize existing delineations of the population diversity inherent within Fraser River sockeye salmon. These delineations are necessary to form the basis for summarizing habitat conditions (Section 2.2), analyzing landscape level disturbances (Section 3.0), and evaluating the relationship between changes in freshwater ecology and changes in biological production (Section 4.0). Strategy 1 of DFO's Wild Salmon Policy (DFO 2005) deals with standardized monitoring of wild salmon status, including a framework for delineating and assessing the conservation status of salmon populations. DFO delineated individual salmon stocks as Conservation Units (CUs), determined using three major axes: ecology, life history, and molecular genetics (see Holtby and Ciruna 2007). We use DFO's delineations of CUs to define the spatial boundaries for all sockeye salmon stocks within the Fraser basin (see Figure 3 and Table 1). However, it should be noted that the delineation of the CU boundaries put forward by DFO have not been subject to the peer review process in the traditional sense of the term. It is our understanding that CU delineation will be independently evaluated in the near future.

Our second task is to evaluate the method that DFO has developed for assessing CU status. Action Step 1.2 of the Wild Salmon Policy requires DFO to develop criteria to assess CUs and identify benchmarks to represent biological status. Two technical reports summarize the method that DFO has developed (Holt 2009; Holt et al. 2009). There are a variety of published methods on how to assess a species' conservation status, (e.g., Musick 1999; Mace et al. 2002; Dulvy et al. 2004; Faber-Langendoen et al. 2009), including applications to sockeye salmon (e.g., COSEWIC 2003; 2006; Rand 2008; Pestal and Cass 2009). For this task we compare DFO's approach (Holt 2009; Holt et al. 2009) to two alternative methodologies: one developed for Fraser River sockeye salmon (Pestal and

Cass 2009); and a generic approach (NatureServe) which can be tailored for different species (Faber-Langendoen et al. 2009). We were asked by the Cohen Commission to review the qualitative method proposed by Pestal and Cass (2009) because, similar to that of Holt 2009, the method explicitly takes uncertainty into consideration. We chose to include the NatureServe method in our assessment because of its popularity and ease of use. In particular, we were interested in knowing whether a more generic approach that was less resource intensive (from a technical perspective) was comparable to the two methods developed specifically for salmon. We did not consider additional methods beyond the three listed because of budget and time constraints.

Each method will have different strengths and weaknesses (e.g., Porszt 2009). We use four considerations to summarize the details underlying each approach (see Table 2): (1) ecological criteria and indicators used for assessing conservation status (i.e., measures describing abundance, trend, distribution, diversity, productivity, fishing mortality, and habitat condition); (2) approach for setting benchmarks; (3) data needs and availability; and (4) feasibility of implementation. We then summarize the overall strengths and weaknesses of each method.

Our third and final task is to determine the status of sockeye salmon CUs within the Fraser River basin, or where infeasible due to information gaps provide a logical grouping of status with representative CUs. DFO has not yet published a status assessment of Fraser sockeye salmon using the method developed for the Wild Salmon Policy by Holt (2009) and Holt et al. (2009). To our knowledge, the only assessment of Fraser sockeye salmon CUs was completed by Pestal and Cass (2009), using two dimensions (severity of risk and uncertainty of information) to describe status. They also used several quantitative measures (i.e., abundance, trend, and distribution relative to benchmarks) to separate CUs into five risk categories: UNK – insufficient information; IV – status probably poor, but little information; III – status poor, high confidence; II – status probably good, high uncertainty; and I – status good, high confidence.

We use the work of Pestal and Cass (2009) to summarize existing status rankings for all 36 CUs (see Table 1 and Figure 4). To assist in our overall evaluation of Fraser sockeye salmon, Table 1 also relates the 36 CUs to the 18 stocks for which there are productivity data (as analyzed in Peterman et al. 2010). In cases where we have evidence suggesting that these status rankings may be inappropriate, we've summarized in the last column of Table 1 the direction and magnitude of the change. Changes to the severity score for each CU, as determined by Pestal and Cass 2009, are based on the work of Grant et al. (2010) (see Table 1).

Grant et al. (2010) builds on Holt et al. (2009) and is still under review. As a result, we do not include it in our evaluations of CU status. However, the work of Grant et al. (2010) is useful for our purposes because they determined status of all Fraser River sockeye salmon CUs, thus providing a point of comparison with Pestal and Cass (2009)[4]. Key differences in these methods are that Grant et al.'s assessment is only based on indicators of abundance and trends in abundance, whereas Pestal and Cass (2009) also used fishing mortality and distribution in their assessment. As a result, comparing these two approaches is best restricted to common indicators, namely abundance and trends in abundance.

2.1.2 Evaluation of status methodologies

Before discussing the results of the status methodology evaluation, it is useful to make note of what each method is intending to communicate (i.e., how they define status and hence what a particular outcome means). Doing so provides an additional filter through which we can evaluate each method, i.e., is the definition of status by which a given method evaluates conservation status appropriate for Wild Salmon Policy purposes. The primary purpose of the NatureServe Conservation Status Assessments is to evaluate the potential extinction or extirpation risk of elements of biodiversity, including regional extinction or extirpation. Pestal and Cass (2009) evaluate conservation status using a combination of status (abundance (production) and trends in abundance) and vulnerability (productivity, diversity, fishing mortality, and distribution) risk factors. Holt et al. (2009) assess biological status using four classes of indicators, abundance (i.e., production), trends in abundance, distribution, and fishing mortality. The latter two methods are based more on population abundance and trends as per their definition of status than the NatureServe method. However, Holt et al. (2009) assessment of status is more heavily based on population biomass reference points than that of Pestal and Cass (2009)

Ecological relevance: A comprehensive list of indicators and their respective metrics for each of the three methods is provided in Table 2. We categorized indicators into seven indicator classes:

[4] Holt et al. (2009) did not determine status for Fraser sockeye CU so it is not possible to directly compare their assessment of status to that of Pestal and Cass (2009).

abundance, trends in abundance, distribution, diversity, productivity, fishing mortality, and habitat condition. Holt et al. (2009) explicitly includes indicators from four of the seven classes, Pestal and Cass (2009) includes indicators from all seven classes, while Faber-Langendoen et al. (2009) includes indicators from six of the indicator classes (see Table 3).

The number of indicator classes within an assessment method, although important, does not necessarily correlate with the strength/validity of a method. There is a trade-off between too many and too few indicators. Using fewer indicators produces clearer recommendations, whereas use of multiple indicators produce more consistent evaluations (Pestal and Cass 2009). In addition, it may not be important to explicitly capture each indicator class. For example, Holt et al. (2009) do not include metrics for all components of diversity (i.e., habitat, genetic, ecological), but they do have distribution metrics that may be used as surrogate measures of that diversity (e.g., distribution of spawners among habitat types, distribution in temporal trends). Given the logistic and financial constraints around data collection it is important to consider the use of surrogate indicators where feasible and appropriate.

The metrics associated with each indicator are very important; they determine a method’s ability to appropriately assess conservation status in accordance with management priorities. Holt et al. (2009) and Pestal and Cass (2009) developed metrics that reflect the unique life history of sockeye salmon, while Faber-Langendoen et al. (2009) use more generic metrics that are applicable to a wide array of animals. As a result Holt et al. (2009) and Pestal and Cass (2009) are better able to capture conservation status of Fraser River sockeye salmon and CU specific vulnerabilities than Faber-Langendoen et al. (2009). Both Holt et al. (2009) and Pestal and Cass (2009) have good representation of the various indicator classes. One advantage of the approach taken by Pestal and Cass (2009) is that it explicitly considers habitat condition. This allows the method to be more proactive in its management applications (i.e., management actions related to poor habitat quality can be implemented before the poor habitat condition translates into a population effect).

On a separate note, Grant et al. (2010) do not include distribution metrics in their assessment method. In our opinion this is a substantial oversight because Fraser River sockeye salmon conservation status and population viability within a CU is a product of spatial distribution, habitat condition, and abundance, not population abundance in and of itself. Furthermore, there is a possibility that assessments carried out using Grant et al.'s (2010) method in it current version may become irrelevant or outdated following a COSEWIC assessment, which would weigh distribution indicators heavily in its evaluation of status.

Approach for setting benchmarks: Faber-Langendoen et al. (2009) take a qualitative approach to setting benchmarks which is not consistent across metrics or across evaluation units (in this case CUs). The method uses points along a continuum of extinction risk, rather than break points and thresholds. All metrics are on a scale of 0 to 5.5, with equal contribution to an aggregate score; however different metrics may have different numbers of increments within the 0 to 5.5 scale. Another inconsistency that can arise across CUs is that metrics within indicator classes are weighted differently (see Table 8 in Faber-Langendoen et al. (2009)) as are the indicator classes themselves. The method has no rules that can be applied across CUs to standardize the assessment process which has the potential to result in inconsistent CU evaluations (i.e., each CU is evaluated using different metrics, benchmarks, and weightings).

Pestal and Cass (2009) take a qualitative approach to setting metric specific benchmarks; however they employ clear and consistent rules for benchmark setting and indicator roll-up across all CUs to ensure that results are comparable. In addition, benchmarks are based in part on the magnitude of uncertainty in observed spawner data. As a result the method for setting benchmarks is defensible and transparent. A major advantage of the qualitative approach is that it is not as data intensive as the quantitative approach taken by Holt et al. (2009). Consequently, benchmarks for each metric can be set for all CUs irrespective of data availability. Despite these more modest information requirements, 11 of 36 Fraser sockeye salmon CUs still did not have enough information for risk characterization (Figure 4).

Holt et al. (2009) take a quantitative approach to setting benchmarks for abundance and trends in abundance metrics, but take a similar approach to Pestal and Cass (2009) for distribution metrics. Concrete benchmarks for distribution metrics have yet to be finalized by DFO. Where the quantitative approach is taken, uncertainty in the data is explicitly incorporated into benchmark using Monte Carlo simulations, thus making them robust and defensible.

Data needs: A list of data required by each assessment method is provided in Table 2. The method developed by Holt et al. (2009), and by extension Grant et al. (2010), is the most data intensive. Consequently, it was not possible to evaluate a number of CUs with this method because of insufficient data. Pestal and Cass (2009) and Faber-Langendoen et al. (2009) are not as data intensive. It was possible to evaluate conservation status for a greater number of CUs using Pestal and Cass's method (CUs were not evaluated using Faber-Langendoen et al. (2009)). In general, there are few data on spatial distribution of Fraser sockeye salmon and habitat condition within a CU; this affects all assessment methods to some degree.

Feasibility: By feasibility we mean the ability to effectively implement a conservation assessment method. Both Pestal and Cass (2009) and Holt et al. (2009) are robust methods that are scientifically defensible. They are both geared specifically towards salmon. However, they differ substantially in their feasibility of implementation given DFOs current operating budget and resources (i.e., personnel, historical data availability, monitoring capacity, etc.). We believe that in the short term it's more feasible for DFO to implement the method of Pestal and Cass (2009) than to use the approach of Holt et al. (2009). This conclusion simply reflects the more qualitative nature and less stringent data requirements of Pestal and Cass (2009). Should DFO acquire the necessary resources and capacity to collect the information required by Holt et al.'s method, it would be logical to to switch to this more quantitative and rigorous method. From a management perspective, it is better to have qualitative assessments for many CUs (i.e., Pestal and Cass 2009), than to have very few CUs assessed due to data limitations (i.e., Holt et al. 2009). It is possible that elements of Pestal and Cass (2009) could be incorporated into Holt et al. (2009) to address data poor CUs.

Conservation Status: Of the 36 Fraser River sockeye salmon CUs, conservation status could not be assessed by Pestal and Cass' (2009) in 11 of 36 cases because of insufficient data, resulting in an uncertainty score of 10 (maximum value) for each of these CUs (see Figure 4). The two sockeye salmon management groups with the highest level of uncertainty in the data (are early summer (ES) and river-type sockeye salmon (see Table 1). As previously mentioned, Holt et al. (2009) did not assess conservation status for any CU; however, Grant et al. (2010) did a partial assessment of status for 26 CUs using information on abundance and trends in abundance.

Combining the work of Pestal and Cass (2009) and Grant et al. (2010), we recommend modifying the severity score (i.e., condition of the population) for 9 CUs (see Table 1). The difference between the modified severity score and the original provided by Pestal and Cass (2009) is graphically illustrated in Figure 5. All modifications are relatively minor and consist of moving the severity score up or down by half a point. In no cases does the modification alter the severity category (i.e., quadrant) in which the CU was classified. A more structured and analytical comparison of the two methods (i.e., Holt et al's (2009) method to that of Pestal and Cass (2009)) would be very useful to DFO for WSP implementation because it would allow them to see the extent to which the methods provide similar results and they could then evaluate the tradeoffs between the two. However, this would only be worthwhile if DFO is planning to move forward with Holt et al's (2009) method. If Grant et al's (2010) modified method is favoured over that of Holt et al. (2009), the rigorous comparison should take place between Grant's and Pestal and Cass' methods.

2.2 Habitats

The majority of Fraser River sockeye salmon populations rear in large lakes for their first year of life. Because their rearing lakes are generally large, they are considered to be more buffered from impacts compared to small streams and rivers that are used by other salmon species. However, most of the total egg-adult mortality in sockeye salmon occurs in the freshwater stage of the life cycle. Bradford (1995) estimated that 58% of the total mortality occurred in the natal spawning and rearing areas, and there is additional mortality during migration from natal lakes to the ocean (Welch et al. 2009). Consequently, there is potential for impacts on sockeye salmon populations from development activities (e.g., logging, road construction, dams, etc.) if they significantly affect the quantity or quality of lake, stream, or river habitats used by different life stages.

As most sockeye salmon populations are associated with lakes this can lead to isolation, highly specialized adaptations, and a stronger degree of population genetic differentiation than is found in other Pacific salmon (Burgner 1991; Wood 1995). Although lake-type sockeye salmon populations can be enormously productive these specialized habitats may also be vulnerable to environmental changes, which could move them beyond the range to which local populations are especially well adapted (Waples et al. 2009). Conversely, river-type sockeye salmon are more generalized in their habitat requirements and only weakly differentiated by genetic markers (Wood 1995; Wood et al. 2008). Being highly specialized, there have been suggestions that lake-type sockeye salmon populations could be considered evolutionary dead ends (Wood 1995; 2007; Wood et al. 2008). Though relatively rare, river-type populations are more likely to stray from their natal stream to spawn and colonize new habitats (but see Pavey et al. 2007). While this flexibility would indicate that river-type sockeye salmon could be important in conferring some greater overall resilience to the species as a whole, there is unfortunately little information available on the status of Fraser river-type populations (i.e., status only available for Widgeon and Lower Fraser CUs in Pestal and Cass (2009)) or the condition of their river habitats (Birtwell et al. 1987; M. Bradford, Fisheries and Oceans Canada, pers. comm.).

For lake rearing sockeye salmon, measures of freshwater habitat condition are often not currently available or can be difficult to directly and reliably quantify (J. Hume and D. Selbie, Fisheries and Oceans Canada, pers. comm.), even though Strategy 2 of the Wild Salmon Policy is charged with developing relevant habitat metrics. For example, it may be possible to define the extent of potential spawning reaches but it is more difficult to define actual quality of spawning substrates. To assist our evaluation of freshwater ecology we developed direct and (where required) surrogate landscape level indicators of the quantity and quality of migration, spawning, and rearing habitats for each sockeye salmon lake-type CU using: (1) mapped habitat features we extracted or derived from readily available GIS data, and (2) lake productivity datasets provided to us by Fisheries and Oceans Canada. Data were not available that could be used to reliably describe basic habitat conditions for the six river-type CUs.

Migration: We determined the migration route and distance for each sockeye salmon lake CU by developing a connected hydrology network that allowed us to trace a path from the outlet of each CU's nursery lake to the mouth of the Fraser River. We also defined a 1 km buffer along each migration corridor to represent the "zone of influence" within which we could assess the extent of human stressors. While this 1 km distance is arbitrary, we selected this buffer width to ensure that we capture the most important potential stressors within the riparian zones of both small and large rivers. This buffer width is substantially larger than the distance (typically less than 30 m) used to protect riparian zones of small streams from the effects of forest harvesting across the Pacific Northwest (Young 2000; Stalberg et al. 2009). We used a significantly larger width to ensure that that we captured the effect of activities that have a longer spatial extent than forest harvesting, and to ensure that we captured the effects of riparian disturbance along large rivers, such as the Fraser.

Spawning: We defined sockeye salmon spawning areas within each CU using GIS depictions of spawning extent that are available from the government-maintained Fisheries Information Summary System (FISS). Expert opinion and knowledge of spawning areas then allowed us to assign reaches according to whether they were lake influenced (lake outlet / large mainstem) or not (lake inlet / tributary stream). We used GIS to delineate “zones of influence” for these two types of spawning reaches. For lake inlet / tributary reaches we defined the extent of upstream influence by delineating the total area of the local watershed upstream of the spawning reach. Such tributary stream spawning habitats can be exposed to a variety of human land use impacts immediately adjacent to spawning sites and/or from the more cumulative effects of activities upstream of the spawning zone occurring within the local watershed (Harr and Fredriksen 1988; Hicks et al. 1991; Stednick and Kern 1994). Impacts of land use on spawning habitat are reduced by the presence of a lake upstream of a spawning area because lakes act as sediment traps, reduce flow variation, and reset temperatures in their outlet streams (Arp et al. 2006; Myers et al. 2007; Jones 2010). By contrast, lake outlet / mainstem spawning reaches were considered buffered from upstream effects and the “zone of influence” for these was described simply as the area within a 1 km buffer along either bank of the spawning reach.

Rearing: We identified all nursery lakes within each CU and calculated their combined total area using GIS. We also defined the upstream “zone of influence” by delineating the area of all watersheds upstream of each CU’s nursery lake. Sockeye salmon nursery lakes, with larger dilution volumes and more varied habitat, can better buffer sockeye salmon from land use impacts during rearing, relative to streams (Selbie et al. 2010). Nursery lake habitats will not be completely immune to broader landuse impacts, however, and human activities upstream of the nursery lake(s) may have cumulative effects on lake conditions (Anderson 1974; Klock 1985).

The resulting “zones of influence” on migration, spawning and rearing areas were used as the base layers for calculating the specific indicators of habitat conditions (Table 4) and against which to intersect the human stressor layers so as to understand the potential interactions between human activities and these habitats (see Section 3.0). Table 5 presents data on these indicators for all lake CUs. The sections that follow describe the biological relevance of the individual habitat indicators.

2.2.1 Indicators of migratory habitat quantity / quality

Migration distance: Lengthy migrations can increase stress and the exposure to pre-spawning mortality factors of adult sockeye moving upstream (Crossin et al. 2004), or plausibly affect mortality of smolts during downstream migration or fitness once they reach the ocean. The relationship found by Selbie et al. (in Peterman et al. 2010) suggests that there may be an underlying biological mechanism related to upstream or downstream migration that is differentially affecting survival of sockeye salmon stocks across the Fraser basin (beyond changes in en-route mortality). For instance, migration distance is related to migration timing (i.e., earlier timing required to cover longer distances) and the length of time spent in freshwater (i.e., stocks with longer migrations will have a larger chance of exposure to harmful stressors, including diseases, parasites, contaminants, and high water temperatures). We used migration distance as a surrogate for these more direct biological indicators given the relationship found by Selbie et al. (in Peterman et al. 2010) and because we could measure migration distance consistently across all CUs.

Thermal profile of adult migration (°C): Adult spawning success may be affected by water temperatures encountered during migration. High water temperatures can increase fish energy expenditures, increase the progression of diseases and parasites, and decrease fecundity of eggs (Crossin et al. 2008). Fisheries and Oceans Canada suggests that Fraser River water temperatures above 18-20^{o}C can degrade spawning success, while water temperatures above 24^{o}C can be fatal[5]. Although water temperature is largely driven by natural processes it can be influenced by activities such as riparian clearing, water withdrawal and diversion, logging, and other changes to land cover (Poole and Berman 2000), as well as global warming (Martins et al. 2011). Given the well known and strong relationship between water and air temperatures (Stefan and Preud'homme1993; Poole and Berman 2000; Morrison et al. 2002; Cooke et al. 2008; Voss et al. 2008) we used mean summer/fall air temperature as a surrogate indicator of the quality of the migratory corridor during the period of adult migration. We identified the migration dates for the run-timing group (see Table 6) associated with each CU and calculated the average monthly air temperatures that each CU would have experienced during their upstream migrations (both for the full historical time series and also for the more recent average temperature beginning in 1985).

[5] Fisheries and Oceans Canada. Predicting the Temperature of the Fraser River. Available from: http://www.pac.dfo-mpo.gc.ca/science/oceans/fleuve-Fraser-river/index-eng.htm

Thermal trigger for smolt outmigration (°C): Research has shown that the timing of smolt outmigration can have an important influence on the survival of juvenile salmon to adulthood (Scheuerell et al. 2009). The belief is that changes in timing of smoltification can lead to a mismatch between the timing of arrival at the estuary and the timing of other conditions (e.g., food supply) which ultimately affects survival. Like all life history transitions, sockeye salmon smolts are cued to migrate towards the ocean in response to changing environmental conditions, which includes responding to day length, lake springtime temperatures (related to the timing of ice break-up in nursery lakes), and springtime peak flows (Foerster 1937; Burgner 1991; Quinn 2005). Not surprisingly these variables are strongly associated with local climate conditions and geographic location of the nursery lake, such that more northern and colder nursery lakes tend to have later migration dates (see Figure 6A). Moreover, within a nursery lake, the timing of outmigration is affected by year to year variations in climate conditions (see Figure 6B). Given this relationship, and the known link between air temperatures and lake water temperatures (Sharma et al. 2008), we used springtime air temperature as an indicator of the timing of ice break-up in nursery lakes (one of the cues of smolt outmigration). We used this indicator as a surrogate of the potential for mismatch between the timing of arrival at the estuary and timing of other conditions in the estuary, not a direct measure of the magnitude of mismatch. Our hypothesis is that if lake ice breaks up significantly earlier than experienced historically, there is potential for earlier smolt outmigration and greater potential for a mismatch. A consideration of the changes in spring time temperatures at nursery lakes seems justifiable given evidence that the timing of ice break up on lakes in Canada is becoming earlier (IceWatch no date).

2.2.2 Indicators of spawning habitat quantity / quality

Total spawning extent (m) and ratio of lake influence to total spawning: The total length of stream spawning habitat available to sockeye salmon will determine the scope of opportunities for successful spawning (longer length is better), while the ratio of lake-buffered outlet spawning to tributary/inlet spawning can indicate the degree of sensitivity to upstream impacts (higher ratio is better). Lakes stabilize discharge by buffering flood effects, thereby reducing stream bank erosion and bedload movement compared to streams with more variable discharge regimes (Montgomery et al. 1996). Thus, spawning habitat quality and egg-to-fry survival should be less affected by disturbance in spawning channels buffered by lake influences than in small, non-lake moderated tributaries (Chapman 1988; Northcote and Larkin 1989; Montgomery et al. 1996). Sockeye salmon also spawn along lake shores but mapping of the location and extent of these spawning zones is fairly limited (Stalberg et al. 2009; Brad Mason, Fisheries and Oceans Canada, pers. comm.). However, lake spawning is considered of relatively minor importance (except for Cultus Lake) with most sockeye salmon populations in BC spawning within streams (Roberge et al. 2001).

2.2.3 Indicators of rearing habitat quantity / quality

Nursery lake area and productivity (measured and estimated): The Fraser River is the world's largest single producer of sockeye salmon, being surpassed only by the combined sockeye salmon production from several river systems flowing into Bristol Bay in Alaska (Northcote and Larkin 1989). The Fraser system's exceptionally high productivity is due to the presence of many large lakes (66% of B.C.'s nursery lake area) that are accessible to anadromous fish (Hume et al. 1996; Shortreed et al. 2000). Further, most of these lakes are sufficiently productive to sustain a zooplankton community considered capable of supporting high juvenile sockeye salmon densities (Stockner and Shortreed 1983). It is generally assumed that most Fraser sockeye salmon stocks are recruitment limited (Hume et al. 1996; Shortreed et al. 2000) with freshwater rearing habitats often capable of supporting juvenile sockeye salmon densities far higher than presently occur (i.e., a greater number of spawning escapements would produce additional smolts)[6]. However, most BC nursery lakes are naturally oligotrophic or even ultra-oligotrophic (Stockner and Shortreed 1994) and strongly nutrient-limited (Shortreed et al. 2000). Consequently the continued long term reduction in marine-derived nutrients from anadromous spawner carcasses has likely resulted in the further oligotrophication of lakes and streams, with a corresponding reduction in their productive capacity (Shortreed et al. 2001).

Juvenile sockeye salmon production from nursery lakes can be measured directly either from smolt counts (i.e., from counting fences) or from counts of summer and fall fry (i.e., based on pelagic fish surveys using hydroacoustics and midwater trawling, J. Hume, Fisheries and Oceans Canada, pers. comm.). Long-term time series data exists only for Chilko Lake (smolts), and Quesnel and Shuswap lakes (fry), with limited fry data existing for another 13 lakes (J. Hume, Fisheries and Oceans Canada, pers. comm.). Sockeye salmon fry are almost exclusively linmetic plankitivores, however, so they are strongly coupled to limnetic zooplankton production (Shortreed et al. 2000). Given their

[6] Though we also acknowledge an opposing density dependent hypothesis which suggests that escapement may already be too high in some rivers (see Section 4.7 in Peterman et al. 2010).

use of lake habitats, it is possible to estimate the quantity and quality of sockeye salmon rearing habitat in BC from lake size and measures of lake productivity such as photosynthetic rate (PR) (Hume et al. 1996; Shortreed et al. 2000). Lake area is also considered a reasonable surrogate of habitat productivity since it is a primary driver in productivity relationships (Randall 2003). While fry models provide a direct estimate of rearing capacity, many years of data are required to generate a relationship for any lake. The PR model appears to be a useful predictor of rearing capacity, and predictions can be made after only 1–2 years (Hume et al. 1996). PR-based estimates of productivity have been proposed for habitat benchmark setting within DFO's Wild Salmon Policy (Stalberg et al. 2009; D. Selbie, Fisheries and Oceans Canada, pers. comm.). Correlations between PR and juvenile sockeye salmon abundance can be used to estimate the maximum capacity of a nursery lake to produce smolts (biomass and numbers), as well as estimate optimum escapement (Shortreed et al. 2000). At least one year's PR data now exists for 19 sockeye salmon nursery lakes in the Fraser drainage (J. Hume, Fisheries and Oceans Canada, pers. comm.) representing about 80% coverage of all Fraser nursery lakes. Smaller sockeye salmon nursery lakes (such as Taseko, Nahatlach, and McKinley) have not been evaluated because of funding constraints and the prioritization of evaluations towards lakes which produce more sockeye salmon (J. Hume, Fisheries and Oceans Canada, pers. comm.). Given the broader availability of juvenile production estimates based on PR vs. direct monitoring we have used DFO's PR-based estimates as a comparative measure of juvenile productivity across sockeye salmon CUs.

2.2.4 Integrated summary of habitat vulnerability

Given a general lack of information that could be used to reliably define dynamic changes in condition across sockeye salmon spawning, rearing, and migratory habitats we defined relative sockeye salmon CU habitat "status" as a combination of the: (1) intrinsic habitat vulnerability (see below) and (2) intensity of human stresses on those habitats (Section 3.0). With our approach, a CU that was considered highly vulnerable (relatively more sensitive) to potential habitat impacts, while also exposed to relatively high human development pressures within its spawning, rearing and/or migratory habitats, would be considered as having a *relatively poor* habitat status. Conversely, a CU with limited vulnerability (relatively less sensitive) and relatively little human development pressure would be considered as having a *relatively good* habitat status. **We stress that these are only relative indices.** Even those CUs considered to have relatively *poor* habitat status by the above procedure may not have any demonstrated actual negative impacts of human stressors on sockeye salmon freshwater survival.

To determine intrinsic habitat vulnerability, we believe reporting out on the large number of sockeye salmon habitat indicators presents a challenge in providing an overall and simplified assessment. A possible approach would be to provide a single score using a 'habitat index' that integrates several indicators. This can be easy to interpret, but information will be lost and there may be multiple approaches to aggregating indicators without certainty about which is best. Should all indicators be weighted equally? If not, how should they be weighted? Each approach to summarizing habitat has strengths and weaknesses. For example, agency programs that currently monitor watershed condition in the Canadian and U.S. Pacific Northwest (e.g. FREP, EMAP, AREMP, PIBO) use a variety of methods to aggregate their habitat data (Pickard et al. 2008). No single approach has been widely accepted.

To provide an integrated summary of habitat vulnerability we chose not to develop a single index score. While also reporting out (to the extent possible across CUs) on our full suite of habitat indicators, we instead focused on presenting three independent, static indicators that could be calculated for each CU and that we felt could best define intrinsic habitat vulnerability for each sockeye salmon freshwater lifestage. These independent habitat indicators are: (1) migration distance; (2) total area of nursery lakes; and (3) ratio of lake influence to total spawning extent. First, we chose migration distance as a surrogate indicator for the relative exposure of each CU to a suite of cumulative (but difficult to directly quantify) natural and human stresses that sockeye salmon will experience while migrating upstream as adults and downstream as smolts. Next, we chose lake area to represent a simple, surrogate indicator that could identify the intrinsic capability of a CU's rearing habitats to produce large numbers of smolts. We recognize that incorporation of direct or modelled estimates of juvenile productivity could provide a description of current lake habitat condition. However such productivity estimates are only available for a subset of CUs (and generally lack time series data) while nursery lake area is available for all CUs and is highly correlated with total juvenile production. While annual lake-to-lake differences in productivity per unit area are important, the extent of the rearing habitat available will more strongly dictate the potential total smolt production from a CU. Lastly, we chose the ratio of lake-influenced spawning to total spawning reaches as a surrogate indicator of the long term ability of a CU to consistently maintain good quality spawning habitat. Spawning reaches below lake outlets will be buffered from natural and human watershed impacts that can affect substrate quality, water quality, and flows.

The three independent measures of habitat vulnerability are represented by separate axes within 3-dimensional figures (see Figure 7). The placement of an individual CU across these dimensions illustrates its vulnerability to watershed disturbances relative to other CUs in the Fraser River basin. Figure 7 illustrates the relationship among these variables across all CUs, while the dashboard summaries (see Appendix 3) highlights the values of habitat vulnerability for each CU.

3.0 Freshwater stressors affecting Fraser River sockeye salmon

To understand the potential role of freshwater stressors in recent declines of sockeye salmon we compile and analyze the best available data describing six categories of human activities which have the potential to affect sockeye salmon: forestry (e.g., forest harvesting activities, Mountain Pine Beetle disturbance, and log storage), mining, hydroelectricity (e.g., large scale and run of river power projects), urbanization upstream of Hope[7], agriculture, and water use. These activities have the potential to affect sockeye salmon during freshwater life stages, in particular, by having effects on the: (1) quantity and quality of spawning habitats; (2) productivity of nursery lakes for rearing juveniles; and/or (3) habitat conditions associated with smolt outmigration / adult migration. To examine the interaction between a stressor and sockeye salmon habitats, we intersect each spatial layer representing a stressor (described below) with the spatial layers delineating "zones of influence" on core habitats for migration, spawning, and rearing across each Conservation Unit (described in Section 2.2). We recognize that not all stressors and pathways of effects on habitat are plausible, however. Table 7 summarizes the linkages between each stressor and habitat that we examined in our analyses and the indicators being generated to represent these stressors. The context for a stressor, related mechanisms of effect, and results from our analysis are described in more detail in the following sections. The role of these stressors in declines of Fraser sockeye salmon is discussed in Section 4.0.

3.1 Forestry

In this section we investigate three topics related to forestry that have had the potential to affect Fraser River sockeye salmon: (1) forest harvesting activities, (2) Mountain Pine Beetle disturbance, and (3) log storage / handling on the Fraser River estuary.

3.1.1 Forest harvesting activities

In the Fraser River basin, 75% of the land area is covered by forests and as a result forestry is an important contributor to rural economies (FBC 2009). Since the early 1970s the area and volume of forested land that has been harvested annually in British Columbia has varied, but remained relatively stable (Figure 8). The Southern Interior and Central Interior Ecoprovinces (which overlap with the majority of sockeye salmon watersheds) have some of the highest cumulative concentrations

[7] See Johannes et al. (2011) for an evaluation of the impacts of urbanization downstream of Hope.

of roads in the province. From 2000 to 2005, in the Southern Interior and Central Interior regions the density of road-stream crossings increased by 21% and 10%, respectively, with a similar level of increase in the density of roads – 18% and 10%, respectively (BC MOE 2008). Accompanying the economic benefits of forest harvesting activities are known impacts on fish and habitats, including effects on sockeye salmon (e.g., Salo and Cundy 1987; Meehan 1991; FPB 2009; Smerdon et al. 2009; Daigle 2010). The state of knowledge about the interaction between forests and fish is based on years of rigourous research in watershed studies across British Columbia and elsewhere in the U.S. Pacific Northwest (e.g., Carnation Creek (Hartman et al. 1996), Queen Charlotte Islands (Hogan et al. 1998), Stuart-Takla (MacIsaac 2003), and Slim Creek (Brownlee et al. 1988)). Though sockeye salmon have not always been the focal species in these kinds of studies, the mechanisms of impact and implications of forestry development on sockeye salmon can be inferred with a relatively high degree of confidence from studies investigating fish-forestry interactions.

Three core forest harvesting activities can have a potential impact on sockeye salmon habitats and survival at different life stages (reviewed by Meehan 1991). Road construction interferes with the natural patterns of water flow through a watershed as water drains across exposed road surfaces, which can increase sediment inputs into streams. Sedimentation can cover spawning redds and reduce oxygenation of incubating eggs. Road-stream crossings can also interfere with access to habitats by adult spawners when these crossings pose obstructions to fish passage. Upslope harvesting can alter the hydrology of a watershed which affects the delivery of water and gravels throughout the stream network. These alterations can affect the amount and timing of water and sediment available to streams and lakes thereby leading to impacts on spawners, eggs, and/or juveniles. Activities in riparian areas can additionally affect water quality by disturbing stream bank integrity, reducing watershed nputs of nutrients and woody debris, and increasing stream temperatures through reduced streamside shading. These changes have the potential to affect the growth and survival of eggs and juveniles.

Coastal and interior B.C. watersheds respond differently to the impacts of logging (Winkler et al. 2009). Along the coast, steeper topography and more intense storms can cause more severe landslides than in interior watersheds, bringing large amounts of sediment and debris into streams. However, the steep topography and flashy hydrology of coastal watersheds also moves sediment and woody debris more quickly downstream, leading to a shorter recovery time from logging impacts than for interior basins. The level of impacts on stream hydrology, sediment transport and fish habitat can change significantly with the percent of the watershed that is clear cut (Grant et al. 1986; Chamberlin et al. 1991; NCASI 2001; MOF 2001; McCaffery et al. 2007; Carson et al. 2008).

To examine these issues we quantitatively assess the geographic extent and history of forest harvesting activities (primarily forest harvesting and road building) across all sockeye salmon Conservation Units in the Fraser River basin. We compile three spatially explicit layers of information to examine this interaction (see Appendix 4). The Reporting Silviculture Updates and Land Status Tracking System (RESULTS) database provides an indication of the extent of forest harvesting; the British Columbia Digital Road Atlas summarizes the extent of all roads (including roads associated with other human activities, see sections below); and a road crossing database identifies road-stream crossings of potential concern. Given the nature of these underlying data, salvage harvesting and related activities associated with Mountain Pine Beetle are included here in these spatial layers.

An examination of the correlation among the indicators derived from these data sources revealed strong correlations between the magnitude of recent harvesting and Mountain Pine Beetle disturbance (see Section 3.1.2) and the density of roads and road-stream crossings, while the magnitude of forest harvesting and road development are largely independent of each other.

Figure 9 through Figure 11 illustrate the intensity, spatial extent, and temporal trends of forest harvesting across all lake sockeye salmon Conservation Units. The level of forest harvesting within the last 15 years is less than 10% of the “zones of influence” on habitat types, though varies widely across CUs and habitat types (Figure 9). Drainage areas upstream of lake inlet spawning, tributary spawning, and nursery lakes tend to be more heavily disturbed than the riparian zones adjacent to spawning downstream of lakes or along migration corridors. The most heavily disturbed headwaters include the following Conservation Units which have had more than 7.5% of their headwaters disturbed within the last 15 years: <u>Early Summer</u> – Pitt, Nahatlatch, Fraser, Francois; <u>Summer</u> – Fraser, Francois, Stuart; <u>Late</u> – Harrison (D/S). In contrast, the headwaters of the following CUs have been mostly undisturbed within the last 15 years: <u>Early Summer</u> – Chilliwack, Chilko, Taseko <u>Summer</u> – Chilko; <u>Late</u> – Cultus, Kawkawa. The distribution of the level of harvesting shows indiscernible changes over time when viewed at the scale of the Fraser River basin (Figure 10), although the pattern of disturbance over time has varied across CUs (Figure 11). In this illustration, some Conservation Units have shown declines in the extent of harvesting (Early Summer – Pitt; Late – Harrison (D/S), Shuswap Complex), while others (Early Stuart – Stuart; Summer – Quesnel) have shown a recent and sharp increase, which is likely due to increases in salvage harvesting associated with Mountain Pine Beetle disturbance (see Section 3.1.2).

Figure 12 and Figure 13 represent the intensity of road development as measured by density of roads (across all development activities) and road-stream crossings. As mentioned these stressor indicators are highly correlated with each other which suggests they represent the same relative level of disturbance associated with roads across CUs. However, there is considerable variation in road development across CUs and habitat types. In contrast to forest harvesting, road development tends to be more concentrated in areas adjacent to spawning zones downstream of lakes and along migration corridors. CUs with high road densities in lake influenced spawning zones include: Early Summer – Kamloops; Summer – Francois, Fraser; Late – Kawkawa, Seton, Kamloops. CUs with the highest road densities along migration corridors include the: Early Summer – Chilliwack, Pitt, Shuswap Complex; Late – Kawkawa, Seton, Cultus.

3.1.2 Mountain Pine Beetle disturbance

The current Mountain Pine Beetle outbreak in the interior of British Columbia has expanded at an unprecedented rate and is considered the largest in the province’s recorded history (reviewed by McGarrity and Hoberg 2005). The interior pine forests of the Fraser River basin have been the focal point for this disturbance agent. Two main factors have contributed to the outbreak. First, the supply of mature lodgepole pine has increased in recent decades due, in part, to fire suppression activities. Second, warmer winters have increased the survival of beetles, which has helped beetle populations flourish. During the initial stages of the outbreak, the management response focused on containing the infestation. As the scale, magnitude, and severity of disturbance increased it became increasingly clear that containment was not possible. Consequently, management efforts shifted to salvage logging to minimize economic losses from the outbreak; in some regions allowable annual cut was increased 78% above pre-outbreak levels (McGarrity and Hoberg 2005). The outbreak has caused a major disturbance to forest ecosystems and watersheds, and therefore has the potential to be a major direct stressor on sockeye salmon of the Fraser River basin (Johannes et al. 2007). As well, the fish habitat impacts sometimes associated with forest harvesting could be exacerbated with greater fractions of clear-cut area under salvage logging.

Our understanding of the effects of Mountain Pine Beetle on watersheds is riddled with uncertainties given the unprecedented magnitude / spatial extent of the outbreak, relatively short time frame within which the outbreak has emerged, and relatively limited research on the topic to date. Key uncertainties include a lack of understanding about how (Uunila et al. 2006):

- beetle-induced hydrologic changes vary across watersheds, climate conditions, and recover through time;
- standing dead timber affects hydrologic processes compared to salvage logging;
- the magnitude of summer low flows will change (i.e., increase or decrease); and
- rates of hydrologic recovery differ between beetle-affected and salvage logged watersheds.

Despite these unknowns, our current understanding is grounded in some certainties (Uunila et al. 2006; EDI 2008; Redding et al. 2008). In general, the effects of beetle disturbance on hydrologic processes are different than timber harvesting because affected forests retain standing timber and understorey vegetation. Hydrologists generally agree that the resulting defoliation of pine forests leads to a decrease in interception of precipitation and loss of transpiration, which increases the amount of water in soils and in turn affects surface water and groundwater supplies. The loss of forest canopy will also affect the accumulation of snow and rates of snowmelt. These changes are expected to lead to an increase in total water yields and higher peak flows (e.g., FPB 2007). Most recent research indicates that hydrological processes within beetle-affected stands are somewhere between a mature forest and clearcut, with hydrologic recovery taking between 20 and 60 years. Even-aged stands lacking understory tend to have greater impacts on hydrologic processes than uneven-aged stands with understorey vegetation. More detailed changes in the magnitude and timing of streamflow are difficult to predict, however, given the complexity of factors governing hydrology (e.g., elevation, topography, type of vegetation cover, weather patterns). For instance, some empirical evidence suggests that is difficult to detect beetle-related changes in hydrology and that the direction of change can vary across watersheds (Stednick and Jensen 2007).

From the perspective of impacts on sockeye salmon watersheds, increased soil water and streamflow can lead to decreased slope stability, increased flooding, and alterations in the quality and quantity of freshwater habitats. In particular, the combined effects of beetles and salvage logging on watershed hydrology will affect the delivery of water and gravels, which can affect the amount of water available for spawning / rearing, sedimentation of streams and lakes, and consequently affect spawners, eggs, and/or juveniles.

The above-described effects will be most evident in years with intense storms. For example, Schwab (1998) estimated that three quarters of all the sediment delivered during the twentieth century in watersheds of the Queen Charlotte Islands occurred during just four storms. While the Fraser River basin generally has both more gently topography and less rainfall than the Queen Charlotte Islands, the intensity of storms is expected to increase with global warming (Spittlehouse and Murdock 2010), which could exacerbate the effects of beetle kill and salvage logging.

Similar to our analysis of harvesting disturbance, we assess the geographic extent and recent expansion of Mountain Pine Beetle as a disturbance agent across interior sockeye salmon watersheds. Due to the nature of the available data, impacts associated with salvage harvesting are described in the analyses of section 3.1.1. To examine the time series of disturbance for the recent outbreak (since 1999), we compiled the Forest Health Network Archives Pest Data for British Columbia from the Canadian Forest Service and Forest Health from the Aerial Overview Surveys from the Ministry of Forests and Range (see Appendix 4).

Mountain Pine Beetle is a dominant disturbance agent across most CUs and all habitat types. Figure 14 through Figure 16 illustrate the intensity, spatial extent, and temporal trends of disturbance due to Mountain Pine Beetle across all lake sockeye salmon Conservation Units. In comparison to the intensity of forest harvesting (maximum disturbance of ~10% by area), the magnitude of Mountain Pine Beetle disturbance across CUs and habitat types has been much greater (maximum disturbance of ~90% by area, see Figure 14). Watersheds upstream of and adjacent to sockeye salmon spawning (both lake influence and tributary spawning locations) and nursery lakes tend to be more heavily disturbed than migration corridors, though some corridors still have a substantial level of disturbance (up to 30%). As has been well documented, the expansion of Mountain Pine Beetle within the last 10 years has been dramatic and now affects land cover across most interior Fraser CUs (Figure 15).

Since 1999 the level of disturbance increased dramatically after 2003 (Figure 16), with the level of disturbance being most dramatic in interior Fraser CUs (e.g., Early Stuart – Stuart; Early Summer – Taseko; Summer – Quesnel) as opposed to coastal CUs whose watersheds are largely absent of ponderosa and lodgepole pine, the beetle's host tree species (e.g., Early Summer – Pitt; Late – Harrison (D/S)).

3.1.3 Log storage / handling in the Fraser River estuary

The history of transportation and storage of logs along major waterways in the Pacific Northwest began over a century ago. In the early days, log drives were the most cost-effective and efficient way of transporting lumber to mills and played a significant role in forestry operations. Today, on the intertidal and estuarine sections of the lower Fraser River, log storage is a key component of forestry operations. Logs reach the lower Fraser by travelling down the coast in booms or by barge and are stored for processing or shipment elsewhere. This area is valued because brackish waters protect logs from wood borers and storage areas are located in proximity to many processing mills (Sedell et al. 1991). In the 1990s, the Fraser River estuary was estimated to support 40 processing operations consuming 25% of B.C.'s coastal production, provide six weeks of inventory for these mills, and store 6% of logs in transit elsewhere (FREMP 1991; FREMP 1994).

For many years industry and government have been working together to manage log storage (the predominant use in the Fraser and Pitt Rivers) and reduce impacts on the estuary. Waterlots are used to designate areas for a variety of purposes, including log storage, which are governed by temporary permits (up to 1 year), licenses of occupation (10 years) and leases (30 years). Port Metro Vancouver is responsible for log storage in the estuary and works with government, communities, and other industry to balance competing uses (see http://www.portmetrovancouver.com/). The Fraser River Estuary Management Program (FREMP) is an inter-governmental partnership that coordinates planning, protection, and decision making among varied interests as related to the estuary (see http://www.bieapfremp.org/main_fremp.html).

Our understanding of the impacts of log storage and handling on estuarine environments is based on summaries of the science from across western North America (e.g., Sedell et al. 1991; Levy et al. 1996), though studies on the effects on salmon in the Fraser River estuary, in particular, are limited. There are four phases of log handling which can cause physical and chemical impacts on estuarine environments – dumping, booming, storage, transport. In general we know that logs can compact, scour, and shade nearshore habitats which in turn can reduce plant cover and food availability for juvenile salmon. As well, wood and bark debris can accumulate beneath storage areas which can alter the composition of food sources, smother emergent vegetation, increase biological oxygen demand, and increase concentrations of potentially toxic log leachates. The magnitude of these disturbances is considered to be a function of the flushing characteristics of the river, the specific methods of log handling / storage, and intensity of use in each area.

These disturbances in the estuary have the potential to affect Fraser sockeye salmon. The brackish and freshwater channels of the lower river are known to support millions of outmigrating salmon which occupy marine foreshore areas after smoltification, and prior to migrating out to sea. The lower reaches of the river also act as a staging area for adults migrating upstream to their natal streams (FREMP 2003). Despite the potential for disturbance and importance of the habitats, a comparative study in the Fraser River estuary revealed that densities of juvenile salmon (chinook, pink, and chum) and amphipods did not differ between a large log storage site and nearby marsh areas (Levy et al. 1982; 1989). Little is known about impacts on adult salmon (Sedell and Duval 1985 as cited by Levy et al. 1996), though there is evidence that log storage at the outlet to sockeye salmon nursery lakes can block upstream migration of adults (DFO 2002).

For waterlots where log storage occurs, temporary permits and leases are currently available through Port Metro Vancouver. Across its area of oversight, the Port estimates there are approximately 48 different tenants distributed across 256 log storage agreements (193 leases and 63 permits), covering a total area of 862 hectares within the estuary (693 hectares under lease and 169 hectares under permits) (Nathan Nottingham, Port Metro Vancouver, pers. comm.[8]).

Data describing the year to year variation in log storage across the Fraser River estuary are not available from the Port. Despite this gap, others have reported on the extent of log storage in the estuary. Given variation in reporting for different spatial areas of the lower Fraser, these data are not comparable across years but are provided here for some context. In the 1980s, about 1,485 hectares of the entire lower Fraser River foreshore was reported as leased for log-boom storage (from Higham

[8] The figures are the most recent estimates, which might include some errors due to the consolidation of databases following the recent amalgamation of the Fraser River and North Fraser Harbour Port Authorities.

1983 as cited in Birtwell et al. 1988; also see FERIC 1980). In 1991, 555 of 970 hectares available for storage were reported as being used (FREMP 1994). While in 1999, 636 waterlot leases, licenses, and permits were being held by 334 tenants on the main reaches of the lower Fraser (i.e., excluding the north arm, VFPA 2008).

Given the gap in data describing year to year variation, the next best available source of information was a time series of aerial photos available from Google with date and year stamps (see Appendix 4). We visually inspected these images to qualitatively examine spatial (across reaches) and temporal changes (across seasons and years) in log storage from 2001 to 2009. Based on visual examinations of air photos from the last decade, four areas were identified as having the highest relative concentrations of log storage: at the mouth of the north arm, along the upper north arm, throughout the north channel around Annacis Island, and within reaches of the Fraser main channel near the confluence of the Pitt and Fraser Rivers (see boxes A-D respectively in Figure 17). The concentration of activity in the north arm is well known, which includes what is considered one of the largest log storage area in the world at its mouth (FREMP 1994; FREMP 2003). Air photo examinations also revealed seasonal variation in log storage, with storage appearing to be lowest during the winter. This observation is consistent with statements that the amount of log storage varies across seasons in response to changes in logging and flows (FREMP 1994). Across years of observation, however, we did not notice any significant changes in the magnitude or spatial coverage of log storage across the estuary. Variation appeared to be larger across reaches than across seasons or years within a reach, which suggests that specific locations are preferred for log storage in response to seasonal and annual needs.

3.2 Mining

Mining development has a long history in the Fraser River basin. Today, the Ministry of Forests, Mines, and Lands (formerly the Ministry of Energy Mines and Petroleum Resources) actively encourages mining development as a generator of economic activity across the province (EMPR 2006). Mining is a contentious issue with respect to salmon conservation. Proponents argue that tight regulation of activities and a small geographic footprint have minimized environmental impacts relative to the potential economic benefits, while others (e.g., Kean 2010) suggest that mining development can still have impacts on fish habitats.

Several processes associated with mining have the potential for impacts on sockeye salmon spawning habitats. In some cases, permanent loss of habitat can occur when a mine site or tailing pond is built directly on top of a lake or stream. Mining of gravel or placer minerals from the stream bed itself leads to less obvious disruption of the stream bed (Kondolf 1997). Silt and sand from roads, pits, and gravel washing can be transported to spawning areas, thereby reducing egg survival (Meehan 1991). In addition, mines can produce acid drainage, heavy metals, and other contaminants[9] that may have lethal or sublethal effects on all life history phases (Nelson et al. 1991). With the exception of contaminants, the processes that link land use to migration and rearing are generally much weaker that the land use to spawning habitat linkage. Sediment from mining activities can increase lake turbidity, which can reduce light penetration and productivity (e.g. Lloyd et al. 1987) or increase nutrients and productivity (Tilzer et al. 1976). High levels of inorganic sediment deposition have also been associated with lower densities of benthic invertebrates (e.g. Edmonds and Ward 1979). Along migration routes, turbidity can reduce mortality of smolting juveniles (Gregory and Levings 1998). However, the net of result of mining sediment on lake and migration habitat appears to be minor in comparison to the potential impacts of mining sediment on stream spawning habitat.

We investigate mining activity as a potential stressor on Fraser sockeye salmon by classifying activities into seven categories: (1) placer mining; (2) gravel mining; (3) industrial mineral production; (4) metal mining; (5) oil and gas production; (6) coal mining; and (7) exploration related to all of these production activities.

Placer Mining

Placer mining targets alluvial deposits in modern or ancient streambeds. Minerals, such as gold, that are denser than sand tend to settle out and concentrate at the base of alluvial deposits. The impacts of placer mining on sockeye salmon populations is potentially severe because many alluvial deposits are closely associated with existing streams and water is often used to separate placer minerals from the gravel matrix (Birtwell et al. 2005). In areas with poor environmental regulation, placer mining and hydraulic mining can convert natural streams into barren, sediment-filled channels with devastating impacts on fish populations (Nelson et al. 1991).

[9] See MacDonald et al. 2011 for an evaluation of related impacts of water pollution.

Actual placer activity is difficult to quantify, but active placer claims can be used as a relative index of placer mining interest in a watershed. There were 2965 placer mining claims in the Fraser that were active at some point between 2000 and 2009 (EMPR 2010a).

Gravel (Construction Aggregate) Mining

Gravel mining also has potential for severe impacts on sockeye salmon populations because it also targets alluvial deposits. Alluvial deposits are desirable sources of aggregate because the action of water eliminates weak materials by abrasion and attrition leaving durable, well-sorted gravels that are ideal for producing concrete (Barksdale 1991). Recognizing the potential for damage to aquatic habitats, the B.C. government has restricted the discharge of both water and sediment from mining operations into natural waterbodies (EMPR 2002). Like placer mining, gravel mining is a widely dispersed activity with 450 operations in the Fraser Drainage (EMPR 2000). Most gravel mining is done close to where it is used, typically near major cities and large rural construction projects such as dams or roads. Rural activity is difficult to track because of large year to year variations.

Industrial Mineral Extraction

Industrial minerals include a range of non-metalic minerals such as clay, diatomite, gemstones, slate, gypsum, limestone, pumic, silica, volcanic ash and rare elements (EMPR 2010b). Most operations are relatively small because of a limited market or a limited supply of raw material. Risks from these operations are lower because, in contrast to placer and gravel mining, most of these minerals are not linked to alluvial deposits and processing does not depend on large volumes of water.

Metal Mining

Metal mining activity is extremely concentrated with only five active metal mines in the Fraser drainage (EMPR 2010c). With the exception of the Endako mine near Francois Lake none of these mines are in close proximity to habitat occupied by juvenile sockeye salmon. A large number of inactive mines are present but most of these have very small footprints. The main risks from abandoned mines are the continuous release of acid drainage and heavy metal contamination[9].

Coal Mining

Active coal mining does not occur in the Fraser River basin (EMPR 2010d). Proposals to mine the Hat Creek deposit have been prepared in the past but have never been implemented. A coal deposit has also been identified in the Horsefly drainage, but little work has been done to develop its potential.

Oil and gas production

Exploration wells drilled in the Nechako Basin, Quesnel Trough, and Georgia Basin have identified oil and gas potential in these areas (Hannigan et al. 1998), though no production has been initiated to date.

Exploration Activities

Exploration activities in British Columbia dropped from $350 million in 1988 (all figures in 2006 dollars) to less than $50 million in 2001 before rising to over $400 million by 2007 (EMPR 2008). Details of the locations and results for individual projects are reported regularly (EMPR 2010b), but a database of exploration is not readily available. Roads are thought to be the major environmental impact associated with mining exploration. The impacts associated with road building and exploration is captured in Section 3.1.1. Other activities (e.g., trenches, drill holes, adits) have likely had few impacts on sockeye salmon populations.

The impact of these processes on Fraser River sockeye salmon will vary with the amount of activity, severity of effects, and overlap with zones of influence on sockeye salmon spawning. We use three spatial layers from the Ministry of Energy, Mines, and Petroleum Resources to identify locations of these mining activities and mineral / placer claims across the province (see Appendix 4). For each mining category, we quantify the extent of each of these activities in watersheds utilized by various stocks and Conservation Units of sockeye salmon.

The occurrence of mining activity in the watersheds of spawning streams varies substantially across sockeye salmon Conservation Units (see Table 8 and Figure 18). These data suggest that the impacts of mining on sockeye salmon population densities will be small and difficult to detect. The causal mechanisms that link mining, particularly sediment deposition, to lower egg survival are well documented, but the contrasts among stocks and the strength of the effect relative to other factors is too low to be easily detected. The Shuswap Complex CUs appear to be the most heavily impacted (Figure 18), but most of the activity is in the upper Shuswap River drainage and is not geographically linked to areas that support the majority of spawning. The majority of CUs have little or no mining activity in the watersheds of tributary spawning streams. Placer mining is the dominant mining activity across sockeye salmon Conservation Units and appears to have the highest potential to reduce early freshwater survival, although we expect that environmental regulations have ameliorated some of the impacts of placer mining (EMPR 2002; 2009). There are also a variety of inactive mine sites which may continue to impact watersheds, particularly through acid mine drainage (Province of BC 2002). The highest density of these is also in the Shuswap Complex CUs. Acid mine drainage also has the potential to impact migration corridors. EMPR (1998) guidelines mandate the control of acid mine drainage, usually by permanent flooding and storage of mine tailing in a tailing pond.

Gravel mining on sockeye salmon migration corridors, such as the lower Fraser River, is a contentious issue that has received considerable public attention (which is outside the scope of this report, see Johannes et al. 2011). Although the immediate physical effects of gravel mining are obvious, biological impacts are difficult to detect because they are obscured by natural variation among sampling sites (Rempel and Church 2009). The major impacts of these activities are thought to be on species that spawn (pink salmon, chum salmon) or rear (Chinook salmon, steelhead trout) in these areas rather than those, like sockeye salmon, that utilize these reaches as migration corridors (Rosenau and Angelo 2000). River-type sockeye salmon CUs may rear in these reaches, but there is very little data on either the ecology or status of these small CUs.

3.3 Hydroelectricity

In this section we investigate two topics related to generation of hydroelectricity that have the potential to affect Fraser River sockeye salmon: (1) large scale hydroelectric projects and (2) small scale hydroelectric projects (i.e., run-of-river independent power projects).

3.3.1 Large scale

Development of hydropower potential in the Fraser River basin began in the early 1900s but has been limited to the tributary systems with the mainstream remaining undammed. The main flow of the Fraser has never been dammed partly because high levels of sediment would shorten any dam’s lifespan, but also due in part to strong support for salmon fisheries (Roos 1991; Ferguson and Healey 2009). Small hydro-electric dams have been in place for many years with many projects in the Lower

Fraser (Alouette, Bunzten, Coquitlam, Ruskin, Stave, and Wahleach) and Bridge River area (Lajoie and Seton). The Bridge/Seton River power project and Alcan's Kemano Project on the Nechako River are the two large-scale hydro facilities in the basin that could potentially impact Fraser sockeye salmon populations (Roos 1991).

Large hydro projects can create physical barriers that block or delay migration to spawning areas; affect the quality, quantity, and accessibility of salmon habitats; create conditions that increase stress on migrating salmon (making them more susceptible to disease and pre-spawning mortality); increase susceptibility to predators, and cause direct mortality of migrating adults or smolts that pass through hydro turbines or over spillways (Roos 1991; Marmulla 2001).

Bridge/Seton River Power Project

The Bridge/Seton Power Project is a hydroelectric power development located near Lillooet. Commissioned in 1956 and later expanded it harnesses the power of the Bridge River, a tributary of the Fraser, by diverting it through a mountainside to the separate drainage basin of Seton Lake, utilizing a system of three dams, four powerhouses and a canal. From the lake's outlet, a specially-built canal carries the diverted flow of the Bridge River to the last possible bit of head before the Fraser River (i.e., elevation drops with the potential for generating hydro power). The power canal, known as Seton Canal, is highly unusual in that it bridges both Seton and Cayoosh Creeks before being briefly tunneled through a low rock bluff to the Seton Powerhouse, located on the Fraser River just below the town of Lillooet.

There are two issues related to the construction and operation of the Bridge / Seton River power project which have the potential to affect the Seton and Anderson sockeye salmon Conservation Units. First, sockeye salmon smolts can migrate downstream of the Seton Dam to the Fraser River via one of five exit routes: power canal/turbine, fish ladder, fish water release, siphon spillway, and radial gate spillway. The entrainment rate is dictated by flow routing; smolts tend to concentrate in the high flows of the power canal. Early studies indicated that over 90% of sockeye salmon smolts were being entrained into the power canal, with the smolt mortality rate estimated as 17% when the plant was fully operational (Groves and Higgins 1995). This estimate includes direct mortalities as well as latent mortality from injuries, cumulative stresses, disease and predation. Based on the number of spawners returning to Gates and Portage Creeks and the estimated number of smolts produced per female spawner, the average number of smolts lost at the canal is estimated at ~200,000 (Levy and Sneep 2006). Assuming a 5% smolt:adult survival, this is equivalent to a loss of ~10,000 adult sockeye salmon annually from entrainment mortality (Levy and Sneep 2006). Actual smolt:adult survival rates can vary tenfold from year to year.

There is a long history of fisheries investigation in the Seton River to determine ways to reduce entrainment mortality of sockeye salmon smolts (Fretwell 1979; 1980; 1982; Fretwell and Hamilton 1983; Groves and Higgins 1995; R.L.& L. 1999; 2000). Many of the earlier solutions to mitigate smolt mortality were largely ineffective (Levy and Sneep 2006). The Northern St'at'imc Fisheries and BC Hydro have been working together since 2006 to devise practical ways for mitigating this mortality at the Seton Generating Plant. Under a draft Settlement Agreement between BC Hydro and St'at'imc Nation, a 5% entrainment mortality rate was selected as a target at the Seton power canal (Levy and Sneep 2009). Recently it has been determined that if seasonal maintenance and nightly shutdowns of the station powerhouse coincide with the peak smolt migration period, approximately 95% of emigrating smolts can be protected from entrainment. While implementing this mitigation measure from 2006-2009, smolt mortality rates were estimated at 1.7%, 3.1%, 10.1%, and 1.8%, respectively (Levy and Sneep 2006; 2009). By undertaking these measures BC Hydro believes it can effectively meet the 5% (or lower) sockeye salmon smolt mortality target (Levy and Sneep 2009).

The second issue was first noted in the late 1960's and early 1970's when adult sockeye salmon migration up Seton Creek was being delayed and fish were getting injured in the power house tailrace while attempting to swim up the draft tube. Initially, homing problems were attributed to a lack of continuous stream of Seton River water in the Fraser River. It was determined that delays could be reduced if outflow were lowered and discharge in Seton Creek were increased, but this option could not initially be incorporated into the operations of the facilities (Roos 1991). Field telemetry and water preference studies in the late 1970's and early 1980's indicated that adult sockeye salmon were able to discriminate between pure Seton water and water diluted by Cayoosh Creek. Gates Creek sockeye salmon would move out of the tailrace area into Seton River without delay if the concentration of Cayoosh Creek water in Seton River was 20% or lower. Portage Creek sockeye salmon would not move into Seton River until the percentage of Cayoosh Creek water was less than 10%. Given these targets, the problem was solved by diverting most of the Cayoosh Creek flow through a tunnel, the Seton/Cayoosh diversion, into Seton Lake (see Figure 19, Fretwell 1989).

As a result, dilution guidelines have been in place since 1979 to reduce the proportion of Cayoosh Creek water in Seton River during sockeye salmon migration so adults will not differentiate between the tailrace and the river (target of 20% dilution for Gates Creek and 10% for Portage Creek).

Direct observations from 1979 to 1981 confirmed the effectiveness of these measures, while more indirect evaluations in subsequent years (e.g., qualitative observations of delay in tailrace, fish counter results, trends in abundance of Gates and Portage stocks) indicated that this action continues to be effective (BC Hydro, unpublished). However, a 2007 assessment of attraction and delay at the Seton powerhouse tailrace indicated that 13% of 27 sockeye salmon released into the tailrace did not reach Seton Dam (Roscoe and Hinch 2008). This was unexpected since dilution levels were 2-6%, much less than the 20% dilution target. It is uncertain whether these fish failed to enter Seton River, or entered the river but fell back before reaching the dam. This study suggests that more research is needed to better quantify delays and their implications on sockeye salmon, which includes a re-evaluation of the 'dilution level' target, and examination of whether the tailrace is acting as a thermal refuge from warmer Fraser River water (Roscoe and Hinch 2008). Gates and Portage Creek fish now typically encounter Fraser water temperatures exceeding 18-19^{o}C, temperatures that can be extremely stressful to migrating sockeye salmon (Crossin et al. 2008).

In spite of the difficulties in providing safe passage for migrating smolts and adults, sockeye salmon in the area have been at higher levels of abundance than they were prior to dam construction; though these abundances have likely been aided by the construction of a spawning channel at Gates Creek in 1968 (see Figure 20, Roos 1991). However, the total productivity of Gates Creek sockeye salmon (recruits per effective female spawner) has declined since the 1990's, due to declines in post-juvenile productivity (Figures D-J3, D-P3 and D-T5 on pages 146, 149 and 154 in Peterman et al. 2010. This is a similar pattern to that observed for seven of the eight Fraser index stocks with monitoring of juvenile abundance.

<u>Kemano Power Project</u>

The Nechako River drains the Nechako Plateau east of the Kitimat Ranges, flowing north toward Fort Fraser, then east to Prince George where it enters the Fraser River (Figure 21). The Nechako is one of the main tributaries of the Fraser River, although for many years most of its flow (up to 80%) has been diverted through the Coast Mountains to the Kemano generating station for the purpose of supplying power to the aluminum smelter in Kitimat. The main reservoir of the Nechako power diversion is the Nechako Reservoir behind Kenney Dam. The Kemano Power Project originated in 1941 when the British Columbia government invited the Aluminum Company of Canada Limited (now Alcan Inc.) to develop a hydroelectric power project and establish an aluminum industry on Canada's West Coast. In 1950, the provincial government entered into an agreement with Alcan granting them a conditional water license for power generation (NFCP 2005).

River flow began being diverted in 1952 and the reservoir took four years to fill. Although the project did not directly block migration to any existing sockeye salmon spawning grounds, the 1950 agreement and conditional water license allowed Alcan to reduce releases at the Skins Lake Spillway during periods of below-average inflows to the Nechako Reservoir (Roos 1991). In 1980, Fisheries and Oceans Canada expressed concern over the volume of water being released through the Spillway. It was anticipated that sockeye salmon migrating through the Nechako River system would be exposed to high summer water temperatures resulting from the low water flows. Most sockeye salmon stocks moving through the river are only briefly exposed to warm thermal conditions, but the concern was that increases in temperature can increase stresses on migrating salmon, making them more susceptible to disease and pre-spawning mortality. Consequently, a river temperature control program, the Summer Temperature Management Program (STMP), was developed in response to these concerns (NFCP 2005).

A *1987 Settlement Agreement* defined how Alcan was to manage water temperatures for the benefit of migrating adult sockeye salmon. The Early Stuart – Stuart, Takla / Trembleur; Early Summer – Nadina, Fraser, Francois; and Summer – Stuart, Takla / Trembleur, Fraser, Francois Conservation Units use the river as a migration corridor, with adults spending two to four days in-river during migration (though a small number of sockeye salmon spawn in the Nechako itself). Of these CUs, those sockeye salmon migrating upstream of the confluence with the Stuart River face the greatest stress as they are exposed to high temperatures for longer periods of time. The *Agreement* specified a schedule of short term water releases, but did not specify the volume of water to be released to protect migrating sockeye salmon. A water temperature model and accompanying protocols are used for daily decisions on the volume of water to be spilled through the Spillway to meet temperature targets in July and August. The need for additional cooling water is assessed daily using this computer model which incorporates real-time data and forecasts of water temperature, water flow, and meteorological conditions. The temperature control point on the Nechako River is located and measured upstream of the confluence with the Stuart River at Finmoore. The long term goal of the flow and temperature control program has been to maintain mean daily water temperatures at or below 20°C during the period of adult sockeye salmon migration from July 20 to August 20 (IPSFC 1979; NFCP 2005).

Water temperatures have been monitored in both the Nechako and Stuart Rivers at their confluence since 1953. Consequently, water temperatures can be evaluated for two periods: pre-STMP (1953 to 1979) and post-STMP (1983 onwards). To evaluate the effectiveness of the program, thermal conditions of the Nechako River have been compared to water temperatures in the unregulated Stuart River (deemed a control watershed), which shares the same hydrological basin and biogeoclimatic influences (NFCP 2005)[10]. Recent reporting indicated that Nechako River summer water temperatures have generally remained between 15°C and 21°C between 1953 and 2000, and have infrequently exceeded the 20°C target (see Table 9). Mean daily water temperatures occasionally exceeded 20°C in both the Nechako and Stuart Rivers, but did so more frequently in the Stuart River (a control system whose temperatures are not influenced by the Kemano Power Project) than in the Nechako River (NFCP 2005). Regular flow monitoring reporting subsequent to the NFCP 2005 summary has indicated similar adherence to temperature targets, with 5 of 8 of the reported years between 2001 and 2009 having zero days in exceedance of the 20°C water temperature target. Temperature targets were, however, exceeded in 2004 (13 days), 2006 (5 days) and 2009 (11 days), with the maximum mean daily water temperature reaching as high as 21.7°C in 2006 (Table 10).

Since 1983 when the STMP was implemented in its current form, the program has managed the release of water from the Nechako Reservoir to limit the frequency of days with mean daily temperatures >20°C at the temperature control point. During this period Nechako River temperatures have only rarely exceeded 20°C during the period of sockeye salmon migration, even though analyses of meteorological conditions suggest some general warming of the area in recent years (NFCP 2005).

[10] We note that this comparison is limited because temperature data only exist for years in which the Nechako River was regulated by flows (i.e., no pre-regulated data).

3.3.2 Small scale

In the last decade, the Provincial government has encouraged the development of Independent Power Projects (IPPs) as an integral part of British Columbia's long term energy plans (Province of British Columbia 2010). IPPs are typically small installations (<50 MW) with diversion dams but little storage capacity. In some cases, several small installations are combined into a single much larger development[11]. Despite their appeal as sustainable sources of electricity, there are public concerns over potential negative impacts of IPPs on the aquatic environment, including salmon (Douglas 2007; UBC 2010).

There are several plausible mechanisms by which IPPs could affect sockeye salmon survival, even though most divert water from a relatively short stream channel that is often fishless. IPP operations can affect Total Gas Pressure (TGP), gravel supply, and water temperature. Each of these effects can be propagated to downstream reaches where they may have negative impacts on sockeye salmon spawning habitat. Although water is not directly diverted from migration corridors, IPPs may affect migration of sockeye salmon smolts or adults by changing TGPs and water temperatures in downstream migration corridors. Assuming no interbasin transfer of water, there are no plausible mechanisms by which IPPs could significantly affect sockeye salmon nursery lakes.

High TGP, usually in the form of nitrogen supersaturation, can occur when gas or air is entrained in water and then subjected to high pressures. Elevated TGP is an issue for many hydro electric facilities because it can produce gas bubble trauma in fish (Weitkamp and Katz 1980), including both adult (Nebeker et al. 1976) and juvenile (Nebeker and Brett 1976) sockeye salmon. Elevated TGP can persist for several kilometers (e.g., Scheibe and Richmond 2002) and therefore fish may be at risk at substantial distance below an IPP installation. However, Douglas (2007) suggests that TGP can be naturally high in turbulent headwater streams and that small hydro installations may actually reduce TGP.

Dams can disrupt the gravel supply to downstream reaches if sediment is either trapped in a reservoir or periodically removed from an intake structure. This disruption in gravel supply can have serious negative effects on channel integrity and the quality of salmon habitat in reaches downstream of dams (Kondolf 1997). On small diversion dams, such as those typical of many IPP installations, low

[11] See http://www.plutonic.ca/s/Home.asp or http://www.purcellgreenpower.com

level outlets can be used to maintain a natural sediment regime if care is taken on the timing of sediment release relative to peak flows and salmon spawning activity. Construction activities and infrastructure may also result in increased sedimentation. The potential for these effects has been recognized and regulations have been implemented in an attempt to reduce the risks from excessive sedimentation (MoFR 2005).

Stream temperatures below reservoirs can be either higher or lower than natural thermal regimes. Large reservoirs with deepwater outlets can depress downstream temperatures by more than 10 °C. Surface outlets typically result in warmer downstream reaches. Even small diversion reservoirs may raise downstream temperatures significantly, especially under low summer flows. Warmer temperatures can stress sockeye salmon and result in delays or mortality during upstream migration (Crossin et al. 2008).

To investigate the potential interaction between these issues and sockeye salmon, we gathered geographic coordinates for all existing IPP locations in the Fraser River basin (see Appendix 4). Next, we used GIS to intersect these IPP locations with sockeye salmon spawning areas / migratory corridors for all CUs in the basin. Given this information we then qualitatively assessed the significance of IPP installations that are directly upstream of a known spawning area or on a direct tributary of a sockeye salmon migration route. We also reviewed the status of IPPs with respect to interbasin transfers and diversions from stream reaches used for migration. The impact of roads associated with IPP development is considered under forest harvesting activities (see Section 3.1.1).

The history of interaction between IPPs and sockeye salmon is very short and limited in number (Figure 22) and spatial extent (Figure 23). Only one IPP has recently begun operating in a watershed that supports sockeye salmon spawning (Harrison -downstream migrating-Late timing) in the lower reaches (Figure 24). Another two installations are in final planning stages on Silver Creek (Late – Harrison (D/S)) and on Sakwi-Weaver Creeks (Late – Harrison (U/S)). In each case, sockeye salmon spawning is concentrated in the lower reaches but on Silver Creek the installation is more than 10 km upstream. The other two installations are directly adjacent to sockeye salmon spawning areas. Survival of sockeye salmon is intensively monitored at the Weaver Creek spawning channel, which is directly below the proposed Sakwi Creek IPP. Historically, adult and egg survivals have been consistently high at the Weaver Creek spawning channel (Essington et al. 2000). Recent increases in mortality of Weaver Creek sockeye salmon adults appears to be the result of higher temperatures associated with climate change and changes in migration timing (Mathes et al. 2010). Although 24 of 30 CUs have IPPs associated with migration corridors, the number of installations is small (see Figure 22 and Figure 23). Three are on small tributaries to major rivers (two on the Fraser River and one on the Quesnel River). The remaining installation is on a tributary to a large lake (Seton) through which sockeye salmon migrate. Interbasin transfers and diversions from stream reaches used for migration was not an issue of concern for Fraser River sockeye salmon. Given the available data and these results, IPPs have not had significant impacts on sockeye salmon populations. This conclusion is based on the small number in proximity to spawning grounds or migration corridors.

3.4 Urbanization upstream of Hope

More than two-thirds of British Columbians live in the Fraser River basin (FBC 2009), many of which live in urban environments. Although the relative size of urban footprints is typically lower than that of other human activities (e.g., agriculture or forestry), the intensity of disturbance is generally regarded as higher, in part, due to the concentration of activities and irreversibility of disturbance associated with the built environment (Paul and Meyer 2001). Due to the effects of human activities on Pacific salmon (including urbanization), population growth has generally been recognized as one of its greatest threats (Hartman et al. 2000). In the Fraser River basin, the potential interaction between people and salmon is a valid consideration given the growth over recent decades and strong overlap between human populations and salmon distribution (Nelitz et al. 2009). The pace of growth from 1981 to 2006 has varied across the basin, being markedly higher (81%) in the lower Fraser than areas upstream of Hope (2%, 5%, and 25% total growth for Nechako, upper Fraser, and Thompson respectively). The distribution of people is similarly varied with the majority living in urban environments of the lower Fraser River valley (Figure 25), though this area is outside the scope of our evaluation (see Johannes et al. (2011) for an evaluation of impacts of urbanization downstream of Hope).

Despite the smaller population upstream of Hope, urbanization and the related built environment have the potential to affect freshwater habitats for Fraser sockeye salmon in three ways (Rosenau and Angelo 2009). First, residential, business, and industrial development, as well as related road construction can increase the amount of impervious surfaces in urban watersheds which affect rates of interception, patterns of runoff, and in turn the magnitude and timing of instream flows (e.g., peak and low flows). Direct extraction from groundwater and surface water supplies for municipal purposes can affect water availability for sockeye salmon spawners and incubating eggs. Second, construction of roads and buildings along stream channels and lake foreshore areas have the potential to reduce riparian vegetation, channelize streams, and block access to habitats (e.g., Radomski et al. 2010). Such activities have been directly linked to alterations in sockeye salmon habitats in the lower Fraser (e.g., Bocking and Gaboury 2003; COSEWIC 2003). Lastly, roads, stormwater runoff, as well as municipal and industrial effluents have been known to alter water quality in watercourses across the Fraser River basin by changing concentrations of sediments, nutrients, and contaminants (Birtwell et al. 1988; Dorcey and Griggs 1991; B.C. Ministry of Environment, Lands and Parks and Environment Canada 1994). Beyond a consideration of the extent of road development in urban watersheds, the impacts of water pollution on Fraser sockeye salmon are outside the scope of this report (see MacDonald et al. 2011 for an evaluation of related impacts of water pollution).

We examined four data sources to evaluate the significance of these issues on Fraser sockeye salmon at a landscape level (see Appendix 4). We use the TANTALIS municipal boundary layer from the provincial government to identify areas of overlap between urban environment and sockeye salmon Conservation Units. Due to the nature of the underlying data, this layer cannot be used to assess changes in the concentration of urban development or urban land cover over time. We use the B.C. Digital Road Atlas to consider the density of roads to assess proximity of potential road impacts on sockeye salmon habitats (see Section 3.1.1). We use the provincial water license layer to identify the location and amount of water designated for domestic or waterworks purposes (see Section 3.6). Lastly, we use the census boundaries and population estimates from the federal and provincial governments to examine spatial and temporal trends in population growth and how these trends might interact with sockeye salmon Conservation Units of the Fraser River. We consider human population numbers as a surrogate indicator of the related impacts of urbanization (e.g., increase in impervious area or destruction of riparian habitats due to construction of buildings and roads adjacent to streams and lake foreshore areas).

Figure 26 through Figure 29 illustrate the results of our examination between these urban stressors and all lake sockeye salmon Conservation Units. Relative to forest harvesting and Mountain Pine Beetle disturbance, urban environments have a relatively small footprint within watersheds and riparian zones that influence sockeye salmon spawning and rearing habitats (Figure 26). However, of all other types of land cover (forest harvesting, Mountain Pine Beetle, and agriculture), urban footprints have the largest interaction with migration corridors. The extent of this interaction across many CUs is largely a function of the need for all sockeye salmon in the Fraser River basin to migrate through the Lower Mainland (Figure 27). CUs with longest migration distances tend to have the lowest proportion of urban development across their migration (e.g., ~ 16% for Bowron and Nadina – Early Summer), while those with the shortest migrations have the greatest proportional extent of urban development along their migration (e.g., > 88% for Pitt – Early Summer and Cultus – Late). The extent of urban development along migration corridors is further illustrated by available human population data which shows that the average density of people along migration corridors across CUs (Figure 28) is significantly higher than the population density within areas influencing sockeye salmon spawning and rearing areas (Figure 29). Conservation Units with the highest population densities along their migration corridors and spawning / rearing areas again include: Early Summer – Chilliwack and Pitt; Late – Cultus. Those CUs with the lowest population densities include: Early Stuart – Stuart, Takla / Trembleur; Early Summer – Fraser, Francois, Nadina, Bowron; Summer – Stuart, Takla / Trembleur, Fraser, Francois. For the past 25 years, the trend in population density has been a steadily increasing and relatively parallel pattern across CUs.

3.5 Agriculture

The Fraser River basin supports 53% of the province's farmland and more than 9,000 farms (FBC 2009). Agriculture can be a significant stressor on freshwater ecosystems because it often occurs within valleys and riparian areas adjacent to larger mainstem rivers that provide high quality salmon habitats. This concern is supported by empirical evidence which has related agricultural development to declines in coho salmon in the basin (e.g., Bradford and Irvine 2000). Two trends are informative for setting the context and understanding the potential impacts of agriculture. First, the extent of land in the Agricultural Land Reserve (ALR) and number of farms has remained relatively stable in recent decades at a provincial level, though trends differ across regions (Figure 30). For instance, from 1979 to 2000 the interior and south coast regions of the Fraser River basin have experienced net losses of 2,686 and 13,136 hectares, respectively, largely the result of population pressure and demands for urbanization in these areas (BC MOE 2008). Second, evidence from British Columbia (Figure 31) and across the country (Statistics Canada 2009) suggests that the agricultural intensity on these lands (e.g., number of livestock) have increased in recent years.

There are three general pathways by which agriculture can have landscape level impacts on salmon habitats (reviewed Platts 1991; Rosenau and Angelo 2009). First, livestock grazing and crop production can lead to physical alterations of streams, riparian zones, and floodplains. Cattle crossing through streams can increase sedimentation, destroy spawning redds, and destabilize stream banks / widen the stream channel. Removal and continuous disturbance of vegetation in the riparian zone can reduce stream shading and increase stream temperatures which affect spawners and eggs. Further upslope, crop production and farm roads in the floodplain can compact soils leading to less interception of precipitation and more surface water runoff. A second impact pathway is the direct removal of water from groundwater and surface water supplies for irrigation and livestock purposes. Extraction of surface waters can constrain access to habitats, while extraction of groundwater can reduce the supply of cool summer baseflows to streams and rivers. Lastly, agricultural activities can have significant impacts on water quality of streams and lakes by increasing biochemical oxygen demand, introducing pathogens, and affecting concentrations of sediments, nutrients, and contaminants through the introduction of manure, fertilizers, and pesticides into waterways (e.g., Schendel et al. 2004; Schindler et al. 2006; Smith et al. 2007; Jokinen et al. 2010). As mentioned earlier, the impacts of water pollution, however, are outside the scope of this report (see MacDonald et al. 2011 for an evaluation of the related impacts of water pollution).

We used two data sources to examine the potential interaction between agriculture and sockeye salmon Conservation Units across the Fraser River basin (see Appendix 4). The Agricultural Land Reserve layer is used to represent the spatial distribution of agriculture in recent decades and the provincial water license layer is use to identify the location and amounts of water allocated (not actual use) for stockwatering and irrigation purposes (see Section 3.6). These are the best data sources available to describe the spatial extent of agricultural activities which at a broad scale does not appear to be changing dramatically (as discussed above). Yet we acknowledge that agricultural impacts will depend on the type of agriculture and intensity of use which have likely changed more dramatically. For instance, given noted increases in livestock it would have been preferable to examine changes in the type and intensity of pressure on lands and streams associated with livestock production. These data, however, are generally lacking in an easily accessible and consistent format across the basin.

Relative to forest harvesting, Mountain Pine Beetle disturbance, and urban development, agriculture has a relatively small footprint within watersheds and riparian zones that influence sockeye salmon spawning and rearing habitats (Figure 32). Agriculture has its greatest interaction with migration corridors, the extent of which is less than that of urban development yet more than that of forest harvesting and Mountain Pine Beetle disturbance. The concentration of agriculture along migration corridors is consistent with the observation that agricultural activities tend to be located adjacent to large rivers or within river valleys that have productive soils and are close to water for crop irrigation and livestock watering. This interaction with migration corridors across many interior CUs is largely due to a concentration of agricultural lands in the Cariboo-Chilcotin along the Fraser River mainstem (Figure 33). Conservation Units with the smallest extent of agricultural lands along their migration corridors include: Early Summer – Pitt, Nahatlatch, Anderson; Late – Harrison (D/S), Harrison (U/S), Seton, Lillooet. CUs with the greatest extent of agricultural lands include: Early Stuart – Stuart; Early Summer – Chilko, Fraser, Francois, Bowron; Summer – Chilko, Fraser, Francois, Quesnel, Stuart.

3.6 Water use

Water has direct and significant influences on the economic, social, and environmental well being of British Columbians. Water use conflicts arise when faced with water scarcity — either limited supply or high demand — which leads to situations where there is not enough water for both human and ecosystem needs. Across the province we already face challenges balancing human and fish needs for water in some locations and on some years[12]. The Fraser River basin, in particular, shows the strongest overlap among water licenses, water allocation restrictions, population density, and salmon distribution in the province (Nelitz et al. 2009). This observation is not surprising given that the region has one of the lowest water yields per person in the country (Statistics Canada 2010). The provincial and federal governments inherently recognize the potential for conflict in the basin due to the extent of natural flow sensitivities, number of heavily developed aquifers, and existing water allocations restrictions (Rood and Hamilton 1995; BC MOE 2008; Government of British Columbia 2010). In recent years, groundwater observation wells have shown a large increase in the percentage of wells with declining levels due to human use (BC MOE 2008). Priority areas of concern related to groundwater use in the Fraser River basin include aquifers in the Lower Fraser Valley, near Merritt,

[12] Ministry of Environment. September 18, 2009. Information Bulletin – Water use reduction order to protect fish populations. See http://www.livingwatersmart.ca/news/docs/2009ENV0020-000367.pdf

lower Nechako River, and upper Shuswap (Government of British Columbia 2010). Moreover, large portions of the Thompson basin, Cariboo plateau, and upper Nechako are considered naturally flow sensitive, regardless of human use (Government of British Columbia 2010).

The potential for conflicts with sockeye salmon are driven by high water demands across a variety of sectors. Industrial, commercial, municipal / domestic, and agricultural withdrawals constitute the top consumptive uses in the province (BC MOE 2006), which is consistent with the top uses in the country (NRTEE 2010). In B.C., per capita rates of water consumption are among the highest in the country and the world, even though rates have generally been declining since the 1980s (BC MOE 2008). Agricultural production is also heavily reliant on consumptive water use, mostly for irrigation and livestock. Across the province 33% of farms rely on irrigation with 13-17% of cultivated lands dependent on irrigation – the highest dependency among provinces (Statistics Canada 2010; NRTEE 2010).

Potential impacts of water use on sockeye salmon habitats are related to alterations in water flows and temperatures. Consumptive use of surface water at critical times of year can reduce instream flows that constrain access to spawning habitats or in extreme cases dewater redds. Extraction of groundwater for irrigation can reduce the amount entering streams which provides important source of cold water and late summer / fall baseflows for migrating adults, rearing juveniles, and incubating eggs (Douglas 2006; Smerdon and Redding 2007). While reductions in both surface water and groundwater supplies can increase water temperatures which affect sockeye salmon adults and eggs.

To examine the significance of water use on sockeye salmon, we used the provincial water license layer to identify the location and amounts of water allocated for consumptive purposes across different sectors (i.e., licenses designated for municipal, domestic, residential, industrial, commercial, irrigation, or stockwatering purposes). We did not examine the significance of water licenses for non-consumptive purposes even though changes in the timing and magnitude of flow releases can affect sockeye salmon habitats. These effects are being explored, in part, by our examination of the operations of large and small scale hydroelectric facilities in the Fraser River basin (see Section 3.3). An analysis of the effects of other non-consumptive licenses is not possible given the need for a detailed understanding of site specific and yearly operating conditions for each license. We also used the water allocation restriction layer to identify streams and watersheds where additional water licenses are currently restricted and conflicts between water use and sockeye salmon might be highest (see Appendix 4).

These data represent the best sources of information for water use, but we acknowledge some significant limitations and weaknesses. Water use licenses represent the amount of water allocated in a river at a single snapshot in time, not actual rates of consumption (i.e., monitoring of water use and compliance with water license conditions does not occur). This gap is problematic because in many streams it has been recognized that water allocations exceed the amount of water available. Consequently for this study, there is no way to assess whether changes in water consumption over the last 15 years are related to declines of Fraser River sockeye salmon. Moreover, groundwater use is unlicensed and not monitored in a consistent way across the province or basin. DFO has recognized the lack of data related to volume and locations of use when developing habitat indicators under the Wild Salmon Policy (Stalberg et al 2009). This gap is problematic because actual water use can be higher than estimates using licenses given known linkages between groundwater and surface water supplies. Lastly, information describing water licenses (long term use) does not represent water allocated through temporary water permits (short term use) which is a regulatory tool being used in the oil and gas sector, an industry that requires an increasing abundance of water (Pembina and Forest Ethics 2010).

Figure 34 and Figure 35 represent the intensity of water use across Conservation Units as measured by total water allocation per year and per hectare, as well as the density of water allocation restrictions. A comparison of the correlation between these indicators revealed that they are largely independent measures of stress on water resources. A clear and perhaps obvious observation is that high water demand is associated with greater concentrations of people across the Fraser River basin, which also coincides with salmon habitats (Figure 36). By both measures migration corridors appear to have the greatest allocation of water through licensing and the greatest density of water allocation restrictions. The CUs of the Lower Mainland have the highest water allocations within their migration corridors, mostly assigned to agricultural purposes (e.g., Early Summer – Pitt, Chilliwack; Late – Cultus, Harrison (D/S), Harrison (U/S)). This observation is consistent with the earlier note that agricultural activities are greatest in areas adjacent to migration corridors. In contrast, the measure of density of water allocation restrictions identifies the Summer – Mckinley, Quesnel, and Late – Shuswap Complex as having the highest pressures within their migration corridors. Both measures of stress on water resources indicate concerns in some CUs that have spawning locations downstream of lakes, and identify the same CUs as having the highest stress: Early Summer – Kamloops; Late – Seton, Shuswap Complex, Kamloops). Figure 37 represents the kinds of water uses and proportions of the total being allocated to that use. The agricultural sector tends to have the greatest allocation across areas that affect spawning locations (lake influenced and tributary) and migration corridors. Allocations to urban activities are second, while industrial allocations tend to be relatively minor across habitat types.

4.0 Freshwater influences on Fraser River sockeye salmon

4.1 Assessment within Conservation Units

We used three approaches to summarize the abundance of data generated to describe habitats (Section 2.2) and freshwater stressors (Section 3.0) so we can begin to discern patterns and gain insights into possible hypotheses about freshwater influences on Conservation Units. First, we developed a series of cumulative stressor tables which summarize the (1) alignment among hypothesized stressors, habitat types, and Conservation Units, (2) relative intensity of and trend in disturbance (from analyses discussed in Section 3.0), and (3) cumulative level of stress on a Conservation Unit. Second, we plotted these cumulative stress results against the indicators of habitat vulnerability (from Section 2.2.4) to generate bivariate plots of the combined stress and vulnerability four each habitat type and Conservation Unit. Lastly, we developed a "dashboard" summary of the data available to describe population status, habitat vulnerability, and freshwater stressors specific to each lake Conservation Units across the Fraser River basin.

To summarize the cumulative level of stress affecting a Conservation Unit, we generated relative intensity scores within each stressor category using a k-means cluster analysis of the data generated for each landscape level stressor indicator. K-means clustering splits a set of values into a selected number of groups by maximizing between-cluster variation relative to within-cluster variation. The procedure allows the user to set the number of similar groups to be identified, which we set up to identify three distinct groups of stressor intensity (i.e., low, moderate, or high values for a stressor indicator).

Using the results from this technique, we then developed a matrix of derived scores for each of the defined stressor indicators where relatively low intensity for a stressor was given a score of 1, moderate intensity a score of 2, and high intensity a score of 3. Where time series data was available for stressors (i.e., forest harvesting and Mountain Pine Beetle disturbance) we modified the scoring based on whether the trend in the stressor appeared to be increasing (+1) or decreasing (– 1) over recent decades. Where a stressor did not spatially overlap with a habitat we assigned a fourth default stressor intensity category of "none", with an associated stressor score of zero (0). For each Conservation Unit, and within each habitat type, a cumulative stressor score was derived by summing individual scores across all applicable stressor types. By default, each stressor was weighted equally in this calculation.

We recognize the use of such a clustering method has limitations and should best be thought of as descriptive methods for pattern analysis. Given our general goal of discerning broad variation in stressor intensities across Conservation Units, we felt the method was well suited for our needs. Moreover, as noted in Section 2.2.4, this clustering provides a measure of the *relative* intensity of stressors across CU habitat types, and it should not be inferred that habitats experiencing a low intensity of stress are somehow immune from detrimental effects. Conversely, habitats defined as experienced high intensity stress or sockeye salmon utilizing those habitats may be sufficiently resilient to withstand those impacts without serious consequences. Further work would need to be undertaken to field validate relative differences across stressor categories. Table 11 to Table 14 provide a summary of the relative ranking of CUs according to the cumulative level of stress on lake influenced / mainstem spawning, lake inlet / tributary spawning, nursery lake rearing, and migration corridors, respectively.

Figure 38 illustrates our second approach to summarizing the complexity of information by combining the stress on and vulnerability of habitats across all lake Conservation Units by habitat type. These graphs are useful for clustering CUs into groups, where those having both high stress and high vulnerability would be less resilient and more prone to disturbance from human activities. If stressors in the freshwater environment are contributing to declines of salmon, then based on our analyses the CUs with high stress and high vulnerability would be the most likely candidates where the effects of freshwater influences could be detected. The ability to detect the effect of freshwater stressors will also depend on the type of habitat disturbance that is most likely to contribute to the declines. For instance, the list of CUs with both high stress on and high vulnerability of migration corridors (Nadina, Francois, Stuart, Fraser, and Takla / Trembleur Conservation Units), is different than those CUs with high stress on and high vulnerability of nursery lakes (Fraser, McKinley, Kamloops, Nadina, and Cultus Conservation Units). Likewise, the relative level of stress / vulnerability on lake influenced vs. tributary spawning is different across CUs.

Lastly, Figure 39 and Figure 40 illustrate our use of a “dashboard” summary to communicate the abundance and complexity of information generated through our analyses in this report. Relative to the summary figures (see Figure 5, Figure 7, and Figure 38) and tables (see Table 1, Table 5, Table 11, Table 12, Table 13, and Table 14) provided throughout this report, these dashboards provide the greatest level of detail describing the conditions and stressors affecting each Conservation Unit. These summaries are based upon Schindler et al.'s (2010) analogy of an investment portfolio as a way to organize and communicate information. With this analogy, we relate the productivity of Fraser sockeye salmon to the performance of a portfolio, which is based on the productivity of its underlying Conservation Units (or performance of its assets). We extend this analogy further by adding that the productivity of each Conservation Unit (i.e., asset or mutual fund) can be described using a prospectus which summarizes the underlying global (population status or ocean conditions) and local (habitat status or human stressors) factors that affect the performance of individual assets. We believe this analogy is useful because it helps clarify the way in which the performance of Conservation Units is nested within the performance of the Fraser aggregate, and helps clarify how there is a complex arrangement of factors that can affect performance. Like an investment portfolio, it is a daunting task to summarize the complexity of information that describes freshwater habitat conditions in a way that helps a person understand the drivers of recent trends in Fraser River sockeye salmon. The dashboards help in this regard by providing a snapshot of all the factors that contribute to the performance of a Conservation Unit. Furthermore, as with investment portfolios, past performance is not necessarily a predictor of future performance (particularly in consideration of the effects of climate change, see Hinch and Martins 2011).

Walking through the results presented for the Quesnel summer timing Conservation Unit illustrates how a user can quickly assess freshwater conditions for an individual Conservation Unit. Using Figure 39, the biological data provides an orientation on the dramatic declines in productivity since the late 1980s, in a period with years of relatively high escapement. The CU is set within a geographic context to orient the user to the location of its nursery lake within the central interior of the basin. Despite the declines, the population status has been rated as relatively good with high confidence. From a habitat vulnerability point of view, the Quesnel appears reasonably resilient due to the moderate migration distance, a relative large proportion of spawning locations being buffered by lakes, and a relatively moderate to large amount of nursery lake capacity.

Using Figure 40 to examine the freshwater stressors on this CU, we can quickly assess key threats on habitats. First, there is a low human population density across spawning and rearing habitat and a much higher density across the migration corridor. Disturbance to lands influencing spawning and nursery lakes is mostly due to Mountain Pine Beetle, while impacts on migration corridors are split across a variety of disturbance types (agriculture, urbanization, Mountain Pine Beetle). Road density associated with land use activities is moderate relative to other CUs. Small hydro is largely non-existent, while placer mining claims are very high in areas affecting the nursery lake and migration corridor. A relative abundance of other mines is also prevalent along the migration corridor. Allocation of water is dominated by agricultural uses, though the number of licenses is dominated by urban uses. Although the total allocation is at the lower end of water allocation across all CUs, the density of water allocation restrictions is relatively high in areas influencing nursery lakes and migration corridors of this CU. Appendix 3 provides the dashboard summaries for all lake Conservation Units across the Fraser River basin.

4.2 Assessment across Conservation Units

We undertook three tasks to assess whether freshwater habitat conditions and stressors on habitats have contributed to the recent declines in Fraser River sockeye salmon (summarized in detail below). First, we summarize key results from the recent work of scientists examining factors that could explain the declines (Selbie et al. in Appendix C of Peterman et al. 2010). This understanding is important for prioritizing our own analytical efforts and developing testable hypotheses that are comparable with the findings from other studies. Second, we analyzed the habitat and stressor data (generated through this effort) to test whether they could explain declines in productivity. Lastly, for those habitat and stressor variables for which we had time series data (i.e., forest harvesting, Mountain Pine Beetle disturbance, summer air temperatures across adult migration, and spring air temperatures at nursery lakes) we examined correlations with the total salmon and juvenile productivity indices developed by Peterman et al. (2010).

Selbie et al. (in Appendix C of Peterman et al. 2010), tested four hypotheses to examine whether changes in freshwater habitat conditions have contributed to the declines of Fraser River sockeye salmon. As the foundation to their analyses, they generated two measures of sockeye salmon productivity that are relevant to our study (see Peterman et al. 2010 for more details). A measure of freshwater or "**juvenile productivity**" was calculated as the annual abundance of juveniles (fry or smolts) per effective female spawner. This measure represents productivity across freshwater life stages. A measure of "**total productivity**" was calculated as the annual abundance of adult recruits per effective female spawner. This measure represents the productivity across all life stages of sockeye salmon, from eggs to adult returns. Noteworthy in the way they calculated total productivity, was the fact that the number of adult recruits included losses due to en-route mortality. To account for the effect of density dependence and allow researchers to more easily detect the effect of other factors on productivity, data from each stock and life stage were fit to a standard Ricker stock-recruitment equation. Annual residuals from the best-fit function were then obtained for each stock and used as indices of total productivity and juvenile productivity.

Using these indices of productivity, Selbie et al. first analyzed the trend in the decline of total productivity across stocks and whether they could be explained by habitat indicators or measures of landscape level stress on those stocks. Next, where data were available they examined whether changes in the productive capacity of nursery lakes (using photosynthetic rate, zooplankton biomass, and spawner production) could explain the declines. Given a limited data set, they also examined patterns of growth and survival of juveniles in nursery lakes. Lastly, they examined smolt outmigration timing to see if any discernable changes have occurred over time. Based on these analyses, they were unable to find any quantitative evidence to support the general hypothesis that declines in total productivity are related to changes in freshwater habitat conditions. An interesting observation, however, was that they found a relationship between migration distance and the trend in the decline across stocks (i.e., those with longer migration distances demonstrated more dramatic declines).

Similar to the work of Selbie et al. (in Appendix C of Peterman et al. 2010), we examined whether variation in the intensity of freshwater habitat stressors could be related to trends in total productivity (using the Ricker model residuals as described above and derived by Peterman et al. (2010)). In other words, we would expect the declines in total productivity to be more extreme in heavily impacted CUs if conditions of freshwater habitat are contributing to the declines. We applied the same analytical approach because of improvements in the data we generated to represent habitat vulnerability and freshwater stressors with our work. Similar to Selbie et al., we calculated the slope of the regression of Ricker residuals across brood years 1984-2004 for each of 17 sockeye salmon CUs (those with time series of total productivity). We then evaluated the trend in Ricker residuals in relation to: (1) our landscape level measures of stress on nursery lakes (i.e., derived using GIS as described in Section 3.0), and (2) measures of habitat vulnerability (i.e., migration distance, nursery lake area, nursery lake productivity, total spawning extent, and ratio of lake influenced spawning). The stressors used in the analysis included: road density, stream crossing density, level of forest harvesting (as a percent of area), accumulated level of Mountain Pine Beetle disturbance (as a percent of area), agriculture land (as a percent of area), urban land (as a percent of area), total water license allocations (volume/per year/ha), active mines (count), placer claims (count), and small scale hydroelectric operations (count).

We initially developed a simple correlation matrix of our full suite of freshwater vulnerability and stressor indicators in relation to the trend in Ricker residuals (Table 15). Migration distance (r = -0.57) and percent Mountain Pine Beetle disturbance (r = -0.46) were the only variables to show even a moderate inverse correlation with the trend, though migration distance and percent of Mountain Pine Beetle disturbance were highly correlated with each other (r = 0.95). There were many other strong correlations across the freshwater indicators (Table 15) which indicates a strong potential for confounding. To address this concern we modified our analytical approach from that of the simple linear regression model used by Selbie et al. (in Appendix C of Peterman et al. 2010) to an information-theoretic framework (Burnham and Anderson 1998) using Akaike Information Criterion (AIC) to identify regression models that could best explain the trend in Ricker residuals across sockeye salmon CUs (see Table 16). AIC is a relative ranking statistic, with AIC values being interpreted in terms of the magnitude of the differences among candidate models rather than the magnitude of any particular value (Thompson and Lee 2002). The approach gives a formal accounting of the relative plausibility of the estimated models and can be helpful in selecting the most plausible models (i.e., those with the lowest AIC scores) when confounding occurs (Paulsen and Fisher 2005).

We assessed 67 possible combinations of the freshwater vulnerability and stressor indicators to the indices of total productivity for sockeye salmon (i.e., trend in Ricker residuals). Each of the three highest ranked models (i.e., most plausible) had migration distance as a predictor variable, with the highest ranked model having migration distance as the sole predictor. The second and third ranked models had percent of Mountain Pine Beetle disturbance and road density as additional predictors, respectively. The explanatory value of the top model (migration distance alone) was low, however, with an adjusted $R^2 = 0.324$. Inclusion of the highly correlated percent of Mountain Pine Beetle disturbance in the second ranked model improved explanatory value only slightly ($R^2 = 0.341$), while the third ranked model had an even lower explanatory value ($R^2 = 0.296$).

Generally consistent with the earlier findings of Selbie et al., our analyses indicated that migration distance was the only freshwater variable to show an appreciably strong (negative) relationship to the trend in residuals (i.e., sockeye salmon CUs with greater migration distances seem to have done more poorly in recent years). We have no direct explanation for why migration distance emerged as a predictor of recent trends in total productivity. It may relate to differential exposure to a suite of stresses along the migration route; stresses which we attempted to quantify with our index of cumulative stress developed for migration corridor of each CU (see description in Section 4.1). Our index of the cumulative stress along migration corridors was negatively correlated with total productivity (r = -0.497), but this cumulative stressor indicator was also highly correlated with migration distance (r = 0.678), so these 2 factors are confounded. None of our other indicators of cumulative stress showed any correlation with total productivity (mainstem spawning, r = 0.163; tributary spawning, r = -0.0047; nursery lakes, r = -0.113). As noted by Selbie et al. (2010) distance from the ocean is also significantly correlated to other factors reflecting watershed position, including elevation and latitude, so migration distance may also be capturing parallel influences on total productivity that are unrelated to stresses associated with human activities.

For those habitat and stressor variables for which we had time series data (i.e., forest harvesting, Mountain Pine Beetle disturbance, summer air temperatures across adult migration, and spring air temperatures at nursery lakes) we examined correlations with total and juvenile productivity indices developed by Peterman et al. (2010) as described above. For these analyses we aligned the years of forest harvesting and Mountain Pine Beetle disturbance with the year of juvenile productivity that represented the year of fry emergence (i.e., brood year + 1). This alignment of years was used to best test for the potential influence of forest disturbances on egg-to-fry survival. For analyses of habitat conditions, we aligned the years of summer air temperature along the migration corridor to brood years, and years of spring time air temperature at the nursery lake to the year of ocean entry (i.e., brood year +2). Again this alignment was necessary to accurately test for the effect of available habitat conditions on total productivity of sockeye salmon. Note that the effects of summer air temperature on en-route mortality are already accounted for in estimates of recruitment and Ricker residuals (as described above); this analysis explores any additional effects on total productivity.

Results of the analysis between total productivity and the two habitat indicators are presented in Table 17. To account for the fact that we are conducting multiple comparisons, we used a Bonferonni adjustment to the alpha level to detect significance (i.e., P value divided by the number of comparisons or P = 0.005 in our case). This adjustment was made because by chance alone we would have expected 1 in 20 stocks to have a significant, though spurious, correlation. When examining correlations between total productivity and summer air temperature across adult migration, 16 stocks had negative correlations (i.e., years with warm summer air temperature along the migration corridor tended to be associated with years of lower total productivity), though only 1 was significant. Similarly when examining correlations between total productivity and spring time air temperatures at the nursery lake, 14 stocks had negative correlations (i.e., years with warm spring air temperatures at the nursery lake tended to be associated with years of lower total productivity), though none were significant. The plausibility of a mechanism underlying a relationship between air temperature and total productivity is questionable given that the total productivity index already accounts for en-route mortality (as described above). In contrast, however, the plausibility of a potential relationship between nursery lake air temperatures and total productivity is more likely (see Section 2.2.1). Despite the plausibility of the underlying mechanisms there are no significant correlations and a lack of consistency in direction of the correlation coefficients across stocks, which suggest the relationship is spurious or that some air temperature indicators are weakly correlated with other factors that have an influence on total productivity. In examining correlations between juvenile productivity, forest harvesting, and Mountain Pine Beetle disturbance, we found no significant correlations across any of the 8 stocks for which there are juvenile productivity data.

4.3 Summary and conclusions

In this report we use the best available data to quantitatively describe the status of Fraser River populations of sockeye salmon (Section 2.1), vulnerability of freshwater habitats that support migration, spawning, and rearing life stages (Section 2.2), and human stressors interacting with those habitats (Section 3.0). Table 18 provides a simple summary of the population status, habitat vulnerability, and relative level of cumulative stress on habitats for each Conservation Unit. We then summarize these data for each Conservation Unit to help gain insights into possible hypotheses about freshwater influences on different Fraser River populations (Section 4.1 and Appendix 3). Finally, we analyze these data to determine whether habitat vulnerability and freshwater stressors are related to trends in productivity or current population status (Section 4.2).

For freshwater life stages of Fraser River sockeye salmon, there is a complex pathway of effects that results from changes in human stressors to changes in habitat conditions to changes in abundance of sockeye salmon populations. Many habitat conditions can be affected by multiple stressors and the biological effects on survival and growth interact to produce an outcome at the population level (see Figure 41). Unless data have been collected using experimental design principles, it is often difficult or impossible to conduct a statistical test of cause and effect that will answer whether a particular stressor or group of stressors has resulted in a particular habitat change or population level effect. The lack of experimental design certainly relates to our inability to test for cause and effect relationships between the freshwater environment and Fraser sockeye salmon declines. An alternative approach is to evaluate the quantitative and qualitative evidence in a structured and rigorous way, where the outcome of the exercise is an evaluation of the "weight of evidence" to reach a conclusion about significance. Stewart-Oaten (1996) propose the use of a series of questions to structure scientific evaluations of evidence for determining cause and effect. This series of questions can be asked in order which provide a summary of the weight of evidence in favour or against a particular cause and effect relationship.

Our assessment of the cumulative effect of freshwater stressors suggests that the recent declines in Fraser River sockeye salmon are unlikely to be due to changes in freshwater habitats (see Table 19). An important piece of evidence in reaching this conclusion is that juvenile survival has remained relatively stable across CUs where data are available (see Peterman et al. 2010), even though there is substantial variation in stressor intensity across CUs. In the literature, there is strong evidence that the stressors examined here can lead to declines and extinctions of populations in a variety of species, including sockeye salmon. A consideration of individual stressors (see Table 20, Table 21, and Table 22) suggests that the highest levels of overall stress are generated by forest harvesting and roads, while water use and large hydro also generate significant stress for individual CUs.

The effect of freshwater stressors on sockeye salmon population resilience is difficult to detect in this type of analysis. Higher density independent survival can lower resilience without noticeable effects on population numbers. High freshwater resilience allows populations to recover quickly from transient stressors and to compensate for lower spawning escapements. Stressors that induce higher density independent mortality may have no noticeable effects unless another factor creates additional stress on the population.

5.0 State of the science

The state of the science related to freshwater ecology can best be described by understanding the state of knowledge and state of data related to Fraser River sockeye salmon. In regards to the state of knowledge, sockeye salmon are one of the most well studied fish species in the world and agencies have historically emphasized monitoring of key Fraser River populations. Consequently, their basic ecology is relatively well understood (Burgner 1991). This strong foundation has helped with implementation of the Wild Salmon Policy (DFO 2005). Specific efforts have focused on delineating sockeye salmon populations into distinct Conservation Units using three major axes: ecology, life history, and molecular genetics (Holtby and Ciruna 2007). The cause-effect pathways of natural and human stresses on stream and watershed processes leading to alterations of sockeye habitats are well documented. Consequently, our general understanding of the interaction among freshwater life stages, habitats, and human stressors has allowed for the identification of defensible indicators to monitor habitat condition (Stalberg et al. 2009). However, our knowledge about the specific effect of human stresses on sockeye salmon habitats is largely dependent on the frequency and intensity of disrupting events and the vulnerability of affected habitats. The strength and form of the relationship between a particular stressor (or the cumulative / synergistic effect of multiple stressors), changes in freshwater habitat condition, and related changes in sockeye salmon survival / productivity remains largely unknown. Moreover, we lack an integrated understanding of how freshwater and marine conditions influence survival and productivity at different life stages and across the entire life cycle.

In regards to the state of data, we have reasonable data related to adult abundance (recruits and spawners), extent of spawning habitats, and nursery lake conditions for strong stocks in the Fraser River. For the human stressors considered in this report, we have reasonable data describing the spatial distribution and intensity of disturbance related to hydroelectric development, forest harvesting, road development, and Mountain Pine Beetle. We also have a reasonable understanding of the spatial distribution of mining, urbanization, and agriculture. However, there are substantial data gaps. Given the emphasis on monitoring strong stocks, we lack good information describing abundance and survival across freshwater life stages of many weak stocks and in-river populations. Similarly, there is a lack of data that consistently quantifies the quality of migratory, spawning, and rearing habitats across all Conservation Units (i.e., both strong and weak stocks). We lack time series data for almost all human stressors considered in this report and for a subset of stressors we lack data on intensity of disturbance (e.g., water use, log storage, agriculture, mining, and urbanization).

6.0 Recommendations

As discussed in Section 1.0, freshwater habitats are known to contribute to the overall diversity and resilience of sockeye salmon. Thus, protecting freshwater habitats is important to the conservation of Fraser River sockeye salmon, even though recent declines are not likely to be directly linked to deterioration in habitat conditions.

Section 5.0 highlights that there are significant data gaps which hinder our ability to effectively manage sockeye salmon populations, habitats, and human activities. Long term and consistent monitoring of a mix of sockeye salmon populations embedded within well planned geographically-based experimental comparisons would help scientists and managers better understand the cause and effect relationships between human activities and resultant sockeye salmon habitat and population responses. However, identifying unique monitoring recommendations that will help improve the state of knowledge and quality of data is a challenge because others working with the sole purpose of identifying monitoring requirements have already reported on key information gaps and the reasons to address them (e.g., Day 2007; Nelitz et al. 2008; Stalberg et al. 2009; Selbie et al. in Appendix C of Peterman et al. 2010; also see Wild Salmon Policy advisories from Pacific Fisheries Resource Conservation Council at www.fish.bc.ca). Despite our heightened awareness of the needs, below we reiterate what we believe are some key recommendations to improve our ability to conduct scientific inquiries into cause and effect, and improve decision making related to land use, water use, and management of freshwater habitats and sockeye salmon populations.

To improve our understanding about survival at critical freshwater life stages scientists need better estimates of juvenile abundance, overwinter survival, and mortality during smolt outmigration. Some data are currently available though for only a few populations and with limited time series. This lack of information means it is difficult to conclusively test for cause and effect between freshwater habitat conditions, human stressors, and salmon productivity across many Conservation Units. If survival in the freshwater life stage is found to be a more important contributor than determined in this report, then management actions can be taken to mitigate impacts on survival.

To improve our understanding about population status across Conservation Units scientists need more information about the abundance and distribution of small lake and all river CUs, though we recognize that filling this gap may be impractical for river CUs. Existing programs for monitoring fry and adults are essential for understanding status, but historically resources have been dedicated to large lake Conservation Units. This emphasis is inconsistent with the Wild Salmon Policy which places importance on protecting diversity of populations. Ensuring conservation of small CUs could have dramatic effects on harvest policies and in-season management.

To improve our understanding about habitat status across Conservation Units scientists need information on habitats monitored in a consistent manner on a regular basis across a larger number of rivers and nursery lakes (i.e., expanded in-river monitoring and limnology programs). The current approach to monitoring habitat condition and stressors is largely *ad hoc*, with monitoring responsibilities distributed across many different government agencies. Habitat evaluations tend to focus on a particular issue (i.e., linkage to a specific habitat variable or stressor activity) in a particular location using a particular methodology. Without a consistent and repeatable methodology much of the information on trends is lost and comparisons across Conservation Units are not possible. In addition to monitoring habitat condition and stressors, it is equally important to track and rigorously monitor the policies and practices taken to protect freshwater habitats and reduce the adverse effect of stressors.

To improve our understanding about the population level effects of stressors on freshwater habitats scientists need more precise estimates of the biological consequences of disturbance as a function of increasing stress. For most human stressors the general mechanisms of effect are known, but estimates of the population level significance of a given stressor level are crude, especially when occurring in the presence of other types of stressors. Attempts to define such thresholds have had limited success (e.g., determining Equivalent Clearcut Area thresholds), but their delineation is a key requirement for more defensible decision making. Once available, this information could be used to model the “environmental envelope” for persistence of sockeye salmon in freshwater habitats so that future conflicts might be better anticipated and avoided. Given the importance and extent of legislation and policies designed to govern land and water use, we believe this gap is critical to fill. Without this information managers can not ensure that policies are achieving their intended objectives of protecting freshwater habitats and reliant fish species like sockeye salmon.

To improve transparency in the science and related decision making scientists, managers, and the public need information that is more accessible. The high level of public interest in the work of the Cohen Commission highlights the large number and diversity of audiences interested in understanding the complex ecology of Fraser River sockeye salmon. Similarly, the challenges of independent scientists working for the Cohen Commission to acquire and compile the necessary data in a useable format for analyses have revealed the lack of integration in data collection and sharing across and within government agencies.

For improved access to information by stakeholders, better communication tools are needed to relay the status of sockeye salmon and clarify expectations for returns in the face of large uncertainties. Though very detailed and technical in nature, the dashboard summaries in this report could be used as a model for condensing large quantities of information into a more digestible summary for the informed public. Web-based platforms such as the Community Mapping Network (http://www.cmnbc.ca/) or HectaresBC (http://www.hectaresbc.org/app/habc/HaBC.html) could be expanded to consolidate and convey population, habitat, and stressor information for sockeye salmon, or examples from elsewhere in the Pacific Northwest could be used to develop a new model for summarizing and reporting out on fish and fish habitat information (e.g., Columbia Basin's Fish and Wildlife Authority's (CBFWA) Monitoring Strategies and Status of the Resource reporting, http://www.cbfwa.org/index.cfm).

For improved access to information by scientists, formal data sharing agreements, pooling of resources for monitoring, and more integrated decision making are needed. The current lack of consistency and integration of monitoring programs exist because many federal and provincial agencies are responsible for collecting, summarizing, and reporting out on key variables of relevance to Fraser River sockeye salmon (e.g., Fisheries and Oceans Canada, Environment Canada, Ministry of Natural Resource Operations, Ministry of Forests, Mines, and Lands, and Ministry of Environment). Others have commented in more detail on the need and ways to improve integration (Day 2007; Nelitz et al. 2008), but at the core is a need to have a well resourced body of scientists (in terms of staff and funding) to coordinate an integrated or harmonized fish and fish habitat monitoring program. A useful working example is the Columbia Basin Fish and Wildlife Authority (CBFWA) and its associated Members Advisory Group comprised of federal, state, and tribal entities in the Columbia River basin (member's charter available at http://www.cbfwa.org/RegionalIssues/Correspondence/CBFWA/CBFWACharterAdopted_20April2010_FINAL.pdf).

7.0 Figures

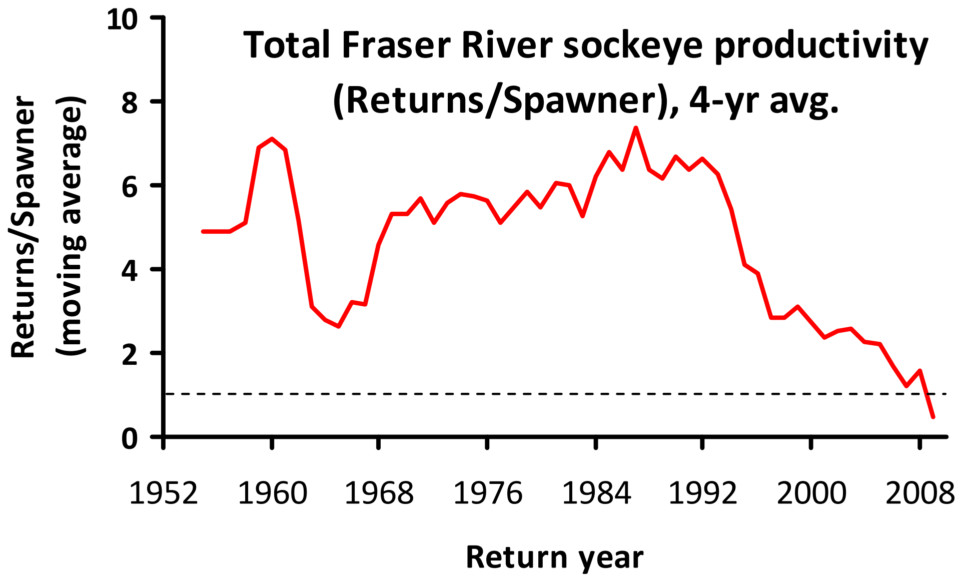

Figure 1. **Four-year moving average of total adult returns per spawner across all Fraser River sockeye salmon stocks divided by total spawners 4 years before. Note this averaging reduces annual variation. The horizontal dashed line indicates the productivity at which the population can replace itself. Data from the Pacific Salmon Commission.**

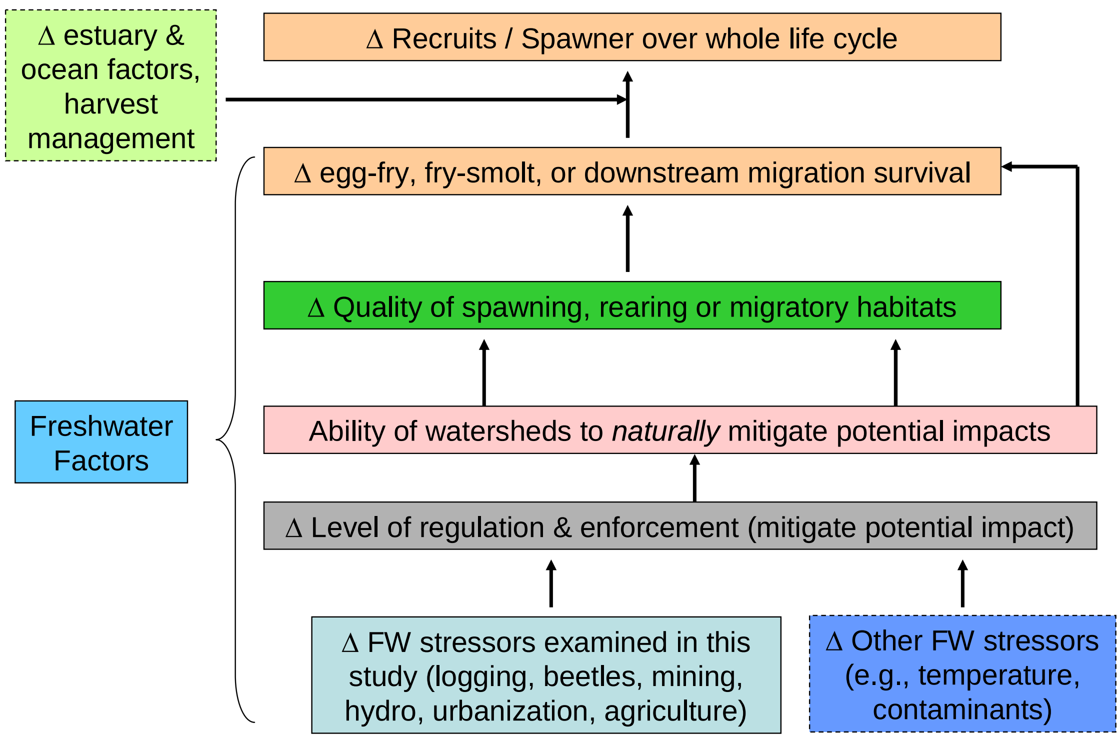

Figure 2. **Conceptual model of the factors considered by this study (boxes with solid lines) and relevant factors considered by other Cohen Commission studies (boxes with dashed lines).**

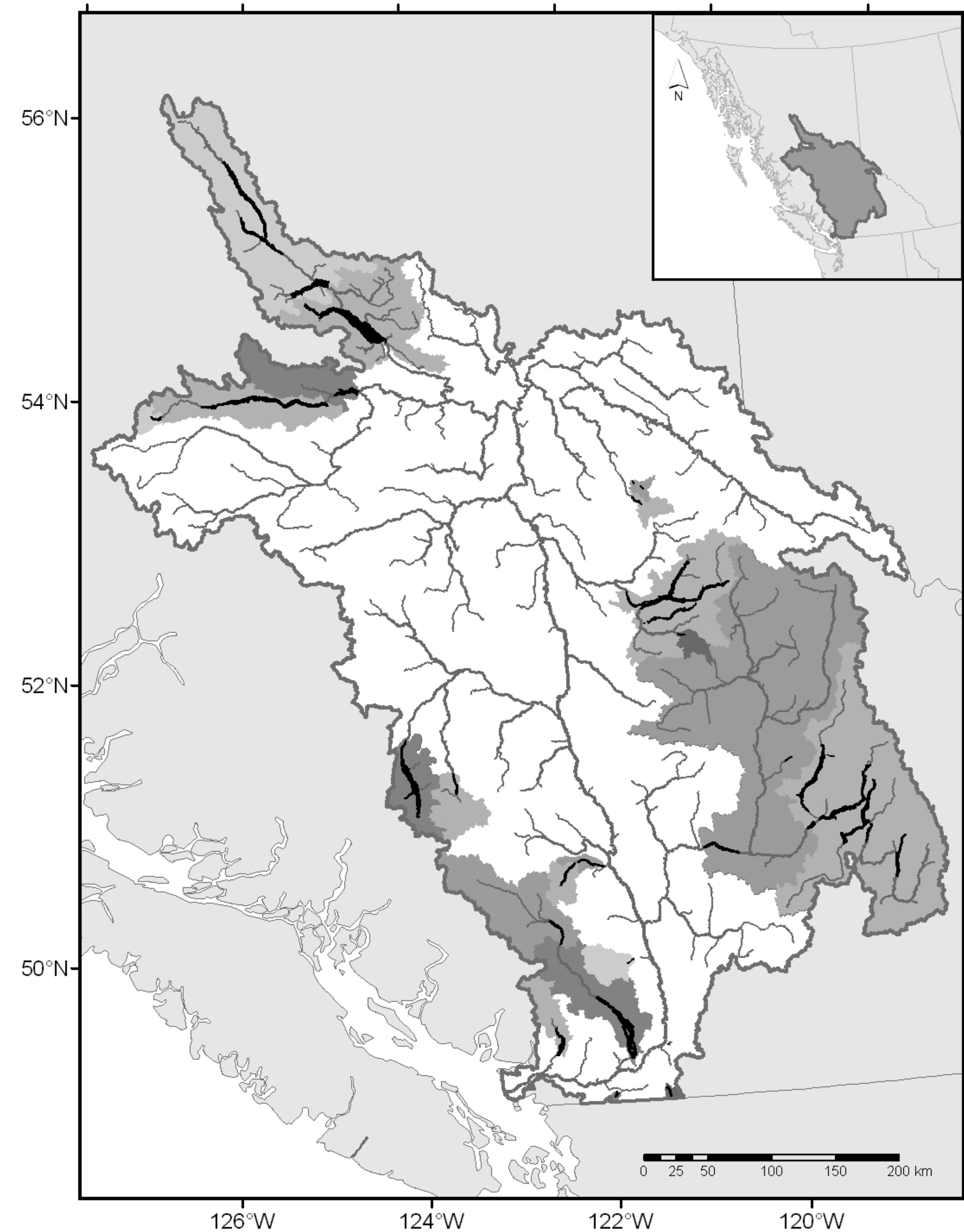

Figure 3. Overview of the Fraser River basin, watershed boundaries (in shades of grey), and nursery lakes (in black) for all lake sockeye salmon Conservation Units. Note that different shades of grey are used to represent the upstream watershed boundaries for different CUs. In some cases several CUs overlap and as a result their boundaries only appear once.

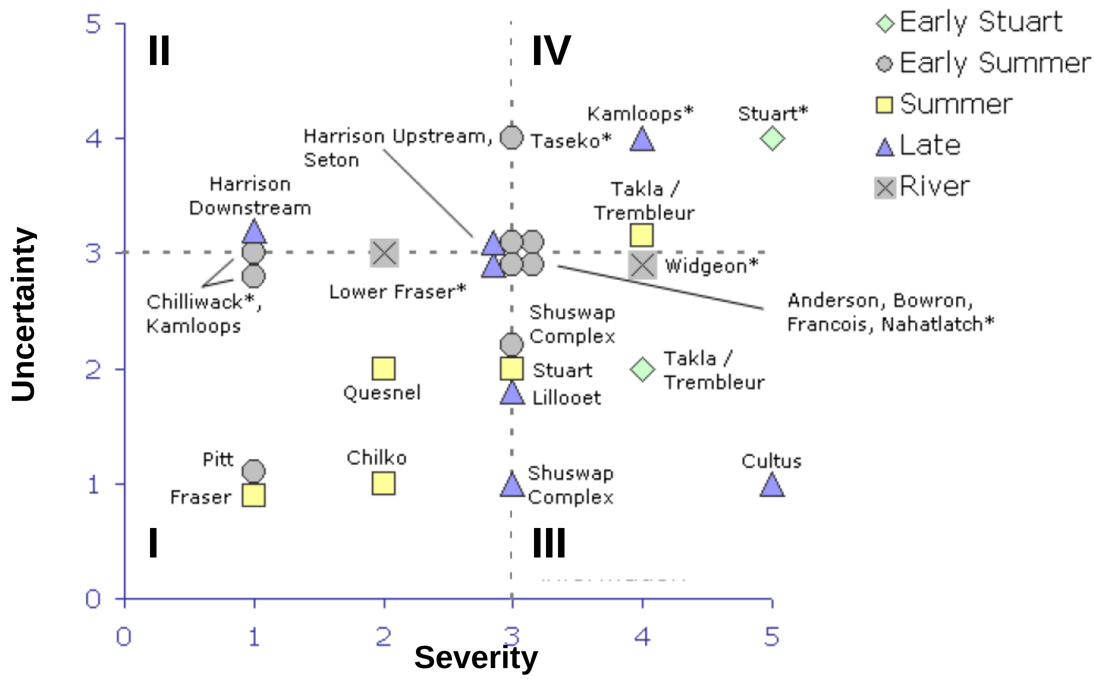

Figure 4. **Summary of the status for 36 sockeye salmon Conservation Units into four risk categories: IV – status probably poor, but little information; III – status poor, high confidence; II – status probably good, high uncertainty; and I – status good, high confidence. Eleven other CUs are classified as having insufficient information (Early Summer – Chilko, Fraser, Indian / Kruger, and Nadina; Summer – Francois and McKinley; Late – Kawkawa; River: Fraser Canyon, Middle Fraser, Thompson, and Upper Fraser). Image and data from Pestal and Cass 2009.**

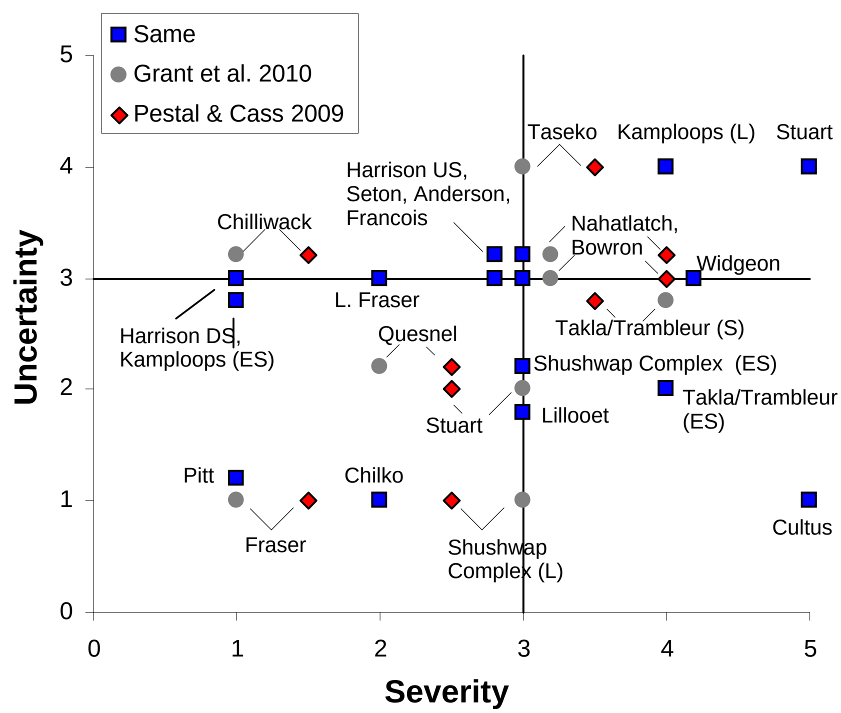

Figure 5. **Modified conservation status for some CUs based on work of Grant et al. (2010). Blue squares indicate conservation status that did not change as a result of Grant et al.'s work. Grey circles represent conservation status as determined by Pestal and Cass (2009), and red diamonds represent modified CU status based on input from Grant et al. (2010).**

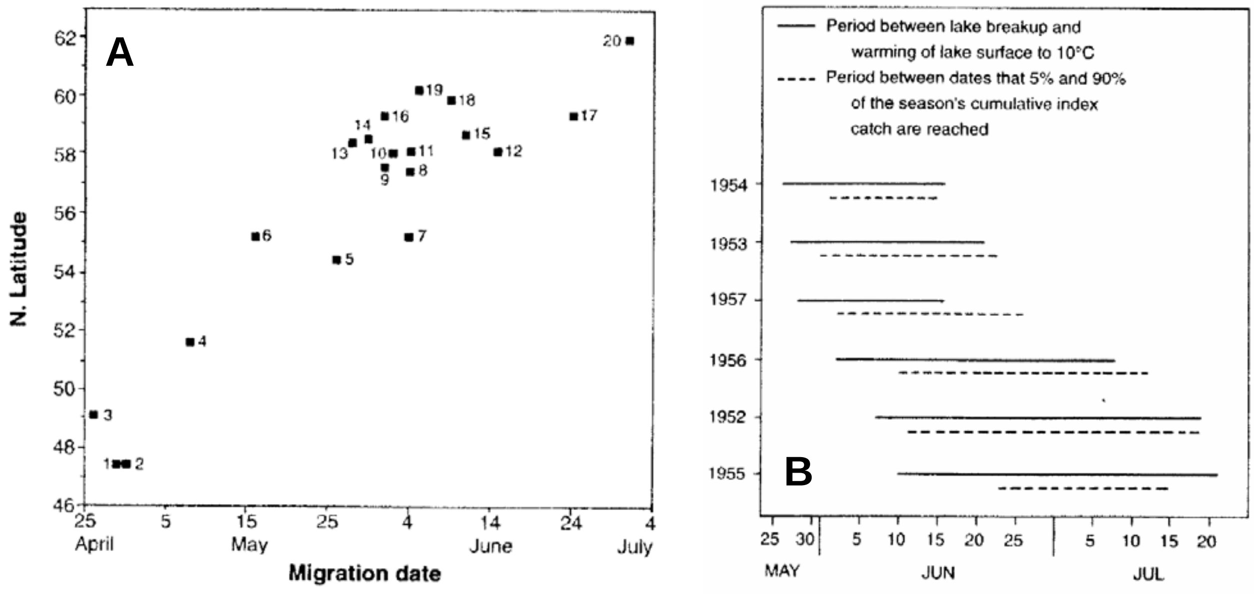

Figure 6. **<u>Panel A:</u> Timing of smolt outmigration as a function of latitude across multiple nursery lakes in BC and Alaska. <u>Panel B:</u> Timing of lake ice breakup within a single nursery lake in Alaska. Images from Burgner (1991).**

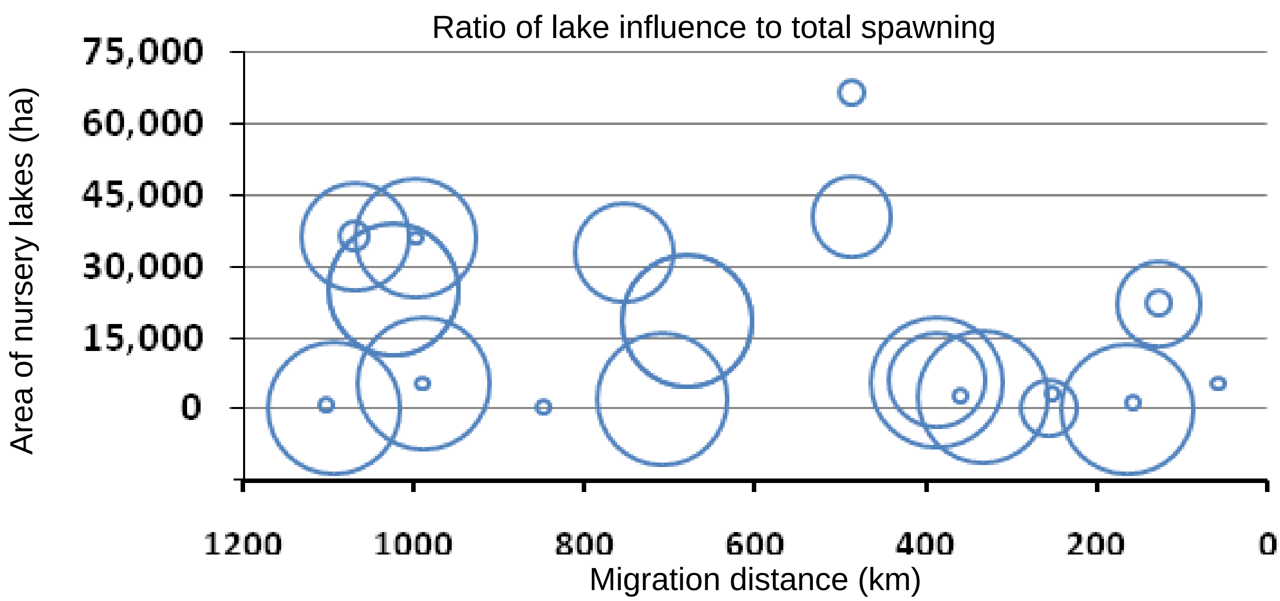

Figure 7. **Summary of the habitat vulnerability for all lake sockeye salmon Conservation Units using three independent indicators of habitat quantity / quality: migration distance (x-axis), total area of nursery lakes (y-axis), and ratio of lake influence to total spawning (size of circles). The Conservation Units with the most vulnerable habitats would appear as small bubbles in the bottom left corner of this graph, while Conservation Units with the least vulnerable habitats would appear as large bubbles in the top right corner. A summary of habitat vulnerability for the 6 river-type Conservation Units is unavailable due to a lack of information on locations of habitat use.**

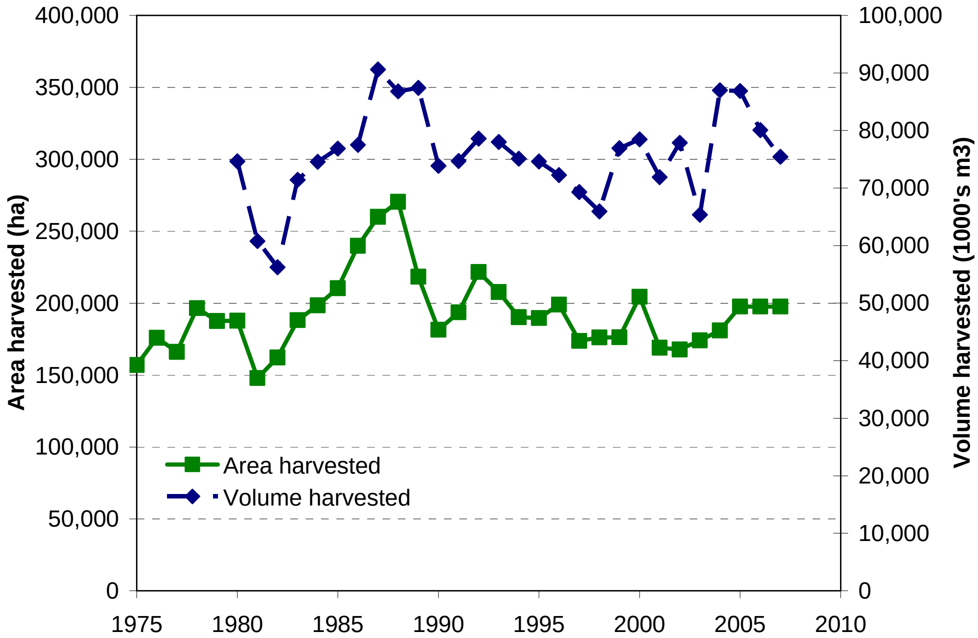

Figure 8. Area (in hectares) and volume (in 1,000s m[3]) of harvested forest in British Columbia from 1975 to 2007 (data from Statistics Canada 2009).

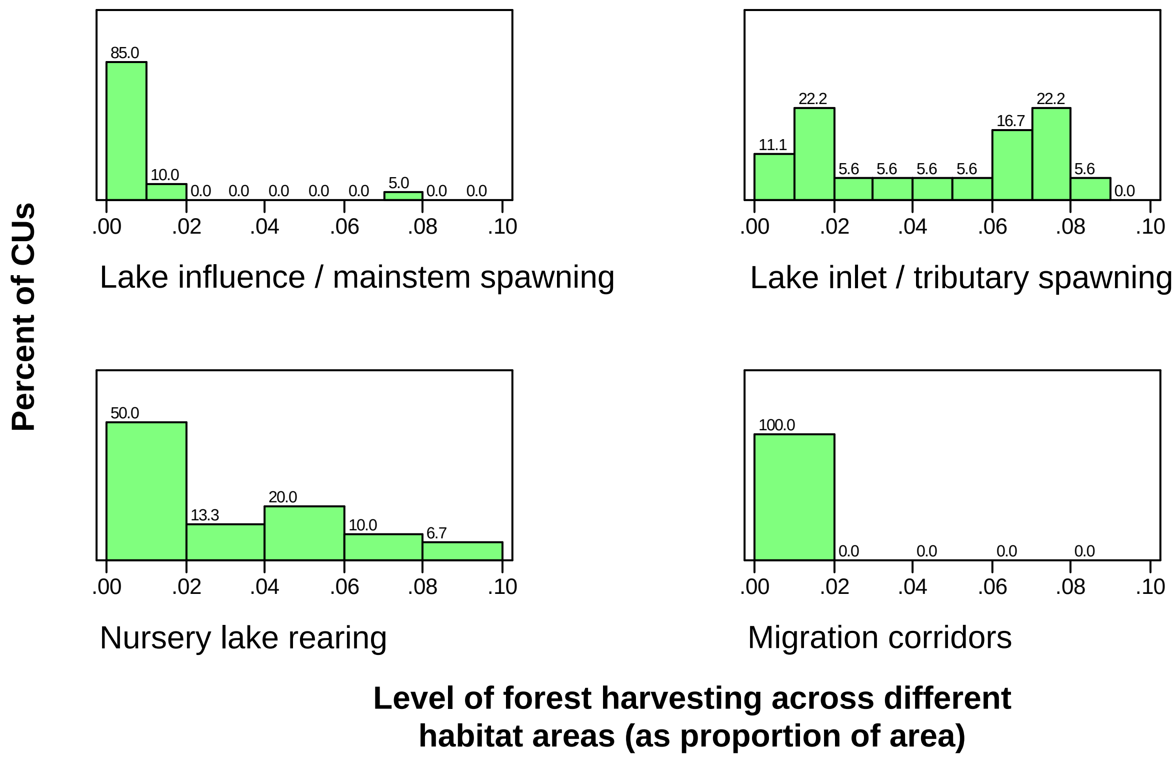

Figure 9. Frequency distribution of the level of forest harvesting within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.

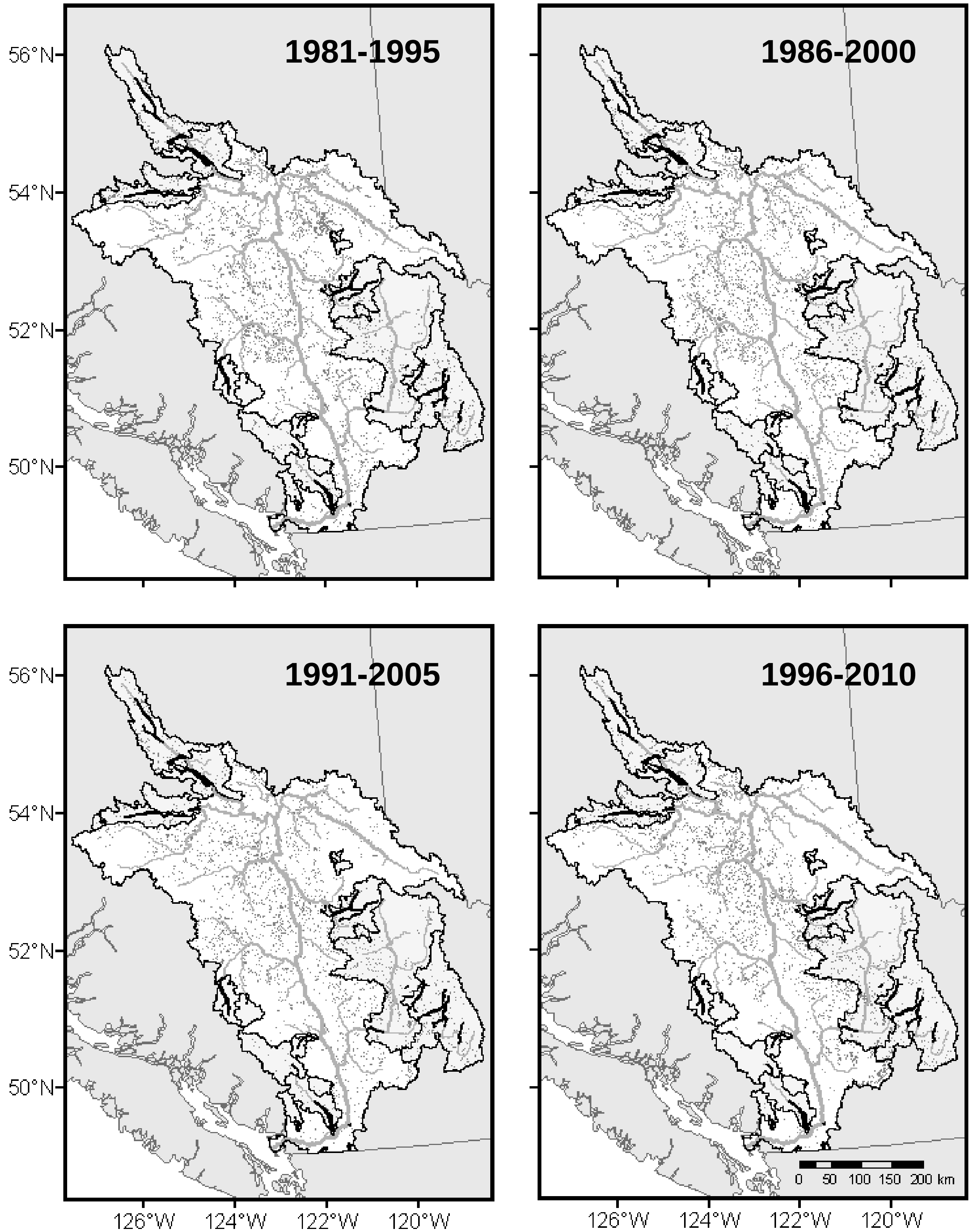

Figure 10. Spatial distribution of forest harvesting cutblocks relative to watershed boundaries (light grey shading) for all lake sockeye salmon Conservation Units. Forest harvesting cutblocks (scattered points of dark grey shading) represent the cumulative level of forest harvesting across four time periods. Nursery lakes are in black.

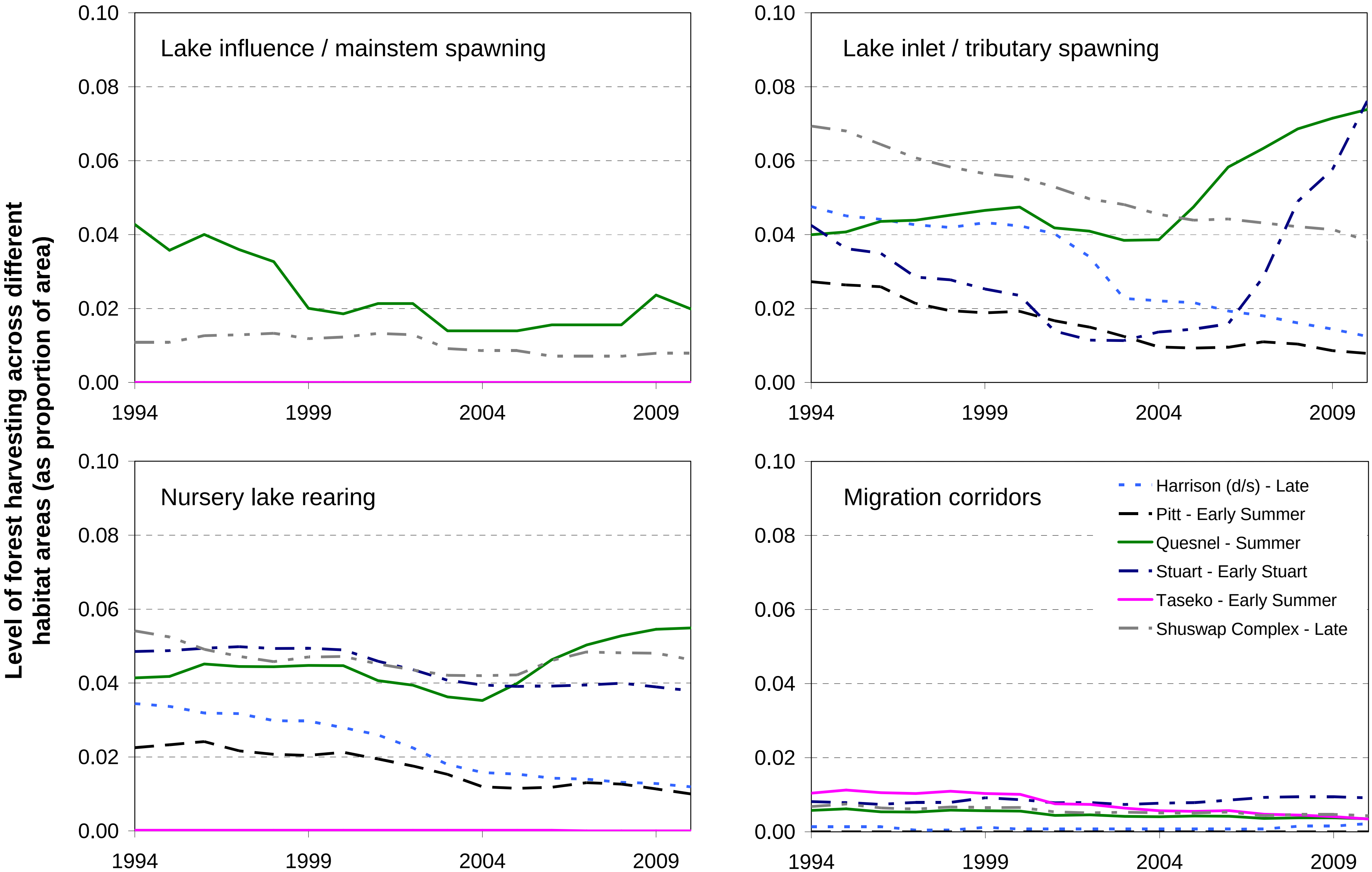

Figure 11. Time series of the level of forest harvesting within "zones of influence" for each habitat type across six Fraser River lake sockeye salmon Conservation Units.

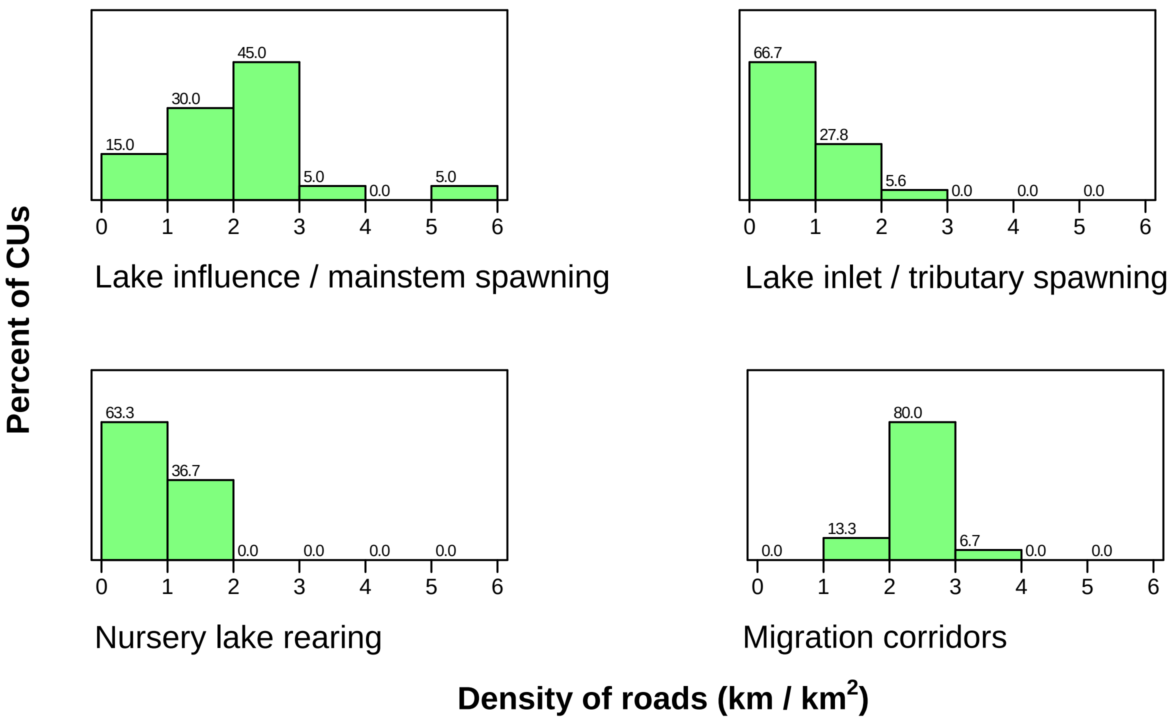

Figure 12. **Frequency distribution of the density of roads (km / km2) within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.**

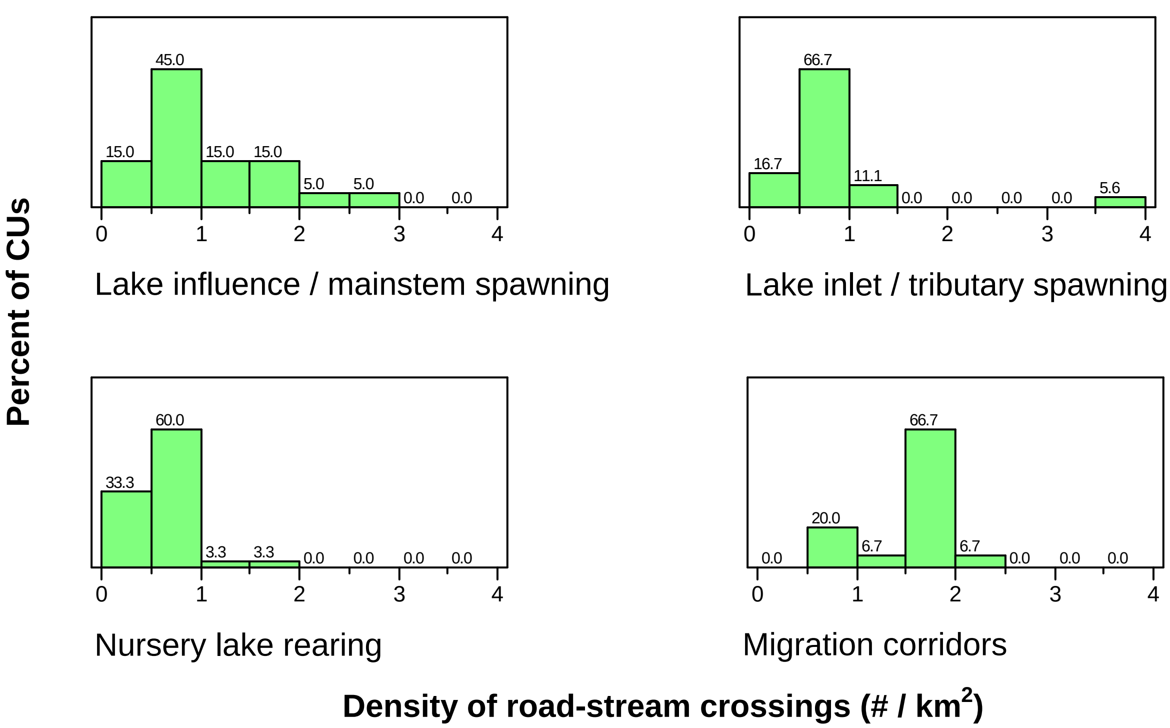

Figure 13. **Frequency distribution of the density of road-stream crossings (# / km2) within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.**

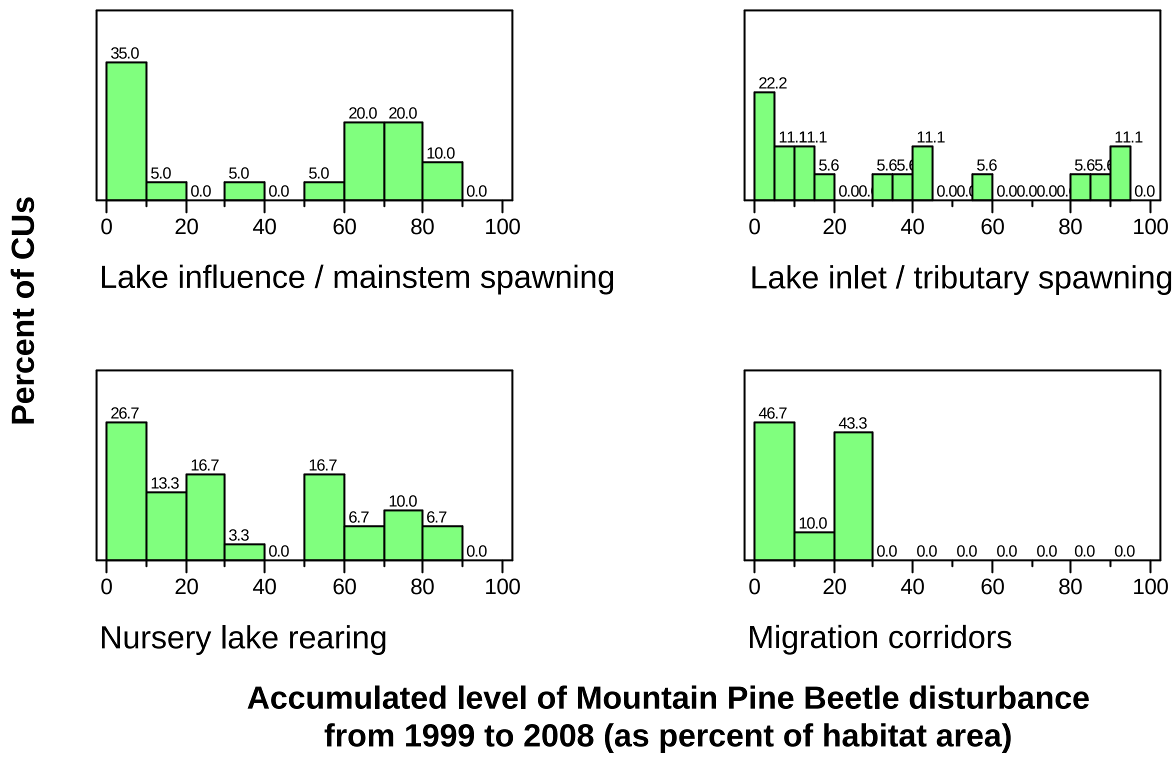

Figure 14. Frequency distribution of the accumulated level of Mountain Pine Beetle disturbance from 1999 to 2008 within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.

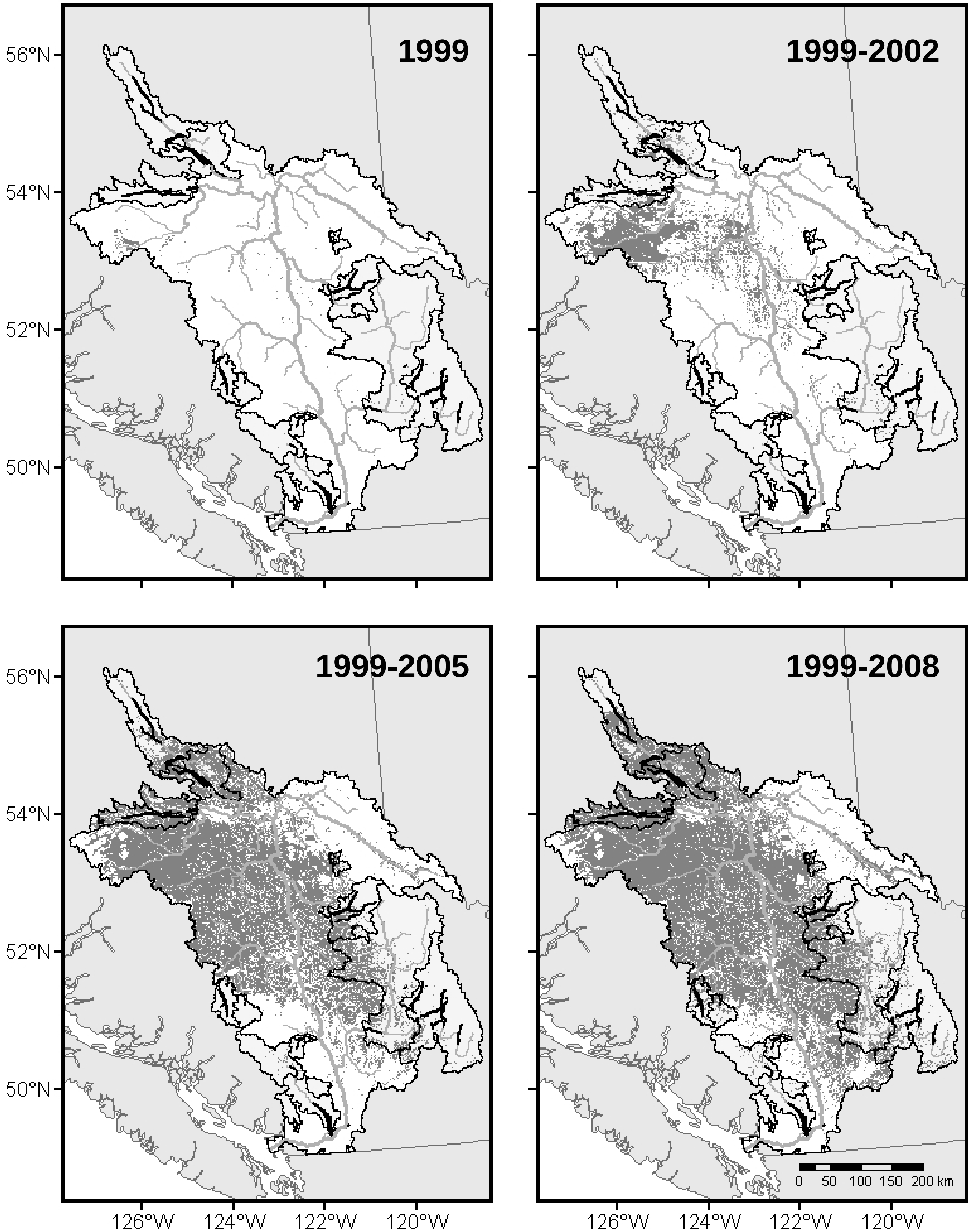

Figure 15. Spatial distribution of the accumulated level of Mountain Pine Beetle disturbance from 1999 to 2008 (dark grey shading) relative to watershed boundaries (light grey shading) for all lake sockeye salmon Conservation Units. Nursery lakes are in black.

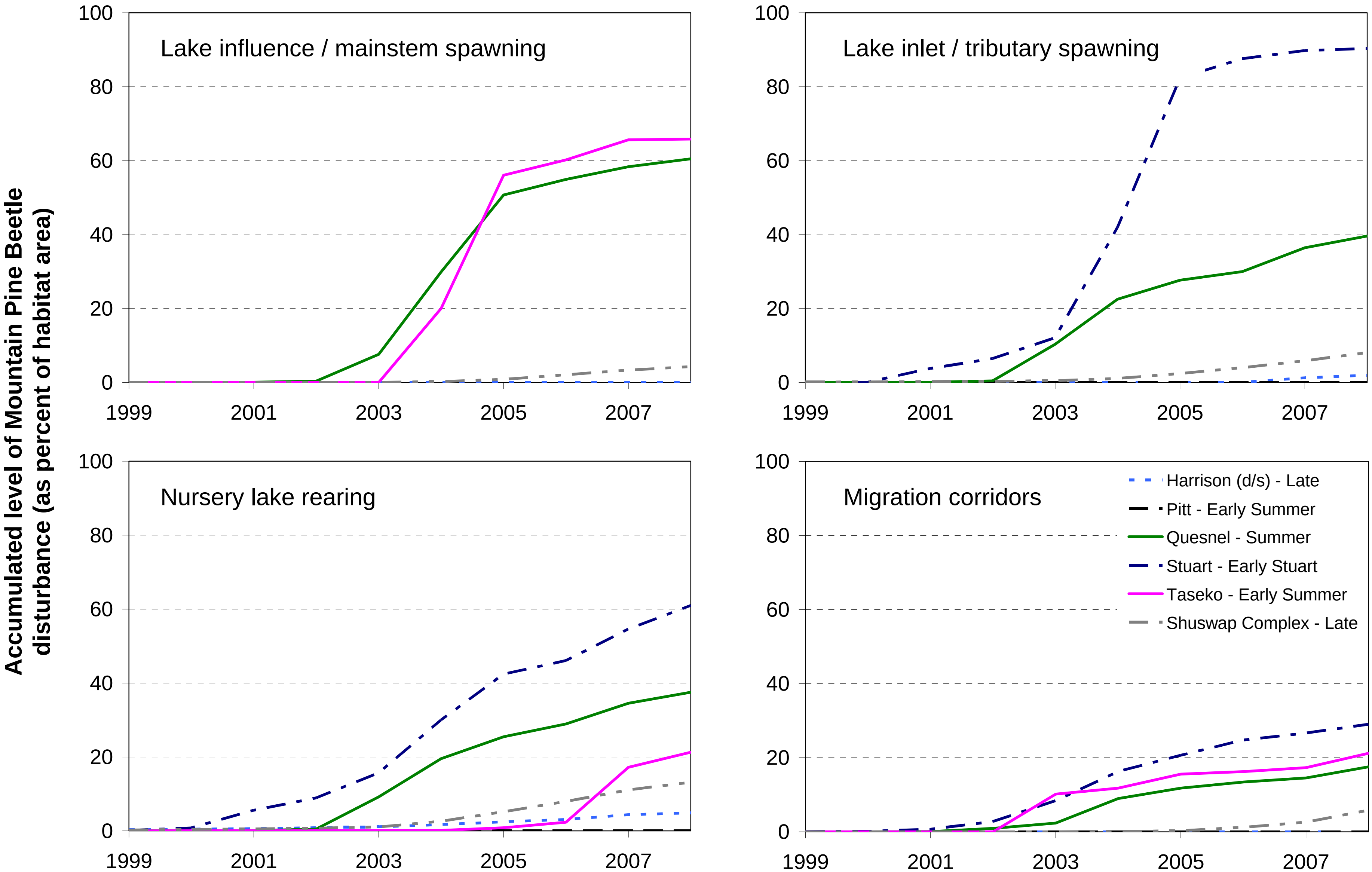

Figure 16. Time series of the accumulated level of Mountain Pine Beetle disturbance from 1999 to 2008 within "zones of influence" of each habitat type across six Fraser River lake sockeye salmon Conservation Units.

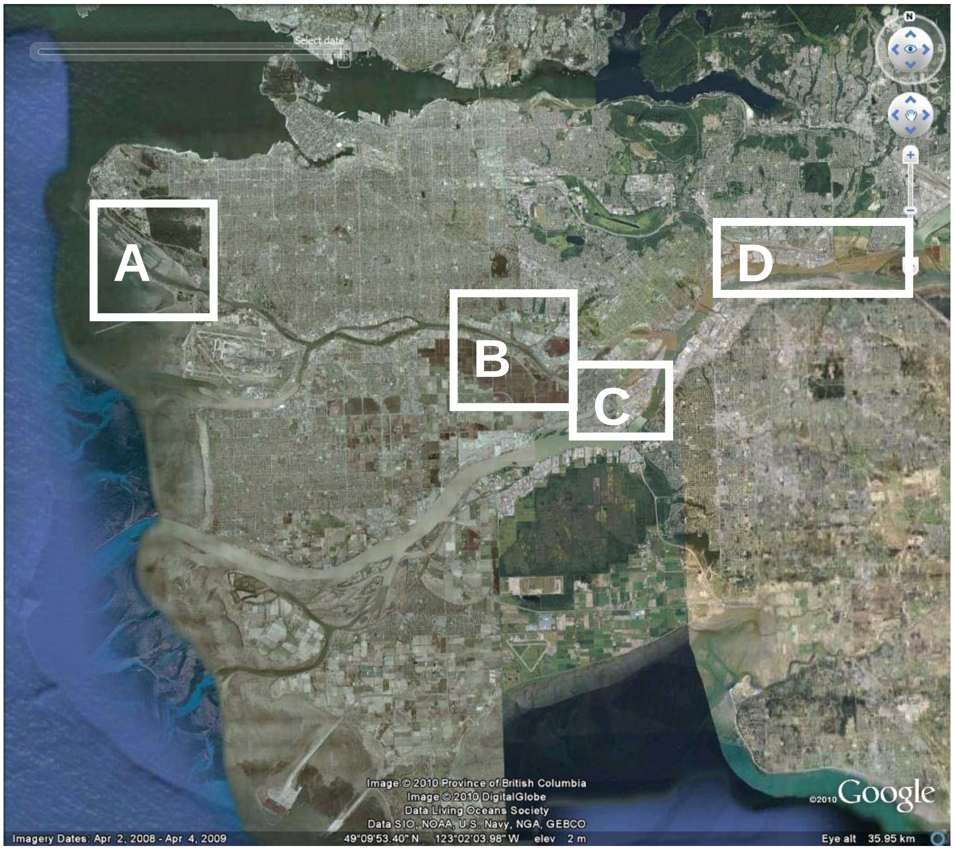

Figure 17. Aerial photo overview of the lower reaches of the Fraser River and estuary in 2009. Boxes A-D delineate areas with the highest relative concentrations of log storage across all years examined.

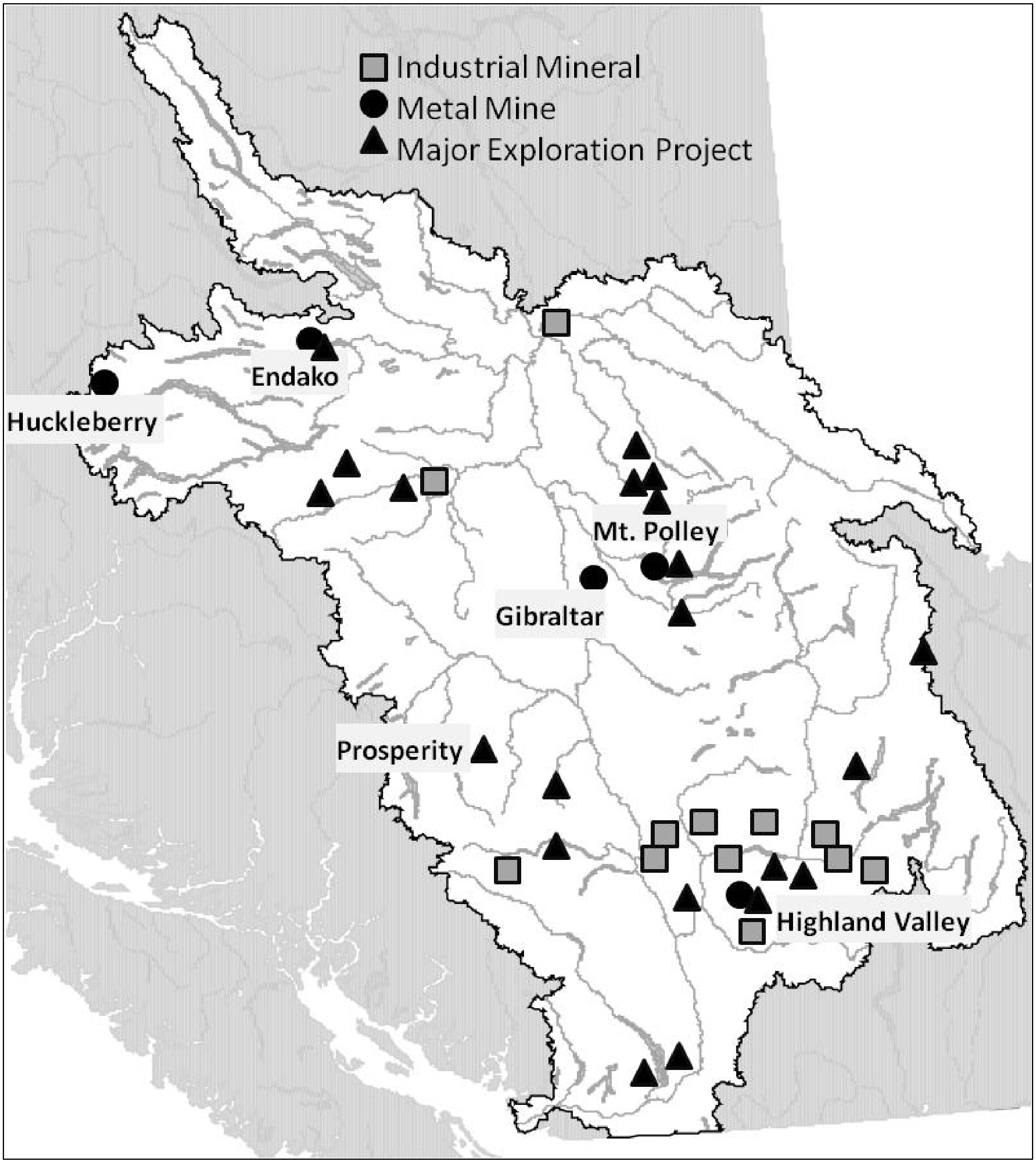

Figure 18. **Overview of the distribution of main categories of mines across the Fraser River basin.**

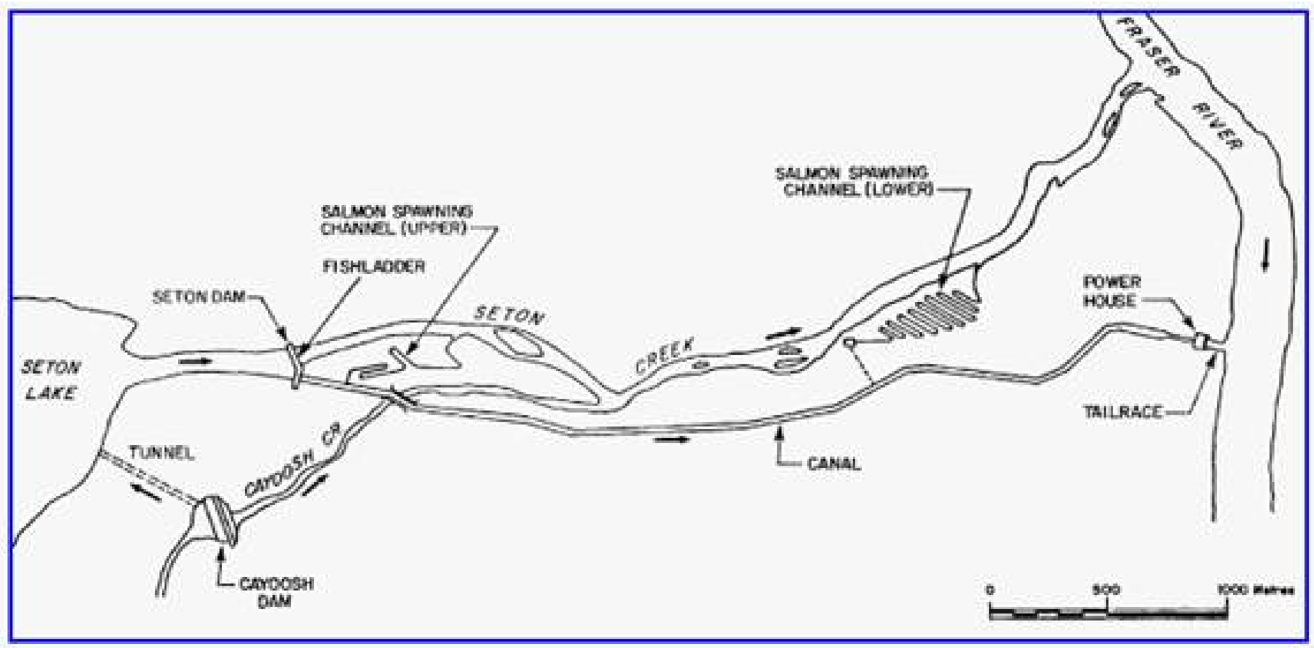

Figure 19. **Schematic representation of the development of the Seton / Cayoosh diversion (from Roscoe and Hinch 2008).**

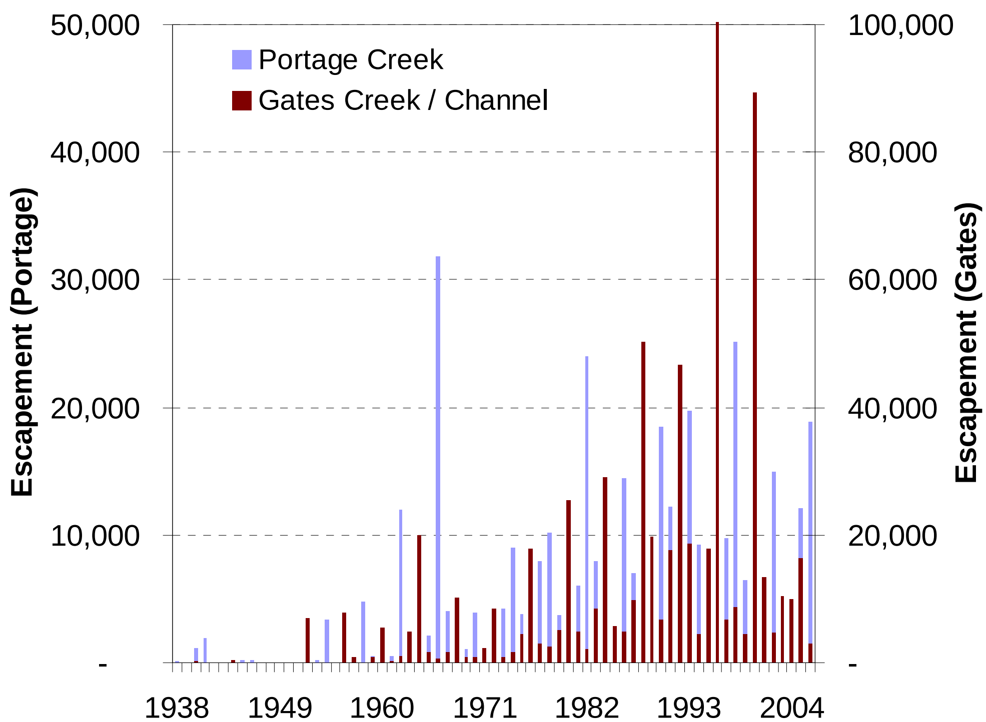

Figure 20. **Portage Creek and Gates Creek sockeye salmon escapement from 1938 to 2006 (data from DFO NuSEDS database).**

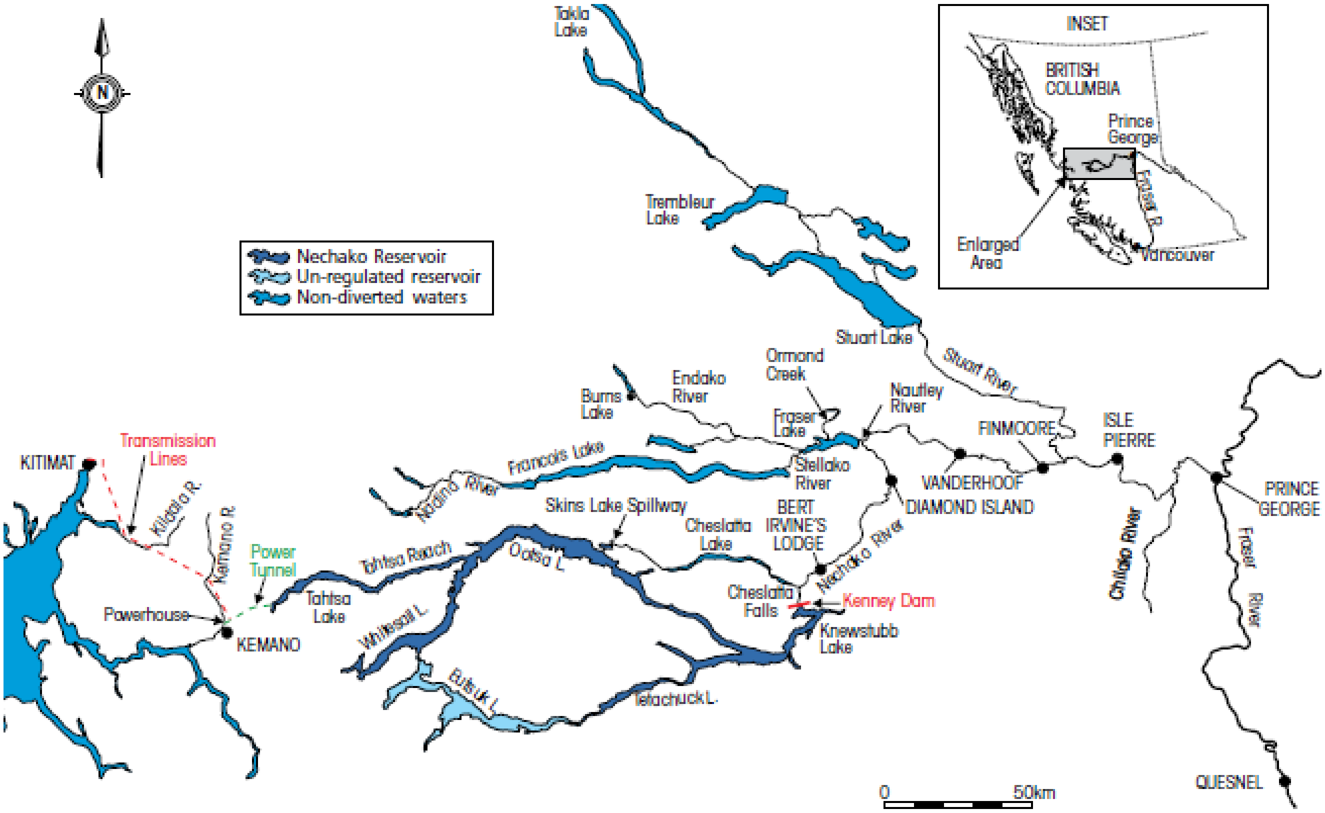

Figure 21. **Nechako River watershed and location of Kenny Dam (Map from NFCP 2005).**

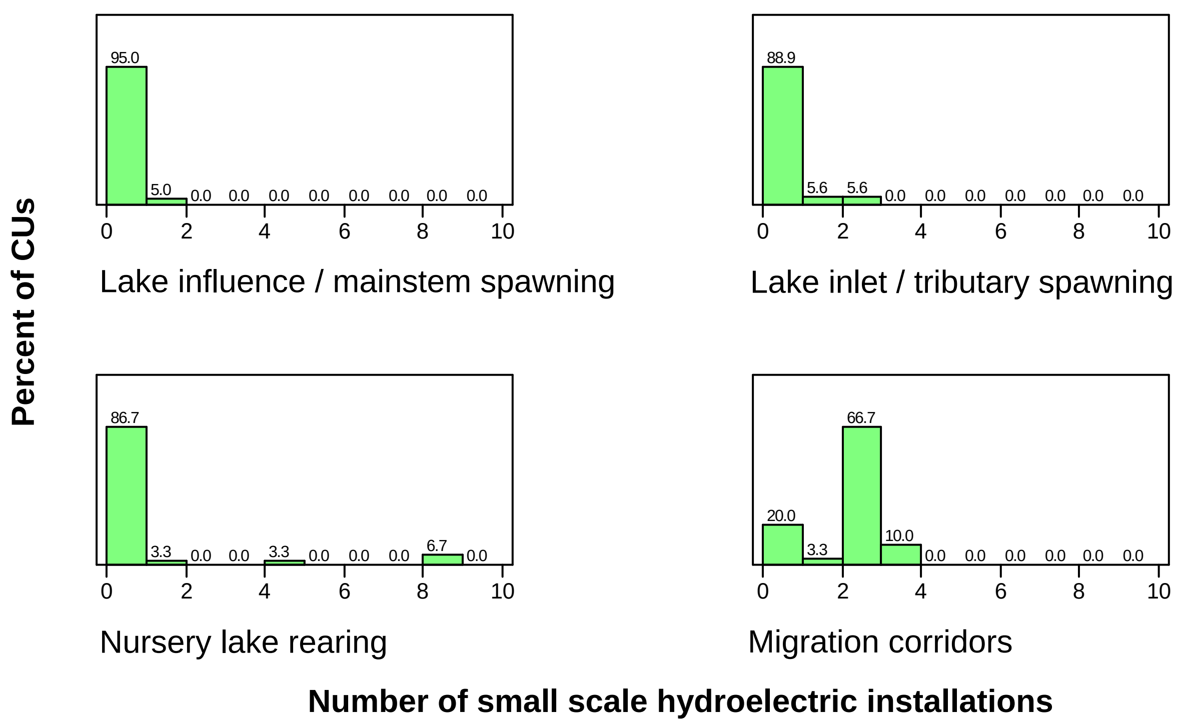

Figure 22. **Frequency distribution of the number of small scale hydroelectricity installations within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.**

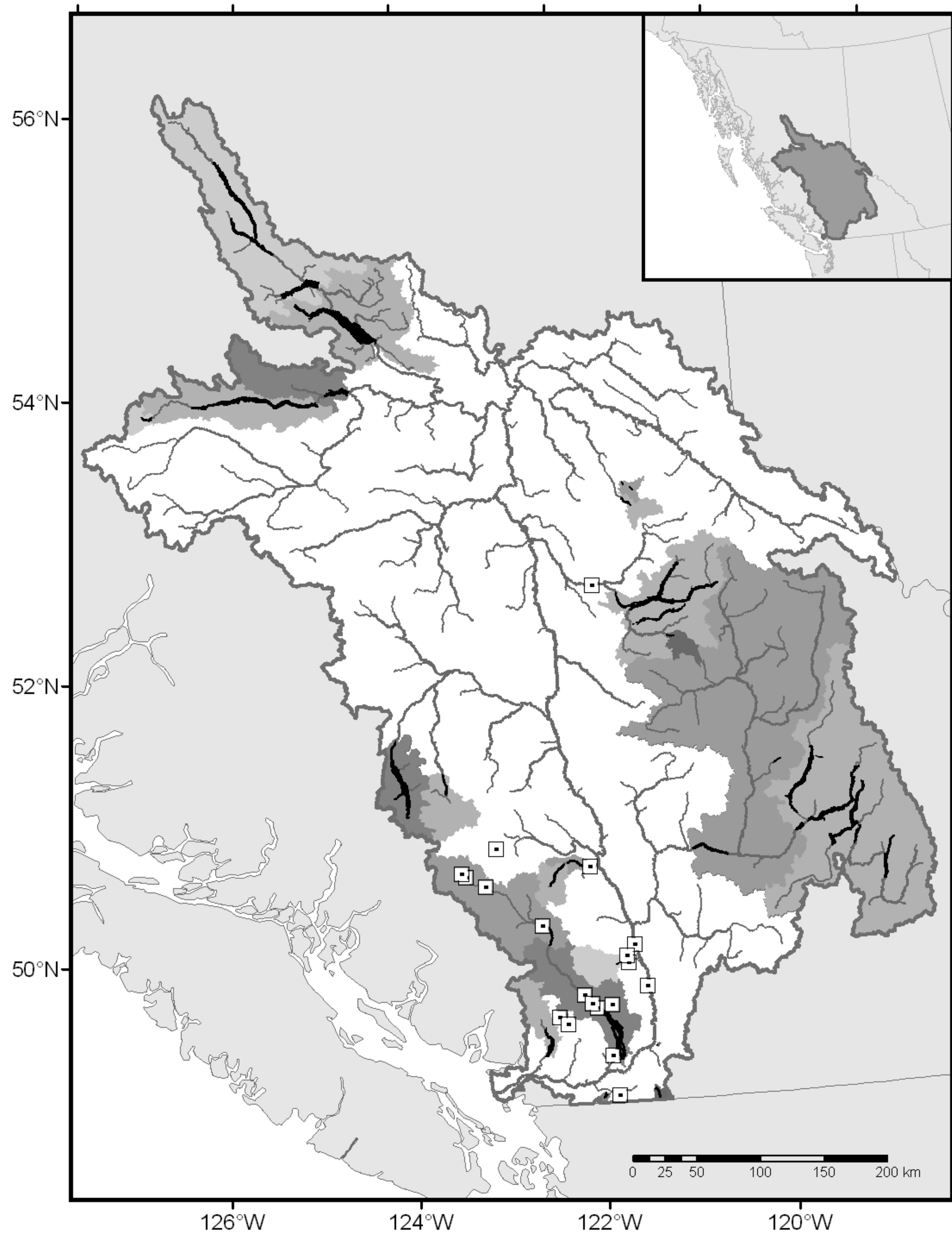

Figure 23. Spatial distribution of small scale hydroelectricity installations (squares with dots) relative to watershed boundaries (grey shading) for all lake sockeye salmon Conservation Units. Nursery lakes are in black.

Figure 24. **Intake and headpond of the Douglas Creek generating station (a typical installation). The intake weir creates a headpond and raises the water so a portion of stream flow can enter the penstock. The size of the headpond is determined by the topography at the intake location. This installation is upstream of an alluvial fan on which Harrison -downstream migrating-Late timing sockeye salmon spawn (image from http://cloudworksenergy.com/projects/photo-tour/).**

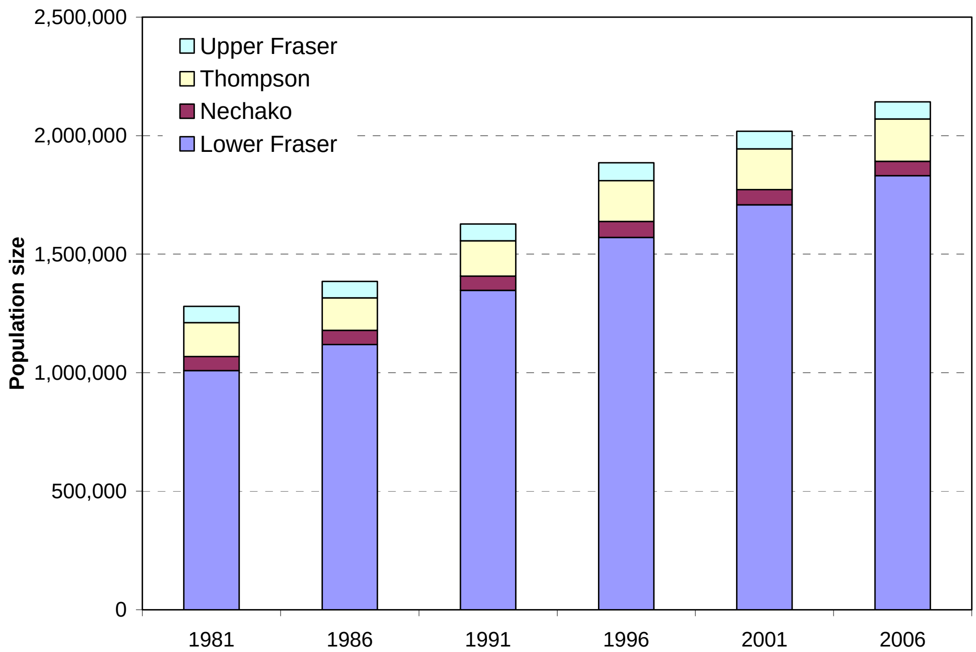

Figure 25. **Human population size in the Fraser River basin by region from 1981 to 2006 (data from Statistics Canada 2009).**

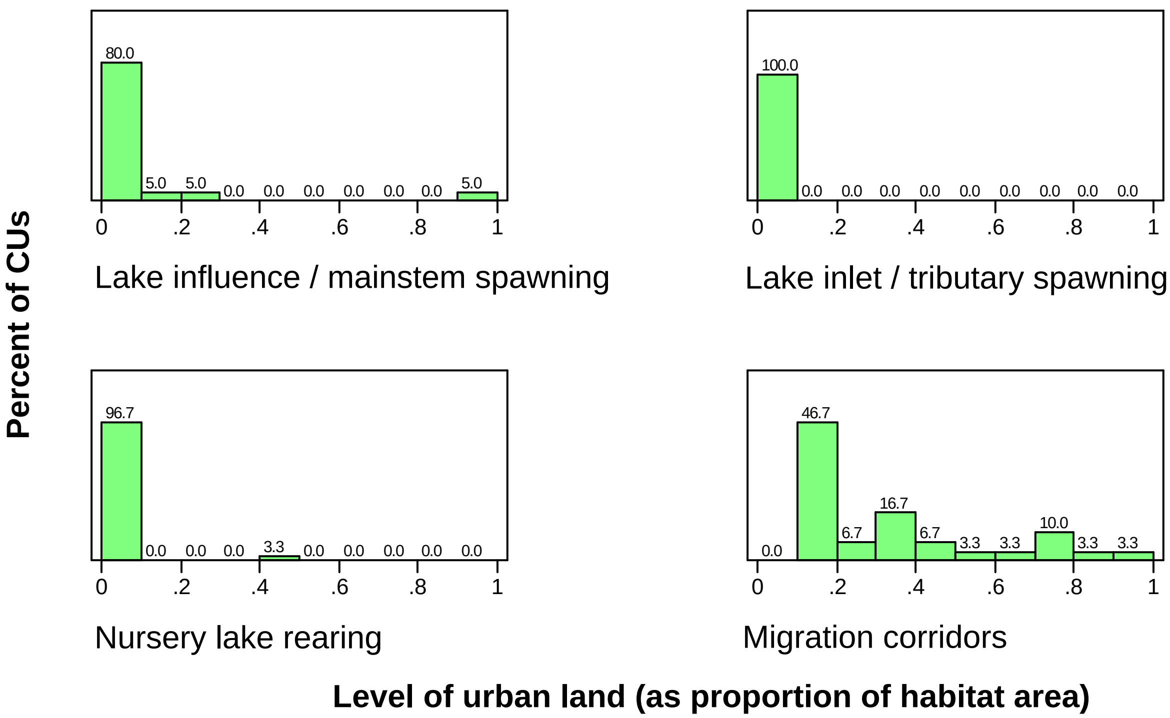

Figure 26. **Frequency distribution of the area of urban land within "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.**

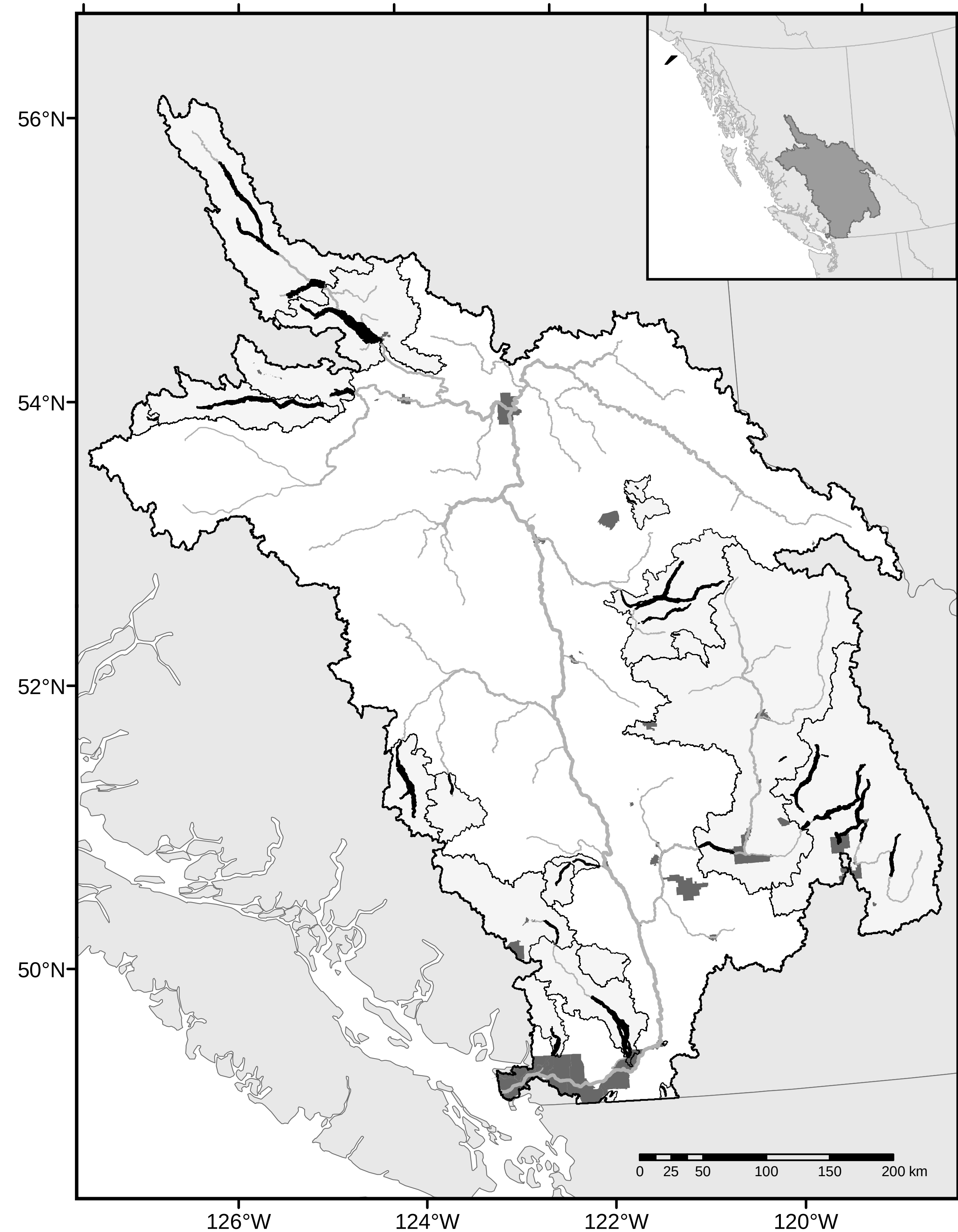

Figure 27. **Spatial distribution of urban areas (dark grey shading) relative to the watershed boundaries (light grey shading) for all lake sockeye salmon Conservation Units. Nursery lakes are in black.**

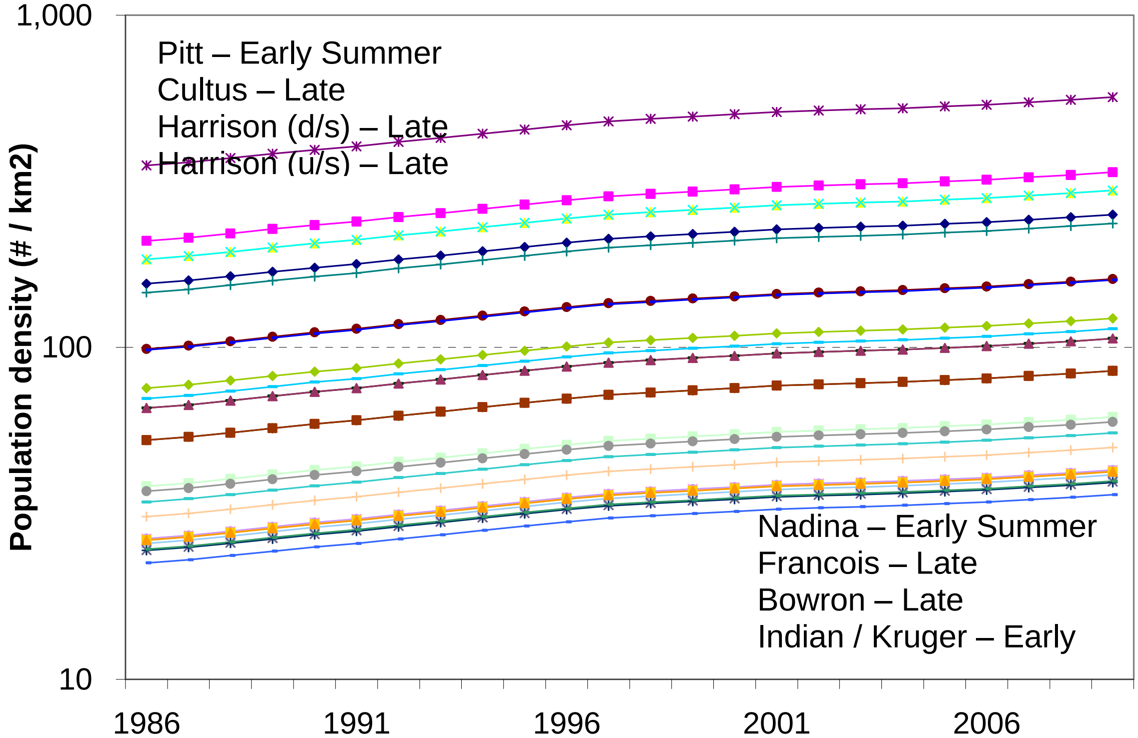

Figure 28. Time series of average human population density along migration corridors of all lake sockeye salmon Conservation Units. Only CU labels for the four highest and four lowest population densities are represented on this graph. Time series for each CU represented separately in Appendix 3.

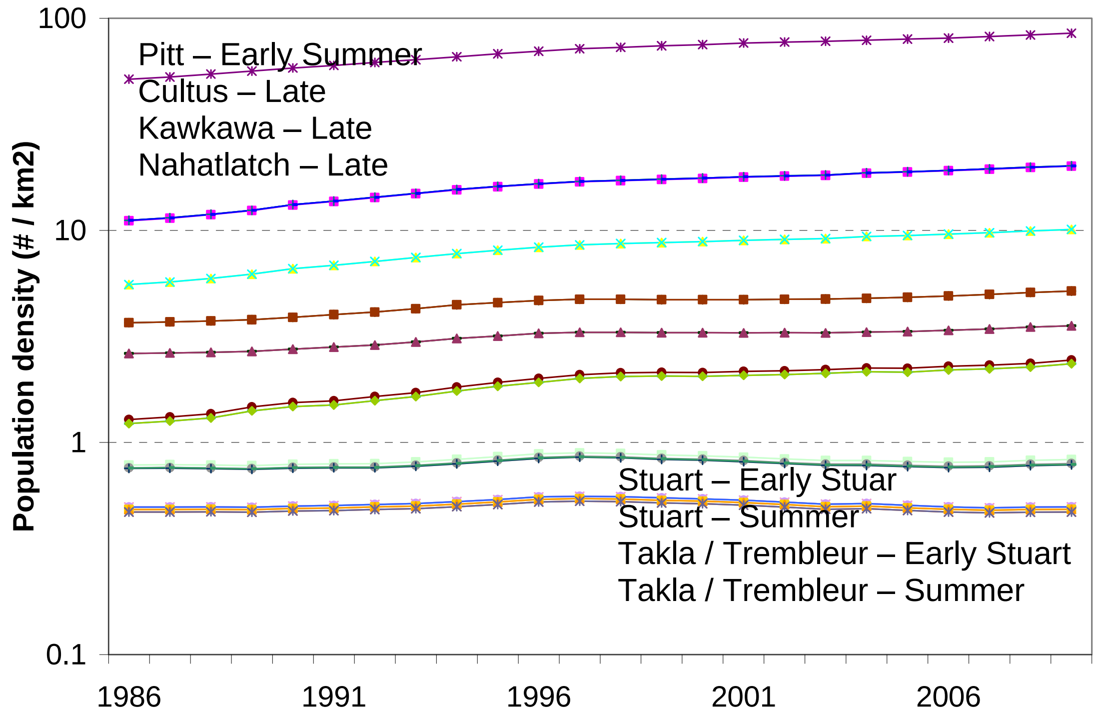

Figure 29. Time series of average human population density adjacent to rearing and spawning habitats for all lake sockeye salmon Conservation Units. Only CU labels for the four highest and four lowest population densities are represented on this graph. Time series for each CU represented separately in Appendix 3.

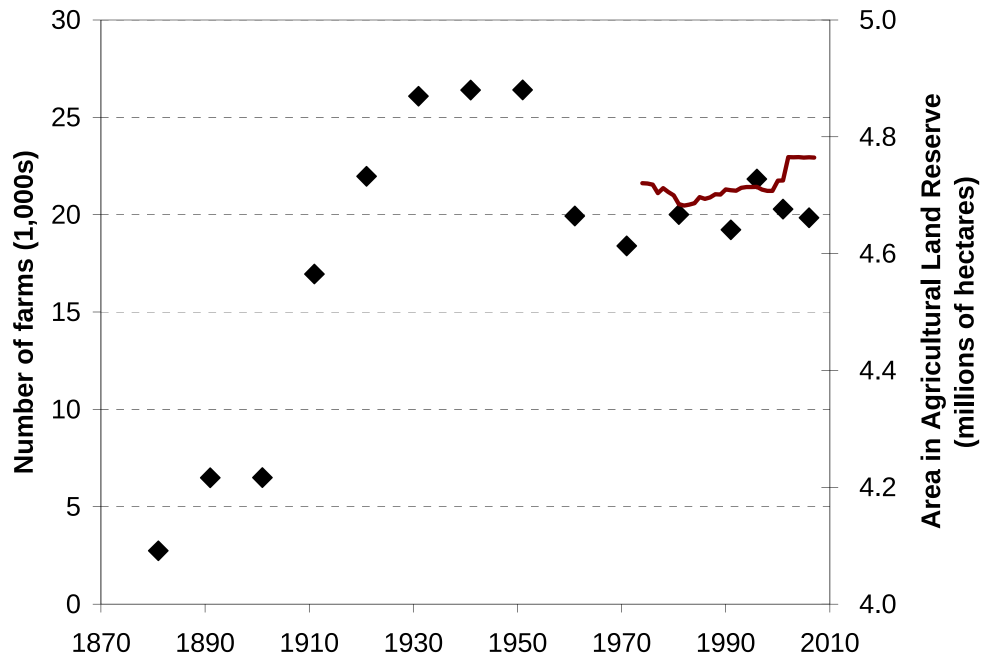

Figure 30. Number of farms in British Columbia from 1881 to 2006 (diamonds, data from Statistics Canada 2009) and total area of the province within the Agricultural Land Reserve from 1974 to 2007 (solid line, data from BC MOE 2008).

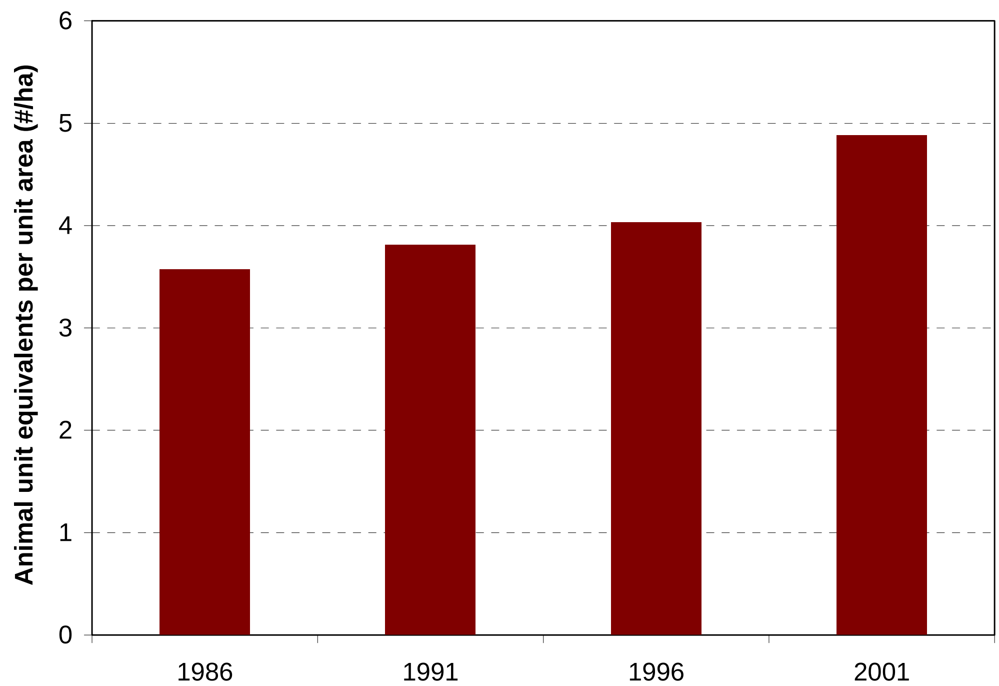

Figure 31. Number of livestock (cattle, pigs, chickens) per unit area (# / ha) in Abbotsford. Number of livestock is represented as an animal unit equivalency (i.e., 1 cow = 3 pigs = 75 hens). Data from Statistics Canada as reported in Smith et al. (2007).

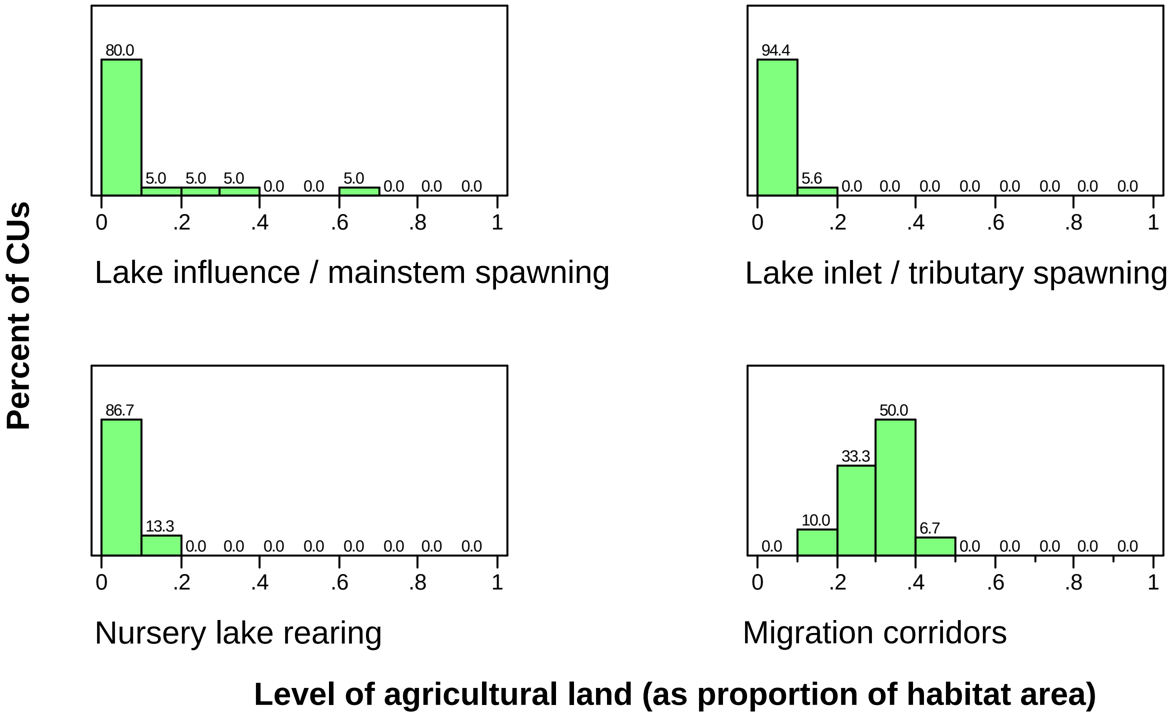

Figure 32. Frequency distribution of the level of agricultural land within "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.

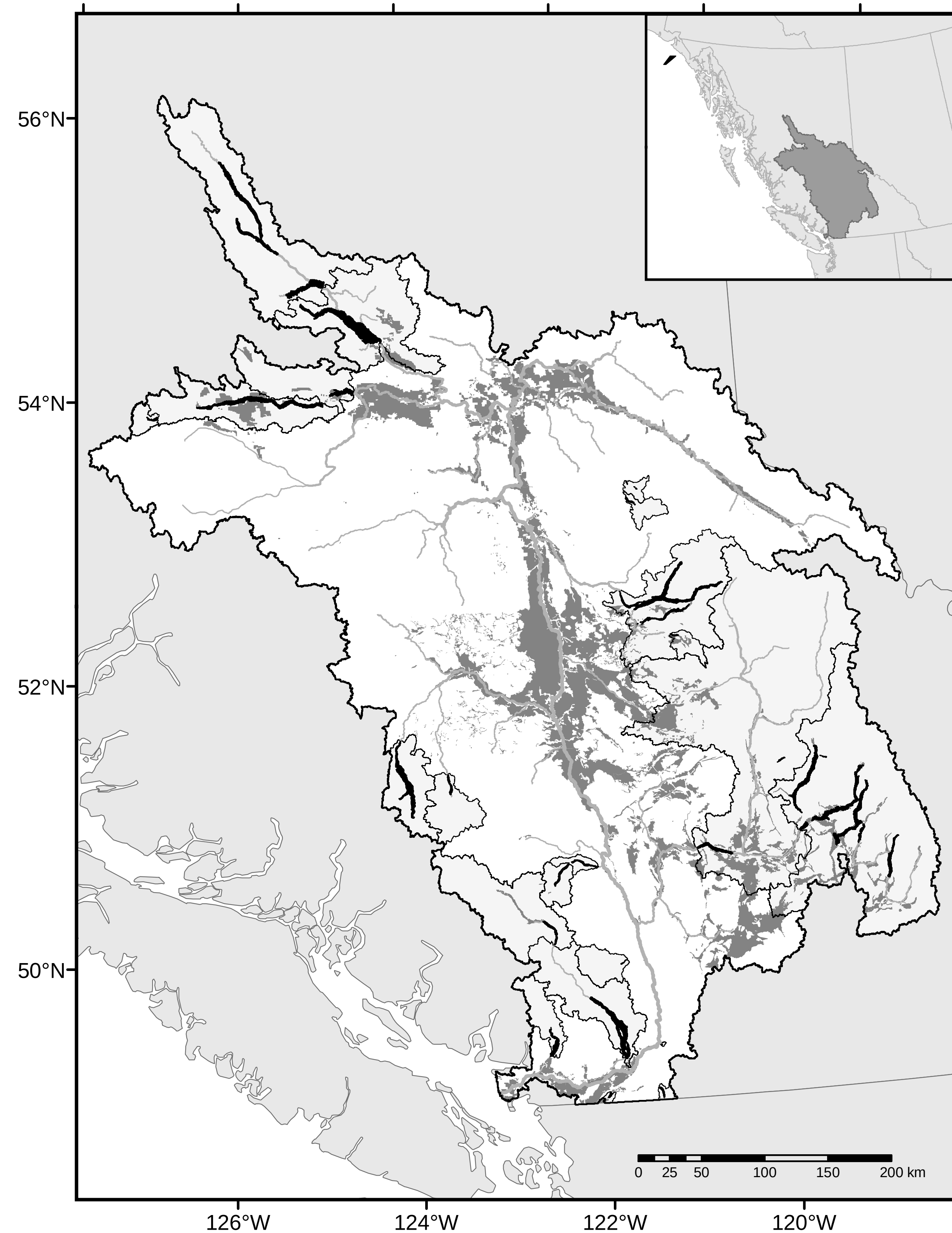

Figure 33. **Spatial distribution of agricultural areas (dark grey shading) relative to the watershed boundaries (light grey shading) for all lake sockeye salmon Conservation Units. Nursery lakes are in black.**

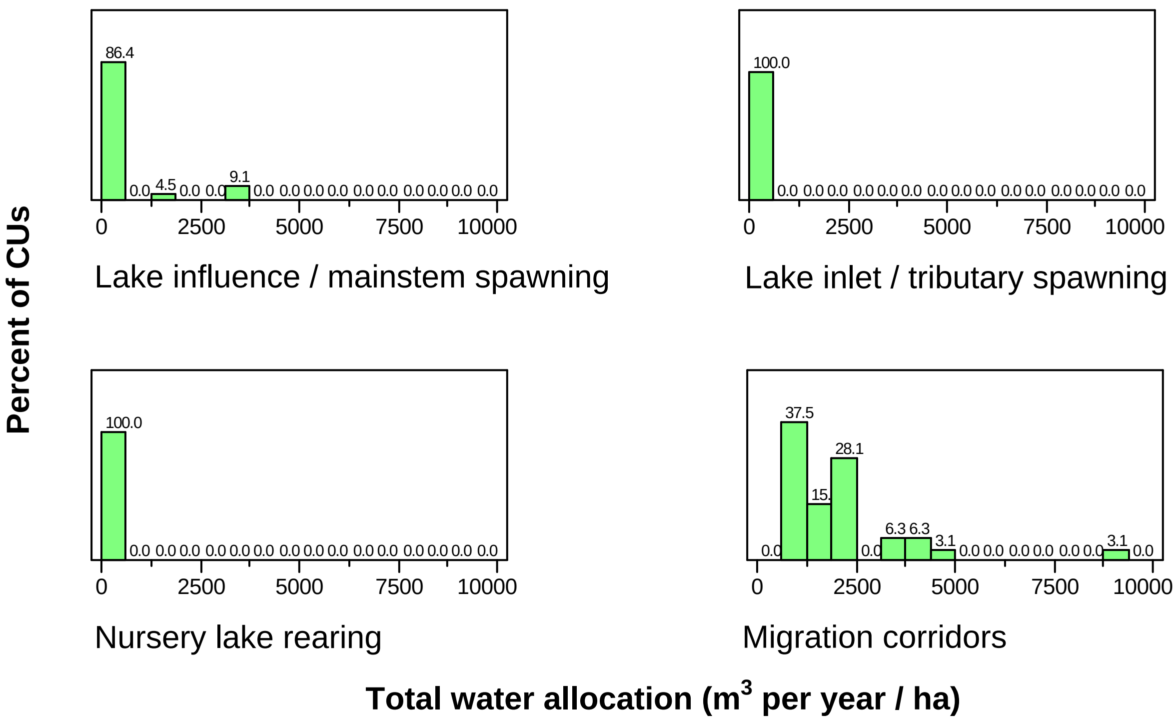

Figure 34. Frequency distribution of total water allocation (cubic metres per year per hectare) within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.

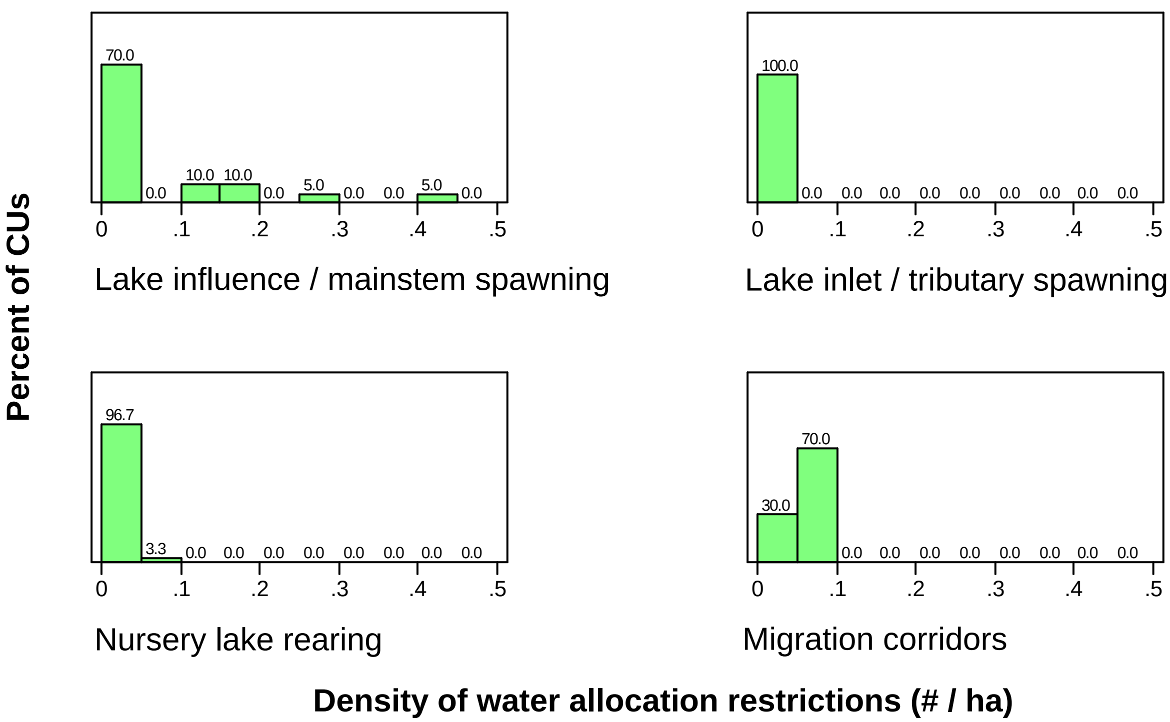

Figure 35. Frequency distribution of the density of water allocation restrictions (number per hectare) within the "zones of influence" of each habitat type across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.

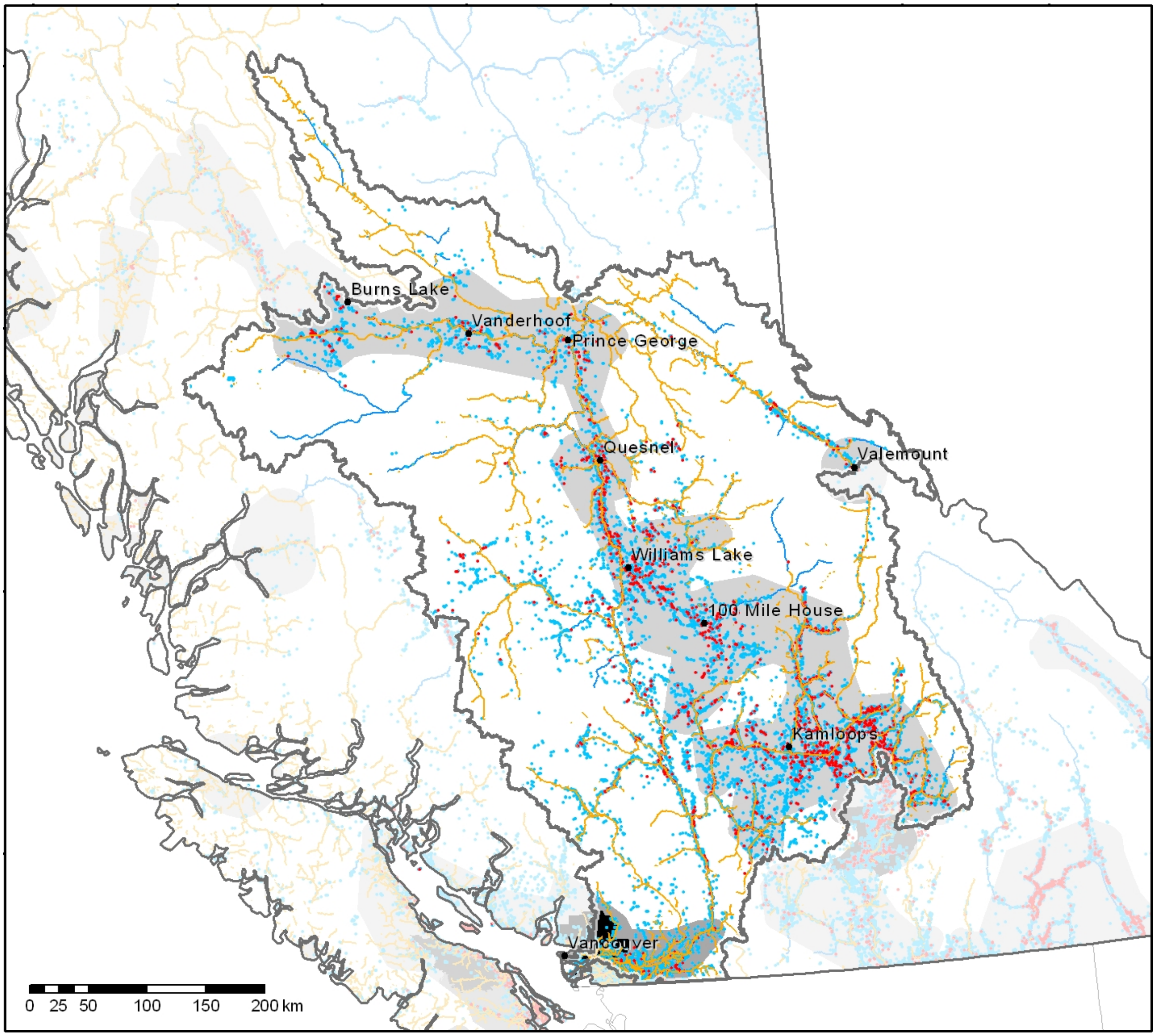

Figure 36. Overlay of water licenses, water allocation restrictions, population density, and distribution of all salmon species in the province (map redrawn from Nelitz et al. 2009).

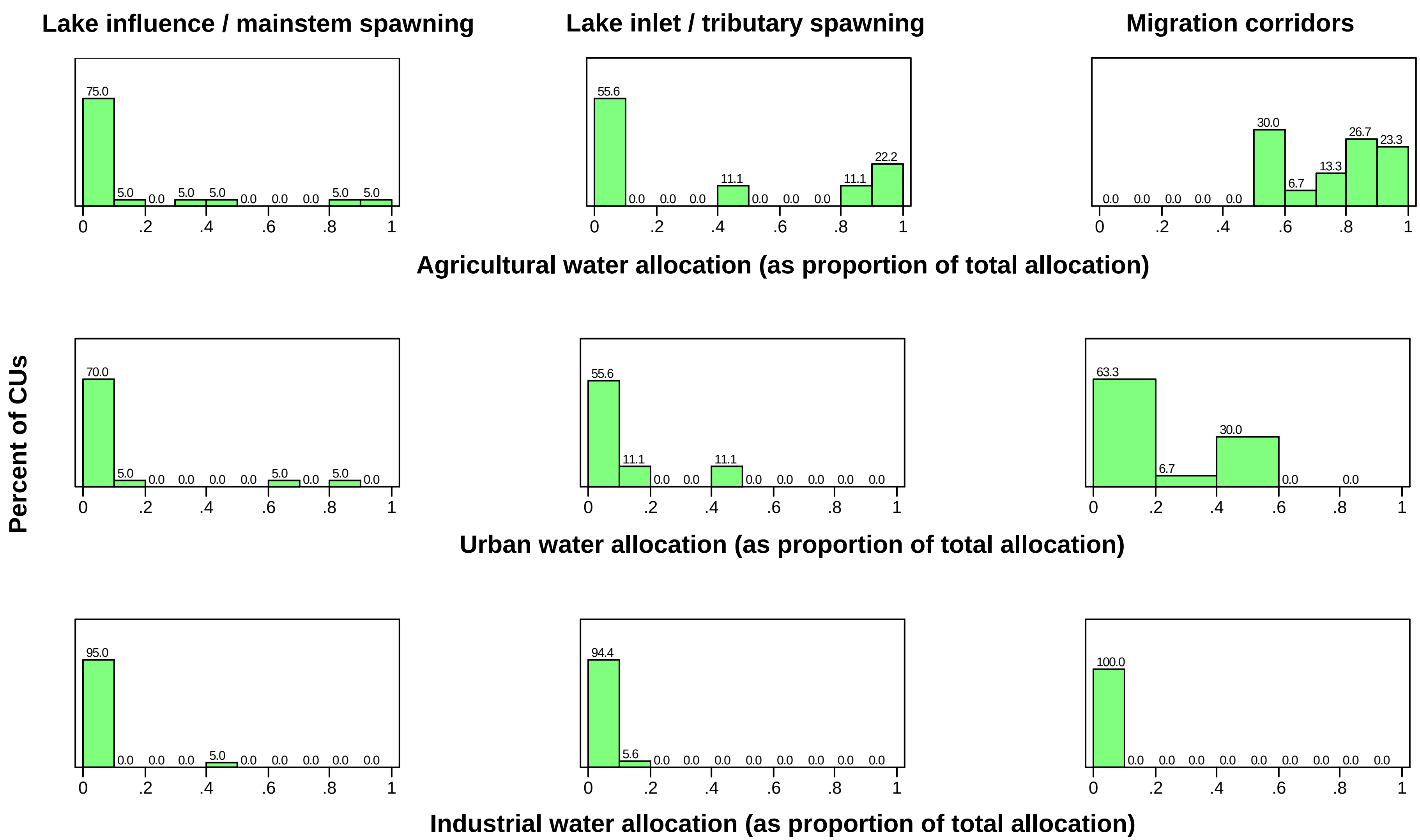

Figure 37. **Frequency distribution of the allocation of water by main uses within the "zones of influence" of spawning and migratory habitats across all Fraser River lake sockeye salmon Conservation Units. Numbers above bars represent percentage of CUs in the respective bin.**

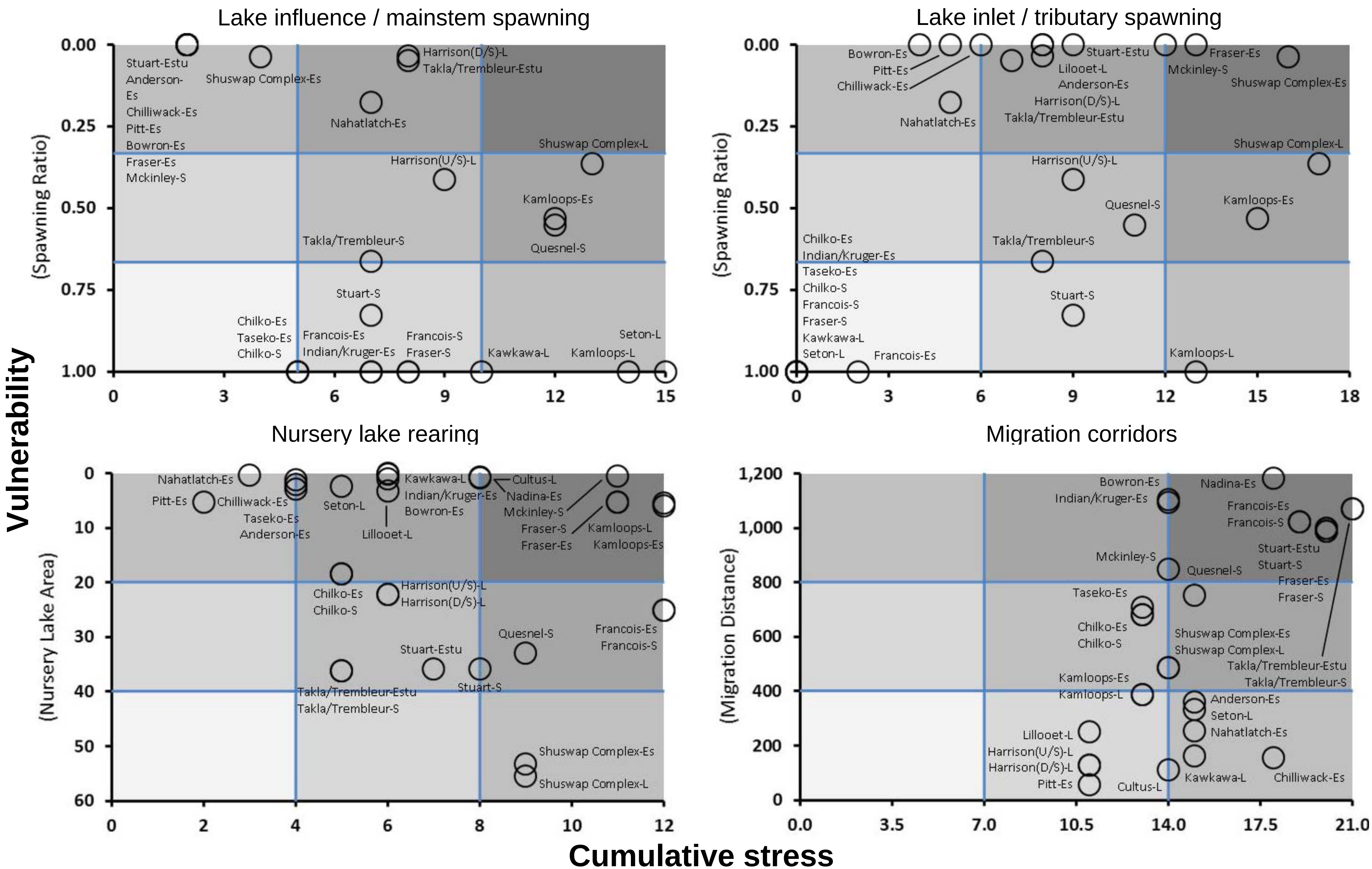

Figure 38. **Representation of the <u>relative</u> level of vulnerability of and stress on freshwater habitats across all lake sockeye salmon Conservation Units. Horizontal and vertical lines are used to highlight separations among Conservation Units into nine quadrants, where the top right quadrant represent those CUs with high stress and high vulnerability and the bottom left represent those CUs with low stress and low vulnerability. Data to represent vulnerability and stress are summarized in Table 5 and Table 11 through Table 14.**

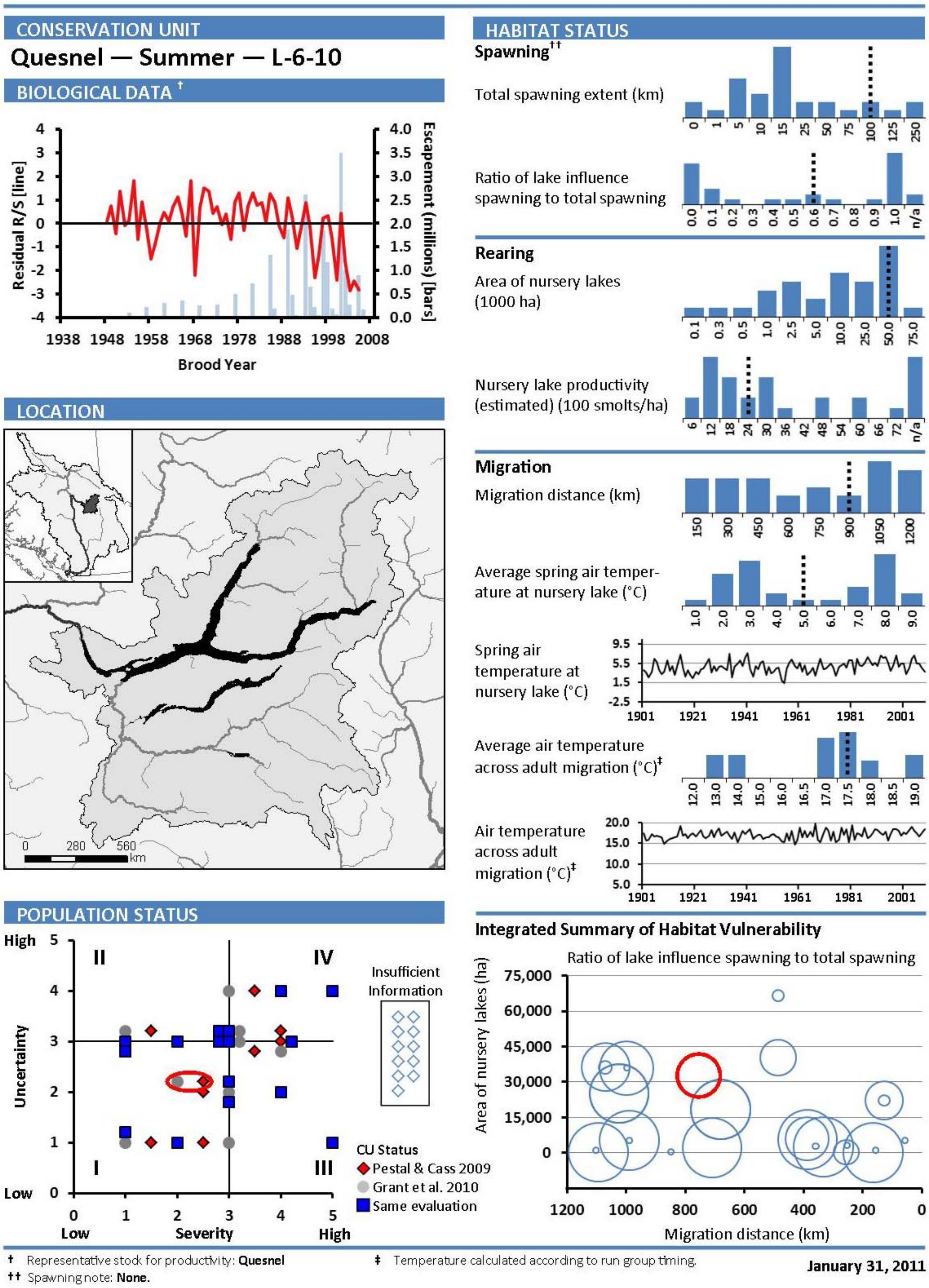

Figure 39. **First page of a "dashboard" summarizing population status and habitats for the Quesnel Conservation Unit (L_6_10, Summer timing group). See Appendix 3 for additional dashboards and a description to help in the interpretation of the graphs and information contained therein.**

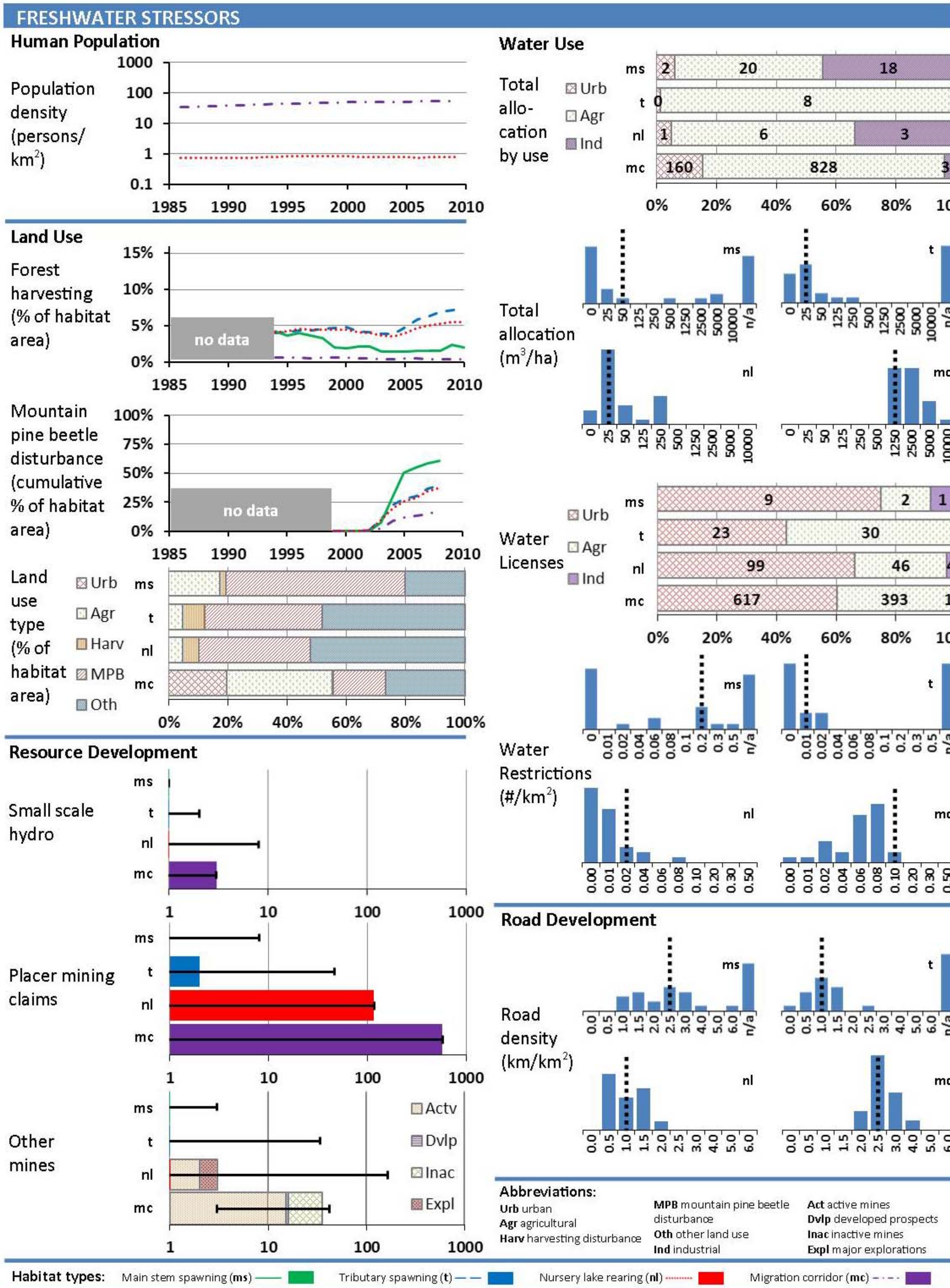

Figure 40. **Second page of a "dashboard" summarizing human stressors on the Quesnel Conservation Unit (L_6_10, Summer timing group). See Appendix 3 for additional dashboards and a description to help in the interpretation of the graphs and information contained therein.**

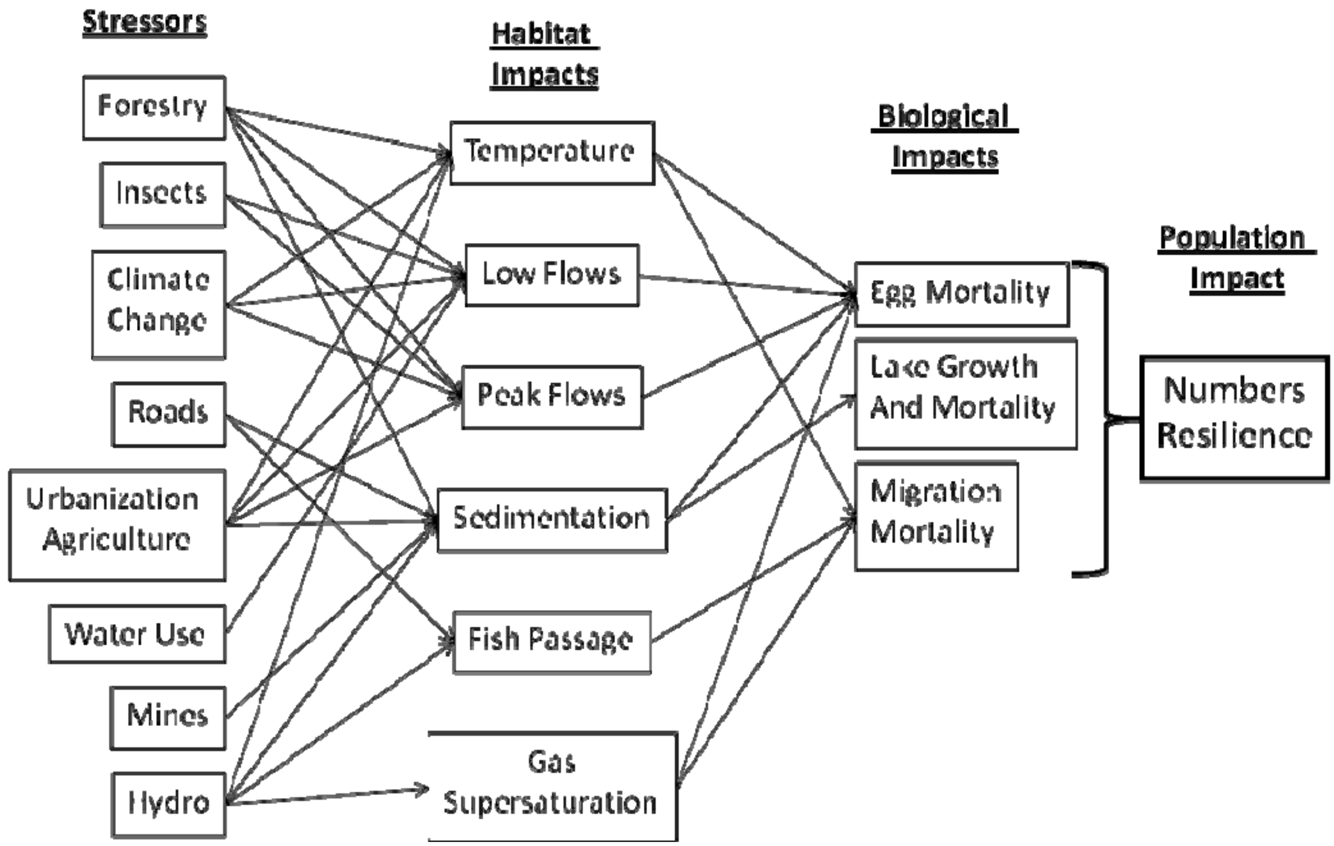

Figure 41. Overview of the mechanisms by which stressors in the freshwater environment can have impacts on habitats, growth and survival across life stages, and ultimately a population level effect on sockeye salmon in the Fraser River basin.

8.0 Tables

Table 1. Status of 36 sockeye salmon Conservation Units (as reported by Pestal and Cass 2009), alignment of these CUs with stocks for which there are productivity data from the Pacific Salmon Commission (as analyzed by Peterman et al. 2010), and summary of evidence / rationale for modifying status where appropriate (as part of this report's evaluation). Status is defined by severity (sev) and uncertainty (unc). Severity: 1 = low risk and 5 = high risk. Uncertainty: 1 = low uncertainty/high confidence, 5 = high uncertainty/low confidence, and 10 = insufficient information.

CU Index	Management group	CU Type	Conservation Unit	Freshwater adaptive zone	Status category	Status scores		Stock name(s) for productivity data	Data avail		Status adjustment based on Grant et al. 2010
						Sev	Unc		Total	Juv	
L-6-12	Early Stuart	Lake	Stuart	Middle_Fraser	IV	5	4	E.Stuart	X	X	Not assessed by Grant et al.
L-6-14	Early Stuart	Lake	Takla/Trembleur	Middle_Fraser	III	4	2				Same
L-3-1	Early Summer	Lake	Chilliwack	Lower_Fraser	II	1	3				Severity 1/2
L-3-5	Early Summer	Lake	Pitt	Lower_Fraser	I	1	1	Pitt	X		Same
L-5-2	Early Summer	Lake	Nahatlatch	Fraser_Canyon	IV	3	3				Severity 4 (at risk by COSEWIC stds.)
L-6-1	Early Summer	Lake	Anderson	Middle_Fraser	IV	3	3	Gates	X	X	Unchanged
L-6-16	Early Summer	Lake	Taseko	Middle_Fraser	IV	3	4				Severity 4/3 (at risk by COSEWIC stds.)
L-6-2	Early Summer	Lake	Chilko	Middle_Fraser	UNK		10	Chilko	X	X	Same
L-6-4	Early Summer	Lake	Francois	Middle_Fraser	IV	3	3	Nadina	X	X	Same
L-6-6	Early Summer	Lake	Fraser	Middle_Fraser	UNK		10				Not assessed by Grant et al.
L-6-9	Early Summer	Lake	Nadina	Middle_Fraser	UNK		10	Nadina	X	X	Not assessed by Grant et al.
L-7-1	Early Summer	Lake	Bowron	Upper_Fraser	IV	3	3	Bowron	X		Severity 4 (at risk by COSEWIC stds)
L-7-2	Early Summer	Lake	Indian/Kruger	Upper_Fraser	UNK		10				Not assessed by Grant et al.
L-9-2	Early Summer	Lake	ShuswapComplex	South_Thompson	III	3	2	Scotch and Seymour	X		Same
L-10-1	Early Summer	Lake	Kamloops	North_Thompson	II	1	3	Fennel and Raft	X		Same
L-6-10	Summer	Lake	Quesnel	Middle_Fraser	I	2	2	Quesnel	X	X	Severity 2/3
L-6-13	Summer	Lake	Stuart	Middle_Fraser	III	3	2	L. Stuart	X		Same
L-6-15	Summer	Lake	Takla/Trembleur	Middle_Fraser	IV	4	3	L. Stuart	X		Severity 3/4
L-6-3	Summer	Lake	Chilko	Middle_Fraser	I	2	1	Chilko	X	X	Same
L-6-5	Summer	Lake	Francois	Middle_Fraser	UNK		10	Stellako	X	X	Not assessed by Grant et al.
L-6-7	Summer	Lake	Fraser	Middle_Fraser	I	1	1	Stellako	X	X	Severity 1/2
L-6-8	Summer	Lake	Mckinley	Middle_Fraser	UNK		10	Quesnel	X	X	Lumped with Quesnel-S
L-3-2	Late	Lake	Cultus	Lower_Fraser	III	5	1				Same
L-3-3	Late	Lake	Harrison(D/S)	Lower_Fraser	II	1	3	Harrison	X		Same
L-3-4	Late	Lake	Harrison(U/S)	Lower_Fraser	IV	3	3	Weaver	X	X	Same
L-4-1	Late	Lake	Lillooet	Lillooet	III	3	2	Birkenhead	X		Severity 2/3
L-5-1	Late	Lake	Kawkawa	Fraser_Canyon	UNK		10				Not assessed by Grant et al.
L-6-11	Late	Lake	Seton	Middle_Fraser	IV	3	3	Portage	X		Same
L-9-1	Late	Lake	Kamloops	South_Thompson	IV	4	4				Same (at risk by COSEWIC standards)
L-9-3	Late	Lake	ShuswapComplex	South_Thompson	III	3	1	L. Shuswap	X	X	Severity 2/3
R02	River	River	Widgeon	Widgeon	IV	4	3				Same (at risk by COSEWIC standards)
R03	River	River	Lower_Fraser	LFR	II	2	3				Same
R04	River	River	Fraser_Canyon	FRCany	UNK		10				Not assessed by Grant et al.
R05	River	River	Middle_Fraser	MFR	UNK		10				Not assessed by Grant et al.
R06	River	River	Upper_Fraser	UFR	UNK		10				Not assessed by Grant et al.
R07	River	River	Thompson_River	THOM	UNK		10				Not assessed by Grant et al.

Table 2. Comparison of alternative methods for evaluating status of sockeye salmon Conservation Units according to their assessment criteria / indicators, feasibility of implementation, approach for setting benchmarks, and data needs / availability.

		Alternative methodologies for assessing conservation status		
		Indicators of Status and Benchmarks for CUs (Holt 2009; Holt et al. 2009)	Qualitative Risk Evaluation (Pestal and Cass 2009)	NatureServe (Faber-Langendoen et al. 2009)
	Definition of Status	- Biological status is defined using four classes of indicators: abundance (i.e., production), trends in abundance, distribution, and fishing mortality. Status is largely driven by productivity.	- Overall status is defined using several classes of indicators: abundance (production), trends in abundance, productivity, diversity, fishing mortality, distribution, and habitat condition. Indicators fall into 1 of 4 risk factors: status, vulnerability, direct human impact, and environmental condition. Status is largely driven by abundance whereas vulnerability is driven by productivity.	- Status is largely driven by the potential extinction or extirpation risk of elements of biodiversity, including regional extinction or extirpation.
Evaluation criteria, indicators, and metrics	Abundance	- spawner abundance in current year - geometric mean spawner abundance (most recent generation) - ratio of geometric mean of current generation to historical geometric mean - ratio of geometric mean of current generation to highest generational geometric mean on record	- geometric mean of escapement over last 4 yrs - recent abundance relative to current capacity (% of observations in last 12 yrs with abundance outside of ± 75% of capacity) - recent abundance relative to potential capacity - recent abundance relative to capacity indicated by traditional ecological knowledge - variability in abundance (CV in avg. escape) - % of recent 4 year abundance in most abundant cycle line	- population size - number of occurrences
	Trends	- reduction in spawner abundance over 3 gens or 10 yrs - probability that declines are ≥ 25% over 3 gens or 10 yrs	- change in escapement over last 3 generations (slope in 4 yr running geometric mean of escapement over last 12 years) - recent avg. escapement (last 4 yrs) / overall average escapement (geometric mean) - recent avg. escapement (last 4 yrs) / highest 10 yr running geometric mean - largest observed decline by cycle line (geometric mean of 2 most recent cycle escapements divided by geometric mean of escapement 3 and 4 cycles ago)	- long-term - short-term
	Distribution	- change in areal extent of spawn / juv over time	- distribn of abundance across populations in CU (decline in abund ance criterion if most	- range extent - area of occupancy

		Alternative methodologies for assessing conservation status		
		Indicators of Status and Benchmarks for CUs (Holt 2009; Holt et al. 2009)	Qualitative Risk Evaluation (Pestal and Cass 2009)	NatureServe (Faber-Langendoen et al. 2009)
		- spatial extent (area of occupancy) - # of spawning groups with abund > 1000 fish, & change in that value over last 3 gens or 10 yrs - min. # of spawning groups that comprise 80% of total abund when ranked from most to least abund & change over last 3 gens or 10 yrs - area under curve between rank of spawning group (as % of total number of groups) versus % contribution of that group to the total abundance - proportion of spawning groups with a geometric mean abundance over most recent generation with > 1000 fish - proportion of spawning groups that have rates of change in abun ≥ 30% over 3 gens or 10 yrs	abundant population were lost (avg. over last 4 yrs))	- % area with good viability/ecological integrity
	Diversity	- type of habitat used by spawners or juveniles and changes over time	- life history (e.g., # of populations in CU) - genetic (TBD)	
	Productivity		- average recruits / spawner over 3 generations	
	Fishing mortality	- fishing mortality in current year - mean fishing mortality over most recent gen	- overlap with CU that is of high harvest potential - average mortality rate over last generation	- catch
	Habitat condition		- sensitivity of critical habitat	- habitat stressors

Feasibility		- Highly technical and complex method
		- High effort
		- Data limitations make it difficult to assess status for half of CUs
		    - Holt et al. 2009 – incomplete
		    - Grant et al. 2010: 15 CUs not assessed
		- Indicator roll up has not been developed.
			- Simple and straight forward method
			- Medium level of effort
			- Data limitations not as restrictive, but exist
			    - 11 CUs not assessed
			- Simple guidelines for rolling up indicators
				- Simple and straight forward method
				- Medium level of effort
				- Method may result in inconsistent evaluation across CUs

	Alternative methodologies for assessing conservation status		
	Indicators of Status and Benchmarks for CUs (Holt 2009; Holt et al. 2009)	Qualitative Risk Evaluation (Pestal and Cass 2009)	NatureServe (Faber-Langendoen et al. 2009)
Benchmarks	- Developed using quantitative approach for abundance and fishing mortality metrics (monte carlo simulation for some metrics) - Some metrics use qualitative method for classifying pop. around benchmarks (based on magnitude of uncertainty in observed spawner data) - incorporates uncertainty from data into the benchmark - robust and defensible - undefined benchmarks for distribn metrics - use fishing mortality remains uncertain	- Metrics use qualitative method for classifying pop. around benchmarks (based on magnitude of uncertainty in observed spawner data) - clear and consistent rules for setting benchmarks across CUs - defensible	Does not use break points for ratings as thresholds, rather points along a continuum of extinction risk. All metrics are on a scale of 0 to 5.5 (each has equal contribution to aggregate score). Metrics may have different number of increments within the 0 to 5.5 scale, but always evenly spaced. Rank of A is the lowest possible value (i.e., most at risk), with the exception of # of occurrences where it is the opposite. Factors within a status factor category are weighted differently (see Table 8, pg 14), as are the status factor categories themselves.
Data needs and availability	- Ricker spawner-recruitment relationship (estimates of a and b parameters; estimate of spawners) - freshwater capacity - time series of spawner abundance by spawning group and counting locations - spawner distribution across habitats - # of spawning groups - # of extant spawning locations, spawner surveys - Fishing mortality - Data availability varies across CUs. Resolution of escapement by populations within a CU is likely variable. High quality escapement data available for 21 CUs, reasonable data available for 6 CUs, and scarce data available for 9 CUs.	- time series of spawner abundance by population and recruitment - spawner abundance by population - freshwater capacity - fishing mortality - habitat sensitivity - Traditional Ecological Knowledge - Data availability varies across CUs. Resolution of escapement by populations within a CU is likely variable. High quality escapement data available for 21 CUs, reasonable data available for 6 CUs, and scarce data available for 9 CUs. - Extent to which TEK is available across CUs is not known. The quality of information on detailed habitat within a CU varies across CUs, with the majority of CUs having poor fine scale information.	- time series of spawner abundance - area / range extent relative to current spawning and rearing - Data availability varies across CUs. Resolution of escapement by populations within a CU is likely variable. High quality escapement data available for 21 CUs, reasonable data available for 6 CUs, and scarce data available for 9 CUs.
	- time series of spawner distribution - spawning habitat/ground surveys - habitat use surveys Not available from stock assessment data.	- lake capacity for sockeye salmon production (based on photosynthetic rate) - Lake productivity estimates readily available.	- habitat condition, extent, and related stressors Not available from stock assessment data.
	- catch and estimate of biomass (stock size) Data availability varies across CUs, though reasonable estimates exist. Direct fishing mortality is available, though no data for FSM.	- lake capacity Traditional Ecological Knowledge, genetic diversity, habitat inventory, and run timing (not available).	- life history characteristics related to specific habitat Unknown availability, stock dependent.

	Alternative methodologies for assessing conservation status		
	Indicators of Status and Benchmarks for CUs (Holt 2009; Holt et al. 2009)	Qualitative Risk Evaluation (Pestal and Cass 2009)	NatureServe (Faber-Langendoen et al. 2009)
		- catch and estimate of biomass (stock size) - High quality data on direct human impact. Level of uncertainty in data is low. Other non-targeted sources of mortality (incidental, non-harvest, harvest induced) not well estimated. But total mortality from these sources is low.	- catch and estimate of biomass (stock size) - High quality data on direct human impact. Level of uncertainty in data is low. Other non-targeted sources of mortality (incidental, non-harvest, harvest induced) not well estimated. But total mortality from these sources is low.
Strengths	- technically robust - clear quantitative rules for assessing status and uncertainty - explicitly incorporates uncertainty - identifies information gaps	- explicitly incorporates uncertainty - straight forward and easy to apply - provides rapid appraisal of Fraser River sockeye salmon - identifies information gaps and major threats - good start at defining clear, consistent qualitative rules for assessing current status and uncertainty that can be applied across CUs - flexibility to include metrics based on TEK	- straight forward and easily applied - general public can understand the method
Weaknesses	- complex method requiring significant resources that lower feasibility of implementation - time consuming - apart from fishing mortality, does not take into consideration stressors on the population	- using this method, 11 of 36 CUs have insufficient information to determine status	- qualitative approach has led to issues with consistency, repeatability, and transparency of status assessment. Need extensive training and review to minimize problem. Subjective assessments are influenced by personal judgments, perceptions of risk, and systemic biases. Need to create a well defined framework to minimize user bias and increase transparency. - not clear on weighting of factors; not obvious documentation. Likely combination of expert judgment and scientific literature. - factors are not salmon centric, and may miss key elements such as productivity - standard benchmarks across CUs may not be appropriate because doesn't take into account unique characteristics and circumstances of CU. - poor performance of trend criterion compared to other metrics (Porszt 2009)

Table 3. Summary of indicator classes included in each assessment method.

Indicator class	Holt et al. 2009	Pestal and Cass 2009	Faber-Langendoen et al. 2009 (NatureServe)
Abundance	x	x	x
Trend in spawner abundance	x	x	x
Distribution	x	x	x
Diversity	indirect	x	
Productivity	Indirect	x	x
Fishing mortality	x	x	x
Habitat condition		x	x

Table 4. Description of indicators of habitat quantity and quality reflecting vulnerability across different sockeye salmon life stages.

Life stage	Habitat quantity	Habitat quality
Migration (adults and smolts)	Migration distance (km): Delineated the migration route for each sockeye salmon CU by identifying the stream reach immediately downstream of a CU's nursery lake outlet point and following the mainstem stream network back from this point to the mouth of the Fraser. A 1 km wide buffer was delineated on each side of the migratory corridors.	Summer air temperatures across adult migration (°C): Determined the average summer/fall air temperatures along the migration corridor for each sockeye salmon CU using ClimateWNA data adjusted for run timing (see Appendix 4). Spring air temperatures at nursery lake (°C): Summarized historical spring air temperatures at each sockeye salmon nursery lake, extracted from ClimateWNA.
Spawning (adults, eggs, alevins)	Tributary / inlet spawning or total spawning extent (m): Delineated the total length of spawning zone(s) within each CU, and separated these into lake inlet / tributary or lake outlet spawning extents (i.e., lake influenced).	Ratio of lake influence spawning extent to total spawning extent: Compared the linear extent of spawning reaches that are lake influenced to the total extent of spawning for each sockeye salmon CU (i.e., upstream disturbance effects would be buffered by the lake).
Rearing (fry and smolts)	Area of nursery lakes (ha): Summed the area of all nursery lakes within each sockeye salmon CU.	Nursery lake productivity (estimated): Summarized a biological measure of juvenile productivity for each CU based on photosynthetic rate (e.g., smolt abundance/density). Data were provided by Fisheries and Oceans Canada's Cultus Lake Salmon Research Laboratory. Productivity was expressed as the average over time for a nursery lake or by an averaging across lakes if multiple nursery lakes were present within a CU.

Table 5. Indicators of habitat vulnerability for spawning, rearing, and migratory habitats across all lake sockeye salmon Conservation Units.

CU Index	Manage-ment group	Conservation Unit	Spawning				Rearing		Migration		
			Total spawn extent (m)	Tributary / inlet spawn extent (m)	Ratio of lake influence: total spawn	Spawning note	Nurs lake area (ha)	Nursery lake productivity (estimated smolts / ha)	Migrat^{n} distance (km)	Summer air temp across adult migrat^{n} (C)	Spring air temp at nursery lake (C)
L_06_12	Early Stuart	Stuart	13,259	13,259	0.00		35,919	1,578	998	17.44	2.7
L_06_14	Early Stuart	Takla / Trembleur	229,647	218,533	0.05		36,253	449	1069	17.23	1.8
L_03_01	Early Sum	Chilliwack	26,174	26,174	0.00		1,182	1,176	156	17.82	5.3
L_03_05	Early Sum	Pitt	13,945	13,945	0.00		5,348	734	57	17.85	8.3
L_05_02	Early Sum	Nahatlatch	3,870	3,188	0.18		303		255	18.59	6.2
L_06_01	Early Sum	Anderson	7,387	7,387	0.00	Gates spawning channel	2,872	3,387	359	18.66	6.8
L_06_16	Early Sum	Taseko	2,395	-	1.00		2,124		709	17.34	0.6
L_06_02	Early Sum	Chilko	12,490	-	1.00		18,447	1,157	680	17.49	1.4
L_06_04	Early Sum	Francois	1,278	-	1.00	Nadina spawning channel	25,164	2,912	1024	17.07	2.5
L_06_06	Early Sum	Fraser	21,702	21,702	0.00		5,385	5,696	989	17.18	2.8
L_06_09	Early Sum	Nadina	-	-		Glacier Creek spawn not mapped	930		1182	16.62	1.6
L_07_01	Early Sum	Bowron	16,450	16,450	0.00		1,021	2,165	1102	16.96	3.3
L_07_02	Early Sum	Indian/Kruger	10,448	-	1.00		235		1094	17.00	2.6
L_09_02	Early Sum	Shuswap Complex	115,549	111,224	0.04		55,491	957	487	18.92	7.3
L_10_01	Early Sum	Kamloops	60,026	28,105	0.53		6,014	4,358	387	18.92	7.5
L_06_10	Summer	Quesnel	82,401	36,931	0.55		32,863	2,137	754	17.58	4.8
L_06_13	Summer	Stuart	77,055	13,259	0.83		35,919	1,578	998	16.89	2.7
L_06_15	Summer	Takla / Trembleur	9,911	3,347	0.66		36,253	449	1069	16.72	1.8
L_06_03	Summer	Chilko	12,490	-	1.00		18,447	1,157	680	17.27	1.4
L_06_05	Summer	Francois	11,460	-	1.00		25,164	2,912	1024	16.80	2.5
L_06_07	Summer	Fraser	11,460	-	1.00		5,385	5,696	989	16.91	2.8
L_06_08	Summer	Mckinley	4,743	4,743	0.00		513		849	17.23	3.5
L_03_02	Late	Cultus	-	-		Foreshore spawning	631	6,841	111	13.33	8.1
L_03_03	Late	Harrison (D/S)	10,534	10,156	0.04		22,192	1,245	127	13.21	7.6
L_03_04	Late	Harrison (U/S)	1,986	1,164	0.41	Weaver spawning channel	22,192	1,245	127	13.21	7.6
L_04_01	Late	Lillooet	31,642	31,642	0.00		3,220	2,762	252	12.67	7.5
L_05_01	Late	Kawkawa	837	-	1.00		76		164	13.19	7.9
L_06_11	Late	Seton	6,766	-	1.00		2,475	2,591	333	12.57	7.0
L_09_01	Late	Kamloops	11,446	-	1.00		5,517	4,358	387	12.50	7.5
L_09_03	Late	Shuswap Complex	134,871	85,881	0.36		53,265	957	487	12.17	7.3

Table 6. Months used to represent historical average air temperature exposure of adult sockeye salmon CUs along the migration corridor based on associated run timing group.

Sockeye salmon run-timing group	Average date that 50% of a run-timing group passes	Months used in our analysis to represent average air temperatures during run-timing
Early Stuart	July 14	July
Early Summer	August 7	July and August
Summer	August 17	August
Late	October 4 (before 1995) September 2 (1995 onwards)	October September

Table 7. Summary of hypothesized links between freshwater stressors and sockeye salmon habitats, and the indicators being generated to represent these stressors.

Freshwater stressor	Quantity / quality of spawning habitats	Productivity of nursery lakes	Conditions related to smolt outmigration / adult migration	Stressor indicators
Forestry				
Forest harvesting activities	X	X	X	** cumulative proportion of habitat type as forest disturbance over rolling 15 year window (%) ** density of roads (km / km^2) ** density of road-stream crossings (# / km^2)
Mountain Pine Beetle disturbance	X	X	X	** cumulative proportion of habitat type as MPB disturbance (%)
Log storage			X	n/a – qualitative evaluation of site specific information / data
Mining	X			** number and type of mines across habitat types
Hydroelectricity				
Large hydro			X	n/a – qualitative evaluation of site specific information / data
Small hydro	X		X	** count of IPPs across habitat types
Urbanization upstream of Hope	X	X	X	** proportion of habitat type as urban area (%) ** density of human population (# / km^2) ** allocation of urban water use per unit area (m^3 / ha)
Agriculture	X	X	X	** proportion of habitat type as agricultural land (%) ** allocation of agricultural water use per unit area (m^3 / ha)
Water use	X		X	** allocation of urban, agricultural, and industrial water uses per unit area (m^3 per year / ha) ** density of water allocation restrictions (# / km^2) ** proportion of water licenses across uses (%)

Table 8. Count and density (number/100km^2) of various types of mining activity in watersheds that support sockeye salmon spawning by Conservation Unit. Mining sites where an intervening lake buffers the impact on downstream juvenile habitat are not included.

CU Index	Conservation Unit	Spawning type	Placer Claims	Gravel Pits	Industrial Mineral Quarries	Metal Mines	Major Exploration Projects	Inactive Mine Sites	Total
L_09_03	Shuswap Complex-Late	Tributary	46 (0.69)	12 (0.18)	0 (0.18)	0 (0)	0 (0)	14 (0.21)	72 (1.26)
L_09_02	Shuswap Complex-Early Summer	Tributary	9 (0.17)	6 (0.11)	1 (0.02)	0 (0)	0 (0)	3 (0.06)	19 (0.36)
L_06_06	Fraser-Early Summer	Tributary	2 (0.1)	10 (0.5)	1 (0.5)	1 (0.05)	0 (0)	0 (0)	14 (1.15)
L_10_01	Kamloops-Early Summer	Tributary	11 (0.52)	0 (0)	0 (0)	0 (0)	1 (0.05)	2 (0.1)	14 (0.67)
L_03_03	Harrison-downstream migrating-Late	Tributary	10 (1.16)	1 (0.12)	0 (0.12)	0 (0)	0 (0)	0 (0)	11 (1.4)
L_06_14	Takla/Trembleur-Early Stuart	Tributary	5 (0.1)	3 (0.06)	0 (0.06)	0 (0)	0 (0)	1 (0.02)	9 (0.24)
L_06_15	Takla/Trembleur-Summer	Tributary	5 (0.57)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	5 (0.57)
L_04_01	Lillooet-Late	Tributary	0 (0)	4 (0.57)	0 (0.57)	0 (0)	0 (0)	0 (0)	4 (1.14)
L_06_10	Quesnel-Summer	Tributary	2 (0.06)	0 (0)	0 (0)	0 (0)	1 (0.03)	0 (0)	3 (0.09)
L_03_01	Chilliwack-Early Summer	Tributary	0 (0)	1 (0.22)	0 (0.22)	0 (0)	0 (0)	1 (0.22)	2 (0.66)
L_06_12	Stuart-Early Stuart	Tributary	1 (0.27)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.27)
L_06_13	Stuart-Summer	Tributary	1 (0.27)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.27)
L_03_04	Harrison -upstream migrating-Late	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_03_05	Pitt-Early Summer	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_05_02	Nahatlatch-Early Summer	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_01	Anderson-Early Summer	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_08	Mckinley-Summer	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_07_01	Bowron-Early Summer	Tributary	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_11	Seton-Late	Mainstem	4 (20.9)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	4 (20.9)
L_09_03	Shuswap Complex-Late	Mainstem	0 (0)	3 (2.77)	0 (2.77)	0 (0)	0 (0)	0 (0)	3 (5.54)
L_10_01	Kamloops-Early Summer	Mainstem	0 (0)	2 (2.7)	0 (2.7)	0 (0)	0 (0)	0 (0)	2 (5.4)
L_09_01	Kamloops-Late	Mainstem	0 (0)	1 (3.45)	0 (3.45)	0 (0)	0 (0)	0 (0)	1 (6.9)
L_06_10	Quesnel-Summer	Mainstem	1 (1.07)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1.07)
L_03_03	Harrison -downstream migrating-Late	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_03_04	Harrison -upstream migrating-Late	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_05_01	Kawkawa-Late	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_05_02	Nahatlatch-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_02	Chilko-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_03	Chilko-Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_04	Francois-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_05	Francois-Late	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_07	Fraser-Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_13	Stuart-Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_14	Takla/Trembleur-Early Stuart	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_15	Takla/Trembleur-Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_06_16	Taseko-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_07_02	Indian/Kruger-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
L_09_02	Shuswap Complex-Early Summer	Mainstem	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 9. Average number of days per year when the mean daily water temperature exceeds 20°C in the Nechako River above the Stuart River, and in the Stuart River, July 20 to August 20, 1953 to 2000* (data from NFCP 2005).

Time period	Nechako River (> 20°C)	Stuart River (> 20°C)
1953 - 1979	3.2	5.0
1983 - 2000	2.9	7.6

*1980, 1981 and 1982 excluded due to different reporting method

Table 10. Number of days when the mean daily water temperature exceeds 20°C, and maximum and minimum mean daily water temperatures in the Nechako River above the Stuart River, July 20 to August 20, 2002 to 2009 (data from Triton Environmental Consultants Ltd. 2003 through 2010 as part of NFCP water temperature and flow management program). Data from 2007 were not reported due to failure of thermographs.

Year	Number of days >20°C	Maximum mean daily water temperature	Minimum mean daily water temperature
2001	0	19.6	16.4
2002	0	19.9	14.4
2003	0	20.0	17.1
2004	13	21.2	18.7
2005	0	20.0	16.8
2006	5	21.7	17.8
2008	0	19.5	15.7
2009	11	21.4	17.3

Table 11. Relative ranking of Conservation Units based on the intensity and trend (where available) of human stressors potentially interacting with spawning locations downstream of lakes or on mainstem rivers. Stressor summary represents a relative measure of the cumulative level of stress on a Conservation Unit across all types of human stressors. Note the following notations are used to denote intensity (I) of disturbance (high ++, moderate +, low -, or none 0) and trend (T) in disturbance (increasing +, decreasing -, or stable 0).

CU Index	Mgmt group	Conservation Unit	Forest harvesting		MPB disturbance		Road density	Urban area	Agric. area	Water alloc'tn	Water rest'cn	Small hydro	Placer Mines	Stressor summary
			T	I	T	I	I	I	I	I	I	I	I	
L_06_11	Late	Seton	-	-	+	-	+	+	-	++	+	0	++	15
L_09_01	Late	Kamloops	0	0	+	+	+	-	++	++	+	0	0	14
L_09_03	Late	Shuswap Complex	-	+	+	-	+	0	++	++	+	0	0	13
L_10_01	Early Sum	Kamloops	-	+	+	+	+	+	+	+	0	0	0	12
L_06_10	Summer	Quesnel	-	+	+	++	+	0	+	-	-	0	-	12
L_05_01	Late	Kawkawa	0	0	0	0	++	++	0	-	++	0	0	10
L_03_04	Late	Harrison (U/S)	+	-	0	0	+	0	-	-	0	++	0	9
L_06_14	Early Stuart	Takla / Trembleur	-	++	+	++	+	0	0	0	0	0	0	8
L_06_05	Summer	Francois	-	-	+	++	+	0	-	0	-	0	0	8
L_06_07	Summer	Fraser	-	-	+	++	+	0	-	0	-	0	0	8
L_03_03	Late	Harrison (D/S)	0	0	0	0	-	++	0	-	++	0	0	8
L_05_02	Early Sum	Nahatlatch	+	-	+	+	+	0	0	0	0	0	0	7
L_06_04	Early Sum	Francois	-	++	+	++	-	0	0	0	0	0	0	7
L_07_02	Early Sum	Indian/Kruger	-	++	+	++	-	0	0	0	0	0	0	7
L_06_13	Summer	Stuart	-	++	+	++	-	0	0	0	0	0	0	7
L_06_15	Summer	Takla / Trembleur	-	++	+	++	-	0	0	0	0	0	0	7
L_06_16	Early Sum	Taseko	0	0	+	++	-	0	0	0	0	0	0	5
L_06_02	Early Sum	Chilko	0	0	+	++	-	0	0	0	0	0	0	5
L_06_03	Summer	Chilko	0	0	+	++	-	0	0	0	0	0	0	5
L_09_02	Early Sum	Shuswap Complex	-	+	+	-	-	0	0	0	0	0	0	4
L_06_12	Early Stuart	Stuart	0	0	0	0	+	0	0	0	0	0	0	2
L_03_01	Early Sum	Chilliwack	0	0	0	0	+	0	0	0	0	0	0	2
L_03_05	Early Sum	Pitt	0	0	0	0	+	0	0	0	0	0	0	2
L_06_01	Early Sum	Anderson	0	0	0	0	+	0	0	0	0	0	0	2
L_06_06	Early Sum	Fraser	0	0	0	0	+	0	0	0	0	0	0	2
L_06_09	Early Sum	Nadina	0	0	0	0	+	0	0	0	0	0	0	2
L_07_01	Early Sum	Bowron	0	0	0	0	+	0	0	0	0	0	0	2
L_06_08	Summer	Mckinley	0	0	0	0	+	0	0	0	0	0	0	2
L_03_02	Late	Cultus	0	0	0	0	+	0	0	0	0	0	0	2
L_04_01	Late	Lillooet	0	0	0	0	+	0	0	0	0	0	0	2

Table 12. Relative ranking of Conservation Units based on the intensity and trend (where available) of human stressors potentially interacting with <u>tributary or lake inlet spawning locations</u>. Stressor summary represents a <u>relative</u> measure of the cumulative level of stress on a Conservation Unit across all types of human stressors. Note the following notations are used to denote intensity (I) of disturbance (high ++, moderate +, low -, or none 0) and trend (T) in disturbance (increasing +, decreasing -, or stable 0).

CU Index	Mgmt group	Conservation Unit	Forest harvesting		MPB disturbance		Road density	Urban area	Agric. area	Water alloc'tn	Water rest'cn	Small hydro	Placer mines	Stressor summary
			T	I	T	I	I	I	I	I	I	I	I	
L_09_03	Late	Shuswap Complex	-	-	+	-	+	++	+	++	+	0	++	17
L_09_02	Early Sum	Shuswap Complex	+	-	+	-	+	++	+	-	+	0	+	16
L_10_01	Early Sum	Kamloops	+	++	+	+	+	-	-	-	-	0	+	15
L_06_06	Early Sum	Fraser	-	+	+	++	0	+	+	-	+	0	-	13
L_09_01	Late	Kamloops	0	++	0	+	+	-	-	-	-	0	+	13
L_06_08	Summer	Mckinley	-	++	+	++	+	0	++	-	0	0	0	12
L_06_10	Summer	Quesnel	+	+	+	+	+	0	0	-	-	0	-	11
L_06_12	Early Stuart	Stuart	+	+	+	++	-	0	0	0	0	0	-	9
L_06_13	Summer	Stuart	+	+	+	++	-	0	0	0	0	0	-	9
L_03_04	Late	Harrison (U/S)	+	+	0	0	++	0	0	+	0	-	0	9
L_06_01	Early Sum	Anderson	-	-	+	-	-	0	-	-	++	0	0	8
L_06_15	Summer	Takla / Trembleur	-	-	+	++	+	0	0	0	0	0	+	8
L_03_03	Late	Harrison (D/S)	-	++	+	-	-	0	0	0	0	-	+	8
L_04_01	Late	Lillooet	-	++	+	-	-	-	-	-	0	0	0	8
L_06_14	Early Stuart	Takla / Trembleur	-	-	+	+	-	0	0	-	0	0	+	7
L_03_01	Early Sum	Chilliwack	-	-	+	-	+	0	-	-	0	0	0	6
L_03_05	Early Sum	Pitt	-	++	0	0	-	-	0	-	0	0	0	5
L_05_02	Early Sum	Nahatlatch	-	++	+	-	-	0	0	0	0	0	0	5
L_07_01	Early Sum	Bowron	0	-	+	+	0	0	0	0	0	0	0	4
L_06_04	Early Sum	Francois	0	0	0	0	+	0	0	0	0	0	0	2
L_06_16	Early Sum	Taseko	0	0	0	0	0	0	0	0	0	0	0	0
L_06_02	Early Sum	Chilko	0	0	0	0	0	0	0	0	0	0	0	0
L_06_09	Early Sum	Nadina	0	0	0	0	0	0	0	0	0	0	0	0
L_07_02	Early Sum	Indian/Kruger	0	0	0	0	0	0	0	0	0	0	0	0
L_06_03	Summer	Chilko	0	0	0	0	0	0	0	0	0	0	0	0
L_06_05	Summer	Francois	0	0	0	0	0	0	0	0	0	0	0	0
L_06_07	Summer	Fraser	0	0	0	0	0	0	0	0	0	0	0	0
L_03_02	Late	Cultus	0	0	0	0	0	0	0	0	0	0	0	0
L_05_01	Late	Kawkawa	0	0	0	0	0	0	0	0	0	0	0	0
L_06_11	Late	Seton	0	0	0	0	0	0	0	0	0	0	0	0

Table 13. Relative ranking of Conservation Units based on the intensity and trend (where available) of human stressors potentially interacting with nursery lake rearing. Stressor summary represents a relative measure of the cumulative level of stress on a Conservation Unit across all types of human stressors. Note the following notations are used to denote intensity (I) of disturbance (high ++, moderate +, low -, or none 0) and trend (T) in disturbance (increasing +, decreasing -, or stable 0).

CU Index	Mgmt group	Conservation Unit	Forest harvesting		MPB disturbance		Road density	Urban area	Agric. area	Stressor summary
			T	I	T	I	I	I	I	
L_06_04	Early Sum	Francois	-	++	+	++	+	-	++	12
L_10_01	Early Sum	Kamloops	+	+	+	+	+	+	+	12
L_06_05	Summer	Francois	-	++	+	++	+	-	++	12
L_09_01	Late	Kamloops	+	+	+	+	+	+	+	12
L_06_06	Early Sum	Fraser	-	++	+	++	+	-	+	11
L_06_07	Summer	Fraser	-	++	+	++	+	-	+	11
L_06_08	Summer	Mckinley	-	++	+	++	+	0	++	11
L_09_02	Early Sum	Shuswap Complex	-	+	+	-	+	+	+	9
L_06_10	Summer	Quesnel	+	+	+	+	+	0	-	9
L_09_03	Late	Shuswap Complex	-	+	+	-	+	+	+	9
L_06_09	Early Sum	Nadina	+	+	+	++	-	0	0	8
L_06_13	Summer	Stuart	-	+	+	++	-	-	-	8
L_03_02	Late	Cultus	-	-	0	0	++	+	++	8
L_06_12	Early Stuart	Stuart	-	+	+	++		-	-	7
L_07_01	Early Sum	Bowron	+	-	+	+	-	0	0	6
L_07_02	Early Sum	Indian/Kruger	-	-	+	++	+	0	0	6
L_03_03	Late	Harrison (D/S)	-	-	+	-	-	+	-	6
L_03_04	Late	Harrison (U/S)	-	-	+	-	-	+	-	6
L_04_01	Late	Lillooet	-	-	+	-	-	+	-	6
L_05_01	Late	Kawkawa	-	-	0	0	++	++	0	6
L_06_14	Early Stuart	Takla / Trembleur	-	+	+	+	-	0	0	5
L_06_02	Early Sum	Chilko	-	-	+	+	-	0	-	5
L_06_15	Summer	Takla / Trembleur	-	+	+	+	-	0	0	5
L_06_03	Summer	Chilko	-	-	+	+	-	0	-	5
L_06_11	Late	Seton	-	-	+	-	-	-	-	5
L_03_01	Early Sum	Chilliwack	-	-	+	-	-	0	-	4
L_06_01	Early Sum	Anderson	-	-	+	-	-	0	-	4
L_06_16	Early Sum	Taseko	-	-	+	+	-	0	0	4
L_05_02	Early Sum	Nahatlatch	-	-	+	-	-	0	0	3
L_03_05	Early Sum	Pitt	-	-	0	0	-	-	0	2

Table 14. Relative ranking of Conservation Units based on the intensity and trend (where available) of human stressors potentially interacting with migration corridors. Stressor summary represents a relative measure of the cumulative level of stress on a Conservation Unit across all types of human stressors. Note the following notations are used to denote intensity (I) of disturbance (high ++, moderate +, low -, or none 0) and trend (T) in disturbance (increasing +, decreasing -, or stable 0).

CU Index	Mgmt group	Conservation Unit	Forest harvesting		MPB disturbance		Road density	Urban area	Agric. area	Water alloc'tn	Water rest'cn	Small hydro	Large hydro	Log storag	Stressor summary
			T	I	T	I	I	I	I	I	I	I	I	I	
L_06_14	Early Stuart	Takla / Trembleur	+	++	+	++	-	-	++	-	+	-	++	-	21
L_06_15	Summer	Takla / Trembleur	+	++	+	++	-	-	++	-	+	-	++	-	21
L_06_12	Early Stuart	Stuart	+	+	+	++	-	-	++	-	+	-	++	-	20
L_06_06	Early Sum	Fraser	-	+	+	++	+	-	++	-	++	-	++	-	20
L_06_13	Summer	Stuart	+	+	+	++	-	-	++	-	+	-	++	-	20
L_06_07	Summer	Fraser	-	+	+	++	+	-	++	-	++	-	++	-	20
L_06_04	Early Sum	Francois	-	+	+	++	+	-	++	-	+	-	++	-	19
L_06_05	Summer	Francois	-	+	+	++	+	-	++	-	+	-	++	-	19
L_03_01	Early Sum	Chilliwack	+	++	+	-	++	++	+	+	-	0	0	-	18
L_06_09	Early Sum	Nadina	-	+	+	++	-	-	++	-	+	-	++	-	18
L_05_02	Early Sum	Nahatlatch	+	++	+	-	+	+	-	-	-	-	0	-	15
L_06_01	Early Sum	Anderson	-	-	+	-	+	+	-	-	+	-	++	-	15
L_06_10	Summer	Quesnel	-	-	+	+	+	-	++	-	++	-	0	-	15
L_05_01	Late	Kawkawa	+	-	+	-	+	++	+	+	-	0	0	-	15
L_06_11	Late	Seton	-	-	+	-	+	+	-	-	+	-	++	-	15
L_07_01	Early Sum	Bowron	-	+	+	+	-	-	++	-	+	-	0	-	14
L_07_02	Early Sum	Indian/Kruger	-	+	+	+	-	-	++	-	+	-	0	-	14
L_09_02	Early Sum	Shuswap Complex	-	-	+	-	+	+	+	-	++	-	0	-	14
L_06_08	Summer	Mckinley	-	-	+	+	-	-	++	-	++	-	0	-	14
L_03_02	Late	Cultus	-	++	0	0	++	++	+	+	-	0	0	-	14
L_09_03	Late	Shuswap Complex	-	-	+	-	+	+	+	-	++	-	0	-	14
L_06_16	Early Sum	Taseko	-	-	+	+	-	-	++	-	+	-	0	-	13
L_06_02	Early Sum	Chilko	-	-	+	+	-	-	++	-	+	-	0	-	13
L_10_01	Early Sum	Kamloops	-	-	+	-	+	+	+	-	+	-	0	-	13
L_06_03	Summer	Chilko	-	-	+	+	-	-	++	-	+	-	0	-	13
L_09_01	Late	Kamloops	-	-	+	-	+	+	+	-	+	-	0	-	13
L_03_05	Early Sum	Pitt	0	0	0	0	++	++	-	++	0	0	0	-	11
L_03_03	Late	Harrison (D/S)	-	-	0	0	+	++	+	+	-	0	0	-	11
L_03_04	Late	Harrison (U/S)	-	-	0	0	+	++	+	+	-	0	0	-	11
L_04_01	Late	Lillooet	-	+	+	-	-	+	-	-	-	-	0	-	11

Table 15. Matrix of pairwise correlations among indicators of habitat vulnerability, habitat stressors at the watershed scale (as quantified within our nursery lake "zone of influence"), and stock productivity (trend in Ricker residuals from 1984-2004). All correlations of 0.4 or greater are bolded. (n =18). Note use of the following definitions for variables in the correlation matrix: (1) Migration distance (km); (2) Total spawning extent (m); (3) Ratio of lake influenced : total spawning extent; (4) Area of nursery lakes (ha); (5) Nursery lake productivity; estimated – adj. smolt density (N/ha); (6) Total water license allocations (m3/yr/ha); (7) Agricultural area (% - ALR 2010); (8) Urban area (%); (9) Forest harvest (%); (10) Mountain pine beetle disturbed area (% cumulative 2008); (11) Road density (km / km2 – all roads); (12) Stream Crossing density (# / km2); (13) Placer claims (total count); (14) Active mines (total count); (15) IPPs (total count); and (16) Trend in Ricker residuals.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1																
2	-0.03															
3	0.15	-0.03														
4	0.10	0.75	-0.02													
5	0.02	-0.19	0.23	-0.60												
6	-0.24	0.54	0.04	0.12	0.48											
7	0.11	0.55	0.29	0.46	0.31	0.62										
8	-0.62	0.48	-0.29	0.31	-0.01	0.63	0.35									
9	0.38	0.43	0.25	0.3	0.32	0.46	0.89	0.07								
10	0.95	-0.17	0.24	-0.01	0.17	-0.21	0.20	-0.61	0.50							
11	-0.08	0.80	0.07	0.63	0.15	0.72	0.88	0.52	0.75	-0.07						
12	-0.32	0.38	0.02	0.19	0.37	0.55	0.55	0.40	0.53	-0.24	0.72					
13	-0.25	0.56	0.03	0.32	0.20	0.63	0.48	0.52	0.43	-0.25	0.62	0.39				
14	-0.25	0.56	0.01	0.20	0.43	0.98	0.62	0.70	0.45	-0.21	0.73	0.54	0.64			
15	-0.52	-0.33	-0.16	-0.09	-0.19	-0.22	-0.29	0.46	-0.41	-0.43	-0.29	-0.08	0.10	-0.14		
16	-0.57	-0.13	-0.26	-0.07	-0.16	0.22	0.05	0.38	-0.06	-0.46	0.12	0.27	0.18	0.20	0.34	

Table 16. Predictor variables, AIC_c values, model rankings, and adjusted R-square values for all candidate linear regression models relating sockeye salmon productivity (trend from 1984 to 2004 in Ricker residuals as the response variable) to indicators of habitat vulnerability and stress. The three most plausible models (three highest ranked AIC_c models) are in bold. Note use of the following definitions to describe the predictor variables in the alternative models: (M) Migration distance (km); (L) Lake influenced : total spawning extent ratio; (N) Nursery lake(s) area (ha); (J) Juvenile productivity of nursery lakes; estimated – adj. smolt density (N/ha); (W) Water license allocations (m3 / yr / ha); (U) Urban area (%); (F) Forest harvested area (% - 15 yr cumulative 2010); (R) Road density (km / km2 – all roads); (A) Agricultural area (% - ALR 2010); (P) Pine beetle disturbed area (% cumulative 2008); (AM) Active Mines (total count); and (PC) Placer Claims (total count).

Predictor Variables	AIC_c	AIC_c rank	Adjusted R^{2*}
M	-44.83	1	0.3239
L	-38.44	13	0.0148
N	-37.21	24	-0.0583
J	-37.50	22	-0.0406
W	-37.86	18	-0.0189
U	-39.72	7	0.0870
F	-37.13	25	-0.0635
R	-37.30	23	-0.0530
A	-37.10	26	-0.0654
P	-41.54	4	0.1798
AM	-37.74	20	-0.0260
PL	-37.58	21	-0.0354
M, P	-42.96	2	0.3413
M, U	-41.36	6	0.2763
P, U	-38.41	14	0.1393
P, W	-38.45	11	0.1414
M, R	-41.83	3	0.2960
P, R	-38.44	12	0.1407
R, W	-34.43	33	-0.0881
N, J	-34.93	30	-0.0561
F, R	-34.97	29	-0.0541
M, AM	-41.51	5	0.2828
P, AM	-38.40	15	0.1388
N, AM	-34.51	32	-0.0826
AM, PL	-34.32	35	-0.0947
M, P, U	-38.89	10	0.2929
M, P, W	-39.03	8	0.2988
P, W, U	-34.39	34	0.0786
N, J, M	-37.81	19	0.2466
L, R, A	-31.07	39	-0.1200
R, F, M	-38.17	16	0.2621
M, P, AM	-38.94	9	0.2948
M, L, R, A	-34.21	36	0.2458
M, P, U, W	-34.09	37	0.2405
P, U, W, R	-29.47	41	0.0035
R, N, F, J	-37.87	17	0.3917
R, M, F, U	-33.27	38	0.2028
M, J, N, P	-36.12	27	0.3258
M, P, AM, W	-34.57	31	0.2616
R, N, F, AM	-26.00	44	-0.2223
M, J, N, P, W	-35.07	28	0.4517
M, W, P, U, N	-28.83	42	0.2090
W, P, U, N, J	-26.86	43	0.1113
U, F, L, A, R	-21.69	47	-0.2043

Predictor Variables	AIC_c	AIC_c rank	Adjusted R^{2*}
M, W, P, AM, N	-30.21	40	0.2706
U, F, L, A, R, M	-21.45	48	0.1387
J, F, L, A, R, M	-22.46	46	0.1880
J, P, L, A, R, M	-24.72	45	0.2892
J, P, L, A, R, AM	-18.20	49	0.3480
U, F, L, A, R, M, J	-13.60	51	0.1423
U, F, L, A, R, M, P	-14.86	50	0.2034
W, F, L, A, R, M, P	-12.99	53	0.1109
W, F, L, A, R, U, P	-8.60	55	-0.1507
W, F, N, A, R, M, P	-7.46	56	-0.2306
J, P, L, A, R, AM, M	-13.44	52	0.1344
W, F, L, A, R, U, P, M	-1.91	57	0.1038
W, F, L, A, R, U, P, N	4.31	59	-0.2921
W, F, N, A, R, U, P, M	-0.08	58	0.0020
W, F, N, J, R, U, P, M, A	-10.73	54	0.4666
W, F, N, J, R, U, P, M, A	7.40	61	0.3904
W, F, N, J, R, U, P, M, L	5.49	60	0.4552
W, F, N, J, R, U, P, A, L	13.55	62	0.1247
M, L, N, J, W, U, F, R, A, P	32.31	63	0.3782
M, L, N, J, W, U, F, R, A, AM	36.12	64	0.2221
P, L, N, J, W, U, F, R, A, AM	38.43	65	0.1088
M, L, N, J, W, U, F, R, A, P, AM	66.34	66	0.6163
M, L, N, J, W, U, F, R, A, P, AM, PL	154.24	67	0.5924

*Adjusted R^2 measures the proportion of the variation in the dependent variable accounted for by the explanatory variables. Unlike R^2, adjusted R^2 allows for the degrees of freedom associated with the sums of the squares and so is generally considered to be a more accurate goodness-of-fit measure than simple R^2.

Table 17. Summary of correlation coefficients between indicators of total productivity and two habitat condition indicators related to adult migration (summer air temperatures along migration corridor) and smolt outmigration (spring time air temperatures at nursery lakes). Note use of the following symbols to denote the Bonferroni adjusted significance levels: * = P <0.005 and NS = Not significant.

CU Index	Stock name	Total productivity vs. migration summer air temperatures	N	Sig	Total productivity vs. nursery lake spring air temperatures	N	Sig
L_04_01	Birkenhead	-0.42	58	*	-0.09	58	NS
L_07_01	Bowron	-0.24	58	NS	-0.11	58	NS
L_06_02	Chilko	-0.15	58	NS	0.09	58	NS
L_06_12	E. Stuart	-0.32	58	NS	-0.33	58	NS
L_10_01	Fennel	-0.30	42	NS	0.03	42	NS
L_06_01	Gates	-0.22	38	NS	-0.25	38	NS
L_03_03	Harrison	0.19	57	NS	0.20	57	NS
L_09_03	L. Shuswap	-0.11	57	NS	-0.35	57	NS
L_06_13	L. Stuart	-0.21	57	NS	-0.14	57	NS
L_06_09	Nadina	-0.19	33	NS	0.04	33	NS
L_03_05	Pitt	-0.09	58	NS	-0.25	58	NS
L_06_11	Portage	-0.37	52	NS	-0.03	52	NS
L_06_10	Quesnel	0.07	58	NS	-0.08	58	NS
L_10_01	Raft	-0.13	58	NS	-0.26	58	NS
L_09_02	Scotch	-0.10	41	NS	-0.27	41	NS
L_09_02	Seymour	-0.07	58	NS	-0.20	58	NS
L_06_05	Stellako	-0.05	58	NS	-0.03	58	NS
L_03_04	Weaver	-0.15	40	NS	-0.30	40	NS

Table 18. Summary of population status, habitat vulnerability, and relative level of cumulative stress for all sockeye salmon Conservation Units in the Fraser River basin. This summary is based on more detailed data found in Table 1, Table 5, Table 11, Table 12, Table 13, and Table 14.

CU Index	Management group	Conservation Unit	Population status	Indicators of habitat vulnerability			Relative measures of cumulative stress on habitats			
				Migration distance (km)	Ratio of lake infl: total spawn	Area of nursery lakes (ha)	Stress on migration	Stress on lake infl / main spawn	Stress on lake inlet / trib spawn	Stress on rearing
L_06_12	Early Stuart	Stuart	Poor	998	0.00	35,919	High	None	Moderate	Moderate
L_06_14	Early Stuart	Takla / Trembleur	Poor	1,069	0.05	36,253	High	Moderate	Moderate	Moderate
L_03_01	Early Summer	Chilliwack	Moderate	156	0.00	1,182	High	None	Moderate	Moderate
L_03_05	Early Summer	Pitt	Good	57	0.00	5,348	Moderate	None	Low	Low
L_05_02	Early Summer	Nahatlatch	Poor	255	0.18	303	High	Moderate	Low	Low
L_06_01	Early Summer	Anderson	Poor	359	0.00	2,872	High	None	Moderate	Moderate
L_06_02	Early Summer	Chilko	Unknown	680	1.00	18,447	Moderate	Moderate	None	Moderate
L_06_04	Early Summer	Francois	Poor	1,024	1.00	25,164	High	Moderate	Low	High
L_06_06	Early Summer	Fraser	Unknown	989	0.00	5,385	High	None	High	High
L_06_09	Early Summer	Nadina	Unknown	1,182		930	High	None	None	High
L_06_16	Early Summer	Taseko	Poor	709	1.00	2,124	Moderate	Moderate	None	Moderate
L_07_01	Early Summer	Bowron	Poor	1,102	0.00	1,021	High	None	Low	Moderate
L_07_02	Early Summer	Indian/Kruger	Unknown	1,094	1.00	235	High	Moderate	None	Moderate
L_09_02	Early Summer	Shuswap Complex	Poor	487	0.04	55,491	High	None	High	High
L_10_01	Early Summer	Kamloops	Moderate	387	0.53	6,014	Moderate	High	High	High
L_06_03	Summer	Chilko	Good	680	1.00	18,447	Moderate	Moderate	None	Moderate
L_06_05	Summer	Francois	Unknown	1,024	1.00	25,164	High	Moderate	None	High
L_06_07	Summer	Fraser	Good	989	1.00	5,385	High	Moderate	None	High
L_06_08	Summer	Mckinley	Unknown	849	0.00	513	High	None	High	High
L_06_10	Summer	Quesnel	Good	754	0.55	32,863	High	High	Moderate	High
L_06_13	Summer	Stuart	Poor	998	0.83	35,919	High	Moderate	Moderate	High
L_06_15	Summer	Takla / Trembleur	Poor	1,069	0.66	36,253	High	Moderate	Moderate	Moderate
L_03_02	Late	Cultus	Poor	111		631	High	None	None	High
L_03_03	Late	Harrison (D/S)	Moderate	127	0.04	22,192	Moderate	Moderate	Moderate	Moderate
L_03_04	Late	Harrison (U/S)	Poor	127	0.41	22,192	Moderate	Moderate	Moderate	Moderate
L_04_01	Late	Lillooet	Poor	252	0.00	3,220	Moderate	None	Moderate	Moderate
L_05_01	Late	Kawkawa	Unknown	164	1.00	76	High	High	None	Moderate
L_06_11	Late	Seton	Poor	333	1.00	2,475	High	High	None	Moderate
L_09_01	Late	Kamloops	Poor	387	1.00	5,517	Moderate	High	None	High
L_09_03	Late	Shuswap Complex	Poor	487	0.36	53,265	High	High	High	High
R02	River	Widgeon	Poor	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown
R03	River	Lower_Fraser	Moderate	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown
R04	River	Fraser_Canyon	Unknown	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown
R05	River	Middle_Fraser	Unknown	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown
R06	River	Upper_Fraser	Unknown	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown
R07	River	Thompson_River	Unknown	Unknown	Unknown	N/A	Unknown	Unknown	Unknown	Unknown

Table 19. Seven questions (from Stewart-Oaten 1996) and the related responses to our overall assessment of the cumulative effect of freshwater stressors in contributing to the recent declines of Fraser River sockeye salmon.

Question	Response
(1) How plausible is the hypothesized causal mechanism? Based on known physical and biological principles, is the proposed mechanism realistic?	Freshwater habitat quality is clearly an important component of salmon conservation. A very large scientific literature has demonstrated that changes in factors such as sediment supply, channel structure, temperature, stream hydrology, large woody debris supply, total gas pressure, and migration barriers can have negative impacts on sockeye salmon. These factors are affected by both human activities and natural events.
(2) What is the strength of the estimated effect? The stronger it is, the more likely we are to correctly distinguish the mechanism causing an observed response from background variation and observation error, as well as from changes arising from other simultaneously operating mechanisms. Note that in such analyses, emphasis here is on estimating the strength of some effect and uncertainty in that estimate, rather than on formally testing some null hypothesis about the mechanism.	The cumulative impact of freshwater stressors has the potential to be very strong. The absence of salmon from many streams can be associated with poor habitat quality due to natural or anthropogenic causes.
(3) Does the consistency of direction, magnitude, and duration of observed effects across studies of similar systems also lend credibility to a hypothesis about a given mechanism causing those effects? For instance, does empirical evidence show such a mechanism working in the same way for other species or stocks or situations?	Scientific support is available for the link between stressor, impact and outcome (e.g. more roads → higher sediment load → lower egg survival) for all of the stressors that were considered. In most cases, the chain of evidence for cause and effect for a specific stressor is not available for Fraser River sockeye salmon. However, evidence from other species and stocks consistently supports the mechanisms that have been hypothesized.
(4) Are life stages affected by the proposed mechanism affected whereas others are not? Species or life stages or stocks that should not be affected by the mechanism do not show change, whereas the stages that should be affected do show a response.	Adult returns and lifetime survival of sockeye salmon have consistently declined across many Fraser River CUs, but juvenile populations have not shown the same consistent trend. This suggests that declines in adult populations are not the direct result of cumulative changes in freshwater habitat quality.
(5) Did the timing of observed changes coincide with a change in the state variable of the proposed causal mechanism? If there is a time lag in the response, it should be on a realistic time scale based on what is known about the processes involved.	Upward temporal trends in some freshwater stressors (mountain pine beetle, road density) coincide with recent declines in Fraser sockeye salmon. We believe that this correlation is spurious because juvenile population density remains high for most CUs.
(6) Is there a similarity or coherence of responses across space, time, populations, species, and indicators that strengthens the case for a particular mechanism?	Both the amount and rate of change in freshwater stressors varies substantially among watersheds that support Fraser River sockeye salmon In contrast, the recent decline in adult sockeye salmon populations is coherent across most of the CUs in the Fraser drainage, which suggests that more general decline that is not driven by changes in these freshwater stressors.
(7) Are there natural gradients or contrasting conditions that result in outcomes that are consistent with the proposed mechanism? These are not human-manipulated experiments, but they may create distinct enough contrasting situations to learn about mechanisms causing observed changes.	Variation in habitat quality is generally associated with variation in salmonids survival across various species in many locations. However, patterns of variation among Fraser River sockeye salmon CUs in both stressors and freshwater survival do not support the hypothesis that the recent decline in adult sockeye salmon populations is the result of changes in freshwater habitat quality.

Table 20. Seven questions (from Stewart-Oaten 1996) and the related responses to our overall assessment of the effect of Forest harvesting, Mountain Pine Beetle, and roads in contributing to the recent declines of Fraser River sockeye salmon.

Question	Forest Harvesting	Mountain Pine Beetle	Roads
(1) How plausible is the hypothesized causal mechanism?	An extensive scientific literature documents a variety of plausible mechanisms that link forest harvesting to degradation in stream fish habitat. These include changes in sediment supply, large woody debris supply, channel structure, temperature and hydrology. Forestry impacts on lake and migration habitats are less clear. Suspended sediment can reduce light penetration but the effects of changes in wood supply, stream temperature and hydrology are unlikely to affect sockeye salmon survival or growth in these habitats.	Loss of forest cover has been linked to hydrological changes (timing of flows, low flows, peak flow events) that can affect sockeye salmon spawning habitat. Higher peak flow events can destabilize stream channels, which would lead to lower egg survival. Later, lower base flows could impair migration and spawning of adults. In some watersheds, salvage logging has resulted in short-term increases in the intensity of forest harvesting and road building.	Roads can have direct impacts but they can also serve as a convenient indicator of other human activities. Direct effects include blocking fish passage and increasing sedimentation. Road density is highly correlated with stressors such as forest harvesting and urbanization.
(2) What is the strength of the estimated effect?	The impacts of forest harvesting on streams is likely to be strong because of the continuing, extensive nature of the impact combined with the multiplicity of mechanisms. Forest harvesting takes place in most Fraser River sockeye salmon watersheds. Site specific factors such as unstable soils, steep terrain and high variance in flow can exacerbate logging impacts. Impacts on lake habitat are thought to be much less significant, particularly for pelagic species, such as sockeye salmon. In rare cases, sediment bars at the mouths of small spawning streams may obstruct upstream migration (e.g. early Talka CU).	The effects of mountain pine beetle are expected to be relatively small. The area affected is far larger than that of the other stressors that were considered. However, the effects of the loss of forest cover by itself are considered to be much smaller than the combined effects of roads and mechanical forest removal associated with forest harvesting. Habitat impacts are limited mainly to a single mechanism, hydrological change.	The impact of high road density is strong, but it can be difficult to disentangle the effects of roads from that of related activities, particularly forest harvesting. Culverts may prevent upstream migration, particularly in smaller streams. This effect is expected to be weak in sockeye salmon, which do not rear in streams and tend to use larger rivers. A Provincial project is in the process of identifying impassible road culverts.
(3) How consistent is the direction, magnitude, and duration of observed effects across studies of similar systems?	The impacts of forestry are consistent in direction across a wide range of ecosystem types. However, the strength of the impact can vary widely with site characteristics. The biological effects of stream habitat impacts are consistent across a variety of stream salmonids species.	There is good evidence that the removal of forest cover results in higher peak flows. However, much of this information comes from forestry related research where the effects of forest removal are difficult to separate from the effects of roads and mechanical disturbance.	Road density has been used as an indicator of human impacts on many salmonids species because of the consistent relationship between road density population status. Higher harvest rates associated with better access can be a factor in many species, but not sockeye salmon.

Question	Forest Harvesting	Mountain Pine Beetle	Roads
(4) Are life stages affected by the proposed mechanism affected whereas others are not?	Most of the proposed mechanisms affect the egg-fry in the case of sockeye salmon. Fall fry densities have not declined to the same extent as adult number. This is contrary to the expected effect of lower egg-fry survival.	Peak flows are expected to have the highest impact at the egg stage. While egg survival is rarely monitored directly, fall fry densities have not declined to the same extent as adult number. This is contrary to the expected effect of lower egg-fry survival.	Most of the proposed mechanisms affect the egg-fry in the case of sockeye salmon. Fall fry densities have not declined to the same extent as adult number. This is contrary to the expected effect of lower egg-fry survival. Adult passage issues would be expected to affect escapement numbers more than total recruits. This is inconsistent with observations (but see Section concerning migration mortality in mainstems).
(5) Did the timing of observed changes coincide with a change in the state variable of the proposed causal mechanism?	The overall level of activity has increased through time but has been relatively stable over recent decades. Timing of this activity varies among watersheds but changes in population parameters for individual CUs do not reflect this.	Changes are large but too recent to have affected adult returns prior to about 2006. In addition, the effect on peak flow takes the form of a reduced return time interval for a particular sized event (e.g. a 20 year flow may now occur every 10 years). As a result, stochasticity in weather events is expected to increase the time lag between deforestation and the process of channel disruption.	The overall level of activity has increased steadily through time. Timing of this activity varies among watersheds but changes in population parameters for individual CUs do not reflect this.
(6) Is there a similarity or coherence of responses across space, time, populations, species, and indicators that strengthens the case for a particular mechanism?	There is good support for the proposed mechanisms in terms of both the habitat impacts and the resulting biological impacts on a variety of salmonids.	Similar levels of insect deforestation are very rarely observed.	Road density is a well accepted indicator of human impacts, including impacts on a variety of salmon species.
(7) Are there natural gradients or contrasting conditions that result in outcomes that are consistent with the proposed mechanism?	Contrasting conditions do exist among CUs but a multiple regression analysis does not support the hypothesis that forest harvesting has had a significant impact on Fraser sockeye salmon population parameters.	Contrasting conditions do exist among CUs but a multiple regression analysis does not support the hypothesis that deforestation as a result of mountain pine beetle has had a significant impact on sockeye salmon population parameters. The impact of this factor may become more apparent in future since there is the potential for significant time lags between the occurrence of the stressor and the effect on sockeye salmon populations.	Contrasting conditions do exist among CUs but a multiple regression analysis does not support the hypothesis that road density has had a significant impact on Fraser sockeye salmon population parameters.

Table 21. Seven questions (from Stewart-Oaten 1996) and the related responses to our overall assessment of the effect of agriculture and urbanization, water use, and mines in contributing to the recent declines of Fraser River sockeye salmon.

Question	Agriculture and Urbanization	Water Use	Mines
(1) How plausible is the hypothesized causal mechanism?	Several plausible mechanisms link this stressor to degradation of sockeye salmon stream habitat. These include: increases in sedimentation, increases in peak flows, decreases in low flows and changes to riparian conditions. Scientific support is available for all of these mechanisms, however, the amount of land use change that is required to induce significant impact is not well defined. The mechanisms for impacts on lake habitat and migration corridors are less plausible but may include degradation of water quality or impediments to migration.	The hypothesized causal mechanism is plausible. Adequate water flow is essential to successful sockeye salmon migration and reproduction. Low flows can also result in unfavorably high temperatures and low intergravel oxygen levels.	The hypothesized causal mechanism is plausible. There is strong scientific evidence that increased sediment load in spawning streams can increase egg-fry mortality by smothering eggs and destabilizing channel structure. Mining for gravel or placer minerals from stream beds has been shown to disrupt channel structure. Mines can increase sediment yields in watersheds by exposing mineral soil to erosion. Complete destruction of habitat by poor placement of mine sites is also possible but rare under current legislation. Contaminants, such as acid mine drainage, are excluded from this analysis.
(2) What is the strength of the estimated effect?	The strength of the impact is expected to be generally low for all habitat types. Although agriculture and urbanization has the potential to strongly affect spawning streams, none of the watersheds have high levels of these land uses. The impacts are also expected to be very site specific because of mitigation measures that have been implemented on some land holdings. Migration corridors are bordered by extensive urban and agricultural land use, but these appear to have little impact on migration activities.	There is potential for strong impacts. In some key watersheds, licensed water use exceeds the natural flow of the stream. Poor data quality makes it difficult to directly assess the strength of Water Use impacts.	The impact is expected to be generally weak because of the low level of activity. Impact is proportional to the increased sediment load and, in extreme cases, can be very strong. The sources of sediment in decreasing order of severity are: 1. Extraction of material from stream beds and riparian areas, 2. Roads 3. Non-riparian pits and washing facilities. There are no good data on mines as a source of sediment in the Fraser Basin. However, the effect of mining on Fraser River sockeye salmon is expected to be weak because: (a) mines are not prevalent in watersheds used for sockeye salmon spawning and (b) the introduction of sediment into fish habitat is prohibited under the Fisheries Act.
(3) How consistent is the direction, magnitude, and duration of observed effects across studies of similar systems?	Historical studies have demonstrated a consistent pattern of habitat degradation and loss due to these stressors. Habitat restoration efforts can be very effective in restoring individual salmon runs, which suggests that habitat degradation was a major factor in the original extirpation.	Water Use conflicts are a serious management issue for stream salmonids across much of western North America. As a result, there is a large body of literature that documents and attempts to the quantify the effects of low flows on a variety of salmonids species.	Studies on a variety of salmonids species strongly support the idea that higher sediment loads negatively impacts egg survival. Effects are most severe where sediment both settles out and interferes with hyporheic exchange (groundwater – stream interactions). Effects may be lower for very fine sediment (e.g.

Question	Agriculture and Urbanization	Water Use	Mines
			glacial flour, some clays), which may not settle out, and very coarse sediment, which may not reduce the porosity of the streambed.
(4) Are life stages affected by the proposed mechanism affected whereas others are not?	Most of the proposed mechanisms affect the egg-fry in the case of sockeye salmon. Fall fry densities have not declined to the same extent as adult number. This is contrary to the expected effect of lower egg-fry survival.	For sockeye salmon populations, the effects of low flow should be observable in the course of routine monitoring of spawner numbers. At this point, low flows in streams do not appear to have resulted in consistent increases in prespawning mortality or barriers to migration.	Sediment effects are specific to egg-fry in the case of sockeye salmon. In severe cases, light penetration and primary production might be reduced in nursery lakes. Fall fry densities have not declined to the same extent as adult number. This is contrary to the expected effect of sediment on egg-fry survival.
(5) Did the timing of observed changes coincide with a change in the state variable of the proposed causal mechanism?	The overall level of activity appears to have increased steadily through time. However, there is no data that documents differences in the timing or rate of increase among CUs.	There is very little time series data on water usage.	There are no time series data in the assessment of mines.
(6) Is there a similarity or coherence of responses across space, time, populations, species, and indicators that strengthens the case for a particular mechanism?	Land use practices are one of the key contributors to aquatic habitat degradation worldwide. Salmonids appear to be particularly vulnerable because of their dependence on high water quality.	The most severe water use conflicts typically occur during summer low flow periods. With the exception of migrating adults, sockeye salmon are not typically in streams during this period. Water use does not appear to be an issue for most stocks that spawn during summer low flow (e.g. early Stuart).	There are insufficient data to conduct an analysis of the coherence of responses.
(7) Are there natural gradients or contrasting conditions that result in outcomes that are consistent with the proposed mechanism?	Contrasting conditions do exist among CUs but a multiple regression analysis does not support the hypothesis that intensive land use has had a significant impact on Fraser sockeye salmon population parameters.	Contrasting conditions do exist among CUs but a multiple regression analysis does not support the hypothesis that higher levels of water use have had a significant impact on Fraser sockeye salmon population parameters. Water use varies substantially among CUs but declines in sockeye salmon abundance have occurred in both high and low water use areas.	Studies on a variety of salmonids species strongly support the idea that increases in sediment loads have negative impacts on egg survival. There are no good data on egg survival among CUs for Fraser River sockeye salmon.

Table 22. Seven questions (from Stewart-Oaten 1996) and the related responses to our overall assessment of the effect of small hydro, large hydro, and log storage in contributing to the recent declines of Fraser River sockeye salmon.

Question	Small hydro	Large-hydro	Log storage
(1) How plausible is the hypothesized causal mechanism?	Plausible mechanisms include changes to temperature, total gas pressure, gravel supply, fish passage and water flow in spawning streams. Site specific impacts are important considerations. For example, larger headponds are more likely to result in temperature effects and to interrupt gravel supply, especially if gravel is removed rather than passed into the downstream channel. There are no plausible mechanisms for impacts on lake habitat. Since there are no IPPs on sockeye salmon migration routes, there are no plausible mechanisms for impacts on migration (but see section 3.3.2, Large scale hydro projects).	Plausible mechanisms for Fraser projects involve interference with upstream or downstream migration. Water diversion for the Nechacko project has resulted in higher than optimal temperature for migrating adults from several CUs. In the the Seaton River, sockeye salmon have to pass a dam and a turbine installation. The effects of dams and turbines in delaying upstream migration, and killing or injuring downstream migrating smolts, are well documented in the scientific literature.	The hypothesized causal mechanism is plausible. Log storage and associated activities can damage habitat used by fish, and injure or kill fish through increased biological oxygen demands or exposure to toxic leachates. The magnitude of these disturbances is considered to be a function of the flushing characteristics of the river, the specific methods of log handling / storage, and intensity of use in each area. Outmigrating smolts from all Fraser CUs could potentially be exposed to effects of log handling as they move through the Fraser estuary. Log storage areas in the estuary may also be used as staging areas by adults of all sockeye salmon CUs before they migrate upstream.
(2) What is the strength of the estimated effect?	Currently, there are very few operational IPPs, which means that the cumulative IPP impact is also small. In most cases, the strength of each effect at an individual IPP site will be small because the site footprint is small and located upstream of the sockeye salmon distribution. However, the potential for a strong impact is present, given the right site characteristics. An IPP on a migration corridor poses a clear risk to both upstream and downstream migrants. If the stream channel reach between the intake structure and the powerhouse is occupied by fish, then water diversion is also an issue.	The effect is potentially strong. This stressor is absent from most Fraser sockeye salmon CUs. Large hydro projects do not exist in the Fraser River mainstem and are present only in a limited number of Fraser River tributaries. Only 2 of these projects (Bridge-Seton and Nechako) are considered to have the potential to cause significant impacts on sockeye salmon. The most serious effects are on CUs associated with Nechako (Stuart, Takla/Trembleur, Nadina, Fraser and Francois), where temperatures on the migration route can reach lethal levels. Sockeye salmon appear to be able to pass the Seaton Project in both directions and the strength of the estimated effect on the Seton and Anderson CUs would appear to be weak.	The strength of the estimated effect of log storage would appear to be weak, although evidence in this regard is limited. While there has been no direct study of effects on sockeye salmon, past research in the Fraser estuary has indicated that densities and growth rates of resident salmon juveniles (Chinook, pink, and chum) do not differ in log storage areas vs. nearby marsh areas in the Fraser, nor do densities of their invertebrate prey. Sockeye salmon use of the Fraser estuary is limited in both time and space, lessening their potential exposure to log storage related contaminants.
(3) How consistent is the direction, magnitude, and duration of observed effects across studies of similar systems?	IPPs are a recent phenomenon and are therefore unlikely to be linked to sockeye salmon declines over past decades. Studies on a variety of salmonids species strongly support the idea that changes in temperature, TGP, gravel supply, fish passage and water flow in spawning streams can	Localized impacts of large hydro projects as well as broader consequences for salmon population are well documented. For example, salmon populations that must run a gauntlet of large dams in the Columbia River on their migrations to and from spawning and nursery grounds can experience significant direct and indirect (delayed) mortality as a consequence of dam	Localized impacts of log storage activities on fish and fish habitat are well documented across western North America for a variety of fish species. An assessment of the consistency of broader impacts is impossible because population-level effects of log handling on fish have not been studied. Log storage, however, is unlikely to interfere significantly and directly with

Question	Small hydro	Large-hydro	Log storage
	negatively affect survival.	passage, with resultant population-level effects. Large dams have been cited as a major contributing factor to the near extirpation of Snake River sockeye salmon.	fish outside the relatively small area where the disturbances occur, and sockeye salmon should generally be able to avoid such areas.
(4) Are life stages affected by the proposed mechanism affected whereas others are not?	There are no data that is specific to Fraser River sockeye salmon because of the recent history of IPPs. Specific impacts (e.g., egg mortality, migrant mortality, gas bubble disease) could in theory be observed in the future and linked to specific sites. in practice, detecting such impacts would require focused monitoring efforts.	Large dams existing in Fraser River tributaries could have potentially serious impacts on upstream migrating sockeye salmon adults and downstream outmigrating smolts. Effects on other sockeye salmon life stages should be limited. As there are only two major hydro projects of concern in the Fraser Basin, only a subset of sockeye salmon CUs would be exposed to large hydro impacts.	Log storage activities could effect outmigrating sockeye salmon smolts or migrating adults, as these would be the only life stages exposed to potential impacts within the estuary. These impacts would be observed as lower marine survival. Given the weakness of the expected response, declines in marine survival of sockeye salmon are not likely to be the result of log storage activity.
(5) Did the timing of observed changes coincide with a change in the state variable of the proposed causal mechanism?	There are no time series data in the assessment of IPPs.	The Bridge-Seton and Nechako projects have both been in operation since the 1950's. Both have had known historical impacts on migrating sockeye salmon (direct mortality of smolts and adults at Bridge-Seton, and thermal stress on adults at Nechako). For both projects mitigation measures have been enacted with apparent success so survival should have improved in recent years relative to historical conditions.	Based on our qualitative assessment, log storage in the Fraser estuary appears to have changed little in terms of overall extent, distribution of storage sites, or seasonal intensity over the last decade.
(6) Is there a similarity or coherence of responses across space, time, populations, species, and indicators that strengthens the case for a particular mechanism?	NA	Effects of large hydro projects on salmon survival can be serious and varied, with repeated evidence of negative effects on salmon populations.	While the effects of log handling on fish habitat is relatively clear, the population level effects of these impacts is not.
(7) Are there natural gradients or contrasting conditions that result in outcomes that are consistent with the proposed mechanism?	NA	Presence absence of a large hydro project provides a good contrast among CUs that are affected or unaffected by large hydro projects. Status of the affected CUs is generally poor (or unknown) but most other sockeye salmon CUs are currently considered to have similar status.	Contrasts do not appear to exist because all sockeye salmon CUs experience similar levels of stress as they migrate through the lower River.

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Appendix 1 – Statement of work

Government of Canada Gouvernement du Canada

Contract No. SALMON-044

Appendix "D"

Statement of Work
Consulting and Professional Services

SW1 Background

1.1 The Commission of Inquiry into the Decline of Sockeye Salmon in the Fraser River (www.cohencommission.ca) was established to investigate and report on the reasons for the decline and the long term prospects for Fraser River sockeye salmon stocks and to determine whether changes need to be made to fisheries management policies, practices and procedures.

1.2 The Commission wishes to engage a Contractor to investigate several aspects of Fraser sockeye ecology, including the status of sockeye conservation units, a review of industrial and urban impacts on freshwater ecology and salmon life history, and an expert assessment of potential impacts from industrial and urban activities on Fraser River sockeye during the last 30 years.

SW2 Objective

2.1 To evaluate the status of all of the 36 sockeye CUs and sockeye sub-stocks within CUs in the Fraser River Watershed.

2.2 To evaluate Fraser River sockeye salmon ecology and survival in freshwater environments.

2.3 To evaluate industrial and urban activities (except pollution but including impacts from Mountain Pine Beetle and the associated salvage logging) in the Fraser River Watershed and their potential effects on Fraser sockeye.

2.4 To evaluate the impacts of surface water and groundwater diversions on Fraser sockeye production and survival.

SW3 Scope of Work

3.1 The Contractor shall provide the services of David Marmorek, Katherine Weickowski, Marc Nelitz, Marc Porter, Diana Abraham, Darcy Pickard, Katy Brian, Eric Parkinson and Carl Schwarz to perform the work.

3.2 DFO has identified salmon CUs and has developed a methodology for determining "CU benchmarks" (reference). There are 2 CU benchmarks – upper and lower – which can be used to define the status of CUs1. To date, the CU benchmark methodology has not been applied to Fraser sockeye CUs. The Contractor will be required to evaluate the DFO methodology to determine its applicability and feasibility for defining the status of Fraser sockeye CUs.

3.2 Alternative methodologies for determining CU status, for example those based on escapement, production or other databases, will also be critically evaluated. The Contractor will determine the status of CUs, or if that's not feasible due to information gaps, logical groupings of CUs represented by specific stocks. The Contractor will also make use of other readily available information on the productivity of different Fraser Basin sockeye stocks.

3.3 Once the status of the CUs and sub-stocks within CUs has been determined, then hypotheses will be developed to explain the trends and status of the CUs, focusing on industrial and urban stressors pertaining to the freshwater part of the salmon life cycle, as well as fishing pressure.

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[1] Holt,C., A. Cass, B. Holtby and B. Riddell. 2008 (draft). Indicators of Status and Benchmarks for Conservation Units in Canada's Wild Salmon Policy. PSARC Working Paper S2009-1.

3.4 Existing information on freshwater production will be compiled and analyzed, noting the limitations of existing information. Key variables will include:

- Quantitative estimates of life cycle and life stage specific productivity (available only for some stocks)
- Habitat quantity and quality for eggs, alevins, fry, smolts and adults
- Impacts to stock status and potential causes of premature migration of adult (Late Run) sockeye into freshwater
- Extent of en-route mortality and pre-spawning mortality
- Freshwater predation impacts on sockeye smolts and adults
- Impacts of diseases on sockeye smolts and adults in the freshwater environment

3.5 The logging history of the Fraser River watershed will be summarized with particular attention to logging effects adjacent to Fraser sockeye habitats, with potential impacts on sockeye spawning and rearing habitats during the last 30 years. Literature analysis and evaluation of existing data sets will be undertaken to summarize the understanding of logging impacts on Fraser sockeye. The exposure of sockeye CUs to logging impacts will be evaluated in relation to spawning, incubation, rearing and migratory habitats. Lastly, the research will summarize the effects of Fraser Estuary log storage on juvenile and adult sockeye. A review of the potential current and future impacts of Mountain Pine Beetle on Fraser sockeye CUs will be undertaken as a part of this research.

3.6 Evaluation of mining impacts on Fraser sockeye requires consideration of historical mines, presently operating mines, mines currently proposed for development and mining exploration activities. Historical mines include gold mines in the central interior region developed during the Gold Rush while presently operating mines include gold-copper properties adjacent to sockeye waterways. Mines currently proposed for development include the Prosperity Mine adjacent to Williams Lake which could have downstream impacts on Taseko sockeye. Ongoing gravel mining operations in the Lower Fraser River could potentially impact sockeye migratory habitats, including those in the Lower Fraser, and specifically their effect on sockeye food levels. The Contractor will evaluate the potential risks to sockeye salmon associated with historic and current mining operations in the Fraser Watershed as well as from mining exploration activities, focusing on evidence of potential impacts on sockeye spawning and rearing habitats during the last 30 years. The Contractor will also note proposed mining operations with potential future impacts.

3.7 In regards to the Kemano Project, the Contractor will prepare a summary of the effectiveness of water regulation to achieve temperature objectives of less than 20°C at the Stuart-Nechako confluence during sockeye migrations and will also assess the status of Stellako and Nadina CUs that are affected by the development. The Contractor will also review the efficacy of any other water regulation projects designed for temperature control purposes.

3.8 The Contractor will review all other hydro projects that impact sockeye salmon in the Fraser Watershed, e.g. Bridge-Seton system.

3.9 The distribution of Independent Power Projects in relation to sockeye CUs will be determined and mapped by the Contractor and their potential implications for sockeye habitat and habitat management will be discussed.

3.10 The Contractor will review potential effects on migrating sockeye smolts and adults from urbanization. This will include the effects of dredging in the Lower Fraser River below Hope.

3.11 The Contractor will evaluate the potential impacts of agricultural activities on sockeye habitats.

SW4 Deliverables

4.1 The Contractor will organize a Project Inception meeting to be held within 2 weeks of the contract date in the Commission office. The meeting agenda will be set by the Contractor and will include a work plan for project implementation.

4.2 Within 10 weeks of the contract date, the Contractor will provide an initial assessment and recommendations to the Cohen Commission of the applicability of the DFO Benchmark methodology and alternative methodologies for determining the status of Fraser sockeye CUs.

4.2 The main deliverables of the contract are 2 reports evaluating the status of sockeye conservation units, freshwater ecology and freshwater impacts on Fraser River sockeye: 1) a progress report, and 2) a final report. The style for the Reports will be a hybrid between a scientific style and a policy document. An example of a document which follows this format is the BC Pacific Salmon Forum Final Report (www.pacificsalmonforum.ca).

4.3 A Progress Report (maximum 20 pages) will be provided to the Cohen Commission in pdf and Word formats by Nov. 1, 2010. Comments on the Progress Report will be returned to the contractor by Nov. 15, 2010.

4.4 A draft Final Report will be provided to the Cohen Commission in pdf and Word formats by Dec. 15, 2010. The draft Final Report should contain an expanded Executive Summary of 1-2 pages in length as well as a 1-page summary of the "State of the Science". Comments on the draft Final Report will be returned to the contractor by Jan. 15, 2011 with revisions due by Jan. 31, 2011.

4.5 The Contractor will be available to Commission Counsel during hearing preparation and may be called as a witness.

4.6 The Contractor will participate in a 2-day scientific workshop November 30 – December 1, 2010 with the Scientific Advisory Panel and other Contractors preparing Cohen Commission Technical Reports to address cumulative effects and to initiate discussions about the possible causes of the decline and of the 2009 run failure.

4.7 The Contractor will participate in a 2-day meeting presenting to and engaging with the Participants and the public on the results of the conservation unit status and freshwater ecology investigations on February 23-24, 2011.

SW5 Contractor's Proposal

5.1 The Contractor's proposal, designated as Annex 1, in so far as it is not at variance with the Terms and Conditions contained herein, shall apply to and form part of this agreement.

Appendix 2 – Reviewer evaluations and author responses

The authors' responses to each reviewer's comments are provided in bold below.

Report Title: Evaluating the status of Fraser River sockeye salmon and the role of freshwater ecology in their decline

Reviewer Name: John Reynolds

Date: 6 January 2011

1. Identify the strengths and weaknesses of this report.

This report is very thorough, clearly written, and thoughtful. I like the dashboard summaries and the large amount of analyses that went into them. Most of the weaknesses are due to lack of data availability rather than being the fault of the authors. Many of the figures and their captions should be improved, as detailed in my report below.

2. Evaluate the interpretation of the available data, and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

I have no major problems with the interpretation of the data and the conclusions.

3. Are there additional quantitative or qualitative ways to evaluate the subject area not considered in this report? How could the analysis be improved?

There are very few statistical analyses, and I do have concerns (e.g. Table 15) as explained in my detailed report. I have also suggested below the use of more stream data from other sources.

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

Yes, these seem straight-forward, if a little vague. I have suggested in my report that it would be nice to flesh these out a little, e.g. monitoring, or at least mention other similar calls to arms.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

I agree with the suggestions in the report.

6. Please provide any specific comments for the authors.

See below.

Review of Freshwater Report – John D. Reynolds
Earth to Ocean Research Group, Department of Biological Sciences, Simon Fraser University

I found this report to be exceptionally readable and clear, with a well thought-out progression from objectives to methods and results of the analyses. Each of the key steps in methods and corresponding data are presented clearly in tables, making this a very accessible report.

The authors have faced a key short-coming: lack of time series of change for most of the habitat stressors they consider. This is noted on p. 16: there is "a general lack of information that could be used to reliably define dynamic changes in condition across sockeye spawning, rearing, and migratory habitats…". As a result, much of the report is based on relative differences among sockeye conservation units in indicators of status. This matches the terms of reference for this study. But that comment by the authors is very important when considering the terms of reference for the Cohen Commission itself, in particular the investigation of declining productivity and the low returns of 2009. The lack of temporal information weakens the ability of this report to help the Commission understand the changing fortunes of Fraser Sockeye salmon. All is not lost, of course, as there is some temporal information here, such as with forestry and the spread of mountain pine beetles. Furthermore, much of the other information in this report will provide a foundation for understanding spatial variation in status and vulnerability. But I do think we should understand the limitation that's summarized in a sentence on p. 16 right up front. I want to emphasize that this is not a criticism of the report, but a lament about the data that were available in the tight timeline, and I give the authors a lot of credit for stressing on p. 17 the fact that their vulnerability indicators for each CU are relative to the other CUs.

What we have, then, is in my opinion the most comprehensive analysis that could be expected in the time available, summarizing a huge amount of patchy information. This summary is aided by an innovative dashboard representation in the Appendix of the status and trends (where available) for each sockeye conservation unit.

I agree with the authors' conclusion that changes in freshwater habitats are unlikely to be the main cause of the decline in productivity of Fraser River sockeye salmon. While freshwater habitat status never was very high on most peoples' list of suspects, including the Peterman et al. Pacific Salmon Commission report, we needed more to go on more than mere impressions. This report looks hard for evidence to support the freshwater habitat theory, and does not find it.

Below I provide a set of comments that range from minor editorial to more substantive.

p. 3. Line 1. "Both 2009 and 2010 returns were within the statistical distributions of forecasted returns but at opposite ends of these distributions." This depends on how the statistical distributions are defined. There is always some probability of stocks falling within a certain range, even if it is very small. This sentence should be more precise in giving the probabilities for each of the years.

<u>Response:</u> Included probabilities for returns in 2009 and 2010.

p. 4, top. I agree with the value of comparing findings from this report with those of the Peterman et al. 2010 report, which examines additional habitats, but note that the Peterman et al. report was somewhat preliminary, and I understand that another report that uses more standardized methods of analysis is currently being done.

<u>Response:</u> Added "preliminary review" to description of Peterman et al. report.

Fig. 1. The caption should state that the data are based on rolling averages, which smooth out annual variation.

<u>Response:</u> Revised figure caption to include this point.

Fig. 3. It's not clear from the caption what, exactly, this figure is meant to show. Only major nursery lakes are shown, presumably the 18 for which good time series data are available, and these are not labeled. The caption should probably mention that there are others. There are three shades of grey, but only dark grey is referred to.

<u>Response:</u> Revised figure caption to clarify purpose of figure and different uses of shading.

Fig. 4. The tops of some of the lake names are cut off.

<u>Response:</u> Revised figure to ensure CU names are fully included.

p. 6. Bottom. As the authors note, there are many ways of determining status of fish populations. It would help to have an explanation of why they chose to focus on the three that they did, and ignored the others. If this was for pragmatic reasons given limited time, for example, they could state this.

<u>Response:</u> Inserted text explaining rationale for why alternative two methodologies were chosen as well as why did not include additional methods in our review.

The tables do not indicate what, exactly, each of the three methods of determining status, are aimed at. In other words, do each of the three methods use exactly the same definition of "status"? For example, fisheries-type methods are usually focused on status in terms of productivity or reference points for population biomass, whereas IUCN-type methods (which includes COSEWIC) focus on extinction risk. Some discussion of the objectives of status methodology would help here.

<u>Response:</u> Inserted paragraph at the beginning of section 2.1.2 speaking to this point. Described status as defined by each of the methods. Also added a row to Table 2 summarizing status definition.

p. 8, line 9. I believe the reference should be to Table 2, not Table 1.
p. 10, line 18. Typo "is" should be "in".
p. 19, line 22. Typo should be "handling" not "handing"
p. 90, Table 2, line 10 up from bottom. Should be "life" not "ife"

<u>Response:</u> All of these changes have been made.

p. 10, bottom. In assessing the pros and cons of Pestal and Cass vs Holt et al., it might be worth using both methods to assess the same stocks where data permit, to ask how congruent their answers are, and then if the answers are highly correlated, finish the more data-deficient stocks using Pestal and Cass only (though there will still be a problem for the 11 of 6 CUs that even the Pestal and Cass method cannot handle due to lack of information.)

<u>Response:</u> Valid point, however it is beyond the scope of our analyses to undertake such a comparison. Holt et al's (2009) has not been applied across all CUs and we do not have the resources to carry out this analysis. Consequently, it is not possible for us to compare the results of Holt et al. (2009) to those of Pestal and Cass (2009). Grant et al. 2010 (modified version of Holt et al. 2009) has been applied across all CUs and we have done a rudimentary comparison of the results of their work to that of Pestal and Cass (2009). Changes in Pestal and Cass' status assessment based on the work of Grant et al. are illustrated in Figure 5 and summarized in Table 1. To address this point, we also included a suggestion that DFO should undertake a more structured and quantitative comparison.

p. 12. Bottom. I see the logic of distinguishing between populations that spawn upstream or downstream of lakes, but I question the assumption that those that are downstream of lakes are not affected by what happens upstream in the watershed. Indeed, the authors acknowledge this in the next section on nursery lakes. I feel that this assumption therefore warrants further justification.

<u>Response:</u> We continue to support this assumption. In response to the reviewers comment, we added a statement with citations strengthening the justification in the report.

p. 13. In addition to using air temperatures as a surrogate for stream temperatures, why not use actual stream temperatures where available, e.g. from the Fraser mainstem, which are readily available from the Water Survey of Canada and other places, such as the Fraser River Environmental Watch program headed up by Dave Patterson at DFO?

<u>Response:</u> We agree that it would have been better to use actual stream temperatures in our analysis as opposed to / in addition to air temperature. However, inclusion of these data was not possible / practical for a combination of reasons.

First, the tasks to assess the "extent of en-route mortality and pre-spawning mortality" and "impacts to stock status and potential causes of premature migration of adult (Late Run) sockeye into freshwater" were shifted from our scope of work to that of another project for the Cohen Commission (see Hinch, S.G. and E.G. Martins. 2011. A review of potential climate change effects on survival of Fraser River sockeye salmon and an analysis of interannual trends in en route loss and pre-spawn mortality. Cohen Commission Tech. Rep. 9). We acknowledge, however, that water temperature is an important consideration for understanding survival across adult migration, so we wanted to capture this variable in some way despite the reduced emphasis in our scope of work.

Second, a key motivation guiding our selection and development of habitat indicators was to ensure that the indicator could be generated for all Conservation Units over a long time series, and that the indicator was different than what others have already tested. Based on our understanding, actual stream temperature data are not available across the entire extent of large river migration for all 30 lake Conservation Units, while the air temperature indicator that we selected was available at regular intervals across the full extent of migration corridors for a long time series. As well, Selbie et al. (in Appendix C of Peterman et al. 2010) examined the potential influence of stock specific Fraser mainstem (at Qualark) water temperatures in declines of sockeye salmon and found no significant relationship, which motivated us to use a different indicator for our analysis.

Lastly, data from the Fraser River Environmental Watch program were deemed not readily available to represent water temperatures at multiple locations across the migration corridors because Selbie et al. did not develop or use this more complicated measure even though Dave Patterson was a contributor to their analysis (they chose to use the simpler measure of Qualark water temperatures).

p. 14. Thermal trigger for smolt outmigration. The logic of using this indicator is that a temperature cue for outmigration could produce a mismatch between outmigration timing and conditions such as food that affect survival. I don't understand how a measurement of springtime air temperature captures this mismatch potential. Is a high temperature good or bad? This would depend on the phenology of food and predators that the smolts will encounter when they migrate, but that match/mismatch is not captured by this metric.

<u>Response:</u> We have clarified the text in the report to say that springtime air temperature at the nursery lake is being used as an indicator of the timing of ice break-up (one of the cues of smolt outmigration). Thus, this indicator is a surrogate of the potential for mismatch between the timing of arrival at the estuary and timing of other conditions in the estuary, not a direct surrogate of the magnitude of mismatch. If a relationship exists, the magnitude of mismatch would depend on how springtime air temperatures have changed relative to historic conditions to which local stocks have adapted.

As illustrated by the correlations in Table 16, our initial examination of the relationship between springtime air temperatures and total productivity indices for some stocks suggested that years with warmer springtime air temperatures (and presumably earlier ice-break up and smolt outmigration) were associated with years of lower total productivity. However, upon further examination this relationship was not significant across many stocks.

p. 17. Personally, I don't find migration distance to be a very compelling habitat indicator, though I acknowledge the relationships found by Selbie et al. in the Peterman et al. 2010 report. I am not suggesting the authors should drop this, and it does hold up in the simple regression presented later, but it would help to have more rationale for using it.

<u>Response:</u> We maintain our support for and use of this indicator as a measure of the relative habitat vulnerability across Conservation Units for three reasons. First, as mentioned by the reviewer, the relationship found by Selbie et al. (in Peterman et al. 2010) suggests that there may be an underlying biological mechanism related to upstream or downstream migration that is differentially affecting survival of sockeye salmon stocks across the Fraser basin. Second, this mechanism is plausible as we intuitively expect sockeye salmon with longer migration distances will spend relatively longer periods in freshwater during their migration, which in turn would increase the chance and magnitude of exposure to harmful stressors, including diseases, parasites, contaminants, and high water temperatures. Lastly, in our view migration distance is the best indicator available, given a need to use only one indicator that represents habitat vulnerability across both upstream and downstream migrations and a lack of other options due to data limitations.

To strengthen our rationale for using this indicator we have included some of these points in the report.

p. 19. It would be helpful to explain here why urbanization is only considered upstream of Hope, i.e. because downstream of Hope is covered in another report.

<u>Response:</u> Included a footnote clarifying how urbanization downstream of Hope is captured by Johannes et al. 2011.

Fig. 7 (p. 60). It would help to have labels on the circles to indicate which CUs they are.

<u>Response:</u> Given a lack of spacing between circles in this figure, we can not include labels for all CUs. We also do not believe that such labeling is necessary given the purpose of this figure and other options for viewing this information. The intent of this specific figure is to illustrate whether there are relationships among the three variables of habitat vulnerability, not to illustrate the value of these dimensions for a particular CU. The dashboard summaries in the Appendices include this figure, which highlights values for all CUs individually. As well, Figure 38 illustrate the relationship between each vulnerability indicator and level of cumulative stress for each CU (with labels).

The text in the report has been revised to clarify the purpose of this figure and other options for viewing this information.

Fig. 9. This is the first of many figures using this format, and it would be helpful to take readers by the hand through it. When I first encountered it I found it very hard to interpret. More explanation in the caption, and labeling of the y-axes, would help. The word "cumulative" in the caption seems misleading, and I think it would be better described as a frequency distribution (if I understand correctly). That leads to the question of what the units are for the x-axis.

<u>Response:</u> We have ensured that both x and y axes are labeled on this and all similar graphs. We have also clarified the captions of these figures to help with their interpretation and ensure it is clear that they are indeed frequency distributions. The use of the word "cumulative" to represent the forest harvesting data was a term used to represent the way the indicator was generated (i.e., a summation of forest harvesting across a rolling 15 year window). Given the confusion, we have removed the use of this term in the caption and the text of the report has changed to clarify how the indicator was calculated.

Fig. 10. What is the scale indicated by the dots?

<u>Response:</u> Clarified caption to clarify that the "dots" are actually forest cutblock polygons, which appear as dots at this scale.

Fig. 11. Better to just use CU names and not codes in the legend. Then the codes can also be scrapped from the text here and elsewhere. If these are cumulative plots, why do the lines go down sometimes? From text elsewhere, I think these must be some sort of rolling averages, not cumulative plots.

<u>Response:</u> We have removed the use of CU codes in the legend. Again, the use of the word "cumulative" to represent the forest harvesting data was a term used to represent the way the indicator was generated (i.e., a summation of forest harvesting across a rolling 15 year

window). It is possible that the values go down over time. Given the confusion, we have removed the use of this term in the caption and the text of the report has changed to clarify how the indicator was calculated.

Fig. 14. I suggest this figure can be omitted as Fig. 16 makes the same point much better.

<u>**Response:**</u> **Removed Figure 14.**

p. 28. Placer mining and gravel mining. Isn't there anything to say about these, other than these cursory descriptions of the activities? Gravel extraction from the mainstem of the Fraser River is a very controversial issue, especially (but not exclusively?) downstream of Hope, which is outside the scope of this report. But are there no data on changes in gravel extraction over time above Hope? This topic is in the spotlight.

<u>**Response:**</u> **We have added a paragraph discussing the issue of gravel extraction in more detail. In general, our analysis reveals that there is little overlap between areas of gravel / placer mining and spawning habitats for sockeye salmon.**

I didn't notice any reference to the Coquitlam dam, though Bocking and Gavoury's report is cited. The damage was probably done well before the drop in aggregate Fraser productivity since the early 1990s, but the authors could consider mentioning such projects.

<u>**Response:**</u> **We included Coquitlam dam in our list of hydroelectric facilities in the Lower Fraser, but note that construction of this dam in the early 1900s pre-dates the recent declines of sockeye salmon in the Fraser.**

p. 35. The discussion of water temperatures in the Nechako in relation to the Kemano power project refers to how often (or rarely) the temperature exceeds 20 C, but as stated elsewhere in the report, sockeye in the Fraser start experiencing difficulties in the upper teens. This is a very detailed discussion about the history of the operation, but what is the message that readers are to take from it? I would reduce the historical detail and cut more quickly to the chase.

<u>**Response:**</u> **Edited the historical preamble to remove some unnecessary details.**

Fig. 28. I presume this is a work in progress because this map is very poor resolution and there is no legend to interpret the shading.

<u>**Response:**</u> **Imported a map with better resolution and changed the caption to clarify use of shading.**

Figs. 29 and 30. There is no legend for the colour coding so I have no idea what this means. It would be better to simply use lines instead of dots.

<u>**Response:**</u> **Changed figures so they are line graphs and labeled a sub-set of CUs on this images. Time series of population density for individual CUs are represented in the dashboard summaries.**

Fig. 32. It would help if the figures could stand better on their own, which could include explaining

in the caption what an “animal unit equivalent” is, exactly, though I can guess.

<u>Response:</u> Revised caption to clarify the term “animal unit equivalent”.

Fig. 34. Same comment as for Fig. 28.

<u>Response:</u> Imported a map with better resolution and changed the caption to clarify use of shading.

p. 42. Water use. The report does the best it can within the time available to provide a snapshot of spatial variation in some kinds of water use in the Fraser watershed. The fact that BC does not monitor actual rates of consumption, including groundwater, is very troubling, and the Commission should be aware of this short-coming (no fault of the authors, of course). Another limitation, which is not brought out explicitly in the report, is that there is no information presented on changes in water use through time. Therefore it is not possible to assess whether increases in water use relative to availability over the past 15 years have corresponded with the decline of salmon stocks in those areas relative to areas where consumption has not increased to the same extent. It would be very helpful to have such an analysis if there are any data to support it.

<u>Response:</u> Included these points in the weaknesses / limitations description of these data in the report and clarified the need for time series of allocations and use in the recommendations. We also note, however, that even with such data it remains difficult to attribute cause and effect between water use and fish population dynamics given the high natural variability in flow and uncertainty in defining thresholds for ecosystem needs for water.

p. 50 and Table 15. This is an important table, containing virtually the only statistical analyses in the entire report (except for Table 16). I do not think that a simple step-wise regression does the question justice, as there are much more sophisticated ways of handling multiple explanatory variables (which are often correlated). I would prefer to see first a correlation matrix between the explanatory variables, or at least have some indication of how correlated they were, followed by AIC to compare the explanatory power of competing models. Stepwise regressions can give misleading answers based simply on what other variables are in the equation. At the very least the authors should test for this effect by trying different combinations of variables.

<u>Response:</u> The draft final version of the report did not fully describe the details of our original analysis. Our original analyses looked at the correlation among different explanatory variables, and used an AIC approach to compare the explanatory power of competing models. It was our oversight to not include these details in the draft final, and have included more detail in the final report (i.e., correlation matrix and AIC comparison of competing models).

I found the summary provided by Table 17 to be very helpful.

p. 55. Recommendations. These seem fairly straightforward. There have been many calls for improved monitoring. The authors could draw from some of these to flesh out what an effective, and fully costed-out, long-term monitoring scheme would look like for watersheds, including full representation of small systems. I’m thinking of some of the projects funded by the Fraser Salmon and Watersheds Program, such as the harmonized monitoring initiative. Also, what about changes to federal or provincial legislation? Are salmon freshwater habitats protected adequately by existing legislation?

__Response:__ **We agree that our recommendations are relatively straightforward, and that clear, specific, and fully costed recommendations are always better. However, we highlight that our scope of work was focused on an evaluation of freshwater factors in the decline of sockeye salmon. We were not tasked with a review of existing legislation or monitoring initiatives across different agencies and whether they are sufficient to protect freshwater habitats or detect cause and effect relationships between human stressors and declines of sockeye salmon.**

Having said this, we have added more details to our recommendations to include more examples where other reports have commented on the need for improved monitoring and integration across agencies in BC and elsewhere across the Pacific Northwest.

Freshwater Ecology in their Decline

Reviewer Name: Ken Ashley

Date: January 6, 2011

1. Identify the strengths and weaknesses of this report.

The strength of the report is that it used a comprehensive GIS analysis based approach to examine the status of and threats to the freshwater environment for each of the identified 36 Fraser River sockeye Conservation Units (30 lake and 6 river type CU's), and generated a 'Dashboard Summary' for each Conservation Unit.

The weakness of the report is that the 'Dashboard Summaries' are somewhat complicated and not particularly intuitive, and the report was mainly GIS based and used existing information, hence did not explore in any detail the possibility of climate change altering the underlying ecological processes in Fraser Basin sockeye nursery lakes that could reduce their capacity to produce healthy fry and smolts.

Response: **In Section 4.1 we have clarified the purpose of dashboards as providing the greatest level of detail describing the population status, habitat vulnerability, and habitat stressors for each Conservation Unit. This level of detail is being presented in the report while also providing readers with other summaries that simplify the level of detail in the dashboards into more digestible formats (see Figures 5, 7, and 38). We believe it best to provide a variety of ways to summarize the data given the abundance and complexity of information that is available.**

An explicit and detailed consideration of the effects of climate change on Fraser River sockeye was covered by another report for the Cohen Commission (see Hinch and Martins 2011), and was not the primary purpose of our work.

2. Evaluate the interpretation of the available data, and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

The interpretation of the available data and the validity of the derived conclusions are sound.

The report represents a scientifically defensible interpretation of the available data.

3. Are there additional quantitative or qualitative ways to evaluate the subject area not considered in this report? How could the analysis be improved?

The analysis could be improved by exploring the possibility that climate change is altering the underlying ecological processes in Fraser Basin sockeye nursery lakes that could reduce their capacity to produce healthy fry and smolts. The reality is that most of this data is not currently available. However, in a few lakes there may be adequate time series of duration of thermal stratification and concentration of limiting nutrients in the epilimnion to conduct a preliminary analysis.

Ideally, data on size fractionated primary production and the biomass and species composition of phytoplankton and zooplankton are required to examine the trend over the past 50 years to determine if there has been a change in the length of thermal stratification, the concentration and ratio of limiting nutrients, and the amount and quality of juvenile sockeye food supply in these nursery lakes.

Response: See response under Section 5.

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

The recommendations provided in this report are supportable.

I recommend that a limnology program is initiated on a sub-set of sockeye nursery lakes to examine the hypothesis that the quantity and quality of planktonic food required to maintain historical sockeye productivity may be declining as a result of climate change.

Response: We agree that limnology data are currently limited to a few nursery lakes for a limited time series, and that better data could be collected to improve our understanding of change in nursery lake conditions and juvenile productivity. We have explicitly added the need for improved monitoring of nursery lakes in the recommendations.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

It has been known for some time that one of the fundamental differences between coastal and interior sockeye nursery lakes is the length of their respective pelagic food webs, and the existence and role of the ‘microbial loop’.

In general, interior sockeye nursery lakes have shorter food webs; hence intrinsically produce more sockeye per unit limnetic area or volume than coastal lakes (see Figure 1).

48 *Stockn*

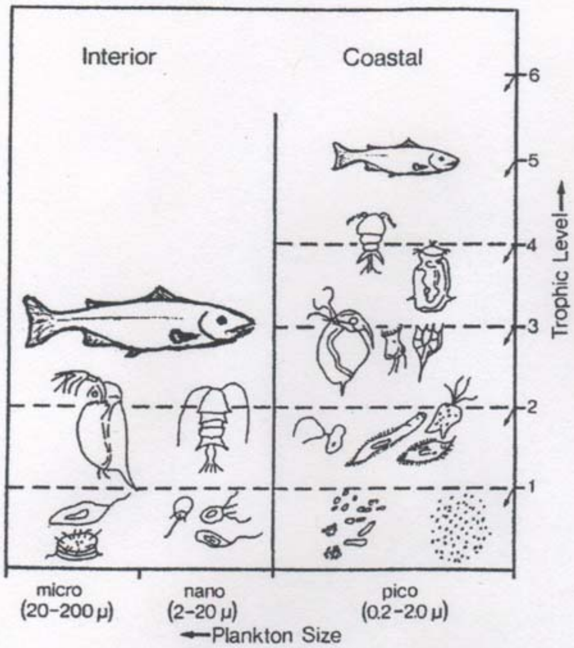


Fig. 17. Schematic of the pelagic food webs of interior and coastal British Columbia lakes (Stockner and Porter 1988).

Figure 1. Schematic of pelagic food webs of interior and coastal BC sockeye lakes. The reason for this intrinsic difference in productive capacity is that most of the carbon fixed in interior lakes flows through a shorter nanoplankton and microplankton food web to sockeye juveniles, whereas in coastal lakes a greater fraction of the carbon flows through longer picoplankton and microbial pathway and less to sockeye (see Figures 2 and 3).

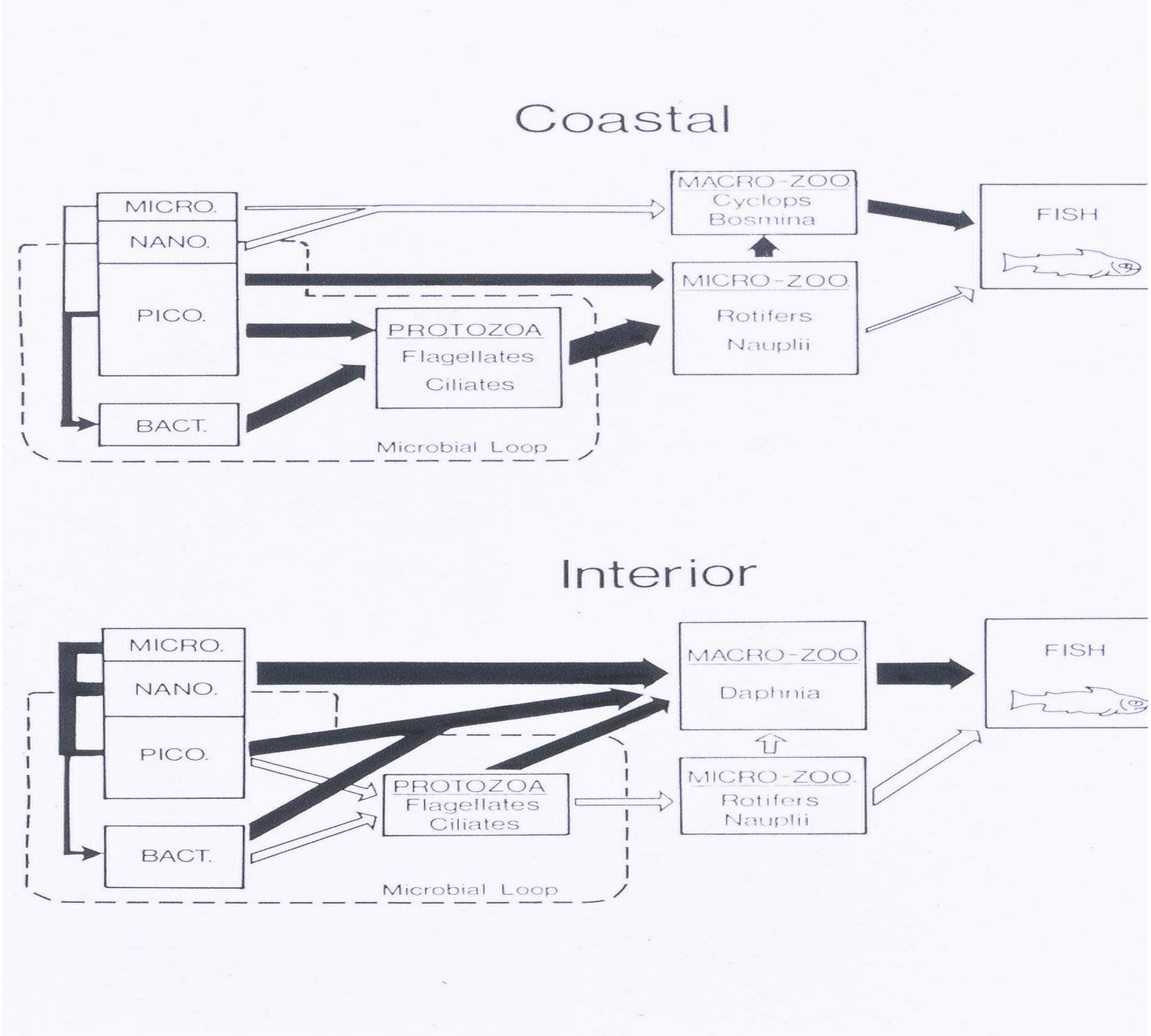


Figure 2. Relative magnitude of energy and carbon flow in coastal and interior sockeye lakes.

One of the known effects of climate change on lakes is an earlier melting of ice, and/or a longer period of thermal stratification. If climate change is increasing the duration of thermal stratification in Fraser Basin sockeye lakes, which are naturally oligotrophic (i.e., nutrient poor), in theory, this could cause a shift towards a less productive food web as the lakes would stay stratified longer at the end of the summer when there was less watershed nutrient loading, which would trend the lake towards becoming less productive, a process known as ‘oligotrophication’.

Characteristics of microbial loop dominated lakes are increased C production by pico-nanoplankton, nutrient regenerative recycling systems, long food chains, microbially dominated long food webs, trophically inefficient, microzooplankton dominated and little or no benthic-pelagic coupling and low pelagic or demersal fish production.

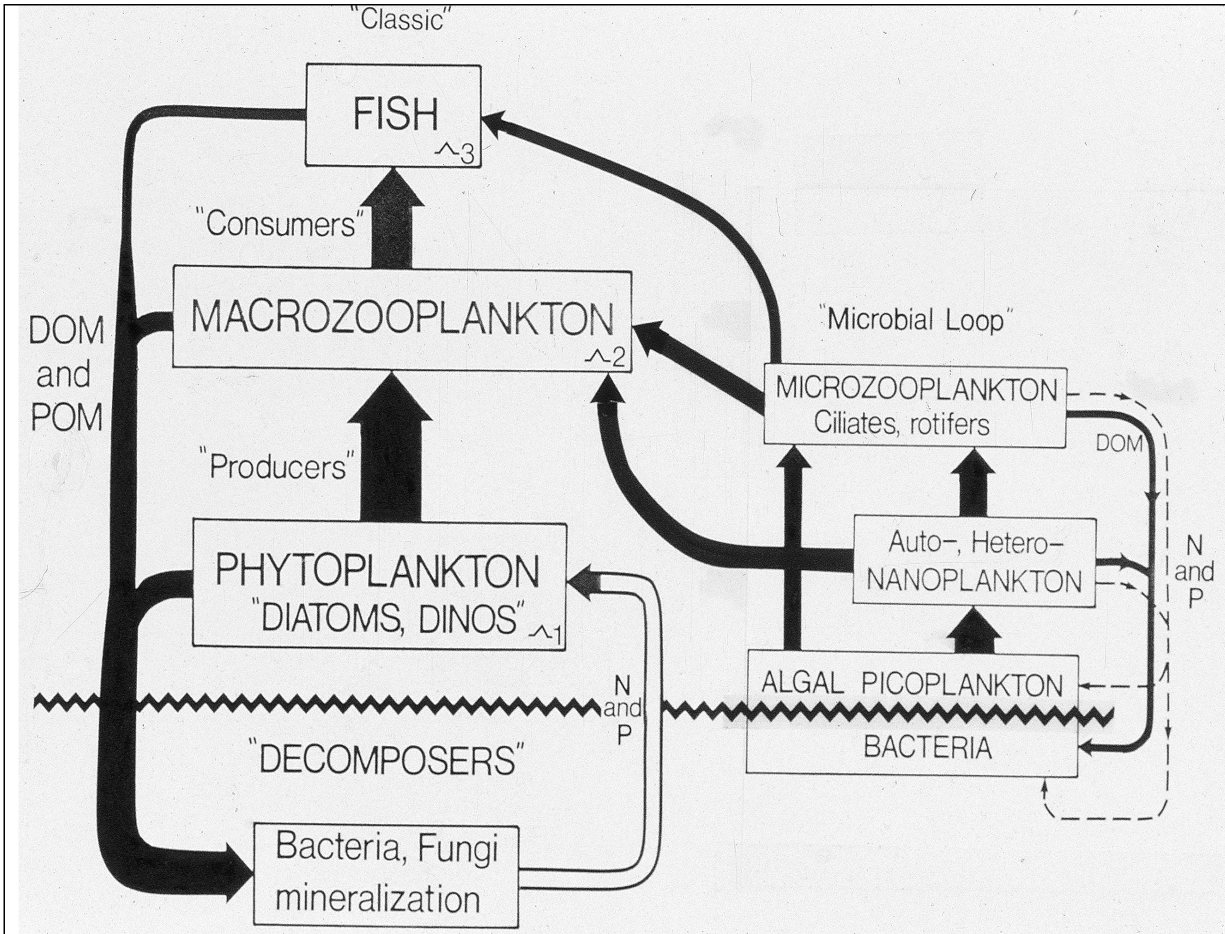


Figure 3. Schematic of the microbial food web relative to the ‘classic food web.

In addition, climate driven changes in watershed nutrient loading may also alter the concentration and chemistry of limiting nutrients in the epilimnion. This was observed to be occurring in Okanagan Lake during the 1990s and 2000s, where the ratio of dissolved inorganic nitrogen (DIN) to soluble reactive phosphorus (SRP) declined, which produced phytoplankton and zooplankton which contained lower concentrations of essential fatty acids for juvenile kokanee (same species as sockeye – O. nerka).

It was hypothesized that this subtle change in watershed nutrient loading and resultant N:P ratio was responsible for the decline of kokanee in Okanagan Lake, because the *quality* of juvenile kokanee food had been reduced. This was experimentally verified by a series of enclosure and lab experiments conducted by Dr. Mike Brett and Dr. Joe Ravet of the University of Washington in Seattle (see Figures 4 and 5).

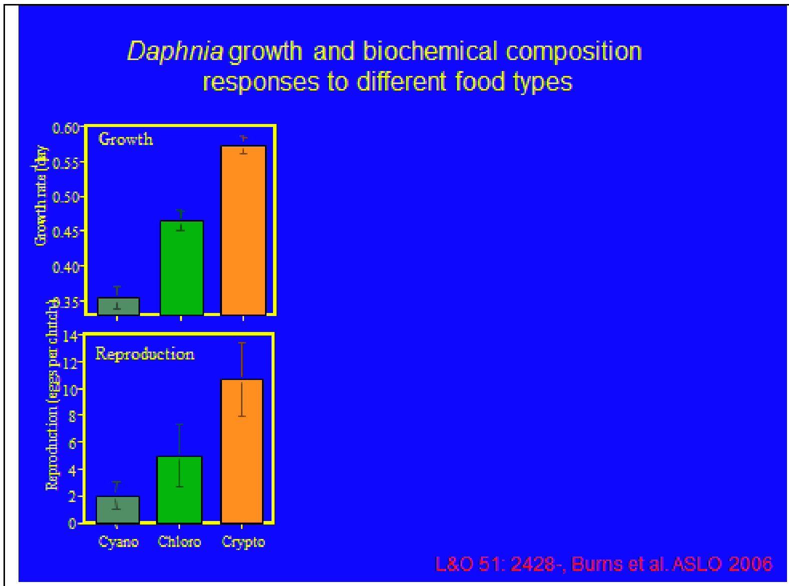


Figure 4. Daphnia growth and biochemical composition responses to different food types. Note: Cyano = Blue-green algae, Chlor = green algae, Crypto = Cryptomonad algae.

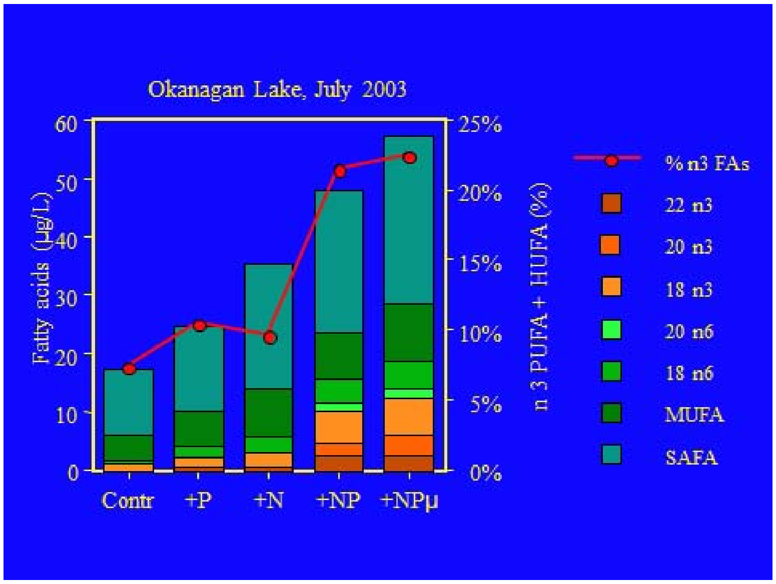


Figure 5. Nutrient addition experiment conducted in Okanagan Lake in July, 2003 demonstrating that N and P and micronutrients were required to produce the highest concentration of essential fatty acids in phytoplankton, necessary for the production of high quality planktonic food for juvenile kokanee.

In summary, it is possible that subtle climate driven changes in the ecology of the nursery lakes may be producing less food, or food of *lower quality* than historically, which is creating higher mortalities in juvenile sockeye during their migration to the open ocean as they are nutritionally deficient in energy reserves.

This may be the explanation to statements given at the Nov 30-Dec 1/10 workshop and in various Cohen Commission science reports that "…This observation indicates either that the primary mortality agents in the sockeye occurred in the post-juvenile stage, *or that certain stressors that were non-lethal in freshwater caused mortality later in the sockeye's life history*" (Peterman et al., 2010).

Nutritionally deficient juvenile sockeye may be more susceptible to variations in food quantity and quality in Georgia Strait, to ward off microbial pathogens and parasitic sea lice from open net pen fish farms, and variable ocean productivity on their early ocean migrations in Georgia Strait and on the continental shelf.

In other words, some juvenile sockeye may have left home on an empty stomach, or a diet of junk food, and were poorly equipped to deal with the rigors of smoltification, migration and predator/disease avoidance.

Response: **We acknowledge the plausibility of this hypothesis. We are also aware, however, that Selbie et al. (in Appendix C of Peterman et al. 2010) examined the data for Quesnel, Shuswap, and Chilko Lakes to investigate whether changes in growth and primary / secondary productivity have occurred and found no detectable changes over time. Given the evidence above that interior and coastal lakes have different food webs, it is not clear how or whether this hypothesis is consistent with the observation that Harrison (a coastal nursery lake) and Shuswap Complex (an interior nursery lake) CUs have not seen declines to the same extent as other CUs (which include a mix of coastal and interior nursery lakes). We also note that the effects of climate change are being considered by another report (see Hinch and Martins 2011) and was not the primary purpose of our work. For these reasons we do not believe it would be feasible or practical for us to explore the available data to test this hypothesis.**

We do, however, believe this hypothesis is worth testing in the future with better research and monitoring of a strategically selected set of inland lakes, and would be informed by our recommendation to improve monitoring of smolt condition and timing of outmigration.

6. Please provide any specific comments for the authors.

There are no specific comments for the authors.

Literature cited:

Peterman et al. 2010. Synthesis of evidence from a workshop on the decline of Fraser River sockeye. June 15-17, 2010. A report to the Pacific Salmon Commission, Vancouver, B.C., 123 pp. + 35 pp. of appendices.

Stockner, J.G. 1991. Autotrophic picoplankton in freshwater ecosystems: the view from the summit. Int. Revue ges. Hydrobiol. 76:483-492.

Weiss, T. and J.G. Stockner. 192. Eutrophication: the role of the microbial food web. Memorie dell'Istituto Italinao di Idrobiologia 52:133-150.

Stockner, J.G., E. Rydin and P. Hyenstrand. 2000. Cultural oligotrophication: causes and consequences for fisheries resources. Fisheries 25:7-14.

Report Title: Freshwater Ecology
Reviewer Name: Eric B. Taylor
Date: January 2011

1. Identify the strengths and weaknesses of this report.

The report is well-written and accomplishes the rather daunting task of both reviewing the general life history of sockeye salmon in freshwater as well as potential and actual land uses that may impact sockeye salmon.

1. The k-means clustering method (page 46) is a useful approach to identify groups of similarly-impacted sockeye salmon CUs. An alternative would be to employ the IUCN Threats Calculator which is basically an excel-spreadsheet-based calculator that generates overall threat levels to populations from qualitative input on cumulative threats. This would allow an alternative objective ranking of each CU based on an internationally-recognized threats assessment system. I am a bit concerned that there are different threat-based assessments going around and how they will be integrated. For instance, COSEWIC is reviewing the status of sockeye salmon CUs and may use the IUCN calculator and how it will mesh with what is in this report may be an issue.

Response: Early on we decided to use the current assessment approach for our evaluation and received support from the Cohen Commission for doing so. It might have been possible to use an alternative approach if directed to do so earlier on, but is not possible to go back at this time to use an alternative assessment method.

Regardless, we stand by the scientific defensibility of our approach because it uses the best available data to quantify the magnitude, spatial extent, and where possible, temporal changes in stressors across sockeye habitats. It is an approach that relies on detailed information about the specific location of stressors and vulnerability of specific habitats across CUs. Although internationally recognized, the IUCN alternative is a more generic approach that does not explicitly account for the level of detail considered herein. Moreover, qualitative interpretations of the cumulative level of stress would be required as inputs, which would ultimately be based on the kind of data generated in this report. If not, the inputs would rely on expert based interpretations of the cumulative level of stress which could be difficult to justify with existing evidence. For these reasons we believe the quantitative approach used here is more objective, transparent, and defensible than a generic assessment tool that uses qualitative inputs.

As well, we are not as concerned about the use of alternative methods for assessing threats. Regardless of whether there are differences or similarities in results, these findings would be important to document and understand. Differences in results would highlight CUs where we are least certain about the cumulative level of stress. CUs with similar relative rankings of the levels of stress would highlight areas where we are the most certain. If the models provide completely different results, it would be important to understand the dynamics driving each model, underlying assumptions, and why differences exist. Comparative techniques and methods for explicitly considering uncertainties are available. The resulting insights would be important to understand if COSEWIC were developing

conclusions about threats.

2. As in at least one other report, I am struck by the lack of comparative analysis to other population aggregates in British Columbia. For instance, this report makes no mention of trends in other important areas like the Skeena River or Barkley Sound? Surely some information could be obtained that might support or refute some of the conclusions of this report. For instance, have any of these other areas been assessed for habitat changes in freshwater or habitat vulnerability and population status? If these aggregates have shown less fluctuation than Fraser populations and yet experience similar changes in freshwater parameters relevant to productivity would this not be useful information and support the authors' overall conclusion that freshwater conditions are unlikely to be the primary driver of fluctuations in Fraser River sockeye salmon adult abundance?

<u>Response:</u> We agree that insights from a comparative analysis would be useful for providing support for / against our conclusions. Moreover, such a consideration is consistent with the questions from Stewart-Oaten (1996) that we use to guide our assessment of the role of different freshwater factors in declines of sockeye salmon.

However, a comparison to other systems was not within our scope of work, and not possible with the time available. In doing our work, we were also aware that a comparative analysis of patterns of productivity for sockeye salmon across the North Pacific was being completed by another Cohen Commission project (see Peterman, R.M. and B. Dorner. 2011. Fraser River sockeye production dynamics. Cohen Commission Tech. Rep. 10). Our understanding is that the results from this other study would help assess whether the patterns of decline are unique to the Fraser or more broad-scale, which can help support or refute some of our conclusions. Moreover, the Cohen Commission project on cumulative effects (see Marmorek et al. 2011. Fraser River sockeye salmon: data synthesis and cumulative impacts. Cohen Commission Tech. Rep. 6) is tasked with integrating the findings of individual projects to identify consistencies / inconsistencies and assess the role of factors influencing all life stages in declines of sockeye.

3. Section 5 (*The State of the Science*) is the weak point of the report. It is quite vague and does not really summarize the "state of the science". What, for instance, has been the major progress made in understanding sockeye salmon ecology and persistence in terms of freshwater ecology? What are the remaining uncertainties? What are examples of minor populations for which information is lacking? Who collects watershed-level data, how can the Province of BC contribute. Does DFO have the capacity or willpower to initiate these critical studies? What are the specific research questions that remain unanswered?

<u>Response:</u> We have strengthened the "State of the science" section to highlight uncertainties about our state of existing knowledge (e.g., understanding of the population level effects of freshwater stressors) and state of existing data (e.g., gaps in space or time for populations, life history stages, or specific stressors). This summary and clarification is intended to help justify the recommendations that follow. It was not our purpose with this section or the report to summarize the state of and capacity for monitoring within provincial and federal agencies (and we were not tasked to do so). Also, the brevity /

vagueness of this section was purposeful because we were constrained to writing a summary of the "State of the science" within a 1 page limit.

4. The statistical analyses (Table 15 and 16) seem, perhaps, a bit simplistic and dated. Just wondering if any alternative Bayesian type model construction and assessments have been considered. There are methods such as "Bayesian Belief Networks" that assess species (or CUs within species) under uncertainty that might be useful. See Environmental Modelling & Software 25 (2010) 15–23

Response: **We agree that the statistical analyses presented in this report are relatively simple, but also acknowledge that our original description of these analyses was limited. In the final version of the report we have added a matrix of correlations among different explanatory variables, and described our use of an AIC approach to compare the explanatory power of the competing models evaluated in our analyses.**

Our ability to develop a more complex model (using a Bayesian Belief Network, for instance) was constrained by a number of factors. First, we were limited in our ability to account for other explanatory factors that would likely have important effects on survival across the entire life cycle and freshwater life stages. These factors were being quantified by other Cohen studies (e.g., effect of marine conditions, contaminants in freshwater, in river conditions and enroute losses, or stressors in the lower Fraser River). Second, we were faced with severe constraints in the availability of measurements of productivity across juvenile life stages (i.e., few CUs and years of productivity across freshwater life stages).

Due to limitations in availability of the response and explanatory variables, we would have been constrained in our ability to define the probability distributions needed in a Bayesian Belief Network. We were also aware that another study by the Cohen Commission (see Marmorek et al. 2011. Fraser River sockeye salmon: data synthesis and cumulative impacts. Cohen Commission Tech. Rep. 6) was tasked with investigating the effect of explanatory variables across freshwater and marine conditions and would be using more sophisticated methods than could have been applied here.

5. Other more explicit suggestions are given in section 6 below.

2. Evaluate the interpretation of the available data, and the validity of any derived conclusions. Overall, does the report represent the best scientific interpretation of the available data?

The report does a good job of trying to handle a vast and unwieldy dataset (information collected from a diversity of sources and methods). I have made suggestions that might help tighten-up some of the statistical procedures (see below) that are basically fine. With the caveat that disease/pathogen factors in freshwater have not being addressed, I think the overall conclusion of the authors is correct and is what I have suspected. Although I admit to being predisposed to this conclusion, I do believe that the authors have done a good job at testing the underlying hypotheses as best as is possible.

3. Are there additional quantitative or qualitative ways to evaluate the subject

area not considered in this report? How could the analysis be improved?

See comments above about IUCN Threats Calculator, Bayesian Belief Networks, etc to help better quantify threats to individual CUs.

4. Are the recommendations provided in this report supportable? Do you have any further recommendations to add?

Yes, the recommendations are supportable, but I find them vaguely-worded. Who exactly are the “scientists” or “government agencies” the recommendations refer to?? Without naming species groups of scientists or agencies, the recommendations appear too vague to be useful. Similarly, I’d like to see more specificity about the “communication tools” recommendation. I fully believe that transparency and sharing of data for a public resource like salmon is critical. It would be very informative for “independent scientists” like the authors of this report to suggest a specific model/structure of how this could happen. For instance, perhaps DFO, in the interests of transparency should allocate some of its funds (or obtain more funds specifically for this purpose) to set-up an arms-length assessment and monitoring “board” made up of DFO and independent scientists that plan such programs. It would be useful for the authors to suggest a specific model rather than just make vague suggestions for greater transparency. What can be learned from other jurisdictions (i.e., outside BC and Canada)?

Response: **We agree that our recommendations are relatively vague, and that clear, specific, and fully costed recommendations are always better. However, we highlight that our scope of work was focused on an evaluation of freshwater factors in the decline of sockeye salmon. We were not tasked with a review of existing legislation, agency capacity, or monitoring initiatives to assess whether they are sufficient to detect cause and effect relationships between human stressors and declines of sockeye salmon.**

Having said this, we have added more details to our recommendations to include more examples where other reports (specifically charged with addressing some of the issues raised here) have commented on the need for improved monitoring and integration across agencies in BC and elsewhere across the Pacific Northwest.

5. What information, if any, should be collected in the future to improve our understanding of this subject area?

The factors all discussed in this report will be to varying extents subject to changes from climate shifts and human demographic changes. Some modelling of the “environmental envelope” for persistence of sockeye salmon in freshwater habitats under human and climate change should be undertaken so that future conflicts might be anticipated.

Response: **We fully agree that the factors considered in this report are influenced by human activities and climate shifts, and that these factors can ultimately affect survival of sockeye salmon. Thus, some modeling of the “environmental envelope” of acceptable changes in human stressors and freshwater habitat conditions would be informative to improve our understanding of the persistence of sockeye salmon in freshwater habitats. We**

also agree that this information would be valuable to fisheries and habitat managers "so that future conflicts might be anticipated."

However, such a modeling approach is no small undertaking and was not within the scope of what we were tasked to do. Undertaking this task would require developing a model that explicitly accounts for the interaction among all factors affecting survival across marine and freshwater life stages, because these factors do not interact in isolation of each other. We believe such a modeling approach is necessary, but we were unable to do so without a significant investment of additional resources.

This comment is consistent with our recommendation "To improve our understanding about the population level effects of stressors on freshwater habitats…". As a result we have elaborated on this recommendation to include this suggestion.

6. Please provide any specific comments for the authors.

This report will be related closely to at least two others in the biological sense; those on diseases and parasites and cumulative effects (in freshwater). I think some comments on these factors and how they might relate to the issues in the current report would be appropriate.

<u>**Response:**</u> **We acknowledge that contaminants (MacDonald et al. 2011), diseases and parasites (Kent 2011), habitat conditions in the lower Fraser River and Strait of Georgia (Johannes et al. 2011), and changes to in-river conditions (Hinch and Martins 2011) might be acting independently, cumulatively, or synergistically with the stressors considered in this report. Consequently, we have edited the introduction to clarify the links between this report and these other studies. We have also clarified the link to the study that has been tasked with integrating the findings from all Cohen studies and investigating the role of environmental conditions and stressors across both freshwater and marine life stages on Fraser River sockeye salmon (see Marmorek et al. 2011).**

Page 1, Line 3. What is the evidence that sockeye salmon are a "keystone" species?? This has a rather precise ecological definition and I am aware of no studies that demonstrate such a status of sockeye salmon. Suggest substituting "important" for "keystone".

<u>**Response:**</u> **Replaced "keystone" with "important".**

Page 2, Line 17. The Sakinaw AND Cultus lakes' populations are actually <u>assessed</u> under COSEWIC as "Endangered", not "threatened" as implied here (although the Minister of Fisheries decided not to <u>list</u> them as Endangered under SARA).

<u>**Response:**</u> **Replaced "threatened" with "endangered".**

Page 2, Lines 24-26. It would be helpful to include the upper and lower confidence intervals of these estimates rather than just the median. It is critical that in documents such as these that, I assume, the public will eventually have access to that some explicit presentation of the variability around these median estimates be given, preferably in graphical form. The statement included about "…contained with the statistical distributions.." will not be generally understandable and a graphic will make the point more forcefully.

<u>Response:</u> Graphics of the statistical distributions are neither readily available nor can be easily produced from readily available data. To address this comment as best as possible we included statements of forecasted probabilities associated with returns in 2009 and 2010.

Page 4, line 9. "…increase in MARINE mortality…"??

<u>Response:</u> Added the following text: "increase in mortality during marine life stages."

Section 2. While for the purposes of the Cohen Commission reports the justification for 36 conservation units as defined by DFO can be accepted, it should be known that the delineation of these units has not be subject to peer review in the normal sense of the term and will be evaluated in the near future in an independent analysis.

<u>Response:</u> Included a note about this point in the first paragraph of 2.1.1.

Page 8, lines 8-11. This is an important point. Distributional criteria (number of locations, index of area of occupancy, extent of occurrence) are key variables in assessing conservation status both under COSEWIC and IUCN criteria. The DFO-based assessments, therefore, may well be come irrelevant after the COSEWIC assessments that are underway.

<u>Response:</u> All three methods reviewed include distribution indicators so none of them would be irrelevant after a COSEWIC assessment. Grant et al. 2010 on the other hand does not include distribution criteria. These points are noted in the report. We added some language around the possibility of the assessment outcomes becoming irrelevant / outdated following a COSEWIC assessment.

Page 12, line 24-25. Agreed (re: arbitrary), but surely there is some literature to support this statement.

<u>Response:</u> We included some citations that summarize the buffer widths that are being used to protect streams elsewhere and added to our discussion of the rationale for using this distance.

Throughout: inconsistent use of "sockeye" and "sockeye salmon" in text. The full common name of "sockeye salmon" should be used.

<u>Response:</u> Ensured all references to "sockeye" use the full common name "sockeye salmon".

Page 17, line 29. Is there not a basic limnological concept or citation that could be used to support this measure? Otherwise it all seems rather arbitrary and *ad hoc*.

<u>Response:</u> Added the following citation to support use of lake area – Randall, R.G. 2003. Fish productivity and habitat productive capacity: definitions, indices, units of field measurement, and a need for standardized terminology. Canadian Science Advisory Secretariat Research Document 2003/061. Available from: http://www.dfo-mpo.gc.ca/CSAS/Csas/DocREC/2003/RES2003_061_e.pdf

Page 19, line 6. How about urbanization d/s of Hope. Changes to the lower Fraser Valley and estuary could impact sockeye smolts, no?

<u>Response:</u> Included a footnote clarifying how urbanization downstream of Hope is captured for the Cohen Commission by Johannes et al. 2011.

Page 21, line 26 and throughout. I have no idea what the annotation in parentheses means, e.g., "…Harrison (D/S) (L_03_03), Pitt (L_03_05), Nahatlatch (L_05_02), Fraser and Francois (L_06_04;27 L_06_05; L_06_06; L_06_07), and Stuart (L_06_13)…"

It is very cumbersome and distracting.

<u>Response:</u> We have removed the use of the CU index labels and replaced them with the Conservation Unit name and timing group throughout the text of the report. The use of the CU index labels remains in the tables of the report.

Page 22, line 9. They are INTERcorrelated or correlated "…with each other…"

<u>Response:</u> Added "…with each other…" to this sentence.

Page 27, lines 17-20. This seems rather qualitative and should be replaced with some quantitative analysis (e.g., area covered from digitized maps)

<u>Response:</u> Yes, understanding the spatial and temporal variation in log storage was based on a qualitative interpretation of air photos. We pursued this approach because we were unable to locate digitized maps of log storage from federal (DFO), provincial (MOE, ILMB), or private (Vancouver Port Authority) agencies. Though we agree that a quantitative analysis would have been preferred (as consistent with most other stressors we examined) it was not possible within the scope of this project to digitize log storage using available air photos. We also do not believe this more accurate data would have changed our conclusions about the role of log storage in the declines of sockeye salmon.

Page 30, lines 28-29. As the Prosperity Mine has been shelved by the feds perhaps this should be modified.

<u>Response:</u> Removed reference to Prosperity Mine.

Page 50, lines 25-30. Could migration distance not be related to migration **time** (i.e., time spent in the freshwater migration) or **timing** (i.e., is early, summer, late, fall run timing associated with migration distance) and the real driver of the poor performance of the father-migrating populations?

<u>Response:</u> We agree that the underlying biological mechanism is likely related to the length of time spent in freshwater (and thus time of exposure to a stressor) or timing of migration (i.e., earlier timing required to cover longer distances). We are using migration distance as a surrogate for these more direct indicators, because we can measure migration distance consistently across all CUs, which we can not do for time spent during freshwater migration and migration timing. As well, others (Selbie et al. in Appendix C of Peterman et al. 2010) tested for the relationship between the declining trends and timing of migration and found no relationship, yet did find a relationship with migration distance.

We added details in the report to clarify that migration distance is related to migration time and migration timing.

Page 50. What percentage of the variation in productivity did migration distance account for?? It may be significant statistically, but still account for only a small amount of variation in productivity which might ease the interpretation here.

<u>Response:</u> Adjusted R^2 values associated with different models and explanatory variables have been included in a new table in the report.

Table 15. What is the number of populations used in this analysis (i.e., mention in caption to Table)?

<u>Response:</u> The number of populations used in the analysis has been included in the report.

Page 50. Is the Ricker model the best one to use? Are there alternatives that might be appropriate? At the least, briefly explain what "Ricker model residuals" are and why they are used here.

<u>Response:</u> We used the "Ricker model residuals" in our analyses to allow for comparisons to the work of Peterman et al. 2010 (work commissioned by the Pacific Salmon Commission). An additional study conducted for the Cohen Commission (see Peterman and Dorner 2011) compared the Ricker model to the Larkin model, which confirmed that the Ricker model was the best model for almost all of the Fraser River stocks. In Section 4.2 we have included a description of what the "Ricker model residuals" are based on how they were calculated by Peterman et al. 2010.

Page 51, line 13. You need to define "productivity" and "total productivity" in biological terms.

<u>Response:</u> At the beginning of the report we clarify that "productivity" of sockeye salmon is referring to the number of adult recruits produced per spawner. In Section 4.2 we have included a definition of "total productivity" in terms of how it was calculated by Peterman et al. 2010.

Page 51, line 22. I think this is the first mention of "en route" mortality and you need to more explicitly explain how it is accounted for in the measure of "total productivity" to allow the reader to better understand your logic for this impt. conclusion.

<u>Response:</u> In Section 4.2 we describe how indices of "total productivity" were calculated by Peterman et al. 2010, which includes a description of how enroute mortality is accounted for in this calculation.

Page 51, line 29. Define "juvenile productivity"

<u>Response:</u> In Section 4.2 we have included a definition of "juvenile productivity" in terms of how it was calculated by Peterman et al. 2010.

Table 16 and associated analyses. There should be some accommodation made for the multiple testing issue here (multiple correlations tested simultaneously). Sequential Bonferroni adjustments to the alpha level or similar <u>false discovery rate controls</u> need to be implemented. This will undoubtedly lower the number of "significant" associations here.

<u>Response:</u> We adjusted our analyses to account for the multiple testing issue by making a Bonferroni adjustment to the alpha level.

Appendix 3 – Dashboard summaries

Biological Data

Productivity and escapement data reported by brood year for the stock representing the CU:

- Total productivity index – where available, Ricker residuals of adult recruits/effective females vs. effective females (data from Peterman et al. 2010). The stock used to represent the CU is indicated in the footnote.
- Total annual escapement – measured in number of individual fish, thousands of fish, or millions of fish, depending on the scale of escapement for each CU.

Location

A map of the area of upstream influence for the CU and the CU's location within the Fraser watershed. Nursery lakes are indicated in black. The migration route between the mouth of the Fraser and the most downstream point of the CU is indicated by a thicker, darker river.

Population Status

The overall status of each CU and the level of uncertainty embodied in that assessment are plotted on this figure. The results of two independent CU status assessments are recorded (Pestal and Cass 2009; Grant et al. 2010), identifying where each agree or disagree on the status of each CU. The present CU is identified on this figure with a bold circle or oval. This figure represents all 36 lake- and river-type CUs, even though dashboards have only been developed for the 30 lake-type CUs.

Habitat Status

Metrics representing habitat status are presented by life-history stage: spawning, rearing, and migration. Histograms describe the distribution of values across all CUs. The value of the present CU is identified by a vertical dashed bar. The temperature time series are specific to the present CU.

Spawning

- Total spawning extent (km) – total linear length of all spawning areas
- Ratio of lake influence spawning to total spawning – ratio of the total extent of spawning areas buffered by lake influence (km) to the total extent of all spawning areas (km).

Rearing

- Area of nursery lakes (1000 ha) – total area of all nursery lakes within the CU
- Nursery lake productivity (estimated) (100 smolts/ha) – the number of smolts produced in nursery lakes scaled to the total area (of links for which smolts production data is available), as an estimated measure of nursery lake productivity within the CU.

Migration

- Migration distance (km) – total distance of migration, measured as the distance between the mouth of the Fraser and the most downstream entrance to the nursery lake(s) of each CU.
- Average spring air temperature at nursery lake (°C) – average spring (March – May) air temperature at the nursery lake(s) of each CU, averaged over the period of 1901-2009.
- Spring air temperature at nursery lake (°C) – average spring (March – May) air temperature at the nursery lake(s) of each CU, from 1901-2009.
- Average air temperature across adult migration (°C) – average air temperature during adult migration (based on seasonal timing of CU's run timing group), averaged across entire migration corridor of each CU over the period of 1986-2009. Table 6 indicates how run timing groups are aligned with monthly temperature data.
- Air temperature across adult migration (°C) – average air temperature during adult migration (based on seasonal timing of CU's run timing group), averaged across entire migration corridor of each CU, from 1901-2009.

Integrated Summary of Habitat Vulnerability
This figure compares all CUs according to three independent measures of habitat that contribute to habitat vulnerability (i.e., migration distance, nursery lake area, and the ratio of lake influenced spawning extent to total spawning extent). Each circle represents a CU that is plotted according to its total area of nursery lakes and its migration distance. The ratio of lake influenced spawning extent to total spawning extent determines the size of the circle (the smallest being 0.0 and largest is 1.0).

Freshwater Stressors

Human Population

- Population density (persons/km^2**)** – population density over time within the nursery lake rearing and migration corridor or habitat areas for each CU. Note that population is plotted on a log scale.

Land Use

- Forest harvesting (% of habitat area) – total area of Forest harvesting over a 15 year trailing period within each habitat area, expressed as a percentage of the total area of that habitat type.
- Mountain pine beetle disturbance (accumulated % of habitat area) – the accumulated area of mountain behind beetle disturbance within each habitat area, expressed as a percentage of the total area of that habitat type.
- Land use type (% of habitat area) – the proportional distribution of land use types within each habitat area. Land use is classified as urban area, agricultural area, forest harvesting disturbance, mountain pine beetle disturbance, and other remaining land uses. If a habitat type is shown to be 100% “other”, this indicates that the specific habitat type is not applicable for the CU – this only occurs for mainstem and tributary spawning habitats.

Resource Development

All three resource development figures are plotted on a log scale to display the large range of variation among all CUs. Each figure is overlaid with “error” bars that represent the range between the minimum and maximum value across all CUs for that particular metric within each habitat type. For the graphs of small scale hydro and placer mining claims, the occasional absence of these “error” bars for mainstem or tributary spawning habitat types indicates that the specific habitat type is not applicable for the CU.

- Small scale hydro – the number of independent power producers located within each habitat area.
- Placer mining claims – the total number of placer mining claims located within each habitat area.
- Other mines – the total number of mines and mining claims (other than placer mining claims) located within each habitat area of each CU. These "other mines" have been categorized as active mines, developed prospects, inactive mines, and major exploration projects.

Water Use

- Total allocation by use – the proportional distribution of water allocation among urban, agricultural, and industrial uses, by habitat type. Each use, for each habitat type is labeled with the actual allocation value (measured in m^3/ha).
- Total allocation (m^3/ha) – the total water allocation (across all uses) by habitat type
- Water Licenses – the proportional distribution of water licenses among urban, agricultural, and industrial uses, by habitat type.
- Water Restrictions (#/km^2) – the total number of water restrictions within each habitat type.

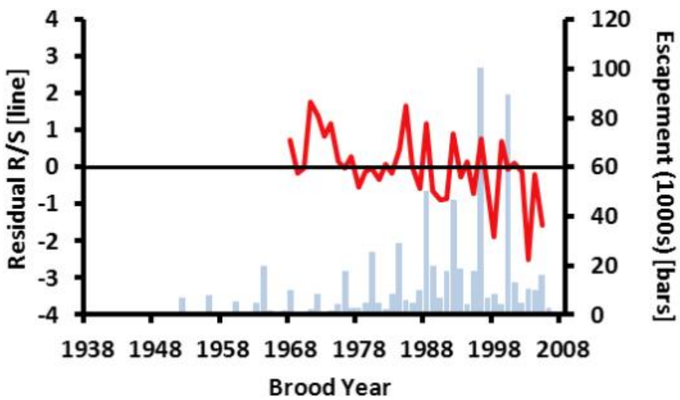
Road Development

- Road density (km/km^2) – the density of all roads (highways, urban streets, and resource roads) within each habitat type.

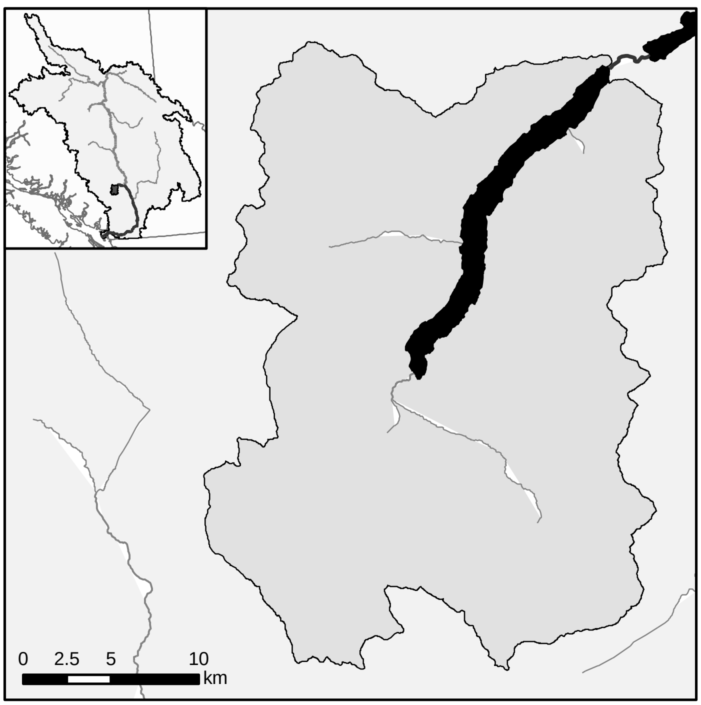
CONSERVATION UNIT

Anderson — Early Summer — L-6-1

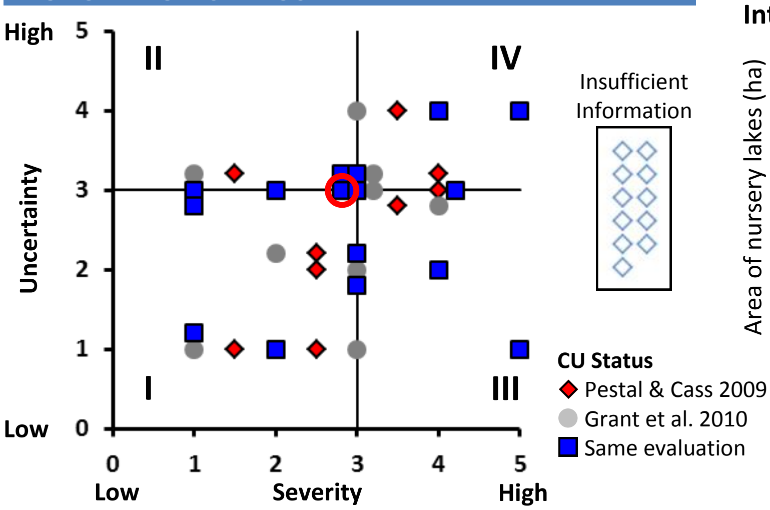
BIOLOGICAL DATA †



LOCATION



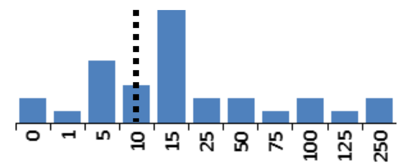
POPULATION STATUS



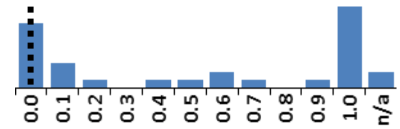
HABITAT STATUS

Spawning††

Total spawning extent (km)

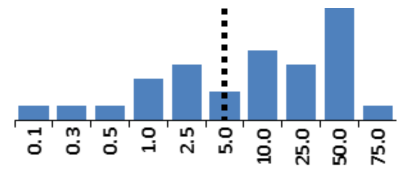


Ratio of lake influence spawning to total spawning

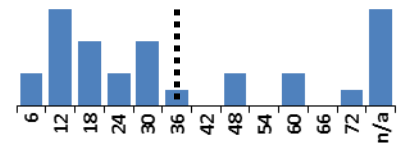


Rearing

Area of nursery lakes (1000 ha)

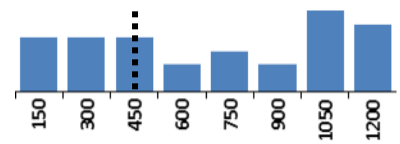


Nursery lake productivity (estimated) (100 smolts/ha)

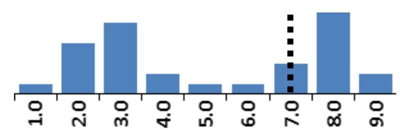


Migration

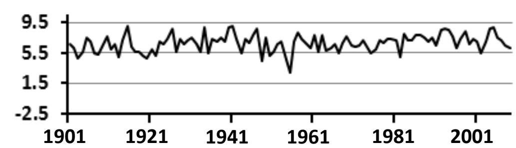
Migration distance (km)



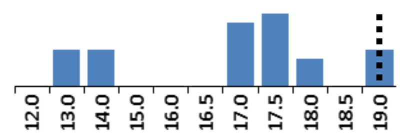
Average spring air temperature at nursery lake (°C)



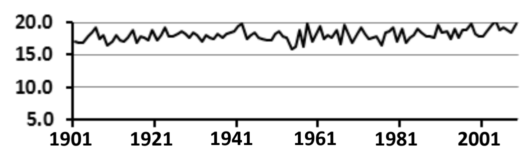
Spring air temperature at nursery lake (°C)



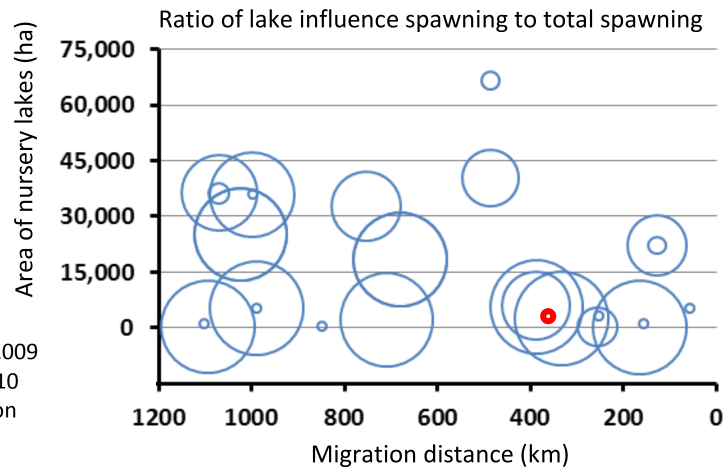
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Gates**

†† Spawning note: **Gates spawning channel.**

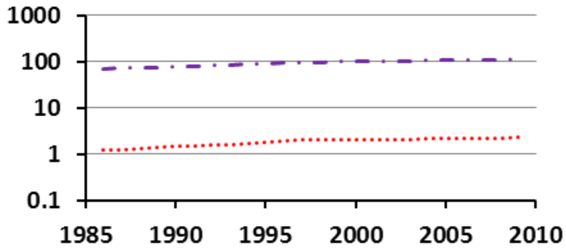
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

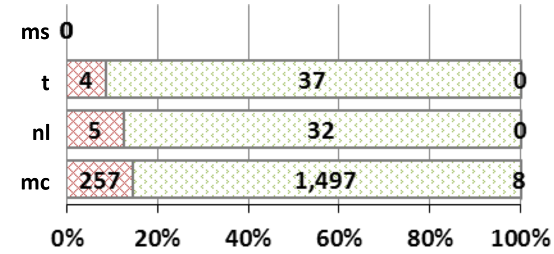
Human Population

Population density (persons/km^2)

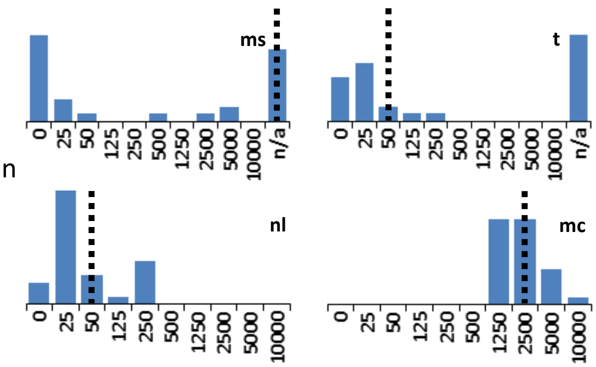


Water Use

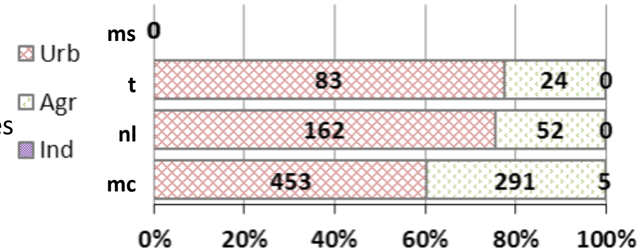
Total allocation by use



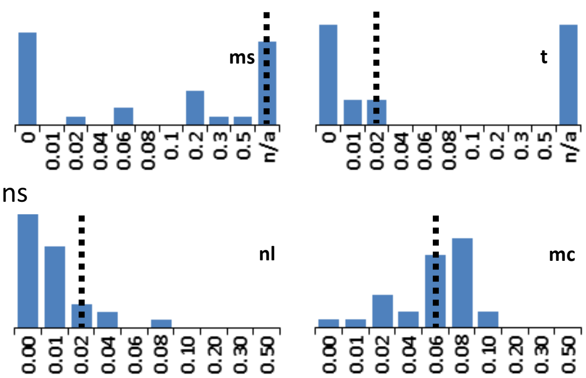
Total allocation (m^3/ha)



Water Licenses

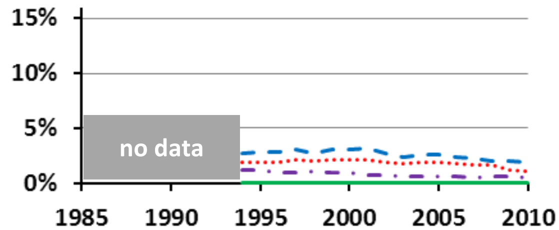


Water Restrictions (#/km^2)

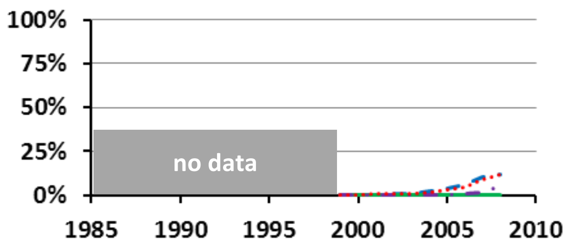


Land Use

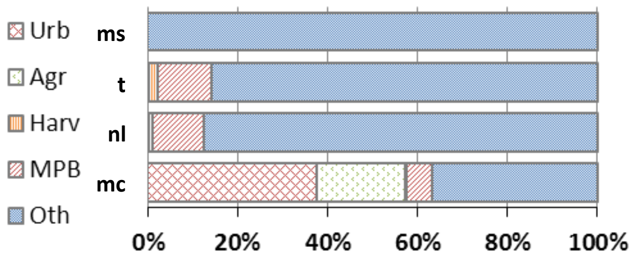
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

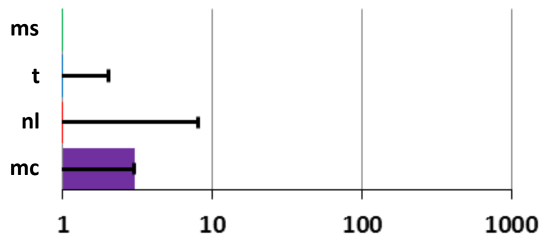


Land use type (% of habitat area)

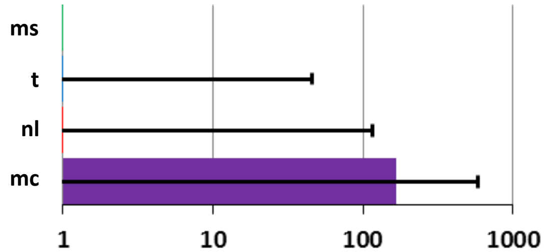


Resource Development

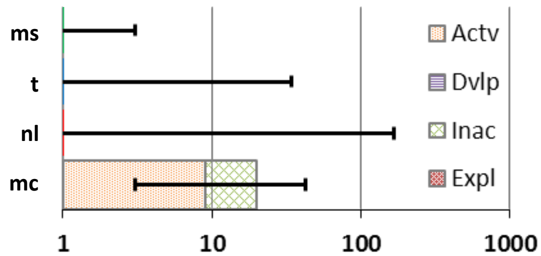
Small scale hydro



Placer mining claims

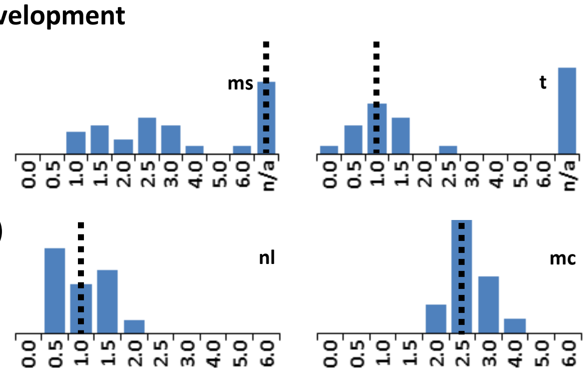


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

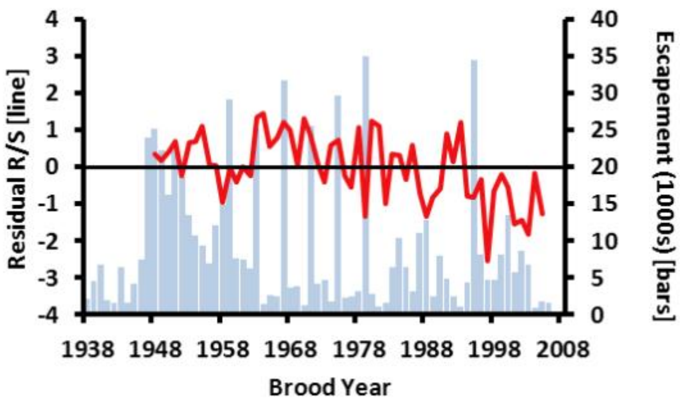
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

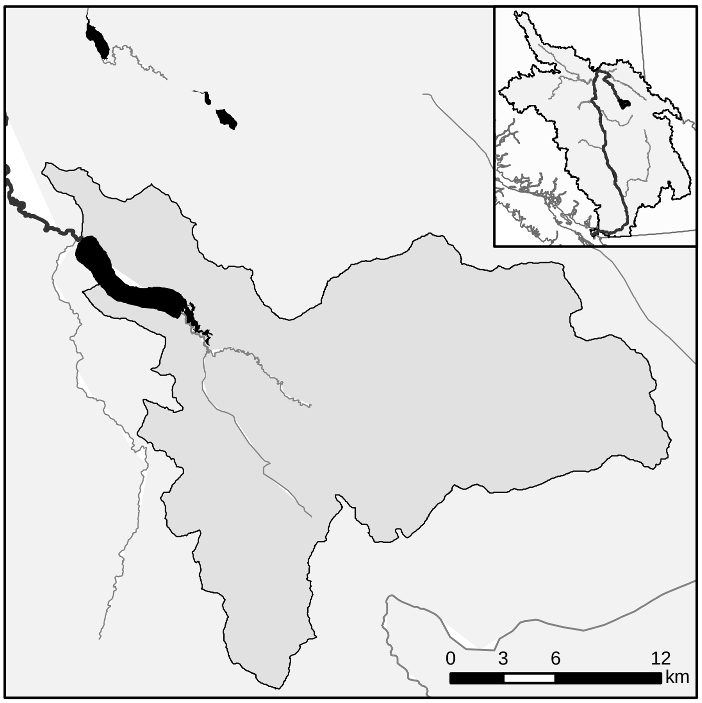
CONSERVATION UNIT

Bowron — Early Summer — L-7-1

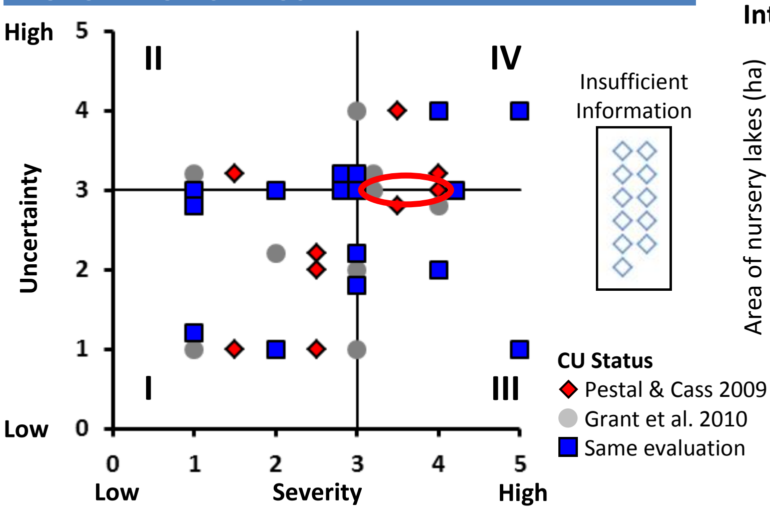
BIOLOGICAL DATA [†]



LOCATION



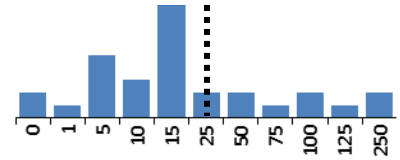
POPULATION STATUS



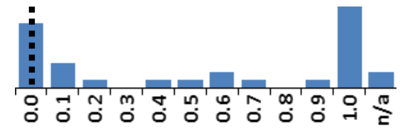
HABITAT STATUS

Spawning[††]

Total spawning extent (km)

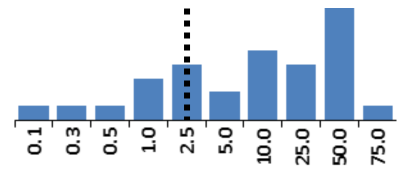


Ratio of lake influence spawning to total spawning

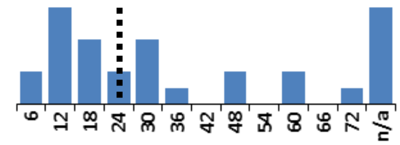


Rearing

Area of nursery lakes (1000 ha)

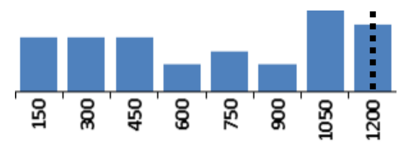


Nursery lake productivity (estimated) (100 smolts/ha)

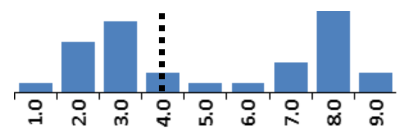


Migration

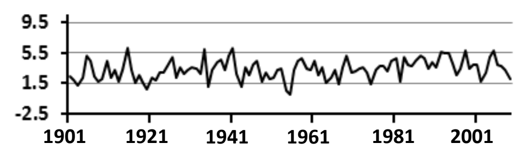
Migration distance (km)



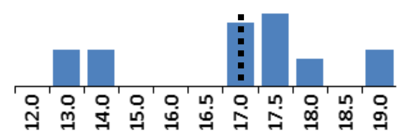
Average spring air temperature at nursery lake (°C)



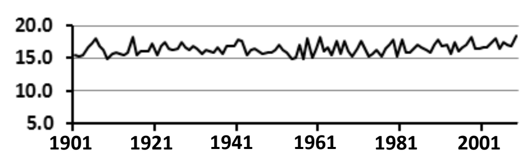
Spring air temperature at nursery lake (°C)



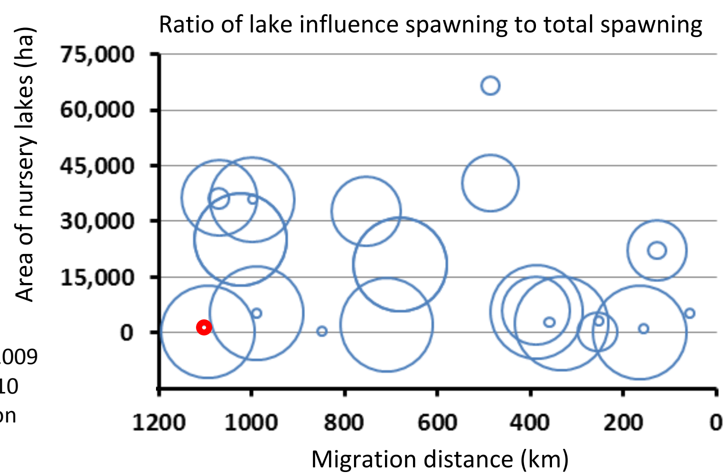
Average air temperature across adult migration (°C)[‡]



Air temperature across adult migration (°C)[‡]



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Bowron**

†† Spawning note: **None.**

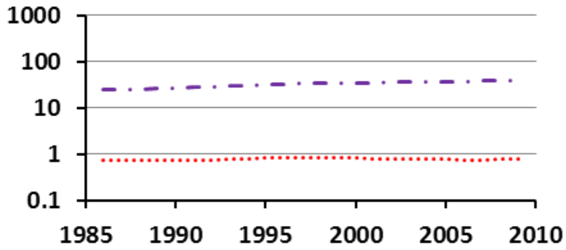
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

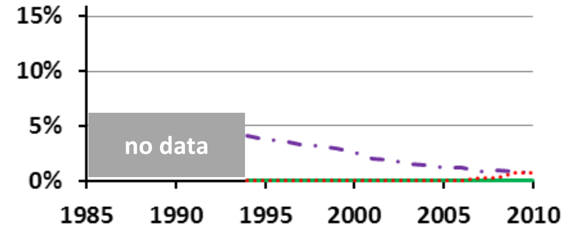
Human Population

Population density (persons/ km^2)

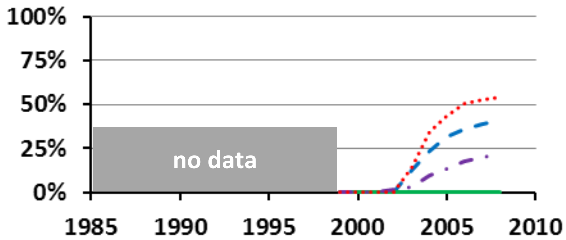


Land Use

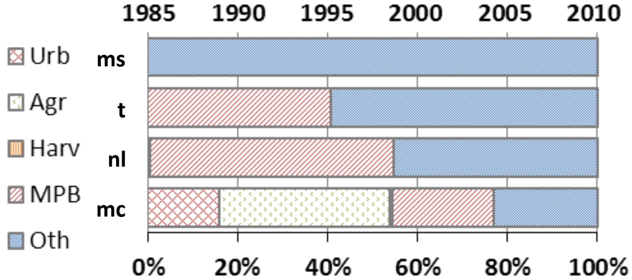
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

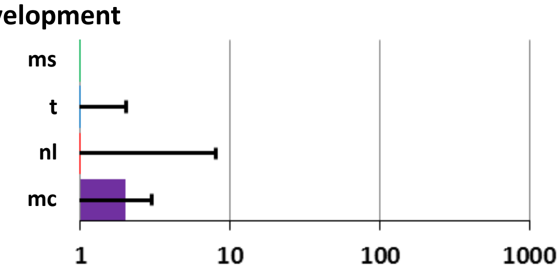


Land use type (% of habitat area)

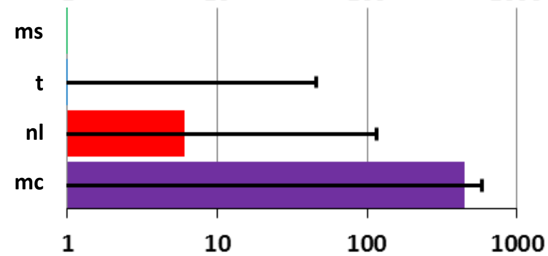


Resource Development

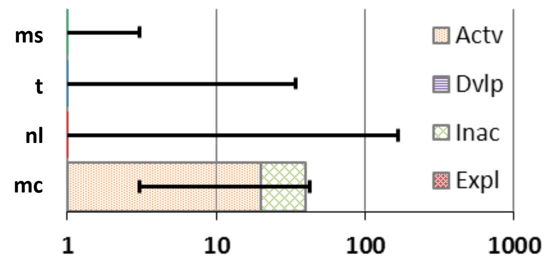
Small scale hydro



Placer mining claims

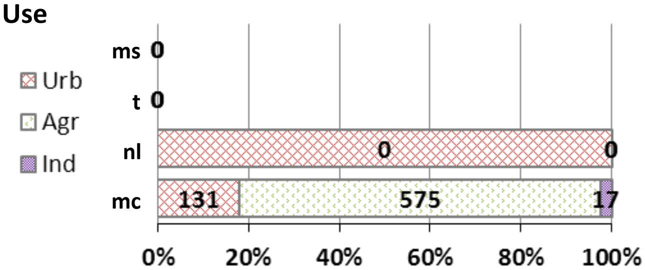


Other mines

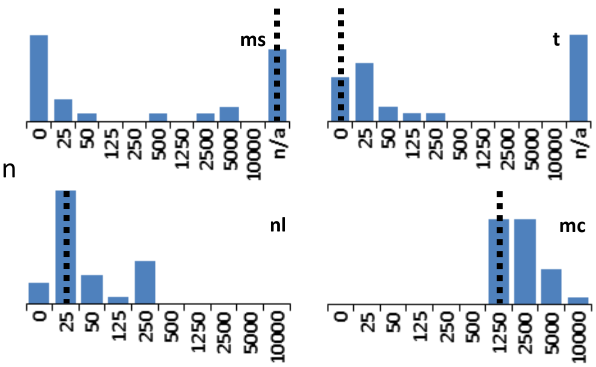


Water Use

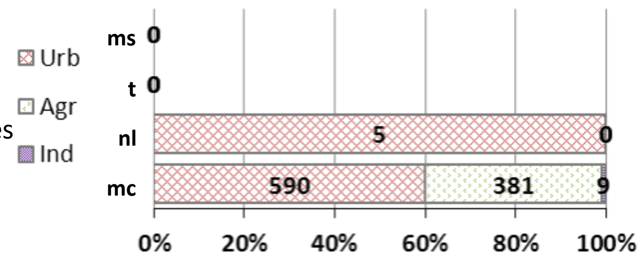
Total allo-cation by use



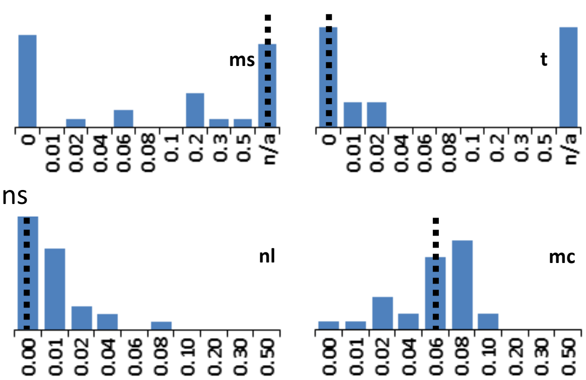
Total allocation (m^3/ha)



Water Licenses

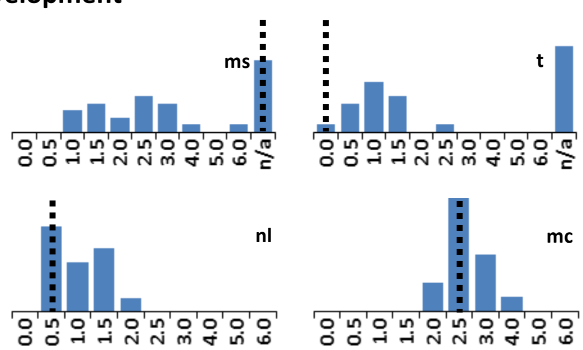


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

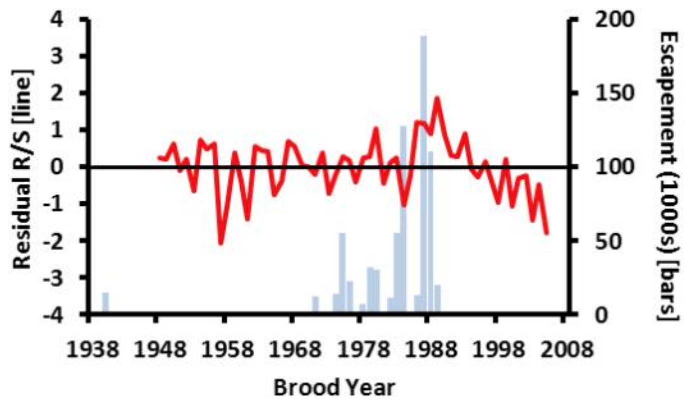
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

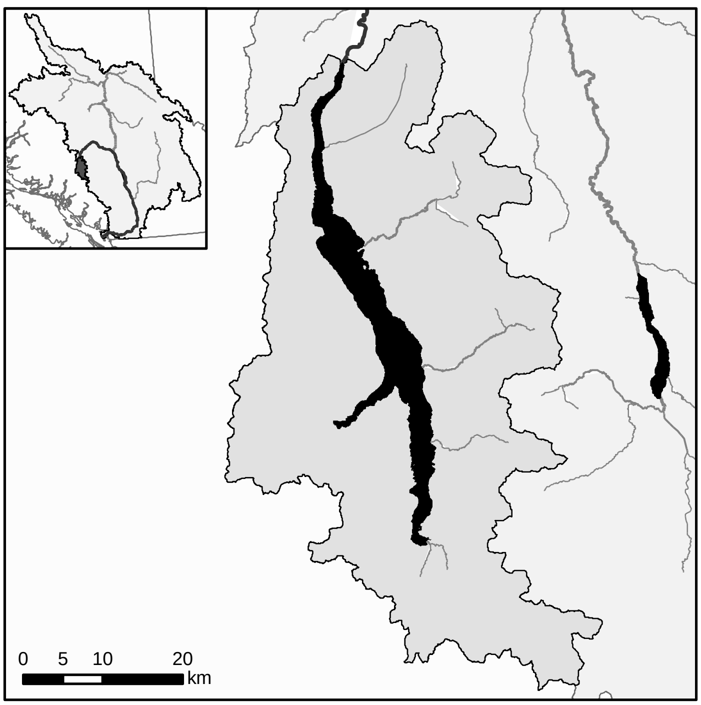
CONSERVATION UNIT

Chilko — Early Summer — L-6-2

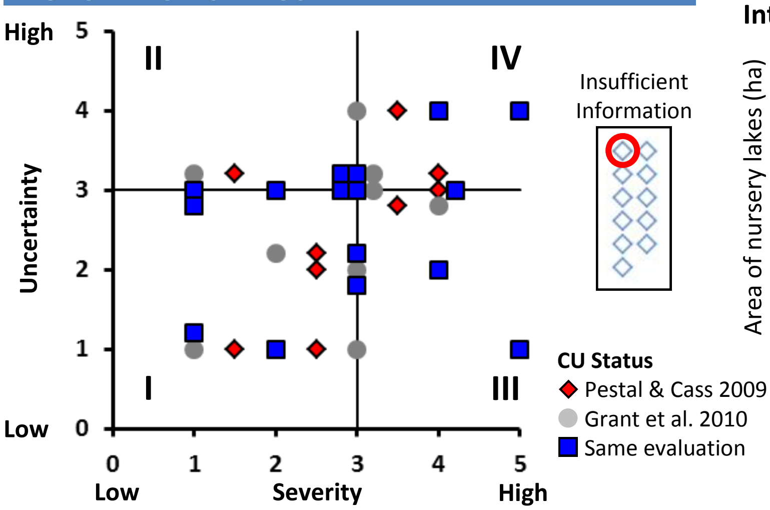
BIOLOGICAL DATA †



LOCATION



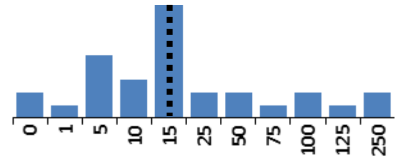
POPULATION STATUS



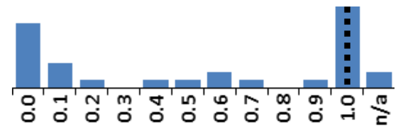
HABITAT STATUS

Spawning††

Total spawning extent (km)

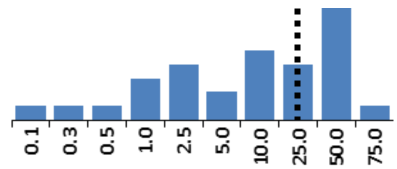


Ratio of lake influence spawning to total spawning

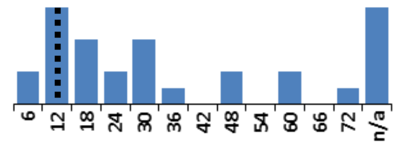


Rearing

Area of nursery lakes (1000 ha)

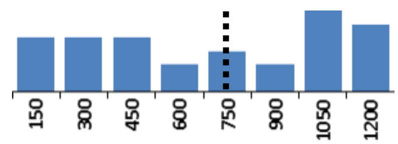


Nursery lake productivity (estimated) (100 smolts/ha)

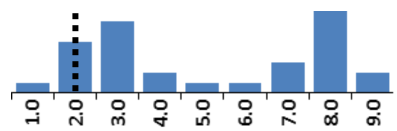


Migration

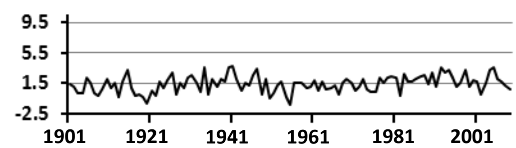
Migration distance (km)



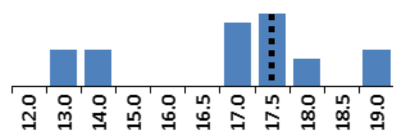
Average spring air temperature at nursery lake (°C)



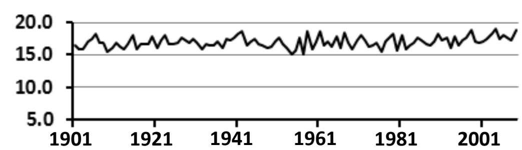
Spring air temperature at nursery lake (°C)



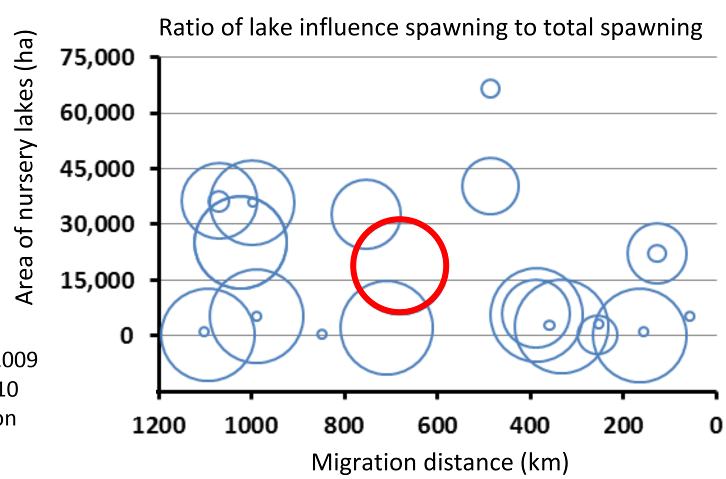
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Chilko**

†† Spawning note: **None.**

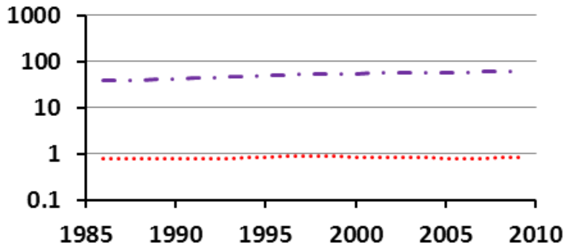
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

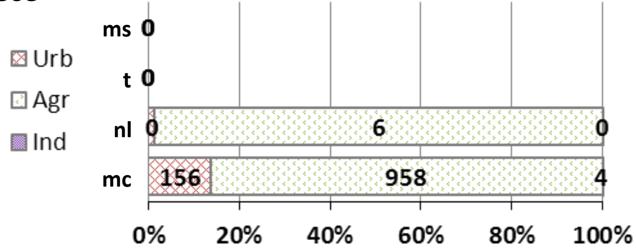
Human Population

Population density (persons/km^2)



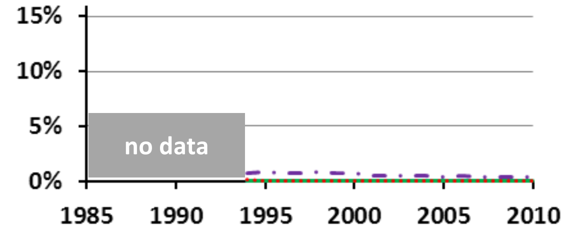
Water Use

Total allocation by use

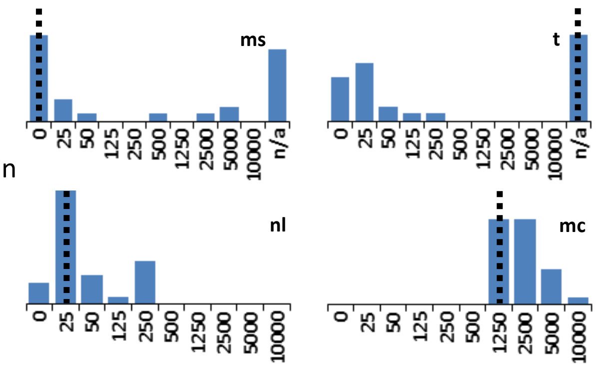


Land Use

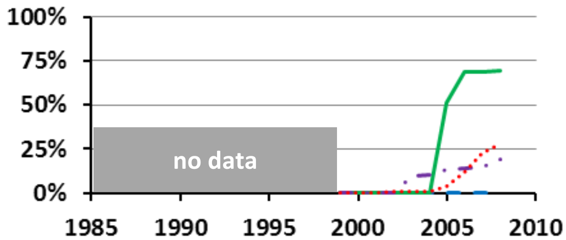
Forest harvesting (% of habitat area)



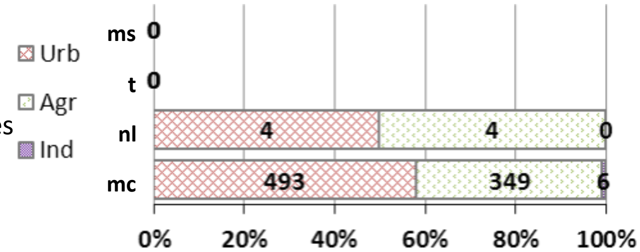
Total allocation (m^3/ha)



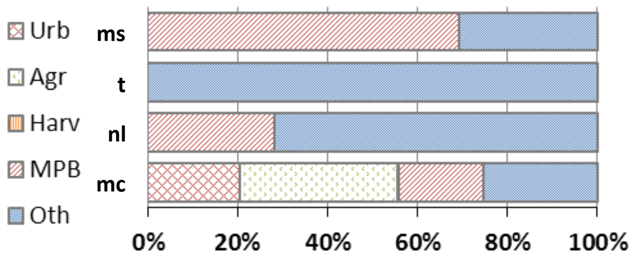
Mountain pine beetle disturbance (cumulative % of habitat area)



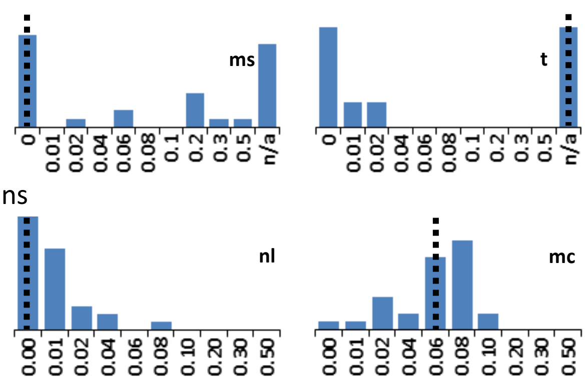
Water Licenses



Land use type (% of habitat area)

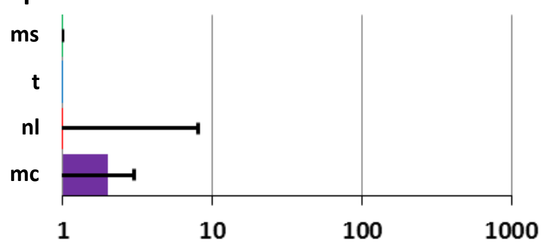


Water Restrictions (#/km^2)

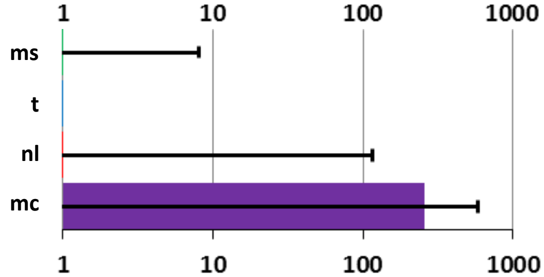


Resource Development

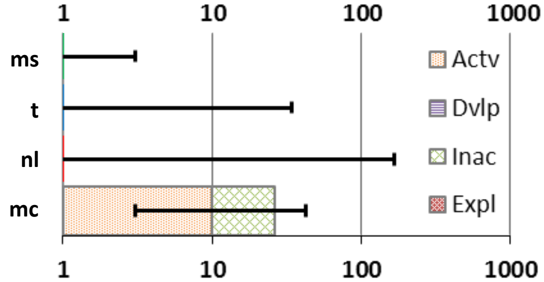
Small scale hydro



Placer mining claims

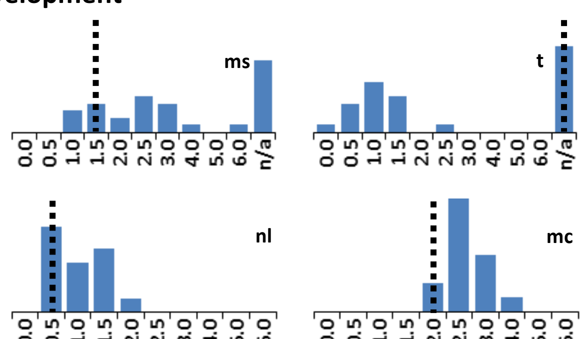


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

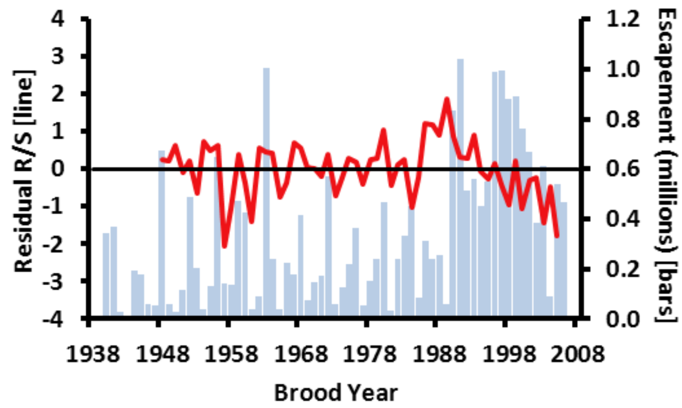
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

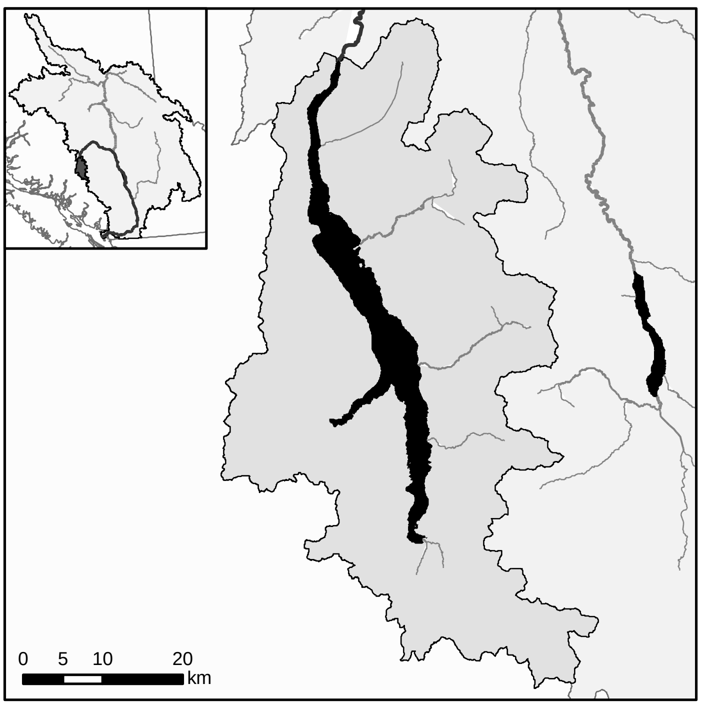
CONSERVATION UNIT

Chilko — Summer — L-6-3

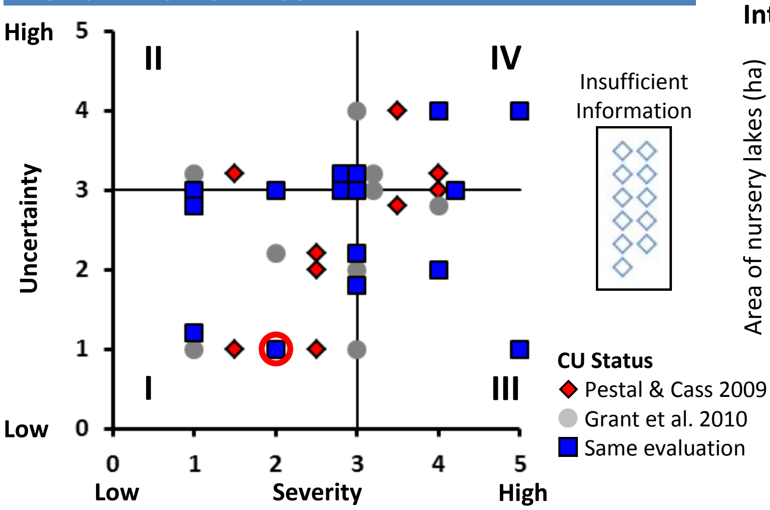
BIOLOGICAL DATA †



LOCATION



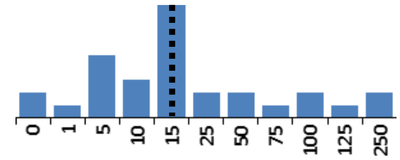
POPULATION STATUS



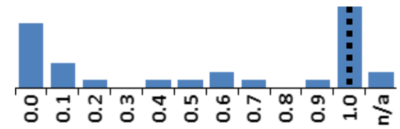
HABITAT STATUS

Spawning††

Total spawning extent (km)

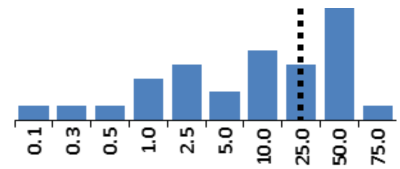


Ratio of lake influence spawning to total spawning

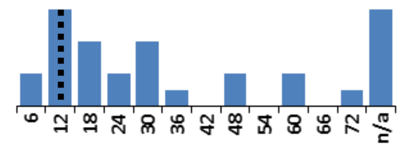


Rearing

Area of nursery lakes (1000 ha)

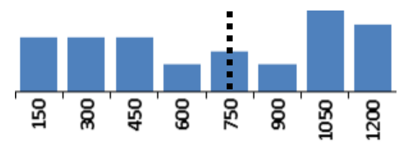


Nursery lake productivity (estimated) (100 smolts/ha)

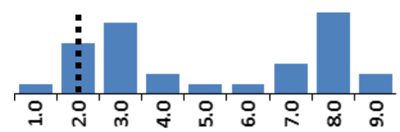


Migration

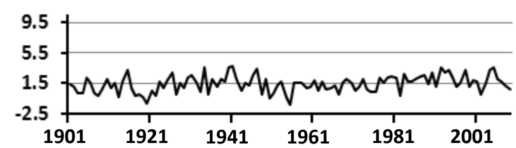
Migration distance (km)



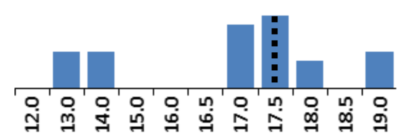
Average spring air temperature at nursery lake (°C)



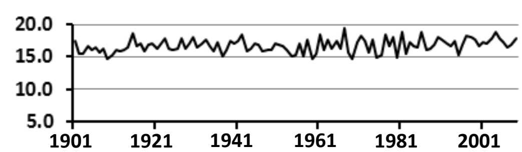
Spring air temperature at nursery lake (°C)



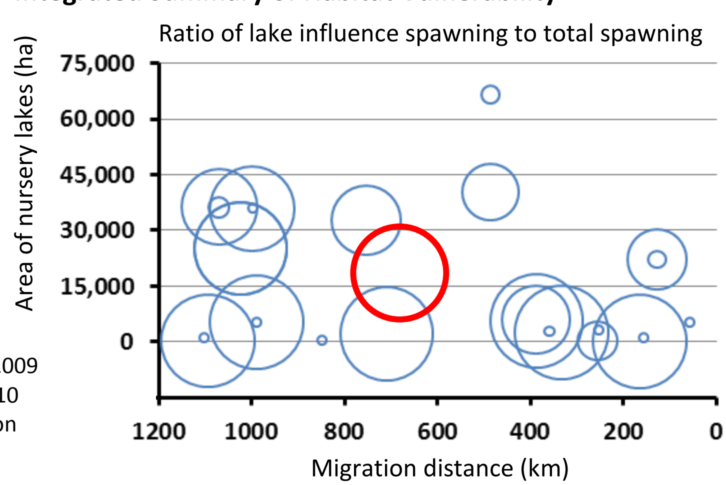
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Chilko**

†† Spawning note: **None.**

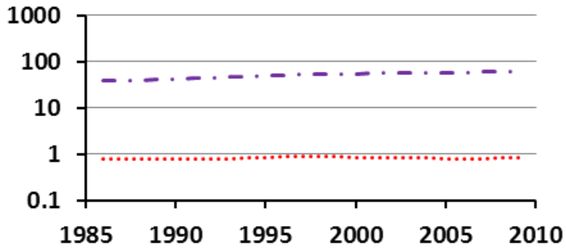
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

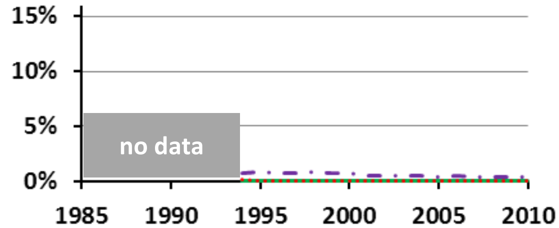
Human Population

Population density (persons/km^2)

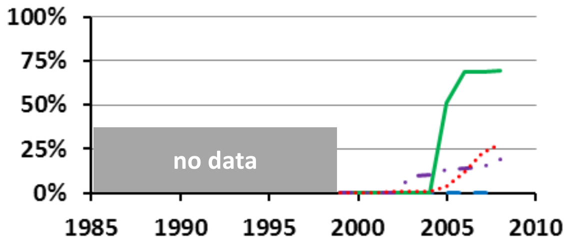


Land Use

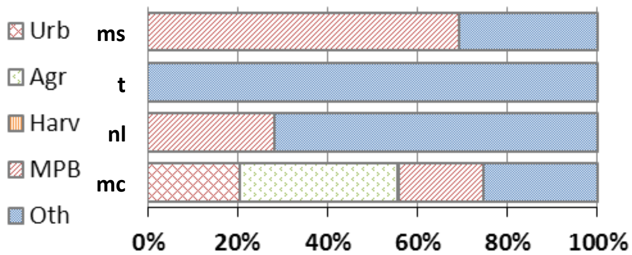
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

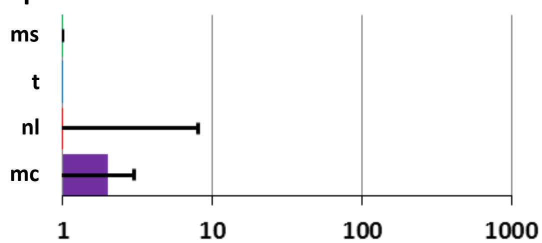


Land use type (% of habitat area)

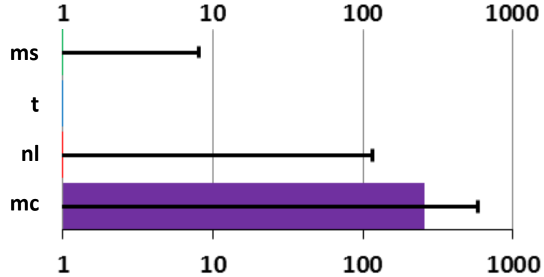


Resource Development

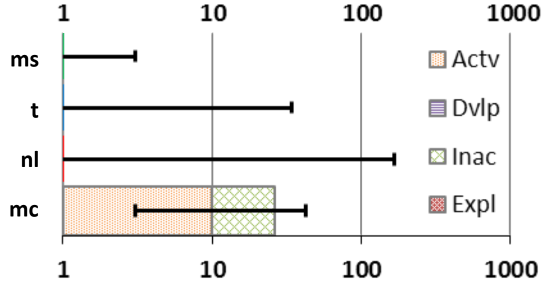
Small scale hydro



Placer mining claims

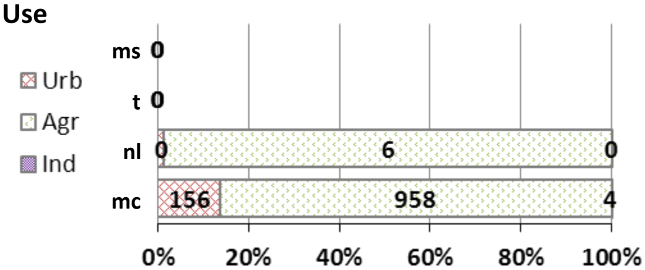


Other mines

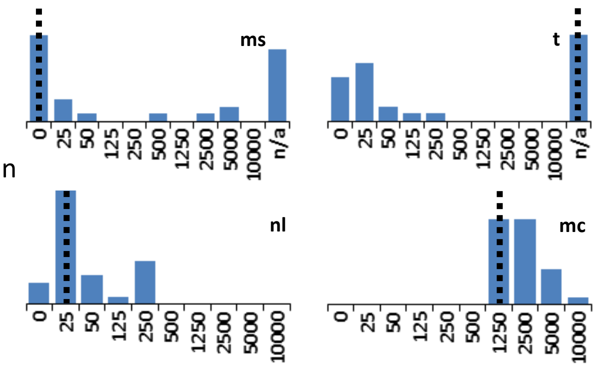


Water Use

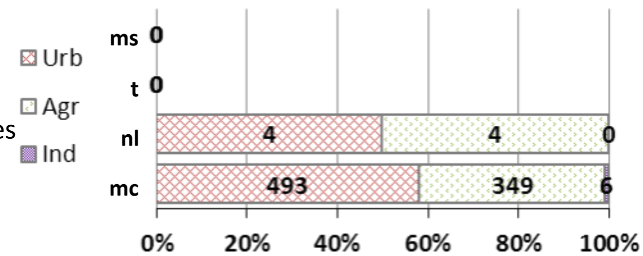
Total allocation by use



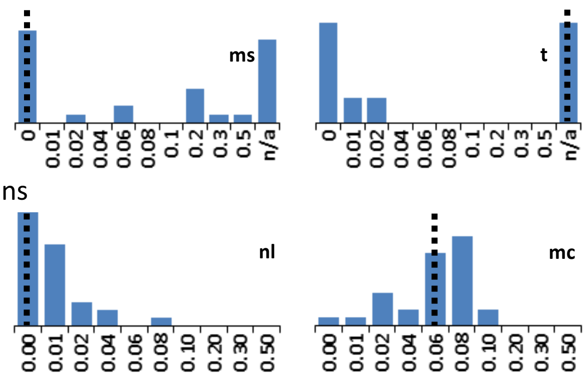
Total allocation (m^3/ha)



Water Licenses

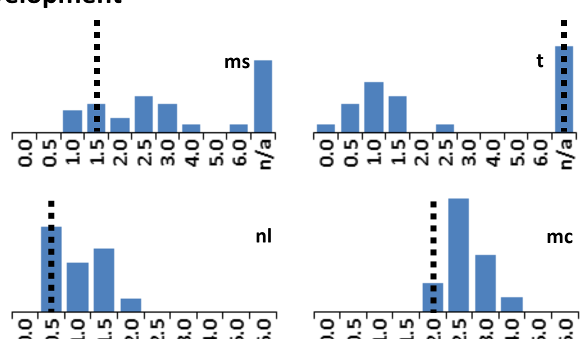


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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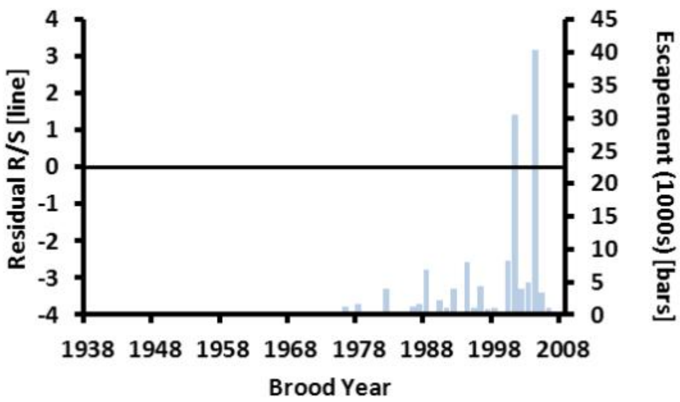
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

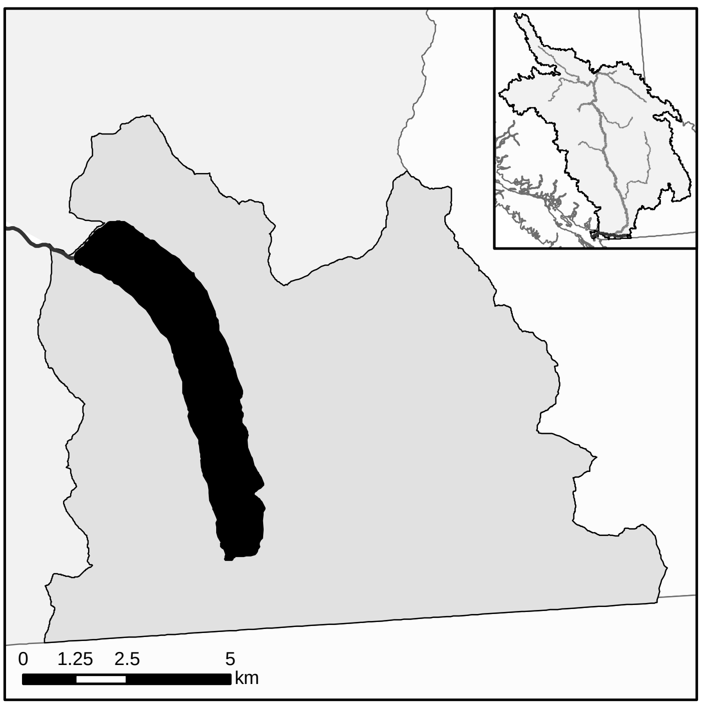
CONSERVATION UNIT

Chilliwack — Early Summer — L-3-1

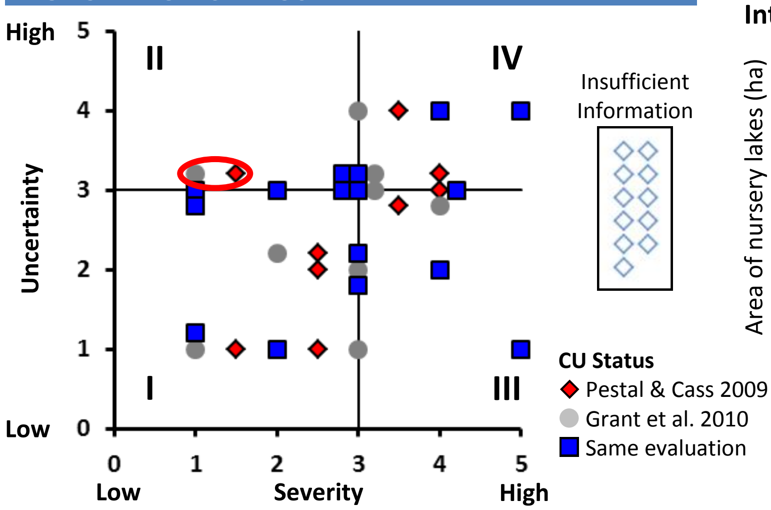
BIOLOGICAL DATA †



LOCATION



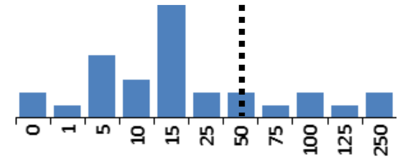
POPULATION STATUS



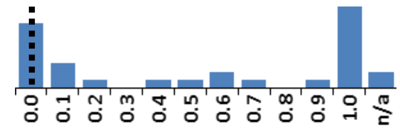
HABITAT STATUS

Spawning††

Total spawning extent (km)

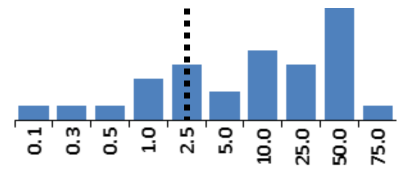


Ratio of lake influence spawning to total spawning

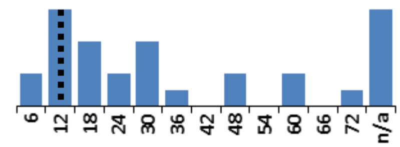


Rearing

Area of nursery lakes (1000 ha)

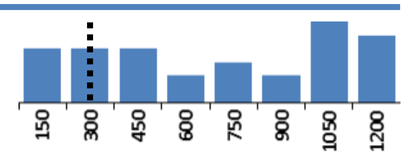


Nursery lake productivity (estimated) (100 smolts/ha)

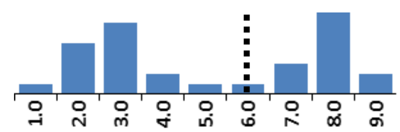


Migration

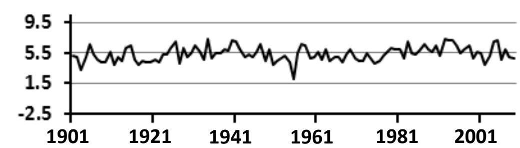
Migration distance (km)



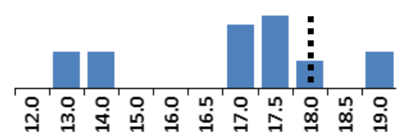
Average spring air temperature at nursery lake (°C)



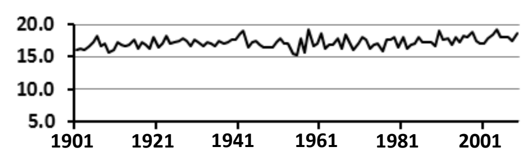
Spring air temperature at nursery lake (°C)



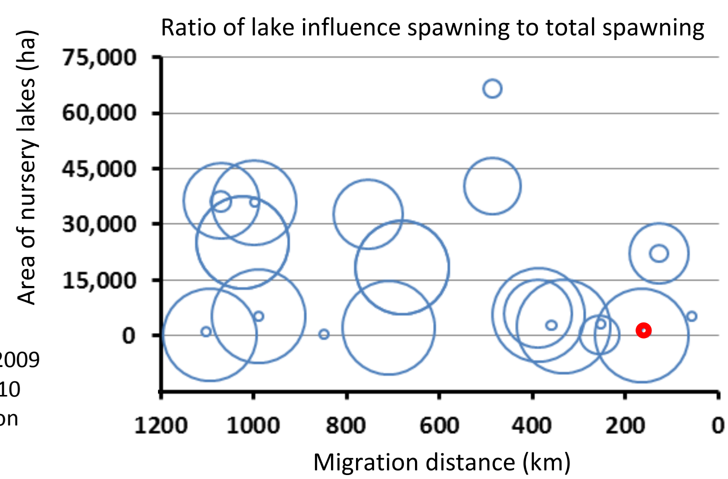
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

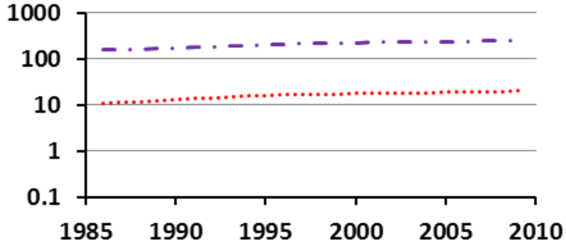
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

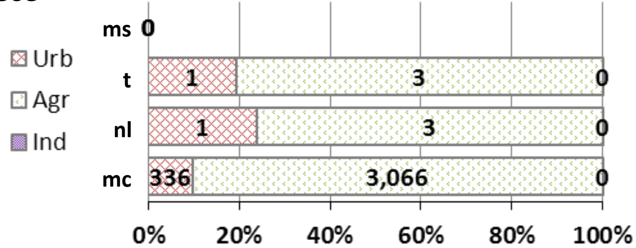
Human Population

Population density (persons/ km^2)

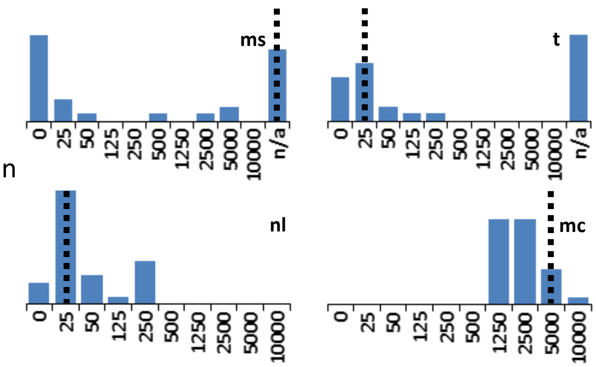


Water Use

Total allo- cation by use

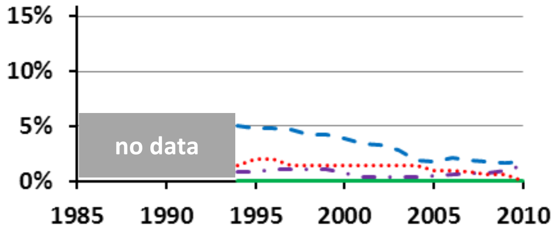


Total allocation (m^3/ha)

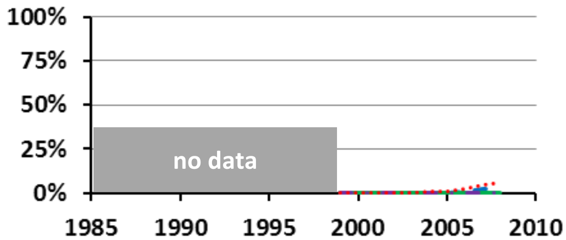


Land Use

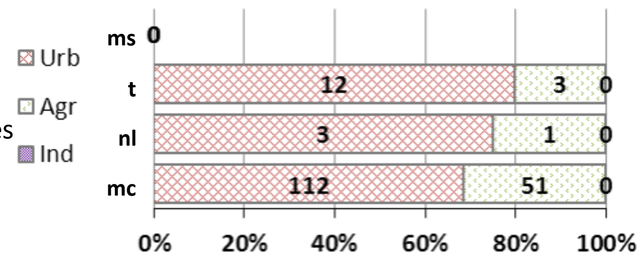
Forest harvesting (% of habitat area)



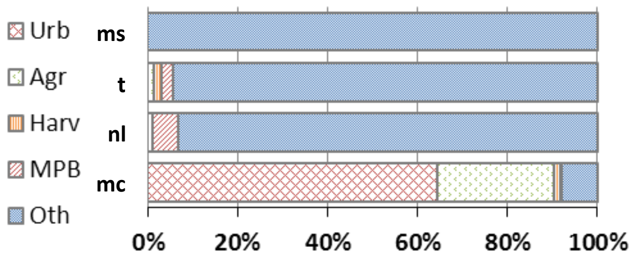
Mountain pine beetle disturbance (cumulative % of habitat area)



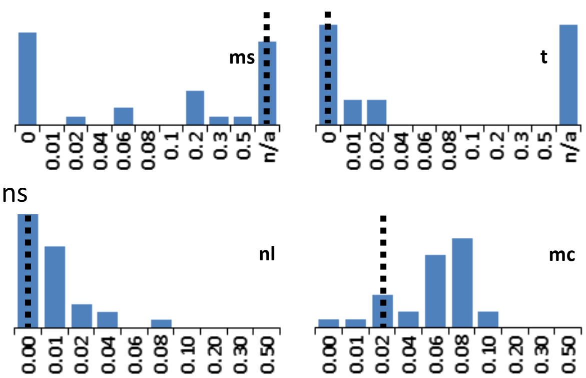
Water Licenses



Land use type (% of habitat area)

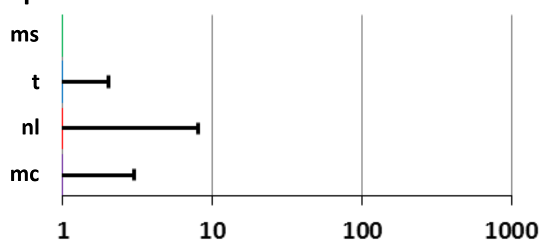


Water Restrictions (#/km^2)

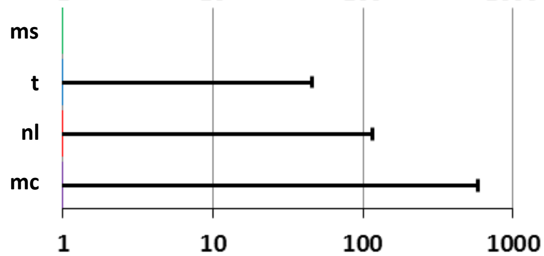


Resource Development

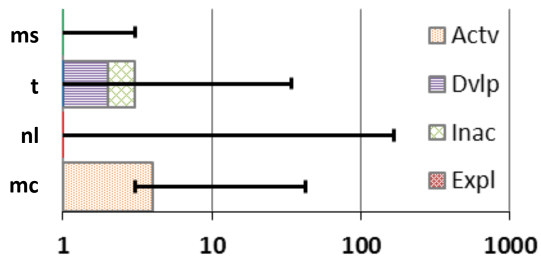
Small scale hydro



Placer mining claims

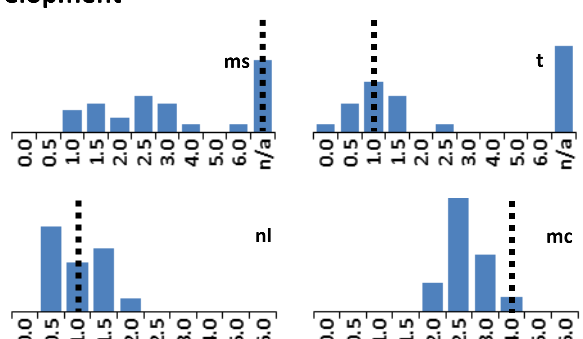


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

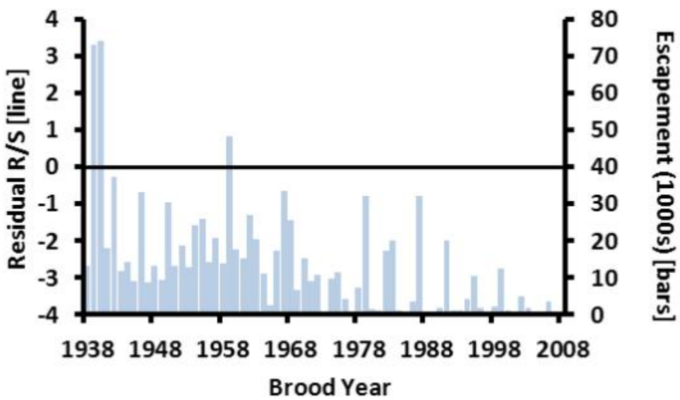
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

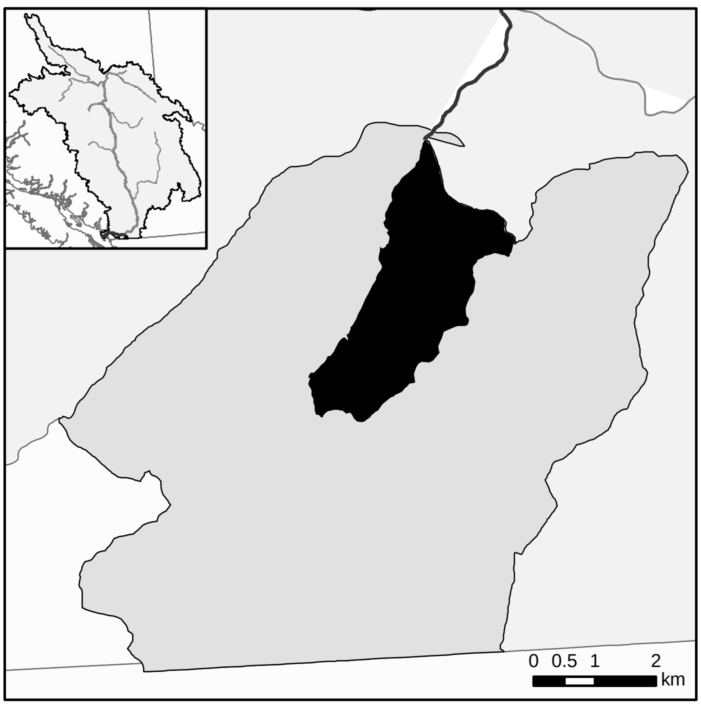
CONSERVATION UNIT

Cultus — Late — L-3-2

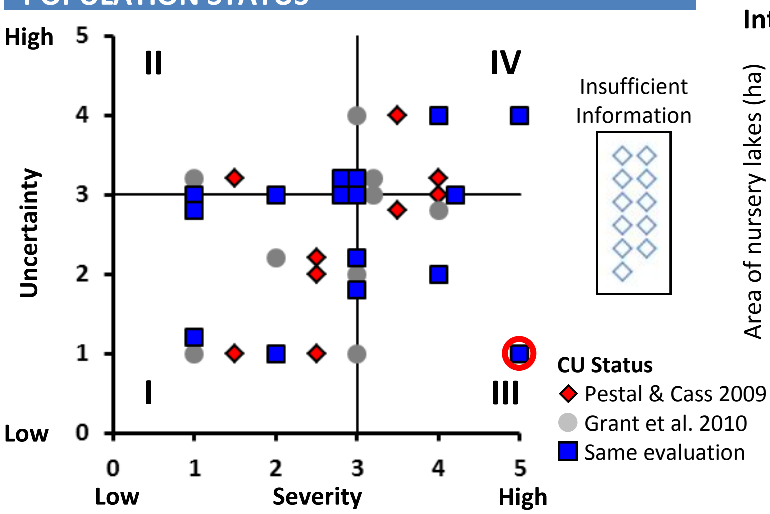
BIOLOGICAL DATA †



LOCATION



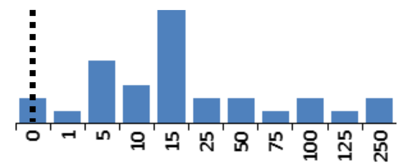
POPULATION STATUS



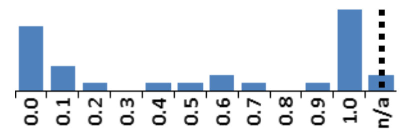
HABITAT STATUS

Spawning††

Total spawning extent (km)

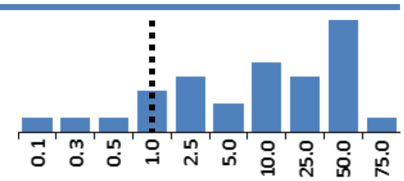


Ratio of lake influence spawning to total spawning

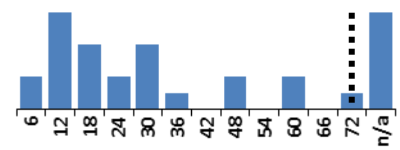


Rearing

Area of nursery lakes (1000 ha)

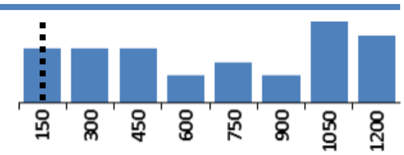


Nursery lake productivity (estimated) (100 smolts/ha)

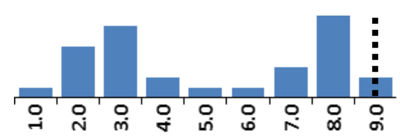


Migration

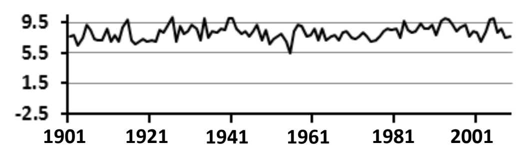
Migration distance (km)



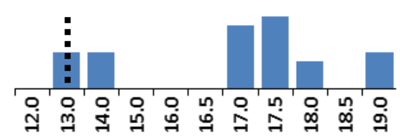
Average spring air temperature at nursery lake (°C)



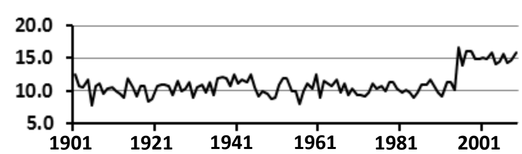
Spring air temperature at nursery lake (°C)



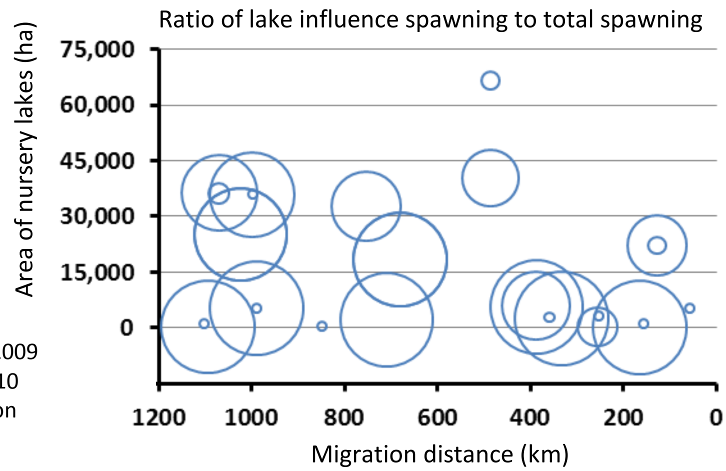
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability‡‡



† Representative stock for productivity: **None**

†† Spawning note: **Foreshore spawning.**

‡ Temperature calculated according to run group timing.

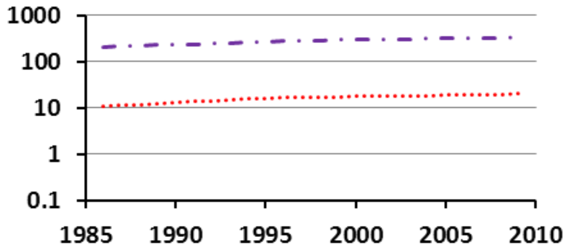
‡‡ Cultus CU cannot be represented on this figure (spawning ratio = n/a)

January 31, 2011

FRESHWATER STRESSORS

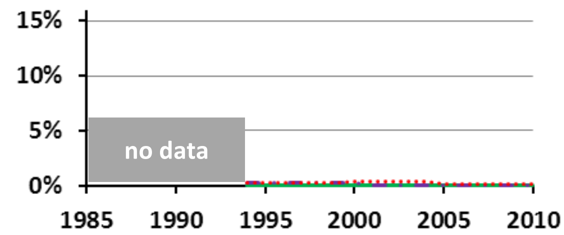
Human Population

Population density (persons/km^2)

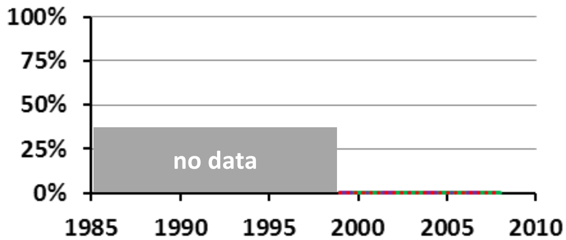


Land Use

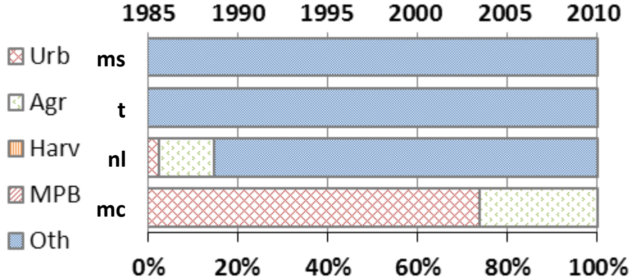
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

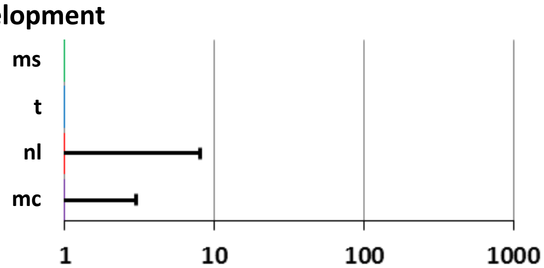


Land use type (% of habitat area)

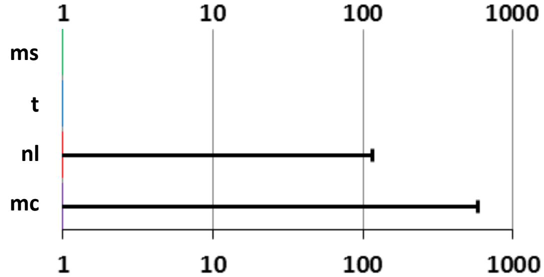


Resource Development

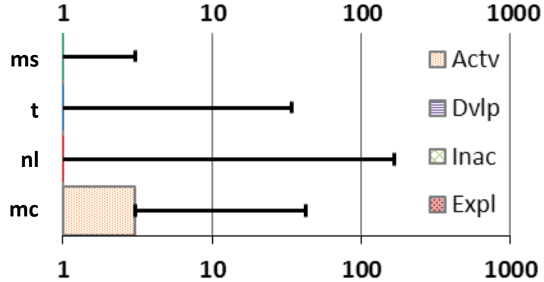
Small scale hydro



Placer mining claims

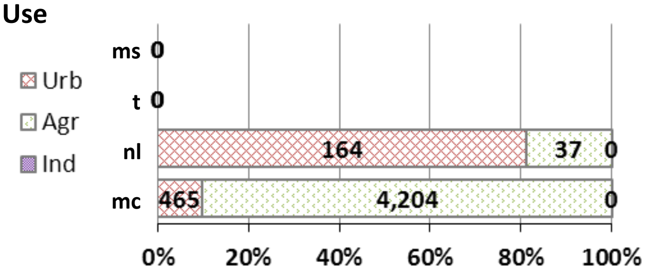


Other mines

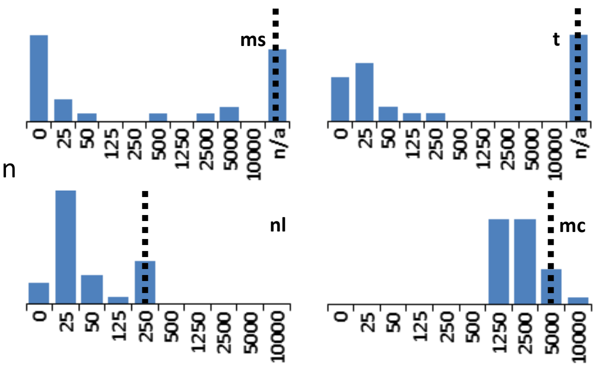


Water Use

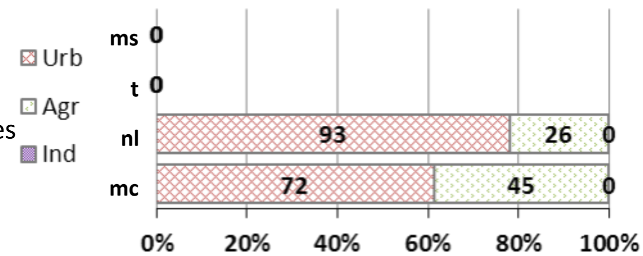
Total allo-cation by use



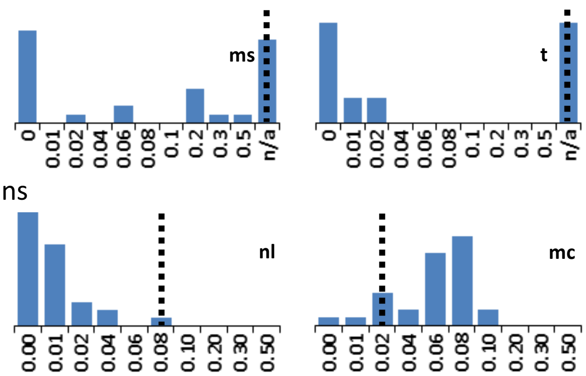
Total allocation (m^3/ha)



Water Licenses

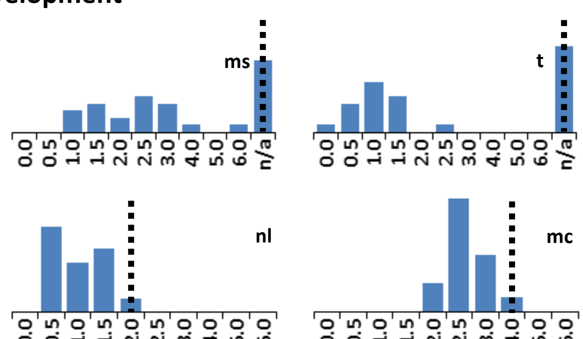


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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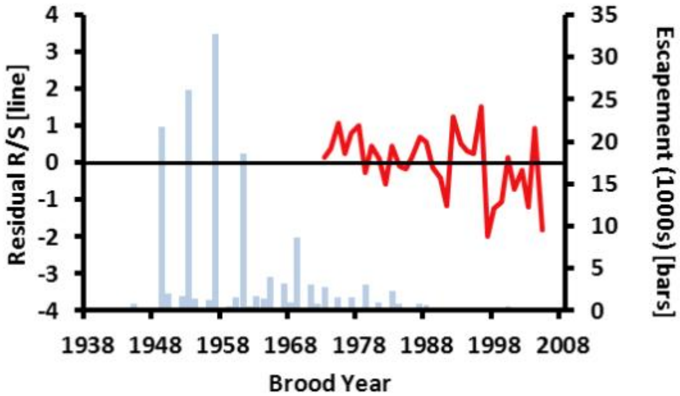
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

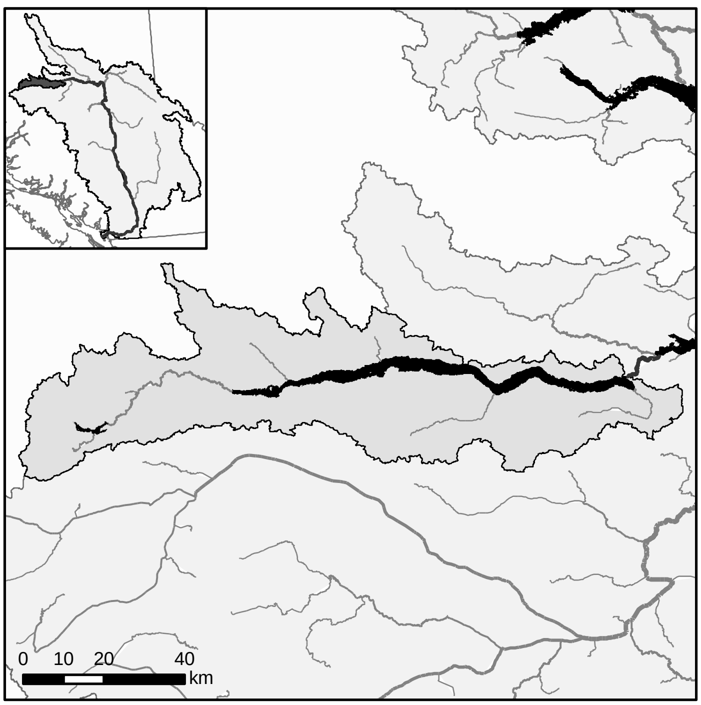
CONSERVATION UNIT

Francois — Early Summer — L-6-4

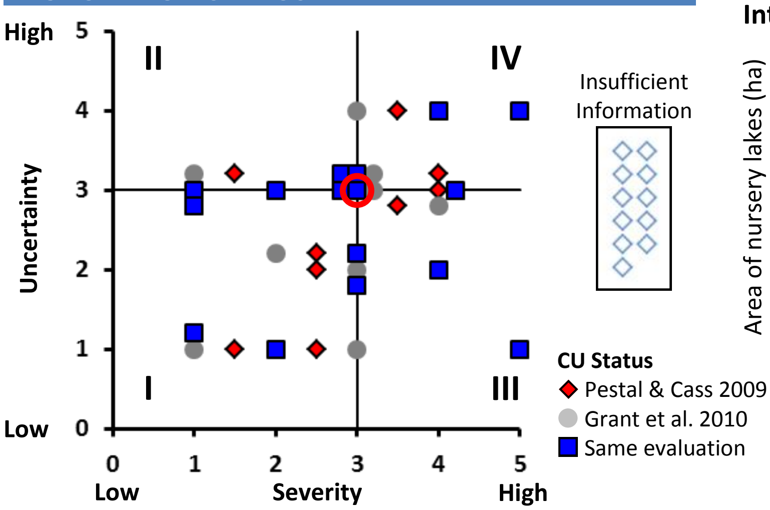
BIOLOGICAL DATA †



LOCATION



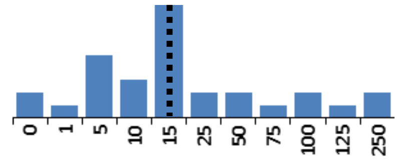
POPULATION STATUS



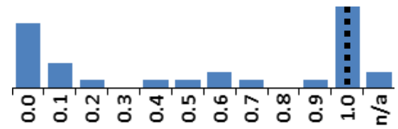
HABITAT STATUS

Spawning††

Total spawning extent (km)

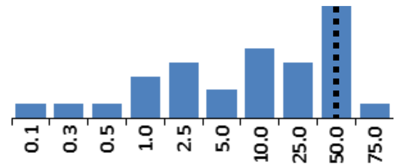


Ratio of lake influence spawning to total spawning

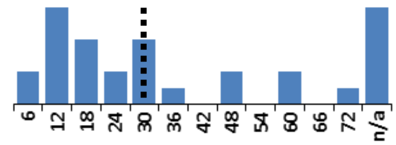


Rearing

Area of nursery lakes (1000 ha)

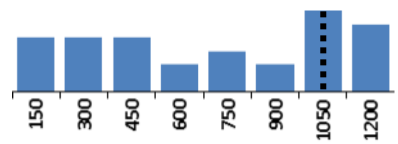


Nursery lake productivity (estimated) (100 smolts/ha)

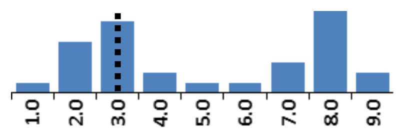


Migration

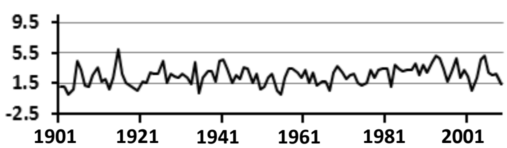
Migration distance (km)



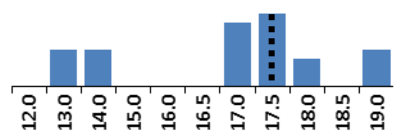
Average spring air temperature at nursery lake (°C)



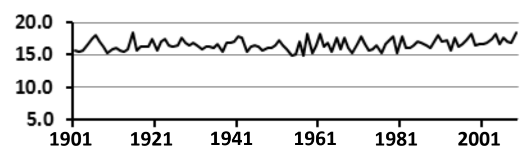
Spring air temperature at nursery lake (°C)



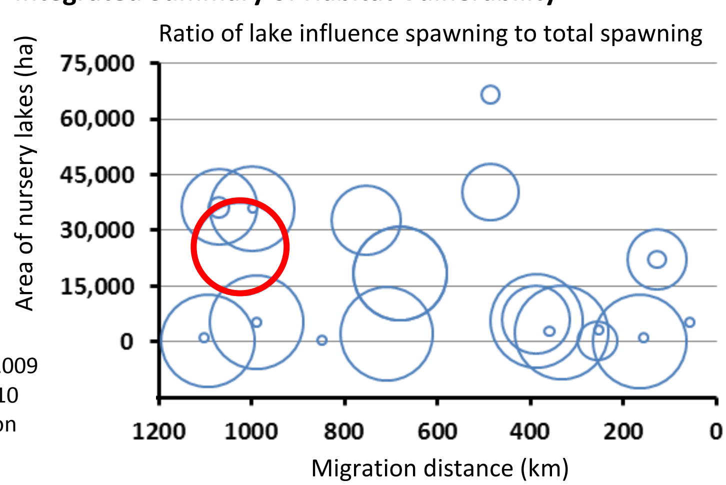
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Nadina**

†† Spawning note: **Nadina spawning channel.**

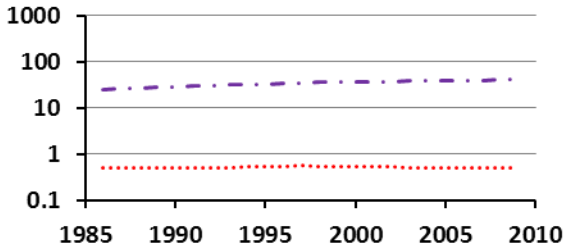
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

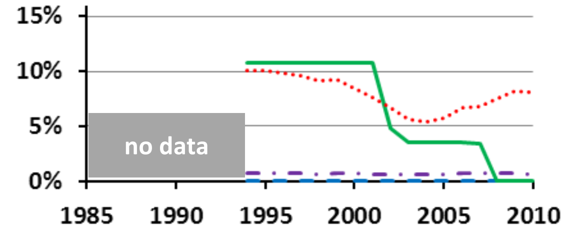
Human Population

Population density (persons/km^2)

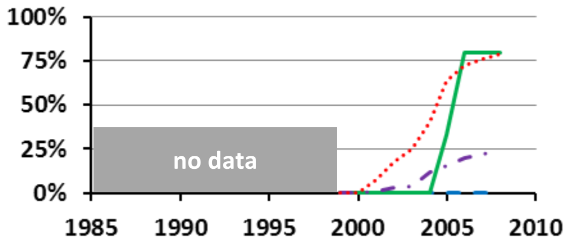


Land Use

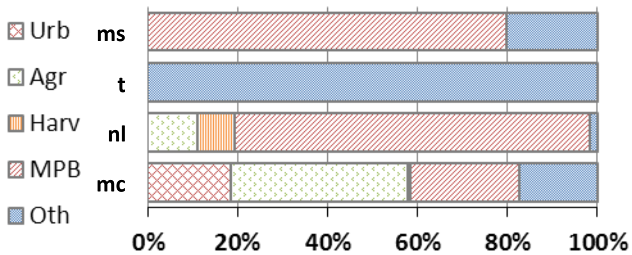
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

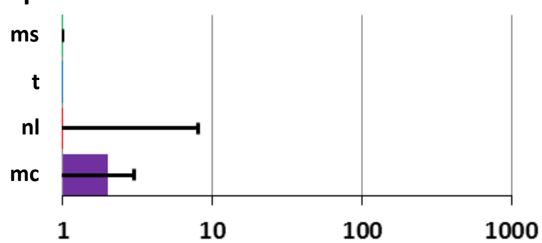


Land use type (% of habitat area)

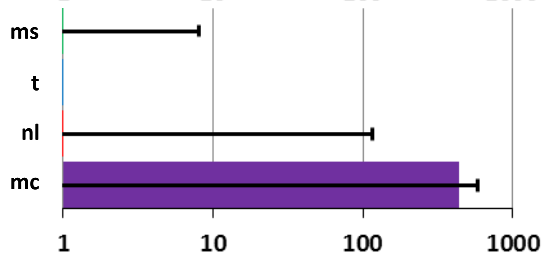


Resource Development

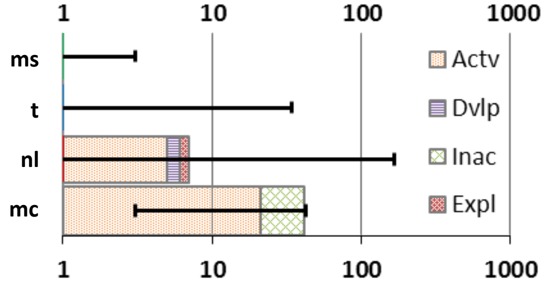
Small scale hydro



Placer mining claims

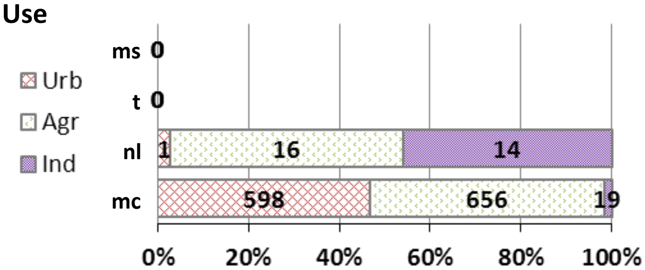


Other mines

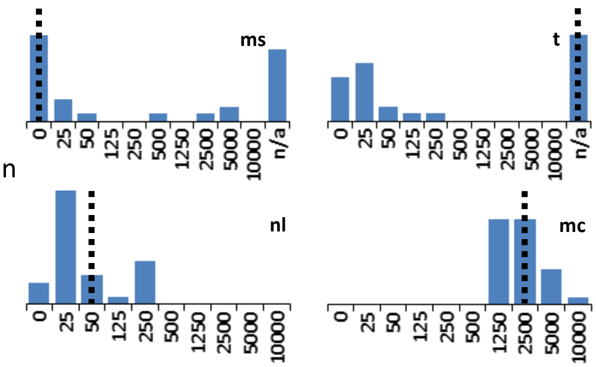


Water Use

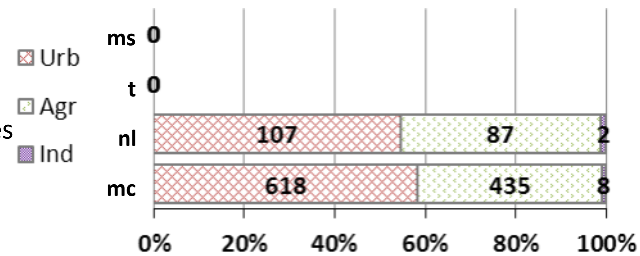
Total allo-cation by use



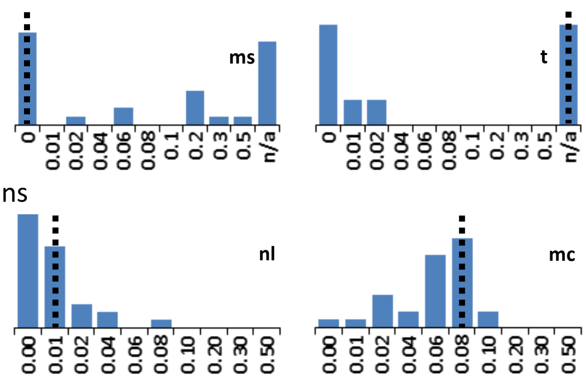
Total allocation (m^3/ha)



Water Licenses

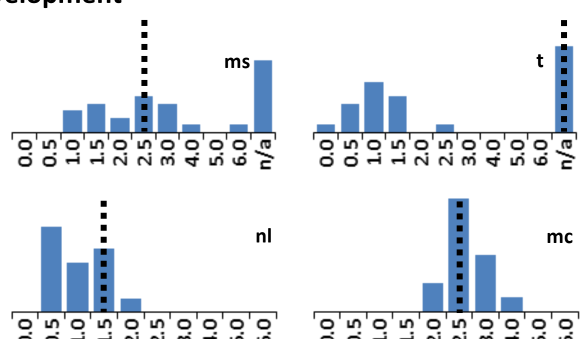


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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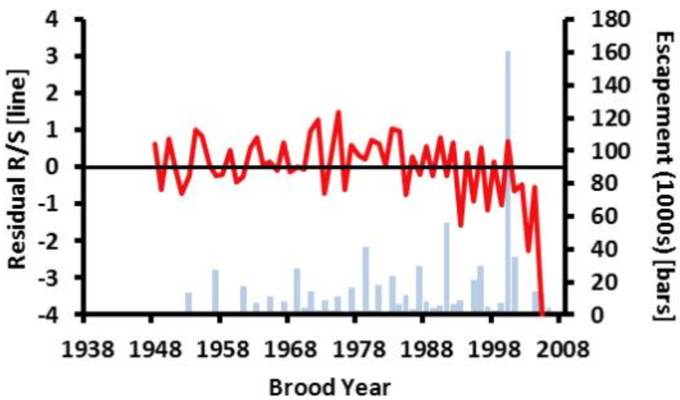
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

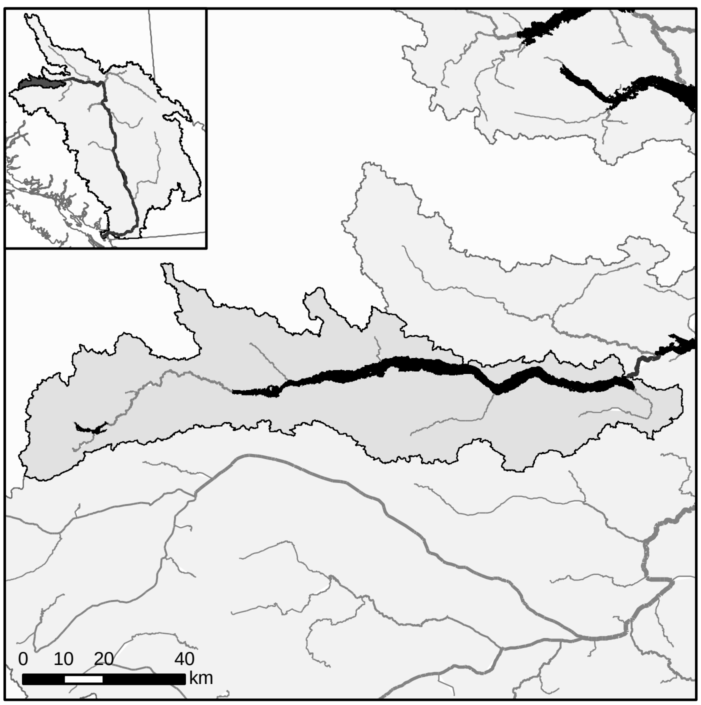
CONSERVATION UNIT

Francois — Summer — L-6-5

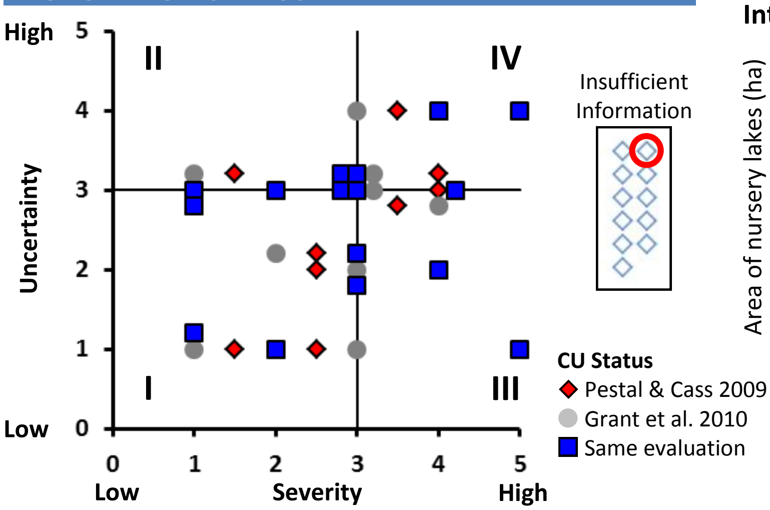
BIOLOGICAL DATA †



LOCATION



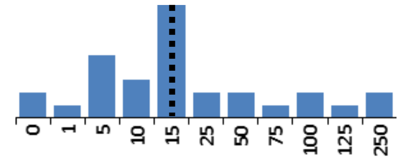
POPULATION STATUS



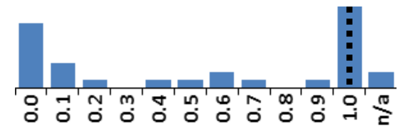
HABITAT STATUS

Spawning††

Total spawning extent (km)

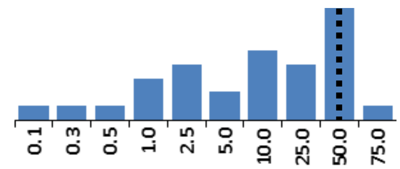


Ratio of lake influence spawning to total spawning

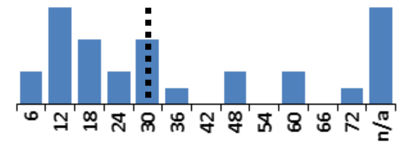


Rearing

Area of nursery lakes (1000 ha)

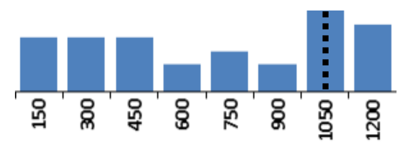


Nursery lake productivity (estimated) (100 smolts/ha)

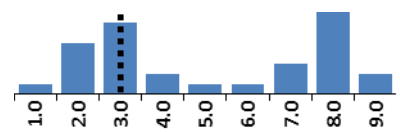


Migration

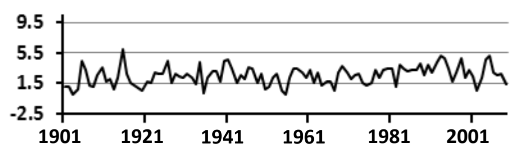
Migration distance (km)



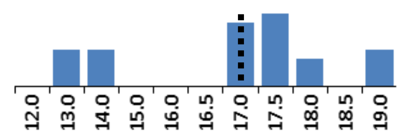
Average spring air temperature at nursery lake (°C)



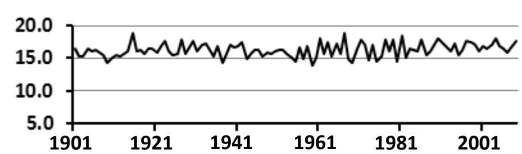
Spring air temperature at nursery lake (°C)



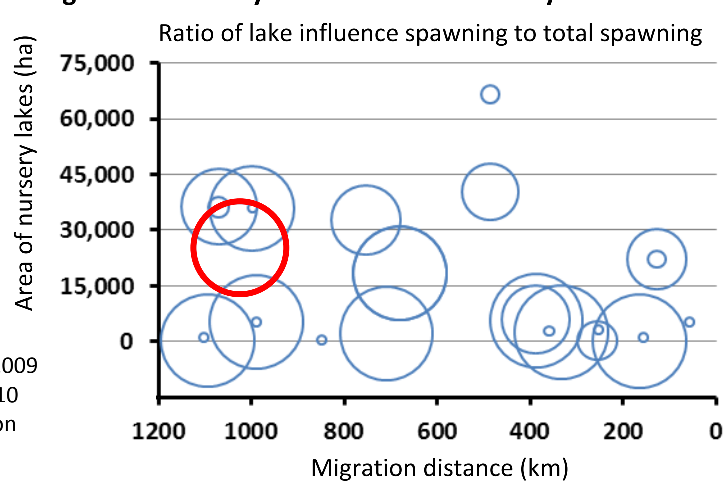
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Stellako**

†† Spawning note: **None.**

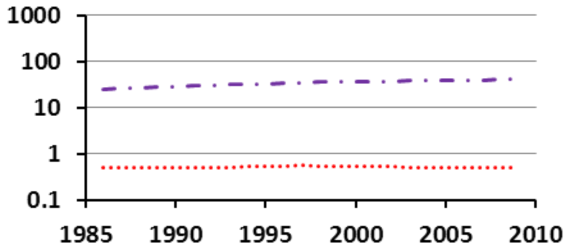
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

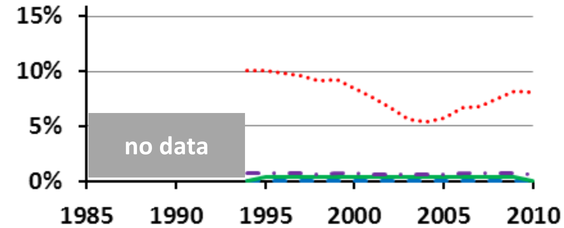
Human Population

Population density (persons/km^2)

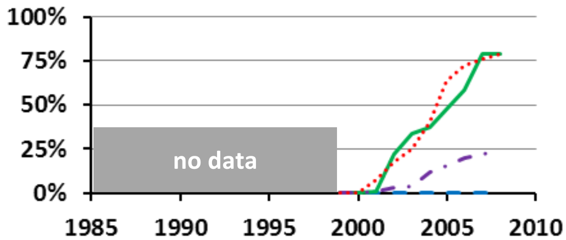


Land Use

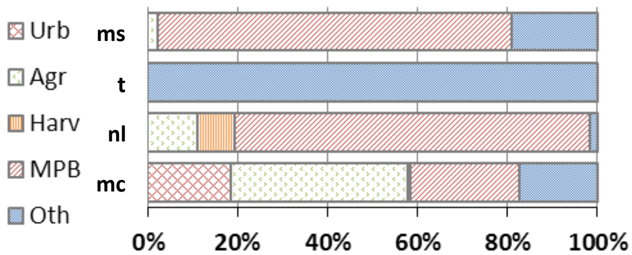
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

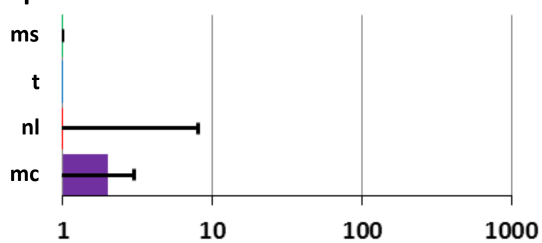


Land use type (% of habitat area)

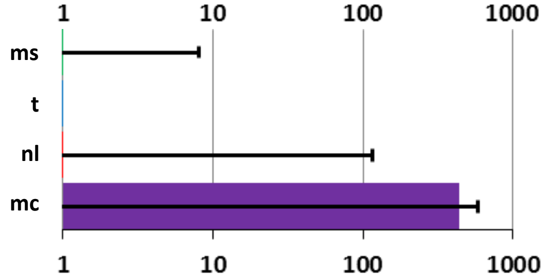


Resource Development

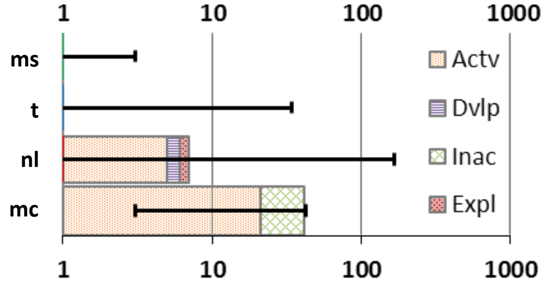
Small scale hydro



Placer mining claims

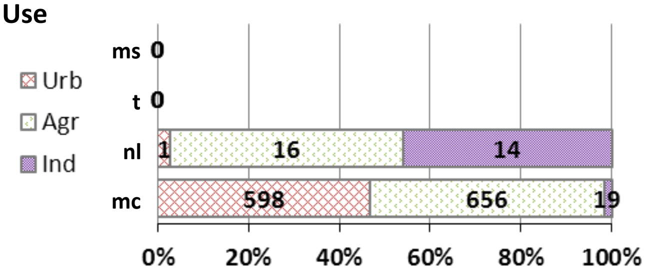


Other mines

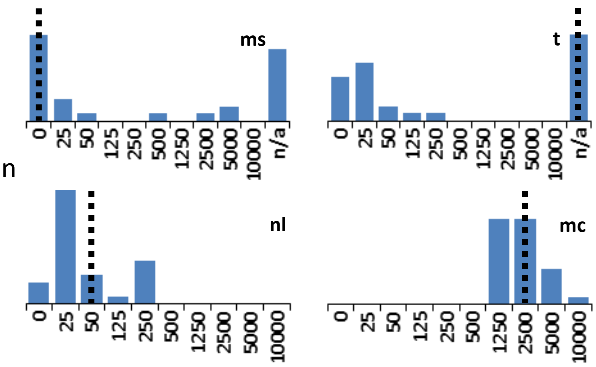


Water Use

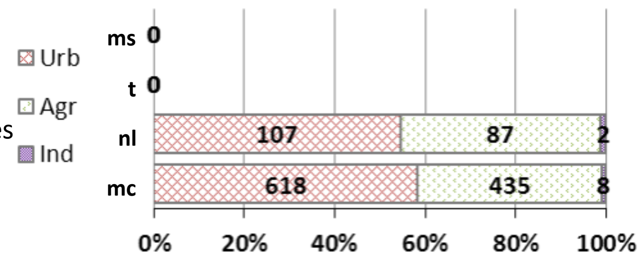
Total allo-cation by use



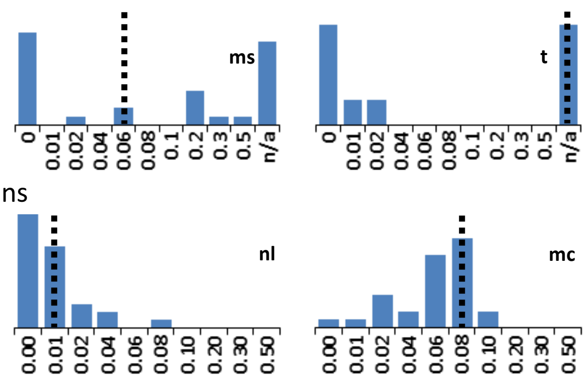
Total allocation (m^3/ha)



Water Licenses

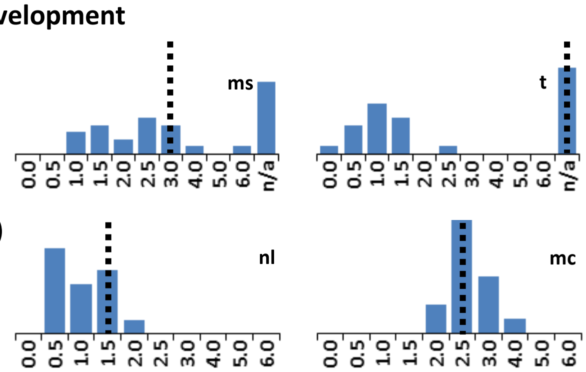


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

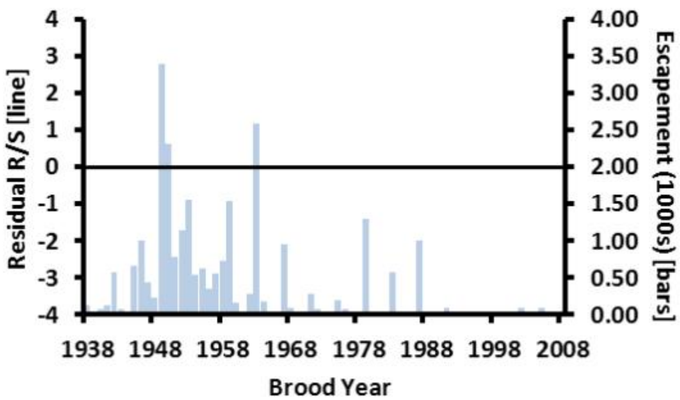
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

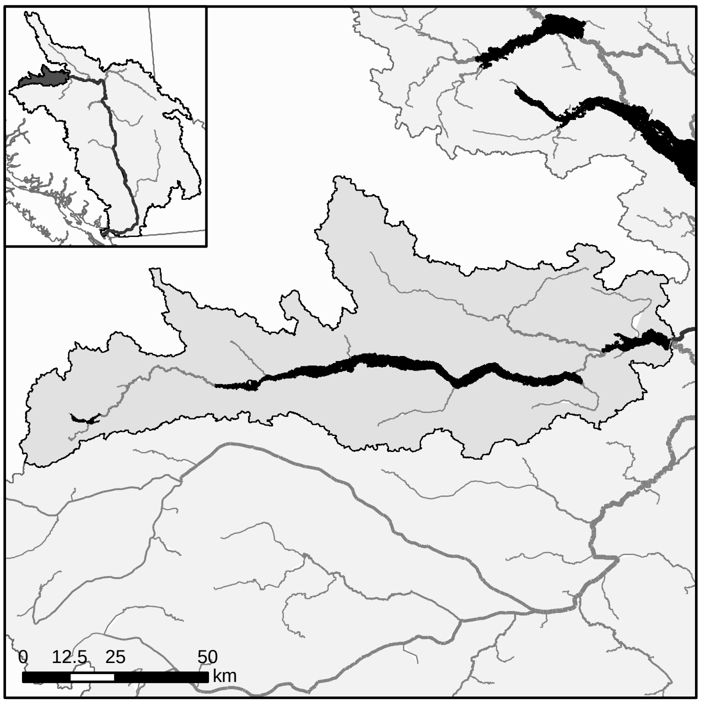
CONSERVATION UNIT

Fraser — Early Summer — L-6-6

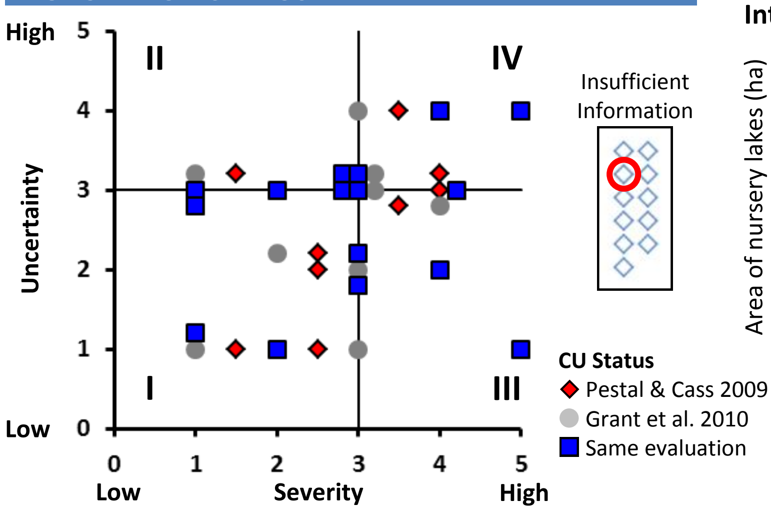
BIOLOGICAL DATA †



LOCATION



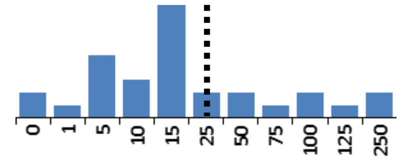
POPULATION STATUS



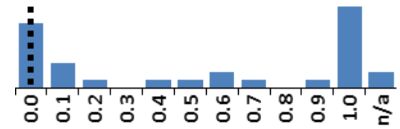
HABITAT STATUS

Spawning††

Total spawning extent (km)

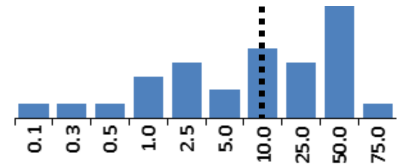


Ratio of lake influence spawning to total spawning

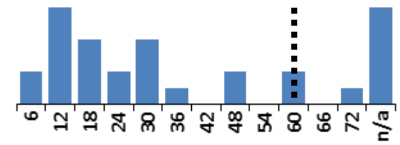


Rearing

Area of nursery lakes (1000 ha)

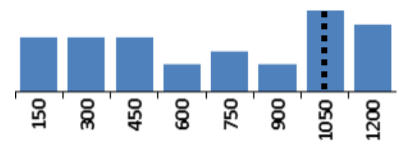


Nursery lake productivity (estimated) (100 smolts/ha)

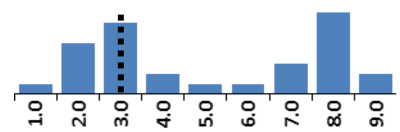


Migration

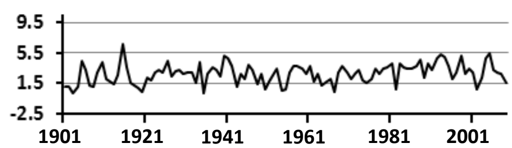
Migration distance (km)



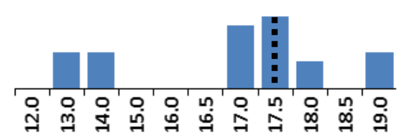
Average spring air temperature at nursery lake (°C)



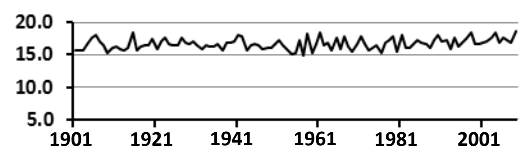
Spring air temperature at nursery lake (°C)



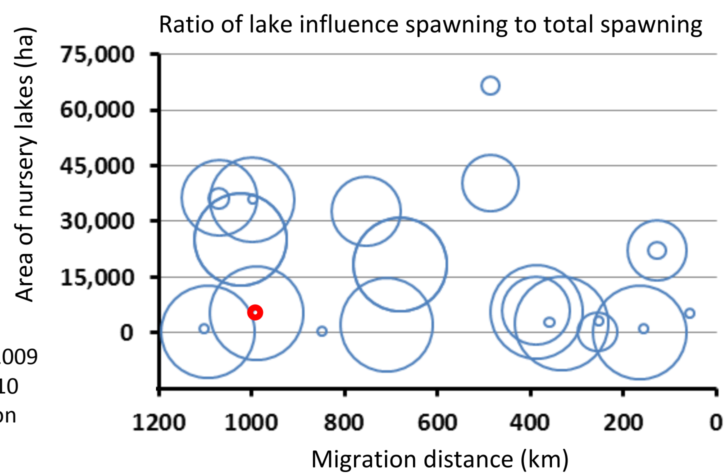
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

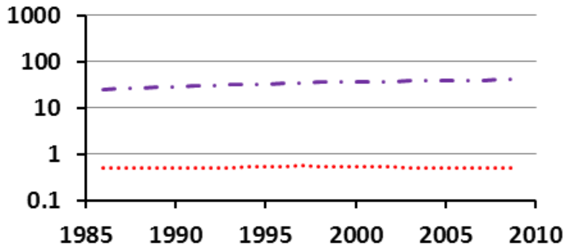
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

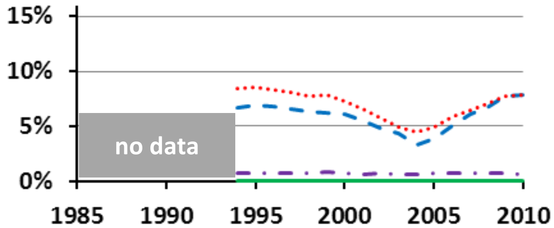
Human Population

Population density (persons/km²)

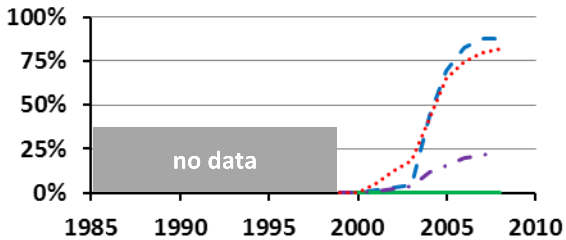


Land Use

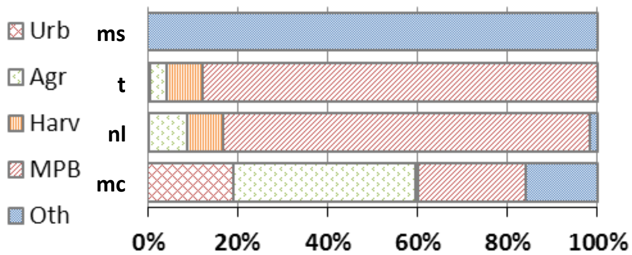
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

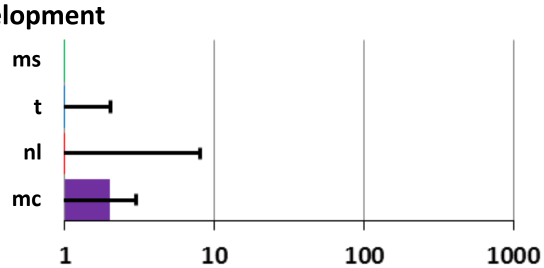


Land use type (% of habitat area)

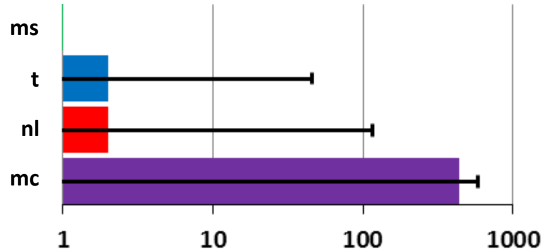


Resource Development

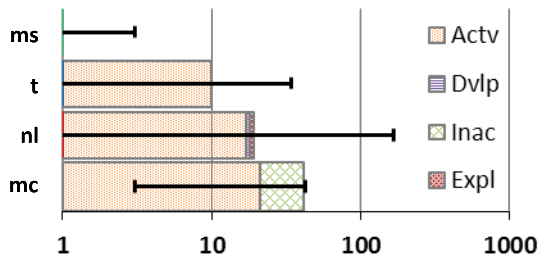
Small scale hydro



Placer mining claims

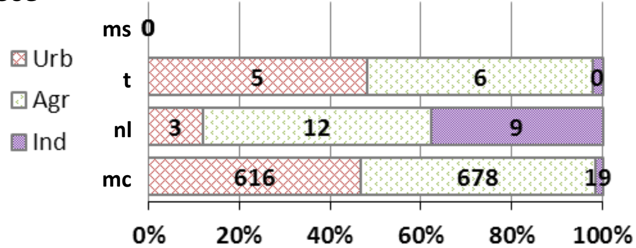


Other mines

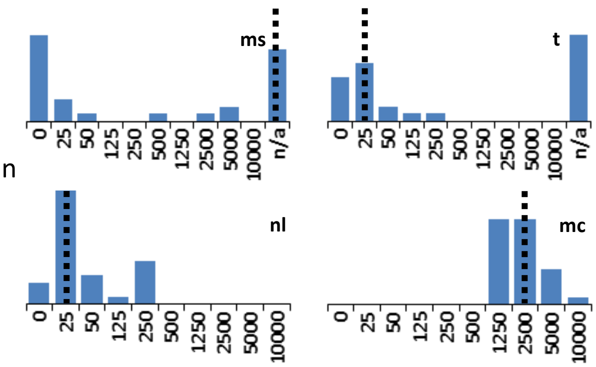


Water Use

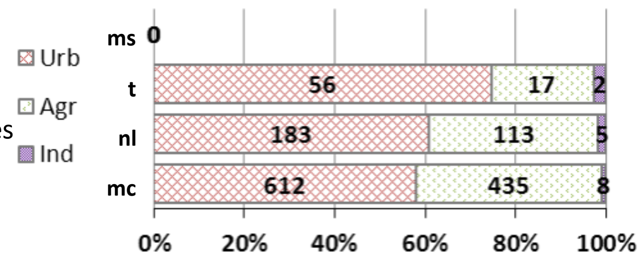
Total allo-cation by use



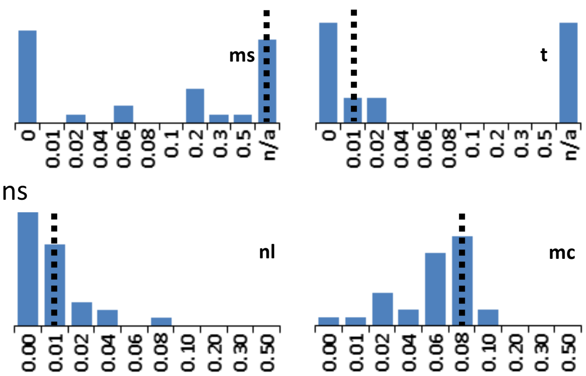
Total allocation (m^3/ha)



Water Licenses

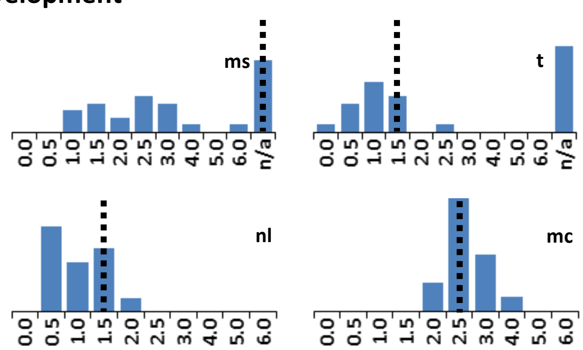


Water Restrictions (#/km²)



Road Development

Road density (km/km²)



Abbreviations:

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Act active mines
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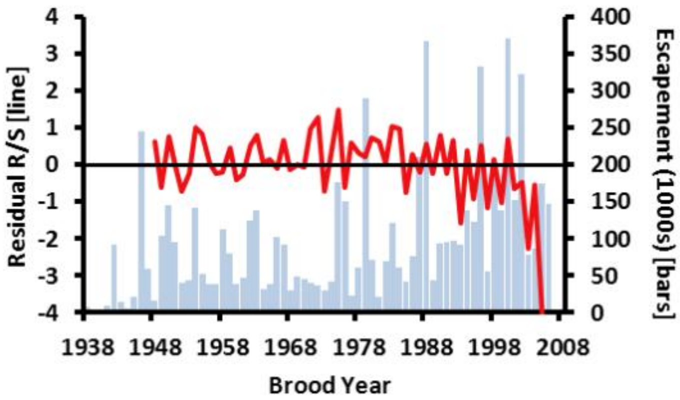
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

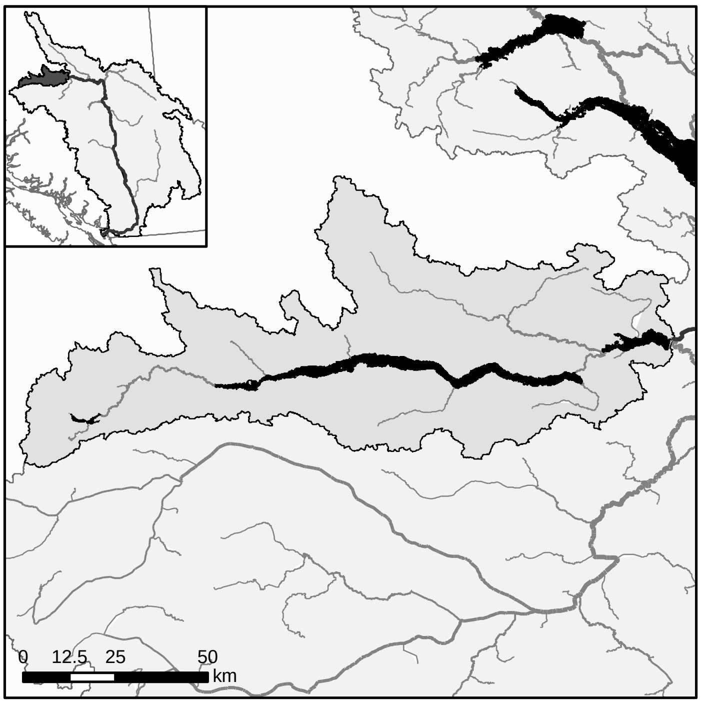
CONSERVATION UNIT

Fraser — Summer — L-6-7

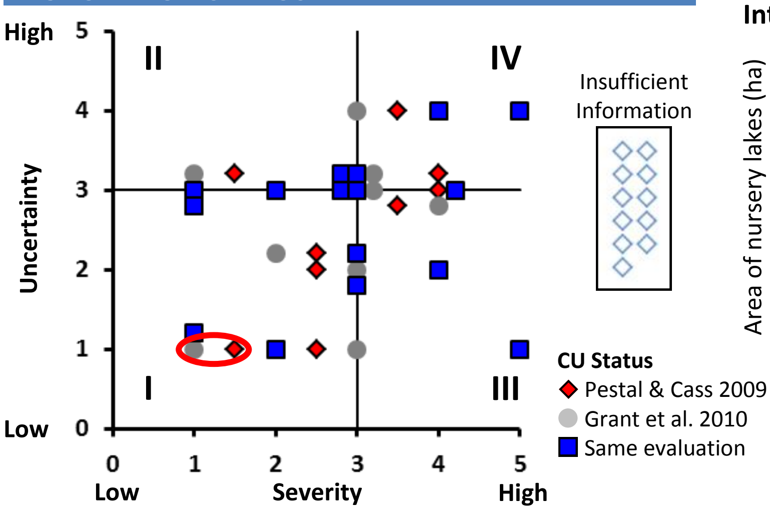
BIOLOGICAL DATA †



LOCATION



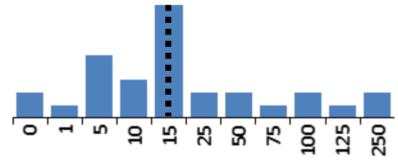
POPULATION STATUS



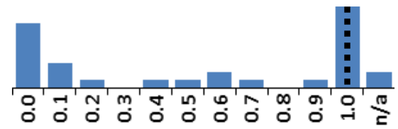
HABITAT STATUS

Spawning††

Total spawning extent (km)

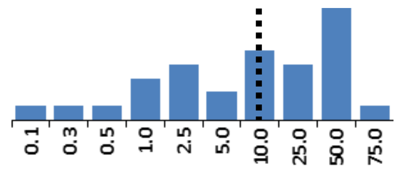


Ratio of lake influence spawning to total spawning

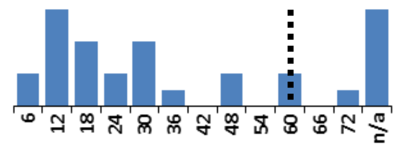


Rearing

Area of nursery lakes (1000 ha)

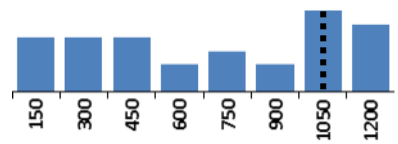


Nursery lake productivity (estimated) (100 smolts/ha)

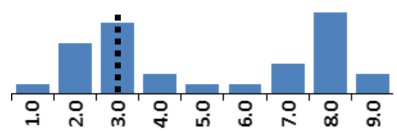


Migration

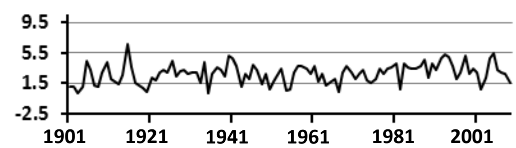
Migration distance (km)



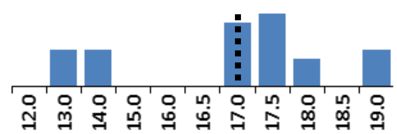
Average spring air temperature at nursery lake (°C)



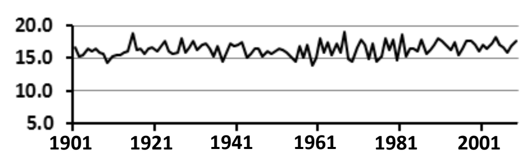
Spring air temperature at nursery lake (°C)



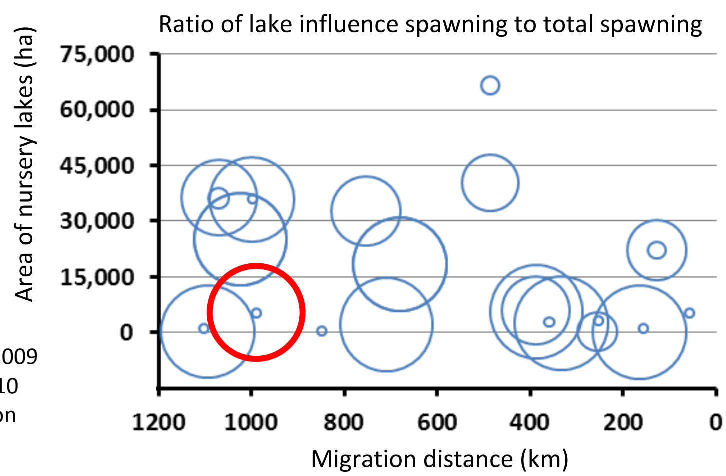
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Stellako**

†† Spawning note: **None.**

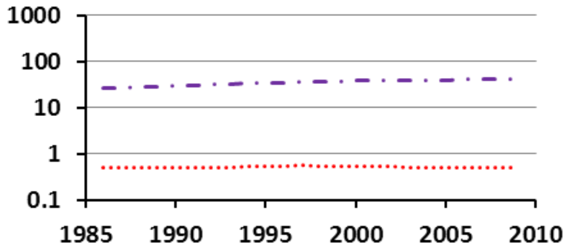
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

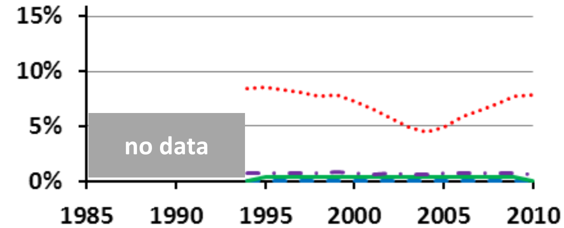
Human Population

Population density (persons/km^2)

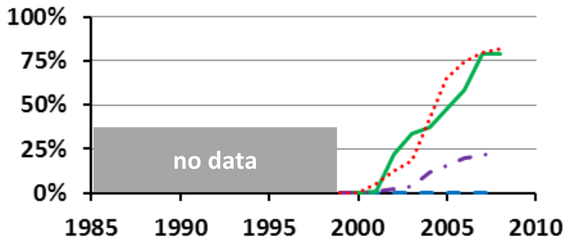


Land Use

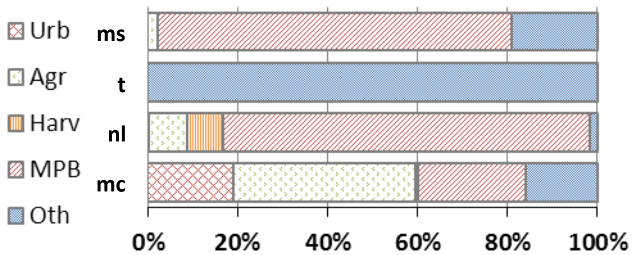
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

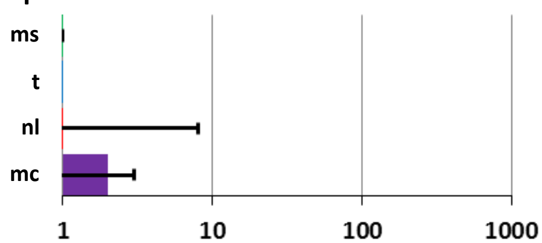


Land use type (% of habitat area)

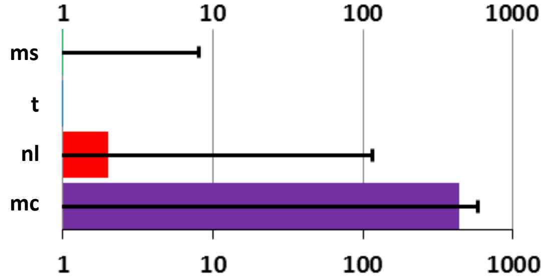


Resource Development

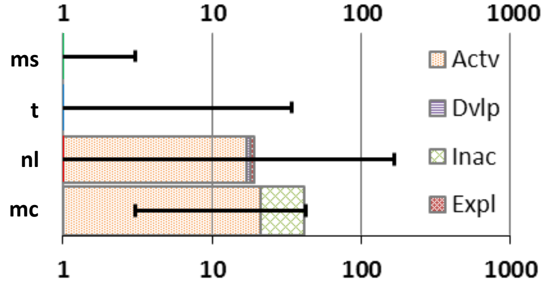
Small scale hydro



Placer mining claims

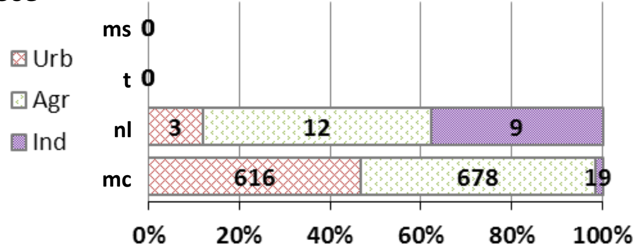


Other mines

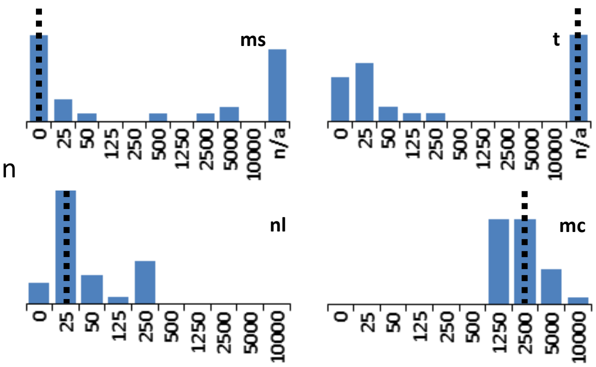


Water Use

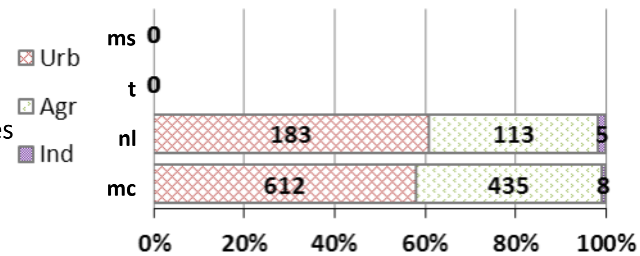
Total allocation by use



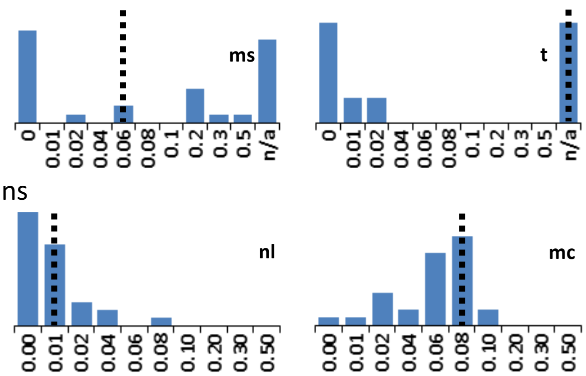
Total allocation (m^3/ha)



Water Licenses

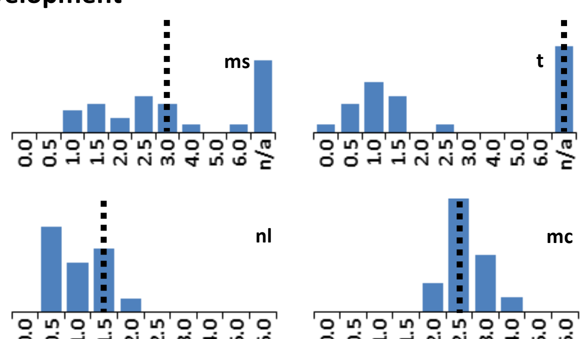


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

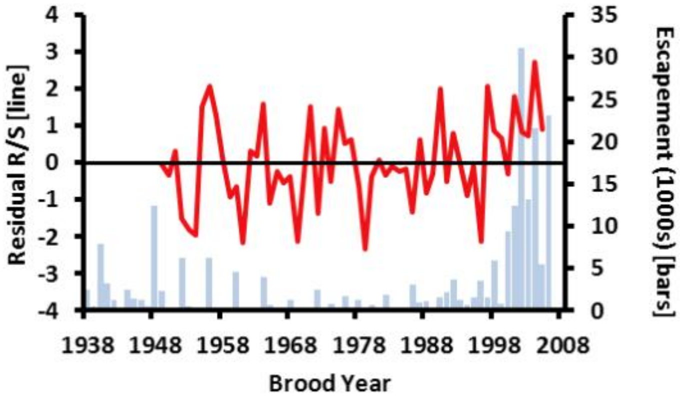
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

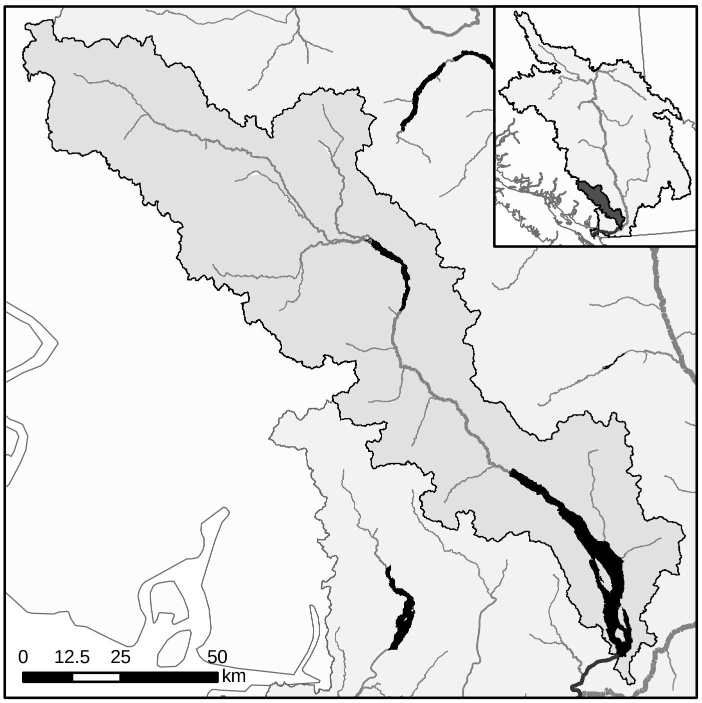
CONSERVATION UNIT

Harrison (downstream) — Late — L-3-3

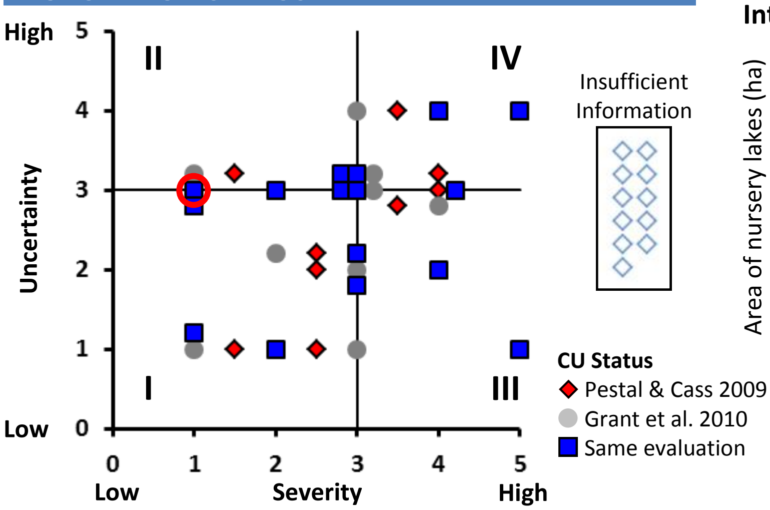
BIOLOGICAL DATA [†]



LOCATION



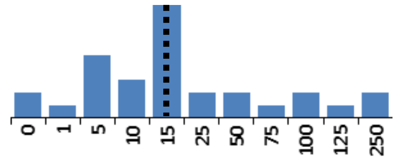
POPULATION STATUS



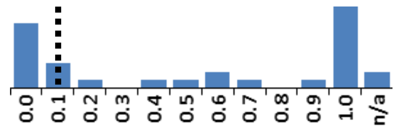
HABITAT STATUS

Spawning[††]

Total spawning extent (km)

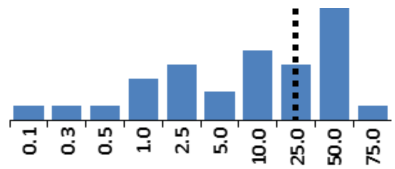


Ratio of lake influence spawning to total spawning

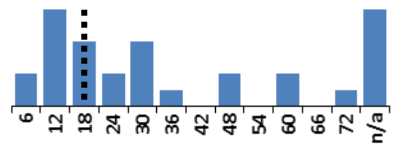


Rearing

Area of nursery lakes (1000 ha)

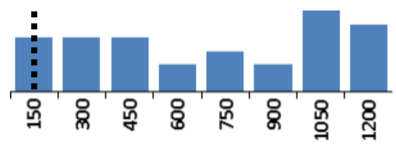


Nursery lake productivity (estimated) (100 smolts/ha)

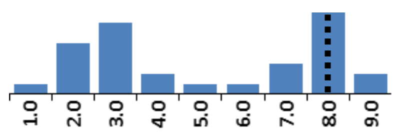


Migration

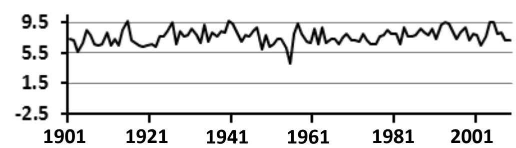
Migration distance (km)



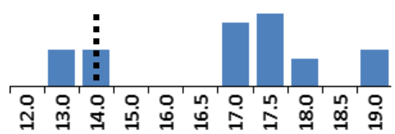
Average spring air temperature at nursery lake (°C)



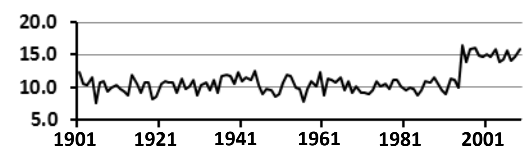
Spring air temperature at nursery lake (°C)



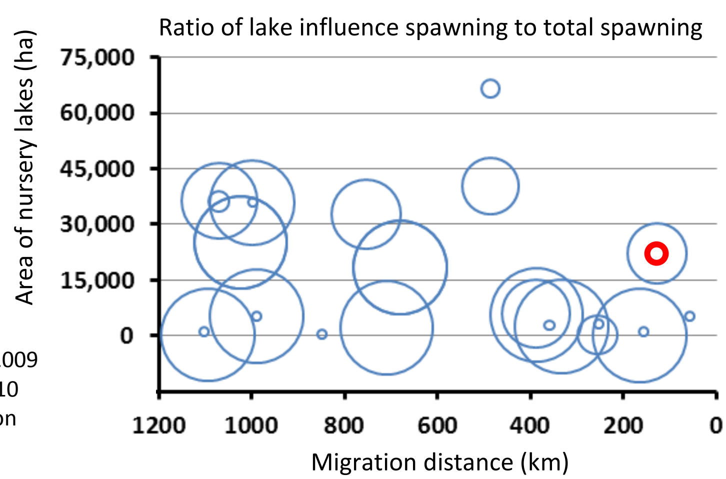
Average air temperature across adult migration (°C)[‡]



Air temperature across adult migration (°C)[‡]



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Harrison**

†† Spawning note: **None.**

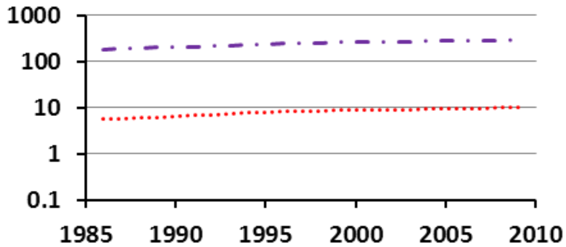
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

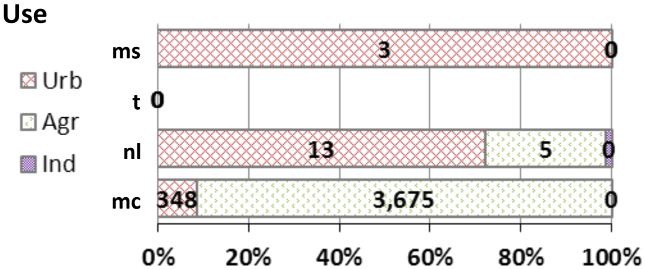
Human Population

Population density (persons/km^2)

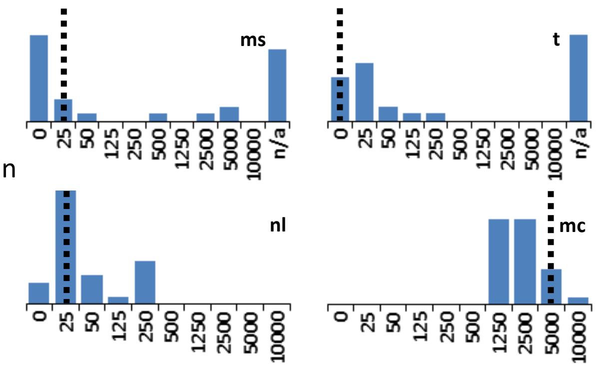


Water Use

Total allo-cation by use

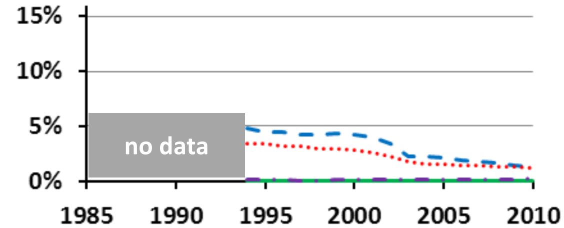


Total allocation (m^3/ha)

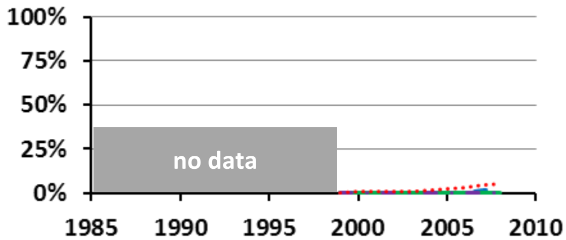


Land Use

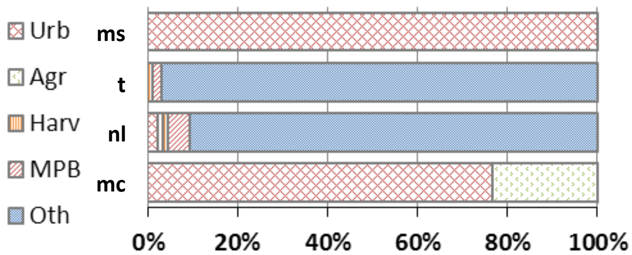
Forest harvesting (% of habitat area)



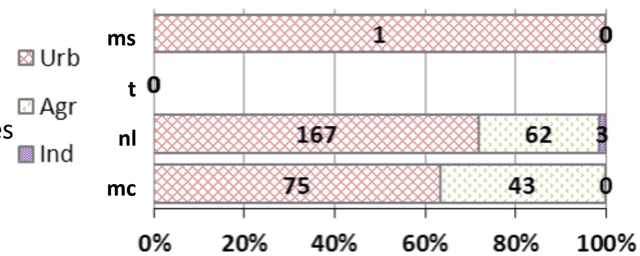
Mountain pine beetle disturbance (cumulative % of habitat area)



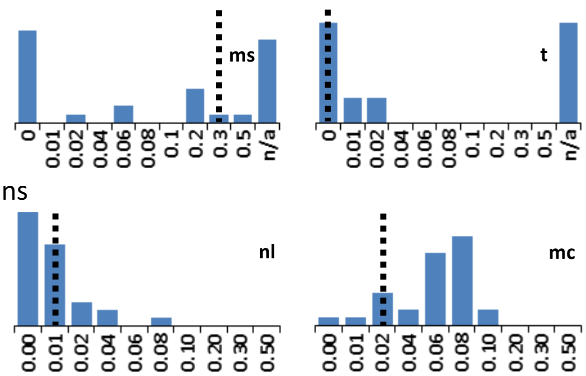
Land use type (% of habitat area)



Water Licenses

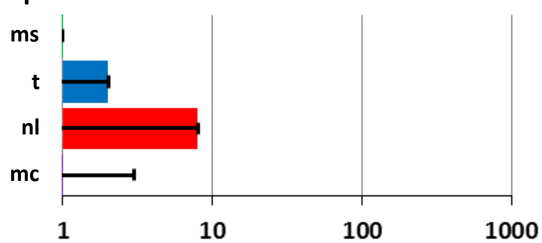


Water Restrictions (#/km^2)

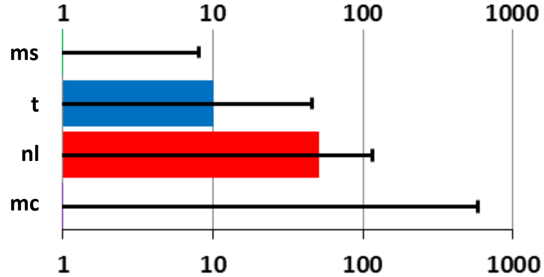


Resource Development

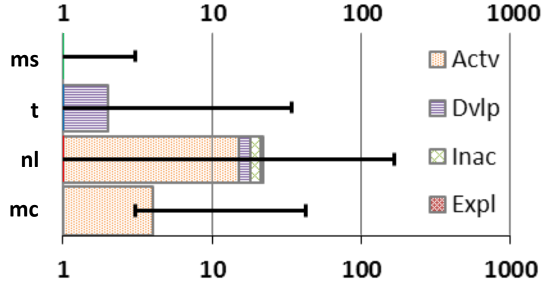
Small scale hydro



Placer mining claims

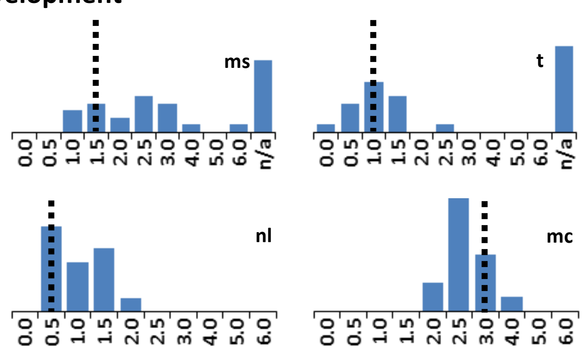


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

Urb urban
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Harv harvesting disturbance
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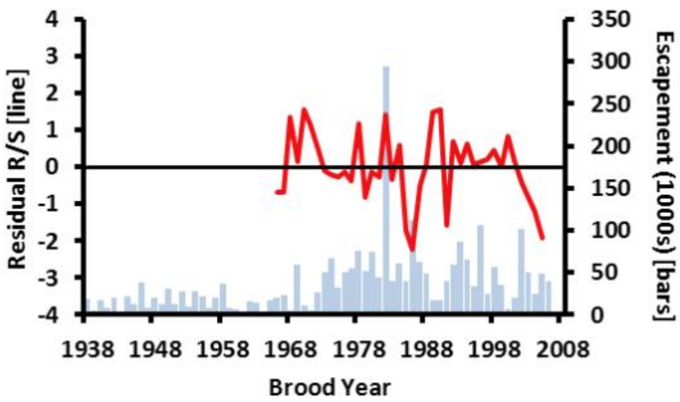
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

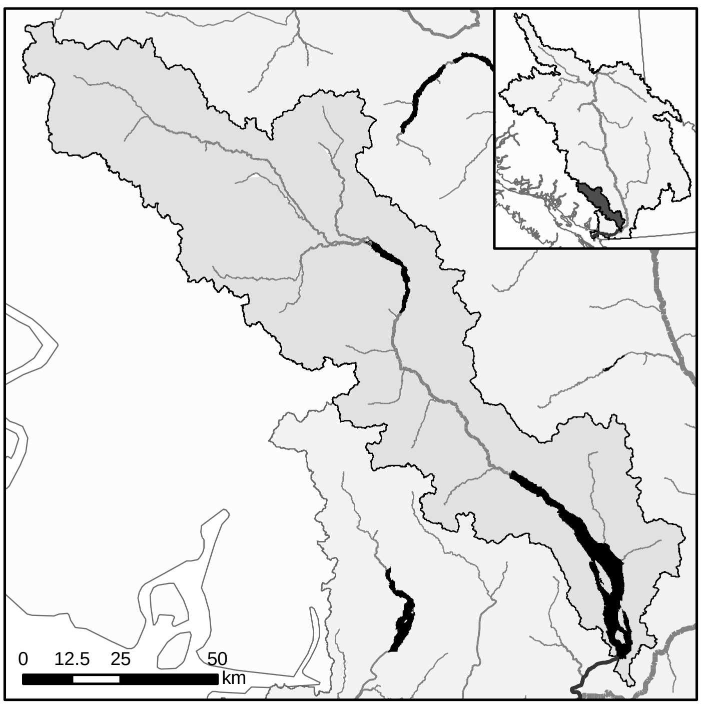
CONSERVATION UNIT

Harrison (upstream) — Late — L-3-4

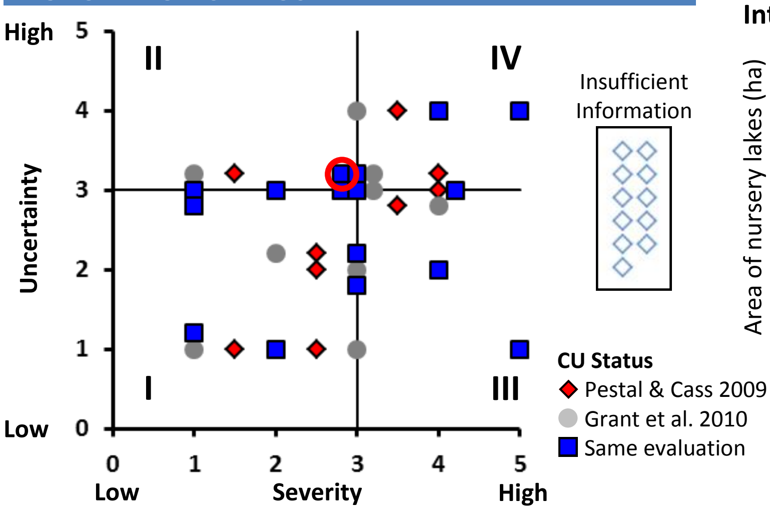
BIOLOGICAL DATA †



LOCATION



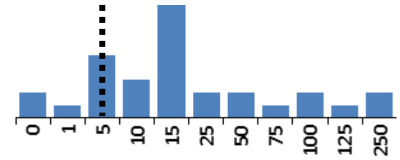
POPULATION STATUS



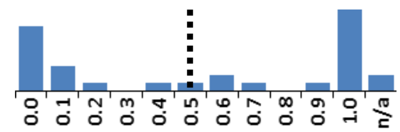
HABITAT STATUS

Spawning††

Total spawning extent (km)

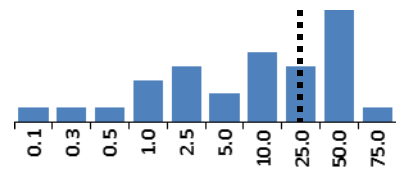


Ratio of lake influence spawning to total spawning

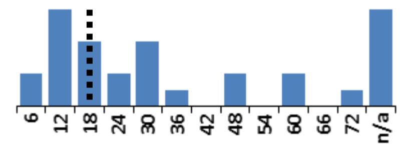


Rearing

Area of nursery lakes (1000 ha)

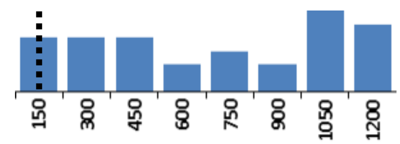


Nursery lake productivity (estimated) (100 smolts/ha)

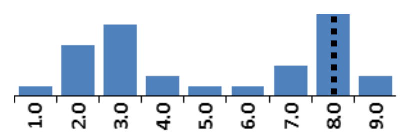


Migration

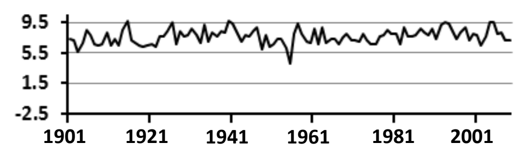
Migration distance (km)



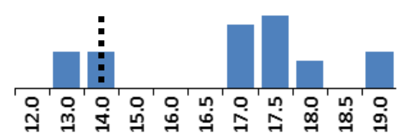
Average spring air temperature at nursery lake (°C)



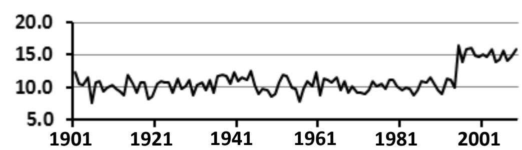
Spring air temperature at nursery lake (°C)



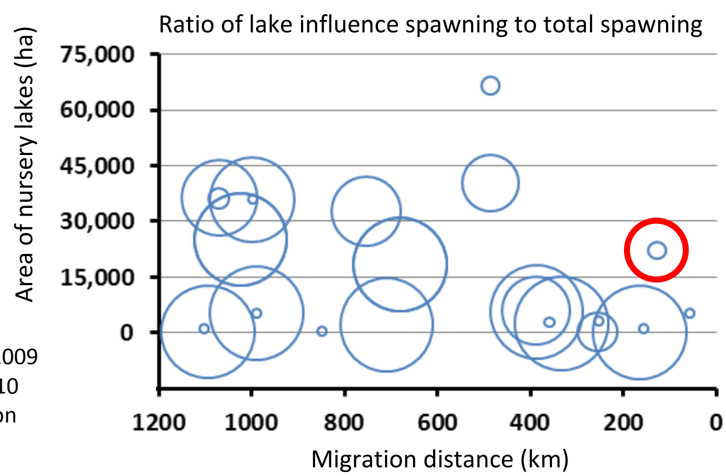
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Weaver**

†† Spawning note: **Weaver spawning channel.**

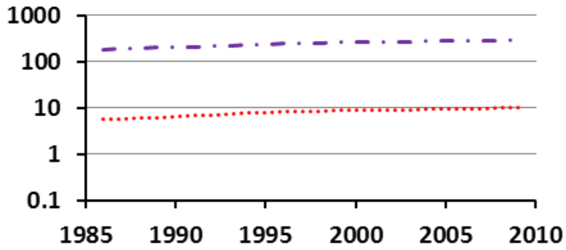
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

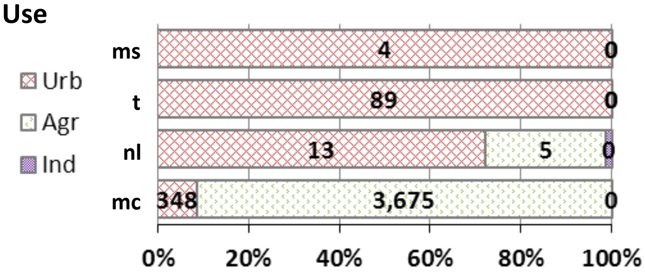
Human Population

Population density (persons/km^2)

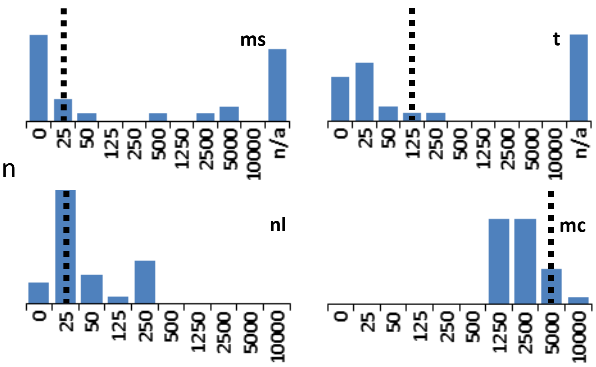


Water Use

Total allo-cation by use

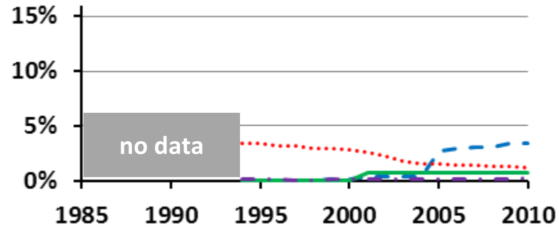


Total allocation (m^3/ha)

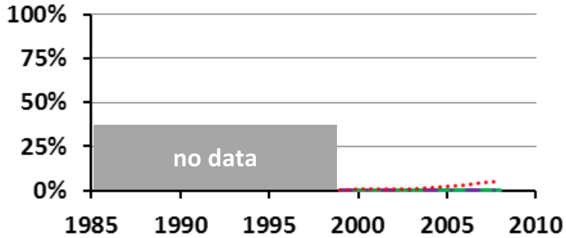


Land Use

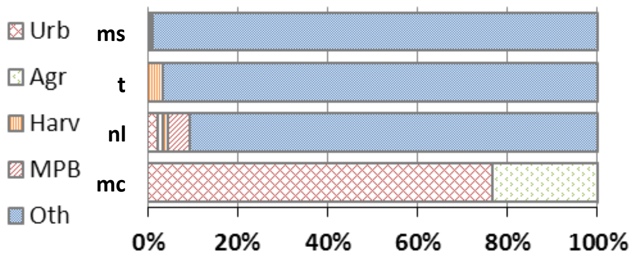
Forest harvesting (% of habitat area)



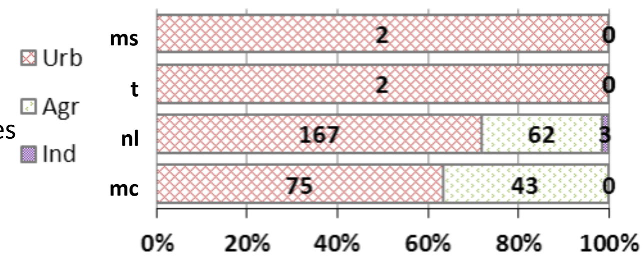
Mountain pine beetle disturbance (cumulative % of habitat area)



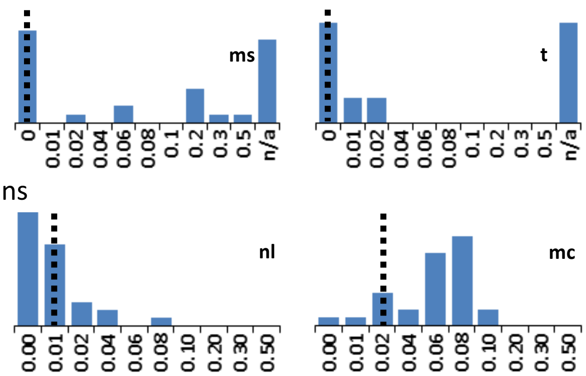
Land use type (% of habitat area)



Water Licenses

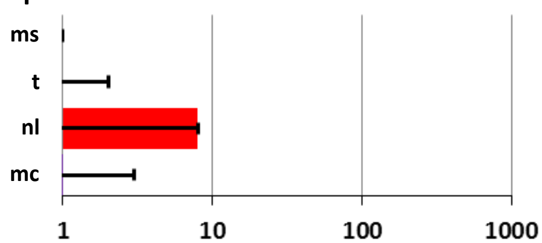


Water Restrictions (#/km^2)

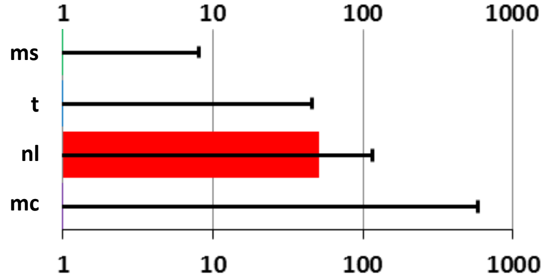


Resource Development

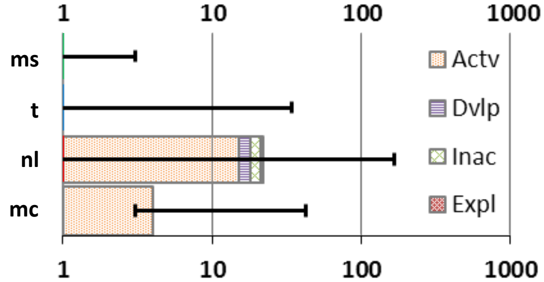
Small scale hydro



Placer mining claims

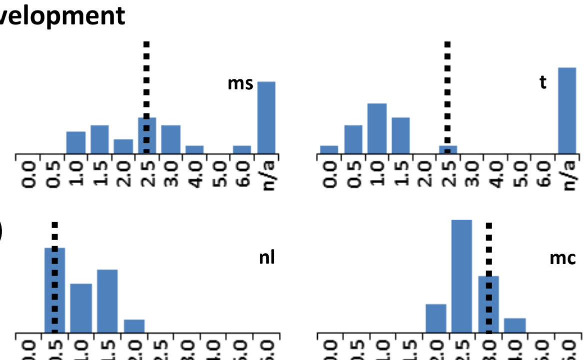


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

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Harv harvesting disturbance
MPB mountain pine beetle disturbance
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Dvlp developed prospects
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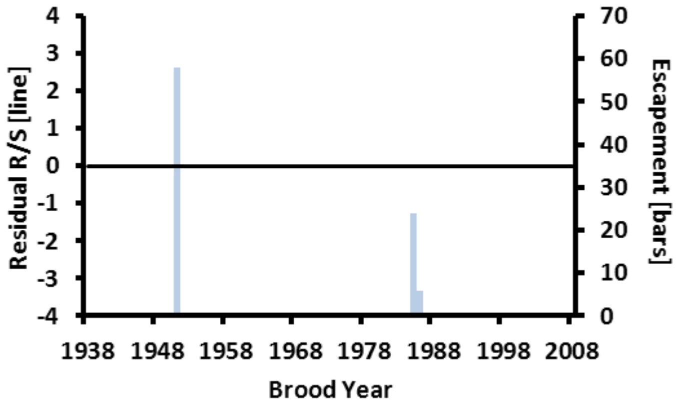
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

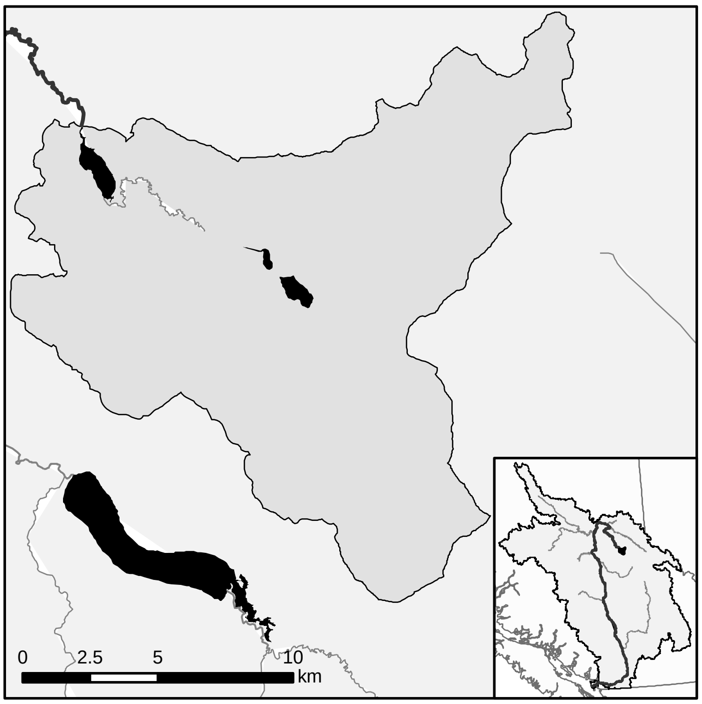
CONSERVATION UNIT

Indian/Kruger — Early Summer — L-7-2

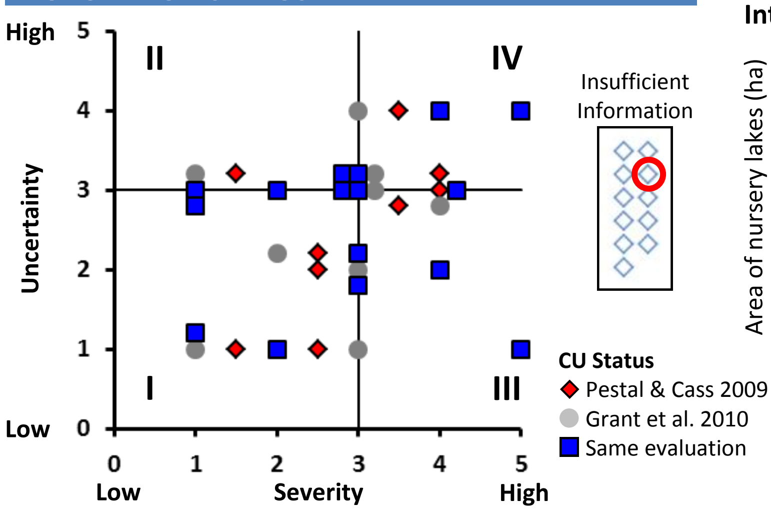
BIOLOGICAL DATA †



LOCATION



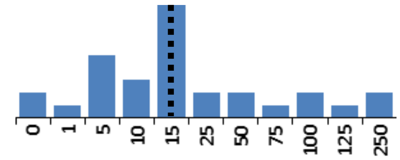
POPULATION STATUS



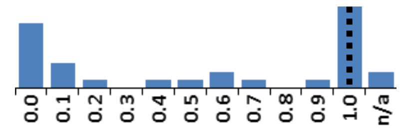
HABITAT STATUS

Spawning††

Total spawning extent (km)

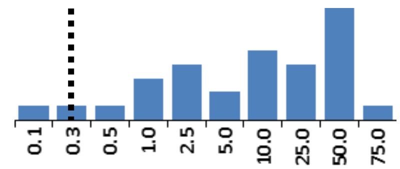


Ratio of lake influence spawning to total spawning

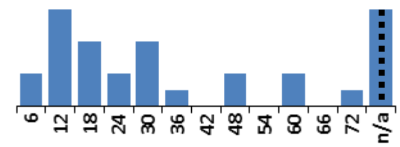


Rearing

Area of nursery lakes (1000 ha)

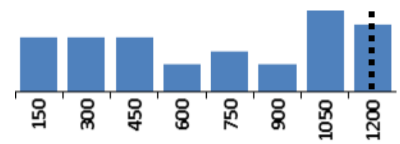


Nursery lake productivity (estimated) (100 smolts/ha)

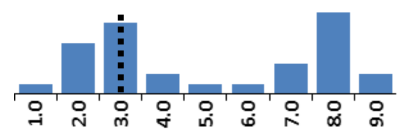


Migration

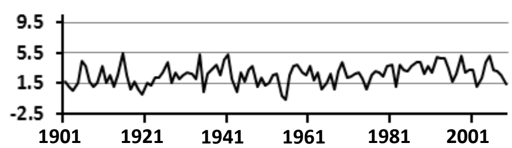
Migration distance (km)



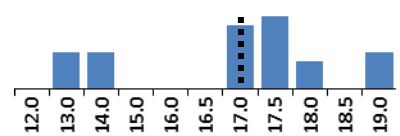
Average spring air temperature at nursery lake (°C)



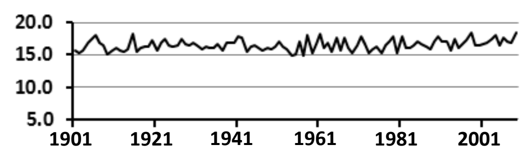
Spring air temperature at nursery lake (°C)



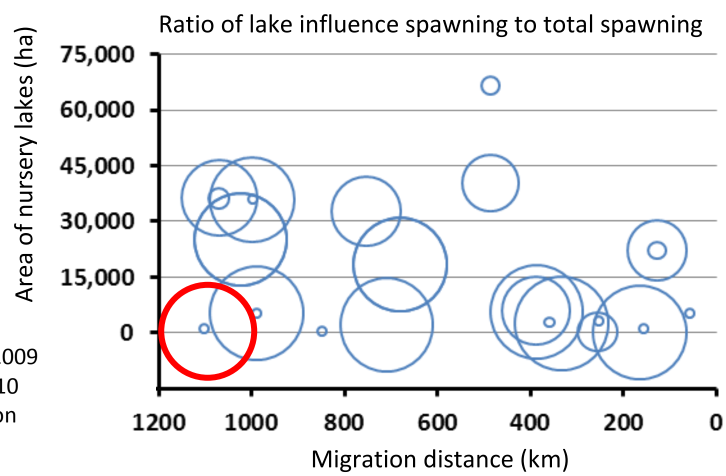
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

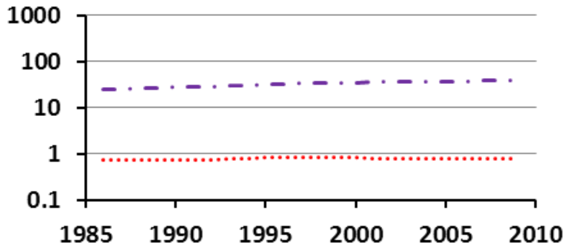
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

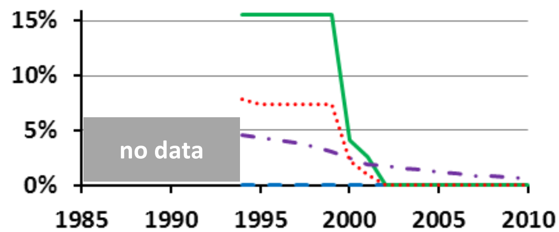
Human Population

Population density (persons/ km^2)

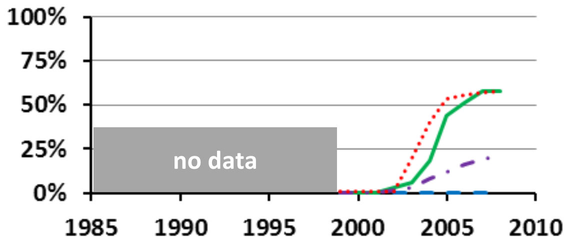


Land Use

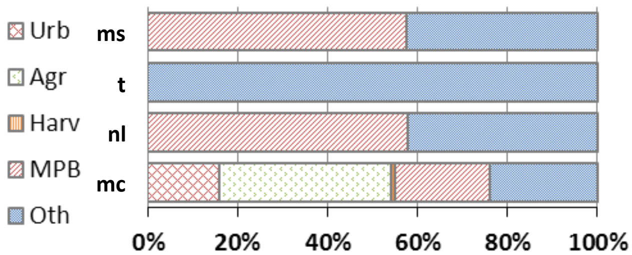
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

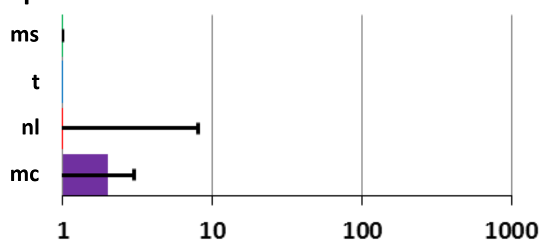


Land use type (% of habitat area)

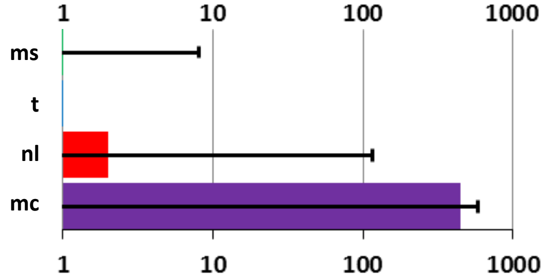


Resource Development

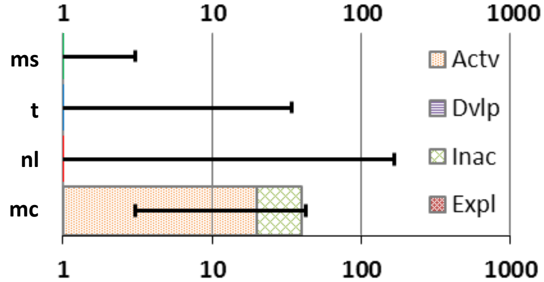
Small scale hydro



Placer mining claims

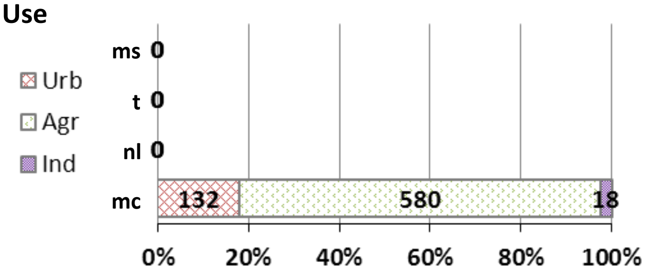


Other mines

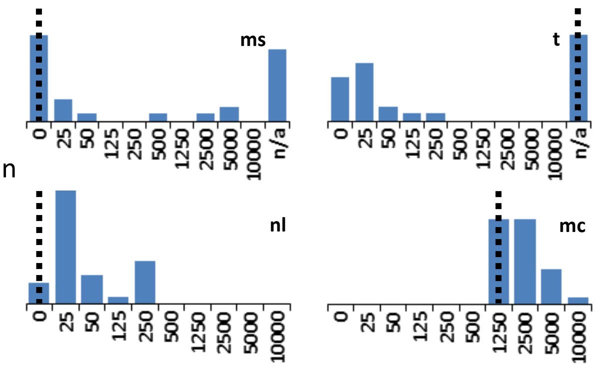


Water Use

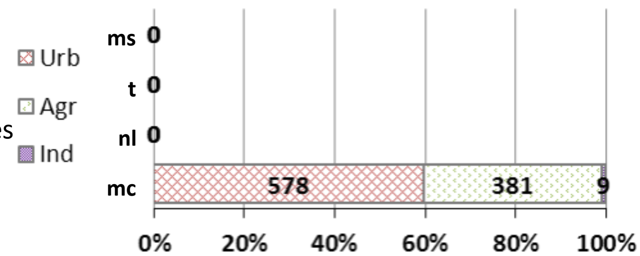
Total allo-cation by use



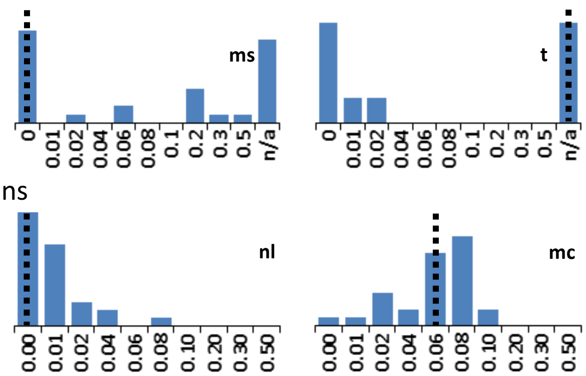
Total allocation (m^3/ha)



Water Licenses

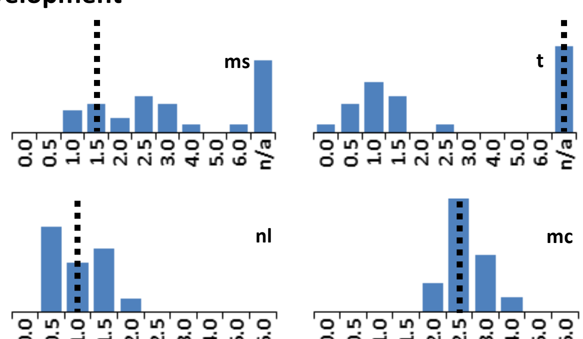


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

Urb urban
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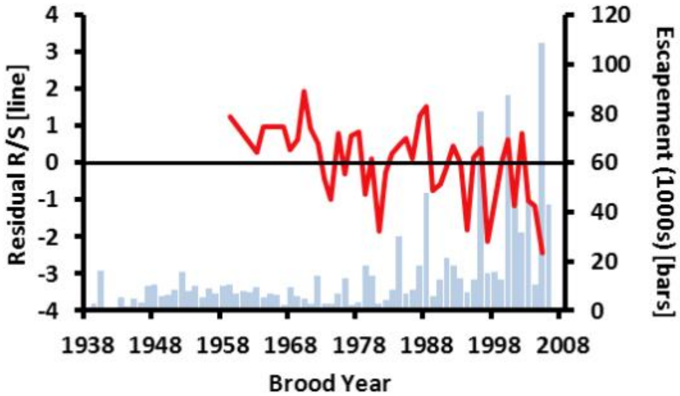
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

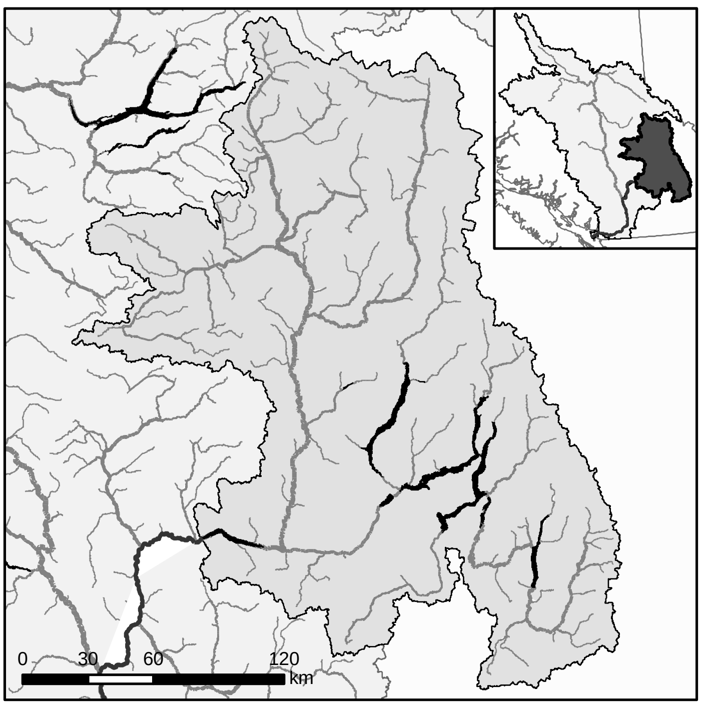
CONSERVATION UNIT

Kamloops — Early Summer — L-10-1

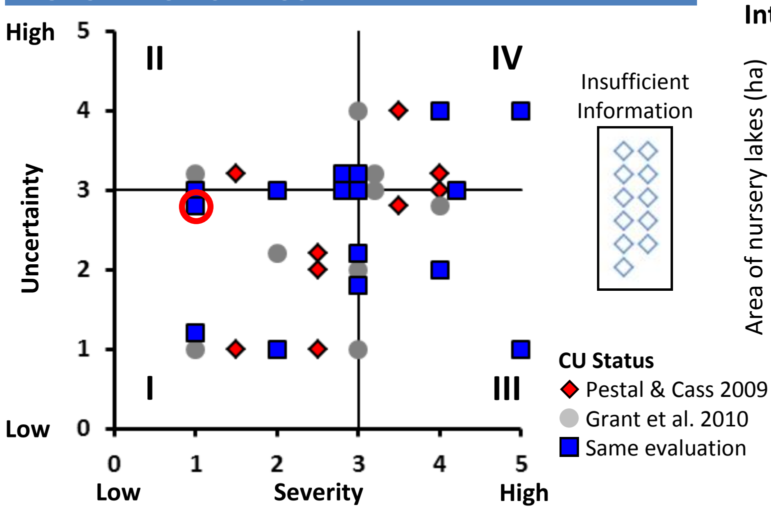
BIOLOGICAL DATA †



LOCATION



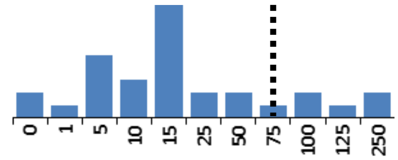
POPULATION STATUS



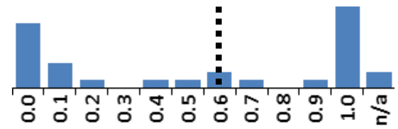
HABITAT STATUS

Spawning††

Total spawning extent (km)

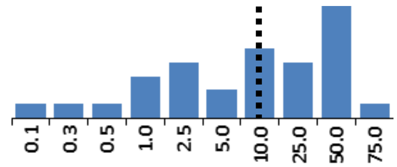


Ratio of lake influence spawning to total spawning

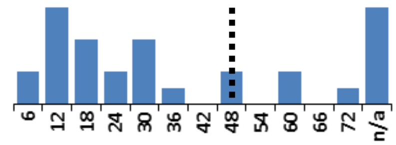


Rearing

Area of nursery lakes (1000 ha)

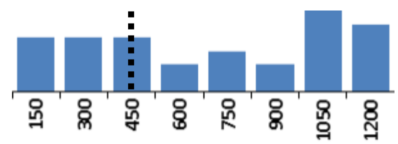


Nursery lake productivity (estimated) (100 smolts/ha)

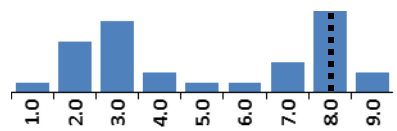


Migration

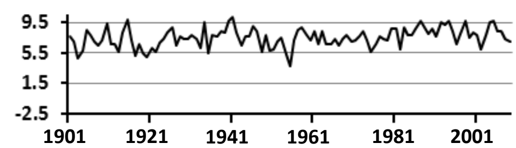
Migration distance (km)



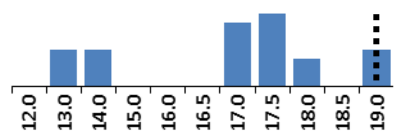
Average spring air temperature at nursery lake (°C)



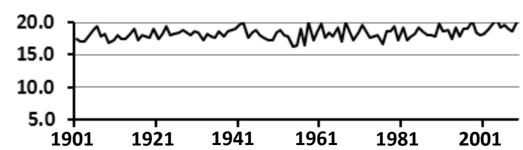
Spring air temperature at nursery lake (°C)



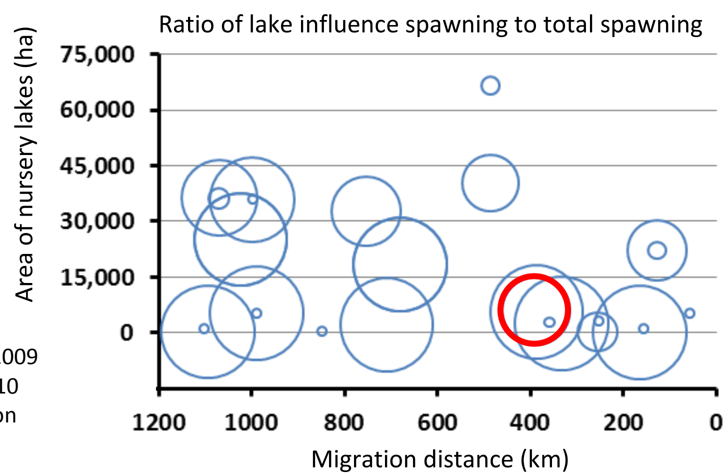
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Raft**

†† Spawning note: **None.**

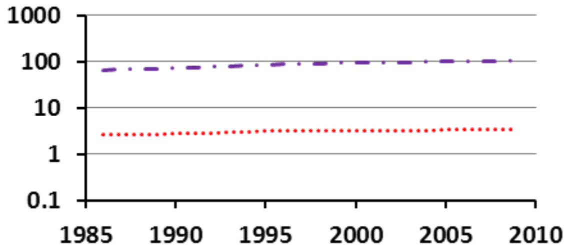
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

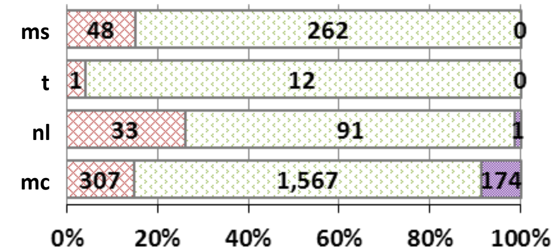
Human Population

Population density (persons/km²)



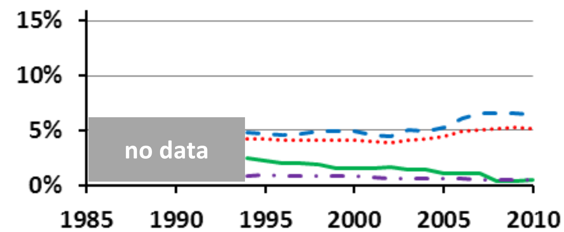
Water Use

Total allo-cation by use

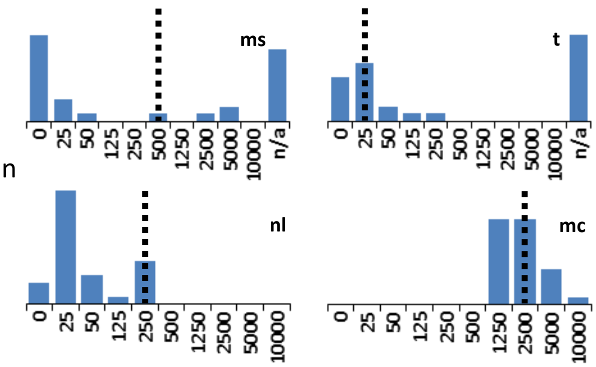


Land Use

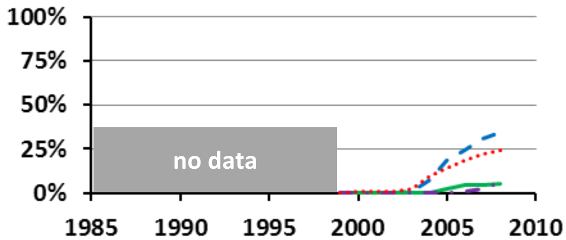
Forest harvesting (% of habitat area)



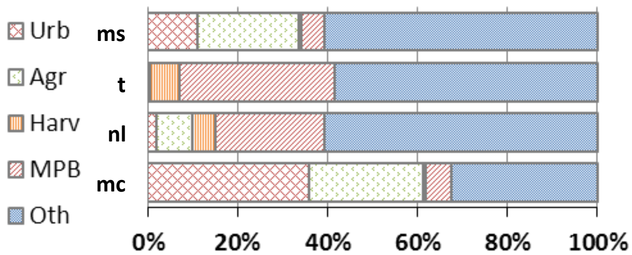
Total allocation (m³/ha)



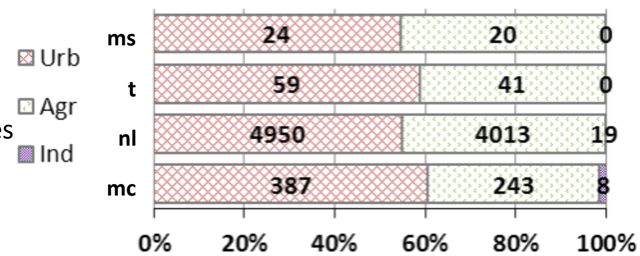
Mountain pine beetle disturbance (cumulative % of habitat area)



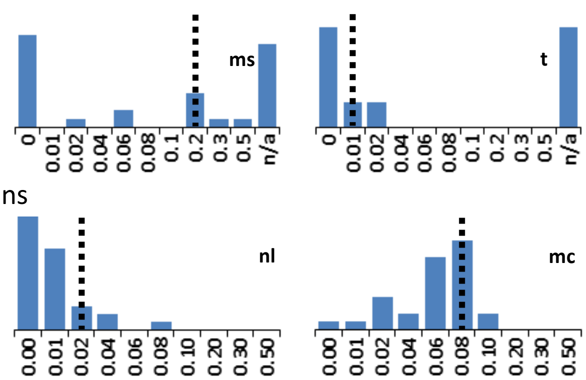
Land use type (% of habitat area)



Water Licenses

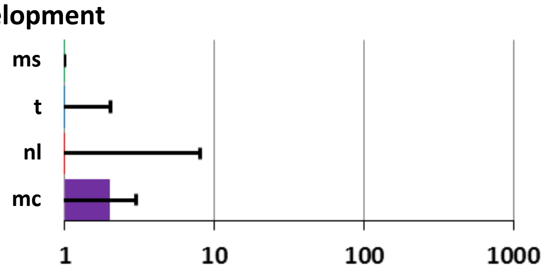


Water Restrictions (#/km²)

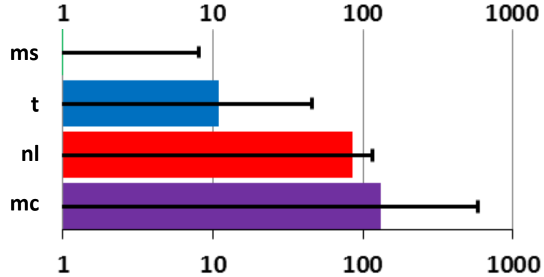


Resource Development

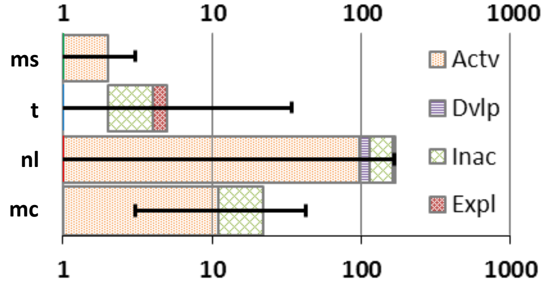
Small scale hydro



Placer mining claims

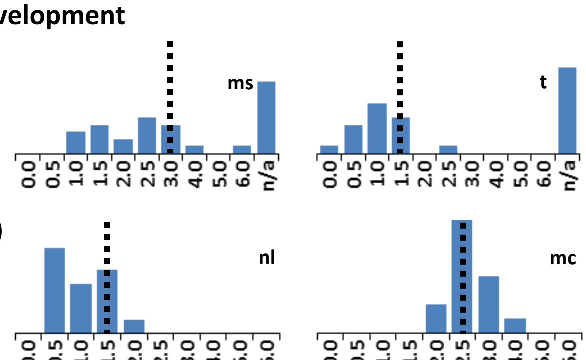


Other mines



Road Development

Road density (km/km²)



Abbreviations:

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Dvlp developed prospects
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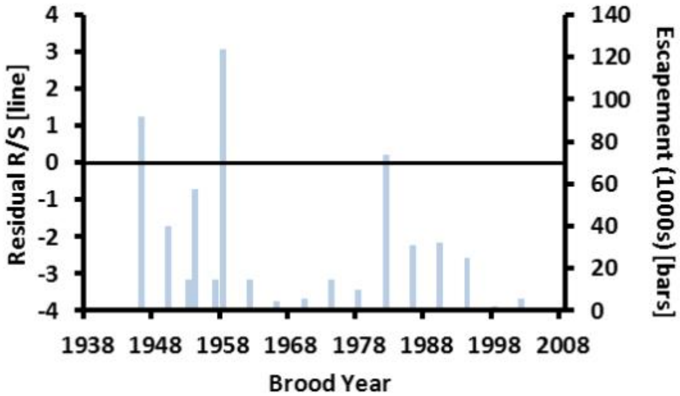
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

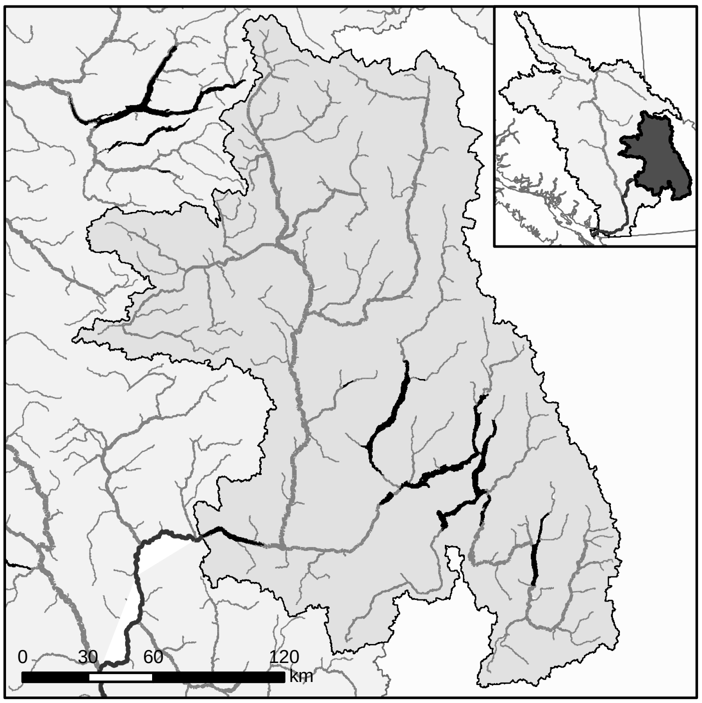
CONSERVATION UNIT

Kamloops — Late — L-9-1

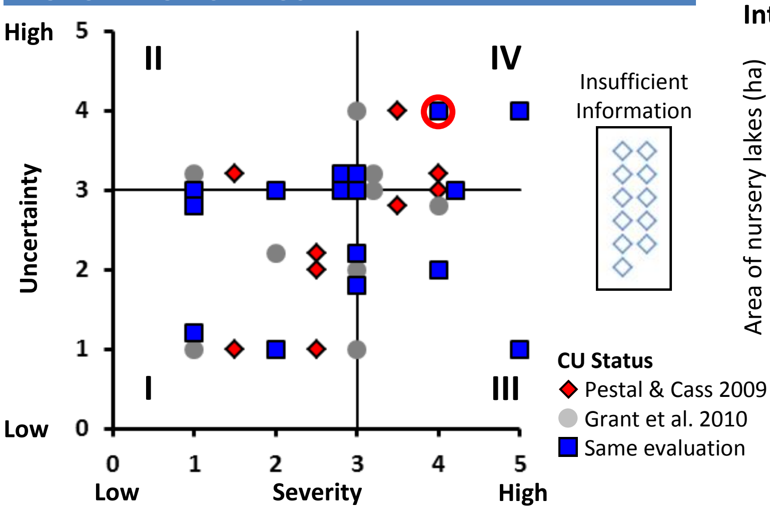
BIOLOGICAL DATA †



LOCATION



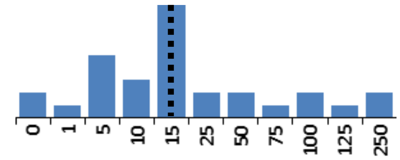
POPULATION STATUS



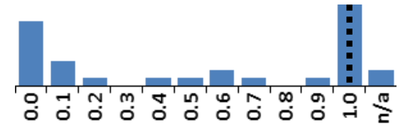
HABITAT STATUS

Spawning††

Total spawning extent (km)

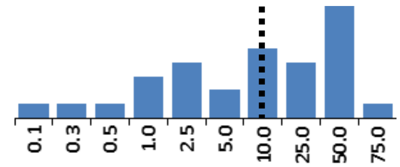


Ratio of lake influence spawning to total spawning

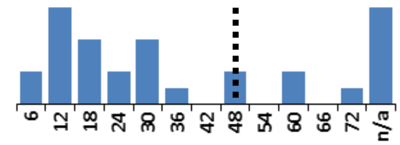


Rearing

Area of nursery lakes (1000 ha)

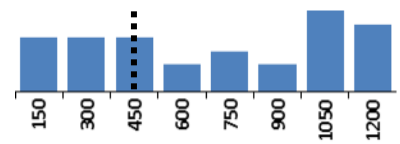


Nursery lake productivity (estimated) (100 smolts/ha)

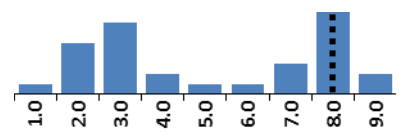


Migration

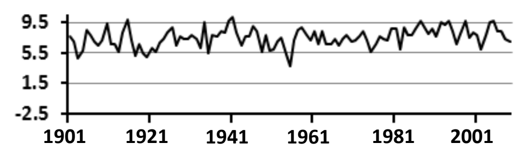
Migration distance (km)



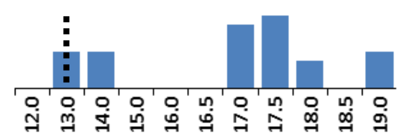
Average spring air temperature at nursery lake (°C)



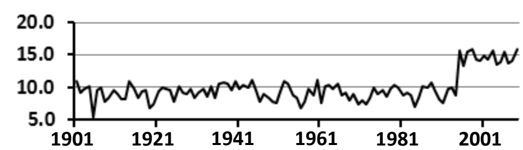
Spring air temperature at nursery lake (°C)



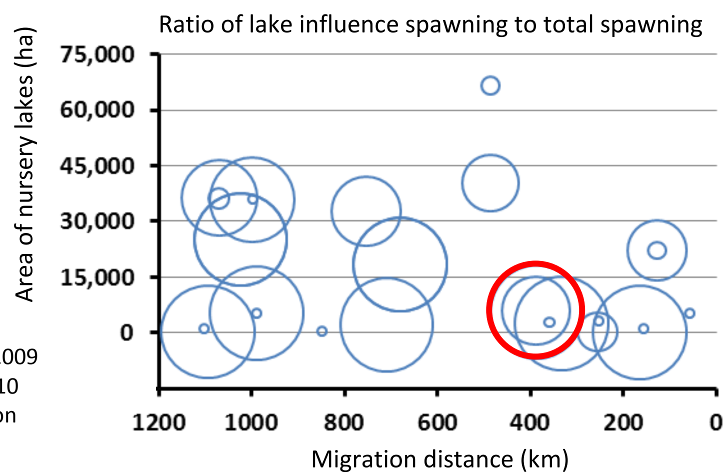
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

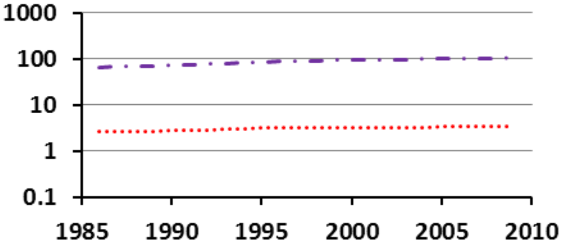
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

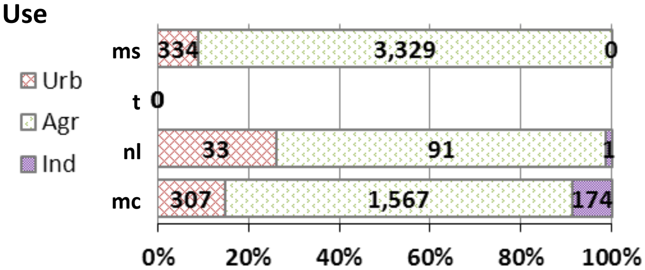
Human Population

Population density (persons/km²)



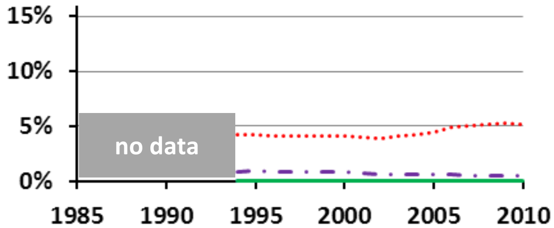
Water Use

Total allocation by use

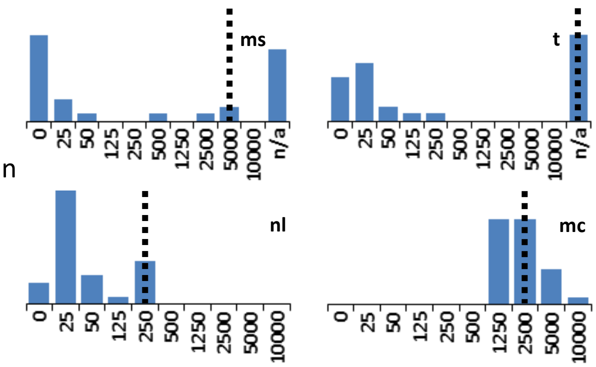


Land Use

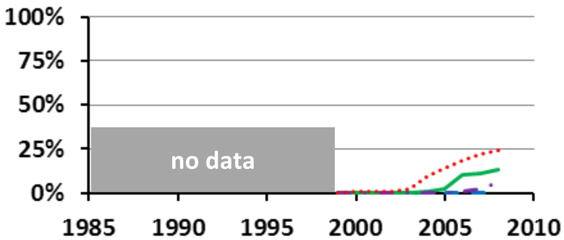
Forest harvesting (% of habitat area)



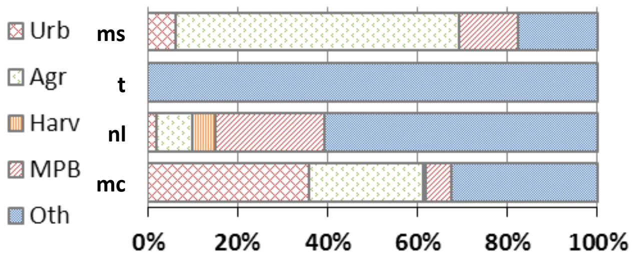
Total allocation (m³/ha)



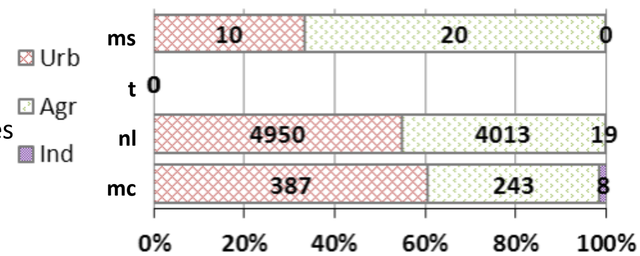
Mountain pine beetle disturbance (cumulative % of habitat area)



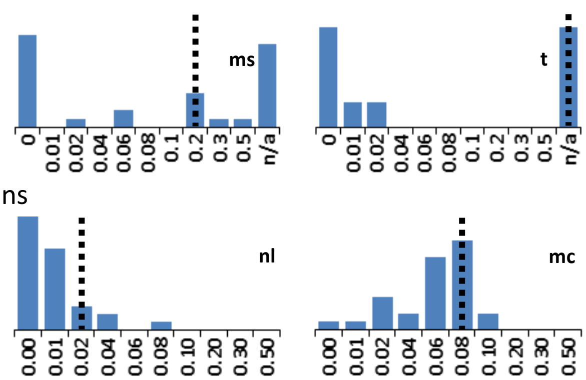
Land use type (% of habitat area)



Water Licenses

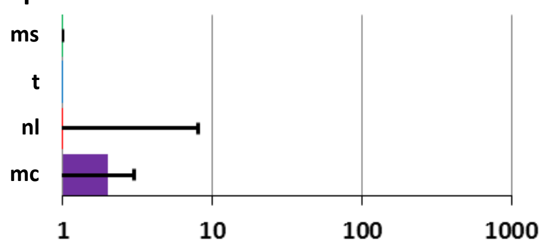


Water Restrictions (#/km²)

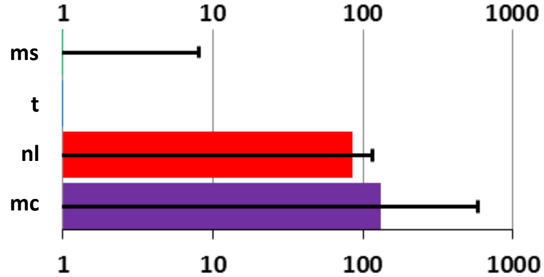


Resource Development

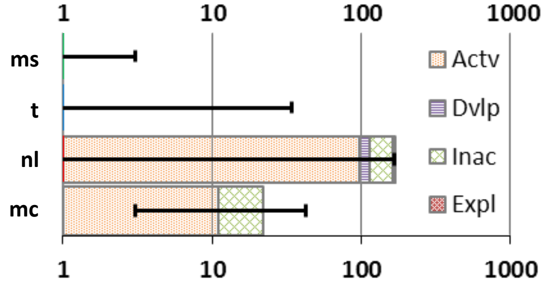
Small scale hydro



Placer mining claims

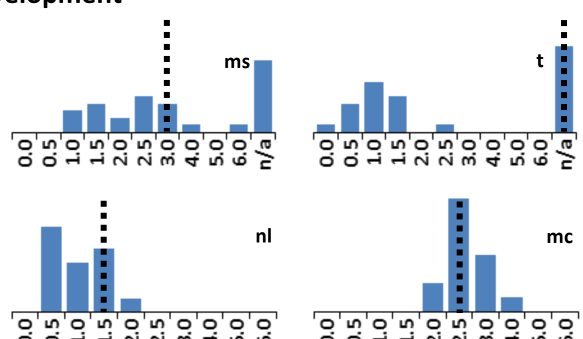


Other mines



Road Development

Road density (km/km²)



Abbreviations:

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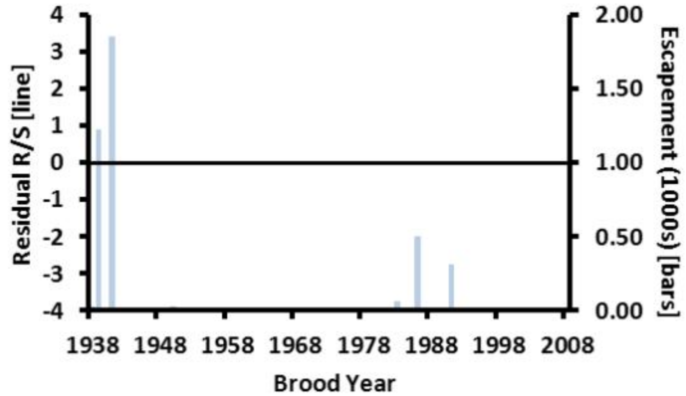
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

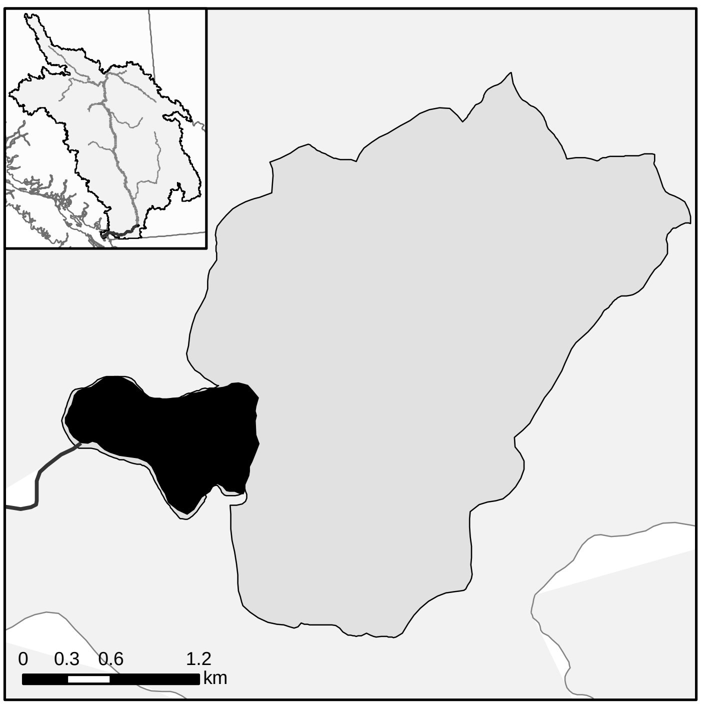
CONSERVATION UNIT

Kawkawa — Late — L-5-1

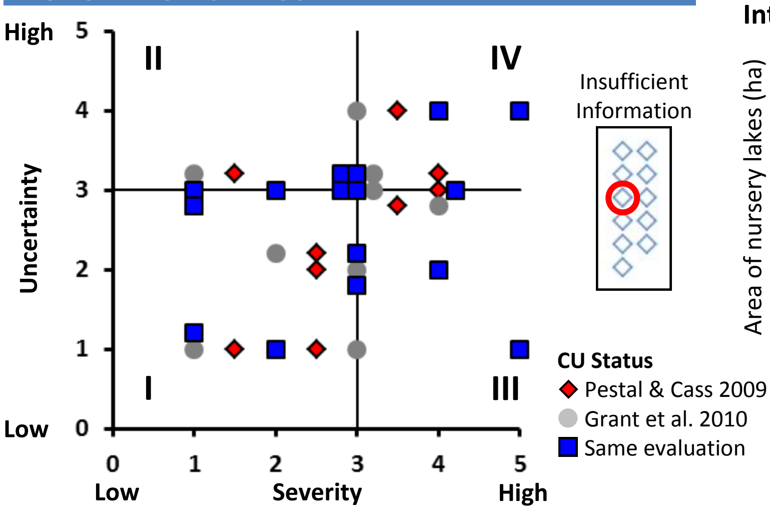
BIOLOGICAL DATA [†]



LOCATION



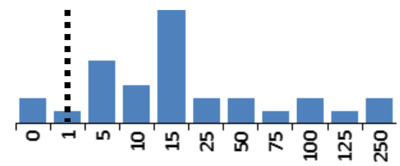
POPULATION STATUS



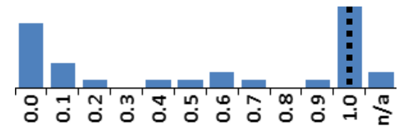
HABITAT STATUS

Spawning[††]

Total spawning extent (km)

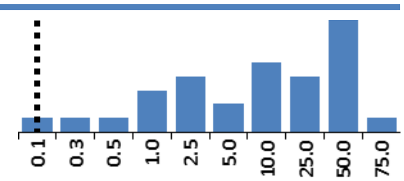


Ratio of lake influence spawning to total spawning

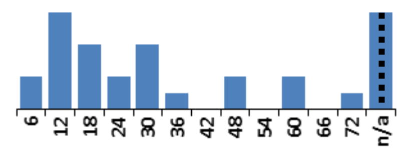


Rearing

Area of nursery lakes (1000 ha)

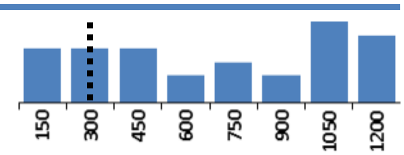


Nursery lake productivity (estimated) (100 smolts/ha)

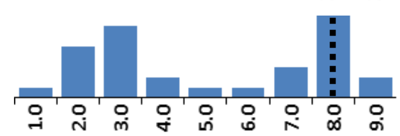


Migration

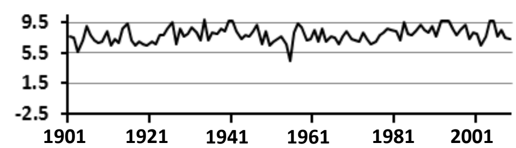
Migration distance (km)



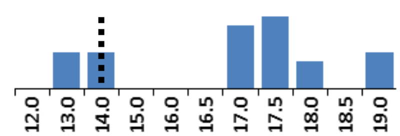
Average spring air temperature at nursery lake (°C)



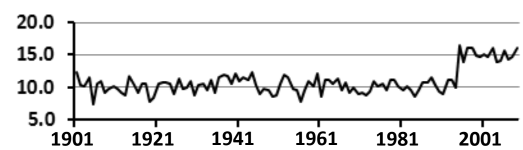
Spring air temperature at nursery lake (°C)



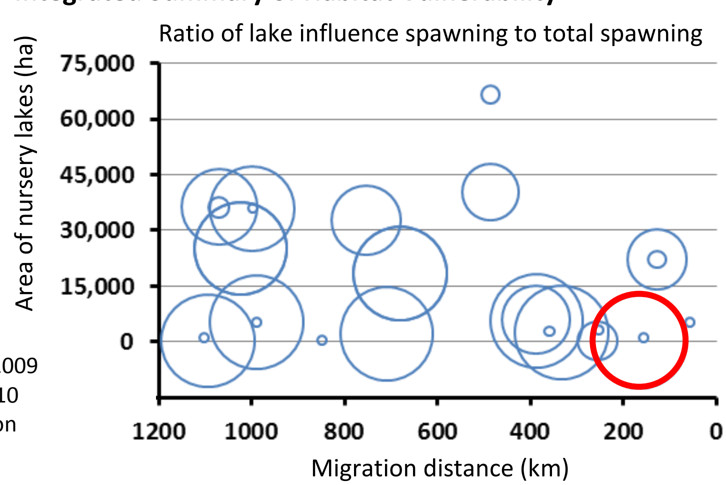
Average air temperature across adult migration (°C)[‡]



Air temperature across adult migration (°C)[‡]



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

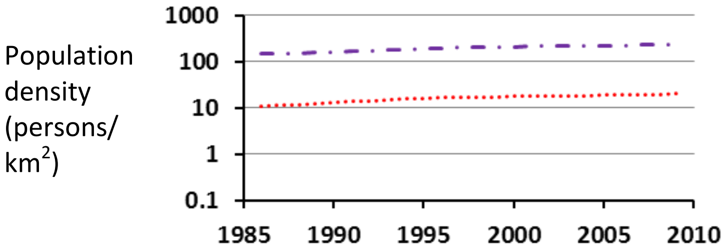
†† Spawning note: **None.**

‡ Temperature calculated according to run group timing.

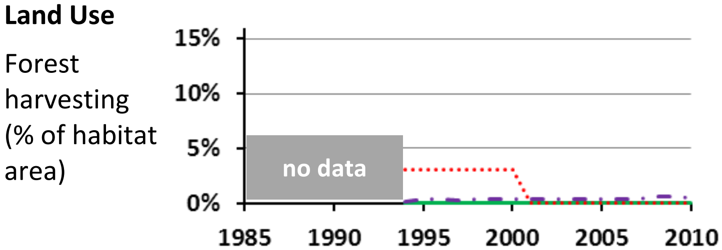
January 31, 2011

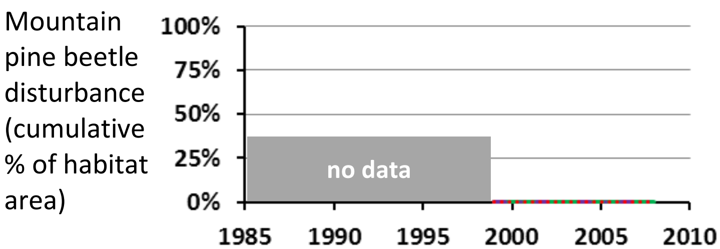
FRESHWATER STRESSORS

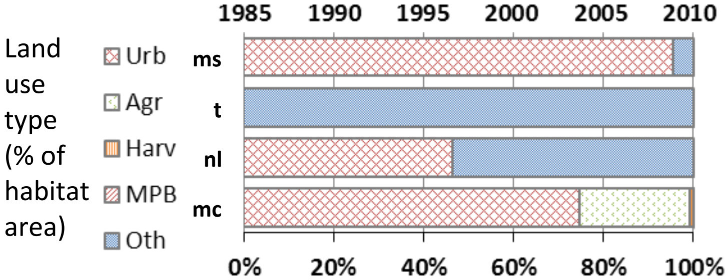
Human Population



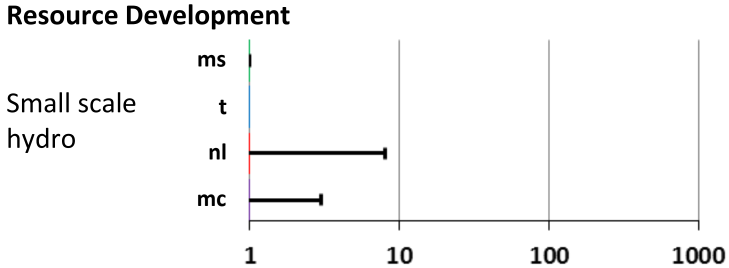
Land Use

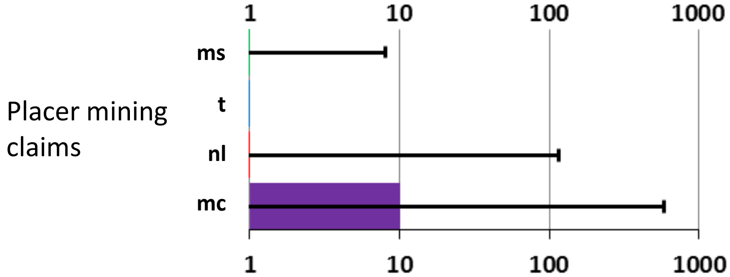


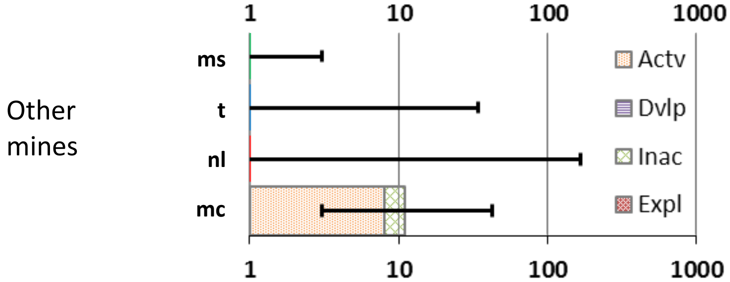




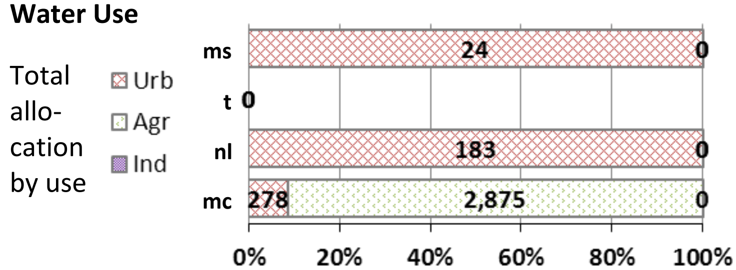
Resource Development

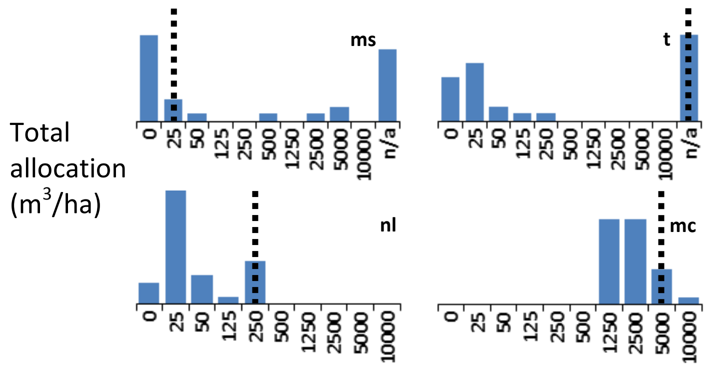


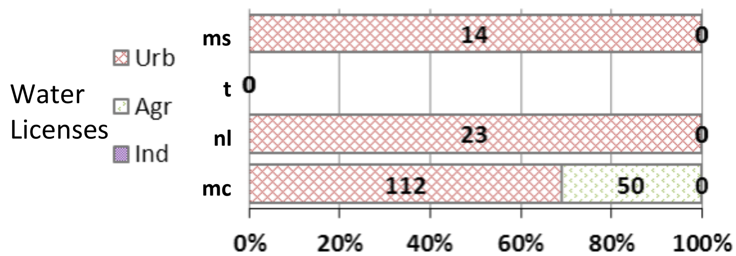


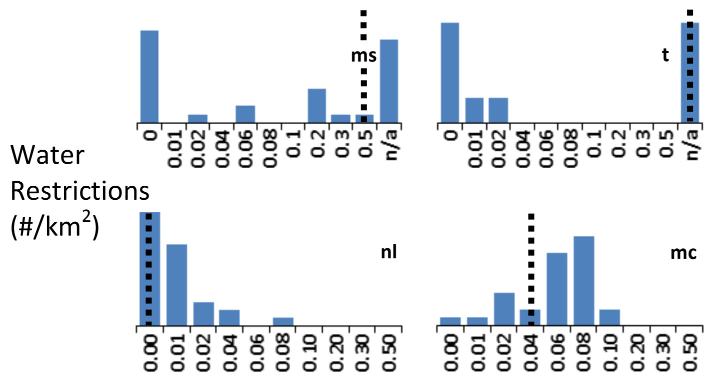


Water Use

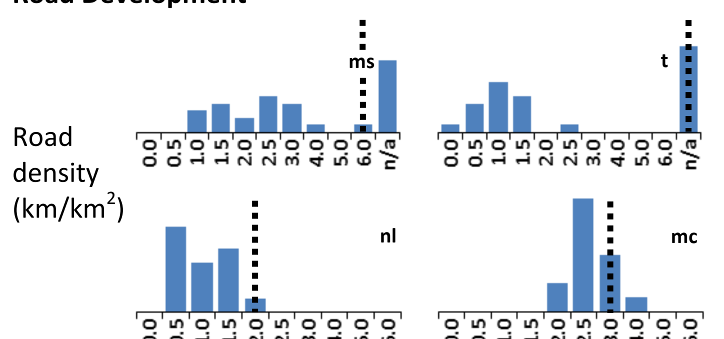








Road Development



Abbreviations:

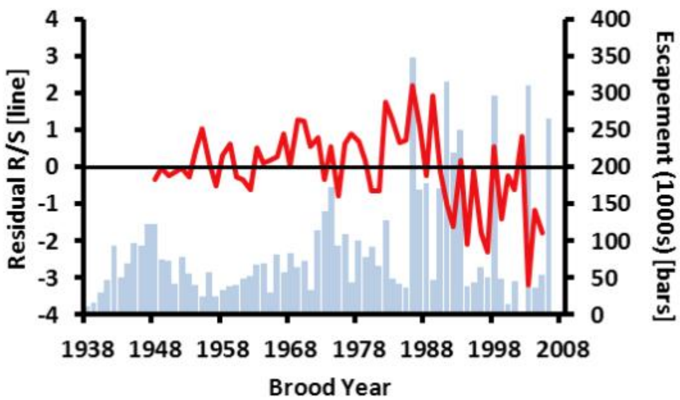
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

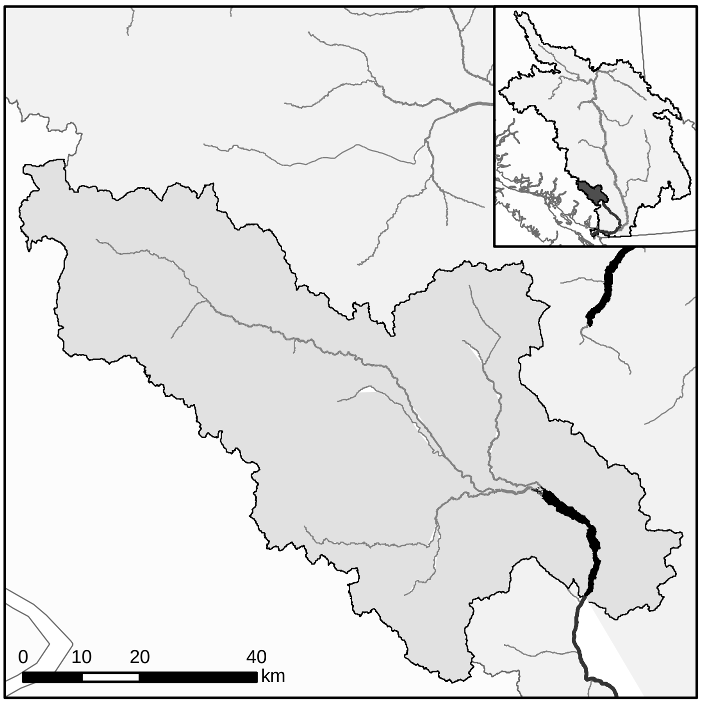
CONSERVATION UNIT

Lillooet — Late — L-4-1

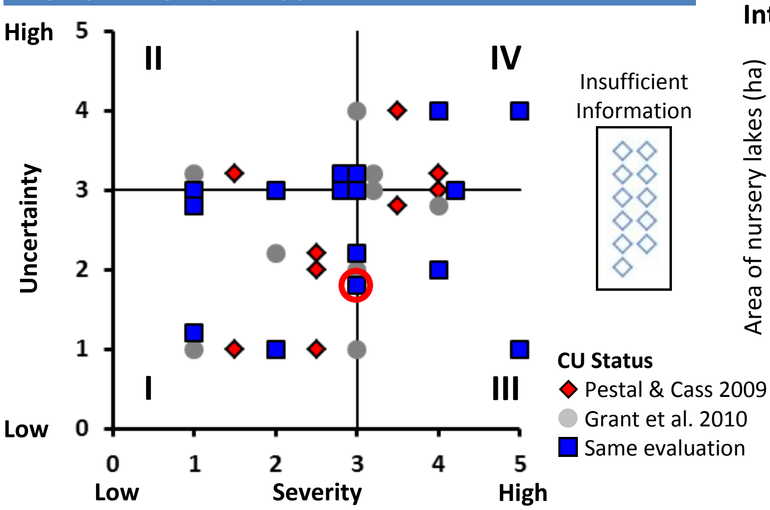
BIOLOGICAL DATA †



LOCATION



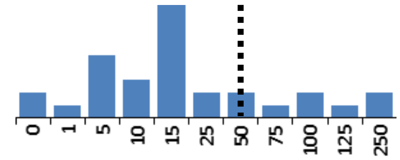
POPULATION STATUS



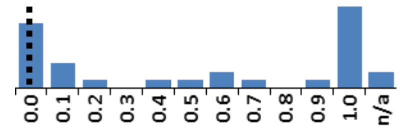
HABITAT STATUS

Spawning††

Total spawning extent (km)

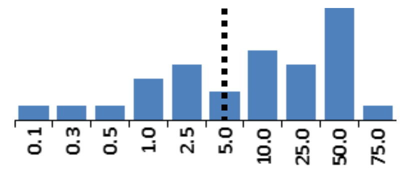


Ratio of lake influence spawning to total spawning

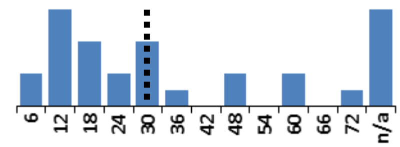


Rearing

Area of nursery lakes (1000 ha)

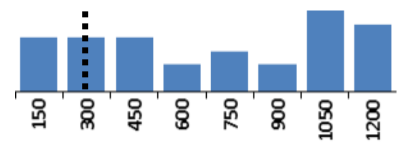


Nursery lake productivity (estimated) (100 smolts/ha)

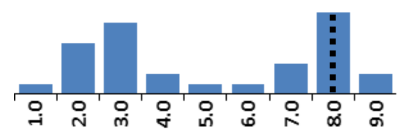


Migration

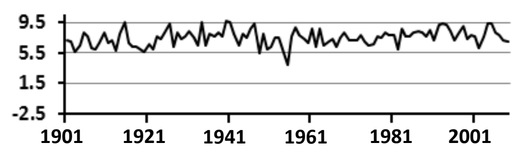
Migration distance (km)



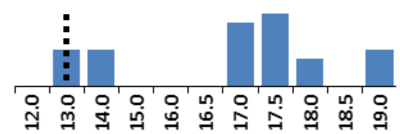
Average spring air temperature at nursery lake (°C)



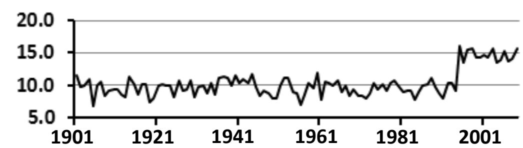
Spring air temperature at nursery lake (°C)



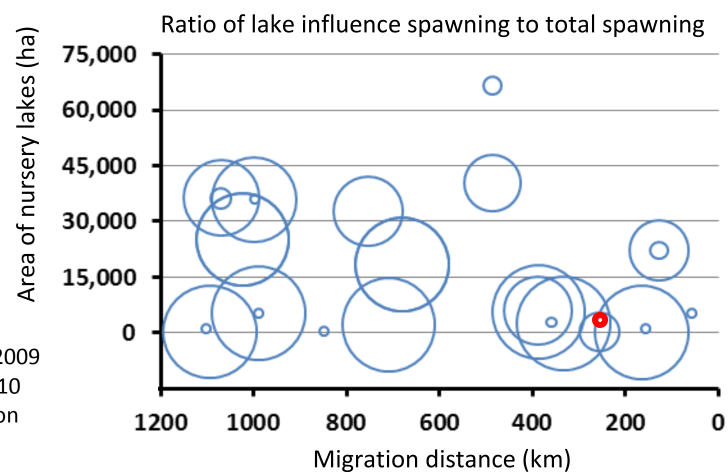
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Birkenhead**

†† Spawning note: **None.**

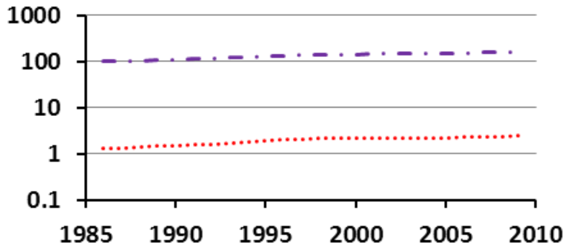
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

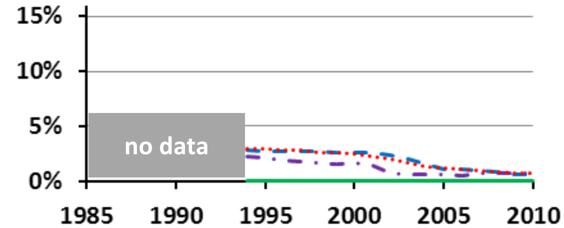
Human Population

Population density (persons/ km^2)

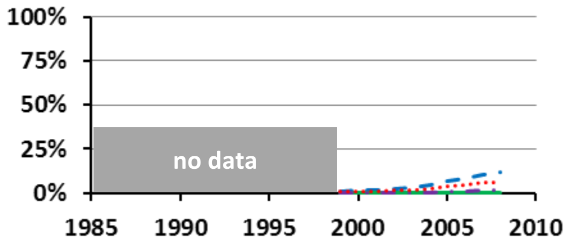


Land Use

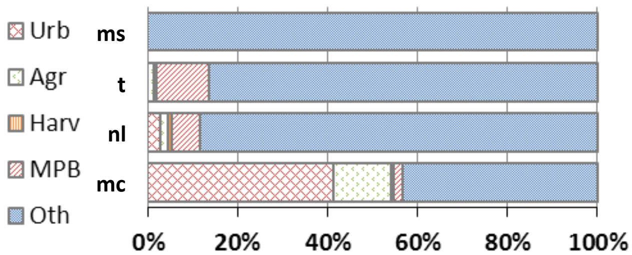
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

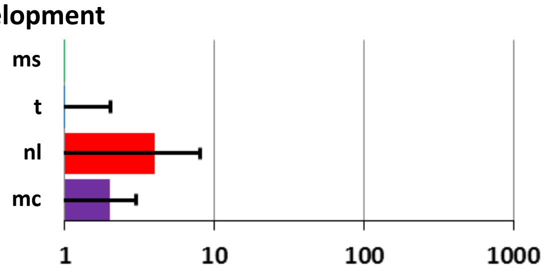


Land use type (% of habitat area)

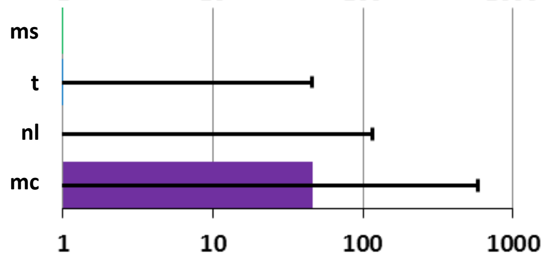


Resource Development

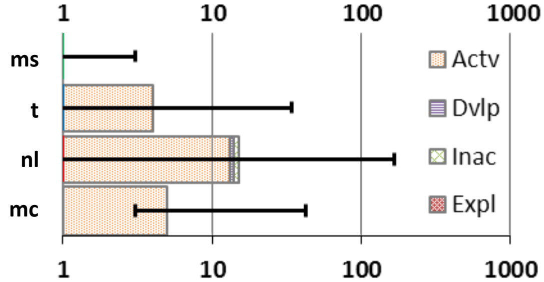
Small scale hydro



Placer mining claims

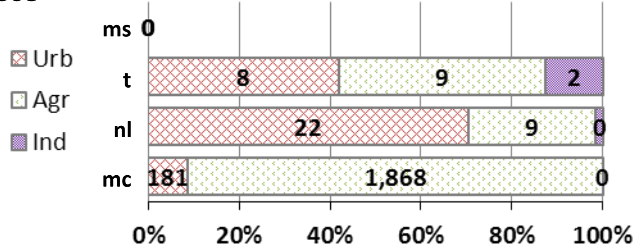


Other mines

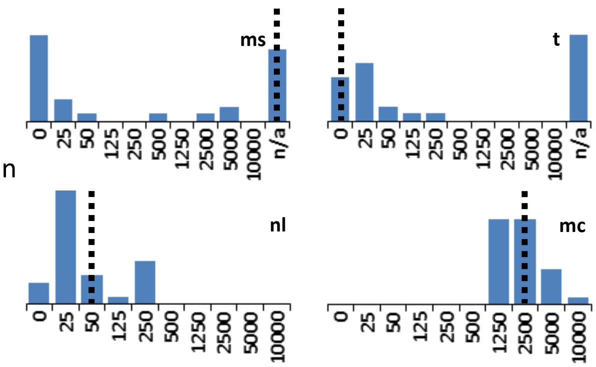


Water Use

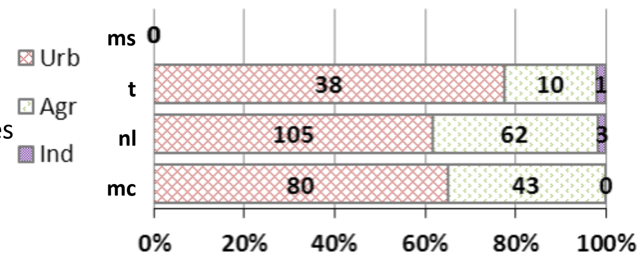
Total allo-cation by use



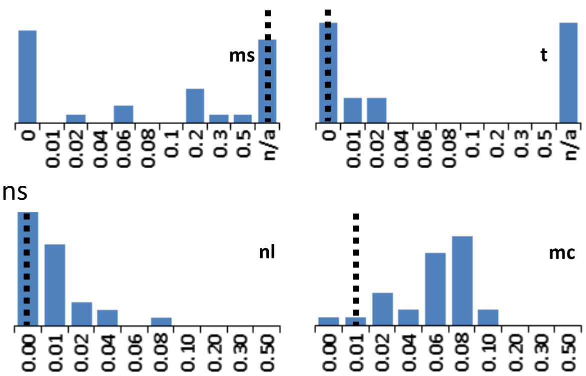
Total allocation (m^3/ha)



Water Licenses

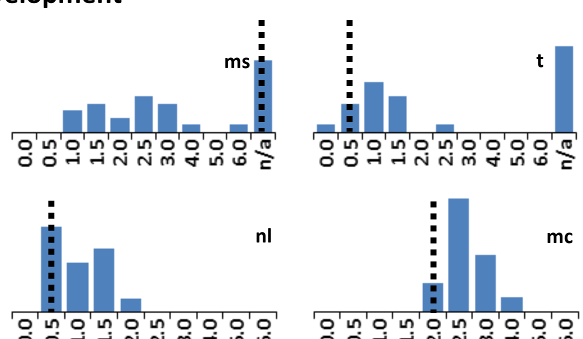


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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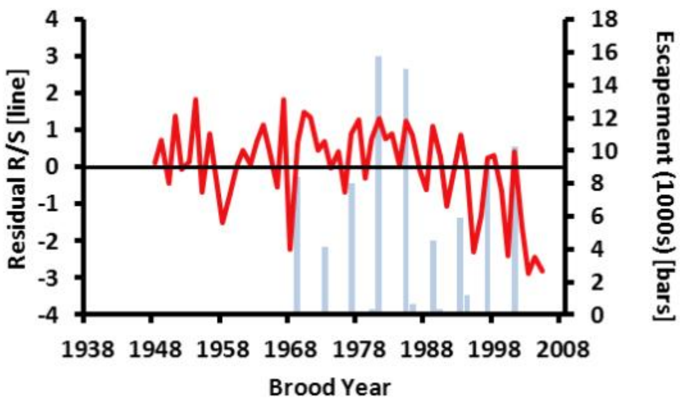
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

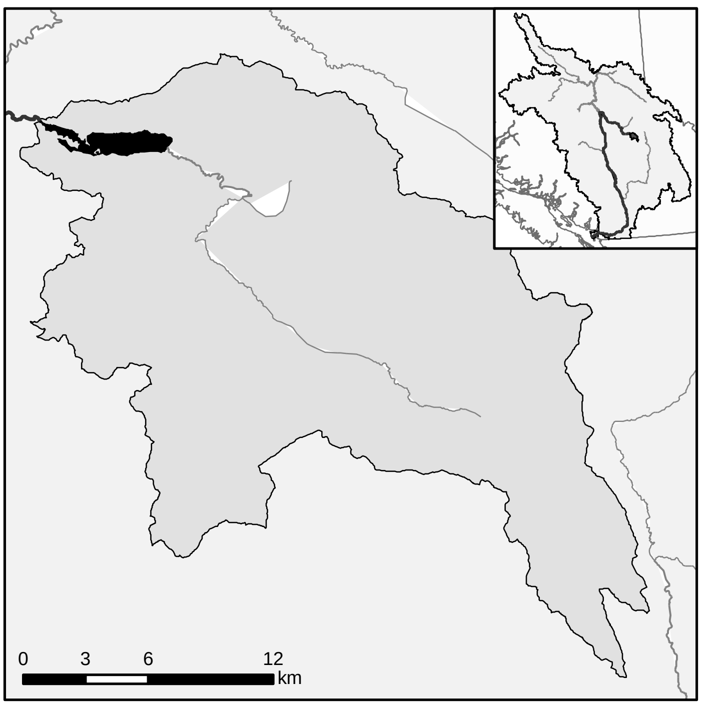
CONSERVATION UNIT

McKinley — Summer — L-6-8

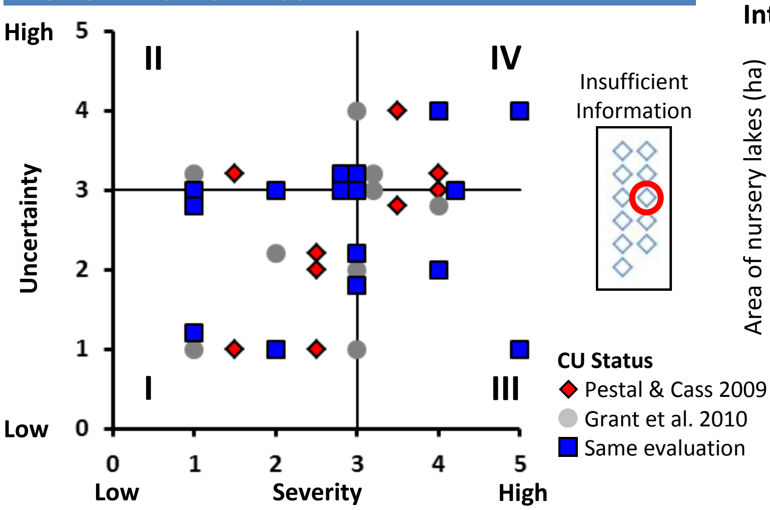
BIOLOGICAL DATA †



LOCATION



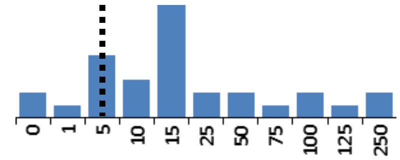
POPULATION STATUS



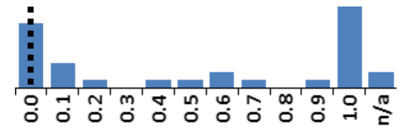
HABITAT STATUS

Spawning††

Total spawning extent (km)

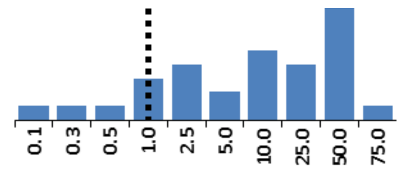


Ratio of lake influence spawning to total spawning

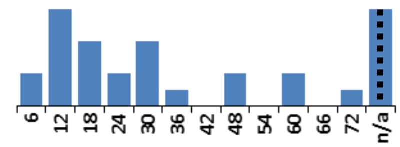


Rearing

Area of nursery lakes (1000 ha)

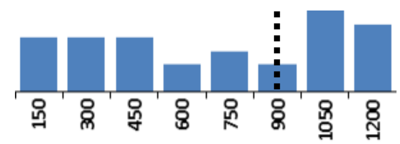


Nursery lake productivity (estimated) (100 smolts/ha)

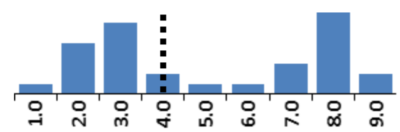


Migration

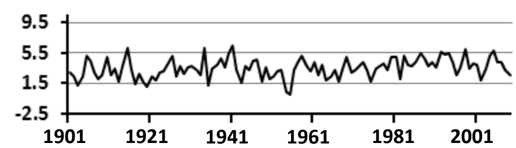
Migration distance (km)



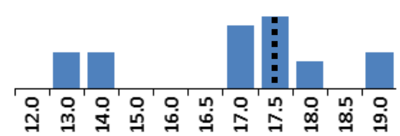
Average spring air temperature at nursery lake (°C)



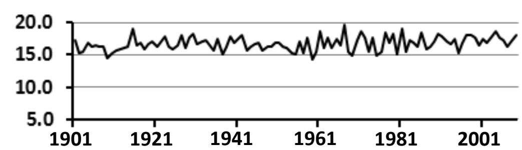
Spring air temperature at nursery lake (°C)



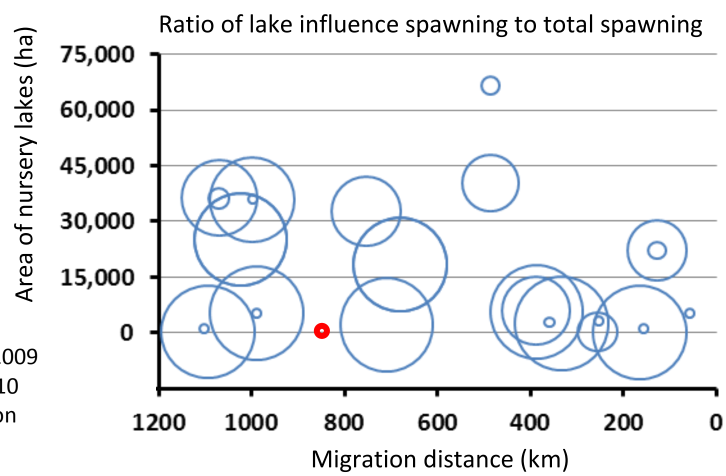
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Quesnel**

†† Spawning note: **None.**

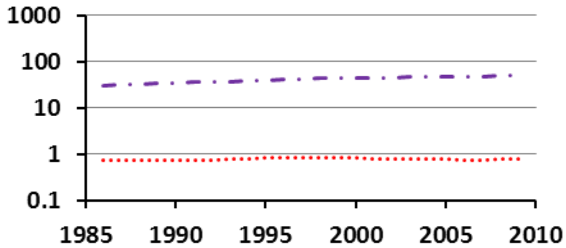
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

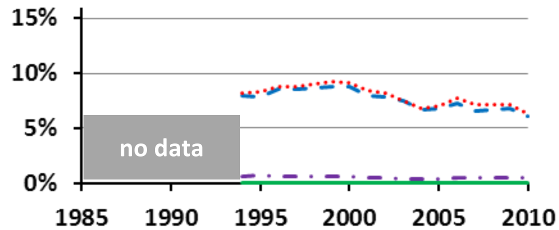
Human Population

Population density (persons/km^2)

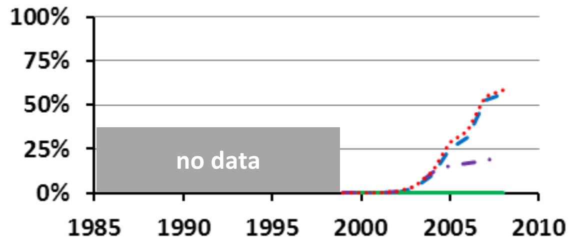


Land Use

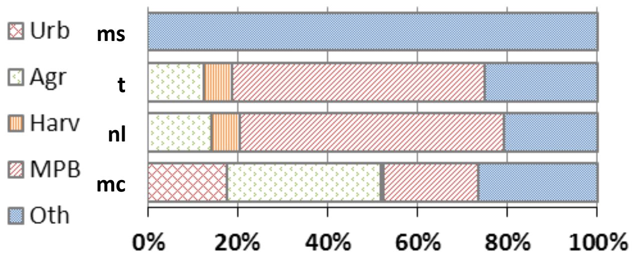
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

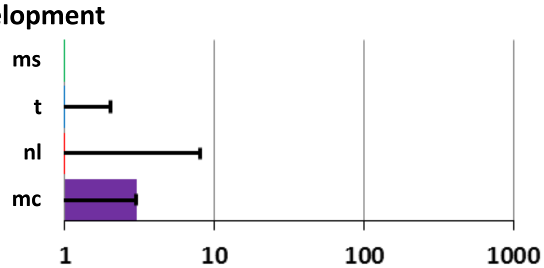


Land use type (% of habitat area)

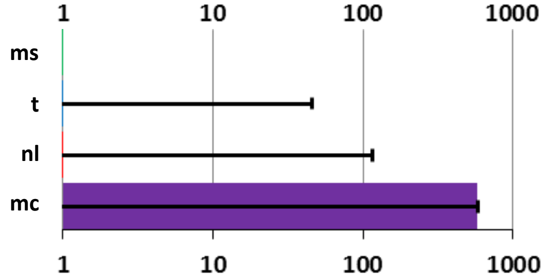


Resource Development

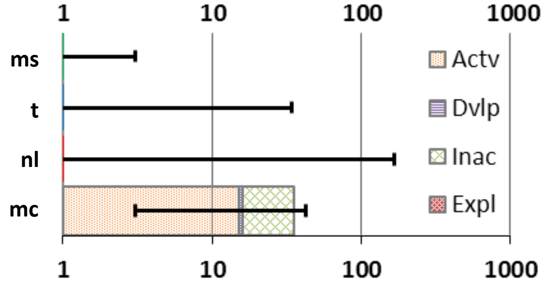
Small scale hydro



Placer mining claims

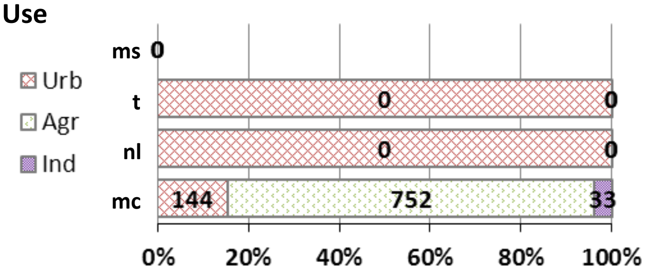


Other mines

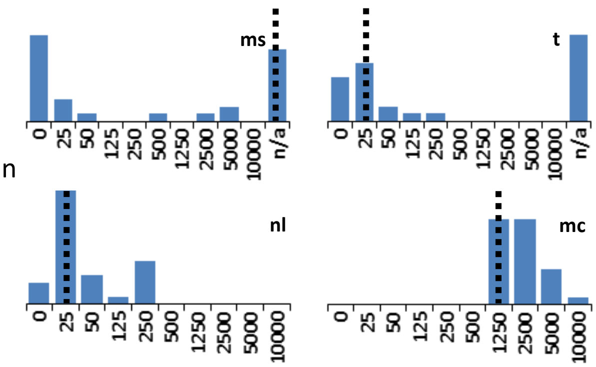


Water Use

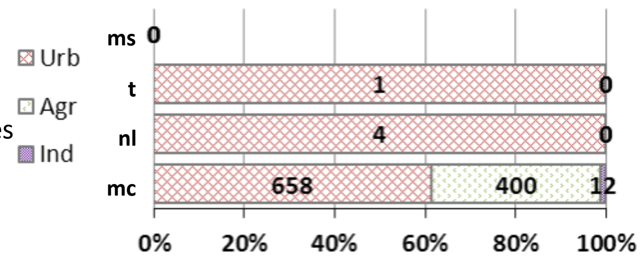
Total allo-cation by use



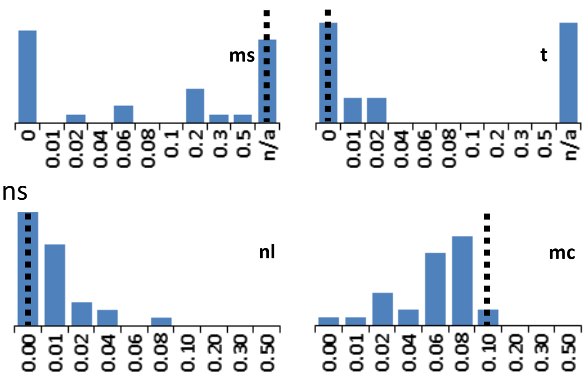
Total allocation (m^3/ha)



Water Licenses

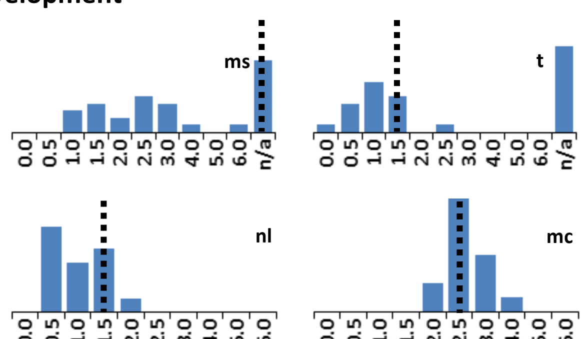


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

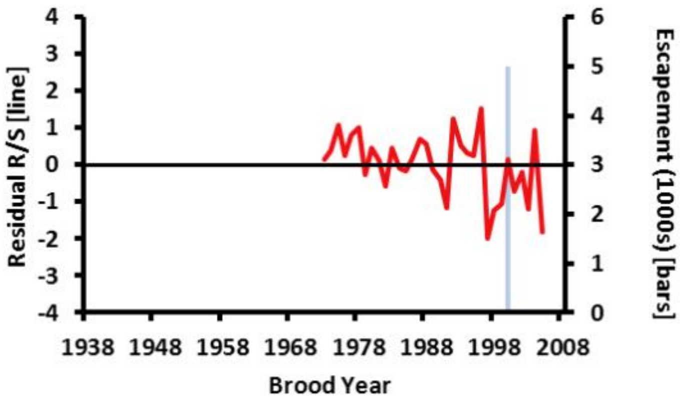
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

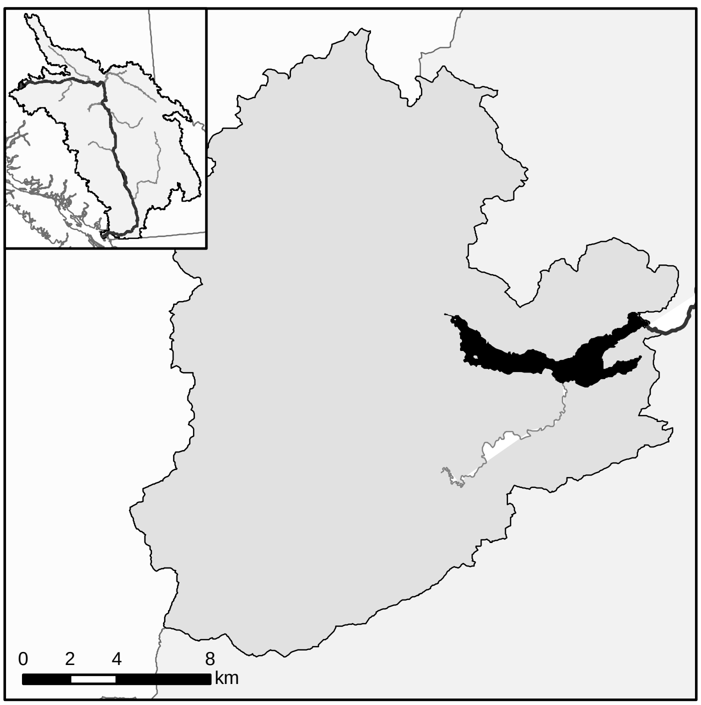
CONSERVATION UNIT

Nadina — Early Summer — L-6-9

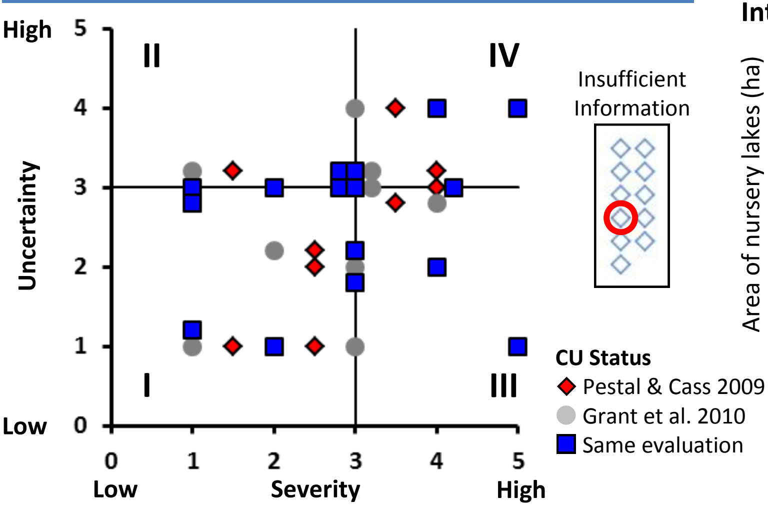
BIOLOGICAL DATA [†]



LOCATION



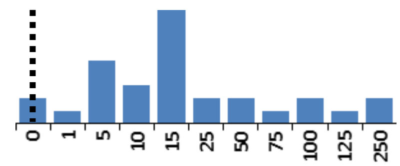
POPULATION STATUS



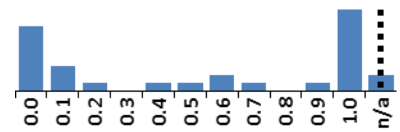
HABITAT STATUS

Spawning[††]

Total spawning extent (km)

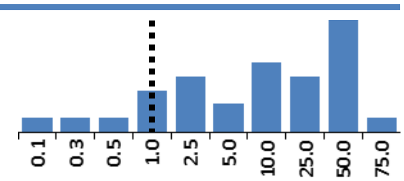


Ratio of lake influence spawning to total spawning

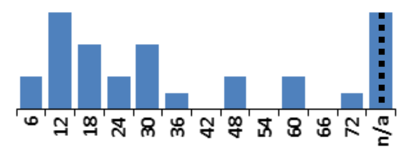


Rearing

Area of nursery lakes (1000 ha)

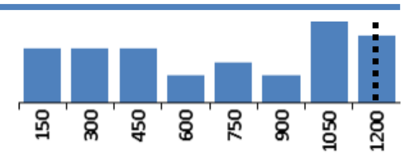


Nursery lake productivity (estimated) (100 smolts/ha)

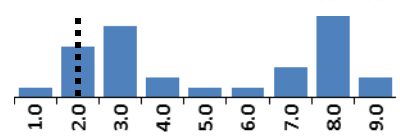


Migration

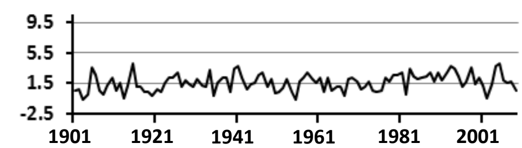
Migration distance (km)



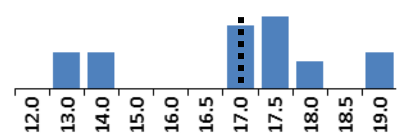
Average spring air temperature at nursery lake (°C)



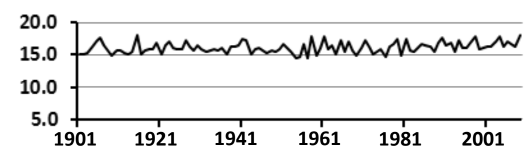
Spring air temperature at nursery lake (°C)



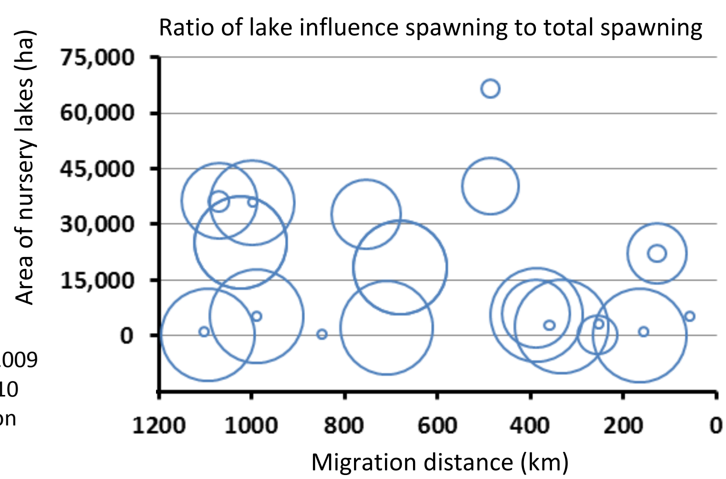
Average air temperature across adult migration (°C)[‡]



Air temperature across adult migration (°C)[‡]



Integrated Summary of Habitat Vulnerability [‡‡]



† Representative stock for productivity: **Nadina**

†† Spawning note: **Glacier Creek spawning not mapped.**

‡ Temperature calculated according to run group timing.

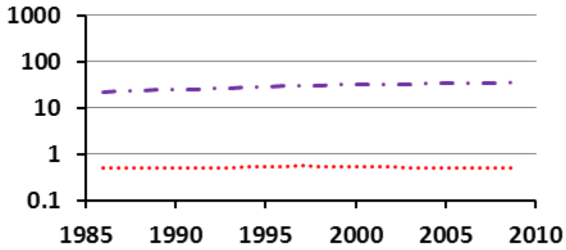
‡‡ Nadina CU cannot be represented on this figure (spawning ratio = n/a)

January 31, 2011

FRESHWATER STRESSORS

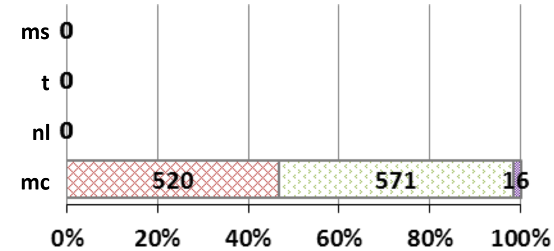
Human Population

Population density (persons/km²)



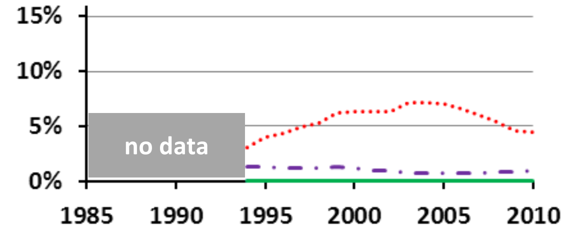
Water Use

Total allocation by use

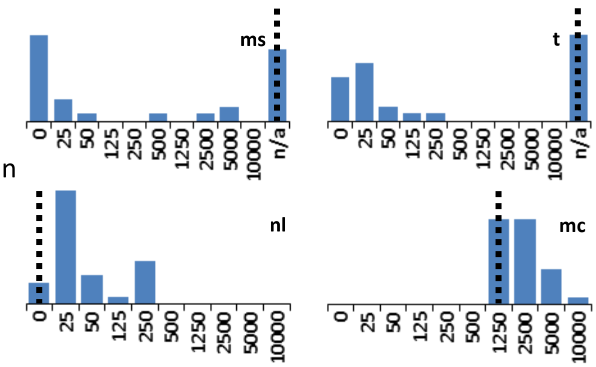


Land Use

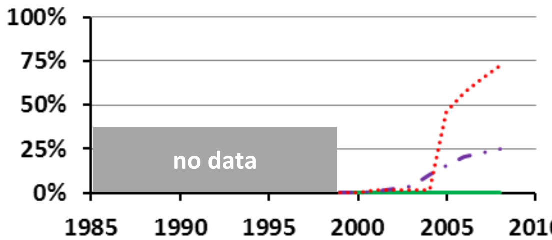
Forest harvesting (% of habitat area)



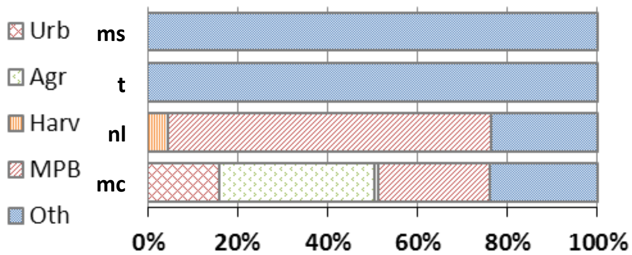
Total allocation (m³/ha)



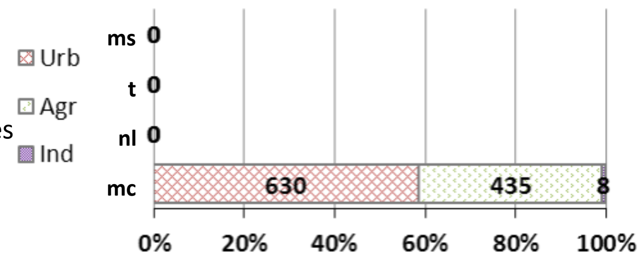
Mountain pine beetle disturbance (cumulative % of habitat area)



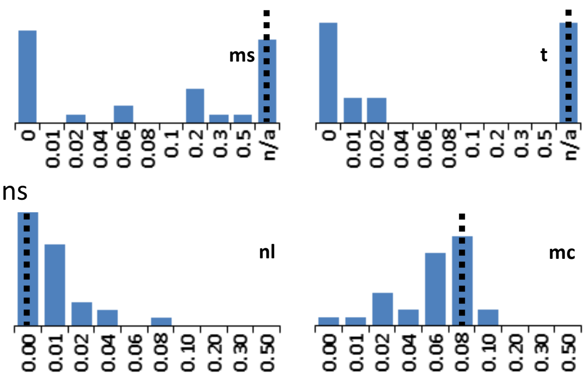
Land use type (% of habitat area)



Water Licenses

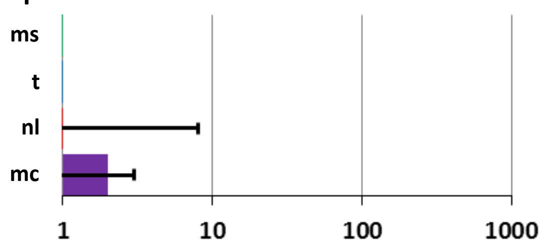


Water Restrictions (#/km²)

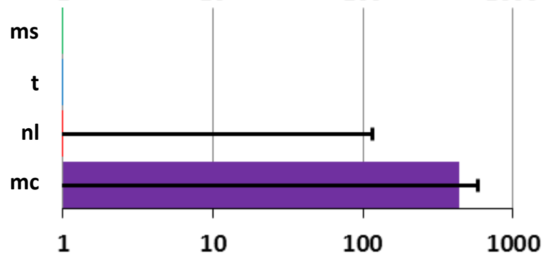


Resource Development

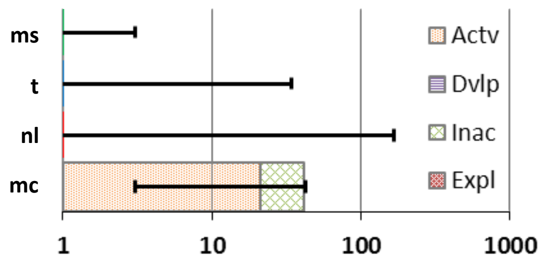
Small scale hydro



Placer mining claims

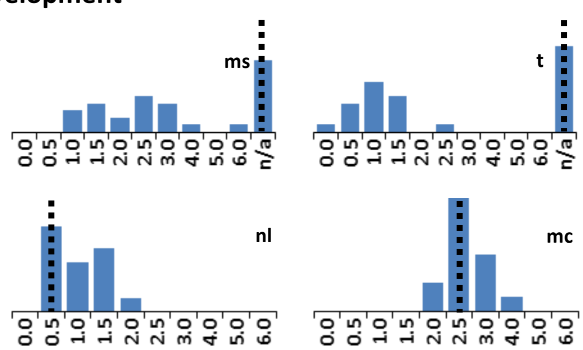


Other mines



Road Development

Road density (km/km²)



Abbreviations:

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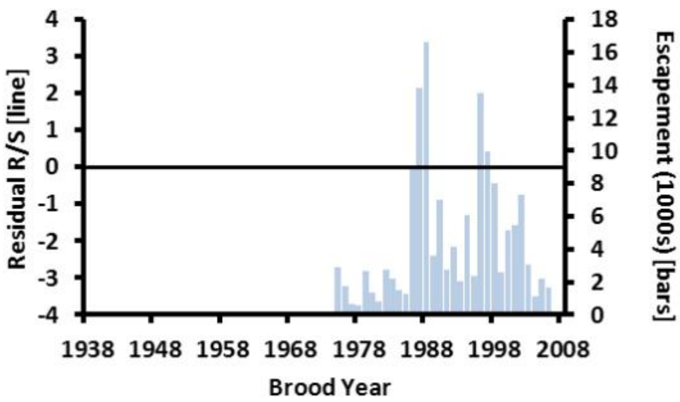
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

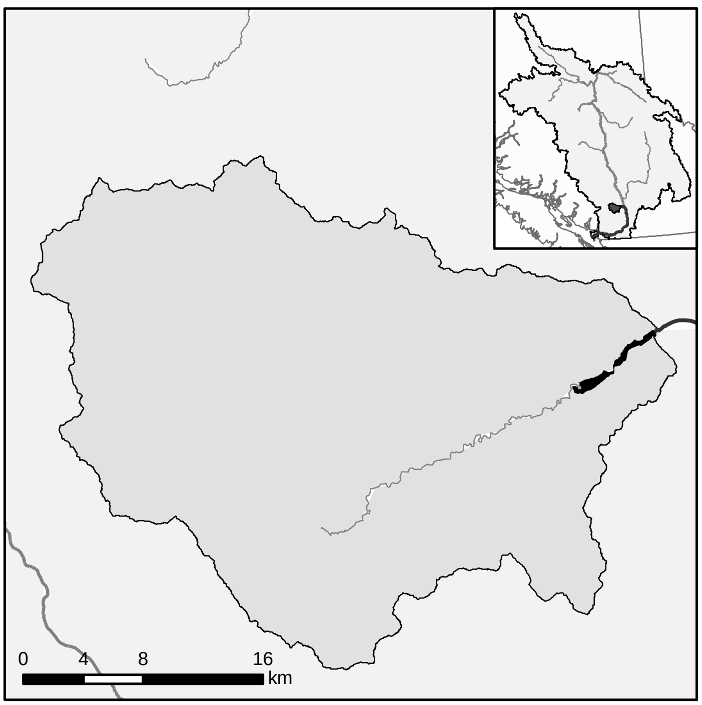
CONSERVATION UNIT

Nahatlatch — Early Summer — L-5-2

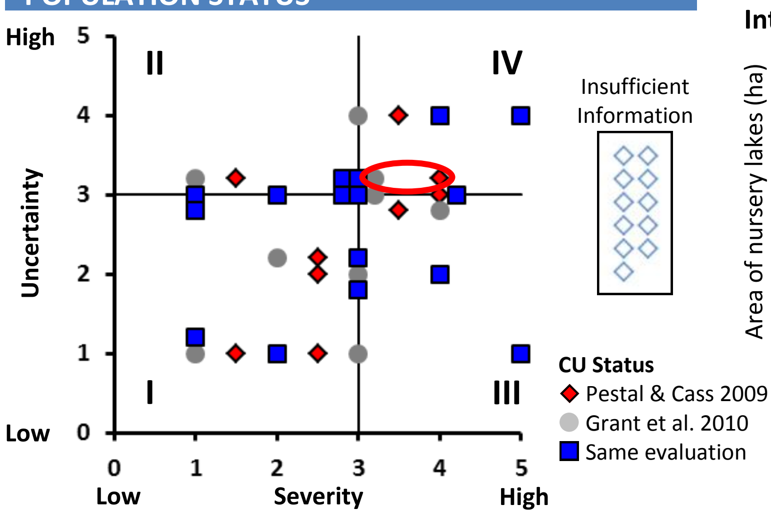
BIOLOGICAL DATA †



LOCATION



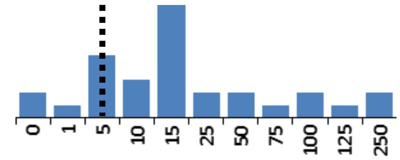
POPULATION STATUS



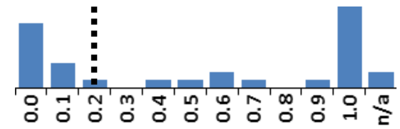
HABITAT STATUS

Spawning††

Total spawning extent (km)

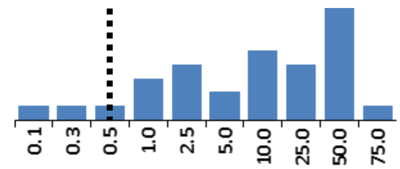


Ratio of lake influence spawning to total spawning

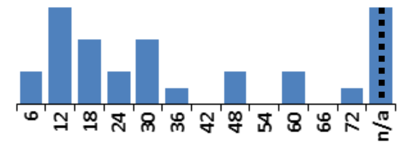


Rearing

Area of nursery lakes (1000 ha)

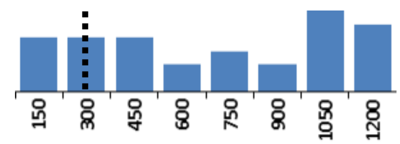


Nursery lake productivity (estimated) (100 smolts/ha)

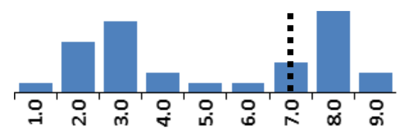


Migration

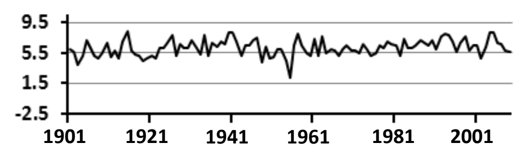
Migration distance (km)



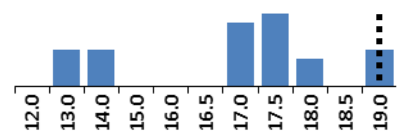
Average spring air temperature at nursery lake (°C)



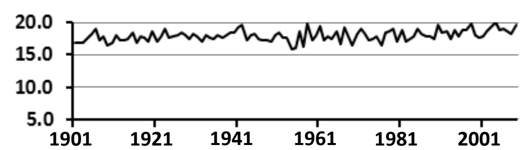
Spring air temperature at nursery lake (°C)



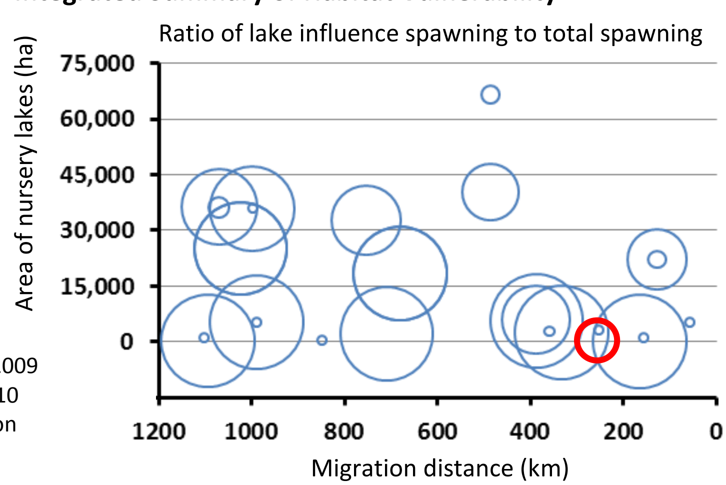
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

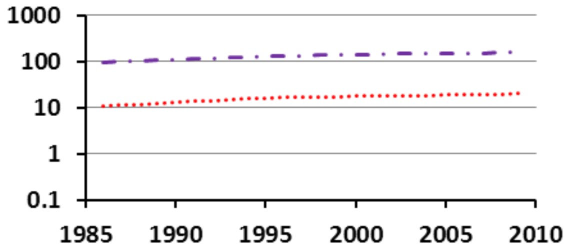
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

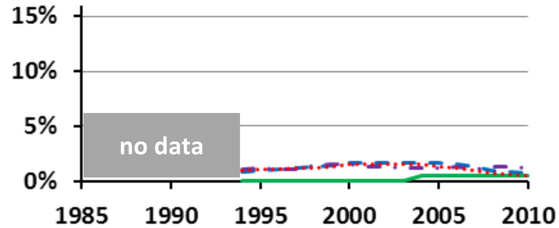
Human Population

Population density (persons/km^2)

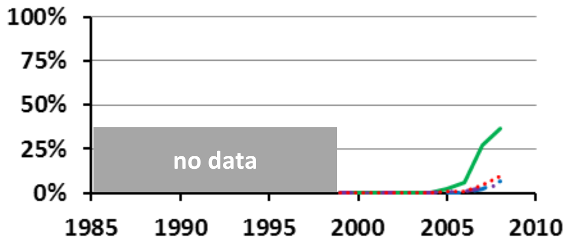


Land Use

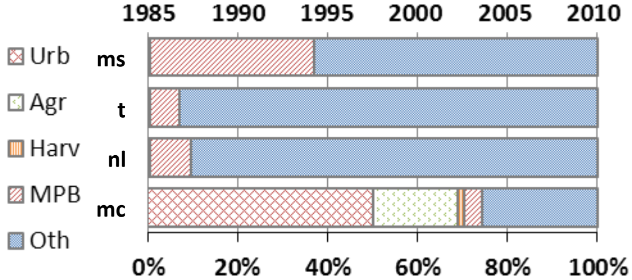
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

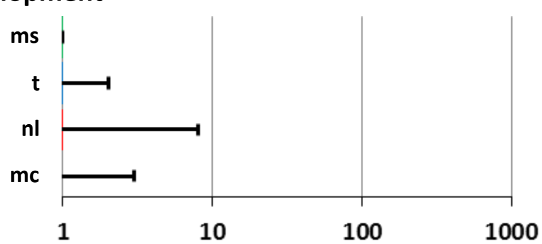


Land use type (% of habitat area)

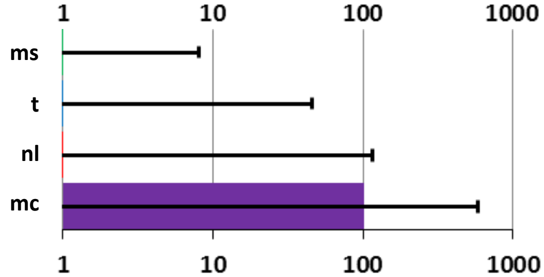


Resource Development

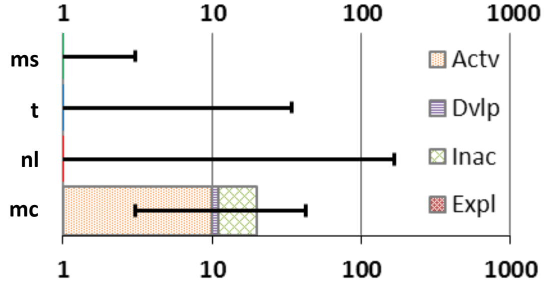
Small scale hydro



Placer mining claims

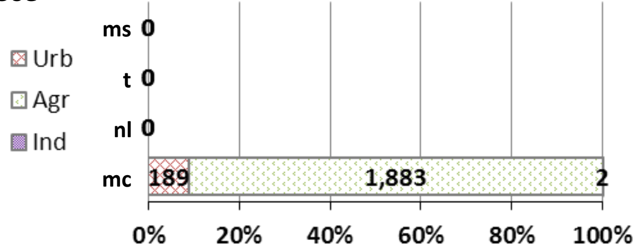


Other mines

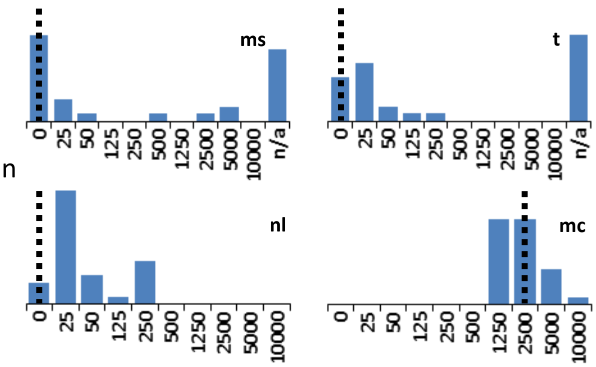


Water Use

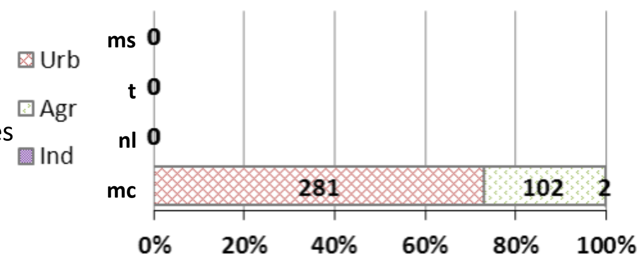
Total allo-cation by use



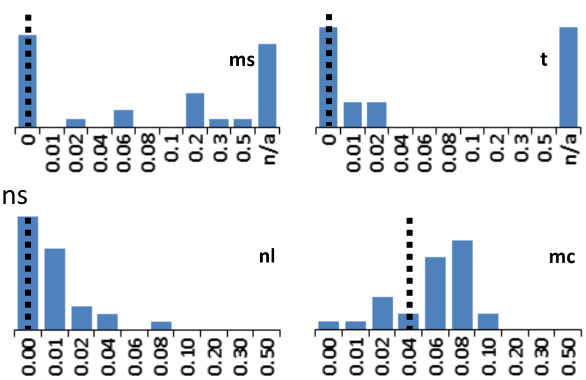
Total allocation (m^3/ha)



Water Licenses

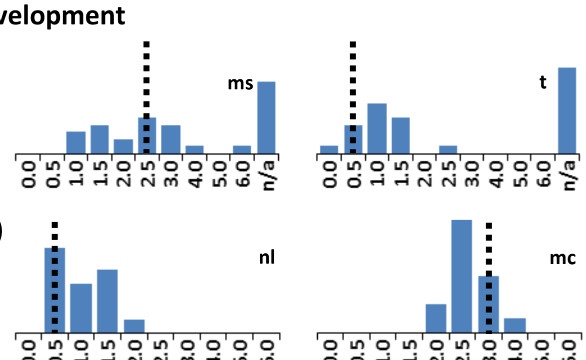


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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Agr agricultural
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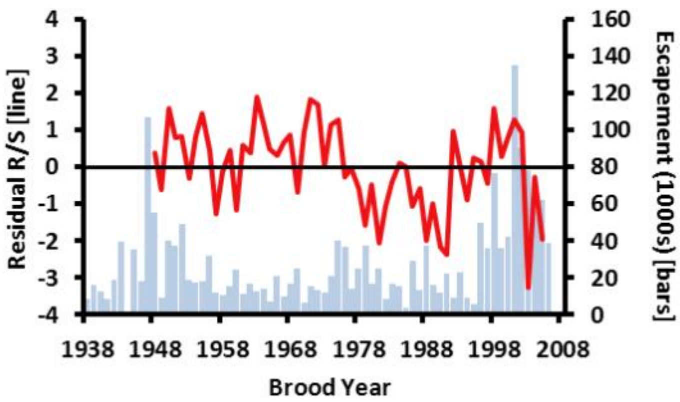
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

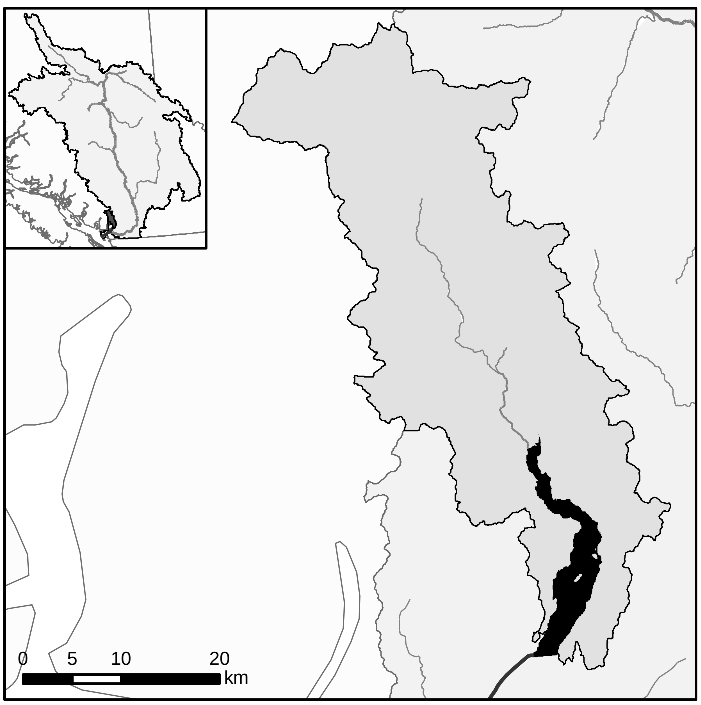
CONSERVATION UNIT

Pitt — Early Summer — L-3-5

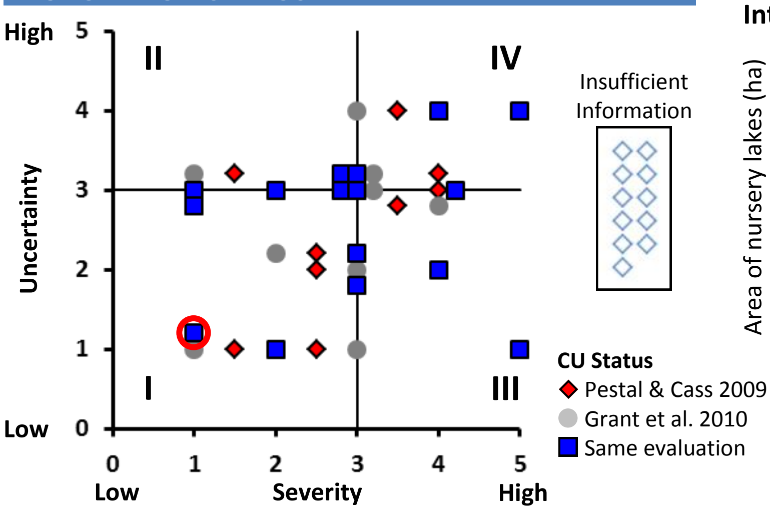
BIOLOGICAL DATA †



LOCATION



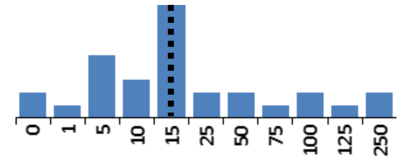
POPULATION STATUS



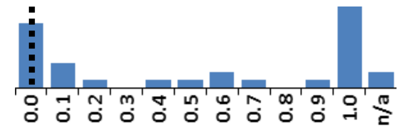
HABITAT STATUS

Spawning††

Total spawning extent (km)

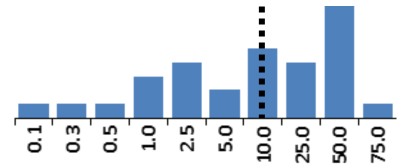


Ratio of lake influence spawning to total spawning

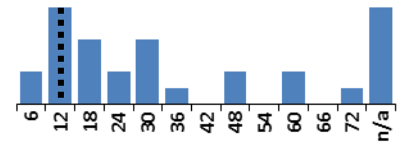


Rearing

Area of nursery lakes (1000 ha)

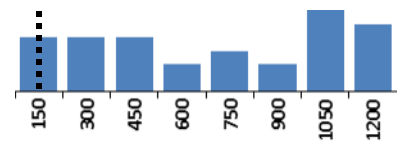


Nursery lake productivity (estimated) (100 smolts/ha)

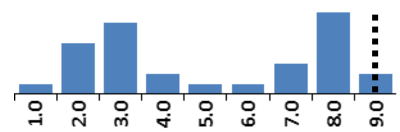


Migration

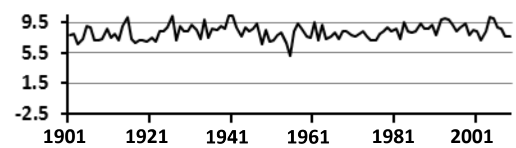
Migration distance (km)



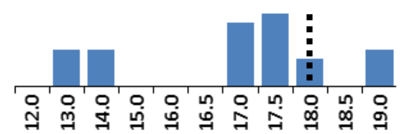
Average spring air temperature at nursery lake (°C)



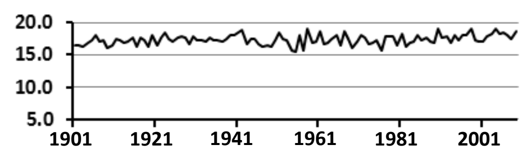
Spring air temperature at nursery lake (°C)



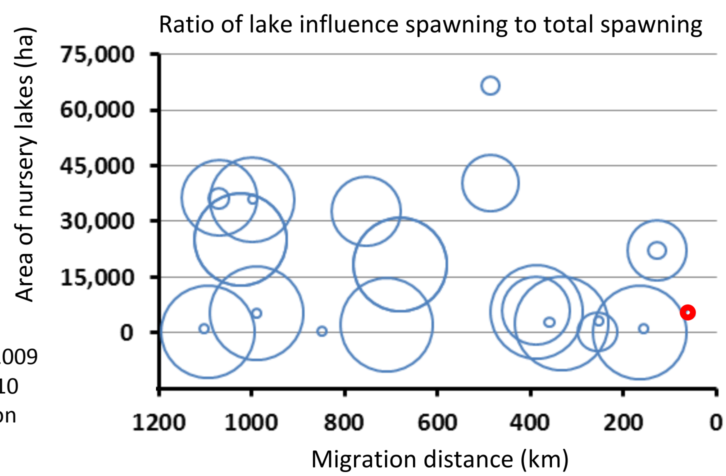
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Pitt**

†† Spawning note: **None.**

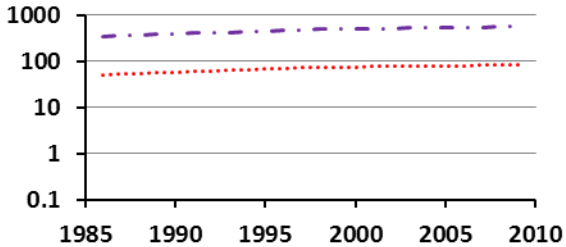
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

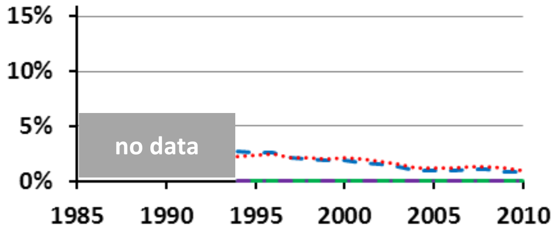
Human Population

Population density (persons/ km^2)

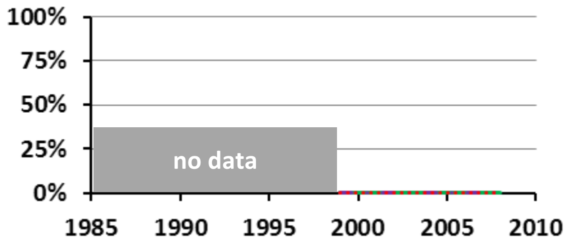


Land Use

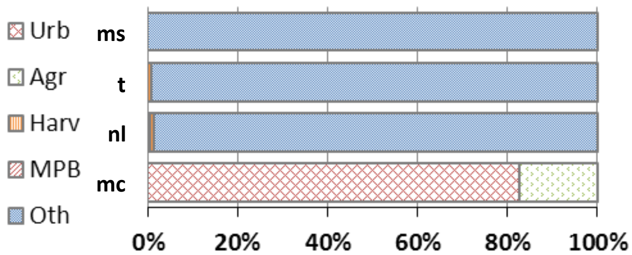
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

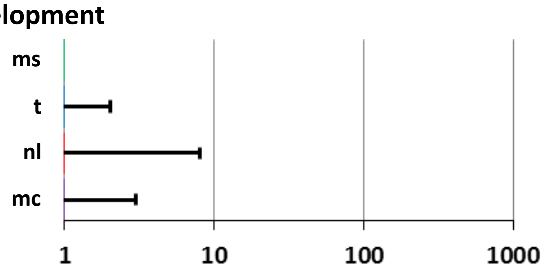


Land use type (% of habitat area)

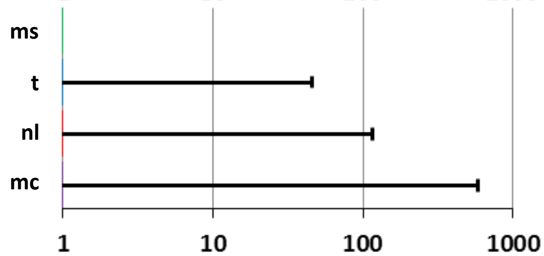


Resource Development

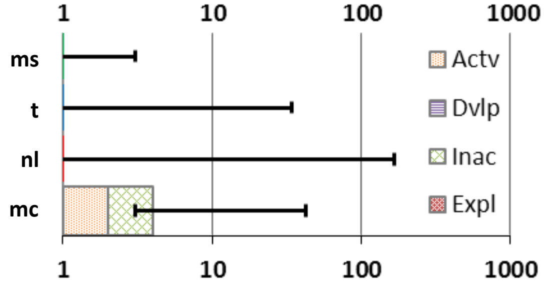
Small scale hydro



Placer mining claims

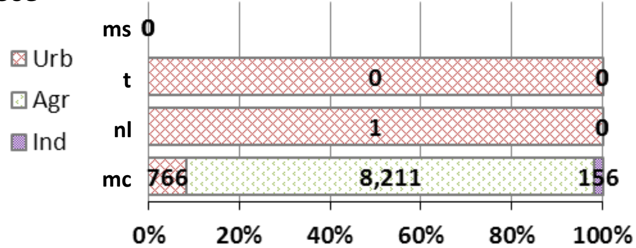


Other mines

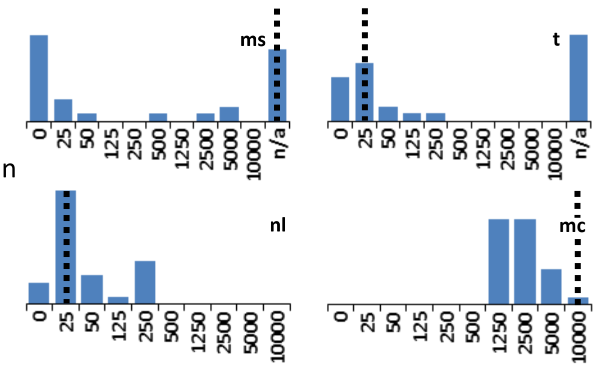


Water Use

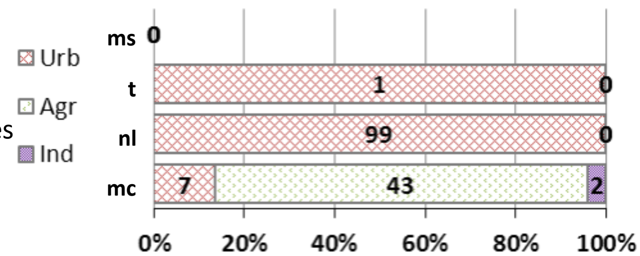
Total allocation by use



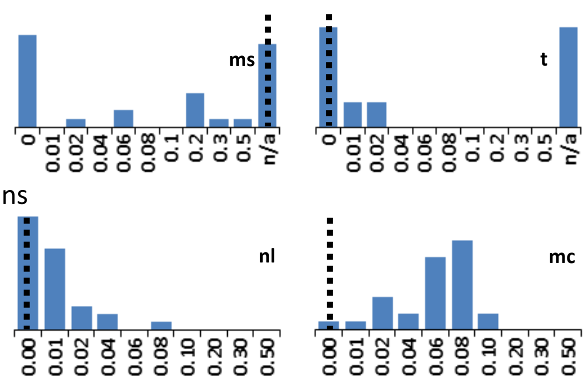
Total allocation (m^3/ha)



Water Licenses

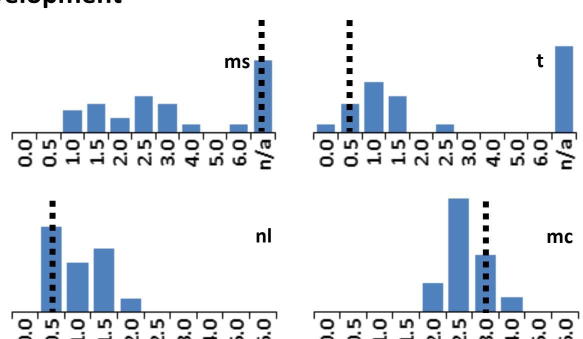


Water Restrictions (#/ km^2)



Road Development

Road density (km/ km^2)



Abbreviations:

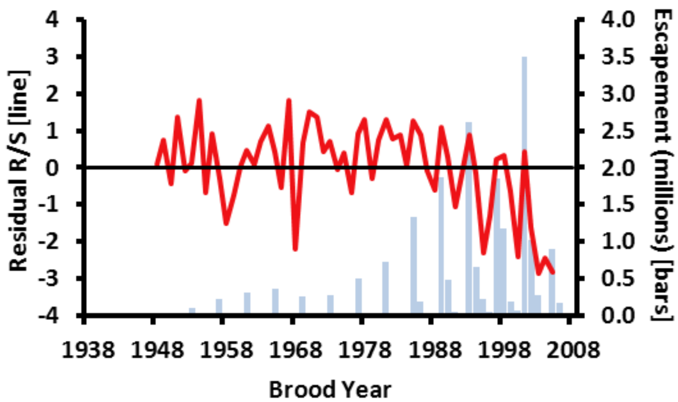
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

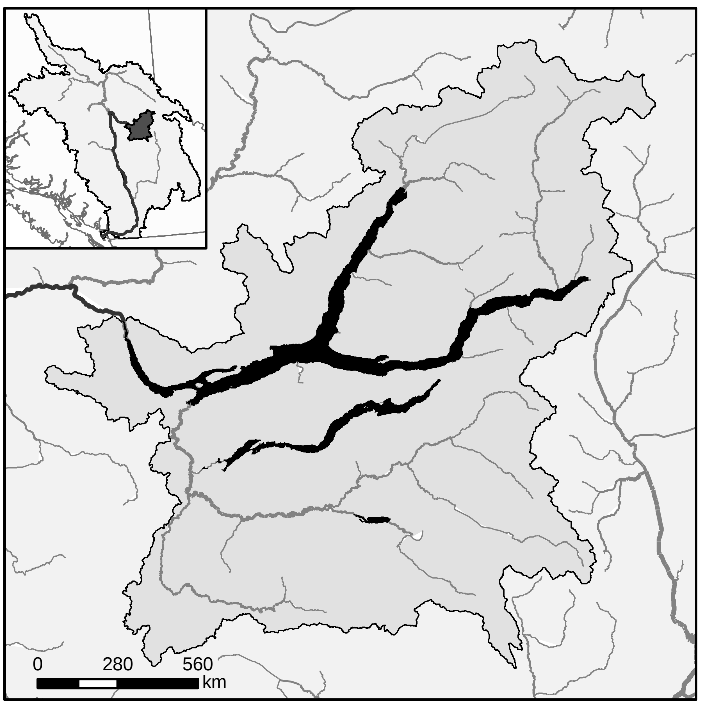
CONSERVATION UNIT

Quesnel — Summer — L-6-10

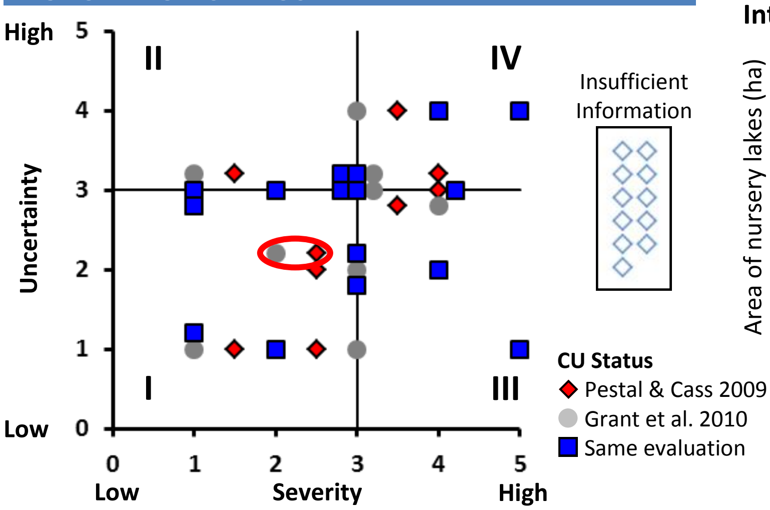
BIOLOGICAL DATA †



LOCATION



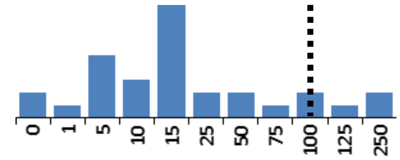
POPULATION STATUS



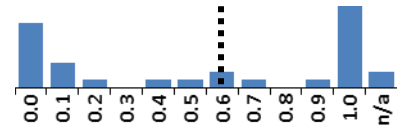
HABITAT STATUS

Spawning††

Total spawning extent (km)

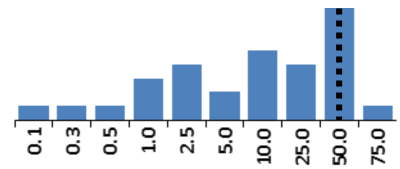


Ratio of lake influence spawning to total spawning

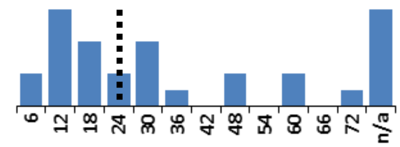


Rearing

Area of nursery lakes (1000 ha)

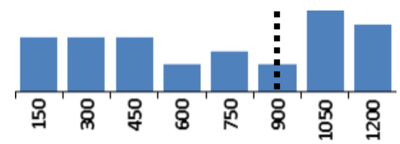


Nursery lake productivity (estimated) (100 smolts/ha)

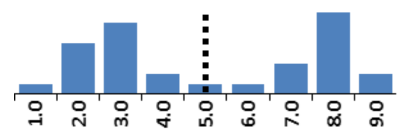


Migration

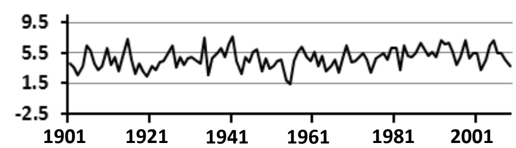
Migration distance (km)



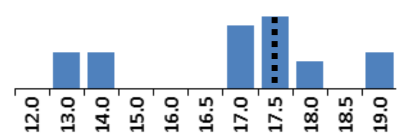
Average spring air temperature at nursery lake (°C)



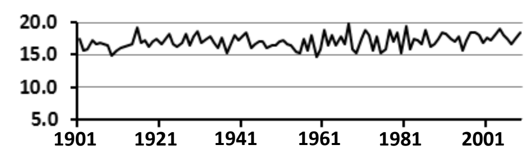
Spring air temperature at nursery lake (°C)



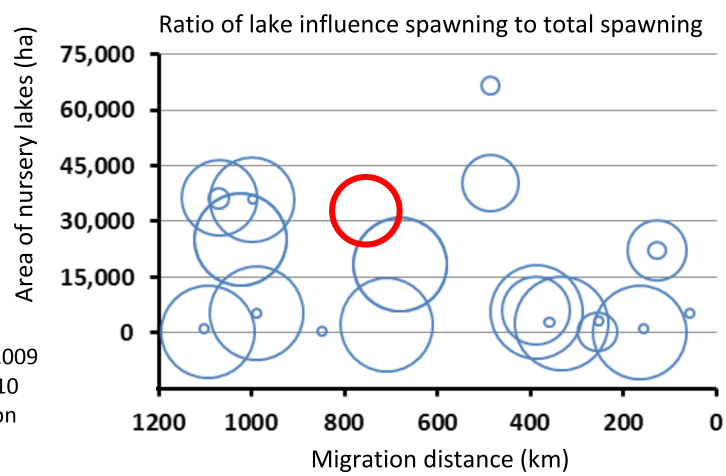
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Quesnel**

†† Spawning note: **None.**

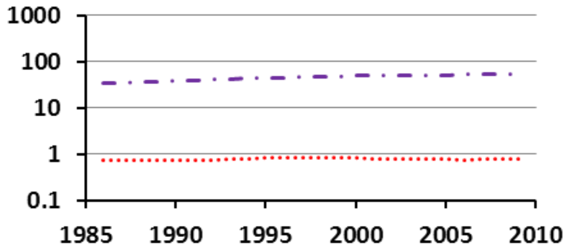
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

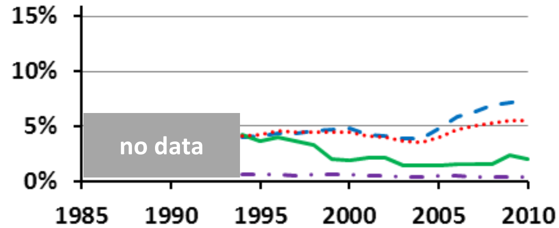
Human Population

Population density (persons/km^2)

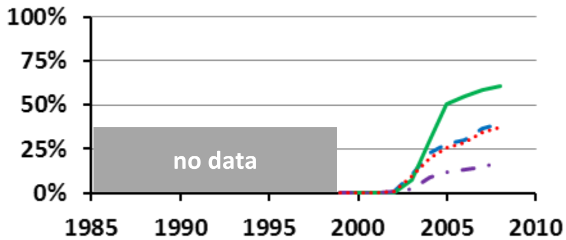


Land Use

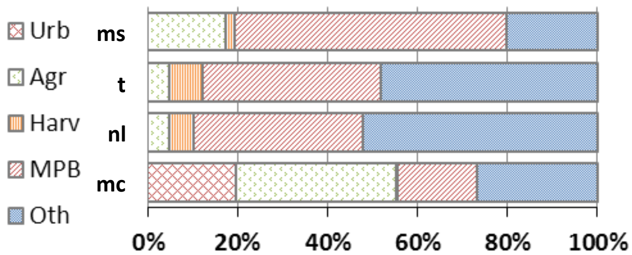
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

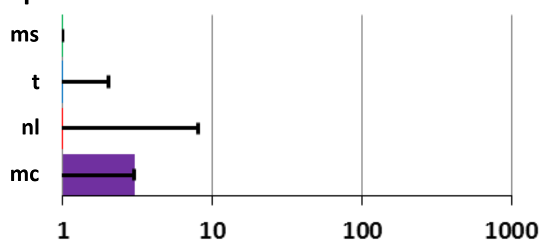


Land use type (% of habitat area)

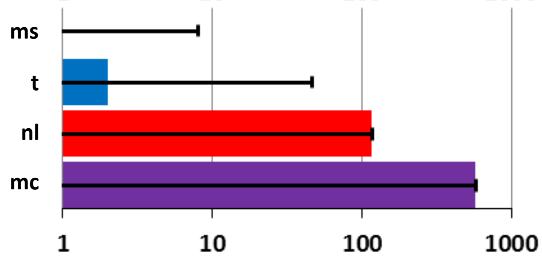


Resource Development

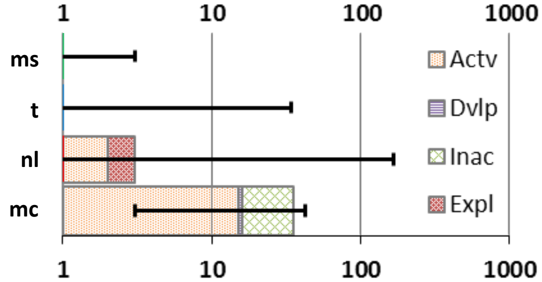
Small scale hydro



Placer mining claims

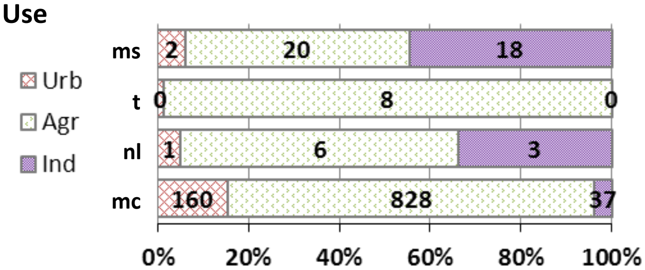


Other mines

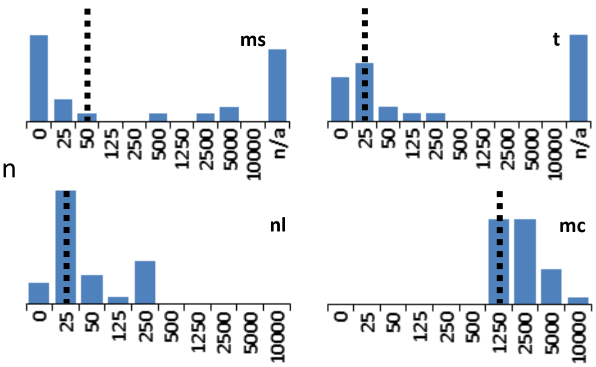


Water Use

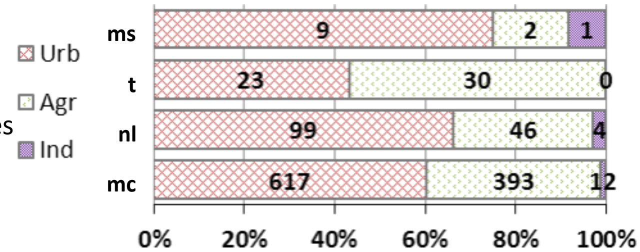
Total allo-cation by use



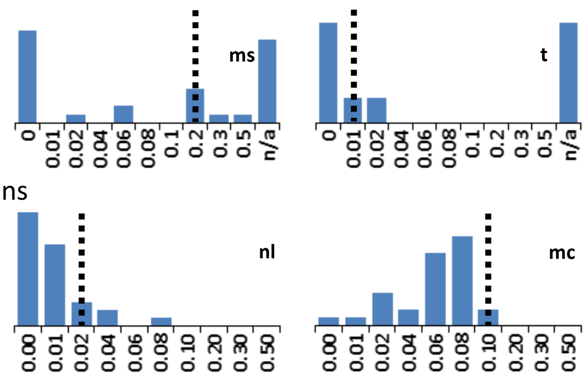
Total allocation (m^3/ha)



Water Licenses

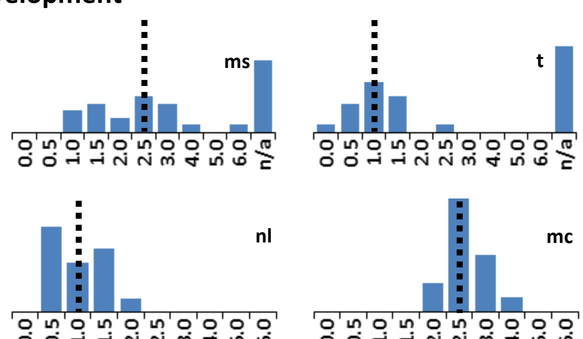


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

Urb urban
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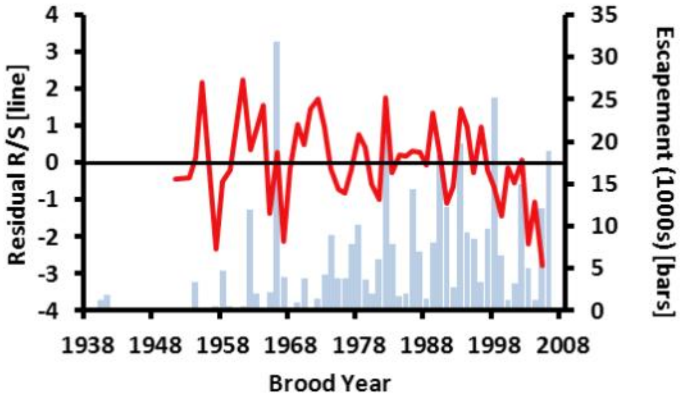
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

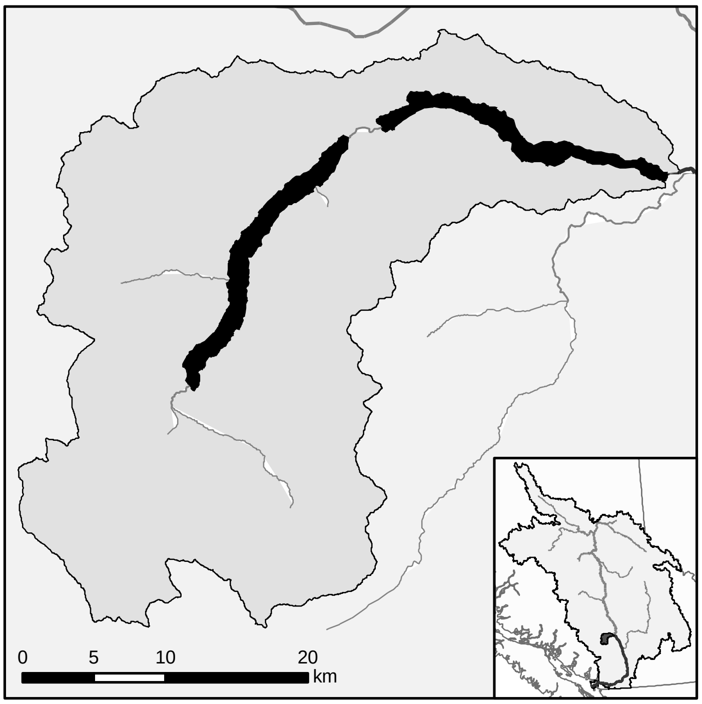
CONSERVATION UNIT

Seton — Late — L-6-11

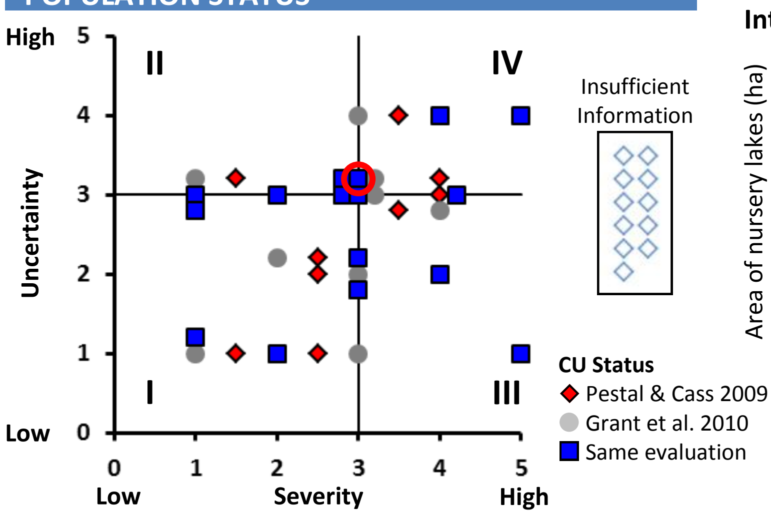
BIOLOGICAL DATA †



LOCATION



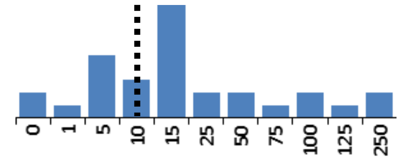
POPULATION STATUS



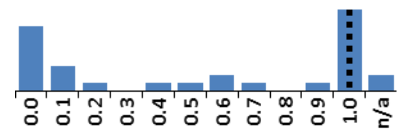
HABITAT STATUS

Spawning††

Total spawning extent (km)

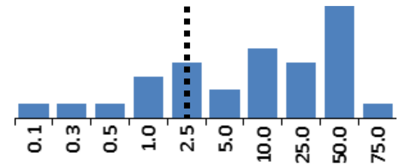


Ratio of lake influence spawning to total spawning

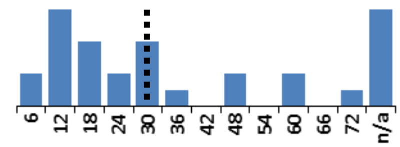


Rearing

Area of nursery lakes (1000 ha)

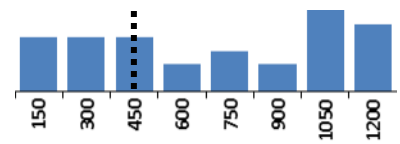


Nursery lake productivity (estimated) (100 smolts/ha)

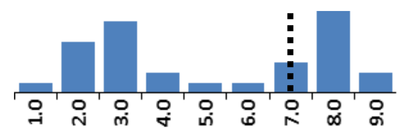


Migration

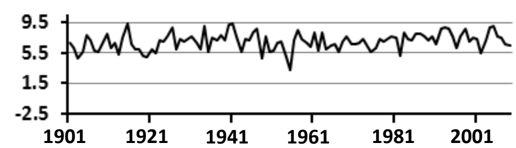
Migration distance (km)



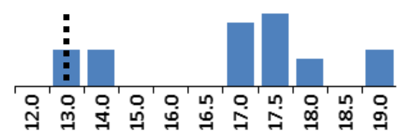
Average spring air temperature at nursery lake (°C)



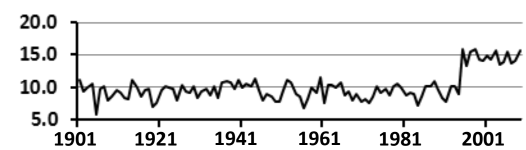
Spring air temperature at nursery lake (°C)



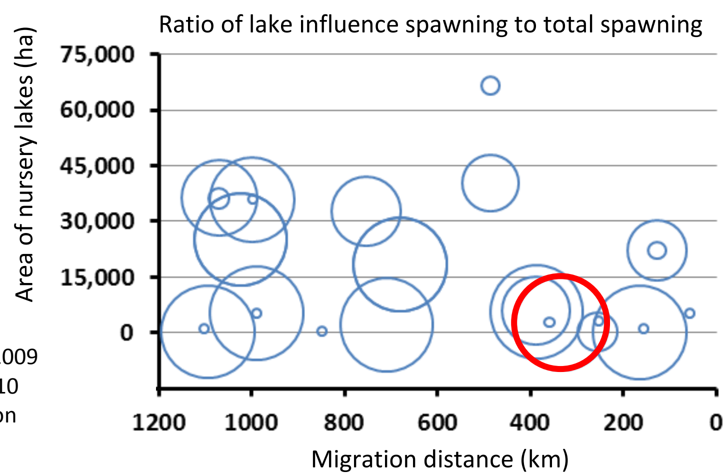
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Portage**

†† Spawning note: **None.**

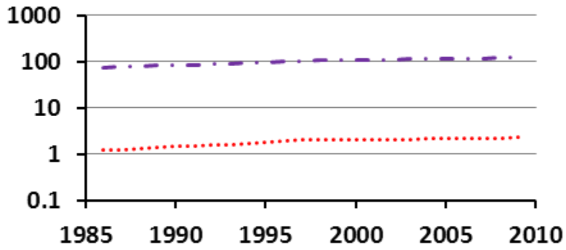
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

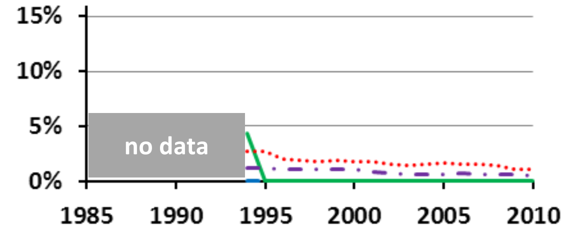
Human Population

Population density (persons/km^2)

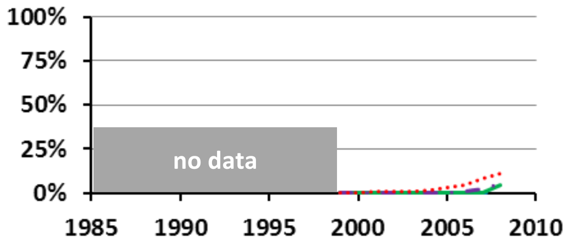


Land Use

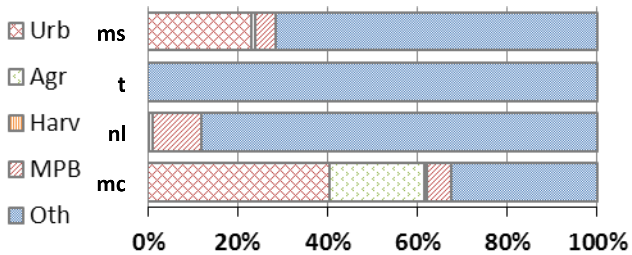
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

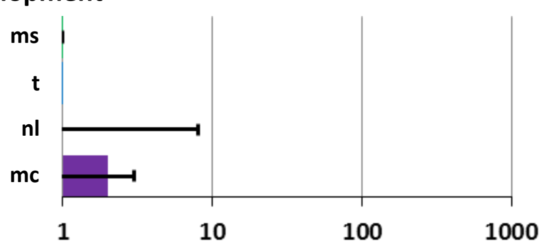


Land use type (% of habitat area)

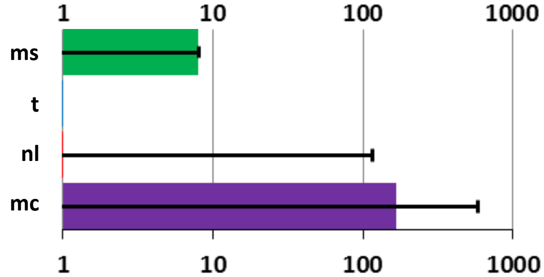


Resource Development

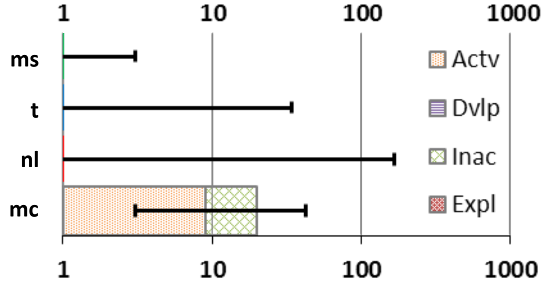
Small scale hydro



Placer mining claims

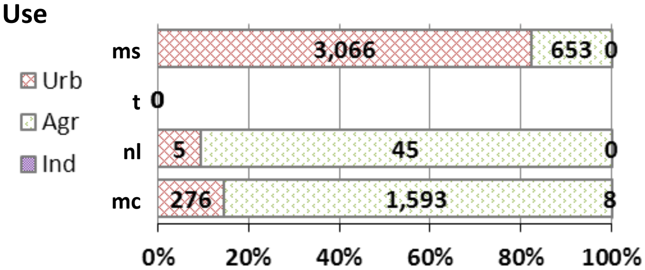


Other mines

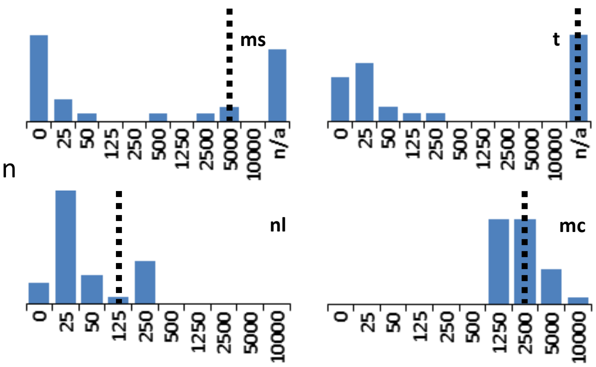


Water Use

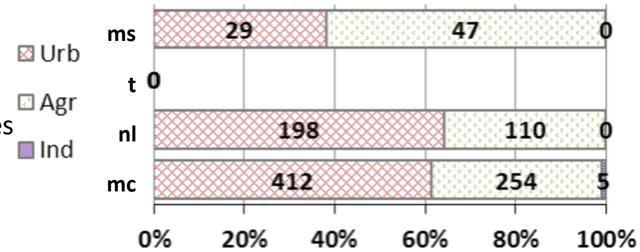
Total allo-cation by use



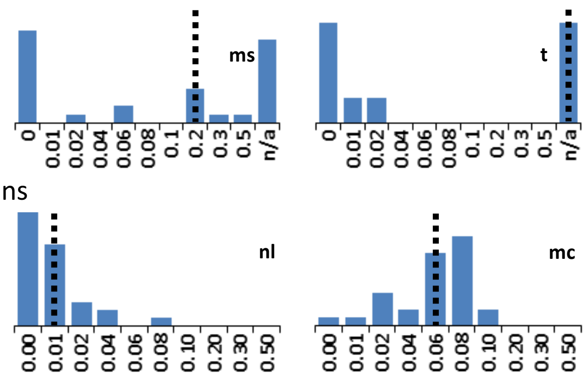
Total allocation (m^3/ha)



Water Licenses

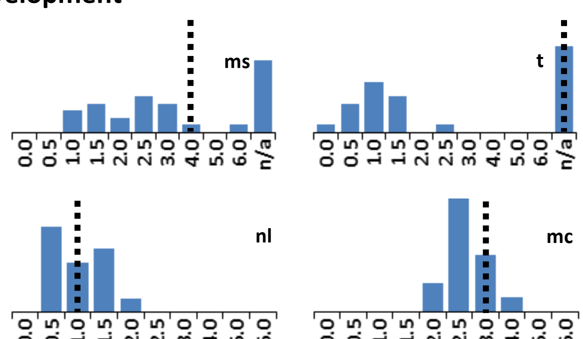


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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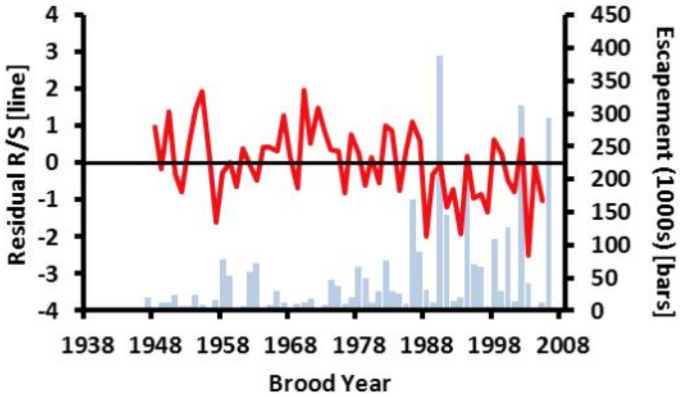
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

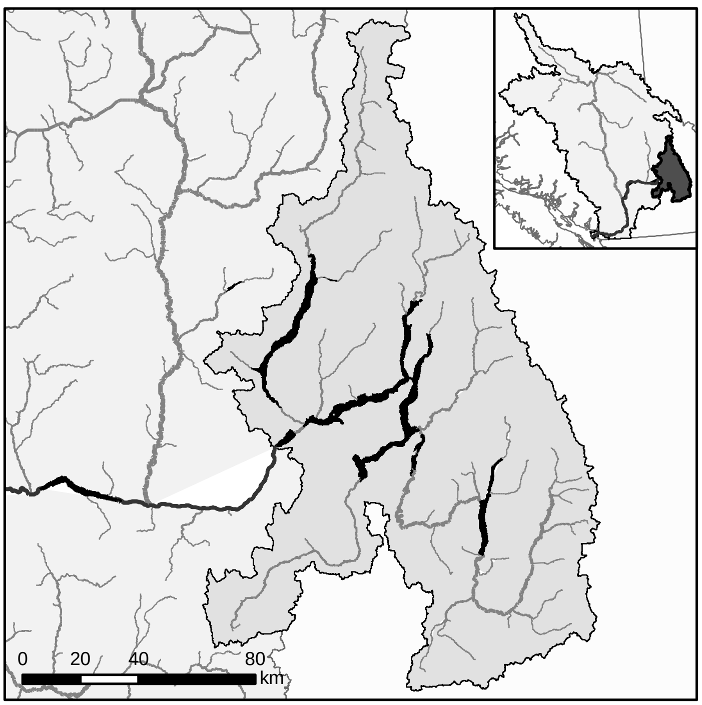
CONSERVATION UNIT

Shuswap Complex — Early Summer — L-9-2

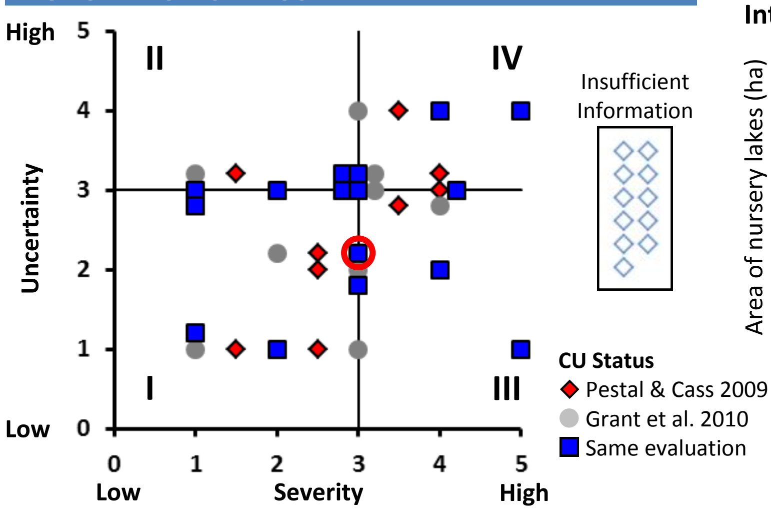
BIOLOGICAL DATA †



LOCATION



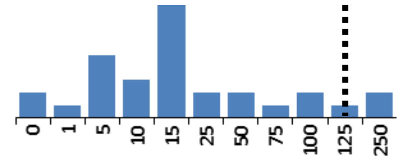
POPULATION STATUS



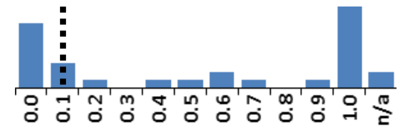
HABITAT STATUS

Spawning††

Total spawning extent (km)

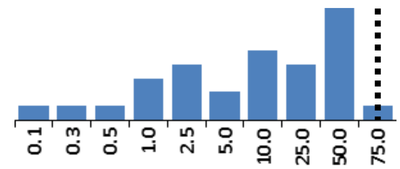


Ratio of lake influence spawning to total spawning

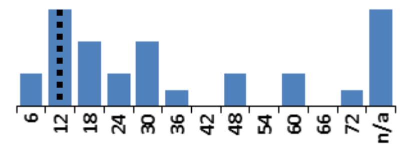


Rearing

Area of nursery lakes (1000 ha)

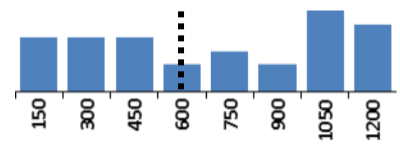


Nursery lake productivity (estimated) (100 smolts/ha)

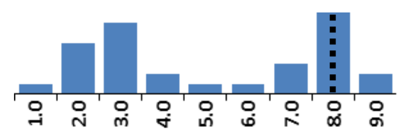


Migration

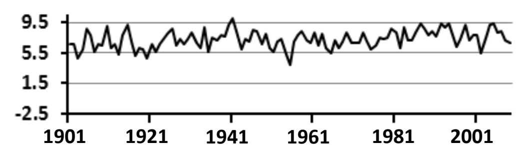
Migration distance (km)



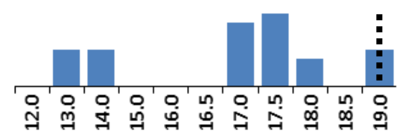
Average spring air temperature at nursery lake (°C)



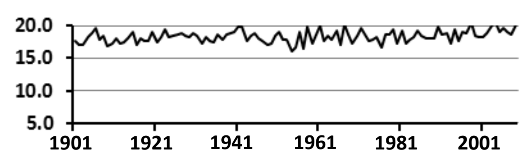
Spring air temperature at nursery lake (°C)



Average air temperature across adult migration (°C)‡

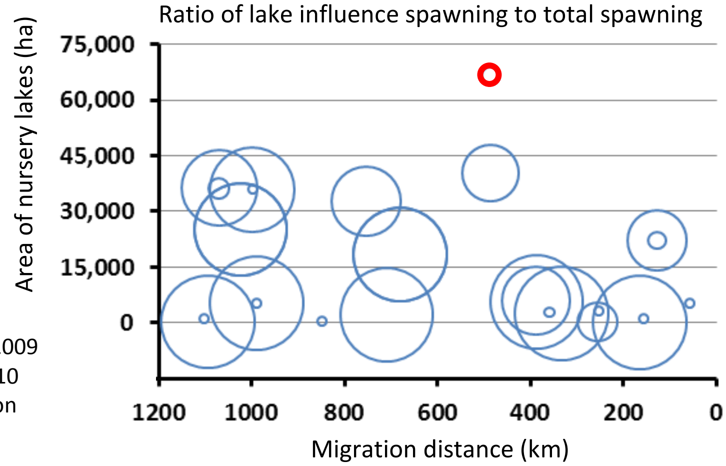


Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability

Ratio of lake influence spawning to total spawning



† Representative stock for productivity: **Seymour**

†† Spawning note: **None.**

‡ Temperature calculated according to run group timing.

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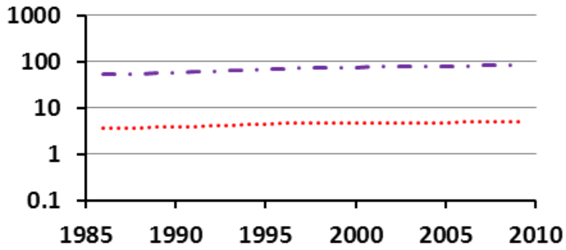
FRESHWATER STRESSORS

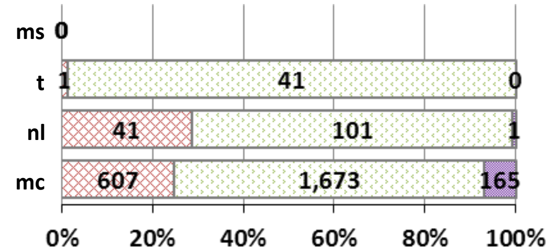
Human Population

Population density (persons/km^2)

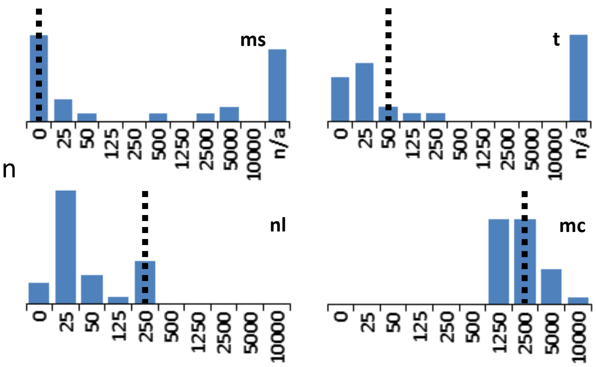


Water Use

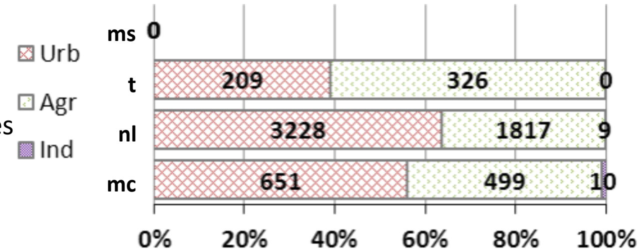
Total allocation by use



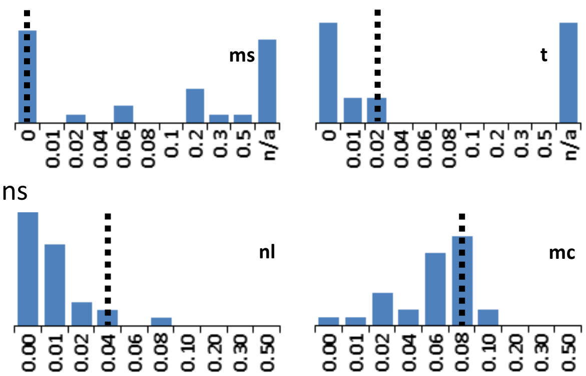
Total allocation (m^3/ha)



Water Licenses

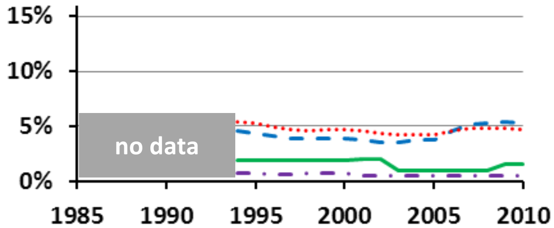


Water Restrictions (#/km^2)

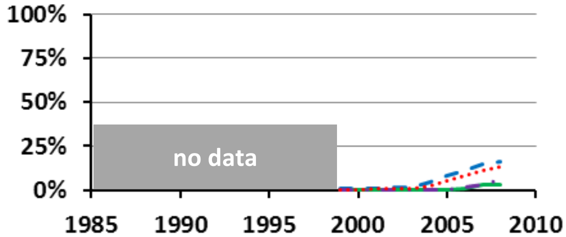


Land Use

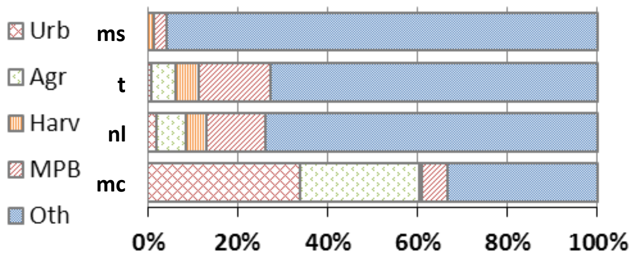
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

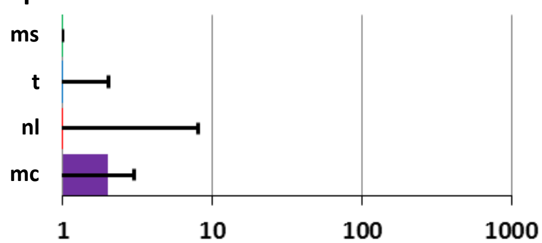


Land use type (% of habitat area)

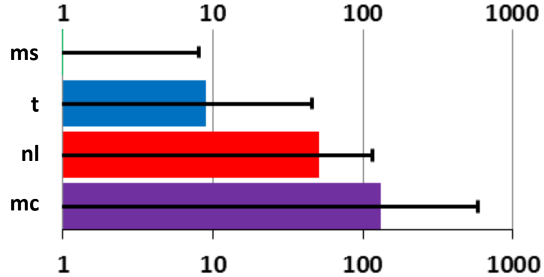


Resource Development

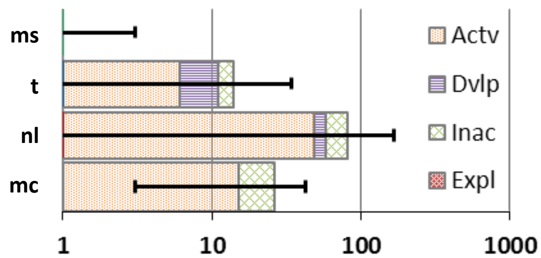
Small scale hydro



Placer mining claims

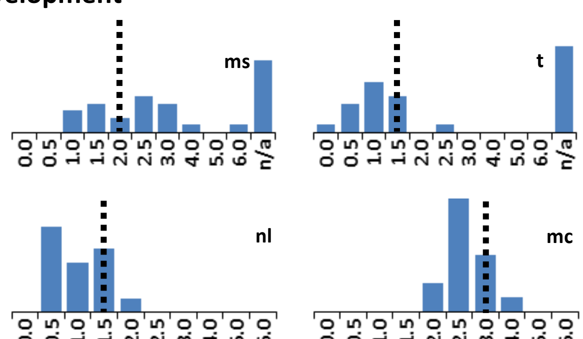


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

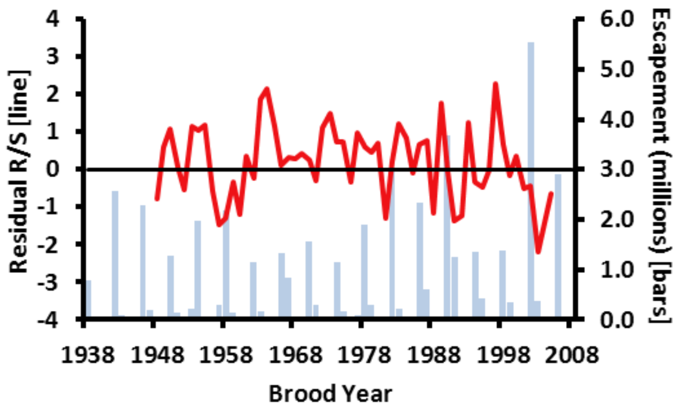
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

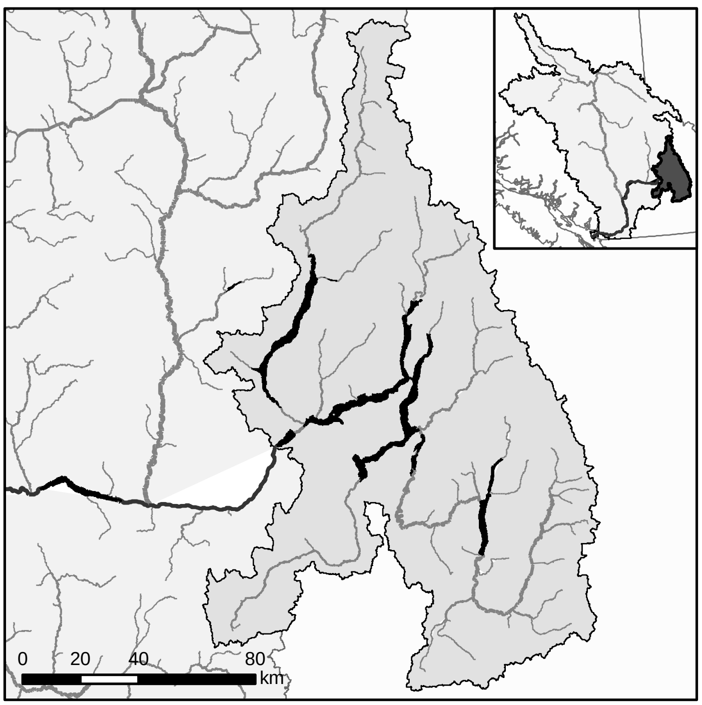
CONSERVATION UNIT

Shuswap Complex — Late — L-9-3

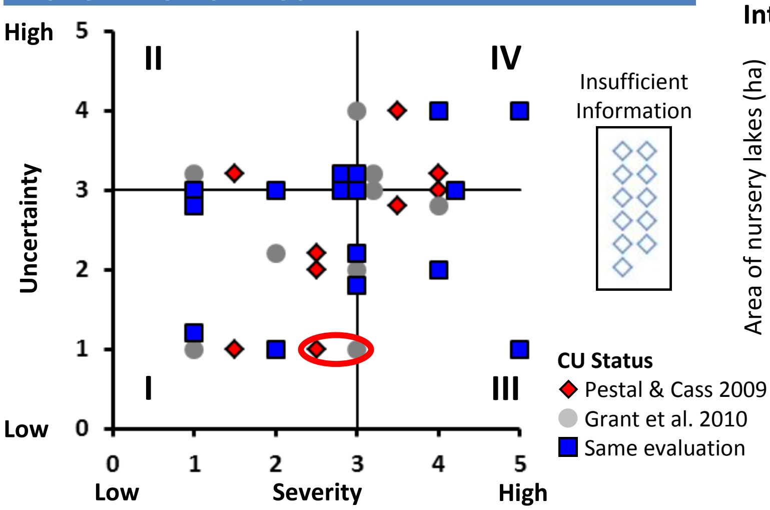
BIOLOGICAL DATA †



LOCATION



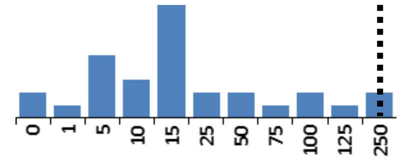
POPULATION STATUS



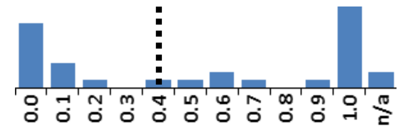
HABITAT STATUS

Spawning††

Total spawning extent (km)

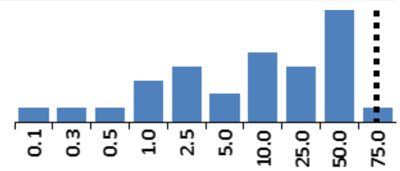


Ratio of lake influence spawning to total spawning

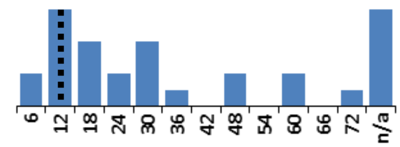


Rearing

Area of nursery lakes (1000 ha)

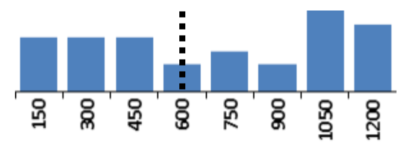


Nursery lake productivity (estimated) (100 smolts/ha)

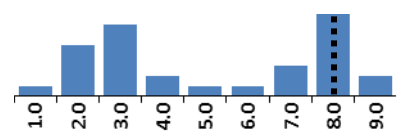


Migration

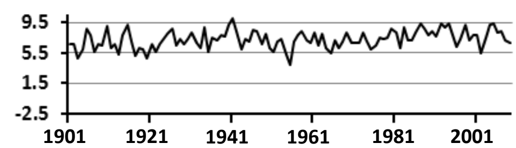
Migration distance (km)



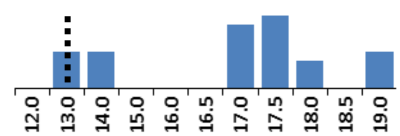
Average spring air temperature at nursery lake (°C)



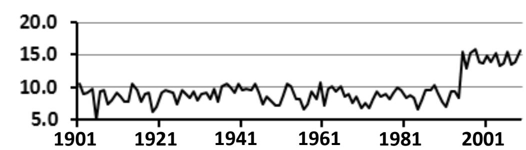
Spring air temperature at nursery lake (°C)



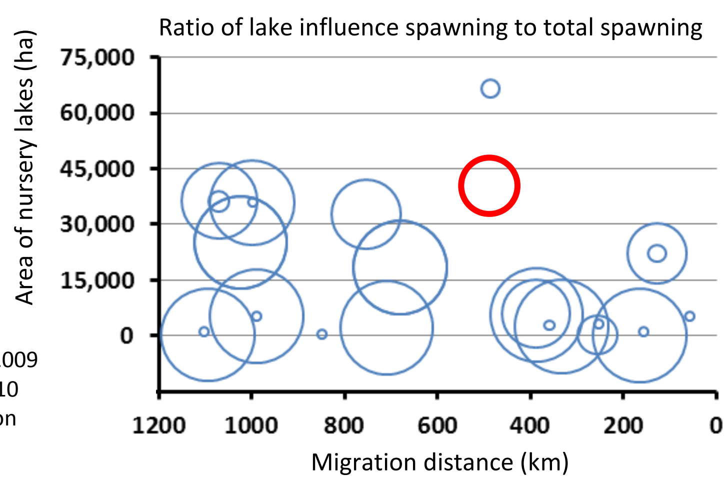
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Late Shuswap**

†† Spawning note: **None.**

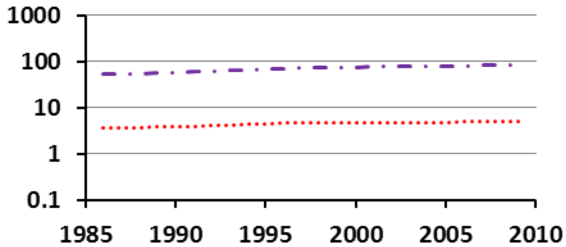
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

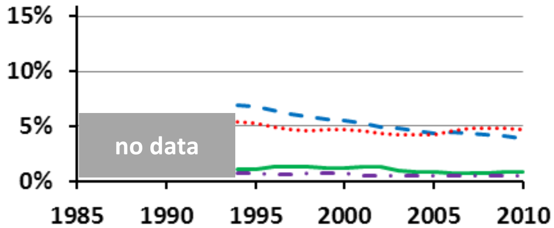
Human Population

Population density (persons/km^2)

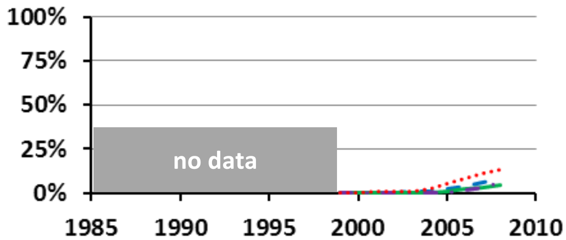


Land Use

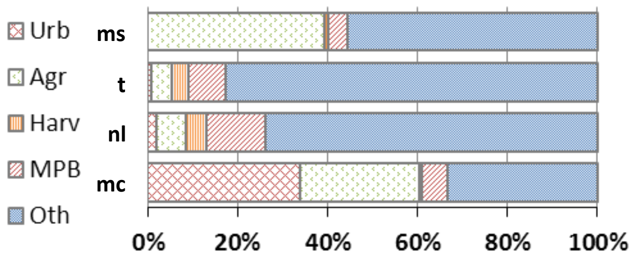
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

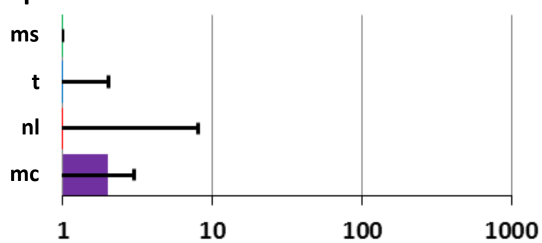


Land use type (% of habitat area)

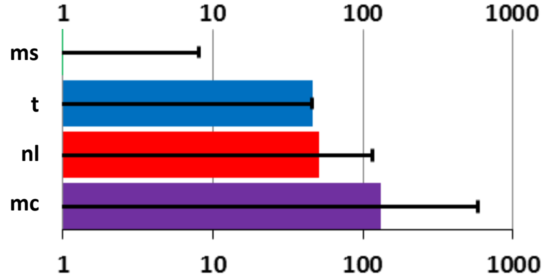


Resource Development

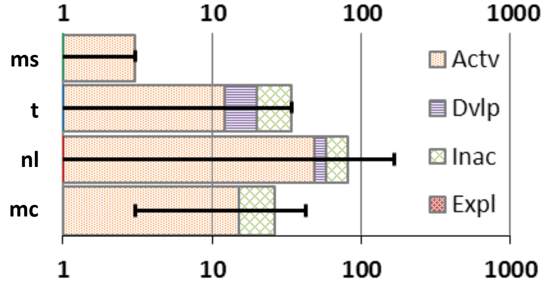
Small scale hydro



Placer mining claims

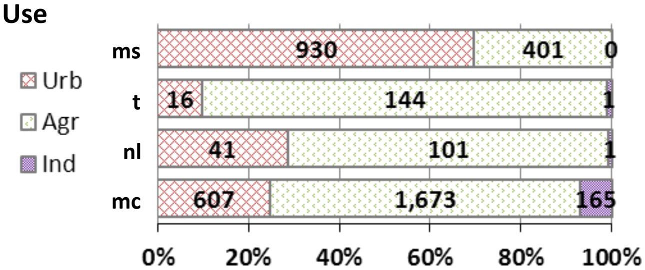


Other mines

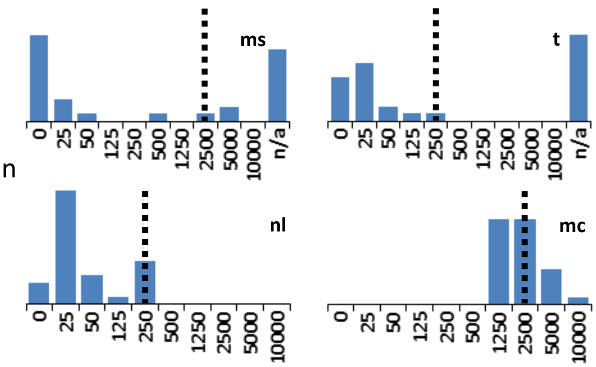


Water Use

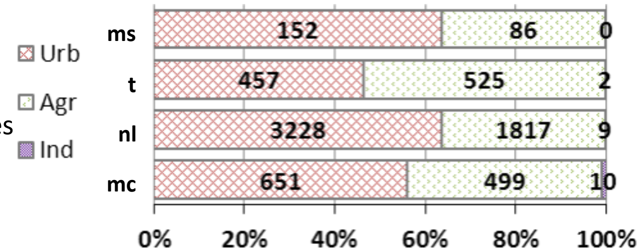
Total allo-cation by use



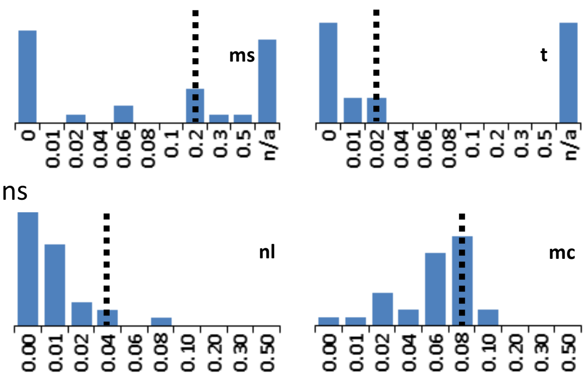
Total allocation (m^3/ha)



Water Licenses

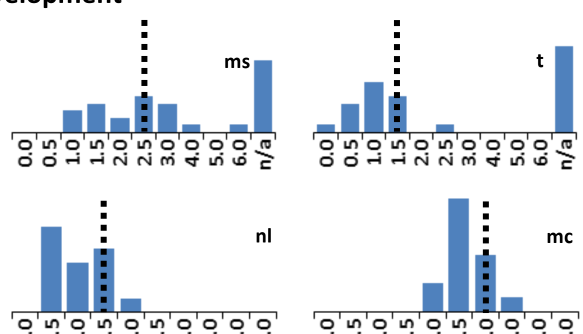


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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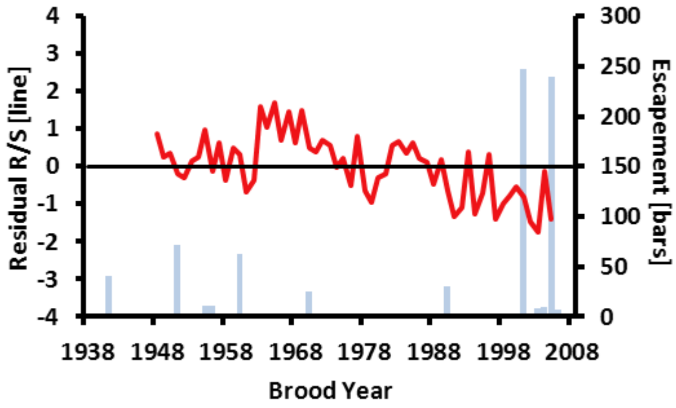
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

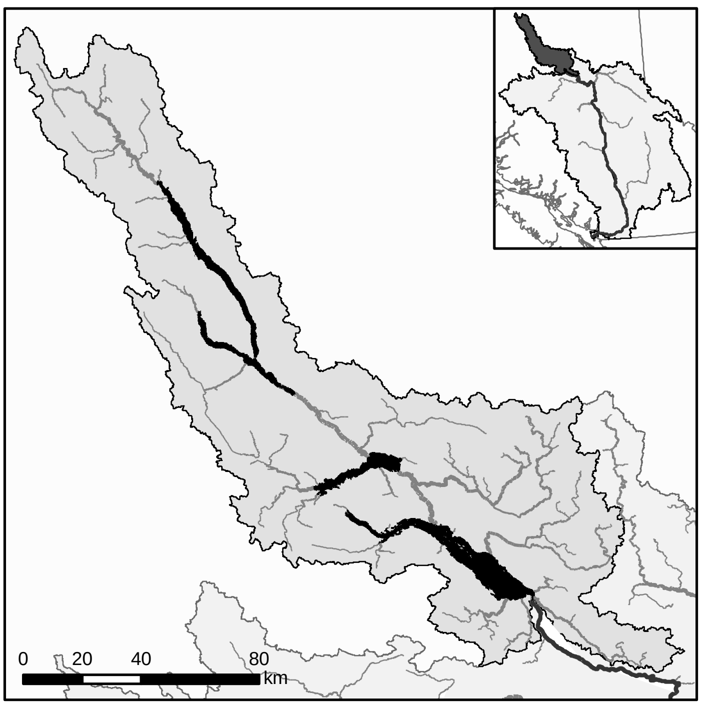
CONSERVATION UNIT

Stuart — Early Stuart — L-6-12

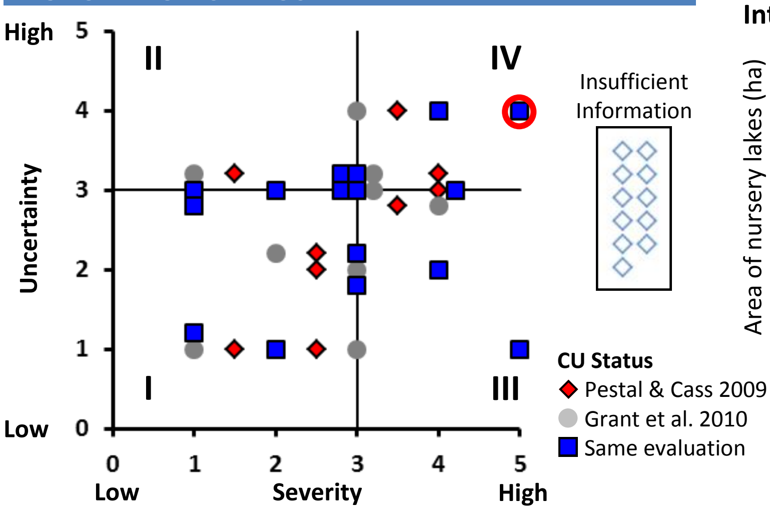
BIOLOGICAL DATA †



LOCATION



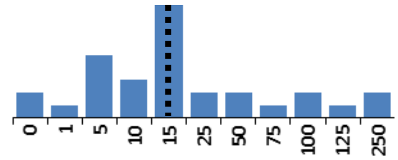
POPULATION STATUS



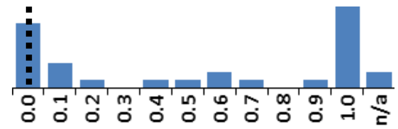
HABITAT STATUS

Spawning††

Total spawning extent (km)

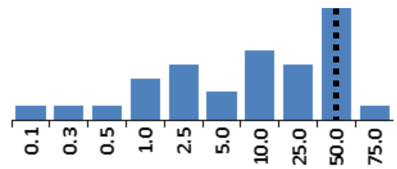


Ratio of lake influence spawning to total spawning

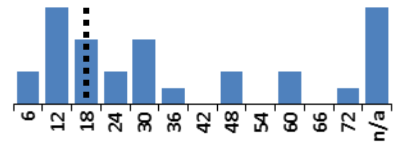


Rearing

Area of nursery lakes (1000 ha)

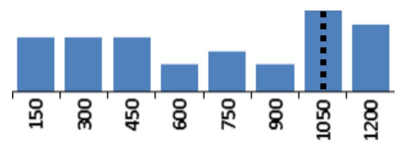


Nursery lake productivity (estimated) (100 smolts/ha)

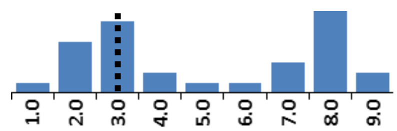


Migration

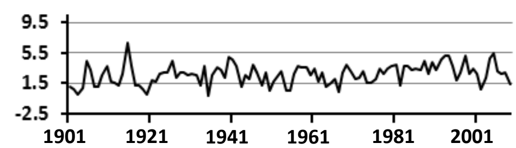
Migration distance (km)



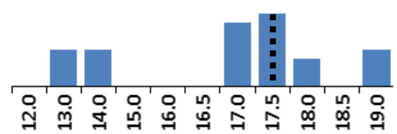
Average spring air temperature at nursery lake (°C)



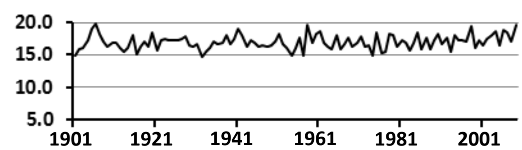
Spring air temperature at nursery lake (°C)



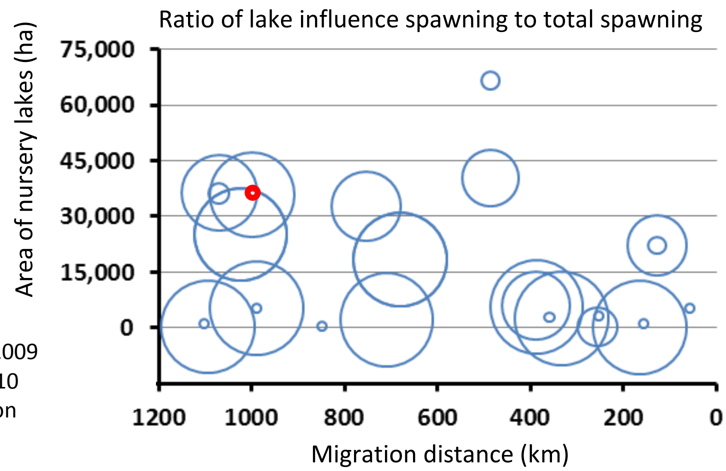
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Early Stuart**

†† Spawning note: **None.**

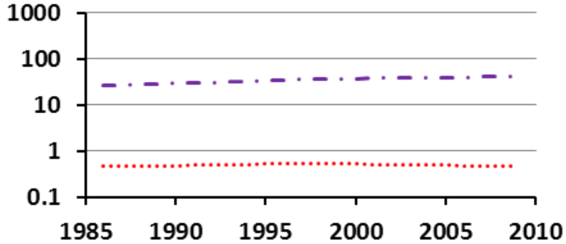
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

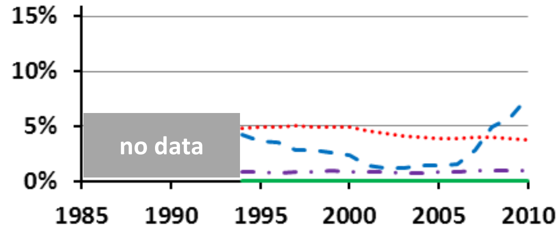
Human Population

Population density (persons/km^2)

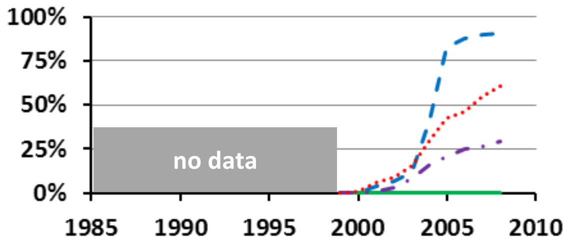


Land Use

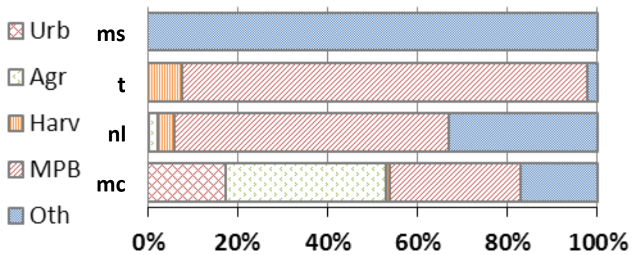
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

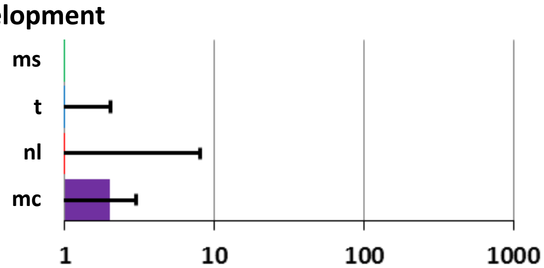


Land use type (% of habitat area)

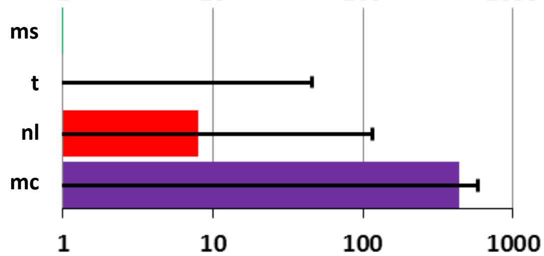


Resource Development

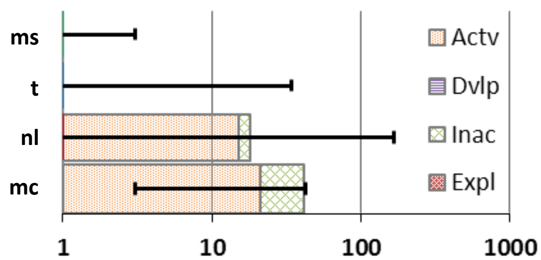
Small scale hydro



Placer mining claims

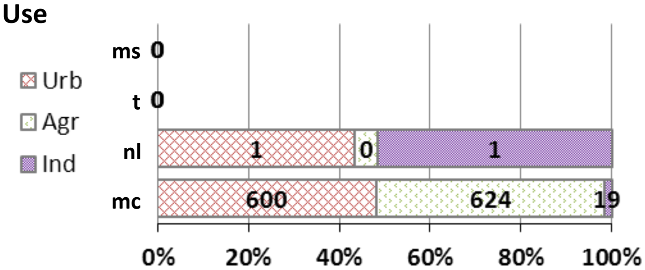


Other mines

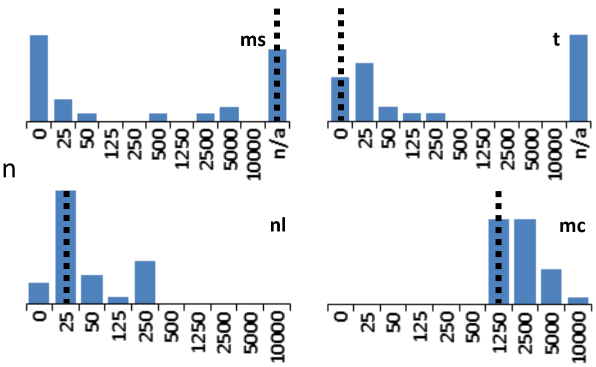


Water Use

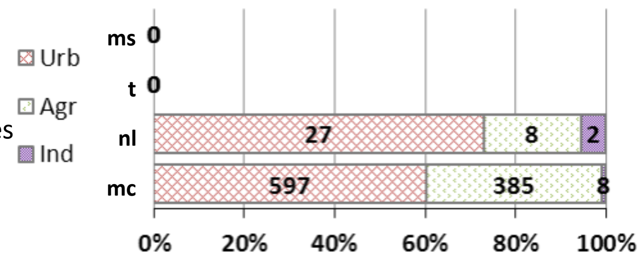
Total allo-cation by use



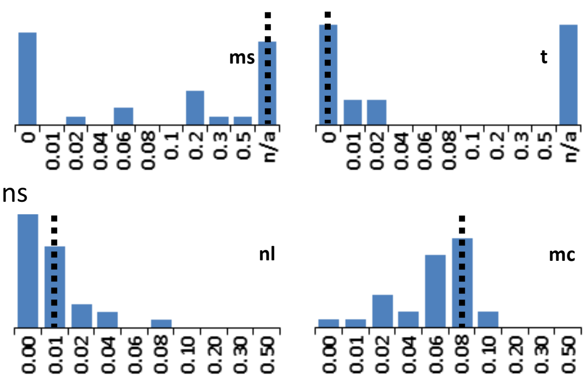
Total allocation (m^3/ha)



Water Licenses

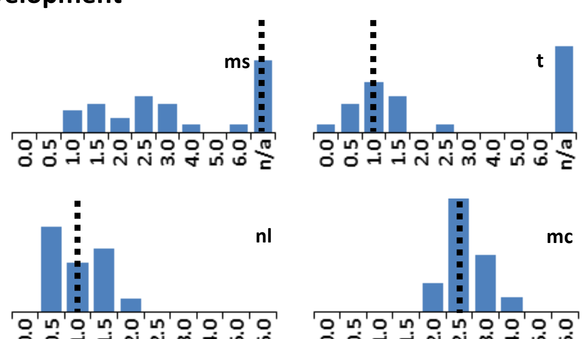


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

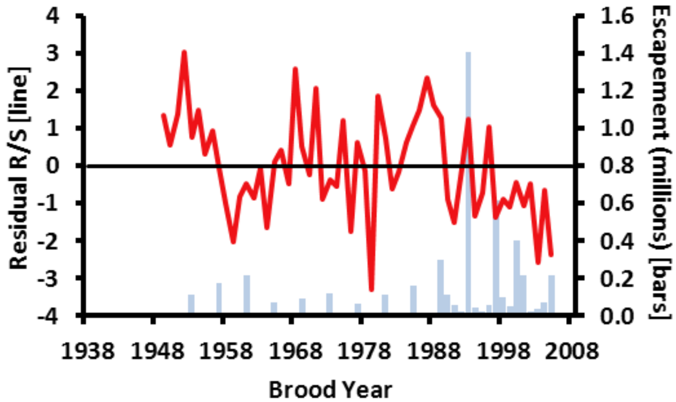
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

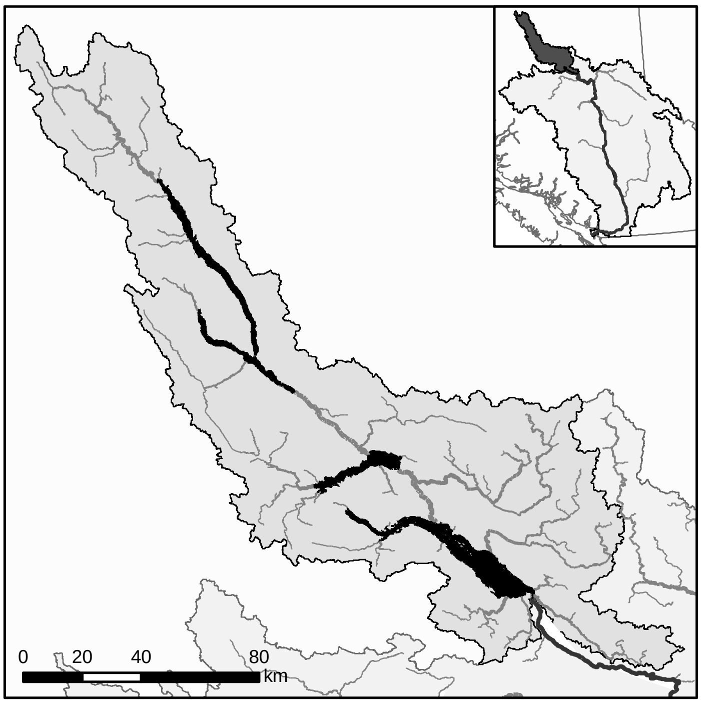
CONSERVATION UNIT

Stuart — Summer — L-6-13

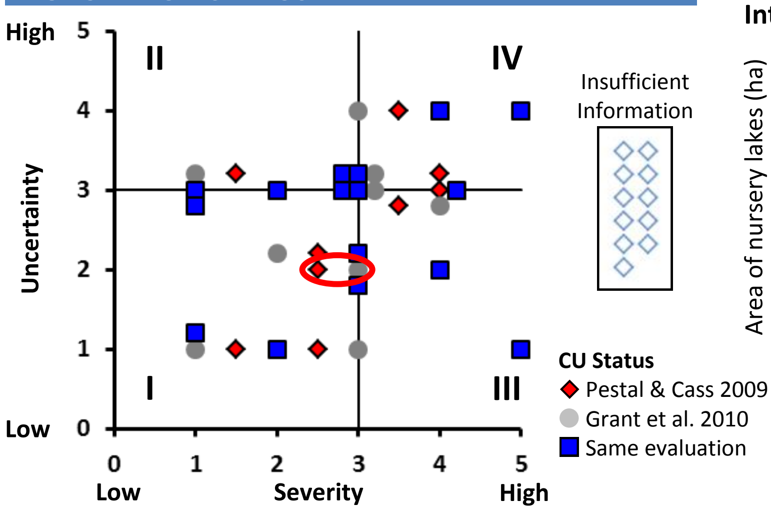
BIOLOGICAL DATA †



LOCATION



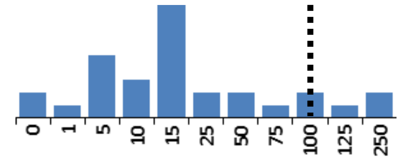
POPULATION STATUS



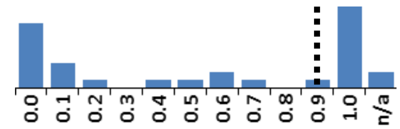
HABITAT STATUS

Spawning††

Total spawning extent (km)

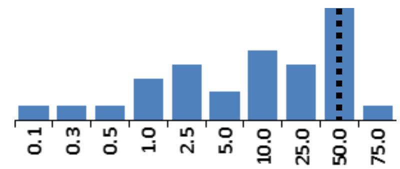


Ratio of lake influence spawning to total spawning

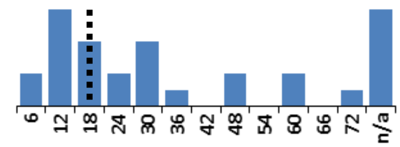


Rearing

Area of nursery lakes (1000 ha)

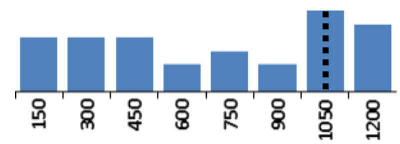


Nursery lake productivity (estimated) (100 smolts/ha)

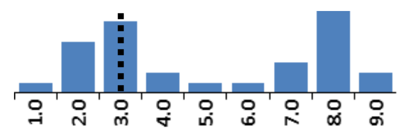


Migration

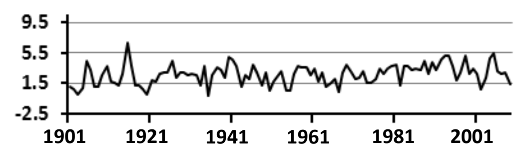
Migration distance (km)



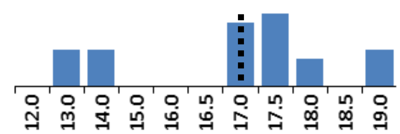
Average spring air temperature at nursery lake (°C)



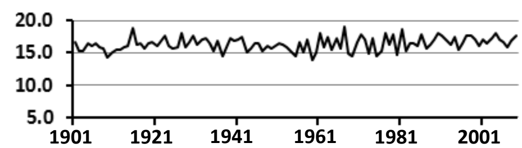
Spring air temperature at nursery lake (°C)



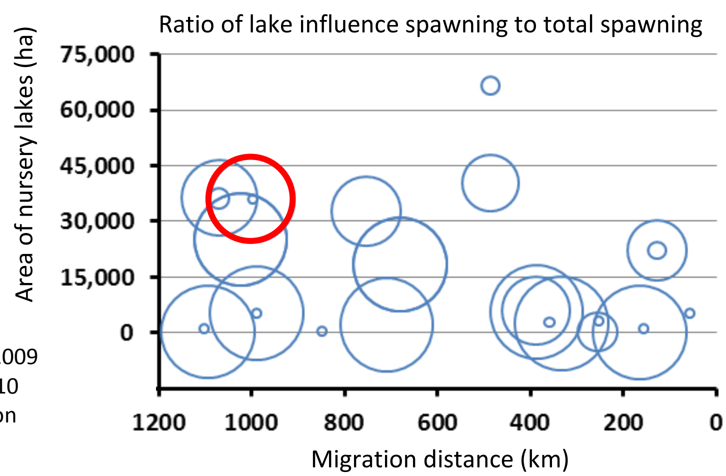
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Late Stuart**

†† Spawning note: **None.**

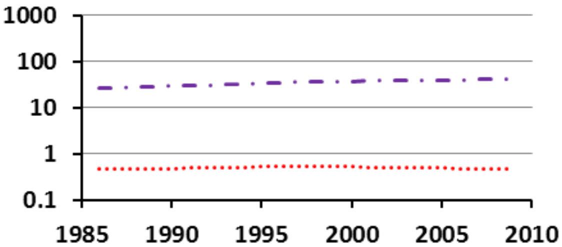
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

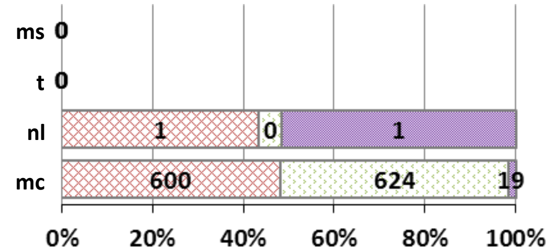
Human Population

Population density (persons/km²)



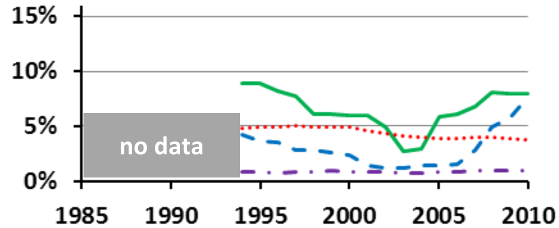
Water Use

Total allo-cation by use

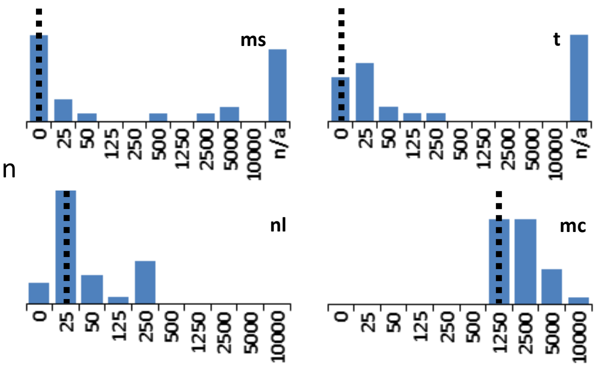


Land Use

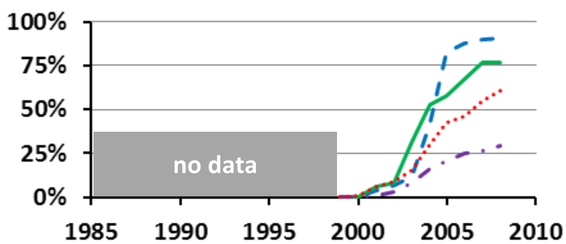
Forest harvesting (% of habitat area)



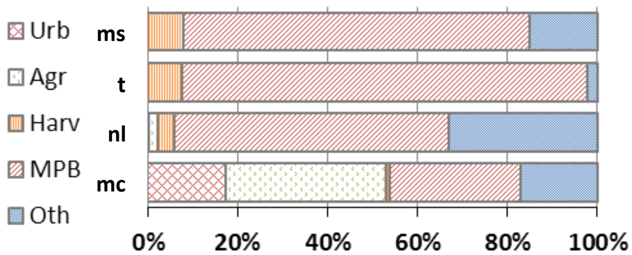
Total allocation (m³/ha)



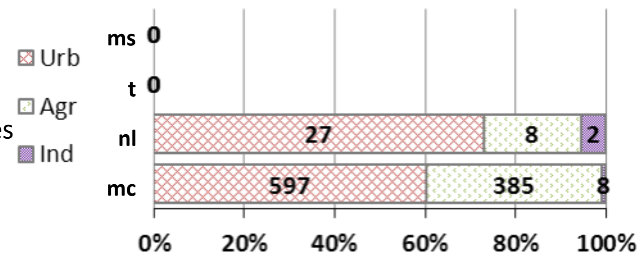
Mountain pine beetle disturbance (cumulative % of habitat area)



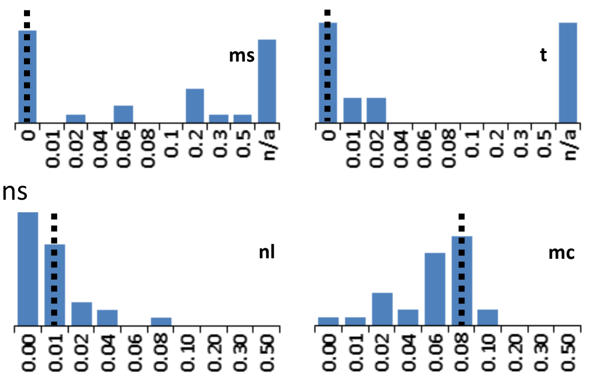
Land use type (% of habitat area)



Water Licenses

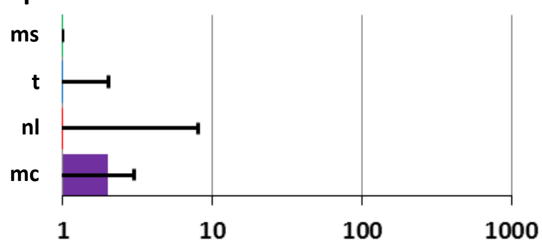


Water Restrictions (#/km²)

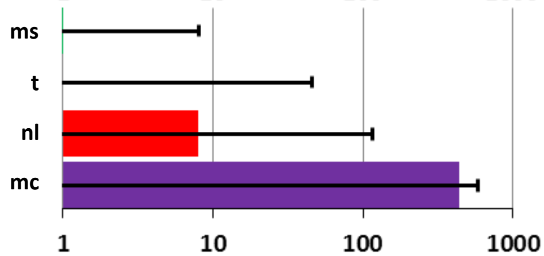


Resource Development

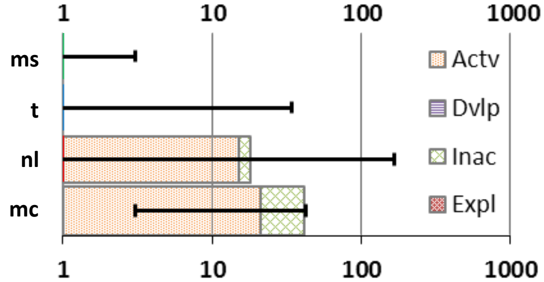
Small scale hydro



Placer mining claims

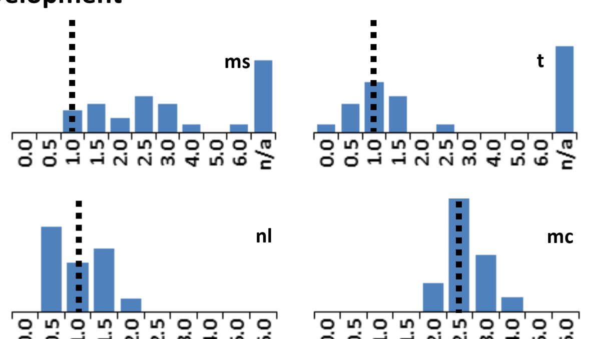


Other mines



Road Development

Road density (km/km²)



Abbreviations:

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Dvlp developed prospects
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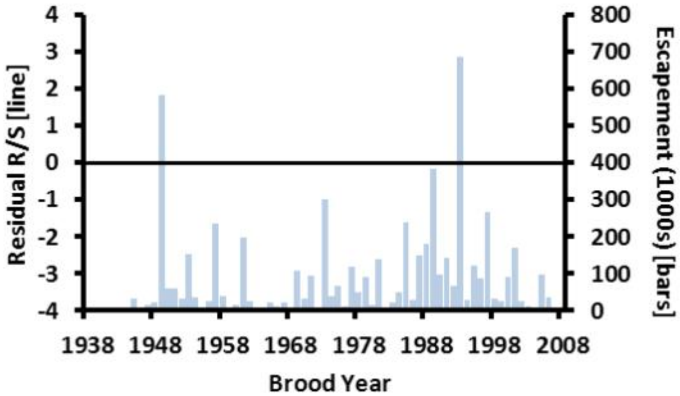
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

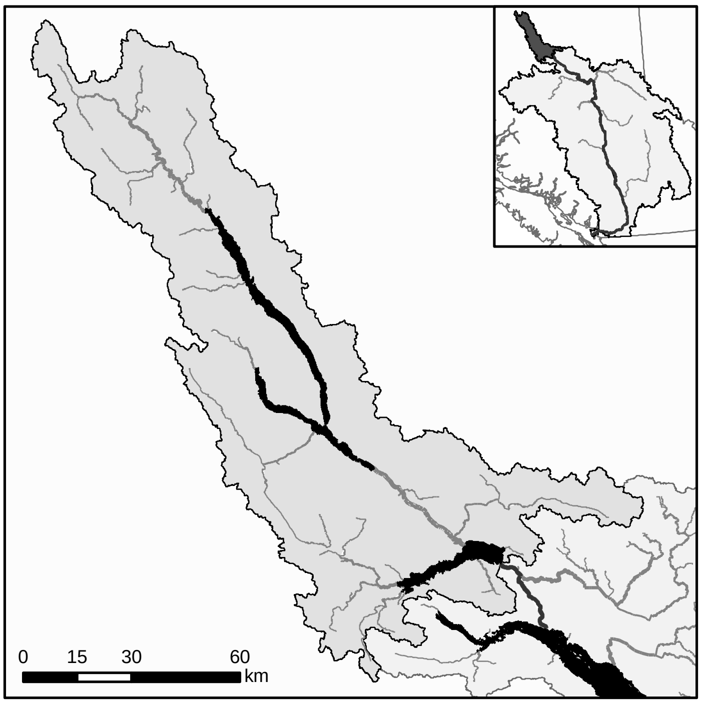
CONSERVATION UNIT

Takla/Trembleur — Early Stuart — L-6-14

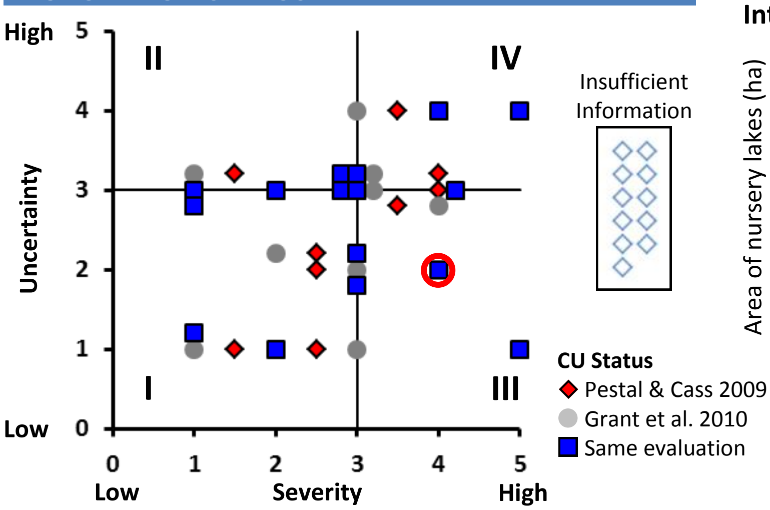
BIOLOGICAL DATA †



LOCATION



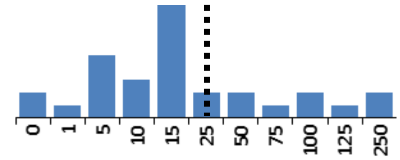
POPULATION STATUS



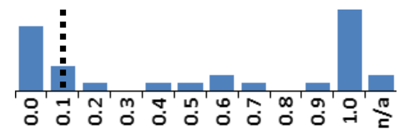
HABITAT STATUS

Spawning††

Total spawning extent (km)

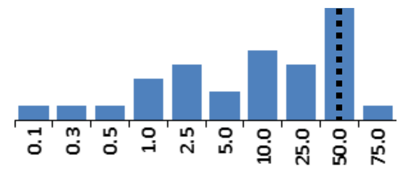


Ratio of lake influence spawning to total spawning

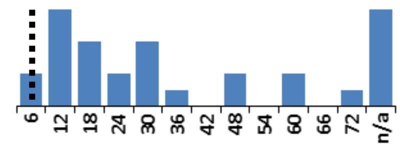


Rearing

Area of nursery lakes (1000 ha)

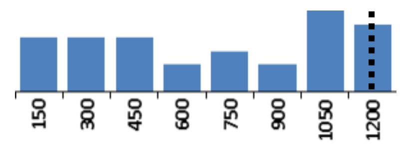


Nursery lake productivity (estimated) (100 smolts/ha)

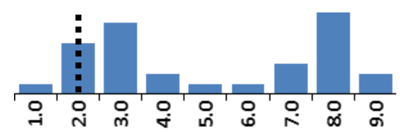


Migration

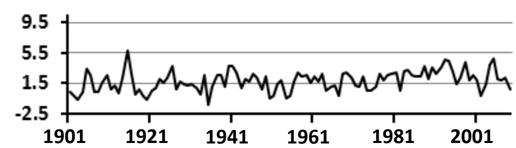
Migration distance (km)



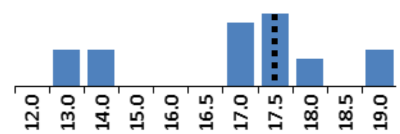
Average spring air temperature at nursery lake (°C)



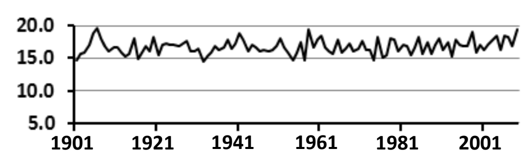
Spring air temperature at nursery lake (°C)



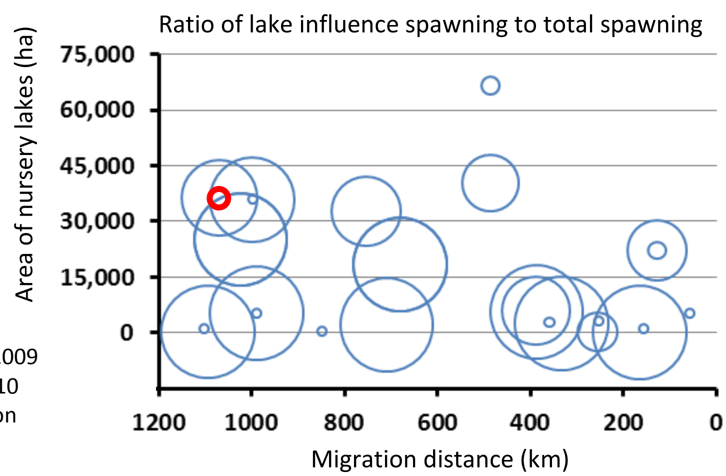
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

†† Spawning note: **None.**

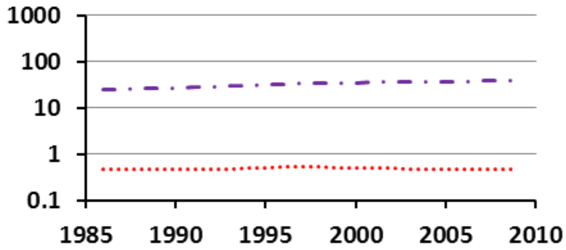
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

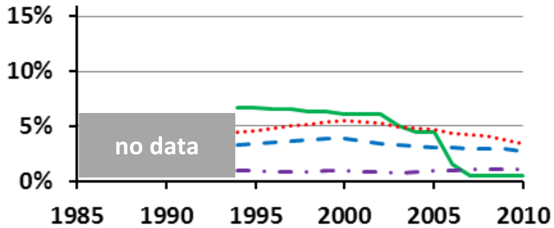
Human Population

Population density (persons/km^2)

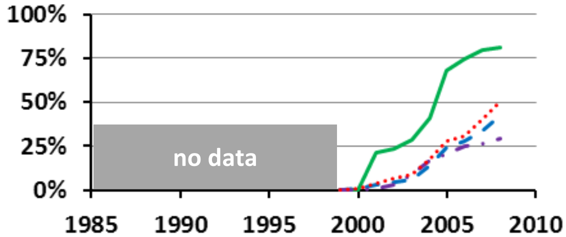


Land Use

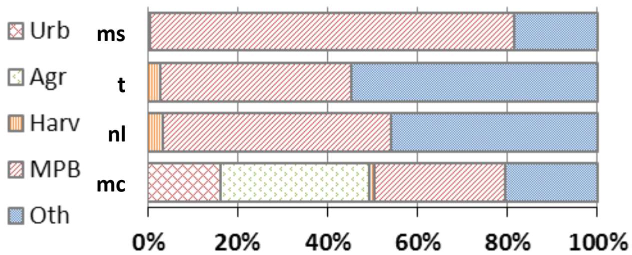
Forest harvesting (% of habitat area)



Mountain pine beetle disturbance (cumulative % of habitat area)

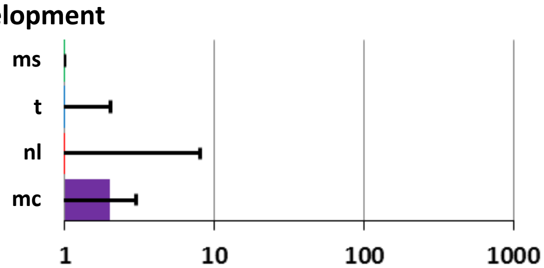


Land use type (% of habitat area)

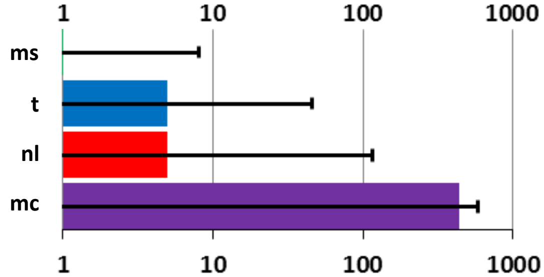


Resource Development

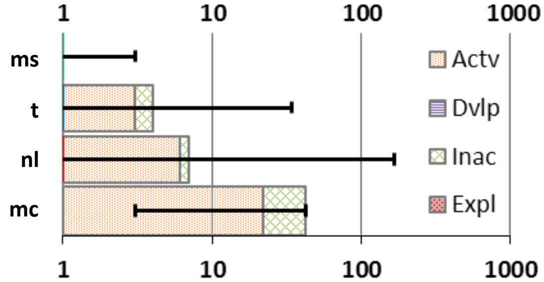
Small scale hydro



Placer mining claims

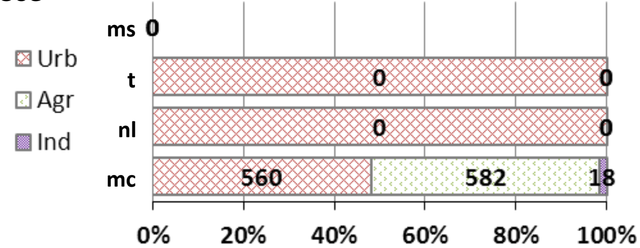


Other mines

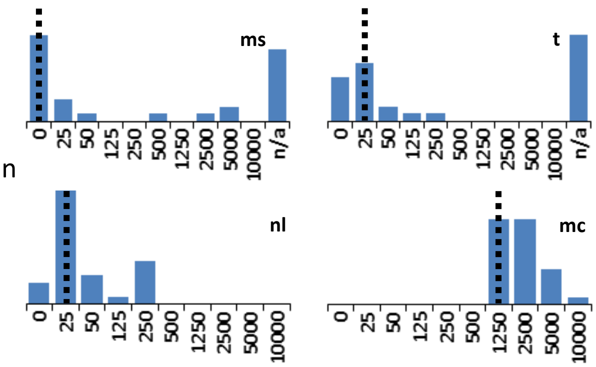


Water Use

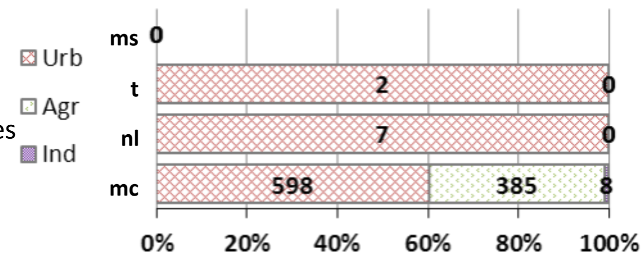
Total allocation by use



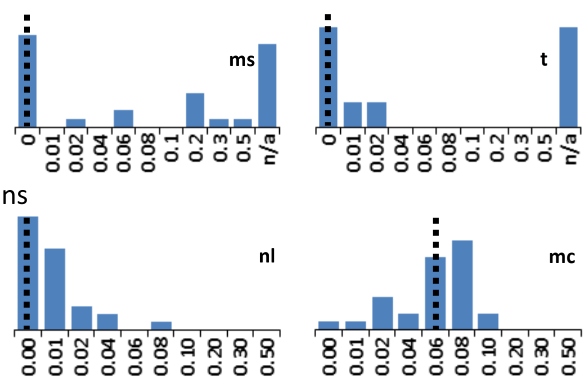
Total allocation (m^3/ha)



Water Licenses

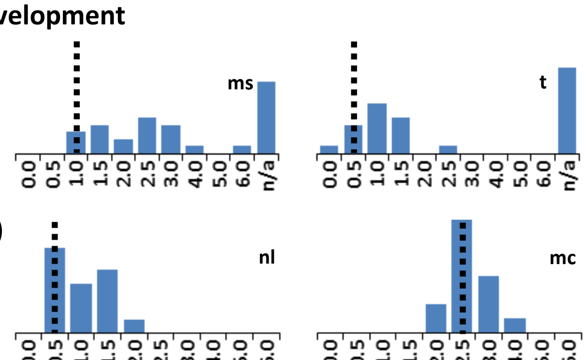


Water Restrictions (#/km^2)



Road Development

Road density (km/km^2)



Abbreviations:

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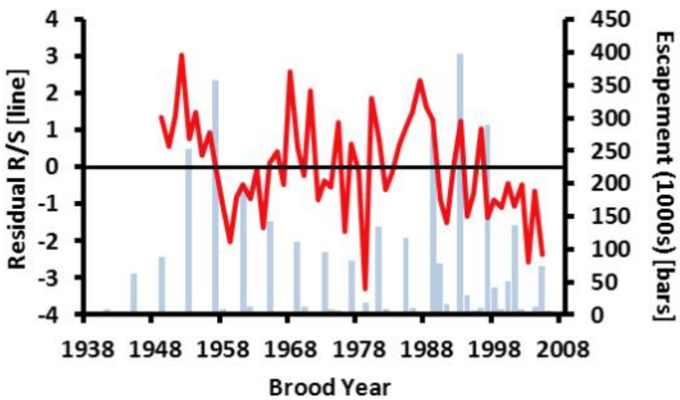
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

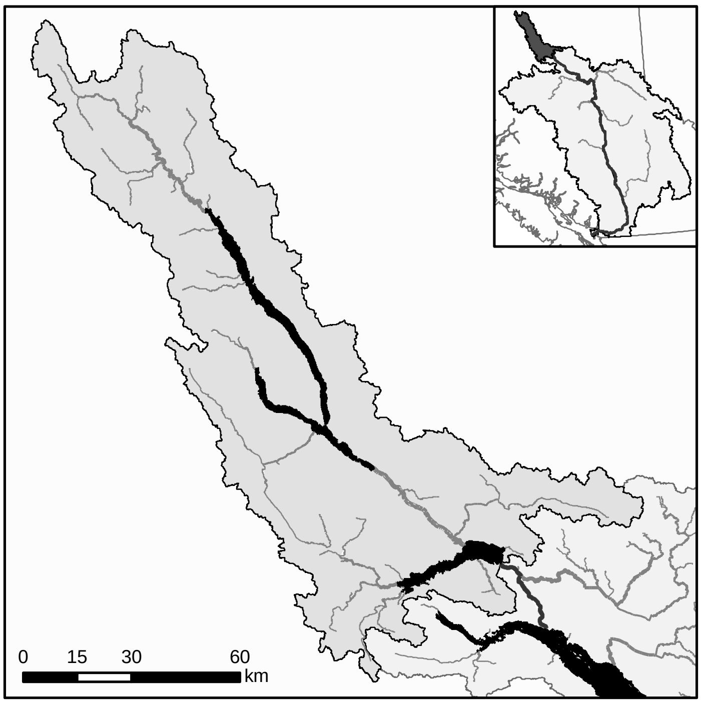
CONSERVATION UNIT

Takla/Trembleur — Summer — L-6-15

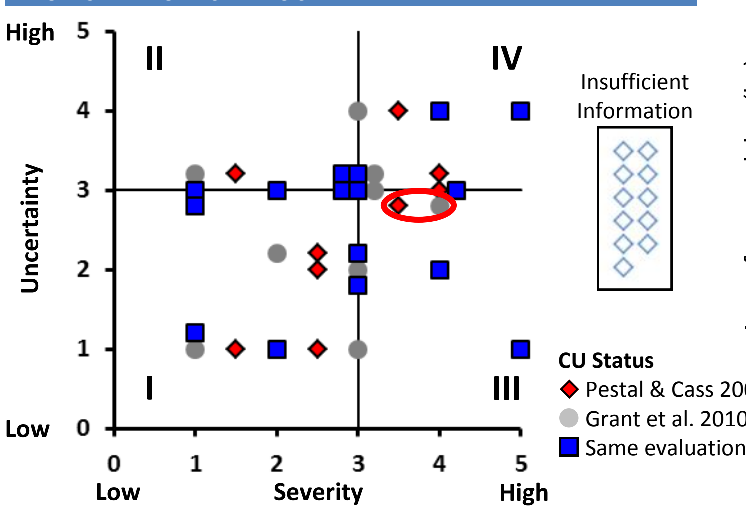
BIOLOGICAL DATA †



LOCATION



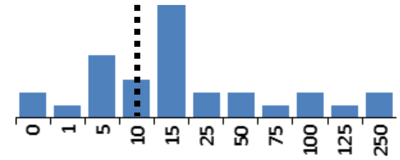
POPULATION STATUS



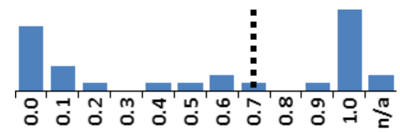
HABITAT STATUS

Spawning††

Total spawning extent (km)

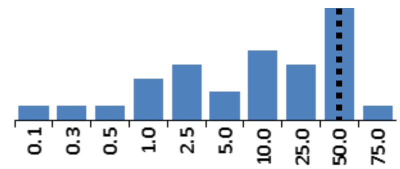


Ratio of lake influence spawning to total spawning

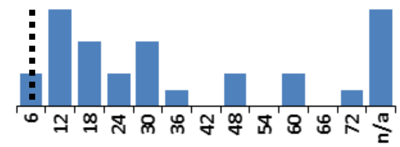


Rearing

Area of nursery lakes (1000 ha)

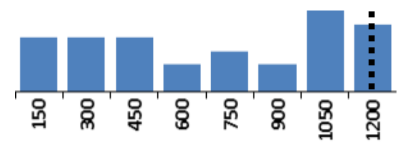


Nursery lake productivity (estimated) (100 smolts/ha)

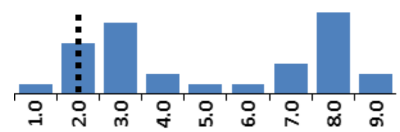


Migration

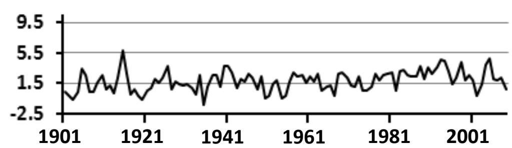
Migration distance (km)



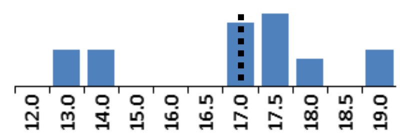
Average spring air temperature at nursery lake (°C)



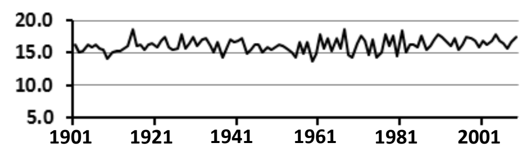
Spring air temperature at nursery lake (°C)



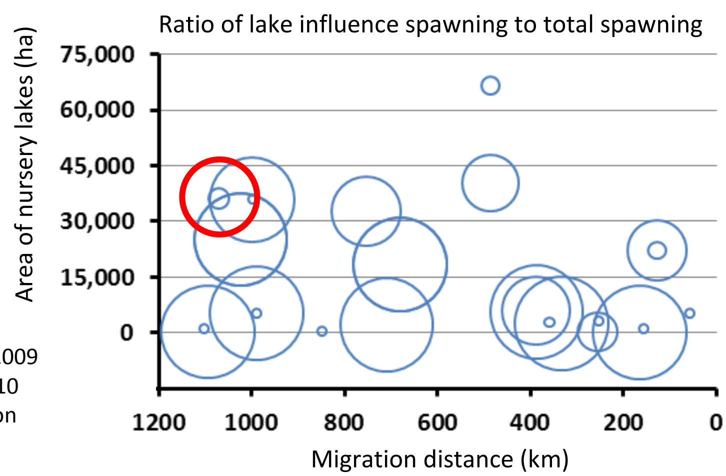
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **Late Stuart**

†† Spawning note: **None.**

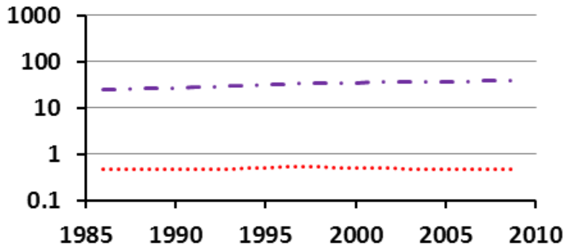
‡ Temperature calculated according to run group timing.

January 31, 2011

FRESHWATER STRESSORS

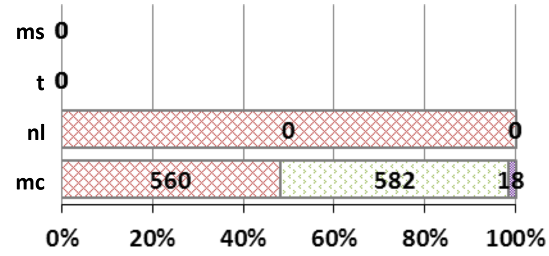
Human Population

Population density (persons/km^2)

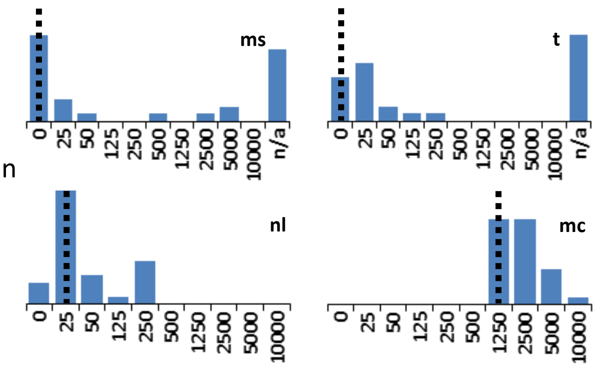


Water Use

Total allo-cation by use

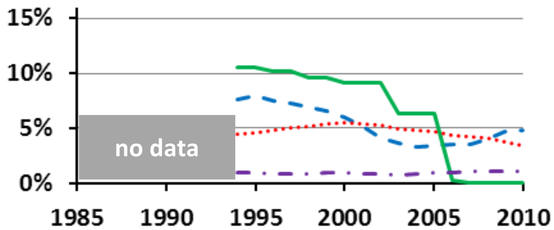


Total allocation (m^3/ha)

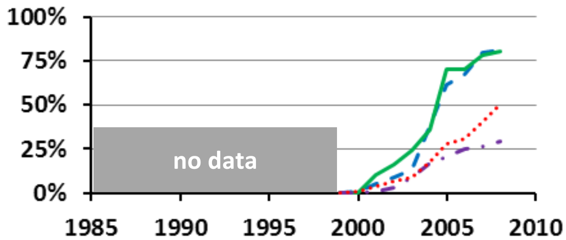


Land Use

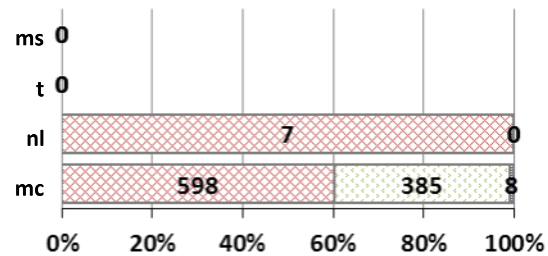
Forest harvesting (% of habitat area)



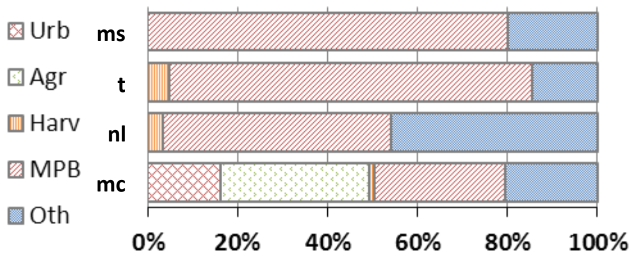
Mountain pine beetle disturbance (cumulative % of habitat area)



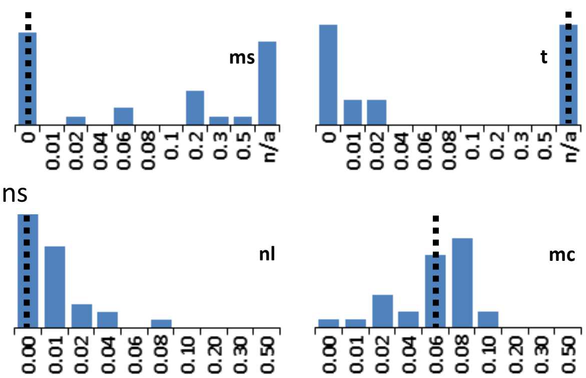
Water Licenses



Land use type (% of habitat area)

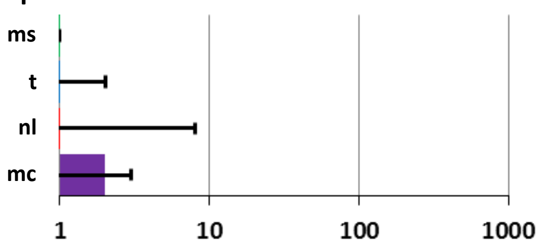


Water Restrictions (#/km^2)

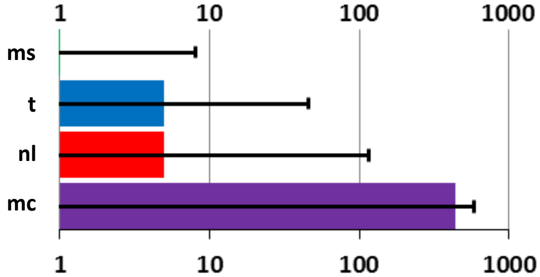


Resource Development

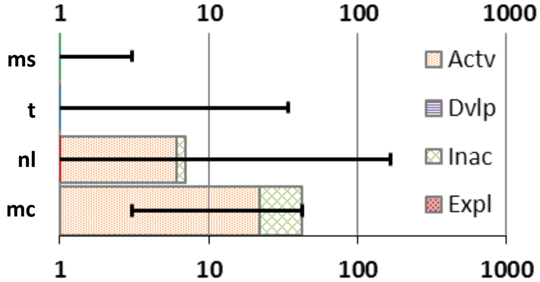
Small scale hydro



Placer mining claims

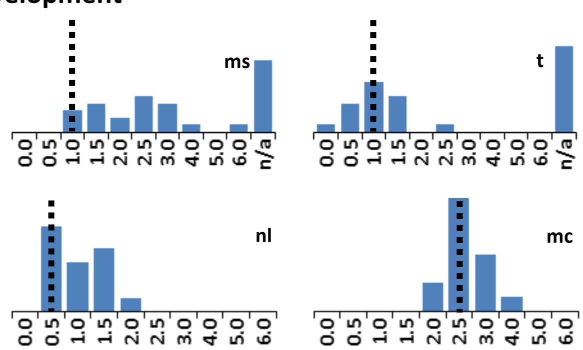


Other mines



Road Development

Road density (km/km^2)



Abbreviations:

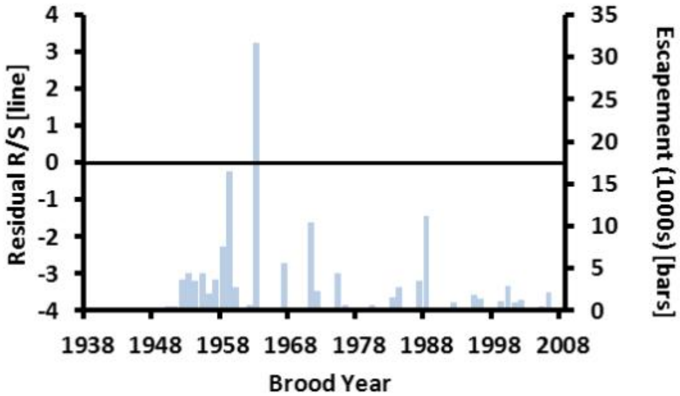
Urb urban
Agr agricultural
Harv harvesting disturbance
MPB mountain pine beetle disturbance
Oth other land use
Ind industrial
Act active mines
Dvlp developed prospects
Inac inactive mines
Expl major explorations

Habitat types: Main stem spawning (**ms**) Tributary spawning (**t**) Nursery lake rearing (**nl**) Migration corridor (**mc**)

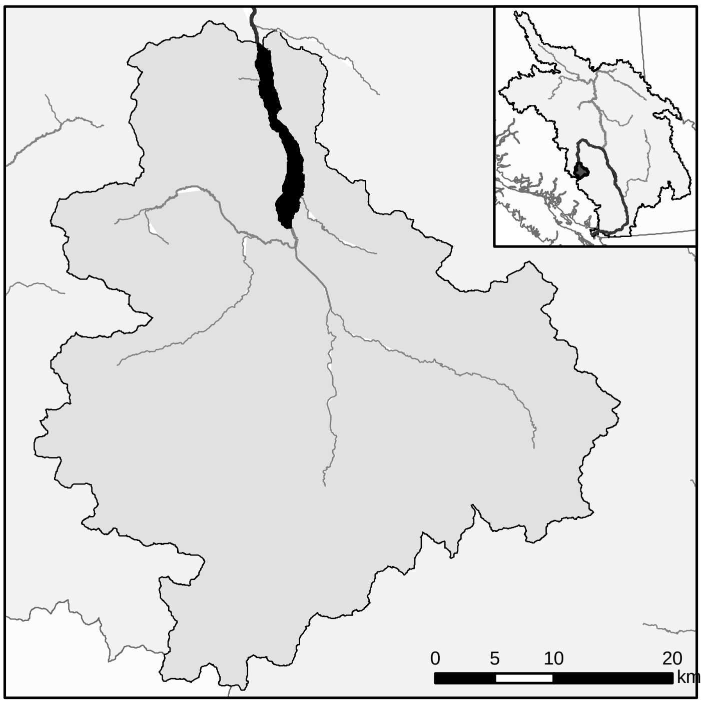
CONSERVATION UNIT

Taseko — Early Summer — L-6-16

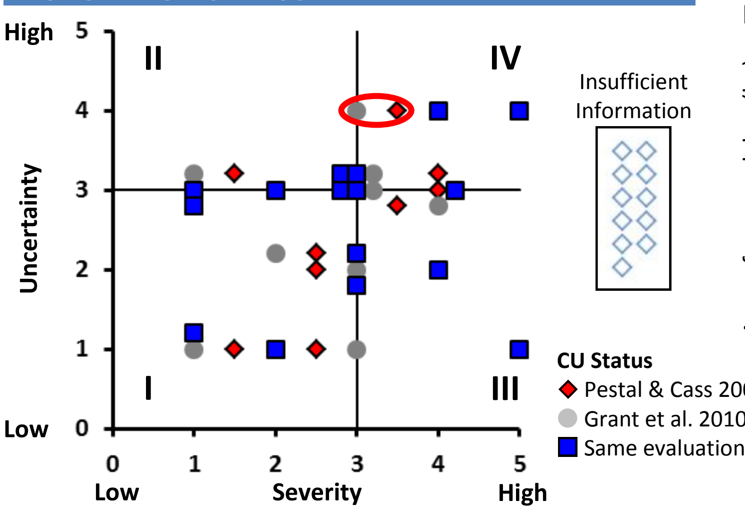
BIOLOGICAL DATA †



LOCATION



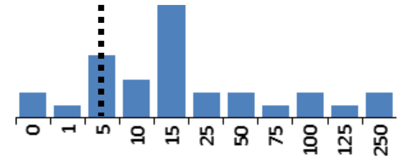
POPULATION STATUS



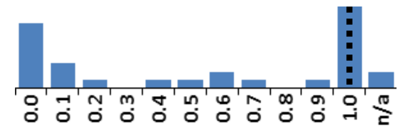
HABITAT STATUS

Spawning††

Total spawning extent (km)

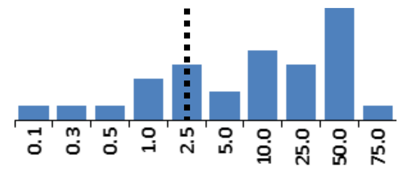


Ratio of lake influence spawning to total spawning

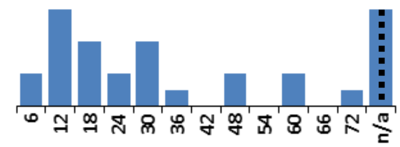


Rearing

Area of nursery lakes (1000 ha)

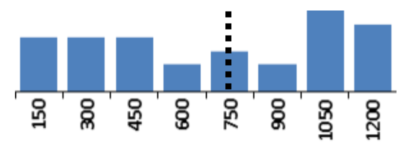


Nursery lake productivity (estimated) (100 smolts/ha)

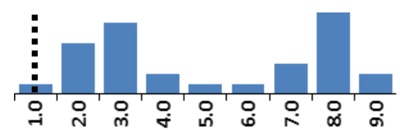


Migration

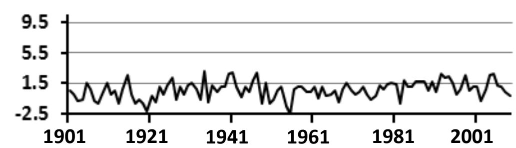
Migration distance (km)



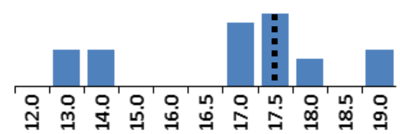
Average spring air temperature at nursery lake (°C)



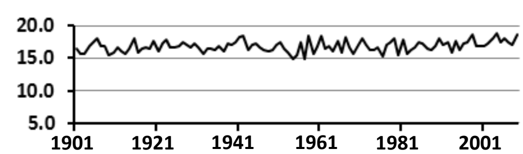
Spring air temperature at nursery lake (°C)



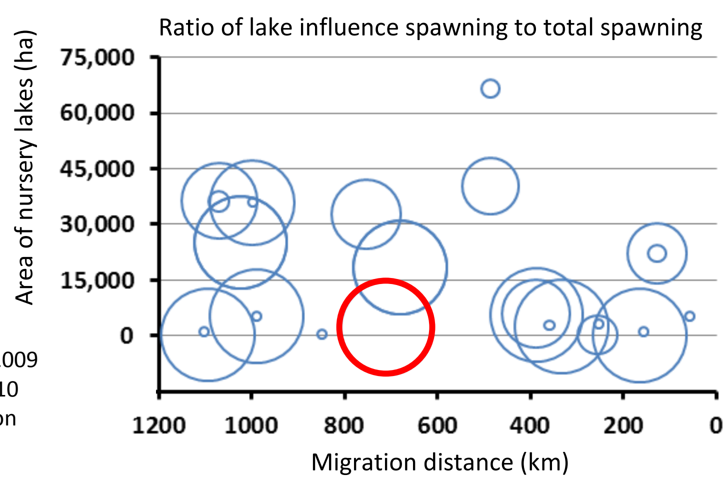
Average air temperature across adult migration (°C)‡



Air temperature across adult migration (°C)‡



Integrated Summary of Habitat Vulnerability



† Representative stock for productivity: **None**

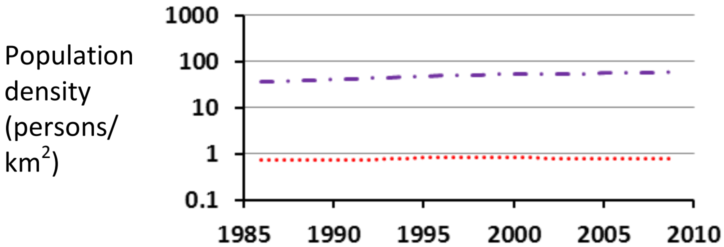
†† Spawning note: **None.**

‡ Temperature calculated according to run group timing.

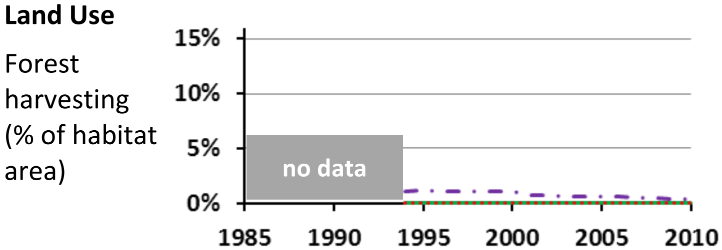
January 31, 2011

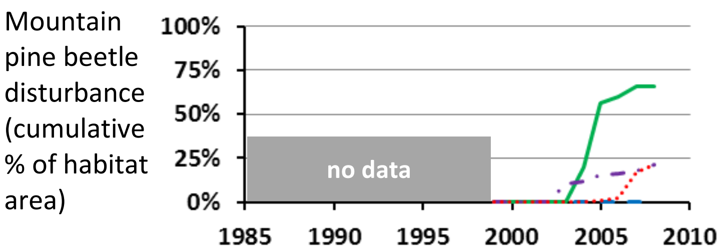
FRESHWATER STRESSORS

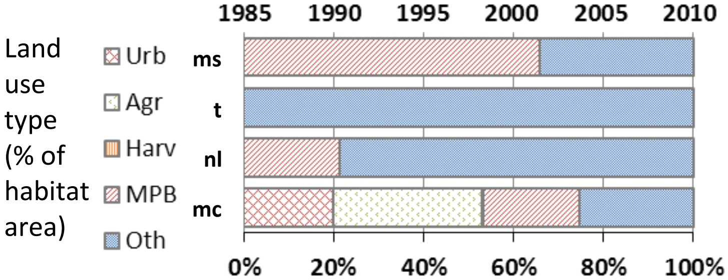
Human Population



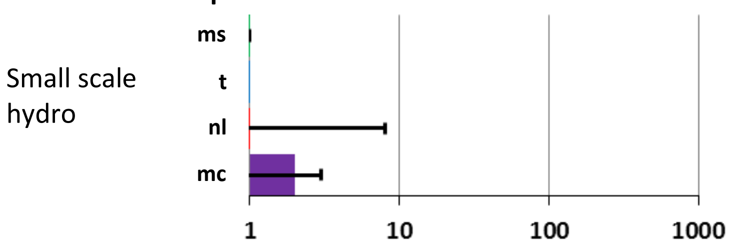
Land Use

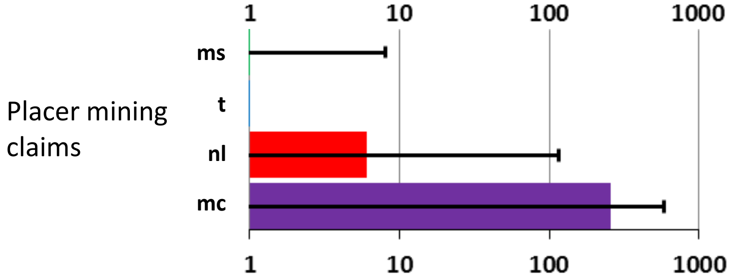


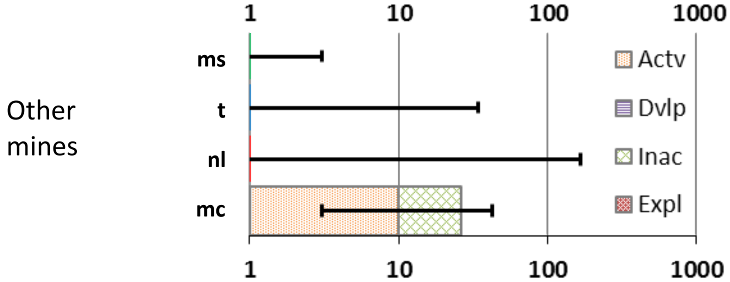




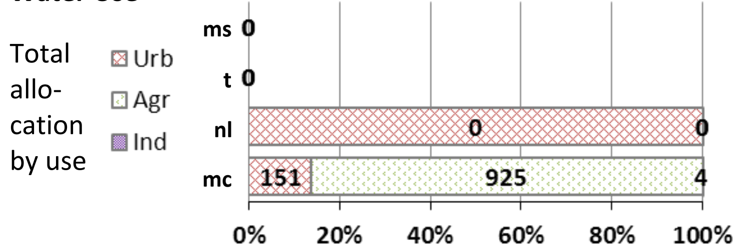
Resource Development

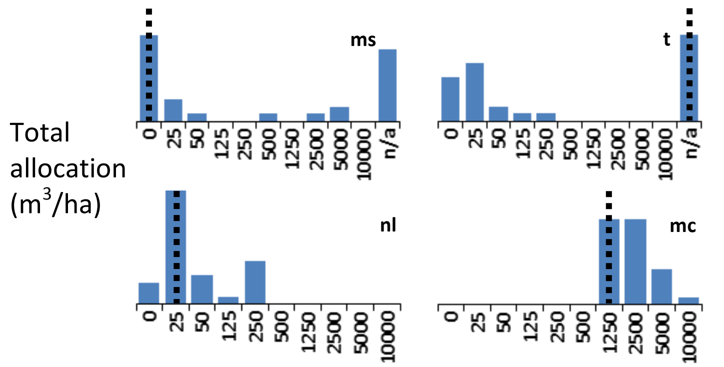


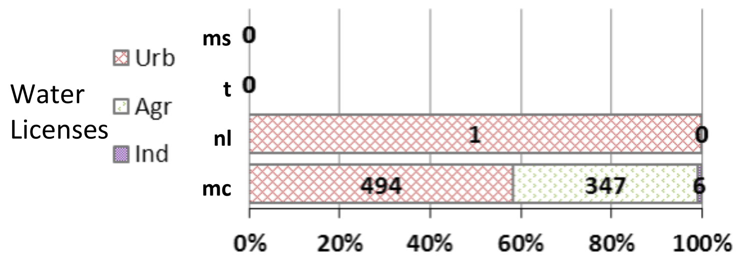


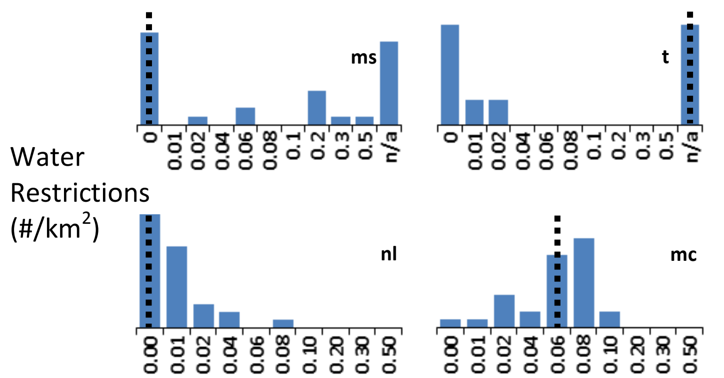


Water Use

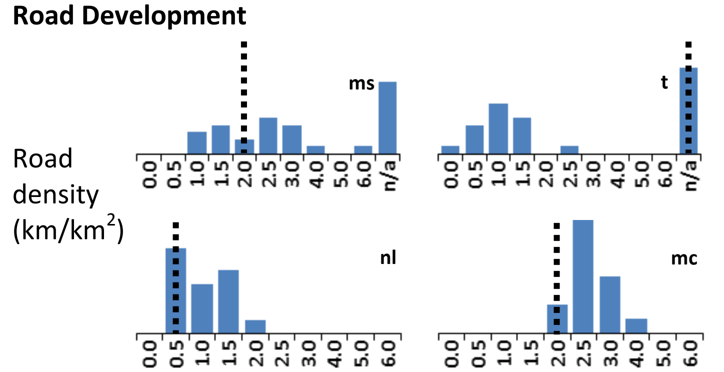








Road Development



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Appendix 4 – Data sources

Data label	Data description	Source	Data provider	Report section
FISS Sockeye Salmon Points	1:50K Sockeye salmon distribution points as recorded in the BC Fisheries Information Summary System.	http://www.canbcdw.pac.dfo-mpo.gc.ca/ows/metadata/sk_bc_pt.html	Fisheries and Oceans Canada	2.2
FISS Sockeye Salmon Presence	1:50K Watershed Atlas streams with line features coded for presence of sockeye salmon.	http://www.canbcdw.pac.dfo-mpo.gc.ca/ows/metadata/FISSSalmon_bc.htm	Fisheries and Oceans Canada	2.2
FISS Sockeye Salmon Waterbody Points	1:50K Points representing streams where sockeye salmon distribution is recorded in the BC Fisheries Information Summary System.	http://www.canbcdw.pac.dfo-mpo.gc.ca/ows/metadata/fisswb_sk_blpt.html	Fisheries and Oceans Canada	2.2
FISS Sockeye Salmon Waterbody Polygons	1:50K Waterbody polygons representing sockeye salmon distribution as recorded in the BC Fisheries Information Summary System.	http://www.canbcdw.pac.dfo-mpo.gc.ca/ows/metadata/fisswb_sk.html	Fisheries and Oceans Canada	2.2
Historical Climate Data	ClimateWNA generates historical climate data for Western North America.	http://www.genetics.forestry.ubc.ca/cfcg/ClimateWNA/ClimateWNA.html	UBC Forestry and Genetics	2.2
BC Watershed Groups (1:50K)	BC Watershed Atlas watershed group polygons (1:50K).	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=43753&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Freshwater Atlas Assessment Watersheds	1:20K mesoscale aquatic units designed to replace the 3rd order 1:50K watersheds.	http://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=57079&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Freshwater Atlas Lakes	All lake polygons for the province (1:20K).	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50640&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Freshwater Atlas Stream Network	1:20K flow network arcs, directionalized and connected. Contains hierarchical key and route identifier.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50648&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Freshwater Atlas Watershed Groups	1:20K polygons delimiting the watershed group boundary.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50651&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2

Data label	Data description	Source	Data provider	Report section
Third Order and Greater Watersheds	BC Watershed Atlas third order and greater watershed polygons (1:50K).	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=43756&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Watershed Atlas Lakes	1:50K Lake polygons for the province.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=43693&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Watershed Atlas Stream Centreline Network	Stream centerline network (1:50K).	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=43752&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	2.2
Logging History (RESULT – Openings)	Administration boundary that has been harvested with silviculture obligations or natural disturbance with intended forest management activities on Crown Land.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=52583&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.1.1
BC Road Crossings layer	Point locations of stream crossings within BC. Crossing locations have been determined based on a GIS intersection of the province's Freshwater Atlas 1:20K stream hydrology with roads that are delineated in the province's Digital Road Atlas.	Not currently available to the public; must be accessed through Ministry of Environment	Richard Thompson, Ecosystems Protection and Assurance Branch, BC Ministry of Environment	3.1.1
Digital Road Atlas – Master Partially Attributed	Partially attributed road data for the named roads from the Digital Road Atlas.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=45674&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.1.1
Mountain Pine Beetle disturbance (1992-1996)	Forest Health Network Archives Pest Data for British Columbia.	http://www.pfc.cfs.nrcan.gc.ca/entomology/pests/bc/mpb_e.html	Canadian Forest Service	3.1.2
Mountain Pine Beetle disturbance (1999-2009)	Forest Health – Aerial Overview Survey.	http://www.for.gov.bc.ca/hfp/health/overview/overview.htm	Ministry of Forests and Range	3.1.2
Aerial photos of the Fraser River estuary	Time series (2001-2009) of aerial photos of the Vancouver area accessed using Google Earth software.	http://maps.google.com/maps?t=k&hl=en&ie=UTF8&ll=49.143089,-123.071594&spn=0.352161,0.455246&z=11	Google	3.1.3

Data label	Data description	Source	Data provider	Report section
Gravel mining activities in BC	Locations of gravel pits in BC.	http://www.empr.gov.bc.ca/Mining/Geoscience/SurficialGeologyandHazards/AggregateProject/Pages/Downloads.aspx	Vic Levson, Ministry of Energy Mines and Petroleum Resources	3.2
Mineral and Placer Claims in BC	Shapefile with polygons of mining claims with valid from and to dates.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=49898&recordSet=ISO19115	Laurel Nash, Ministry of Energy Mines and Petroleum Resources	3.2
Mining activities in BC	Locations, type of activity, local geology, production history for exploration and mining activities.	http://www.empr.gov.bc.ca/MINING/GEOSCIENCE/MINFILE/Pages/default.aspx	Sarah Meredith-Jones, Ministry of Energy Mines and Petroleum Resources	3.2
Drainage Points for Independent Power Producers in the Fraser	Clean Energy Projects with BC Hydro Electricity Purchase Agreements located on rivers that drain into the Fraser River.	n/a	David Ingleson, BC Hydro (16 Sept 2010)	3.3.2
Census boundaries	2006 census division boundaries.	http://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=56799&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.4
Population Estimate by Census Division	Population estimates from 1986 to 2009.	http://www.bcstats.gov.bc.ca/data/pop/pop/dynamic/PopulationStatistics/Query.asp?category=Census&type=DR&topic=Estimates	BC Statistics	3.4
TANTALIS - Municipalities	Representation of all municipalities in BC, a subset of Admin Areas	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=50339&recordSet=ISO19115	Scott MacPhail, LRDW/Integrated Land Mgmt Bureau	3.4
Agricultural Land Reserve Polygons	Spatial representation for agricultural reserve land.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=3553&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.5
Points of Diversion with Water License Information	Province-wide spatial layer displaying water license points of diversion joined with license information.	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=47674&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.6
Water Allocation Restrictions	Province-wide layer showing streams having a water allocation restriction	https://apps.gov.bc.ca/pub/geometadata/metadataDetail.do?recordUID=34251&recordSet=ISO19115	LRDW/Integrated Land Management Bureau	3.6