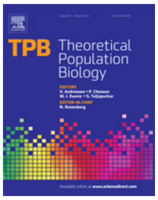
Theoretical Population Biology 103 (2015) 71–83

Contents lists available at ScienceDirect

Theoretical Population Biology

journal homepage: www.elsevier.com/locate/tpb



# Modeling population responses of Chinook and coho salmon to suspended sediment using a life history approach

H. Andres Araujo[a,*], Andrew B. Cooper[b], Erland A. MacIsaac[c], Duncan Knowler[b], Antonio Velez-Espino[a]

[a] *Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia, 3190 Hammond bay Road, Canada V9T 6N7*
[b] *School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada V5A1S6*
[c] *Co-operative Resource Management Institute, Fisheries & Oceans Canada / Pêches et Océans Canada, 8888 University Drive, Burnaby, BC, Canada V5A1S6*

## ARTICLE INFO

*Article history:*
Received 25 November 2014
Available online 8 May 2015

*Keywords:*
Population dynamics
Salmonid population
Sedimentation events
Watershed
Suspended sediment concentration

## ABSTRACT

This study develops a quantitative framework for estimating the effects of extreme suspended-sediment events ($SSC > 25$ mg $L^{-1}$) on virtual populations of Chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon in a coastal watershed of British Columbia, Canada. We used a life history model coupled with a dose–response model to evaluate the populations' responses to a set of simulated suspended sediments scenarios. Our results indicate that a linear increase in SSC produces non-linear declining trajectories in both Chinook and coho populations, but this decline was more evident for Chinook salmon despite their shorter fresh-water residence. The model presented here can provide insights into SSC impacts on population responses of salmonids and potentially assist resource managers when planning conservation or remediation strategies.

© 2015 Elsevier Inc. All rights reserved.

## 1. Introduction

Pacific salmon are subject to a variety of environmental pressures in both the freshwater and marine stages of their life history. In freshwater, many factors have been identified as contributing to declines in population abundance including habitat damage, pollution, high water temperatures, changes in hydrology, and increased sediment levels due to human activities (Reice et al., 1990; NRC, 1996). Forestry and other resource extraction and land development activities can significantly increase the sediment concentrations in freshwater stream habitats above background (natural) levels (Meehan, 1991; Gucinski et al., 2001).

Suspended sediment concentrations (SSC) and deposited fine sediments above background levels in streams can adversely impact salmon productivity. Fine sediments deposited in spawning gravels negatively impact the survival of incubating salmonids from eggs to emergent fry by reducing intergravel water flow and inhibiting their movements (Megahan et al., 1978; MacDonald et al., 1991). Increased fine sediment deposition can also smother populations of certain benthic invertebrates and decrease algal production, both of which directly affect the availability of food for juvenile salmonids (Alexander and Hansen, 1986; Everest et al., 1987). In addition, sediment deposits in the stream can decrease habitat availability and may cause loss of cover, thus increasing predation risks (Bjornn et al., 1977; Chapman and McLeod, 1987).

Increases in SSC affect juvenile fish by reducing growth and feeding rates, promoting gill abrasion, and impairing foraging efficiency (Newcombe and Jensen, 1996). Elevated SSC has been shown to impede growth in coho salmon (Smith and Sykora, 1976; Sigler et al., 1984) and Chinook salmon (Birtwell and Korstrom, 2002), and these delays could have important effects at the population level (Suttle et al., 2004). Adult salmonids show more resilience to the presence of elevated SSC than juveniles; however, very high SSC and long exposure can cause behavioral changes and affect spawning success (Whitman et al., 1982; Galbraith et al., 2006).

It is difficult to develop a comprehensive framework that defines the functional and physiological responses of salmonids to sediments due to the complexity of the responses, the variability and uncertainty in population-specific behaviors, and the challenge of field data collection. However, Newcombe and Jensen (1996) designed a concentration–duration (dose) response model

---

* Corresponding author.
*E-mail addresses:* Andres.Araujo@dfo-mpo.gc.ca (H.A. Araujo), andrew_cooper@sfu.ca (A.B. Cooper), Erland.MacIsaac@dfo-mpo.gc.ca (E.A. MacIsaac), djk@sfu.ca (D. Knowler), Antonio.Velez-Espino@dfo-mpo.gc.ca (A. Velez-Espino).

http://dx.doi.org/10.1016/j.tpb.2015.04.003
0040-5809/© 2015 Elsevier Inc. All rights reserved.

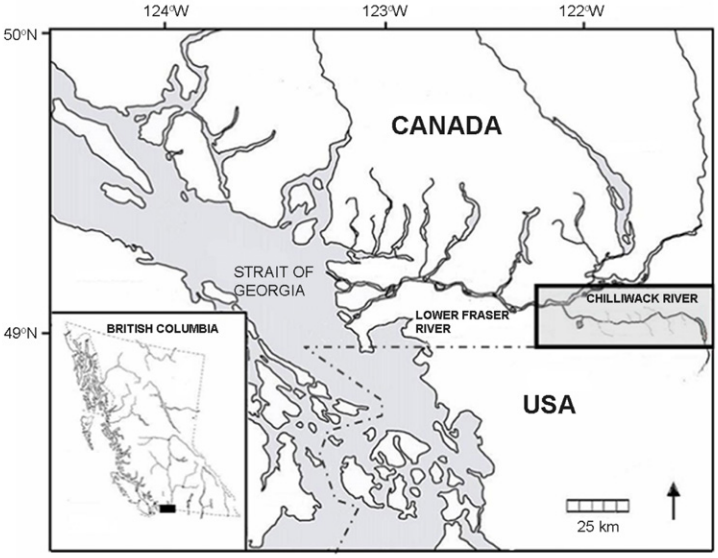


**Fig. 1.** The Chilliwack River, a tributary of the Lower Fraser River, British Columbia, Canada.

as a predictive management tool for assessing the environmental effects of SSC on anadromous and freshwater fish at different life stages. Their meta-analysis of 264 data sets resulted in what the authors call the severity of ill effect (SEV), a ranked scale with empirically-determined scores calculated based on the concentration and duration of exposure in six fish categories and at all life stages. In their model, the SEV scores include a series of behavioral, sublethal, and lethal effects.

Although there is a good qualitative understanding of how elevated SSC affect fish and other aquatic biota, particularly the individual-level response (Kerr, 1995; Trombulak and Frissell, 2000), there is a lack of adequate quantitative tools that allow managers to make inferences regarding sediment impacts at the population level (Moore and Wondzell, 2005). In recent years in southwestern British Columbia and the American Pacific Northwest, several models have been developed to link human-elevated SSC and fish dynamics with the intention of creating management tools. Alexander et al. (1998) developed the Fish Forestry Interaction Program Management Model (FFIP-MM), a prototype to link upslope processes, sediment and large organic debris transport with habitat conditions for small watersheds ($<40$ km$^2$). Heinzelmann (2002) developed an integrated modeling framework to assess trade-offs associated with forestry management that involve habitat conditions for coho salmon. Harvey and Railsback (2009) employed a spatially explicit, individual-based model to estimate the cumulative effects of forestry activities on cutthroat trout habitat. These models have focused primarily on assessing the impacts of forestry activities on fish habitats (e.g., channel scour) but there is a lack of studies that address suspended sediment impacts at the population level.

In this study, we develop a modeling framework to estimate the effects of simulated freshwater SSC on the dynamics of two virtual populations of Chinook and coho salmon in a coastal watershed of British Columbia, Canada. The novelty of our approach relies on the integration of different models (a dose–response model and a stage-structured model) into a stochastic life history population dynamics modeling framework that takes into account the exposure to suspended sediments concentrations at different life stages. The main outcomes are the populations' response to increased sedimentation during the simulation period (100 years).

## 2. Methods

### 2.1. Area of study

The Chilliwack River watershed (1230 km$^2$) is located in the Skagit Range of the Cascade Mountains, British Columbia (Fig. 1). The watershed consists of a number of sub-basins, some of which contain important fish habitat. Wild and hatchery-enhanced populations of steelhead (*Oncorhynchus mykiss*), chum (*O. keta*), Chinook (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye (*O. nerka*), and pink salmon (*O. gorbuscha*) are present. The Chilliwack River has gravel beds throughout the spawning and rearing area. Silt and clay-sized sediments are carried as washload, and there are no significant fine sediment storage elements downstream from Chilliwack Lake (Scott et al., 1993).

### 2.2. Data

The primary SSC data required to run the model are daily values of SSC (mg L$^{-1}$) for a period of time sufficiently long to represent seasonal patterns in the watershed of interest. For the Chilliwack River, SSC data were extracted from the Water Survey of Canada (WSC). These data consist of daily averaged SSC (mg L$^{-1}$), measured at the Vedder Crossing station (station number 08MH001) during the period 1965–1976, the only period with continuous monitoring. SSC data provided by the WSC is a mix of directly sampled data and estimates from SSC-discharge curves. To extend the time series of SSC from 1976 onwards we followed the method by Araujo et al. (2012), who used a mixed effects model to extrapolate daily values for SSC using discharge as a proxy.

To explore the effect of increased SSC on the populations, we multiplied the baseline (real) time series by values ranging from 1 to 250 in increments of 25 and used these to create ten scenarios of SSC (each indexed by $k$). We also examined the conditions of elevated SSC under which the populations could face collapse, defined as a population at $<1\%$ of its initial median abundance. A one-year sample of the simulated time series using the multiplier for SSC is shown in Fig. 2.

For each scenario, we constructed four seasonal databases from the set of all extreme events present in the SSC time series from 1965 until 2010, details of dates associated with each season can be found in Appendix. Subsequently, we estimated the average

Download English Version:

https://daneshyari.com/en/article/4502286

Download Persian Version:

https://daneshyari.com/article/4502286

Daneshyari.com