Assessment and Management of Environmental and Health Factors Affecting Early Marine Survival of Hatchery Reared Coho Salmon in the Strait of Georgia, British Columbia

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Salmon enhancement program (SEP) hatcheries operated by Fisheries and Oceans Canada (DFO) that are located in the Strait of Georgia target annual releases of 12.4 million coho salmon (*Oncorhynchus kisutch*). However, since the 1980s coho smolt-to-adult survival from facilities bordering the Strait of Georgia has diminished from 8-10% to a present value of around 1% (Beamish et al. 2008). One of the reasons for this shift may be that temporal patterns of productivity in the Strait of Georgia have changed and reduced survival is a consequence of a mismatch between spring zooplankton blooms and the standard single release date still used by most hatcheries. In the early 1980s, survival rates for coho salmon were highest when fish were released near the third week of May at a size of 20-25 g (Bilton et al. 1984). In 2004, the Quinsam Hatchery, located in Campbell River (the town), switched to a staggered release strategy for coho salmon from a single strategy in response to poor adult returns and to address the possibility of mismatched timing between release of juveniles and marine food availability.

The diet of coho salmon during early marine development changes both monthly and interannually depending on the availability of their preferred prey items (Daly et al. 2009). Juvenile salmon are highly selective for prey items regardless of the abundance and composition of available zooplankton (Schabetsberger et al. 2003). Since development of the original plankton monitoring protocol nearly three decades ago, several factors have likely influenced the availability of juvenile salmon food resources, including oceanographic changes, declines in groundfish stocks (source of larval fish prey) and changes to plankton communities (Emmett and Brodeur 2000; Daly et al. 2009).

Changes in the magnitude and timing of ocean productivity in the Strait of Georgia (Beamish et al. 2004) have likely resulted in a mismatch between the timing of smolt release and the occurrence of spring plankton blooms that coho salmon rely on as a primary food source. However, there is a lack of data monitoring the abundance of juvenile salmon prey in plankton communities (Daly et al. 2009). There seems to be a strong correlation between the abundance of coho salmon juveniles in the Strait of Georgia in early summer and the corresponding return of this population as adults (Beamish and Neville 1999; Beamish et al. 2010). Survival of juvenile coho salmon is likely associated with fish reaching a critical size (snout to fork length) by the summer solstice (Beamish and Mahnken 2001). A study conducted on the west coast of Vancouver Island suggests that feed type, particularly zooplankton, and abundance during spring play a primary role in ensuring early marine growth (Tanasichuk 2002).

Discovery Passage is a channel that forms part of the Inside Passage between Vancouver Island and the Discovery Islands off the north end of the Strait of Georgia. The passage is 25 km long and about 2 km wide. The constricted passages in the area create rapid tidal streams and the water is well mixed from top to bottom. This prevents stratification that is typical in the Strait of Georgia and its inlets. Campbell River (the river, not the town) is located in the city limits and registers flows that are the third largest on Vancouver Island. Five species of salmon (Chinook, coho, pink, chum, and sockeye) as well as sea-run trout are distributed in the river. The Quinsam River is a tributary of the Campbell River and joins it 3 km inland. The Quinsam Hatchery is located approximately 2 km upstream on the Quinsam River.

In 2007 a 5-year pilot project was initiated with the objective of developing a monitoring program that could best determine an optimum time frame to release coho salmon to coincide with favourable marine food availability. For this study, we collected juvenile coho salmon during the early spring outmigration to analyze growth, diet, and health. Fish-specific information was related back to plankton data to establish what the juveniles were eating when they exited the estuary and entered the near-shore marine environment. The success of this program was measured by monitoring survival of returning adult coho salmon to the hatchery and assessed by the retrieval of coded-wire tags (CWT).

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Early in the project it was determined that estuary conditions as well as ocean conditions made it difficult to make in-season predictions for the best timing for releases from the hatchery. Zooplankton data could be useful, however, in establishing the conditions at release of coho salmon and, along with other studies done in the Strait of Georgia, potentially provide additional information for fishery management, broodstock collection, and establishing escapement targets when the fish returned as adults.

Plankton sampling began each year in late February and continued weekly through to end of June. Zooplankton sampling was conducted using vertical tows from near bottom (20 m depth) to the surface with a 350 µm dark-mesh Bongo net, and chlorophyll *a* levels were determined from analysis of filtered water samples. Chlorophyll-*a* samples collected in 2007-2009 were compared to phytoplankton abundance. The correlation between phytoplankton concentration and chlorophyll *a* was good ($r=0.65$ $p=0.0002$), so we discontinued phytoplankton sampling and continued collecting the filtered water samples after the second year. Water turbidity estimates were added in 2010 and evaluated using a Secchi disk. Water temperature, salinity, and dissolved oxygen profiles were recorded from 0 to 20 m depth, and we observed that water in Discovery Passage was well mixed with temperature and salinity values uniform throughout the water column.

Beach seining to sample juvenile salmonids in the nearshore marine habitat and the Campbell River estuary was initiated about one week after coho salmon were released from Quinsam Hatchery and continued weekly or bi-weekly until the end of June. Tissue samples of kidney, gill, liver, spleen and pyloric caeca were collected from coho for fish health analysis, specifically for *Renibacterium salmoninarum* the causative agent of Bacterial Kidney Disease (BKD) and a significant disease of Pacific salmon. Coho salmon production groups were released from Quinsam Hatchery with clipped adipose-fin patterns and CWTs that allowed for later comparison of release date and adult return.

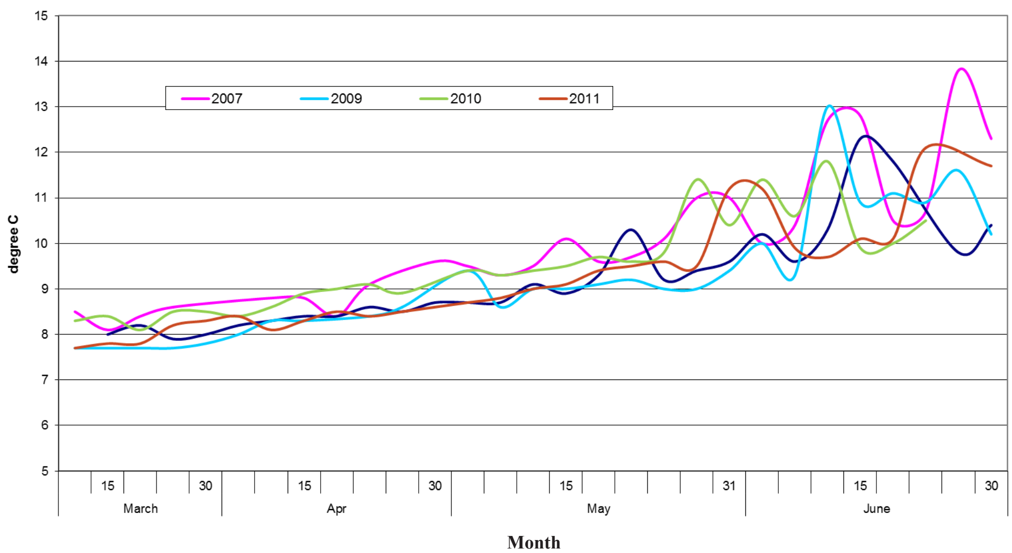

Fig. 1. Water temperature at 5 m depth in the Strait of Georgia, 2007-2011.

The first year of the project occurred near the end of a warming cycle in the Strait of Georgia, which was reflected in the slightly elevated water temperatures compared to the next four years (Fig. 1). Salinity was lowest during 2007. Zooplankton density (count/m^3) varied year to year, but 2007 was distinct because densities were substantially lower than those seen during the next four years. Density in 2008 proved to be the highest, and density in 2010 was high as well. For all years of the project, except the 2007, zooplankton densities attained high levels in late April to mid/late May.

As the Campbell River estuary freshwater flows are regulated by BC Hydro, conditions in the estuary vary from year to year. These conditions have an impact on how quickly coho salmon migrate to the ocean. Adult coho salmon returning to the hatchery over the four years of the project (Fig. 2a-d; brood-year 2005-2008) showed that returns were highest for mid-May releases (brood-year 2008 data are not yet compiled). These data are based only on release numbers of tagged smolts and escapement, not expanded to unmarked fish, and do not include other sources of CWT data in fisheries. Quinsam Hatchery now plans releases of the majority of their coho salmon by mid-May to take advantage of the zooplankton blooms. An early release group is still monitored (late April) to determine if there is a shift in the environment that favours earlier release timing. The change to a May 10-15 release for the majority of the Quinsam Hatchery coho salmon, which is based on consistently higher zooplankton density at this time, has resulted in cost savings at the hatchery (mainly from decreased fish feed). It is important to recognize that shifts in the productivity of the marine environment/ecosystem are dynamic; localized conditions as well as larger decadal ocean cycles require continuous repetitive/annual monitoring that also provides information for flexible decision making by management at the individual hatchery level.

Fig. 2. Annual (2007-2010) zooplankton density (count/m^3) in the Strait of Georgia in the spring when marked coho salmon juveniles from brood-year 2005-2008 entered the marine environment (arrows; left column), and the same brood-year returns (2005-2008) of adult and jack coho salmon to the Quinsam Hatchery (right column).

We examined stomach contents of captured fish collected during the first three years of the study (during the following two years, we were unable to collect enough coho salmon in our beach seines for stomach analysis). The hatchery coho salmon appeared to have a slightly more varied diet than the wild fish we retrieved in the beach seine. This may indicate that hatchery coho salmon have a learning curve in selecting optimum prey.

Coho salmon kidneys were tested for *R. salmoninarum* using ELISA (Enzyme-linked Immunosorbent Assay), and the presence of the bacteria was found to be very low.

We continue to assess the data. Beach seine catch data will be analyzed to establish trends in diversity and abundance of species caught over the five years that will be compared to ocean conditions existing at the time when sampling was conducted. In the future we will take a closer look at the zooplankton data to see how community composition varies over the spring of each year and between years.

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