is an important factor for Chinook survival; however, this cannot be easily distinguished from the same covariates mentioned by Magnusson and Hilborn (2003). There are few, if any, situations where contamination and a high percentage of pristine or unaltered habitat occur together. As mentioned by other authors, the determinants of survival are numerous and complex, and few studies address all of them simultaneously.

Prey availability and growth rate in the estuary

A major consideration for evaluating juvenile survival in these local estuaries is the availability of prey for growth. Few data were available for these estuaries; however, adequate prey species may have been available for many of those considered contaminated (Table 1 and Supplementary data[1]). It is important to note that contamination will also affect invertebrates in the estuary; however, there are numerous pollution-tolerant taxa, and these will often increase in abundance over sensitive species and contain higher concentrations of contaminants. Even though invertebrate communities may be impaired, as indicated by various metrics such as species diversity and taxa dominance, benthic biomass and suitable prey for salmonids may not be substantially impacted.

Juvenile Chinook in an estuary are capable of growing at rates of 3%–5% body mass·day^{-1} (Healey 1982, 1991; Brett 1995). This very high rate of growth is due to an ingestion rate of 12%–20% body mass·day^{-1} (Brett 1995), which is noteworthy because these fish are likely accumulating contaminants at a high rate. Healey (1982) reported growth rates of 3.5% body mass·day^{-1} in the relatively pristine Nitinat estuary and up to 5.5% body mass·day^{-1} in the less pristine Nanaimo estuary on Vancouver Island, British Columbia. Interestingly, the Nitinat does not contain intertidal areas, indicating that relatively high growth rates can be achieved without this type of habitat. As noted by Healey (1991), this technique of estimating growth by assessing mean fish size in the estuary over time likely underestimates actual growth by 50%, implying that many of the estimated growth rates may be higher. A number of authors have concluded that food was not limiting or that density-dependent growth effects were not observed for some Pacific Northwest estuaries (Duwamish, Nanaimo, and Campbell rivers) (Healey 1980; Levings et al. 1986; Cordell et al. 2011); however, these factors may be occurring during the peak migration of hatchery fish (Reimers 1973; Nelson et al. 2004) (see Supplementary data[1]).

After juvenile Chinook leave their local estuary for more open water in Puget Sound and beyond, it appears that prey abundance is sufficient to allow continued growth. Duffy (2009) found that juvenile hatchery Chinook during their first summer in open water exhibited consumption rates that were between 50% and 100% of the expected maximum value. These estimates varied by year and location (north, central, or south Puget Sound) for 2 of the years examined and were also within the predicted range for fish in Puget Sound. Growth was estimated to be between 0.9% and 2.3% body mass·day^{-1}, which varied by year and season. Also, Brennan et al. (2004) noted very low percentages of empty stomachs (2%–5%) in Chinook captured at 16 sites in mid-Puget Sound in 2001 (n = 410) and 2002 (n = 409). These data indicate that juvenile Chinook likely encountered sufficient prey. Therefore any differences in growth or survival for hatchery fish was possibly due to factors other than prey availability in estuaries or open marine waters of the greater Puget Sound area where fish comingled.

Even though habitat quality was quite variable, it appears that juvenile Chinook within estuaries often increased in mass at rates that were comparable among contaminated and uncontaminated estuaries (Table 1). Although the data are sparse, a few of the more contaminated estuaries (Duwamish, Puyallup, Sinclair, and Budd Inlet) indicated relatively high densities of prey and high percentages of full stomachs in juvenile Chinook (see Supplementary data[1]). Based on the available data, it was concluded that growth for juvenile Chinook residing in local estuaries was not a function of the state of contamination; hence this factor may not be important for determining the differential rate of survival. It is important to note that inhibited growth due to contaminant exposure in local estuaries may be delayed and not manifest until fish leave these systems for open water.

Physical habitat alterations

Most of the small delta estuaries in Puget Sound are considered degraded compared with their preindustrial state, and some have lost more than 99% of their intertidal and subaerial habitat (Bortleson et al. 1980). A recent compilation for several local estuaries examined in this study, including the Duwamish, Nisqually, Nooksack, Puyallup, Samish, Snohomish, and Stillaguamish river estuaries, reported large reductions in the amount of tidal freshwater and oligohaline transition habitat (Simenstad et al. 2011). The residence time and areal extent needed for the salinity transition zone is difficult to quantify and is dependent on species, life stage, and stock. Ocean-type Chinook are known to tolerate seawater at an early stage (Healey 1980) and juveniles from the hatchery likely transition quickly to full-salinity seawater. In some of the more degraded estuaries, the salt wedge and mixing zone extends several kilometres upstream from the river mouth, as noted for the Duwamish and Puyallup river estuaries (Supplementary data[1]), thereby providing some habitat for salinity acclimation.

While several of the Puget Sound estuaries categorized as contaminated also exhibit poor habitat quality for juvenile Chinook rearing, this is not always the case. The estuaries for Gorst Creek and the Snohomish are not as highly altered as the Duwamish, but do exhibit a high degree of contamination. Even though the Puyallup and Duwamish river estuaries have lost essentially all their intertidal habitat, their shallow subtidal areas provide rearing habitat and prey for juvenile Chinook. Healey (1991) noted that subtidal habitat is desirable for this life stage, and as mentioned above, juvenile Chinook will prey on benthic species.

One interesting comparison is between the Nisqually and Snohomish river estuaries. The Nisqually has lost 22% of its intertidal habitat, which is similar to the 32% loss for the Snohomish River estuary (Bortleson et al. 1980). The Nisqually is considered uncontaminated, whereas the Snohomish River estuary was judged contaminated, and the SAR values for these two estuaries reflects that categorization. Another noteworthy observation is for fish released in Gorst Creek that outmigrate through Sinclair Inlet (contaminated) and those from Grover's Creek transiting Miller Bay (uncontaminated). The Gorst Creek fish are spawned, incubated, and reared at Grover's Creek hatchery (Hatchery Scientific Review Group 2003). When considered by year when these hatcheries overlapped (2002–2004), the SAR for Gorst Creek Chinook ranged from 40% to 60% lower than the mean SAR for fish released from the Grover's Creek hatchery.

Fish size and release day

Juvenile fish size has been strongly associated with survival to the adult phase (Cowan et al. 2000; Beamish and Mahnken 2001; Duffy and Beauchamp 2011). In this analysis there were no discernible differences in juvenile fish mass at release among hatcheries and years, and there was no correlation with the SAR, which was also reported in other studies (Quinn et al. 2005; Duffy and Beauchamp 2011). Fish release dates are also considered an important factor but were limited in this analysis to 10–12 weeks during the spring for both species. There was no correlation between Chinook SAR and release DoY, which is likely due to high interannual variability. As shown in Duffy and Beauchamp (2011), DoY release can be an important factor for survival when considered within a short time frame.