Hallum 1990). Of course the local estuaries of Puget Sound continue to change with development and restoration; therefore these values may change with more recent evaluations. Several of the rearing estuaries are considered highly degraded owing to anthropogenic activity, and the degree of contamination is confounded with urbanization and loss of prime habitat. Many of these local estuaries occur near human-impacted (urban or agricultural) areas and have been contaminated by industrial waste, stormwater effluent, chemical spills, wastewater treatment facilities, and runoff from impervious surfaces and other modified areas (e.g., farms, ranches, and logged areas). Historically, concentrations of several contaminants were low, as measured in sediment, but rose to high levels as urbanization increased (Crecelius et al. 1985). Even though levels of some contaminants have declined over the past few years, others have increased recently, and many of the legacy contaminants are still elevated in sediment and fish (Puget Sound Ambient Monitoring Program 2007), especially during the time frame of this analysis.

The main characteristics of a local estuary that are necessary to enhance the probability of survival for juvenile salmonids have been addressed by several authors and include refuge from predation, freshwater–seawater transitional areas, and productive foraging allowing increased growth (Simenstad et al. 1982; Healey 1982; Macdonald et al. 1988; Thorpe 1994). Additional parameters to consider include water quality (oxygen, temperature, and salinity), water velocity, physical habitat, pathogen occurrence, competition, and chemical contamination. By considering a large number of hatcheries and estuaries within the Puget Sound area over several years, many of the important parameters that determine survival to the adult stage can be minimized or accounted for in the analysis. Data were available or generated for a few of these factors such as growth rate, prey abundance, fish density, predation, and distance from the hatchery to Puget Sound and were examined in light of their potential effect on survival. The quality of freshwater habitat is also a crucial factor for salmonid vitality (Myers et al. 1998); however, this factor was considered not critical for these comparisons because I examined only hatchery fish, which quickly move downstream to the estuary (Nelson et al. 2004; Seattle Public Utilities 2008; Chittenden et al. 2008).

The primary metric to assess life-cycle success is the smolt-to-adult return rate (SAR), which provides a percent value based on the number of juvenile salmon (smolts) released and the number of adults enumerated and estimated from fisheries and hatchery returns. Survival for first-year ocean-type Chinook in the Pacific Northwest has been estimated at 0.4% (compiled by Spromberg and Meador 2005). Rates of survival over successive years are considerably higher for 2-, 3-, 4-, and 5-year-old fish at 60%, 70%, 80%, and 90%, respectively (Pacific Salmon Commission Chinook Technical Committee 2002). Clearly, first-year survival is important for Chinook, and most of the mortality for first-year ocean-type Chinook is attributed to predation, poor growth, pathogens, starvation, and toxicants.

Hypothesis

The goal for this analysis was to examine the SAR as an indicator of survival for outmigrating ocean-type Chinook from hatcheries within the Greater Puget Sound area and to examine the influence of contamination in the estuaries where fish rear before migrating to open water. The main hypothesis was that contaminant exposure for outmigrating juvenile Chinook was sufficient to affect the probability of survival during their first year in marine water. SAR values for coho salmon, a species that spends little time in the estuary, were also assessed, and the comparison to those for Chinook was used as another line of evidence to test the hypothesis that contaminated estuaries are one of the main factors determining the rate of survival for Chinook. Additionally, coho SAR values were useful for identifying hatcheries that practiced poor husbandry, as both coho and Chinook SAR values would likely be lower than the mean.

Salmonid survival is dependent on a large number of factors, many that co-occur. The analysis presented here is simplistic, but highlights an important relationship between hatchery Chinook survival and contaminated estuaries. Because this analysis examined the smolt-to-adult survival rate in fish from a large number of hatcheries and estuaries over several years in one geographical location, many of these factors were likely accounted for and therefore had less of an effect on the overall results.

Methods

Only hatchery-released Chinook and coho salmon were considered in this analysis. All releases over the years 1972–2008 were included for both species over all areas of Puget Sound and the northern Washington State portion of the Salish Sea (Table 1; Fig. 1). The Skagit River hatchery was not included because of several factors, including the limited availability of data that met the criteria listed below, the high probability of density-dependent mortality and emigration (Greene and Beechie 2004), and the fact that this system is dominated by wild fish, whereas all other systems in this study are hatchery dominated. Estuaries in the Hood Canal were also excluded because of persistent low dissolved oxygen levels (Brandenberger et al. 2011) that would likely confound the analysis. All major estuaries within Puget Sound and northern Washington (Thom and Hallum 1990) were included except for the Skagit (mentioned above) and the Lummi (no data) in addition to several minor estuaries.

Fish data

Data for hatchery-released juvenile salmon were obtained from the Regional Mark Information System (RMIS), which is maintained by the Regional Mark Processing Center (RMPC) as part of the Pacific States Marine Fisheries Commission (PSMFC) (Nandor et al. 2010). Coded wire tag (CWT) data, release masses, dates of release, and SARs were obtained from the online RMPC database (http://www.rmpc.org) (Regional Mark Information System 2006). The SAR was obtained by running SA1 queries for a given tag code group from all available years (release years 1972–2008). The recoveries are estimated based on the observed number of CWT fish captured in all fisheries and the number of hatchery returns. All fisheries were selected in the SA1 query, which included all adult fish landings from troll, gill net, purse seine, sport fishing, and others. The number of fish returning to the hatchery (escapement) is variable but usually averages in the 25%–50% range of the total recoveries for ocean-type Chinook (Pacific Salmon Commission Chinook Technical Committee 2002), indicating that a high percentage of the SAR was determined by fish returning to their natal hatchery. The SAR values represent survival for the entire cohort and are not year specific. Survival for a tag code group was estimated by comparing the total number of CWT fish released with the number of adult fish found with CWTs retrieved at the hatchery (100% sampling rate) and from commercial and sport fisheries (20% sampling goal) (Nandor et al. 2010). Final estimated recoveries from the various fisheries were estimated according to specific algorithms (Pacific Salmon Commission Chinook Technical Committee 2002). I assumed that the available CWT recovery information based on escapement and fisheries did not contain values for juveniles, because there is no fishery for this life stage, except for the small number taken for research.

For Chinook and coho, a number of criteria were applied to the data to ensure adequate statistical power and to reduce variability when possible. Only tag code groups with more than 10 000 CWT fish were selected; however, most groups contained 50 000 to over 200 000 tagged fish. For most hatcheries and years, several tag code groups were released (mostly groups of two, but occasionally three to five groups per year). All values from a hatchery for a given year were reduced to mean values. The variability for