differences, and no explanation or theories for these anomalous values were found in the literature. Noteworthy are the relatively high SAR values for coho released from nearby marine net pens on Squaxin and Fox islands. The mean SAR for netpen coho (1974–2006) fitting the same requirements listed above for release date, mass, and tag code group size was 6.7% (n = 32 mean SARs, 68 total tag code groups), indicating no unusual problems with the marine phase of their life cycle in this area of Puget Sound.

Implicit within this analysis is that there were no major differences in husbandry practices for juvenile fish, including CWT procedures, disease, and rearing conditions among the hatcheries examined that would differentially affect salmonid survival in the estuary or marine environment. The only highly disparate values observed were for the Kalama Creek and Clear Creek hatcheries mentioned above. It was also assumed that there was no relationship between the SAR and hatchery location within Puget Sound, and differences in fish physiology and genetics were inconsequential. Additional assumptions for the open-water phase (marine) include similar conditions for prey availability, predation, and all others factors that would determine survival during this phase of their life cycle.

Determining the state of contamination in a local estuary

Multiple lines of evidence were used a priori to categorize estuaries as either contaminated or uncontaminated, and data were available for most locations. For one estuary (Chambers Bay) the determination was based on a narrative analysis (qualitative) (see online Supplementary data[1]). Four independent factors were used to categorize a local Puget Sound estuary as clean or contaminated: (*i*) tissue concentrations of contaminants in juvenile Chinook and other species determined from animals collected in the estuary; (*ii*) results of sediment toxicity bioassays; (*iii*) evaluation of numerical criteria from the Washington State Sediment Management Standards (SMS) and Effects Range Medium (ERM) values; and (*iv*) the siting of Superfund sites and Puget Sound Initiative and Washington Department of Ecology (Washington Department of Ecology 2012) cleanup sites. Even though the determination of contamination could be due to only a few toxicants, most contaminated estuaries contain myriad chemicals at concentrations known to cause adverse effects in biota.

Tissue contaminants

Fish and invertebrate tissue concentrations were available for 8 of the 14 estuaries. A number of studies reported contaminant concentrations in tissue for outmigrating juvenile Chinook in many of the local estuaries of Puget Sound and from the hatcheries that raise those fish. Most of the data were for polychlorinated biphenyls (PCBs) in liver, whole-body, and stomach contents and polycyclic aromatic hydrocarbons (PAHs) in stomachs. Local estuary data were compared with concentrations determined in juvenile Chinook from several hatcheries, including Soos Creek, Puyallup, Kalama Creek, McAllister Creek, and Wallace River. Several studies (Mac et al. 1979; Varanasi et al. 1993; Easton et al. 2002; Maule et al. 2007) were used to determine concentrations of contaminants in stomach contents for hatchery fish based on measured values for stomach contents and hatchery food. For a given contaminant and tissue, the mean concentration +1 standard deviation (SD) for fish from the estuary was selected to represent the degree of exposure. This value was then compared with the mean value for all hatchery data and shown as a factor difference (Table 2). Differences between hatchery and estuary Chinook greater than two-fold indicated that outmigrating salmon had bioaccumulated or been exposed to contaminants, supporting the conclusion that an estuary was contaminated. Data for English sole liver, fillet, and stomach contents were also included in addition to values for clams. These additional data were compared on a relative basis between contaminated and uncontaminated estuaries.

Sediment

The first sediment index is based on bioassay results, which were obtained from a series of reports to gauge the potential toxicity of sediments in local Puget Sound estuaries. These studies conducted bioassays with sediment from a large number Puget Sound sites, including an amphipod mortality bioassay and a sea urchin fertilization test with sediment pore water (Long et al. 1999, 2000, 2002, 2003). If one of these tests indicated toxicity for a given local estuary, then the sediment was considered toxic.

The second sediment index was based on sediment standards and guidelines. For this index, the Washington State SMS (Washington Department of Ecology 1995) and ERM values (Long et al. 2003) were used to determine whether a local estuary was contaminated. The SMS comprise different levels of criteria for Puget Sound sediment, including the Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL). The SQS are numeric values for a large number of contaminants that are designed to protect biological resources and human health and are considered to be "no effect levels". The SQS serve as the cleanup objective for all cleanup actions; however, these are based on severe responses (amphipod mortality, polychaete growth inhibition, and large reductions in the number of benthic invertebrates). The CSL values include Minimum Cleanup Levels (MCUL) and Maximum Chemical Criteria (MCC). These are higher for a given contaminant than their corresponding SQS value and are based on sediment quality that may result in minor adverse effects. The ERM is the 50th percentile sediment concentration determined from a database of matched bioassay and sediment concentrations where adverse biological responses were observed. In many cases these adverse effects were severe (e.g., mortality). Based on the data presented in Long et al. (2003), a failure for any one of these metrics (SQS, CSL, or ERM) led to the conclusion of sediment contamination. Contaminated sediment is likely reflective of high concentrations of harmful chemicals in salmon prey species and is usually correlated with elevated water concentrations that fish ventilate.

Listed sites

If any of the estuaries contained US Environmental Protection Agency Superfund sites or Puget Sound Initiative and Washington Department of Ecology cleanup sites, then the estuary was considered contaminated. Listed sites are considered severely contaminated and are studied in depth to consider options for remediation.

Estuary description

The hatcheries and rivers used by outmigrating juvenile salmon to their local estuary are listed in Table 1. Areal size of each local river estuary and distance from the hatchery to the estuary was calculated using Google Maps with the program provided by Daftlogic (http://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm). Bortleson et al. (1980) provided estimates of the area for subaerial and intertidal habitat and the percent loss from the mid- to late 1880s to 1980 for 7 of the 14 river estuaries examined in this study, which can also be found in Thom and Hallum (1990). These two references were used as a guide for most calculations. In some cases the areal values were similar to those in Bortleson et al. (1980), as was the case for Samish Bay, indicating a predominance of intertidal habitat. These data along with the distance from each hatchery to the local estuary are shown in

[1]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/cjfas-2013-0130.