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Spatial extent, magnitude, and patterns of persistent organochlorine pollutants in Pacific herring (*Clupea pallasi*) populations in the Puget Sound (USA) and Strait of Georgia (Canada)

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ABSTRACT

We examined the geographic distribution and magnitude of three persistent organic pollutants (POPs) in Pacific herring, representing three populations from Puget Sound, Washington State, USA and three from the Strait of Georgia (British Columbia, Canada and Washington State). We measured PCBs, DDTs and DDT isomers, and hexachlorobenzene in whole herring using high performance liquid chromatography, which provided a relatively inexpensive estimation of total PCBs, including the most commonly encountered congeners, and DDT isomers. Puget Sound herring were 3 to 9 times more contaminated with polychlorinated biphenyls (PCBs) compared to Strait of Georgia herring and 1.5 to 2.5 times more contaminated with DDTs. Hexachlorobenzene levels were low in all samples, relative to PCBs and DDTs, and one Strait of Georgia population (Cherry Point) had significantly lower HCB levels than the rest. A multidimensional scaling map of the pattern or "fingerprint" of POPs in the six herring populations suggests strong environmental segregation of Puget Sound herring from the Strait of Georgia populations, and isolation of all Strait of Georgia populations from each other. This segregation likely resulted from differential exposure to contaminants, related to where these populations reside and feed, rather than differences in their age, size, trophic level, or lipid content.

1. Introduction

Much attention has been paid to the accumulation and effects of persistent organic pollutants (POPs) in marine organisms, especially high trophic-level predators, starting with investigations of Baltic Sea biota some 40 years ago (Jensen et al., 1969). In more recent years, biomagnification of POPs resulting from trophic transfer via prey species has been identified as an important pathway for movement of POPs in both marine and freshwater food webs (Thomann, 1989; Bentzen et al., 1996; Fisk et al., 2001; Hoekstra et al., 2003). In addition, the burden of POPs carried in the bodies of these marine fishes is now being viewed as a significant environmental reservoir of POPs (Mackenzie et al., 2004).

Lipophilic POPs such as polychlorinated biphenyls (PCBs), dichlorodiphenyl-trichloroethane (DDT), chlordanes, polychlorinated dibenzodioxins (PCDDs), and dibenzofurans (PCDFs) have been reported in a food-web context in a number of small, schooling pelagic planktivorous (commonly referred to as forage fish) including Atlantic herring, *Clupea harengus* (Hording et al., 1997; Weisbrod et al., 2001), Baltic herring, *C. harengus* (Strandberg et al., 1998), anchovies, *Engraulis* spp

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(Jarman et al., 1996), sprat, *Sprattus sprattus* (Vuorinen et al., 2002), and smelt, *Osmerus mordax* (Hording et al., 1997).

Pacific herring (*Clupea pallasi*), Pacific sandlance (*Ammodytes hexapterus*), osmerid smelts and northern anchovies (*Engraulis mordax*) make up the bulk of the forage fish guild in the Puget Sound and Strait of Georgia food web. Because of their high abundance, high body fat, broad geographic distribution, and central position in the region's food web, they may play an important role in transferring lipophilic POPs to their predators, as well as predators at higher trophic levels. These species are important prey to virtually every large carnivorous fish species, several species of marine mammals, and many piscivorous seabirds in these waters.

Fish predators on this guild include migratory pelagic species such as chinook and coho salmon, *Oncorhynchus tshawytscha* and *O. kisutch* (Brodeur and Pearcy, 1992; Gearin et al., 1994; Higgs et al., 1995), less migratory pelagics such as Pacific hake, *Merluccius productus* (Outram and Haegle, 1972; Tanasichuk et al., 1991) and spiny dogfish *Squalus acanthias* (Jones and Geen, 1977; Tanasichuk et al., 1991), wide-ranging demersal species such as Pacific cod *Gadus macrocephalus* (Westrheim and Harling, 1983; Walters et al., 1986; Westrheim et al., 1989), reef-resident demersal species such as copper and quillback rockfish, *Sebastes caurinus* and *S. maliger* (Murie, 1995), and benthic predators such as lingcod, *Ophiodon elongatus* (Cass et al., 1990). In addition, small, schooling, pelagic planktivores are important prey to marine mammals including harbor seals, *Phoca vitulina* (Olesiuk, 1993) and harbor porpoise, *Phocoena phocoena* (Gearin et al., 1994), and they dominate the diet of a number of Puget Sound/Strait of Georgia seabirds, including common murre, *Uria aalge* and rhinoceros auklet, *Cerorhinca monocerata* (Lance and Thompson, 2005).

The inland marine and estuarine waters of Washington State and British Columbia comprise an extensive series of relatively deep, fjord-like basins, including the Strait of Georgia and Puget Sound. Over the last 100 years the region has experienced many of the stressors typically endured by nearshore marine ecosystems such as overfishing and habitat loss (West, 1997). Of particular concern is exposure of biota to anthropogenic toxic contaminants, because the region is experiencing rapid population growth. Puget Sound's watershed is more densely populated, and its shoreline more developed with industry and urban centers than the Strait of Georgia, and the Puget Sound is a much smaller body of water than the Strait of Georgia, occupying roughly one-third its surface area and one-sixth its volume. Moreover, the enclosed nature of these inland marine and estuarine waters may impede the dilution of contaminants relative to more

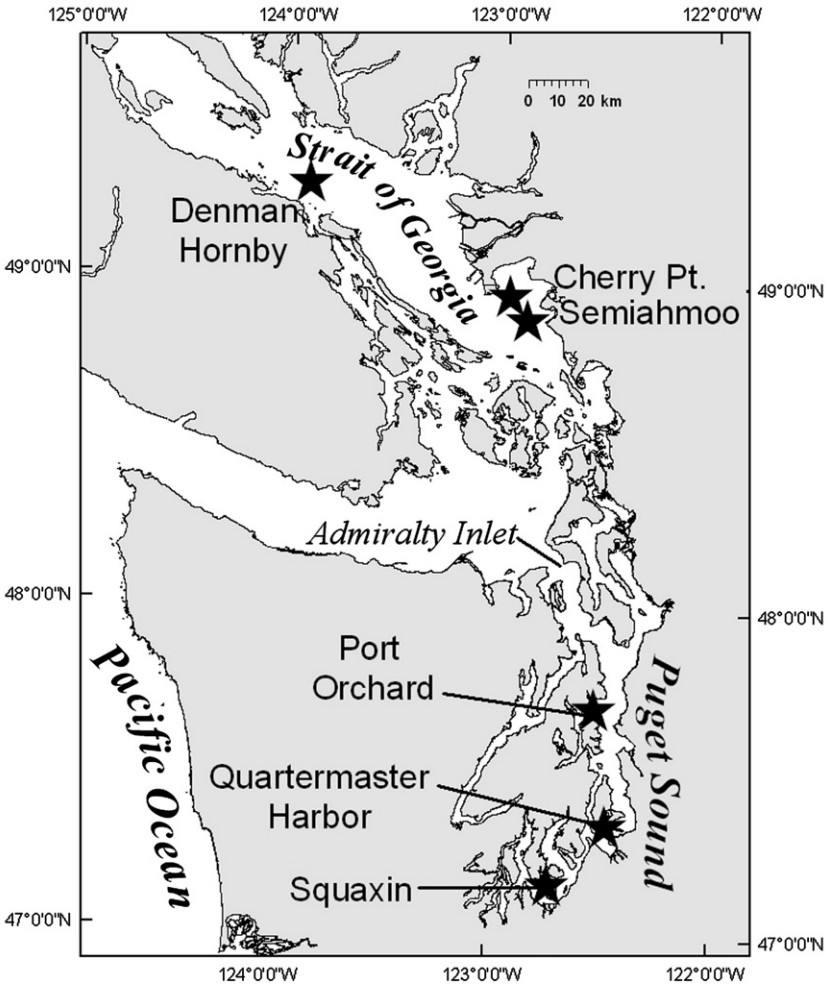

Fig. 1 – Capture location (denoted with black stars) of Pacific herring from six Puget Sound and Strait of Georgia populations.