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Persistent organic pollutants in forage fish prey of rhinoceros auklets breeding in Puget Sound and the northern California Current

Thomas P. Good [a,*], Scott F. Pearson [b], Peter Hodum [c], Daryle Boyd [d], Bernadita F. Anulacion [d], Gina M. Ylitalo [d]

[a] Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, USA
[b] Wildlife Research Division, Washington Department of Fish and Wildlife, Olympia, WA 98501, USA
[c] Biology Department, CMB 1088, University of Puget Sound, Tacoma, WA 98416, USA
[d] Environmental and Fisheries Sciences Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, USA

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ABSTRACT

Organochlorine contaminants in upper trophic-level consumers inhabiting Puget Sound are consistently higher than in those species inhabiting other west coast locations. We analyzed persistent organic pollutants (POPs) in the six most common fish prey of rhinoceros auklets breeding on Protection Island (Puget Sound), Tatoosh Island (WA coast), and Destruction Island (WA coast). Wet-weight concentrations of POPs ranged widely (PCBs: 1.6–25.0 ng/g; DDTs: 0.2–56.0 ng/g; PBDEs:<LOQ-49.0 ng/g), but overall patterns showed fish from Puget Sound were 2–4 times more contaminated and had similar contaminant profiles compared to fish from the outer coast. Unexpectedly elevated PCB and PBDE concentrations in Chinook salmon from the outer coast likely reflected Columbia River. Calculating contaminant loads for auklet nestlings magnified differences observed between inland and outer coast fish prey. Monitoring of breeding auklets, their prey and other resident marine birds is needed to assess biomagnification impacts in the Puget Sound marine ecosystem.

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1. Introduction

Persistent organic pollutants (POPs) have been documented in disparate aquatic ecosystems throughout the world as a consequence of their wide-spread usage, long-range transport, and recalcitrance to metabolism (Strandberg et al., 1998; Muir et al., 1999; Ross et al., 2009). This class of pollutants includes a variety of industrial compounds, organochlorine pesticides, and flame retardants, including polychlorinated biphenyls (PCBs), dichlorodiphenyl-trichloroethan (DDT), polybrominated diphenyl ethers (PBDEs), chlordanes, hexachlorocyclohexanes (HCHs), and hexachlorobenzene (HCB). Fat soluble and not readily degradable in the environment, POPs can occur in high concentrations in individuals via bioaccumulation and in food webs via biomagnification.

Persistent organic pollutants are a cause for concern for nearshore marine ecosystems already threatened by a variety of human activities and pressures. In Puget Sound, these include pollution, overharvest of fishery stocks, the introduction of non-native and invasive species, climate change, and habitat loss and degradation associated with development and regional population expansion (Fresh et al., 2011). These impacts have led to changes in food web dynamics, an increase in hypoxic "dead zones", declines in pelagic fish populations such as Pacific herring (*Clupea harengus pallasi*; Stick and Lindquist, 2009), and many threatened and endangered marine species (Pearson et al., 2010).

Signs of ecosystem deterioration in the form of increasing levels and types of persistent organic pollutants have already been detected in a variety of Puget Sound marine organisms. At key middle trophic levels, Pacific herring are at least three times more contaminated with PCBs in Puget Sound than in the Strait of Georgia (West et al. 2008). Studies of juvenile salmonids in West Coast estuaries found high levels of PCBs and DDTs in the more urban estuaries, including Puget Sound (Johnson et al., 2007a, 2007b). At higher trophic levels, studies of adult and subadult salmonids have shown high concentrations in Chinook salmon (*Onchorynchus*

* Corresponding author. Tel.: +1 (206) 806 3469; fax: +1 (206) 860 3335.
E-mail addresses: tom.good@noaa.gov (T.P. Good), scott.pearson@dfw.wa.gov (S.F. Pearson), phodum@ups.edu (P. Hodum), daryle.boyd@noaa.gov (D. Boyd), bernadita.anulacion@noaa.gov (B.F. Anulacion), gina.ylitalo@noaa.gov (G.M. Ylitalo).

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tschawytscha; O'Neill and West, 2009; Cullon et al., 2009). Residency in the contaminated Puget Sound environment was likely a major factor contributing to the higher and more variable PCB concentrations in these fish (O'Neill and West, 2009). Higher trophic level harbor seal (*Phoca vitulina*) pups from Puget Sound, WA had PCB levels seven times that of pups from the Strait of Georgia, BC (Ross et al., 2004), and recreating and analyzing their diets for both locations using documented dietary preferences (a food basket approach) corroborated the PCB differences as well as the dietary source of the contaminants (Cullon et al., 2005).

At the top of the food web, killer whales (*Orcinus orca*) that spend time in Puget Sound (fish-eating Southern Resident killer whales and marine mammal-consuming transient killer whales) are among the most contaminated marine mammals in the world, with relatively high levels of PCBs and PBDEs found in individuals throughout the Puget Sound and Georgia Basin (Ross et al., 2000; Ross, 2006; Krahn et al., 2007, 2009). Concentrations of some POPs in harbor seal pups from a southern Puget Sound site have declined since the mid-1980s (Ross et al. 2013), and PBDE concentrations in great blue heron (*Ardea herodias*) and double-crested cormorant (*Phalacrocorax auritus*) eggs have declined after peaking in the mid-1990s (Elliott et al., 2005). These hopeful signs of reduced inputs into nearshore systems notwithstanding, Puget Sound continues to represent a regional PCB "hotspot," and movement of persistent organic pollutants through the food web may be extensive (Ross, 2006).

The forage fish guild in the Puget Sound food web is dominated by Pacific herring, Pacific sandlance (*Ammodytes hexapterus*), surf smelt (*Hypomesus pretiosus*) and juvenile *Oncorhynchus* salmonids (Rice et al. 2012), and these species are likely important vectors for POPs to upper trophic level taxa such as piscivorous fish, marine mammals, and seabirds (West et al., 2008). Pacific herring have been analyzed from sites throughout Puget Sound and Georgia Strait (West et al., 2008), but there is a need for broader food-web based toxics research. While a food basket approach (Cullon et al., 2005) has provided information on contaminant loads associated with composite samples representing the diets of harbor seals, no regional studies have captured and analyzed captured prey of upper trophic level predators.

Seabird diet, in addition to tracking foraging patterns of the seabird themselves, has been used to indicate fish population status and fishery recruitment (Bertram et al., 2005; Thayer and Sydeman, 2007). Seabirds foraging in nearshore waters also experience a suite of environmental stressors, and many responses to these stressors (e.g., mortality, body condition, disease/parasites, pollutants) may serve as indicators of overall ecosystem health (Mallory et al., 2010). Being central place foragers, breeding seabirds are generally constrained to areas close to their colonies, thus seabirds breeding in inland waters may be particularly vulnerable to local stressors including contaminants. Tracking seabird diet can also enhance our understanding of trophic position and contaminant monitoring, as well as potential bioaccumulation and biomagnification effects in the food web (Hebert and Weseloh, 2006; Jarman et al., 2007).

Rhinoceros auklets (*Cerorhinca monocerata*) are medium-sized members of the Family Alcidae. Most of the North American population breeds in underground burrows on a small number of islands in British Columbia, Washington State and southeast Alaska, although some colonies exist as far south as California (Gaston and Dechesne, 1996). In Washington, auklets breed on rocky islands on the outer Washington coast and on undeveloped islands in the otherwise developed Puget Sound's inland waters (Speich and Wahl, 1989; Pearson et al., 2013). These birds capture prey through wing-propelled pursuit-diving, feeding mainly on schooling fishes in nearshore areas (Thayer and Sydeman, 2007). During breeding, the foraging distance of rhinoceros auklets at colonies ranges from ~40 km in inland Washington waters up to 80–90 km on the outer Washington coast (Wahl and Speich 1994). After chicks hatch, each adult brings back one load (1–30 fish)/night crosswise in their bill for approximately 50 days until the chicks fledge (Wilson, 1977).

Research on the diet of rhinoceros auklets in Washington State has indicated that fish prey delivered to chicks varies considerably among three distinct study locations (Pearson et al. unpubl.). In Puget Sound, rhinoceros auklets breeding on Protection Island show a diet relying on few prey species, primarily Pacific sandlance (76% by weight) and Pacific herring (16% by weight). Auklets breeding on the outer Washington coast on Destruction Island show a reliance on northern anchovy (*Engraulis mordax*; 48% by weight), smelt (*Osmerus* spp. 30% by weight), and rockfish (*Sebastes* spp. (12% by weight), with much lower reliance on Pacific sandlance (2% by weight) and Pacific herring (2% by weight). Auklets breeding on Tatoosh Island on the Washington coast at the tip of the Olympic Peninsula showed the most variable diet delivered to chicks, including Pacific sandlance (45% by weight), Pacific herring (15% by weight), rockfish (10% by weight), Pacific saury (*Cololabis saira*; 7% by weight), smelt (7% by weight), and salmonids (7% by weight).

Based on concentrations of contaminants detected in other species in the Puget Sound food web, we hypothesized that patterns of persistent organic pollutants in the prey of rhinoceros auklet chicks would differ among breeding colony locations. Specifically, we predicted that fish prey from the inland Washington water colony in Puget Sound would have greater mean concentrations of persistent organic pollutants than fish prey from study colonies on the outer Washington coast (Tatoosh Island, Destruction Island). Moreover, we predicted that the overall calculated contaminant intake of rhinoceros auklet chicks (via prey delivered by provisioning adults) would be greater in Puget Sound than on the outer Washington coast. Specifically, we examined the following questions: (1) Do contaminant levels (concentrations of POPs) of fish prey differ among rhinoceros auklets breeding colonies on Washington's outer coast and inland marine waters? (2) Do contaminant levels (concentrations of POPs) of fish prey of rhinoceros auklets breeding on Washington's outer coast and inland marine waters differ among prey species? (3) Do calculated contaminant burdens (based on observed diet differences and using a quasi-food basket approach) differ among observed chick diets on breeding colonies?

2. Materials and methods

2.1. Study sites

The study colonies were located in the inland waters of Puget Sound (Protection Island) and the outer coast of Washington state (Tatoosh Island; Destruction Island; Fig. 1). Protection Island (48°08′N, 122°55′W) is a 143-ha island located 3.2 km off the mouth of Discovery Bay at the eastern end of the Strait of Juan de Fuca. Approximately 36,000 rhinoceros auklet pairs breed on its grass-dominated habitats on slopes and cliff edges (Pearson et al., 2013). Tatoosh Island (48°24′N, 124°44′W), is a 6-ha complex of flat-topped rocky islets located 0.6 km off the northwest tip of the Olympic Peninsula. Recent monitoring suggests at least 200 rhinoceros auklet pairs have burrows on the island's cliff top grass and shrub habitats (Pearson et al., 2013). Destruction Island (47°40′N, 124°24′W) is a 15-ha island located 4.8 km west of the Olympic Peninsula and 29 km south-southeast of La Push. An estimated 6500 rhinoceros auklet pairs breed in grass, shrub and willow habitats on cliff tops and the island's steep slopes (Pearson et al., 2013).