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Bioaccumulation of organochlorines in relation to the life history in the white-spotted charr *Salvelinus leucomaenis*

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ABSTRACT

The bioaccumulation of organochlorines (OCs) in the muscle tissue of sea-run (anadromous) and freshwater-resident (fluvial) white-spotted charr (*Salvelinus leucomaenis*) was determined to assess the ecological risk related to intraspecies variations in diadromous fish life history as they migrate between sea and freshwater. Generally, there were significant correlations between the accumulation of OCs such as DDTs, HCB, HCHs and CHLs. In addition, various biological characteristics, such as total length (TL), body weight (BW) and age, and number of downstream migration (NDM) were correlated. A positive correlation occurred between the lipid content and the OC concentrations. Close linear relationships were found between TL, BW and NDM and the lipid content. Although they are both the same species, the OCs concentrations in the anadromous fish were significantly higher than those in the fluvial individuals. These results suggest that anadromous *S. leucomaenis* have a higher ecological risk for OCs exposure than the fluvial fish.

1. Introduction

Persistent organic pollutants are of global concern because of their toxicity, resistance to degradation, potential for long-range transport and their tendency to accumulate in fatty tissues (lipophilicity). Lipophilicity of organisms can lead to the bioaccumulation of pollutants through the food webs (Jones and de Voogt 1999). Organochlorines (OCs), including DDT compounds (DDTs), hexachlorocyclohexane isomers (HCHs), hexachlorobenzene (HCB) and Chlordane compounds (CHLs), have been extensively used for the relief of mankind. The use of these chemicals has resulted in a number of negative effects on terrestrial and aquatic organisms. Some of these chemicals are considered to function like environmental hormones that disturb the humans and wildlife reproductive cycles (Colborn and Smolen, 1996). Despite the ban and restrictions regarding the use of persistent OCs in developed countries since the 1970s, some developing countries still use for agricultural and public health purposes because they are low cost and effective against various insects. OC residues have been widely identified and reported from around the world, including in Antarctica and the Arctic Zone (Fu et al., 2001; Chiuchiolo et al., 2004). This global occurrence is due to the potential of OCs for long-range atmospheric transport, cold condensation (Bidleman et al., 1993; Iwata et al., 1993; Wania and Mackay, 1996) and their intensive use in agricultural and industrial activities. Another possible pollutant transport route is biotransport, in which migrating animals act as vectors between ecosystems. For example, the role of salmon in transferring nutrients and pollutants is an important factor in the global transport of these chemicals. Some salmonid fish have an anadromous life history pattern and return to their natal streams to spawn. In addition, these fish are semelparous (they die after spawning once), and leave many carcasses in the upstream area. These fish can transport pollutants from the Great Lakes to its tributaries (Merna, 1986; Lum et al., 1987; Scrudato and McDowell, 1989) and transfer nutrients and pollutants between marine and freshwater environments (Ewald et al., 1998; Naiman et al., 2002; Krümmel et al., 2003). Biotransport reportedly has a greater influence on lake biota than atmospheric input (Ewald et al., 1998; Krümmel et al., 2003). Although biotransport studies in a few anadromous salmon species have been conducted, few studies have looked at the relationship between OC accumulations and salmonid fish migratory histories.

White-spotted charr, *Salvelinus leucomaenis* (Pallas), are distributed throughout far east Asia (Kawanabe, 1989). As for many other salmonids, the species is characterized by anadromous and fluvial life histories (Kawanabe, 1989). In its northern distribution area (including the northern part of Honshu Island, Japan, north to the Kamchatka Peninsula, Russia), most females and some males undergo a complex physiological process, which includes changing from the brownish color of parr to the silvery color of smolt. They migrate downstream to the sea and return to the natal river as large individuals to spawn (Yamamoto et al., 1992, 1996). The

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males that resident in the river mature to a much smaller size than the migrant fish (Yamamoto et al., 1996). In contrast, populations near the southern limits (occurring mostly in the central part of Honshu Island) are composed of only mature parr (Kawanabe, 1989). Charr generally spend 2 to 5+ yr in rivers in the parr stage (Yamamoto and Nakano, 1996; Yamamoto et al., 1992). After the parr stage, the charr smolt and descend to the sea. However, some charr mature in freshwater without migration (resident charr) (Morita et al., 2000). Smolting occurs during April and May, and sea-run charr ascend rivers from June to August (Takami, 1995). Reproduction of returning sea-run charr and mature parr (resident) occurs in rivers during September and October. Sea-run charr descend to the sea again from November to April and move along the coast. Thus, the life cycle of this species is iteroparous (reproducing more than once in a life time), variable and complex.

The migratory history of the species was studied with microchemical analytical techniques to determine the ratios of strontium to calcium (Sr:Ca) in the fish otoliths. The Sr:Ca ratio in the fish otoliths differs depending on the amount of time they spend in freshwater and seawater (Arai and Morita, 2005; Arai et al., 2005). Thus, the Sr:Ca ratios of otoliths may enable us to determine whether individual salmons actually move between different habitats with differing salinity regimes. The otolith Sr:Ca ratios of freshwater resident (fluvial) were consistently low. In contrast, the Sr:Ca ratios of the *S. leucomaenis* migrants (anadromous) fluctuated greatly along the life history transect according to the sea to freshwater migration (habitat) pattern. In migrant fish, several spikes consisting of low and high otolith Sr:Ca ratios were found in the life history transect. The numbers of otolith Sr:Ca ratio spikes in each fish were nearly consistent with the downstream migration times that were estimated from tag-recapture field observations (Arai and Morita, 2005). These findings suggested that the white-spotted charr migrated between freshwater and marine environments several times during their life history. Therefore, different ecological risks for pollutants, including OCs, could be considered depending on their life history patterns even within the same species.

The aim of this study was to assess the accumulation pattern differences in the muscles of two migratory types of the white-spotted charr, *S. leucomaenis*, which were collected in sea and freshwater habitats in Japan. The OCs that were monitored in this study included DDTs, hexachlorobenzene (HCB), hexachlorocyclohexanes (HCHs), chlordanes (CHLs) and mirex. These differences were examined by comparing OC accumulations with the life histories of the two types of *S. leucomaenis*. The environmental histories of *S. leucomaenis* were reconstructed by using the ontogenic otolith Sr:Ca ratio changes that occurred along the life history transect. These results may provide valuable clues for quantifying the bioaccumulation of OCs and their variations according to diadromous fish migration.

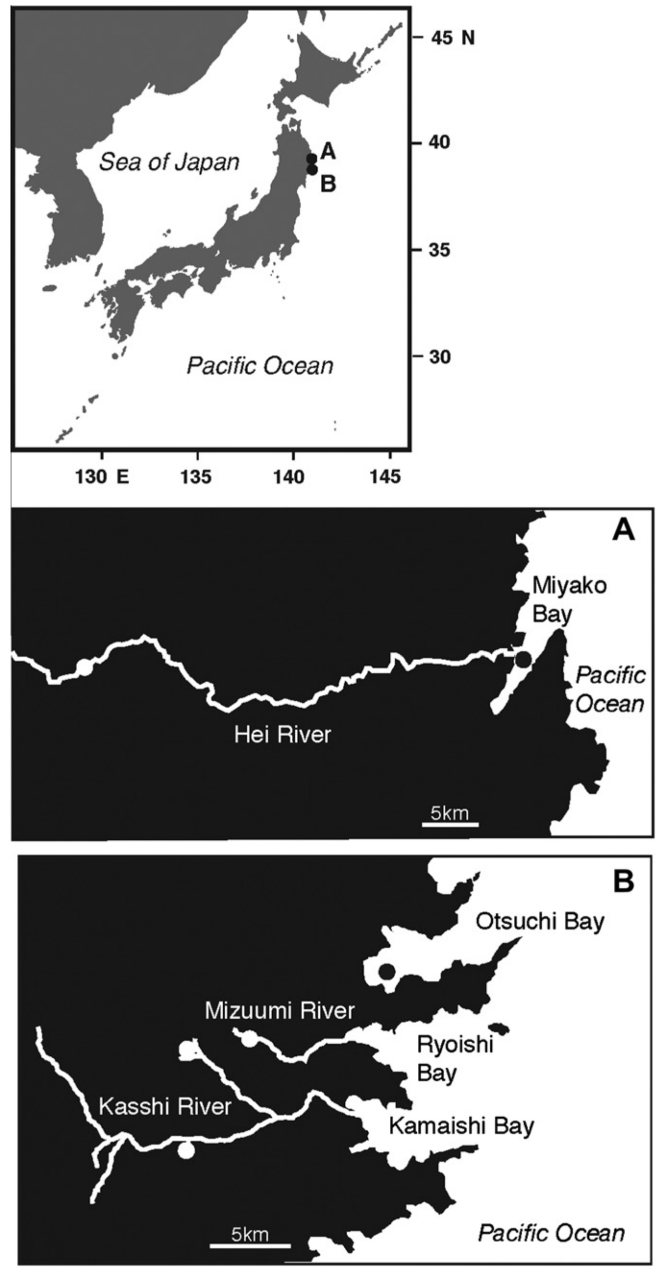

Fig. 1. Sampling sites in the Miyako Region (A) and the Otsuchi Region (B), Japan. Sampling sites are indicated with black and white symbols. In the Miyako Region, fish were collected from the Hei River and from the Miyako Bay. In the Otsuchi Region, fish were collected from one site in the Otsuchi Bay, two sites in the Kasshi River and one site in the Mizuumi River. Sampling was conducted at six sites that belonged to four Japanese water systems.

2. Materials and methods

2.1. Fish

S. leucomaenis were collected from June 2006 through May 2007 by set nets or angling at six sites in four Japanese sea water systems and Iwate Prefecture fresh waters on the Pacific side of northeastern Honshu Island, Japan (Fig. 1). Otsuchi Bay covers an area of 20.2 km^2 and is located in the southeastern coastal area of Iwate Prefecture. The fish were collected from one site in this bay. Kamaishi Bay covers an area of 8.7 km^2 and is located in southern Otsuchi Bay and. The Kasshi River is adjacent to this bay. Ryoishi Bay is located between Otsuchi Bay and Kamaishi Bay and is adjacent to the Mizuumi River. The fish were collected from two sites at the Kasshi River and one site at the Mizuumi River. The sites at the upper reach of the river were not influenced by the tidal effect and had a salinity of 0. Here, these two sites are collectively referred to as the Kasshi River. In addition, the other rivers and the Otsuchi Bay are collectively referred to as the Otsuchi Region. Miyako Bay covers an area of 24.1 km^2 and is located in the central coastal area of the Iwate prefecture adjacent to the Hei River (Fig. 1). The fish were collected from one site in the bay and one site in the river where the tidal effect has no influence and the salinity is 0. Here, these two sites are collectively referred to as the Miyako Region. Eighteen specimens were collected from the Miyako Region between June 2006 and May 2007. In addition, 10 specimens were collected from the Otsuchi