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Effects of prey assemblage on mercury bioaccumulation in a piscivorous sport fish

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HIGHLIGHTS

- We model mercury bioaccumulation in a freshwater piscivore (walleye).
- We examined effects of changes in prey assemblage on walleye mercury.
- Prey assemblage had a substantial influence on walleye mercury concentration.
- Predictions were consistent with independent observations with different prey.
- Management of prey has potential for mitigating mercury contamination in piscivores.

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ABSTRACT

Mercury (Hg) is a persistent global contaminant that biomagnifies, often reaching maximum levels in apex predators. Mercury contamination in piscivorous fish is a serious health risk for anglers and other fish consumers. We used data collected from a reservoir in Colorado to develop bioenergetics-based simulations of Hg bioaccumulation to estimate Hg concentrations in walleye (*Sander vitreus*), a popular sport fish. We evaluated how changes in the prey available to walleye might affect walleye Hg concentrations. Our simulations showed that such changes could result in almost a 10-fold range in walleye Hg concentration. Walleye consuming invertebrates had low growth, low growth efficiency, and high Hg concentrations. Conversely, when walleye diet contained only fish prey their growth and growth efficiency were higher and Hg concentrations were about 85% lower. These predictions were consistent with independent measurements in the study system observed under two different prey regimes in 2008 and 2013. Because prey assemblages in freshwaters can exhibit high natural and anthropogenic variability, understanding variation in predator Hg and providing accurate fish consumption advice to anglers and their families will require frequent monitoring of both predator and prey species. Further, manipulation of prey assemblages is a routine fishery management strategy that could be applied to reduce Hg contamination in piscivorous fishes.

1. Introduction

Mercury (Hg) contamination is a serious environmental problem and public health risk throughout the world (Driscoll et al., 2007; Mergler et al., 2007). Mercury impairs behavior and motor skills, disrupts endocrine function, harms reproduction and immune response, and can cause neurological, liver and kidney damage (Clarkson and Magos, 2006). Mercury exposure in animals comes mostly from their food (Hall et al., 1997; Mergler et al., 2007), and Hg biomagnifies as it moves through food webs, reaching the highest levels in apex predators (Morel et al., 1998). In freshwater ecosystems, Hg concentrations are typically highest in piscivorous fish (Depew et al., 2013; Lavoie et al., 2013). Because many freshwater piscivores are also desirable sport fish, Hg contamination presents a serious health risk for anglers and their families. Consequently, environmental and public health agencies have established thousands of fish consumption advisories for Hg in the United States alone (USEPA (United States Environmental Protection Agency), 2013). However, variability in fish Hg is high even at regional and local scales (Sackett et al., 2009). This suggests that intrinsic characteristics of water bodies influence Hg accumulation in biota (Clements et al., 2012). Understanding the mechanisms that affect bioaccumulation of Hg in fish is an important goal for managing this toxic and widespread contaminant.

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A variety of studies have demonstrated that mercury bioaccumulation in freshwater fish can be affected by environmental conditions such as dissolved organic carbon (Driscoll et al., 1995), productivity (Chen and Folt, 2005; Essington and Houser, 2003), and water level fluctuations (Sorensen et al., 2005). However, it is also known that mercury bioaccumulation is affected by food web characteristics such as the composition of the prey assemblage (Harris and Bodaly, 1998). Prey organisms consumed by fish can vary widely in their energy density (Ciancio and Pascual, 2006; James et al., 2012; Mittelbach and Persson, 1998) and Hg concentration (Depew et al., 2013; Wong et al., 1997). Prey populations can be highly dynamic and sustaining adequate supplies of high quality prey for sport fish is a perpetual challenge to fishery managers (e.g., Johnson and Martinez, 2000; Ney, 1990). When preferred prey are rare, predators may need to expend more energy in foraging for less energetically profitably prey, such as invertebrates (Boisclair and Rasmussen, 1996; Henderson et al., 2004). This situation results in reduced growth efficiency, which can increase bioaccumulation of contaminants (Madenjian et al., 2009; Trudel and Rasmussen, 2006).

The objective of this paper is to evaluate the hypothesis that changes in the prey assemblage could alter bioaccumulation in a widely-distributed piscivorous sport fish, the walleye (*Sander vitreus*). We used modeling to simulate plausible scenarios parameterized from our own work and that of others to generate hypotheses about how prey assemblage characteristics affect predator Hg concentrations and compared these to empirical data from several systems. This work can inform potential mitigation strategies for reducing Hg concentrations in sport fish to protect human health, independent of mercury concentrations in the environment.

2. Methods and materials

2.1. Study site

We chose a well-studied Colorado reservoir as a model system to investigate how the prey assemblage could affect Hg concentrations in walleye. Walleyes are one of the most popular sport fish in Colorado and the state has invested considerable resources to characterize risk to human health and to develop consumption recommendations for anglers and their families (CDPHE (Colorado Department of Public Health and Environment), 2014). Horsetooth Reservoir (Larimer County, CO) is at an elevation of 1655 m, with a surface area of 826 ha, a maximum depth of 55 m, a capacity of 193 million m^3 and was filled in 1951. Like many other Colorado reservoirs, Horsetooth Reservoir has been stocked with a variety of nonnative sport and prey fish species since its construction, resulting in dynamic predator–prey relationships.

In 1983, rainbow smelt (*Osmerus mordax*) were introduced into Horsetooth Reservoir to serve as forage for walleye. Rainbow smelt densities increased for six years and adult walleye growth improved dramatically (Jones et al., 1994), but the effect was temporary. After depleting food resources and experiencing predation by walleye, rainbow smelt abundance started to decline in 1995, and because none were observed in annual fisheries surveys (Kehmeier K, CPW, personal communication) the species was believed to have been extirpated by 2000. Walleye body condition declined in conjunction with the rainbow smelt decline (Johnson and Goettl, 1999) and remained poor during 2000–2008. Apparently, during this period piscine prey were few, and crayfish (*Orconectes* spp.) were the dominant prey in walleye diets (Kehmeier K CPW, personal communication). A fish consumption advisory (FCA) on walleye from Horsetooth Reservoir was established in 2007, because many fish tested for Hg were over 0.5 μg/g wet mass (M_w) — the current FCA limit is 0.3 μg/g M_w (CDPHE (Colorado Department of Public Health and Environment), 2014). Some walleyes tested from Horsetooth Reservoir exceeded 0.8 μg/g M_w, some of the highest Hg concentrations of any fish in the state. Stakeholders were interested in management interventions such as prey stocking that could improve walleye growth and reduce their Hg concentration.

2.2. Simulations

We used simulation modeling to evaluate how the prey assemblage affected bioaccumulation of Hg in walleye. We developed four modeling scenarios that encompassed prey conditions commonly observed in reservoirs in Colorado: 1) "BASE": contemporary Horsetooth Reservoir food web; 2) "INVT": no piscine prey, invertebrate only diet; 3) "SMLT": return of rainbow smelt as walleye prey; and 4) "STCK": stocking hatchery rainbow trout (*Oncorhynchus mykiss*) as walleye prey. Each simulation modeled static prey conditions described above for walleyes from age-3 to age-10. We compared WAL_{Hg} among scenarios at a fixed size (381 mm TL) corresponding with the typical minimum size limit on walleye in Colorado, and at the end of the simulation (age-10). Few walleye older than age-10 were present in our aging or Hg samples.

In the BASE scenario we used the growth, diet, and prey characteristics measured in 2008 (Table 1) to predict WAL_{Hg} and compare it to the observed WAL_{Hg}. The INVT scenario mimics historic conditions observed in Horsetooth Reservoir and present in several other Colorado reservoirs, where forage fish are rare, predators consume invertebrates such as crayfish (*Orconectes* spp.) and chironomids, and growth is slow (as in BASE). In the SMLT scenario, we hypothesized that if the rainbow smelt population rebounded they would again comprise 90% of the walleye diet, and growth of walleye would increase, as observed when rainbow smelt biomass was maximal in the late 1980s (Jones et al., 1994). The last scenario (STCK) simulated the effects of stocking hatchery rainbow trout as prey, a practice that occurs in other Colorado reservoirs (Johnson and Martinez, 2000). Walleyes are known to prey heavily on stocked salmonids in western reservoirs (Baldwin et al., 2003; McMahon and Bennett, 1996), so in this scenario diet consisted

Table 1

Model inputs used to evaluate effects of prey scenarios on bioaccumulation of Hg in walleye at Horsetooth Reservoir, Colorado. Prey taxa: CFI = crayfish, CHI = chironomids, GSD = gizzard shad (*Dorosoma cepedianum*), RBT = rainbow trout, SMT = rainbow smelt, YPE = yellow perch (*Perca flavescens*). Walleye energy density (5879 J/g M_w) and initial Hg (0.151 μg/g M_w) were fixed in all simulations.

Scenario	Walleye weight at age (M_w, g)	Walleye diet			
		Taxon	Proportion	Energy (J/g M_w)	Hg (μg/g M_w)
Baseline (BASE)	$W_3 = 244$	CFI	0.200	2942	0.117
		CHI	0.243	4090	0.008
	$W_{10} = 509$	GSD	0.181	4842	0.044
		YPE	0.375	4336	0.057
Invertebrates only (INVT)	BASE	CFI	0.450	2942	0.117
		CHI	0.550	4090	0.008
Smelt return (SMLT)	$W_3 = 272$	SMT	0.900	4868	0.057
	$W_{10} = 2351$	CFI	0.100	2942	0.117
Trout stocking (STCK)	SMLT	RBT	1.000	5651	0.027