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The importance of dynamic mercury water column concentrations on body burdens in a planktivorous fish: A bioenergetic and mercury mass balance perspective

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A B S T R A C T

Bioenergetic algorithms and mercury (Hg) mass balance approaches are combined into a single modeling framework (BioHg) to investigate sensitivity of methylmercury (MeHg) levels in Sacramento blackfish (*Orthodon microlepidotus*), a planktivorous cyprinid, as a function of dissolved water column concentrations of methylmercury (*DMeHg*). Boundary condition *DMeHg* are defined using observed Carson River contributions to Lahontan Reservoir, Nevada (USA). Influxes of *DMeHg* have a seasonal mean of 0.65 ± 0.21 ng/L (January) to 2.48 ± 1.53 ng/L (August) and blackfish concentrations in Lahontan Reservoir exceed health criterion for human consumption of MeHg by nearly three-fold. Model parameterization relies on laboratory and field data specific to the blackfish to calibrate allometric coefficients related to consumption, respiration, specific dynamic action, egestion, excretion, and spawning. Actual consumption is reliant on feeding strategies, prey selectivity, filtering efficiency, and prey availability. BioHg is able to capture trends in observed growth and wet weight MeHg concentrations in blackfish. MeHg concentrations are obtained in the first year and maintained throughout the lifespan of the fish, with growth dilution an important processes limiting continued increases in MeHg concentrations through time. Model results indicate that coupling dynamic *DMeHg* influxes with periods of maximum plankton growth and maximum fish consumption rates increases fish concentrations by 50% and is a better predictor of observed concentrations in comparison to a constant *DMeHg* condition. Additionally, peak MeHg concentration in fish is directly correlated to maximum *DMeHg*. Simulated phase shifts in *DMeHg* decouples modeled processes and MeHg fish concentration estimates decrease by 50%. BioHg highlights that both the magnitude and timing of *DMeHg* are important predictors of MeHg accumulation in a planktivourous fish.

1. Introduction

The United States Environmental Protection Agency (USEPA) currently lists 4584 impaired waterways as a result of mercury (Hg) contamination with more than 3000 of these systems impaired as a result of Hg in fish. Statistical approaches have attempted to predict Hg in fish to elucidate factors that affect the cycling of Hg in aquatic systems as well as to define consumption guidelines (Peterson et al., 2007). The trophic transfer of Hg accounts for more than 90–99% of bioaccumulated Hg in fish (Spry and Wiener, 1991), with the majority (95–99%) of total Hg in fish associated with the methylated form of Hg, or methylmercury (MeHg) (Spry and Wiener, 1991; Bloom, 1992; Watras et al., 1998). In general, Hg concentrations in fish tend to increase with age and/or size of the fish (Cizdziel et al., 2002; Sackett et al., 2013). However, tremendous variability occurs among fish of the same species and not all fish experience increased Hg levels with age or size. Observed variability has been explained by site-specific geochemical, physical, and/or biological descriptors of the aquatic system (McMurtry et al., 1989; Allard and Stokes, 1989; Jackson, 1991; Lange et al., 1993; Jin et al., 1999; Haines et al., 2003) as well as food web complexity (Cabana and Rasmussen, 1994; Cabana et al., 1994; Kidd et al., 1995; Kidd, 1998; Chen et al., 2014), and uptake efficiency at the base of the food web (Stewart et al., 2008). Most of these approaches can give real, quantitative ranking of the variables influencing Hg concentrations in biota, but they cannot be extrapolated beyond regression ranges

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and are limited to static or steady-state scenarios that fail to capture any time dependencies regarding Hg bioaccumulation.

From a bioenergetic and Hg mass balance perspective, Hg levels in fish will increase if the rate of Hg sequestration is higher than the rate of elimination. This can occur if the growth efficiency of fish decreases for a given quantity of food consumed or by increased Hg exposure (Borgmann and Whittle, 1992; Rowan et al., 1998). Increased exposure in fish requires a dietary shift to more contaminated prey or a temporal gain in prey bioaccumulation. Planktivorous fish depend on algae and zooplankton for the bulk of their energy needs, and these are the principal pathway for Hg transfer. Hg accumulation in plankton is, in turn, dependent on contact with contaminated water (Swackhamer and Skoglund, 1993) with seasonal variability based on growth and size (Carroll et al., 2011). Therefore, Hg body burdens in planktivorous fish could depend on the timing of Hg loads if the loading signal varies strongly through time. The importance of a temporally varying water column signal may increase if maximum water concentrations are coincident with high plankton availability and maximum consumption needs/efficiency of the fish. In this study, we incorporated bioenergetic algorithms (Peterson et al., 2007; Megrey et al., 2007) with Hg mass balance approaches (Trudel and Rasmussen, 2001, 2006) to investigate Hg levels in a planktivorous fish as a function of a highly dynamic water column Hg signal. The species of concern is the Sacramento blackfish (*Orthodon microlepidotus*), a planktivorous cyprinid (minnow) found in northern California and Nevada.

2. Site description

The Carson River and Lahontan Reservoir in west-central Nevada (Fig. 1) is listed by the USEPA as a Superfund site due to its contamination with Hg derived from historic mining with nearly 6.36×10^6 kg (7000 tons) of residual Hg distributed throughout the river bank sediments and floodplain deposits (Miller et al., 1998; Smith and Tingley 1998). The Carson River is the primary

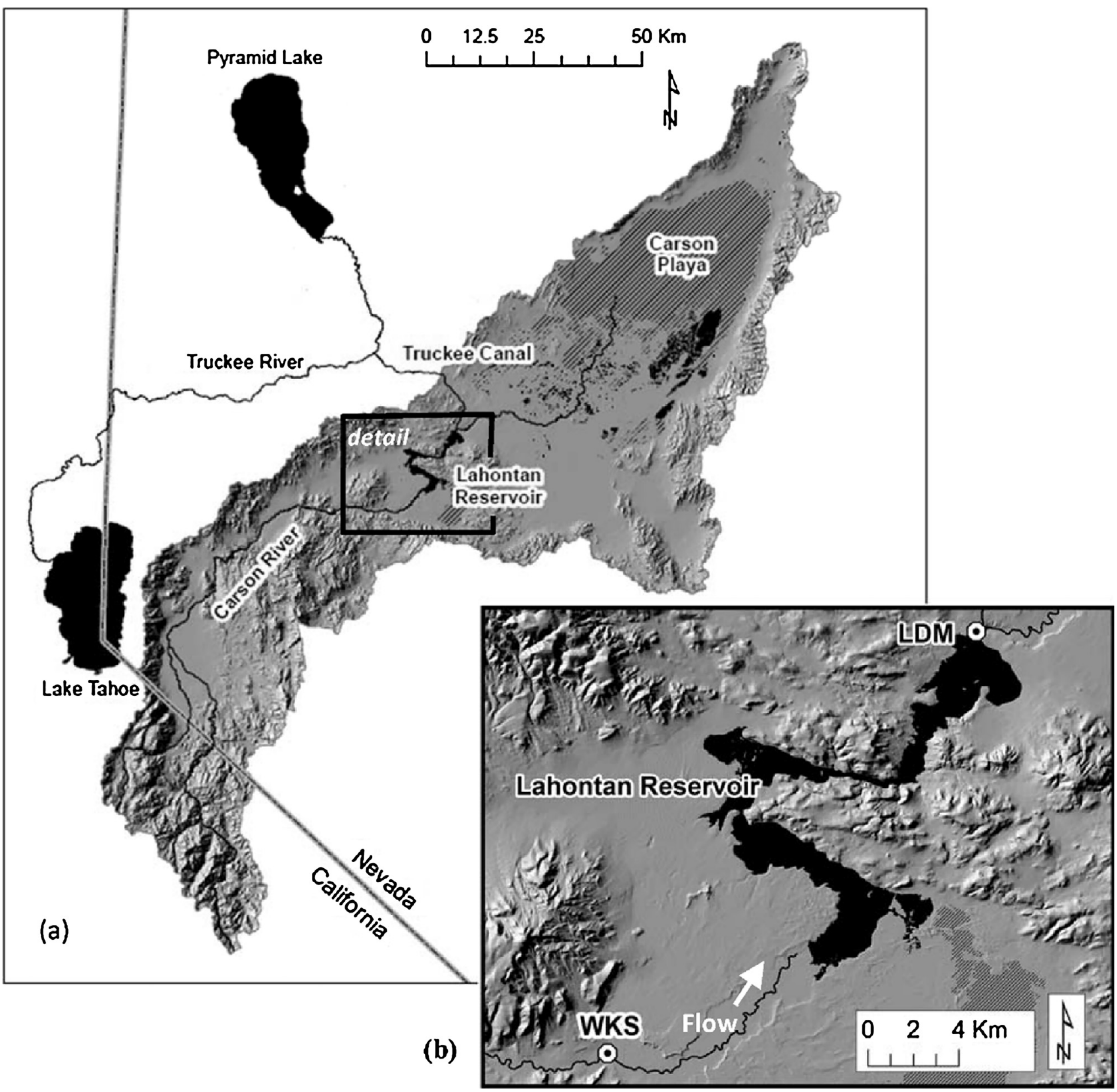

Fig. 1. (a) The Carson River Basin. Flow in the system is west to east. (b) Detail with Weeks Bridge (WKS) and Lahontan Dam (LDM) shown.