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Site-specific environmental quality criteria for survival and growth of farmed abalone exposed to zinc

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Abstract

We develop a simple predictive environmental quality criteria (EQC) model for the survival and growth of farmed abalone *Haliotis diversicolor supertexta* exposed to waterborne zinc (Zn) based on a probabilistic internal effect concentration (IEC)-based modeling framework. We couple a first-order two-compartment bioaccumulation model and a reconstructed dose–response profile based on a three-parameter Hill equation model associated with a field bioaccumulation study to form a probabilistic model to determine acute and chronic EQC. The acute EQC (a-EQC) is predicted from IECs and a field-derived bioaccumulation factors, whereas a statistical procedure with an acute-to-chronic value is used to derive chronic EQC (c-EQC) based on bioaccumulation. Field bioaccumulation study demonstrates a linear relationship between water and tissue Zn concentrations in abalone and algae. Our model, designed for simplicity and theoretical insight, yields explicit mathematical results through a probabilistic analysis to capture EQC modeling methodology in a more realistic way by analyzing computationally through Monte Carlo simulations. Here we show that the median a-EQC ranges from 0.34–0.39 μg ml^{-1}, whereas the median c-EQC is 0.04–0.05 μg ml^{-1} for selected abalone farms. We believe that this probabilistic EQC modeling framework is an effective method for conceptualizing a public policy decision vis-à-vis establishing a site-specific acceptable acute and chronic EQC for better management and restoration of the rapidly degrading aquacultural ecosystems.

Keywords: Abalone; Site-specific environmental quality criteria; Probabilistic; Risk; Toxicity; Zinc

1. Introduction

Richardson (2001) and Wang and Ke (2002) have shown that zinc (Zn) was found in high level (50–120 g g^{-1} dry wt) in the tissues of gastropods. Lin and Liao (1999) and Liao et al. (2002a) indicated that Zn has been detected in many abalone farms.

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The average Zn concentrations in aquaculture waters are reported to range from 60 to 130 ng ml^{-1} in different areas of Taiwan. Abalone *Haliotis diversicolor supertexta* is commercially important for aquaculture in Taiwan. *H. diversicolor supertexta* is appreciated for their delicacy and high market value. Aquaculture of *H. diversicolor supertexta* is therefore a promising business (http://www.fa.gov.tw, 2003). However, the coastal regions of Taiwan where the abalone farms are situated are subjected to polluted discharges from rivers. Conroy et al. (1996) and Knauer et al. (1997) indicated that if Zn levels are elevated, toxicity can occur and can have severe effects on the health of abalone, which will reduce market prices and cause closure of abalone farms. The mechanisms of Zn toxicity involved in the threatening of survival and the inhibition of growth to abalone remain unknown.

US EPA (1995) indicated that environmental quality criteria (EQC) play a pivotal role in protecting ecosystems from undesirable effects of chemicals as it is an essential part of both source- and effects-oriented management for chemical substances. Janssen et al. (2000) and Bergman and Dorward-King (1997) pointed out that neither total nor dissolved aqueous metal concentrations are good predictors of metal bioavailability and toxicity and are inadequate to accurately assess the potential impact of metals on the ecological quality of ecosystems. Rather than develop a single-value waterborne metal concentration for establishing the water quality criteria, it is better to derive a predictive EQC model that explicitly incorporates the factors controlling bioavailability and bioaccumulation in the aquacultural ecosystems.

In the present work, we develop a systematic and quantitative dose-based framework that takes account of the site-specific water quality characteristics to derive the EQC for the survival and growth of farmed abalone. A major complication in deriving EQC for aquacultural species is the high degree of uncertainty resulting from the lack of dose–response information and the large environmental variability in exposures among individuals (Liao et al., 2003; Liao and Ling, 2004). A better approach would be to explicitly model the uncertainties inherent in the toxicity threshold model for aquatic species in that the output would be a distribution of possible toxicity criteria for the survival and growth of abalone from which the level of conservatism can be predicted, e.g., we can choose an appropriate risk criteria value based on a 10% probability of exceedence the effect concentration affecting 10% (IEC10) of sensitive aquatic species as suggested by US EPA (1995).

Suggestions have been made that the IEC5 would be more protective of ecosystem structure and function than IEC10 or IEC50 (Van der Hoeven et al., 1997; Moore and Caux, 1997). Versteeg et al. (1999) and Van der Brink et al. (2002) also suggested that the selection of a hazard external effect concentration (EEC) protecting 95% of the single-specific sensitivity distribution (i.e., EEC5) appears to provide an appropriate level of protection when compared to multispecies tests or field studies. One reason is that if concentrations of this compound are below the EEC5, more than 95% of the biological species set considered will not display effects as determined by the chronic toxicity tests. Because *H. diversicolor supertexta* are commercially important and have high market prices in Taiwan aquaculture, we choose IEC5 and EEC5 as the threshold of Zn toxicity for survival and growth endpoints to derive acute and chronic EQC, respectively.

Because chronic tests are more lengthy and the endpoints are somewhat subjective, it is not surprising that more often chronic and standards are based on the acute-to-chronic ratio (ACR) (US EPA, 1985; Ford, 2001). The ACR is an acute toxicity values measured to its chronic toxicity values, measured under the same experimental conditions. The ACRs are derived on a species-by-species basis, ideally with both the acute and chronic toxicity data developed from the same test. The ACR values are typically greater than one, reflecting the fact that chronic toxicity typically occurs at lower levels than dose acute toxicity. Species mean ACRs ranged from 1.48 in saltwater for the sheepshead minnow (Hughes et al., 1989) to 171.2 in freshwater for the snail *Campeloma decisum* (Arthur and Leonard, 1970). US EPA (1985) suggested that the ACR approach can be served as the basis of the chronic criteria in that the ACR is the geometric mean of the ratio of acute to chronic values.

Our purpose is to present a probabilistic IEC-based approach to derive a predictive site-specific EQC for