Spatially-Explicit Bioaccumulation Modeling to Support Human Health and Ecological Risk Assessments in a Decision Analytic Context

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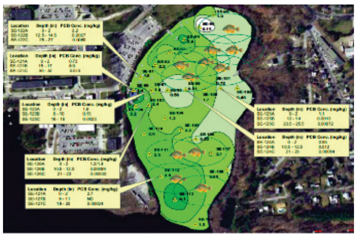
Introduction: Bioaccumulation of sediment-associated contaminants can lead to tissue concentrations in aquatic organisms leading to potential human health and ecological risks. Bioaccumulation modeling approaches range from simple, empirical approaches such as biota:sediment accumulation factors (BSAF) to steady-state and time-varying mechanistic models. Regardless of mathematical framework, bioaccumulation models rely on external characterizations of sediment and water exposure concentrations that fail to account for spatial and temporal variation in exposure combined with preferential foraging strategies and habitat utilization. Typically, preferential foraging in habitat areas is accomplished by calculating sediment exposure concentrations from data that reflect areas within these preferred habitats. However, that alone does not capture the way in which fish are actually exposed in an aquatic environment. Here we present the development of the FishRand spatially-explicit, time-varying bioaccumulation model to demonstrate the improvement in prediction accuracy when spatial characteristics of exposure are directly simulated. We incorporate the results in a decision analytic model to demonstrate the application within an environmental decision making context [1] emphasizing methods for sustainable sediment management.

Methods: The FishRand model was developed in order to provide a more realistic simulation of how population exposures occur by developing a probabilistic analytical framework that simulates random fish movements over a grid or polygon map, allowing for fish to congregate or preferentially forage in particular areas. The model also allows fish to move in and out of the modeling grid if that reflects their particular life histories. The probabilistic framework provides population estimates of tissue concentrations with associated uncertainty that provide greater flexibility for analysts in estimating subsequent risks (e.g., simple deterministic comparisons to no- or lowest-observed adverse effect levels [hazard quotient], distributions of hazard quotients, or convolving the exposure distributions with effects distributions to develop cumulative probabilities of increasing effect.

We provide two case studies demonstrating applications of the FishRand model using under three scenarios: 1) baseline: a steady-state, surface-area weighted exposure concentration input typical of bioaccumulation modeling applications; 2) probabilistic: using probabilistic sediment and water exposure concentrations but not spatially-explicit; and, 3) spatially-explicit exposure concentrations. Contaminants include DDD, DDE, and DDT and polychlorinated biphenyls (PCBs).



The FishRand model assumes a population of fish exposed to local concentrations of sediment and water. Individual fish are caught from a population distribution with associated uncertainty. Figure 1 depicts an example of individual fish and their exposure zones for one simulation of exposure over one time-period. A probabilistic nested Monte Carlo framework is used to estimate variability, uncertainty, and foraging.

Results: Data from two sediment sites show that prediction accuracy is improved using spatially-explicit exposure concentrations together with simulations of fish foraging strategies. The decision analytic framework demonstrates how GIS, environmental modeling results, and socioeconomic and cultural considerations are synthesized to better support sustainable environmental decision making.

Discussion: Evaluating potential bioaccumulation and potential risks represents one aspect of a focused site assessment. Spatially-explicit modeling approaches allow for direct linkages to GIS and other analyses. Sustainable sediment management requires decision support tools that synthesize and integrate data and model results across spatial and temporal scales, and more broadly, incorporate multiple disciplines including social and cultural considerations. The probabilistic, spatially-explicit modeling approach improves prediction accuracy and facilitates linkages to other analyses.

References: [1] von Stackelberg K. 2013. Decision analytic strategies for integrating ecosystem services and risk assessment. *Integrated Environmental Assessment and Management*, 9(2):260-268.