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Cadmium accumulation in the barnacle biomonitor *Balanus amphitrite*: Combining field and laboratory observations with modelling

Thesis submitted by

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for the degree of

Doctor of Philosophy

in the

Department of Chemistry,

School of Pharmacy and Molecular Sciences,

James Cook University

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Abstract

The present study addressed the need to understand how short-term variations in metal concentrations in the environment determine its concentrations in a biomonitor, and how this information affects the use of the biomonitor in environmental monitoring programs. As a case study, the barnacle biomonitor *Balanus amphitrite* present in Ross Creek (Townsville, Queensland, AU) and the heavy metal Cd were used. The research methodology for this study comprised three integrated approaches: field measurements; the performance of laboratory experiments, and the development of an ecotoxicological simulation model, in order to understand the processes controlling Cd accumulation in *Balanus amphitrite* in the field. Two sampling programs were carried out along Ross Creek, in the dry season of 2002 and the wet season of 2004, in which barnacles, their food sources (two class sizes of suspended particulate material, SPM, and microzooplankton) and water (dissolved phase) were sampled weekly for Cd concentrations and mass abundances. Sampling periods were selected to test whether the concentration of Cd in the biomonitor responded to any variation in the dissolved and particulate phase Cd concentrations in Ross Creek, as caused by rainfall variation.

In both sampling periods, the Cd concentration in the dissolved phase increased upstream, ranging from 1.6 to 283 ngL^{-1}. The Cd concentration in the barnacle's food sources exhibited the same pattern – ranging from <0.01 to 2.10 mg kg^{-1} for the small size class of SPM (0.45–50 μm), from 0.07 to 1.62 mg kg^{-1} for large SPM (50–200 μm), and from 0.03 to 0.80 mg kg^{-1} for microzooplankton (50–200 μm). The Cd concentration in two populations of *Balanus amphitrite* increased upstream between two sites 2.20 km apart and ranged from 2.15 to 6.40 mg kg^{-1} and from 5.22 to 12.8 mg kg^{-1}. Even though no significant temporal variation was detected for the Cd sources to the barnacles, the biomonitor Cd concentrations varied over the three sampling months, within each sampling period, exhibiting specific patterns for this variation. These observations suggest that changes in the Cd concentrations in the food sources and the relative mass abundance of these sources may result in a specific Cd concentration in *Balanus amphitrite.*

Similar Cd concentrations, within sites, were observed for the particles between the dry and wet seasons. Only the most contaminated site exhibited significant differences in the dissolved Cd concentration between seasons. Because more than 95% of the total Cd in the Ross Creek water (<200 μm) was in the dissolved phase (<0.45 μm), the differences in the dissolved Cd concentration resulted in the barnacles from the most Cd-contaminated site being exposed to a total Cd concentration in the wet season (45.8 ng L^{-1}) that was a half of that in the dry season (91.6 ng L^{-1}). Such Cd differences were not indicated by the biomonitor whose Cd concentration did not vary significantly between dry (8.4 mg kg^{-1}) and wet (7.4 mg kg^{-1}) seasons. A budget analysis based on Thomann's bioenergetic kinetic model, indicated that Cd flux from food contributes >80% of the Cd concentration in *Balanus amphitrite.* Thus, because no significant variation was identified for the Cd concentration in the food, no variation in the Cd concentration in the biomonitor was observed at the most contaminated site between seasons. A sensitivity analysis on the model showed that physiological characteristics of the biomonitor are the key parameters controlling Cd accumulation in *Balanus amphitrite*, rather than the metal concentration in the dissolved or particulate phases. This, coupled with the fact that the Cd flux from food is the major source of Cd to *Balanus amphitrite* suggests no tight coupling between Cd in the biomonitor and its availability in the environment.

A simulation model was developed based on Thomann's bioenergetic kinetic model. The daily-simulated Cd concentration in *Balanus amphitrite* produced by the model reproduced the general trend observed in the field. However, even though high and low patterns of Cd concentration in this organism could be reproduced by the model, it could not reproduce the short-term temporal variations accurately. A model investigation suggested that variations in the mean weight of the sampled barnacles might mask the real pattern of temporal variation of the barnacles Cd concentration; even though no size effect has been identified in the field data.

Two simulation exercises indicated that *Balanus amphitrite* may present some weakness in indicating temporal variations in Cd concentrations in the environment. The model results suggested that this organism could not indicate a 6-month Cd-pulse in the environment that increased the Cd concentration in its main source (small SPM, 0.45–50 μm) by a factor of 2.8 using a realistic sampling effort. In addition, this organism took more than a year to reach equilibrium for its Cd concentration in a simulated relocation experiment. These problems may be critical for the use of *Balanus amphitrite* as a biomonitor, and suggest that this organism can only provides a poor measure of current bioavailability of the metal in the environment. However, if a long-term mean Cd availability in the particulate fraction (sized <200 μm) is required, *Balanus amphitrite* can provide such an information.

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