

Distribution and Transfer of Elements in a Coastal Baltic Ecosystem – A Stoichiometric Approach

Clare Bradshaw¹, Linda Kumblad¹, Erik Wijnblad² & Ulrik Kautsky² & Karin Aquilonius²

¹ Department of Systems Ecology, Stockholm University, SE-106 91 Stockholm, Sweden.

² SKB, Swedish Nuclear Fuel and Waste Management Co, Box 250, SE-101 24 Stockholm, Sweden

INTRODUCTION

The fate and distribution of radionuclides in an ecosystem ultimately depends on biological processes, such as uptake and elimination, respiration, photosynthesis and predation (trophic transfer). Radionuclide transport is thus related to the flow of energy in the system (i.e. the fate and distribution of carbon, C). The uptake and fate of radionuclides will also depend on whether their stable analogues are biologically essential or non-essential elements, or are chemically similar to such elements. It is therefore crucial to understand ecological processes and ecosystem properties in order to understand uptake and transfer of radionuclides.

Ecological stoichiometry is the study of the balances of chemical elements of components, interactions and processes in ecosystems (e.g., Elser *et al* 2000). This field of science provides a tool for analysing how the chemical balance affects production, nutrient cycling and food web dynamics in ecosystems (Sturner and Elser, 2002). Ecological stoichiometry may also help to identify constraints and consequences of existing mass balance of multiple chemical elements in ecological interactions (e.g., Elser *et al* 1996). A better understanding of stoichiometrical properties of ecological components may therefore help improving our abilities to describe and predict the dispersal and uptake of excessive nutrients, trace elements and non-essential elements in the environment.

In this study we describe the pools and fluxes of 48 elements in and between all major functional components of a coastal Baltic Sea ecosystem. The aim is to better understand the ecological properties and processes that govern uptake and transfer of radionuclides and their stable analogues, and to use this data in a site-specific safety assessment of a nuclear waste repository.

MATERIALS AND METHODS

Collection of field data

Samples of all the main biotic and abiotic components of a brackish water ecosystem in Tixlan Bay (Öregrundsgrepen, Baltic Sea) near Forsmark nuclear power plant (Sweden) were collected in the field, mostly during the spring of 2005. Extreme care was taken to avoid contamination from all possible sources. The sample types taken were: phytoplankton, zooplankton, benthic microalgae, macroalgae, macrophytes, benthic herbivores, benthic filter feeders, benthic detritivores, planktivorous fish, benthic omnivorous fish, carnivorous fish, dissolved and particulate matter in the water column, sediment and porewater.

The spatial distribution of the different habitat types and dominant fauna and flora (e.g., soft bottom with macrophytes, hard bottom with algae etc.) was assessed during extensive field surveys during 2004-7.

Sample analysis

The concentrations of Al, As, Ba, Br, C, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, F, Fe, Gd, Hg, Ho, I, K, Li, Lu, Mg, Mn, N, Na, Nd, Ni, P, Pb, Pm, Pr, Ra, Rb, S, Se, Si, Sm, Tb, Th, Ti, Tm, V, Yb, Zn and Zr were determined by commercial analysis (mass spectrometry) of the samples.

Calculations of pools and fluxes

The area of investigation (250 km²), Öregrundsgrepen, was divided into 28 interconnected basins whose delimitations are based on current bathymetry and projections for future drainage areas predicted to appear within the coming 18000 years due to glacio-isostatic uplift (Brydsten, 2006). These basins vary in the degree to which they are connected to the land, from being almost completely surrounded by land to being completely offshore.

An ecosystem model, based on a food web that consists of biotic pools (11 functional groups), abiotic pools (particulate and dissolved matter) and fluxes of organic matter in the ecosystem (primary production, respiration, consumption, sedimentation, advection and runoff) was adapted from Kumblad *et al* (2003) and used to calculate the pools and fluxes of the elements. These pools and fluxes were calculated for all basins, using the above model, data on the spatial distribution of different bottom types and biomass, and elemental ratios normalised to carbon.

In this paper, data from one inshore basin ('Basin 121', where the majority of the element concentration data was collected) is used as an example, and compared with average data for all 28 basins.

Calculations of transfer factors (TFs) and distribution coefficients (K_d).

For all 48 elements, TFs (mg/kgww)/(mg/kgww) for the 11 functional organism groups and K_{ds} (kg/kgdw)/(kg/m³) for water, and upper and lower sediment were calculated as follows:

TF = concentration of the element in the biota / concentration dissolved in the water

K_d for sediment = concentration in sediment / concentration in porewater

K_d for water = concentration particulate phase / concentration in dissolved phase

RESULTS AND CONCLUSIONS

Distribution of elements in the system

The distribution of total amounts of the elements on a basin-wide scale reflected the usual composition of sea water and the earth's crust and the concentrations were typical for a fairly unpolluted environment. The ten most common elements were Cl, Na, Mg, S, Ca, K, Fe, Al, C and Br. The nearshore Basin 121 generally had slightly lower amounts of all elements than the basin-wide averages, except for C, probably reflecting the high biomass there.

The relative amounts of the elements in the different components of the ecosystem varied widely depending on the element (Fig. 1). Many of the metals and lanthanoids were found mostly in the sediment, while elements such as Na, Mg and halogens were found mainly in the dissolved phase. A few elements (Zn, Ba, Si, Cd) had substantial fractions in the particulate phase in the water column, while others (e.g., C, N, P, Si) had substantial amounts in the biota. These trends were similar for Basin 121 and for the basin-wide averages.

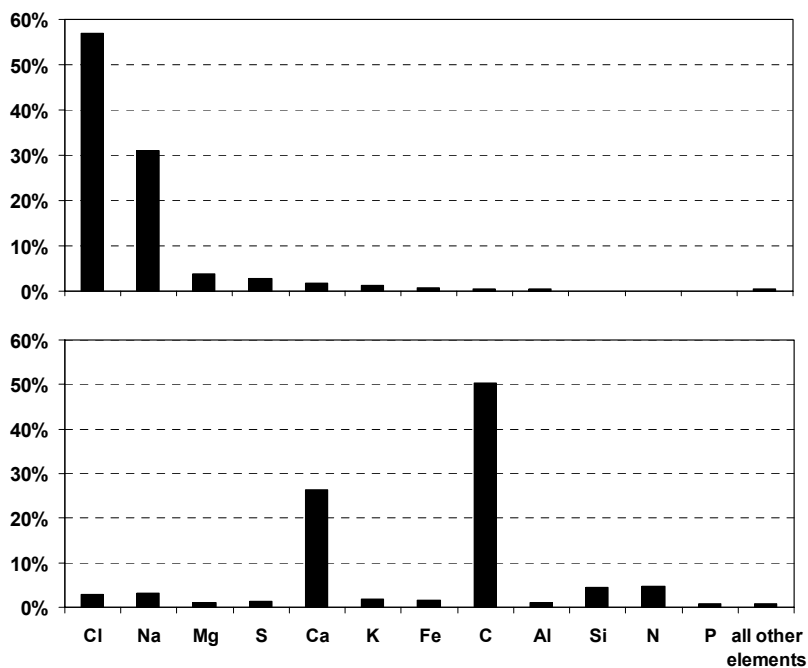


Figure 1. Relative amounts of the main elements the abiotic components (above) and biotic components (below) (average across all basins).

Within the biota, the relative amounts of the elements again varied widely between different trophic groups. Those elements that were common in sediment were also common in benthic microalgae, probably because of the difficulty in separating these two components. Macrophytes contained around 15-20% of the Hg, Cd, Ba, Zn and Rb in the biota, and c. 75% of the K. Around 25% of the lanthanoids was found in the benthic deposit feeders. Fish contained the largest proportions of P, N, Se and Hg. Certain elements were very organism-specific, such as Si in phytoplankton and Ca in benthic filter feeders (the shell-bearing bivalve mollusc *Cerastoderma glaucum*). Again, trends were similar between basin averages and Basin 121. There was a general stepwise decrease up trophic groups for Fe, Mn, Ca, Si, Ti, Ba, Ni, Zr, Cr, Co, Cd, Th, Mo, all actinoids and lanthanoids. Secondary consumers had higher concentrations than primary consumers of K, S, Rb, Se and Hg. The tertiary consumers, here represented by smelt (*Osmerus eperlanus*), were generally quite similar to the secondary consumers, but with slightly lower P, Mg, Fe, Ca, S, Ba, Pb, Cr, Co, Mo, Ti, actinoids and lanthanoids, and slightly higher N, K, As, Cs, Br and I.

The spatial distribution of the elements is clearly related to the type of habitat. For example, of the total amount of Th found in the system the larger part is found in the areas with soft sediment, whereas for C the majority is found in habitats where the biomass of macrophytes is high (littoral zone).

Transfer factors (TF) and distribution coefficients (K_d)

The TFs determined in this study ranged over eight orders of magnitude. The highest TFs were seen for Al, Fe and Ti (most biota, except fish), P, N, and some trace metals (fish). Benthic microalgae, macrophytes and benthic herbivores in general had higher TFs for many of the

transition metals. The K_{ds} for water also ranged over eight orders of magnitude, from Al and Zn ($K_d > 60000 \text{ (kg/kgdw)/(kg/m}^3\text{)}$) to Cl and Br (<0.01). The elements with $K_{ds} < 1$ (i.e. where element concentrations were higher in the dissolved than the particulate phase) were As, F, Na, Mg, S, Br and Cl (in decreasing order of K_d values). The highest K_{ds} for the upper sediment layer (0-3cm) were found for Zr (3750), Ti (1700), Fe (200), and Al (165) whereas for Hg, Cr, Pb, V, Th, Cs they ranged between 30 and 10. The rest were lower than 10. The K_{ds} in the lower sediment layer followed the same pattern as the upper layer but had generally higher values.

Applications of the data

This extensive dataset gives an insight into how the natural distribution of elements is strongly related to the biology and ecology of the organisms. It enables a better understanding of properties and processes that govern uptake and transfer of trace elements, heavy-metals, radionuclides and other non-essential elements/contaminants in coastal environments of the Baltic Sea. The data show a difference in chemical composition between plants and animals, organisms at different trophic levels, and organisms of different functional groups, which indicates that food intake and metabolism has a strong influence on the stoichiometry of an organism.

The study facilitates a transparent site-specific model of the transport and fate of most radionuclides of interest in nuclear waste management, by employing ecological data and stable element residues as proxies for radionuclides. The data also allow the calculation of site-specific transfer factors and distribution coefficients (K_d values) for a large number of elements and organisms. These, together with element:carbon ratios, are being used in ongoing SKB safety assessments at two sites in Sweden that are proposed as locations for a future deep repository for nuclear waste.

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