

Metals and Metalloids in Terrestrial Systems: Bioaccumulation, Biomagnification and Subsequent Adverse Effects

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Abstract: Metals and metalloids are elemental substances that occur naturally in the Earth's crust, and are variously incorporated into biological systems as structural components or proteins. Imbalances in the environmental concentrations of several metals present a challenge to ecosystems because the species that form part of these ecosystems are often not equipped to regulate internal concentrations of these elements, or employ detoxification mechanisms that serve to biomagnify these elements in the food chain. This review examines the trophic movement of metals and metalloids within terrestrial ecosystems and the consequences of biomagnification and toxicity on populations. Several elemental contaminants are given special emphasis, including copper, zinc, arsenic, selenium, molybdenum, cadmium, mercury and lead. All these elements are of high historical importance and continue to be deposited within the biosphere.

INTRODUCTION

Elemental chemicals have a tendency to stick to clayish, peaty or organic-rich materials, and contamination of terrestrial systems generally occurs because soils are capable of acting as a sink for metals and other elemental chemicals [1]. The elemental contaminants of most concern are predominantly metals such as cadmium, lead, mercury or copper, among others. However, a few, like selenium and arsenic are metalloid elements. For the sake of simplicity in this discussion we have used only the term 'metal' to describe both types, even though examples may include metalloid elements like selenium.

Metals in soils originate from two separate sources: from geogenic processes related to the occurrence of metal-bearing geological formations, and from anthropogenic sources. Information on the sources, fate, transport and toxicity of metals and metalloids can be found in Chapter 1 and 2 of this book. Once bound within soils, metals are persistent, because elemental contaminants cannot degrade further (unlike complex organic pollutants), although they can undergo various reversible changes in speciation depending on the chemical environment [2].

Many trace elements are essential for life functions [3], and plants and animals possess various mechanisms for the accumulation of sufficient amounts of trace elements from their environment. These same mechanisms can also facilitate the uptake of non-essential metals [4, 5]. The uptake and retention of a metal (or any other chemical) by an organism is termed bioaccumulation. Bioaccumulation of essential as well as non-essential elements is dependent on both the chemical availability of the metals within the environment and the organism's capacity for uptake and subsequent excretion. A full overview on bioaccumulation is given in Hodson *et al.* [6], in which the different definitions of bioavailability currently in use are reviewed.

The severity of impact on ecosystems will reflect the concentrations of bioavailable metals in the soil. The concentrations of individual metals are dictated by the source of each contaminant. For example, mercury (Hg) contamination occurs predominantly as a consequence of atmospheric deposition, and is therefore rather diffuse. By contrast, a major source of cadmium (Cd) contamination has historically been through the application of rock-phosphate fertilizers, thereby selectively elevating Cd concentrations in agricultural soils. Very high levels of soil contamination usually only occur in the proximity to metal smelting activities, and an examination of studies conducted in these environments are instructive about the relative movements of metals within local ecosystems.

One such study was conducted by Hunter *et al.* [7-9] in the vicinity of a copper refinery within Merseyside in north-west England. Copper (Cu) and Cd content of the soils within a 1 km radius of the refinery typically exceeded 500

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