Fact Sheet on
Environmental Risk Assessment

Published by the International Council on Mining and Metals (ICMM)

12

JANUARY 2002

METALLOREGIONS

by Anne Fairbrother, D.V.M., Ph.D., Parametrix, Inc.
and
Michael John McLaughlin, Ph.D., CSIRO Land and Water

Introduction

Ecological risks associated with the use of chemicals or other human activities will vary depending upon where the activity takes place. It is apparent that ecosystems differ across large spatial scales, such that certain areas can support lush forests while other locations only maintain arid grasslands. What is less obvious is that plants and animals in these ecologically distinct areas respond differently to environmental stressors, including xenobiotic (synthetic) contaminants or elevated levels of naturally occurring elements. Evolutionary adaptation or short-term development of tolerance allows organisms to persist, despite constant and often unpredictable environmental stress (see Fact Sheet No. 2).

This has lead to the development of a classification system of ecologically similar areas into **"ecoregions,"** and to the recognition that different screening criteria are needed for each region when assessing risk from naturally occurring substances such as metals. Thus, region-specific probable no effect concentrations (PNECs) are needed, based on testing conducted with regionally relevant organisms that are acclimated to the background levels of metals within each region (see Fact Sheet No. 5). The challenge lies in how to define the areas for which separate PNECs need to be developed and applied, as they are not likely to be contiguous with previously defined ecoregions. Thus, separate **"metalloregions"** are being derived, using similar methods of aggregating spatially explicit environmental variables. Once these are identified, appropriate organisms cultured and tested in soils and waters from the specific regions can be tested to derive regional PNECs.

What Are Ecoregions?

Plants and animals in both terrestrial and aquatic systems respond to the totality of environmental factors that describe their particular habitat. At the global scale, climatic factors associated with latitude and elevation are the primary determinants of species diversity. Thus, equatorial zones with warm stable temperatures and abundant rainfall support tropical ecosystems with high species diversity. Polar regions or high elevation zones, on the other hand, have fewer species, although these are adapted to temperature extremes and reduced light regimes. These large geographic delineations of various biomes have been aggregated into "ecoregions." An "ecoregion" is defined as "a relatively large area of land or water that contains a geographically distinct assemblage of natural communities that share a large majority of their species dynamics and environmental conditions and whose ecological interactions are critical for long-term persistence" (Abell et al. 2000; Ricketts et al. 1999). Ecoregions are more than place-name areas that are delineated without the basis of underlying controlling factors. Thus, areas that are separated geographically may have the same ecoregional designation but different place-names, e.g. the Great Plains of North America and the Steppes of Central Asia.

Ecoregions are defined primarily on the basis of macroclimate latitudinal bands upon which oceanic temperatures, currents and resulting wind patterns are superimposed (Bailey 1998). Large mountain ranges on the continents add another dimension, both through elevation-related temperature changes and deflection of moisture patterns. Figure 1 shows continental ecoregions of the world as delineated by Bailey (1998).

It has been recognized that ecoregions differ for terrestrial and aquatic systems (Abell et al. 2000). Figure 2 shows a comparison of United States terrestrial ecoregions (derived by Bailey 1998) and aquatic ecoregions developed by Omernik (1987). While both aquatic and terrestrial systems respond to the same latitudinal and elevational climatic forces, aquatic systems are further defined by hydrologic and geologic regimes that are a function of surrounding landforms but also have their own emergent properties.

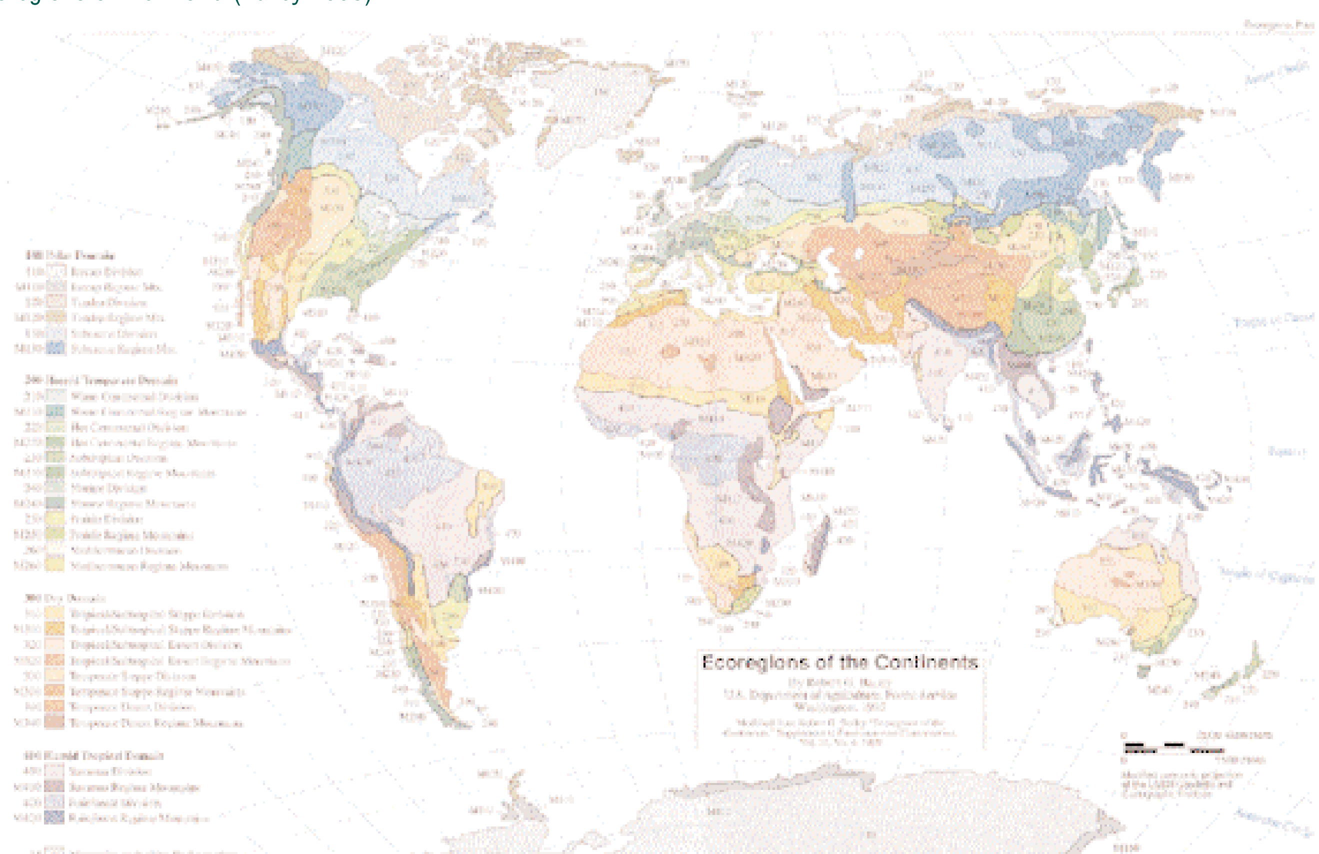
What Are Metalloregions?

Plants and other terrestrial organisms both respond to and affect the type of soil upon which they depend. Aquatic organisms are similarly responsive to differences in water quality parameters and sediment geochemistry. Ecologists have long been aware that differences in composition of plant and animal communities are related to these additional geochemical variables, but they have not been considered explicitly when developing ecoregions until recently. For example, in an effort to develop more accurate vegetation ecoregions for the US, Hargrove and Luxmoore (1998) included soil nitrogen, organic matter and water-holding capacity along with elevation and climatic factors in their mapping of ecoregions of the US (Figure 3). While this is a reasonable approximation at including important soil variables, other characteristics such as clay content, pH and mineral composition are also of sufficient significance that consideration should be given to incorporating these variables into ecoregion delineations.

Furthermore, it has become accepted that organisms will differ in their sensitivity and response to anthropogenically (caused by humans) elevated metal concentrations, depending upon their acclimation or adaptation to naturally occurring levels (see Fact Sheet No. 2). Iron and aluminum are particularly important as they play a large role in the availability

Figure 1

Ecoregions of the World (Bailey 1998)



of phosphorus to plants (Aber and Melillo 2001), and pH, percent organic matter and clay content affect bioavailability of metals. Thus, when defining metal subregions for terrestrial systems, now known as **"metalloregions,"** these controlling factors must receive appropriate consideration. Controlling factors for defining metalloregions in aquatic systems include water hardness and pH.

Using available geographic information system (GIS) technology (i.e. computer-generated maps), metalloregions can be developed relatively easily as further refinements of existing ecoregions. There are many methods for ecosystem classification (Klijn 1994). The metalloregion concept is most closely aligned with a spatially nested hierarchical classification (Klijn 1994). Here, differing thematic maps are overlaid, and a multivariate classification analysis is used to minimize variability within groups and to maximize the variability among groups. Themes include land use, soil type (e.g. pedological units), underlying geological morphology, ambient levels of metals, minerals, macronutrients and other parameters affecting metal bioavailability (pH, CEC, organic matter, etc.). These data are all readily available in spatially explicit government and private databases. However, they need to be appropriately qualified to differentiate natural background levels from those that have been anthropogenically elevated prior to use in delineating natural metalloregions.

Alternatively, metalloregions could be defined on the basis of current ambient conditions, to include changes due to agricultural soil modifications while excluding excessively polluted locations. This would be accomplished by including a land use thematic map in the multilayered statistical clusters. Similarly, water quality data are available for most water bodies, but also require validation as background or ambient conditions prior to use. The question about whether or not aquatic and terrestrial metalloregions would have similar boundaries will need to be explored within the context of existing differences in aquatic and terrestrial ecoregions. Similarly, the level of resolution (i.e. the spatial scale) of metalloregions may be a function of both the input data and the desire to minimize the number of different areas for which PNECs would need to be derived.

Figure 2a

Terrestrial ecoregions of the US, ecosystem provinces (Bailey 1998)

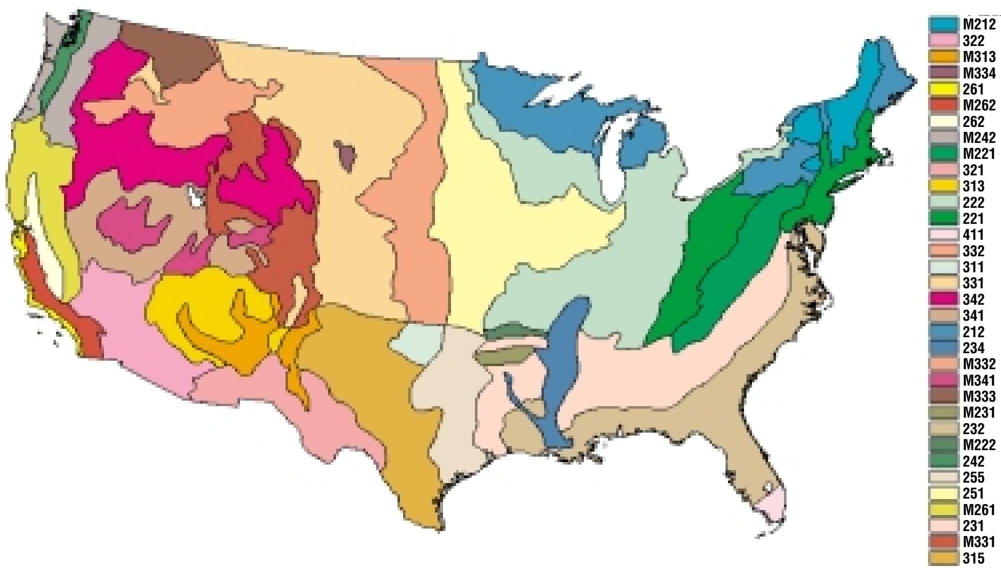
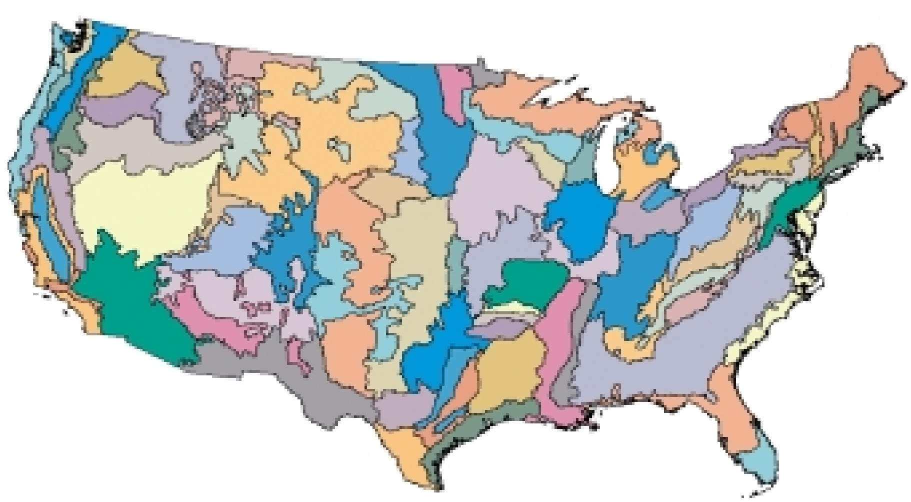


Figure 2b

Aquatic ecoregions of the US (Omernik 1987)



The Value and Application of Metalloregions

Griffith et al. (1999) recognized the utility of aquatic ecoregions for management purposes. Such an approach has been widely applied within the US for development of biocriteria and subsequent delineations of waterbodies as adequate or impaired. While watersheds (also called "basins" or "catchments") have an intuitive spatial boundary and hence popular appeal, they do not always correspond directly to ecological driving functions and generally are too small a unit to make comprehensive land management decisions. Hydrologic units frequently are even smaller, as they often constitute only a particular stream reach and not the entire watershed.

Experience over the past 20 years has shown that general water quality trends will be similar within an ecoregion. That is, intraregional variation in water quality parameters will be less variable than interregional variation (Griffith et al. 1999). This experience suggests that continental or regional scale risk assessments cannot account for ecoregional differences in species composition and ambient water quality. For soils, the spatial boundaries are likely to be delineated more easily, as soils information exists at relatively good spatial resolution in many countries. It is envisaged that soil metalloregions will range from areas of sandy acidic soils through regions having heavy textured alkaline soils, with each deserving a specific PNEC. A similar concept to metalloregions exists for the environmental management of agricultural nutrients in the European Union, where "Nitrate Sensitive Zones" were designated for areas where environmental conditions indicate a greater risk from nitrate leaching to groundwaters.

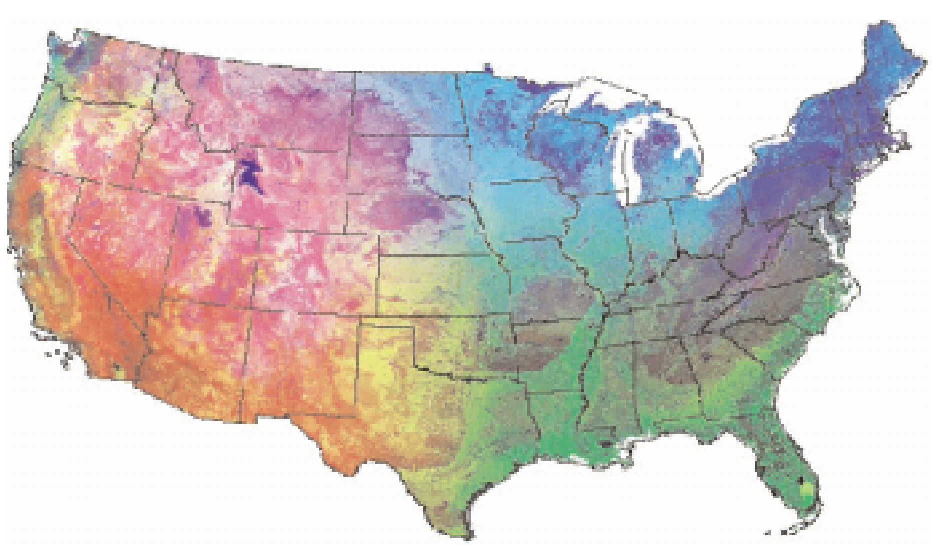
Because many ecosystems have been disturbed greatly from the natural state by human activities, it is important to determine if it is the original ecosystem or the disturbed ecosystem that is being protected, as this will markedly affect the boundaries for metalloregions. For example, large areas of infertile acidic soils have been turned into agriculturally productive systems through inputs of lime and fertilizers. Despite similar climates and "background" soil characteristics between the natural and modified land uses, these systems would be identified as separate metalloregions based on ambient (i.e. current) soil conditions (due to modifications in pH, increased organic matter, input of required micronutrients, etc.). Thus, they would be considered separately when deriving protective PNECs, as the desired suite of organisms differs due to land use requirements.

The value of metalloregions is that they provide the conceptual framework to not only account for the broad regional parameters affecting metal availability in soils and waters, but also to account for the differences in organism response to added metal. Because of the ability of plants and animals to acclimate (near-term) and eventually adapt (long-term) to differing levels of bioavailable metals, risk assessments in both aquatic and terrestrial systems must account for these differences. Thus, a PNEC derived for a metal-deprived system will not be suitable for a metal-rich area. A good example of this is the low requirement for Zn of calcifuge (limestone-loving) plant species versus that of a hyperaccumulating species (one that takes up and stores large amounts of metals in its tissues, e.g. *Thlaspi caerulescens*) that has a high physiological requirement for Zn.

Laboratory or field studies can be used to derive PNECs for organisms adapted to a variety of conditions or empirical relationships can be determined and used to modify an individual PNEC for application to all areas

Figure 3

Ecoregions clustered on elevation, soil and climate factors (Hargrove and Luxmoore 1998)



(McLaughlin and Smolders 2001). Examples of the latter approach are the hardness-adjusted ambient water quality criteria for metals and pH-adjusted criteria in the EU for metals in soils receiving biosolids. However, once these empirical relationships are derived, it is necessary to know where they should be applied spatially. Alternatively, metalloregions will provide the capability of defining the distribution of possible exposure concentrations for soil or water ecosystems on larger continental scales (i.e. interregional). Overlaying this distribution with that of the related PNECs will provide a probabilistic framework for determining potential risk as well as defining locations of highest risk. Regardless of the risk assessment approach chosen, metalloregions will provide the necessary spatial and ecological context required for appropriate determination of risk to both terrestrial and aquatic ecosystems from anthropogenically elevated metals.

References

Abell, R. A., Olson, D. M., Dinerstein, E. and Hurley, P. T. 2000. *Freshwater Ecoregions of North America: A Conservation Assessment.* Island Press, Washington DC.

Aber, J. D. and Melillo, J. M. 2001. Terrestrial Ecosystems. Harcourt Academic Press, San Diego.

Bailey, R. G. 1998. *Ecoregions: The Ecosystem Geography of the Oceans and Continents.* Springer, New York.

Griffith, G. E., Omernik, J. M. and Woods, A. J. 1999. Ecoregions, watersheds, basins, and HUCs: how state and federal agencies frame water quality. *Journal of Soil & Water Conservation,* 54:666-677.

Hargrove, W. W. and Luxmoore, R. J. 1998. A New High-Resolution National Map of Vegetation Ecoregions Produced Empirically Using Multivariate Spatial Clustering. Oak Ridge National Laboratory, TN. *http://research.esd.ornl.gov/~hnw/esri98/* (Sept. 2001).

Klijn, F. 1994. Spatially nested ecosystem: guidelines for classification from a hierarchical perspective. pp. 85-116. In: *Ecosystem classification for environmental management.* Klijn, F. (ed.). Kluwer Academic Publ., Dordrecht, The Netherlands.

McLaughlin, M. J. and Smolders, E. 2001. A rationale for the metalloregion approach to risk assessments for metals in soil — a case study for effects of zinc on microbial functions in soil. *Environmental Toxicology and Chemistry,* 20:2639-2643.

Omernik, J. M. 1986. Aquatic ecoregions of the conterminous United States. Supplement to the *Annals of the Association of American Geographers,* 77:(1).

Ricketts, T. H., Dinerstein, E., Olson, D. M. and Loucks, C. J. 1999. *Terrestrial Ecoregions of North America: A Conservation Assessment.* Island Press, Washington, DC.

About the Authors

Anne Fairbrother, D.V.M., Ph.D., is Senior Wildlife Ecotoxicologist and Certified Wildlife Biologist with Parametrix, Inc., Corvallis, Oregon, USA, and holds an adjunct professorship at the College of Veterinary Medicine of Oregon State University. Before joining Parametrix, she worked as Senior Scientist for the US Environmental Protection Agency and as a senior consultant with Ecological Planning and Toxicology, Inc. She has degrees in Wildlife Management and Veterinary Medicine from the University of California, Davis, and a Masters and Ph.D. in Wildlife Disease Ecology from the University of Wisconsin, Madison. Dr. Fairbrother provides clients in both public and private sectors with technical expertise to develop methods for reducing uncertainty and enhancing realism of ecological risk and damage assessments in terrestrial and wetland systems, including consultation in areas of wildlife ecotoxicology, ecological risk assessment, environmental aspects of metals and mining, pesticide registration and biomarker development and interpretation. She sits on numerous review panels and editorial boards, and has published more than 60 peer-reviewed articles, books and book chapters on wildlife ecotoxicology and environmental risk assessment.

Dr. Michael John McLaughlin is a Senior Principal Research Scientist and a Research Group Leader in Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), Land and Water, located in Adelaide. He acts as National Cadmium Coordinator for the Australian Government's Standing Committee on Agriculture and Resource Management and is an affiliate faculty member in the Department of Soil and Water at Adelaide University. Dr. McLaughlin graduated from the University of Ulster in Northern Ireland with a B.Sc. in Environmental Science, from the University of Reading (UK) with an M.Agr.Sci. in Soil Science and from the University of Adelaide with a Ph.D. in Soil Science. He is a founding Board Member of the International Society for Trace Element Biogeochemistry and sits on the Ecotoxicity Technical Advisory Panel for the international metals industry associations. He has worked in several positions in research and industry and has edited 2 books and written over 90 refereed scientific publications. His field of research spans metal bioaccumulation by terrestrial plants, soil remediation technologies and ecotoxic effects of metals in soils in relation to aqueous and solid phase chemical speciation. He actively collaborates with research groups in USA, France, Belgium, Switzerland and several countries in South East Asia.

Mike.McLaughlin@adl.clw.csiro.au

Fact Sheet on Environmental Risk Assessment

This is the twelfth in an occasional series of *Fact Sheets* to be produced by ICMM on metal-specific issues in environmental risk assessment. Authorship selection and editorial review are coordinated by Dr. Anne Fairbrother of Parametrix, Inc. Each *Fact Sheet* is reviewed for technical merit by Dr. Erik Smolders of Katholieke Universiteit (Catholic University) Leuven, Belgium, and by a panel of experts in metal-related regulatory issues. While the *Fact Sheets* reflect the views of the authors, they are intended to provide an objective review of each topic. ICMM hopes these publications provide insights into complex issues in regulatory science, and welcomes questions and comments.

For additional information, please contact:

The International Council on Mining and Metals

3rd Floor, 19 Stratford Place,
London, United Kingdom
W1C 1BQ

Tel.: (+44)(0)20 7290 4920

Fax: (+44)(0)20 7290 4921

E-mail: info@icmm.com

Web site: www.icmm.com

ICMM
International Council
on Mining and Metals

Dedicated to economic progress, environmental protection and social responsibility.