Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

Determination of sediment metal background concentrations and enrichment in marine environments – A critical review☆

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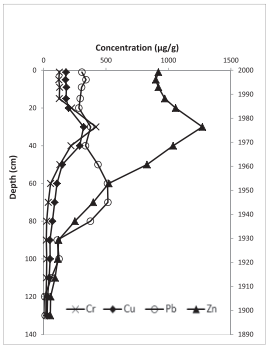
HIGHLIGHTS

- Background metal sediment concentrations and enrichment are key for assessment.
- Fourteen empirical and statistical methods for background estimates are reviewed.
- Background determined using sedimentary cores has advantages.
- Review of twenty index/factor enrichment methods showed two to be superior.
- Analytical procedure and spatial scale are important in assessment of background.

GRAPHICAL ABSTRACT



A pristine Sydney estuary prior to onset of contamination due to urbanisation in 1930 with improving catchment condition since 1980 as depicted by metals in a sedimentary core, Gavin F. Birch, Science of the Total Environment.

ARTICLE INFO

Article history:
Received 19 October 2016
Received in revised form 30 November 2016
Accepted 3 December 2016
Available online xxxx

Editor: D. Barcelo

Keywords:
Index
Pre-anthropogenic
Contamination
Estuarine
Normalisation
Pristine

ABSTRACT

'Background' is the concentration of metals in pristine sediment, unaltered by human activity and 'enrichment' is the extent present-day sediment metal concentrations exceed pre-anthropogenic levels (the magnitude of human-induced change). Background and enrichment are becoming more frequently used for management measures to bring sediment and the environment back to near-pristine levels. Of the six empirical methods reviewed for determining background (global values, pristine marine and fluvial sediments, catchment soils and rocks), the use of sedimentary cores has the greatest advantage. Most of the eight statistical methods reviewed are adversely affected by the polymodality and an absence of normality or log-normality, however robust regression procedures are most commonly used. Sorption hypothesis techniques require further development.

Indices used to determine enrichment incorporate background levels (enrichment indices) or do not (contamination indices). Of the 20 indices reviewed, the New Nemerow Index and the Mean Enrichment Quotient rate highly in performance, based on 5 beneficial attributes assessed: use of background and normalised data, provision of thresholds, a classification scheme, and inclusion of multiple metals.

Variance in background metal concentrations determined in the 43 global projects reviewed is surprisingly moderate, however regional variability may be considerable due to local catchment mineralisation. Chemical analysis of sediment should not include metals bound in the mineral matrix and weak acid extractions are advisable.

The use of appropriate and effective indicators of environmental condition are critical to the protection and restoration of marine regions and ensuring that human activities are carried out in a sustainable manner to promote safe, healthy and productive ecosystems.

☆ Review paper submitted to 'Science of the Total Environment' on19th October, 2016.

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http://dx.doi.org/10.1016/j.scitotenv.2016.12.028
0048-9697/

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1. Introduction

Estuaries provide essential economic and environmental functions. These features deliver goods and ecoservices supporting high ecological and conservation value (Costanza et al., 1997; Boyes and Elliot, 2006; Borja et al., 2008; Costanza et al., 2014), including a wide variety of habitats maintaining high biological diversity (Hutchings et al., 2014). Estuaries also underpin industry and commerce and are intensively used for tourism and recreation. Estuaries are a focus for the development of large capital cities around the world with rapidly growing populations (Niemi et al., 2004; Birch and McCready, 2009). Pollution of estuarine environments has resulted in adverse effects on bottom sediment and the water column, which threatens benthic and pelagic populations and migratory species (Chapman and Wang, 2001; Birch and Hutson, 2009). Balancing human interests, natural resource capital and ecosystem function largely depends on effective estuarine management. Satisfactory management of these systems may only be achieved if sediment condition and biological status can be properly and fully assessed (Burton, 2013; Chapman et al., 2013; Schintu et al., 2015).

1.1. Sediments as environmental indicators

The concept of 'sedimentary ecosystem health' has been introduced due to the interrelated physical, chemical and biological processes that control sediment function (Maher et al., 1999). Sediment quality is the ability of bottom material to support a healthy benthic ecosystem and may be assessed by determining the abundance and structure of biological communities, either in the field or by undertaking laboratory bioassays. However, these analyses are time consuming and expensive and sedimentary chemicals are being used as indicators of environmental condition, especially in the initial stages of assessment.

The water column and biological tissue have traditionally been the preferred media as indicators of estuarine condition. However, the water column is dynamic and highly variable in the short- and long-term requiring considerable spatial and temporal sampling (Birch and Olmos, 2008). Analysis of faunal tissue is variable between animals, genders and organs and may also exhibit change with age. Water contaminant concentrations are generally low and analyses are difficult and expensive due to matrix effects and inter-element interferences (Budd and Lester, 1994; Birch and Taylor, 2000). Increasingly therefore, sediments are being used preferentially to assess the condition of marine environments (Rodriguez et al., 2006; Belin et al., 2014).

The great advantage of sediments in assessment of environmental status is the ability to faithfully record and time-integrate environmental events providing useful spatial and temporal information (Birch, 2007; Birch et al., 2008). Sediments are an extensive habitat and a large storage of contaminants and therefore these materials have a considerable influence on the biological health of the marine environment. Sediments greatly influence the quality of interstitial and overlying water through physical (re-suspension), biological (bioturbation) and chemical (desorption and benthic diffusion) processes.

Toxicants adsorb to fine-grain organic and inorganic materials and thus sediments play a major role in the transport of contaminants as suspended particles in the water column. This finely-disseminated matter influences the feeding habits of benthic and pelagic animals and is part of the uptake process. Sediment quality therefore has a strong influence the biodiversity and ecological health of marine ecosystems.

1.2. Environmental indicators

Renewed impetus for indicator development currently arises from global initiatives on sustainable development and conservation of biodiversity in the marine environment. Recent trends include a shift towards evaluating the environmental consequences of human activities and employing indicators more widely as explicit enforcement tools in the regulatory process (Rees et al., 2008). Sediments have been recognised as good environmental indicators of anthropogenic impact to coastal and estuarine environments (Rodriguez et al., 2006), however the magnitude of contamination of a habitat may only be assessed if the natural levels of contaminants are known (Rodriguez et al., 2006). In recent years many legislations have developed schemes to address ecological quality and integrity of estuarine and coastal systems, e.g. USA, Australia, Canada and South Africa.

Please cite this article as: Birch, G.F., Determination of sediment metal background concentrations and enrichment in marine environments – A critical review, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.12.028