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Ecotoxicologically based marine acute water quality criteria for metals intended for protection of coastal areas

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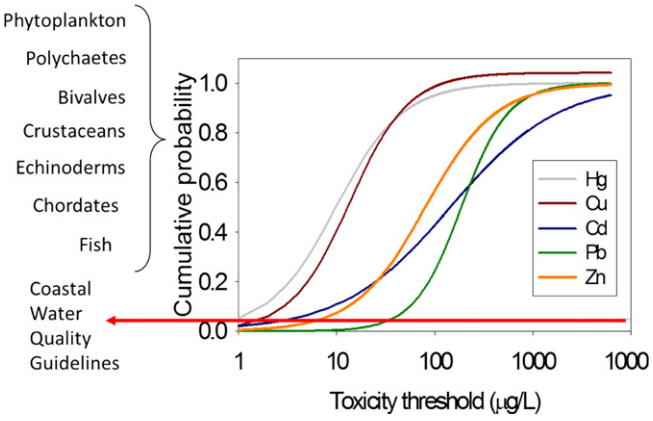
HIGHLIGHTS

- Water quality criteria are derived based on ecotoxicological data from marine species.
- Marine acute water quality criteria are presented for Cd, Cu, Hg, Pb and Zn.
- Data from bioassays with early life-stages of species from the main taxa were used.
- Water quality criteria are derived using species sensitivity distributions.

GRAPHICAL ABSTRACT



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ABSTRACT

Acute water quality criteria (WQC) for the protection of coastal ecosystems are developed on the basis of short-term ecotoxicological data using the most sensitive life stages of representative species from the main taxa of marine water column organisms. A probabilistic approach based on species sensitivity distribution (SSD) curves has been chosen and compared to the WQC obtained applying an assessment factor to the critical toxicity values, i.e. the 'deterministic' approach. The criteria obtained from HC_5 values (5th percentile of the SSD) were 1.01 µg/l for Hg, 1.39 µg/l for Cu, 3.83 µg/l for Cd, 25.3 µg/l for Pb and 8.24 µg/l for Zn. Using sensitive early life stages and very sensitive endpoints allowed calculation of WQC for marine coastal ecosystems. These probabilistic WQC, intended to protect 95% of the species in 95% of the cases, were calculated on the basis of a limited ecotoxicological dataset, avoiding the use of large and uncertain assessment factors.

1. Introduction

Environmental protection of aquatic ecosystems should include the control of point source discharges (limitations on pollutant concentrations in the effluents) and the surveillance of the receiving waters. The latter is attained by comparing measured levels of pollutants with WQC; maximum admissible concentrations obtained in the light of scientific assessments of ecological effects. In order to derive WQC, ecotoxicological data should be compiled and critically discussed. Based on scientific WQC, political authorities may enforce legal imperative values for each pollutant called water quality standards (WQSs), frequently dependent on the uses of water.

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The derivation of a water quality criterion for a substance requires a minimum dataset on the toxicity for that particular substance on aquatic biota (USEPA, 1985, 1994; Bergman and Dorward-King, 1997). USEPA (1994) also identifies the advantage of developing site-specific criteria to protect species of local concern. However, marine species toxicity data are frequently extrapolated from freshwater species (EU, 2011), due to the scarcity of marine data, increasing the uncertainty about the actual level of protection.

For a short list of "priority pollutants" that include the metals Hg, Cd, and Pb, the European Union recently approved acute (maximum admissible concentration) and chronic (annual average) WQS intended for the protection of the ecological status of surface waters (EU, 2008). For some metals, these standards differ in more than one order of magnitude compared to those from the United States Environmental Protection Agency (EPA), and none of them were specifically developed for the protection of aquaculture and shellfisheries. For other substances with deleterious effects, which include Cu and Zn, the European Union urges Member States to "establish programs incorporating the derivation of environmental quality standards" (EU, 2006).

The objective of the present work is to derive acute water quality criteria based on ecotoxicological information with representative species for Hg, Cd, Cu, Pb and Zn, which provide a known degree of protection for coastal species, using an alternative method to the classical deterministic approach. The derived WQC will be compared to national and international criteria and the degree of protection offered by them will be discussed.

2. Material and methods

A database was developed with the results of metal toxicity tests conducted in our laboratory using at least one species of each of the seven major taxonomic groups of marine organisms: microalgae, polychaetes, bivalves, crustaceans, echinoderms, chordates and fish. Test species representative of water-column organisms inhabiting the Atlantic European coastal ecosystems were chosen. These species were selected on the basis of i. occurrence and abundance in temperate Atlantic European waters, ii. ecological and commercial relevance, and iii. feasibility of laboratory in vivo testing. In addition, the most sensitive life stages and endpoints suitable for short term toxicity testing were chosen, most of them were sublethal except for crustaceans and fish (Table 1).

2.1. Toxicity testing

Data used for derivation of WQC were obtained in our laboratory (with the exception of Zn for polychaetes, taken from the literature), following international standard procedures adapted or developed by our group (Mariño-Balsa et al., 2000 for decapods crustaceans; Bellas et al., 2001, 2003 for ascidians; Casas, 2001 for polychaetes; Beiras and Albentosa, 2004 for bivalves; Pérez et al., 2010, for phytoplankton; Pérez and Beiras, 2010 for mysids; Saco-Álvarez et al., 2010 for sea-urchins; Mhadhbi et al., 2010, for fish). The data presented in this paper is the result of 12 years of work to describe the acute toxicity of selected pollutants to the sensitive early life stages of commercially important marine organisms and other ecologically relevant taxa (see also Bellas, 2001; Fernández, 2002; Lorenzo, 2003; Mariño-Balsa, 2003; Saco-Álvarez, 2008; Pérez, 2010; Mhadhbi, 2012). Preference was given to sublethal responses, such as photosynthetic efficiency, population growth, normal embryo-larval development, larval settlement, and early larval growth. Emphasis was placed on quality assurance of the ecotoxicological data. That included strict acceptability criteria for all tests (see Table 1), optimum quality of test organisms, good laboratory practices and analytical measurements to check for precision and stability of metal concentrations.

Bioassays with *Isochrysis galbana* or *Phaeodactylum tricornutum* microalgae were carried out following ISO (2006) modified by Pérez et al. (2010). Methods are described in detail in Pérez (2010). Briefly, microalgae reared in 1/10 f/2 medium (EDTA-free) at the exponential growth phase were inoculated to the experimental flasks (1 L) to reach a density of 5000 cells/ml. The cultures were carried out in an incubator at 18 °C with a 14 h light/10 h dark cycle, under an irradiance of 70 μmol photons/m^2 s, with bubbling filtered air, using either autoclaved filtered (0.22 μm) sea water (FSW) or with artificial sea water prepared as described in ISO (2006). Algal cultures were allowed to grow for 2 days before adding the chemicals in order to guarantee exponential growth at the moment of the addition of the toxicant. Population growth rate and variable fluorescence (Fv) were recorded after 48 h. The acceptability criteria established followed those stated in OECD Guidelines No. 201 (2006) for growth rate, and maximum allowable average variation coefficient for control replicates was 35%.

Sabellaria alveolata adults were collected in Ría de Vigo and maintained in the laboratory until tested as described in Casas (2001). Each individual was extracted from the sand tube, rinsed and placed in

Table 1
Testing conditions, including species used, endpoint recorded and acceptability criteria, for all the bioassays compiled in this study. n.a.: not applicable.

Taxon	Species	Life stage	Endpoint	Acceptability criteria	Reference
Phytoplankton	*Isochrysis galbana*	n.a.	Fv (variable fluorescence) (48 h)	Fv variation coefficient <20%; control Fv increase (control/treatments) >3.8	Pérez (2010), Pérez et al. (2010)
		n.a.	Growth rate (48 h)	Control growth ≥0.96 day^{-1}	Pérez (2010), Pérez et al. (2010)
	Phaeodactylum tricornutum	n.a.	Growth rate (48 h)	Control growth ≥0.96 day^{-1}	Pérez (2010), Pérez et al. (2010)
Polychaetes	*Sabellaria alveolata*	Embryo	Embryo development (48 h)	Normal larvae in controls >95%	Casas (2001)
Bivalves	*Mytilus galloprovincialis*	Embryo	Embryo development (48 h)	Normal larvae in controls >75%	Beiras and Albentosa (2004)
		Larva	Larval growth (8 d)	Normal larvae in controls >75%	Beiras and Albentosa (2004)
	Ruditapes decussatus	Embryo	Embryo development (48 h)	Normal larvae in controls >75%	Beiras and Albentosa (2004)
	Venerupis pullastra	Embryo	Embryo development (48 h)	Normal larvae in controls >75%	Beiras and Albentosa (2004)
Crustaceans	*Palaemon serratus*	Larva	Larval survival (72 h)	Control mortality <30%	Mariño-Balsa et al. (2000)
	Maja squinado	Larva	Larval survival (72 h)	Control mortality <20%	Mariño-Balsa et al. (2000)
	Homarus gammarus	Larva	Larval survival (48 h)	Control mortality <30%	Mariño-Balsa et al. (2000)
	Siriella armata	Neonate	Mortality (96 h)	Control mortality <10%	Pérez and Beiras (2010)
Echinoderms	*Paracentrotus lividus*	Embryo	Embryo development (48 h)	Normal larvae in controls >91%	Saco-Álvarez et al. (2010)
		Larva	Early larval growth (48 h)	Larval growth in controls >253 μm	Saco-Álvarez et al. (2010)
Chordates	*Ciona intestinalis*	Embryo	Embryo development (20 h)	Normal larvae in controls >50%	Bellas et al. (2001, 2003)
		Larva	Larval attachment (20 h)	Normal larvae in controls >50%	Bellas et al. (2001, 2003)
Fish	*Psetta maxima*	Larva	Larval survival (48–96 h)	Control mortality <15%	Mhadhbi et al. (2010)