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From species sensitivity to hypoxia to effect factors modelling in life cycle impact assessment (LCIA)

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Summary

Nutrient enrichment of coastal waters fuels planktonic growth. The subsequent sinking of this organic matter and its aerobic respiration by heterotrophic bacteria in bottom waters results in the consumption of dissolved oxygen (DO) there. If excessive amounts of organic carbon reach the benthic layer DO depletion may drop it down to hypoxic or anoxic levels. Acute and chronic effects on biota may then be expected. The sensitivity of relevant demersal (benthic and benthopelagic) species (n=91) to DO levels, as lowest-observed-effect-levels (LOEL), was used to estimate the community's sensitivity in five climate zone (polar, subpolar, temperate, subtropical, tropical). Species Sensitivity Distribution (SSD) curves combining DO concentrations and Potentially Affected Fractions (PAF) of species were plotted to estimate hazard concentrations ($HC50_{LOEL}$) per climate zone, and Effect Factors (EF, [(PAF)·m^3.kgO_2^{-1}]). Preliminary EF results range from 220 (PAF)·m^3·kgO_2^{-1} (polar zone) to 310 (PAF)·m^3·kgO_2^{-1} (tropical zone). A site-generic value of 260 (PAF)·m^3·kgO_2^{-1} is useful when no relevant spatial differentiation is to consider. The proposed method for effects modelling contributes with an essential component in the characterisation of eutrophying emissions in Life Cycle Impact Assessment (LCIA) and is applicable in a global assessment framework of marine eutrophication impacts.

Introduction

Marine eutrophication is defined here as the set of ecosystem responses to the loading of a limiting nutrient to the photic zone of marine waters. This nutrient enrichment fuels planktonic growth, and the subsequent aerobic respiration of sinking organic matter by heterotrophic bacteria in bottom waters results in the consumption of dissolved oxygen (DO) there (Ducklow et al. 2001; Diaz and Rosenberg 2008; Cosme et al. submitted). If excessive amounts of organic carbon reach the benthic layer the DO may drop down to hypoxic or anoxic levels. Acute and chronic effects on biota may then be expected at the behavioural, physiological, and ecological levels (Gray et al. 2002; Vaquer-Sunyer and Duarte 2008; Levin et al. 2009). Impacts to ecosystems health and local economy may result from altered species composition and their interaction in exposed ecological communities, from the decrease in water quality (Kelly 2008) and ultimately from 'dead zones' occurrence (Diaz and Rosenberg 2008).

Material and Methods

The sensitivity of 91 relevant demersal (benthic and benthopelagic) species to DO levels (Davis 1975; Gray et al. 2002; Vaquer-Sunyer and Duarte 2008) was used to define their lowest-observed-effect-level (LOEL) i.e. the lowest stressor intensity (here corresponding to the highest DO concentration). The geographic distribution of 26 fish, 27 crustacean, 17 mollusc, 9 echinoderm, 7 polychaet, and 5 cnidarian species was assigned to five climate zones – polar, subpolar, temperate, subtropical, and tropical.

The sensitivity of individual species was used to estimate the sensitivity of the community found in each climate zone and then to estimate a hazard concentration ($HC50_{LOEL}$), i.e. the concentration of DO at which 50% of the species are affected above their LOEL. This is obtained from plotting Species Sensitivity Distribution (SSD) curves (Posthuma et al. 2002) that combine DO concentrations and Potentially Affected Fraction (PAF) of species.

For the purpose of effects modelling and its application in Life Cycle Impact Assessment (LCIA) methodologies Effect Factors (EF, [(PAF)·m^3.kgO_2^{-1}]) were also estimated for the five climate zones. The EF expresses the change of effect due to a variation of the stressor intensity, or EF=ΔPAF/Δ[O_2].

Results and Discussion

Estimation of EFs after the proposed method delivers preliminary results ranging from 220 (PAF)·m^3·kgO_2^{-1} (polar zone) to 310 (PAF)·m^3·kgO_2^{-1} (tropical zone). A global site-generic value of 260 (PAF)·m^3·kgO_2^{-1} was also estimated for use when there is no relevant spatial differentiation to consider. Site-dependent and generic species densities as [species·m^{-3}] are required to further quantify the damage dimension as [species·kgO_2^{-1}] affected.

The species sensitivity dataset and species spatial distribution were found essential to produce representative EF results and to increase the discriminatory power and robustness of the sensitivity model.

The proposed approach is to be further combined with environmental fate of N emissions from anthropogenic sources (Azevedo et al. 2013) and ecosystems exposure to N (to deliver DO consumed per mass of N emitted) (Cosme et al. submitted; see also poster R:24 by Cosme et al., this volume) towards a global framework for estimation of impacts to marine eutrophication. The proposed method for effects modelling therefore contributes with an essential component in the characterisation of eutrophying emissions from anthropogenic sources in an LCIA application.

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