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Estimation of Effect Factors for application to marine eutrophication in LCIA

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1. Introduction

Marine eutrophication is defined as the set of ecosystem responses to nutrient loadings in the photic zone of marine waters. Ecosystems use the increased availability of nutrients to boost primary production [1]. The eventual decay and degradation of this organic matter by heterotrophic bacteria in bottom waters result in the consumption of dissolved oxygen (DO). These responses turn more significant as they result in impacts to ecosystem quality and local economy, by (i) changing communities' composition and species interaction, enhancing the growth of toxic and harmful algal species, (ii) decreasing water quality, by high turbidity, colour, and smell, hindering water uses, fish production, and aesthetic value, and (iii) depleting DO in bottom waters down to hypoxic or anoxic levels with resulting impacts on the survival of benthic species [2].

In oligotrophic waters, the increase in phytoplankton biomass is mainly consumed by the secondary production rendering little negative impacts from the nutrients enrichment. However, in eutrophic waters, impacts are more frequent and the degradation of the ecosystem quality by excessive depletion of DO causes a significant stress on biota. The impacts of hypoxia on biota depend much on the severity, frequency and duration of the exposure to low DO [3], and both acute and chronic effects can be expected. Exposure to extreme or prolonged hypoxia leads to mass mortalities, but hypoxia also induces many different sub-lethal responses in organisms at the behavioural level (e.g. avoidance strategies), at the physiological level (e.g. limiting growth, activity and respiration rates) and at the ecological level (e.g. altering structure, function, and services of benthic communities) [4]. In general, crustaceans show the highest sensitivity to lower oxygen saturation rates followed by fish, whereas molluscs, cnidarians and priapulids show more tolerance to oxygen depletion [5].

2. Materials and methods

A dataset of sensitivities of individual species to hypoxia [5] was used for this study. Relevant species were identified (benthic, demersal, or benthopelagic) and their geographical distribution determined. The selected species were grouped into 5 climate zones - polar, subpolar, temperate, subtropical, and tropical (the sample size and lack of representativeness prevented classification at finer spatial resolutions).

Species Sensitivity Distribution (SSD) curves were produced to estimate the Potentially Affected Fraction of species (PAF) at different levels of DO. The SSD methodology uses a probabilistic model to represent the sensitivity of the community to an environmental stressor through a statistical or empirical distribution function of the sampled sensitivities of the individual biological species [6]. For the application in Life Cycle Impact Assessment (LCIA), the distribution of the sensitivities of individual species to hypoxia is used to estimate the sensitivity to low DO levels of the communities found in each climate zone. The distribution is used to estimate the $HC50_{EC50}$, i.e. the concentration of DO (intensity of the stressor) affecting 50% of the species above their EC_{50} level.

Characterisation Factors (CF) are used in LCIA to convert emissions and resources consumed into impact potentials for specific impact categories. The CF integrates the N-fate term (Fate Factor, FF), the habitat exposure term (Exposure Factor, XF), and the term quantifying the effect (Effect Factor, EF) as shown next:

$$CF[PAF \cdot m^3 \cdot yr/KgN] = FF[yr] \times XF[KgO_2/KgN] \times EF[PAF \cdot m^3/KgO_2]$$

The EF expresses the change of effect (ΔPAF) due to a variation of the stressor intensity (depletion of DO, i.e. $\Delta[O_2]$) and it is calculated by:

$$EF = \frac{\Delta PAF}{\Delta[O_2]} = \frac{0.5}{HC50_{EC50}}$$

Where $HC50_{EC50}$ is either obtained from the SSD method, by calculating $HC50_{EC50} = 10^{\text{avg}(logEC_{50})}$ or by calculating the geometric mean of the EC_{50} data, in accordance to the average gradient method [7].

3. Results and discussion

Preliminary results of $HC50_{EC50}$ were produced for 5 climate zones together with a global default. As an example of the obtained SSD curves and the $HC50_{EC50}$, the global case is shown in Figure 1.

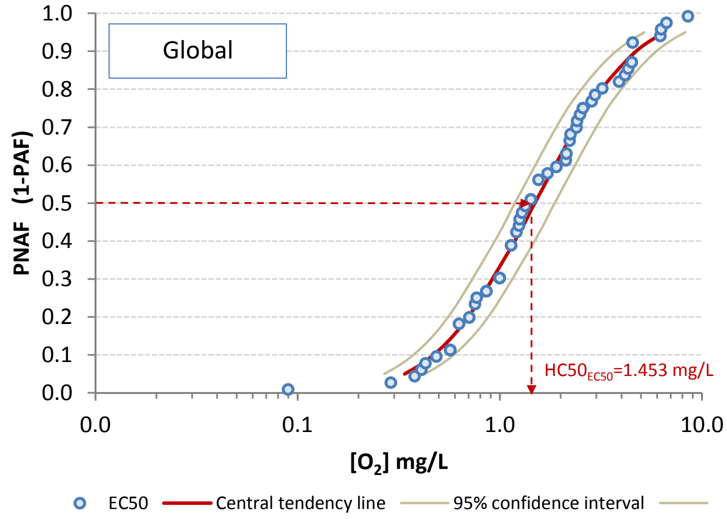

Figure 1. Species Sensitivity Distribution (SSD) curve based on data for sensitivity to hypoxia (EC_{50}). Example of the results for the estimation of the global default $HC50_{EC50}$=1.453 mgO_2/L (n=58). PNAF=Potentially Not Affected Fraction of species.

The preliminary results for the EF estimation for the 5 climate zones and global default are shown in Table 1.

		SSD curve fit parameters					$HC50_{EC50}$		EF
Climate zone	***n* taxa**	**α**	**β**	**Slope**	**Interc.**	**R^2**	mgO_2/L	kgO_2/m^3	$PAF.m^3/kgO_2$
Polar	13	0.195	0.173	3.188	4.290	0.943	**1.568**	1.57E-03	**318.90**
Subpolar	38	0.181	0.555	2.429	4.533	0.967	**1.516**	1.52E-03	**329.88**
Temperate	47	0.158	0.593	2.498	4.569	0.966	**1.440**	1.44E-03	**347.30**
Subtropical	41	0.237	0.481	2.653	4.340	0.935	**1.726**	1.73E-03	**289.70**
Tropical	19	0.242	0.197	3.403	4.154	0.972	**1.745**	1.75E-03	**286.46**
Global default	58	0.162	0.630	2.558	4.558	0.978	**1.453**	1.45E-03	**344.10**

Table 1: Results of the calculations delivering the terms of the SSD fit equations and the $HC50_{EC50}$ used to estimate the Effect Factors (EF) per climate zone, plus a global default EF that includes all 58 species.

4. Conclusions

The spatial differentiation obtained for the EF results was found essential to increase the discriminatory power of the model and to assess the results. This approach to calculate EF will be combined with a suitable methodology for the other factors in the CF expression, i.e. fate of nutrients (FF) and habitat exposure (XF) (in prep.).

5. References

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