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From nitrogen enrichment to oxygen depletion: a mechanistic model of coastal marine ecosystems response

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Summary
Nitrogen (N) emissions from anthropogenic sources may enrich coastal waters and lead to marine eutrophication impacts. Processes describing N-limited primary production (PP), zooplankton grazing, and bacterial respiration of sinking organic carbon, were modelled to quantify the potential dissolved oxygen (DO) consumption as a function of N input. Such indicator is the basis for an eXposure Factor (XF) applied in Life Cycle Impact Assessment (LCIA) to estimate impacts from N enrichment. The Large Marine Ecosystems (LME) biogeographical classification system was adopted to address the spatial variation of the modelled parameters and to characterise spatially differentiated N-emissions. Preliminary XF results range from 0.5 $kgO_2{\cdot}kgN^{-1}$ in the Central Arctic Ocean to 16 $kgO_2{\cdot}kgN^{-1}$ in the Baltic Sea, out of a total of 66 LME-dependent XFs. All the relevant processes were included in a mechanistic model and the uncertainty of the driving parameters is considered low. The presented XF estimation method contributes with a central component for site-dependent characterization factors (CFs) for marine eutrophication, to be coupled with environmental fate of N emissions and effects of oxygen depletion on biota.

Introduction
Agricultural runoff and combustion processes constitute the main anthropogenic sources of N forms that (increasingly) enrich marine coastal waters (Galloway et al. 2008). There, N promotes planktonic growth. The organic carbon synthesized by primary producers is eventually exported to bottom waters where aerobic respiration by heterotrophic bacteria results in the consumption of DO. Excessive DO depletion triggers hypoxic stress on biota and may give rise to local marine eutrophication impacts. A mechanistic model is proposed to quantify the vertical carbon flux and degradation in coastal waters. It also estimates ecosystems XFs used to assess the potential impacts from N inputs.

Material and Methods
The relevant processes modelled are N-limited primary production (PP), zooplankton grazing, and bacterial respiration of the sinking organic material. The model integrates the biological (carbon) pump concept (Ducklow et al. 2001) with site-dependent parameterisation. It comprises four distinct sinking carbon fluxes originating from (i) primary producers (phytoplankton) as cell aggregates, and from secondary producers (zooplankton) as (ii) faecal pellets, (iii) carcasses, and (iv) active vertical transport. Flux losses by consumption and bacterial respiration estimation in the bottom layer are also included. The method is fully described by Cosme et al. (submitted).

The model delivers eXposure Factors (XFs) in [$kgO_2{\cdot}kgN^{-1}$] and represents a nitrogen-to-oxygen 'conversion' potential that quantifies how much a specific coastal ecosystem is capable of assimilating N into organic carbon and degrading it at the expense of DO consumption – the ecosystem response. The LME biogeographical classification system (Sherman and Alexander 1986) was adopted to address the spatial variation of the model parameterisation and to report the site-dependent characterisation model results of spatially differentiated N-emissions. The 18 primary input parameters and 12 derived from these were modelled at a spatial resolution of 66 LMEs, five climate zones (polar, subpolar, temperate, subtropical, and tropical), and site-generic scales.

Results and Discussion

Preliminary results of the estimation of XFs per LME point to a minimum of 0.5 $kgO_2 \cdot kgN^{-1}$ in the Central Arctic Ocean up to a maximum of 16 $kgO_2 \cdot kgN^{-1}$ in the Baltic Sea (Cosme et al. submitted). Sensitivity analysis shows highest contributions to the model results from PP rate, zooplankton assimilation rate, and phytoplankton sinking rate (Cosme et al. submitted). All the relevant processes were included in the model and the uncertainty of the driving parameters deemed low.

The spatial differentiation of the results agrees with the current understanding of the biological and oceanographic processes, e.g. species seasonal succession, geographic location, climate influence, and is consistent with primary productivity patterns and hotspots (Behrenfeld and Falkowski 1997; Chassot et al. 2010).

The model builds on the concept that coastal marine ecosystems show individual responses to nutrient loadings. The sensitivity of the receiving ecosystems is modulated by various physical and biological processes, of which PP is the most relevant. Moreover, geographic location (mainly at the climate zones resolution) influences the model parameterisation.

The XF is potentially applicable to estimate a marine eutrophication impacts indicator in Life Cycle Impact Assessment (LCIA) by contributing with a central component for site-dependent characterization factors (CFs) of coastal eutrophication arising from anthropogenic-N emissions. To fully cover the impact pathway (and the CF), the XF should be further coupled with environmental fate of the N-emissions and an indicator of the effects of oxygen depletion on biota (Azevedo et al. 2013; see also poster R:26 by Cosme and Hauschild, this volume). Such CFs constitute the main operators of LCIA methods and ultimately support the sustainability assessment of human activities.

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