

Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures

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Publication date: 2013

Link back to DTU Orbit

Citation (APA):

Cosme, N. M. D. (Author), Larsen, H. F. (Author), & Hauschild, M. Z. (Author). (2013). Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures. Sound/Visual production (digital) http://www.york.ac.uk/conferences/allatsea/index.html

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Spatially-explicit LCIA endpoint model for marine eutrophication and application to future climatic-driven pressures



Session: Nutrients and ecology of the coastal zone and how they improve our understanding of environmental change Thu July 4th 2013 – University of York

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This research was partly financed by the EU LC-IMPACT project: Development and application of environmental Life Cycle Impact assessment Methods for imProved sustAinability Characterisation of Technologies (Grant agreement No.: 243827 – LC-IMPACT), which is financially supported by the EU Commission within the Seventh Framework Programme Environment ENV.2009.3.3.2.1: Improved Life Cycle Impact Assessment methods (LCIA) for better sustainability assessment of technologies.



Marine Eutrophication

Ecosystem response to the availability of plant nutrients

- PP sustained by **nutrients** released from microbial and animal metabolism.
- Balance disrupted by anthropogenic fertilization.
 Sources: run-off from agriculture, atmospheric deposition, and sewage waters.



- **3** Nutrients enrichment promotes **excessive growth** of phytoplankton and macroalgae.
- 4 Bacterial degradation of biomass **consumes dissolved oxygen.** Excessive oxygen depletion may originate hypoxic to anoxic bottom waters.
- **5** Sublethal and lethal **effects** on resident biota are expected.



Life Cycle Assessment LCA and LCIA

Life Cycle Assessment (LCA)

- Environmental assessment tool
- Evaluates the environmental exchanges (technosphere-ecosphere) ٠
- Potential environmental impacts of a product or service throughout the entire life • cycle (resources extraction, processing, manufacturing, assembly, packaging, transport, use, reuse, recycling, and disposal stages)

Life Cycle Impact Assessment (LCIA)

- Characterisation of emissions with Characterisation Factors (CF)
- CFs are substance-specific and represent the substance potency
- CFs translate emissions into potential impacts
- Regional and global impacts





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Spatially-explicit LCIA endpoint model for marine eutrophication



Future scenarios

Increase in food demand

Climatic-driven pressures

Increase in crops productivity



Projected development of cereal production, global population, fertilizer use and arable land (FAO 2003)







- Understand the **fate processes** affecting nitrogen loadings to coastal waters
- Include ecosystems' sensitivity to obtain a damage dimension (loss of biodiversity)
- Estimate factors for the impact characterisation (CFs)
- Introducing **spatial differentiation** at a suitable scale
- Produce an endpoint damage model to support decision-making processes



How to define CFs for marine eutrophication in a spatially differentiated LCIA endpoint model?





Model framework

From environmental mechanisms to factors



To define the **Characterisation Factor (CF)** in $(PAF \cdot)[m^3 \cdot d/kg]$:

$$CF_{ij} = FF_{ij} \cdot XF_j \cdot EF_j$$

Where:

- FF_{ij} is the **Fate Factor** [d] for emission route *i* to receiving ecosystem *j*
- XF_{*i*} is the **Exposure Factor** [kgO₂/kgN] in receiving ecosystem j
- EF_j is the **Effect Factor** (PAF·)[m³/kgO₂] in receiving ecosystem j



Fate Factor

The FF_{ij} [d] is obtained by:

$$FF_{ij} = \frac{f_{exp\ i}}{\lambda_j}$$

Where:

- $f_{\exp i}$ [dimensionless] is the fraction of the emitted N that reaches coastal marine waters (exported) calculated for each emission route *i*
- λ_i [d⁻¹] is the N-loss rate coefficient in receiving ecosystem j









River-N fate modelling

Fate modelling and export to marine coastal waters







Marine-N fate modelling

Nitrogen losses (λ_i) in the marine compartment may be caused by:

• **Denitrification** \approx 30% (Van Drecht et al., 2003) (microbial mediated reduction of NO₃⁻, NO₂⁻ and NO into N₂ in bottom sediments)

- Sedimentation ≈ 5% (Nixon et al., 1996) (loss to mineralization of N into bottom sediments)
- Advection ≈ 1/τ (transport of nitrogen forms or net flushing)

To find residence time (τ) :

- Search literature
- Build archetypes:

- Output A set of the set of t
- Medium dynamics & exposure to local currents: τ ≈ 2 yr
- Low dynamics: τ ≈ 25 yr
- Very low dynamics or embayment: τ ≈ 90 yr



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Marine-N loss rate coefficient (λ_i)

Includes the 3 loss routes:

- <u>Denitrification</u>
- <u>Adv</u>ection
- Sedimentation

$$\lambda_j = \lambda_{denitr} + \frac{1}{\tau_j} + \lambda_{sed}$$

N-loss routes follow firstorder kinetics with a constant removal rate (λ_r) $N_t = N_0 \cdot e^{-\lambda_r t}$

$$\lambda_{denitr} = -\ln(0.70)$$

 $\lambda_{sed} = -\ln(0.95)$

From literature or archetypes to find τ_j for LME *j*

$$\lambda_{adv} = \frac{1}{\tau_j}$$



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		 кдом	J
after			(photosynthesis)
after ()			(respiration)
(del Giorgio & Cole, 1998) then: ——	()		



Effect Factor (EF)

The EF_j (unit: $PAF \cdot m^3/kgO_2$ is estimated by the average gradient method (Pennington et al., 2004):

$$EF = \frac{\Delta PAF}{\Delta[O_2]} = \frac{0.5}{HC_{50}}$$

where
$$HC_{50} = 10^{avg(logEC_{50})}$$

Species sensitivity to hypoxia (EC_{50}) from Vaquer-Sunyer & Duarte (2008)

- The Potentially Affected Fraction of species (PAF) is a measure of the loss of biodiversity in the receiving ecosystem
- From Species Sensitivity Distribution
 (SSD) curves for 5 climate zones + global
- Probabilistic model that estimates the variability of the sensitivity of individual species to an environmental stressor (Posthuma et al. 2002)







Spatial differentiation of the model results

Geographical distribution of the countries showing the Top10 (red) and Bottom10 (green) CFs (emissions to surface freshwater). **CF unit = ×10³ PAF·m³·d/kgN**







Sensitivity analysis

Sensitivity Ratios (SR) were calculated by:

$$SR_X = \frac{(CF_{end} - CF_{start})/CF_{start}}{(X_{end} - X_{start})/X_{start}}$$
(Strandesen)

Strandesen et al., 2007)

Tested input parameters:

- f_{exp} in FF
- Sedimentation rate in FF
- Denitrification rate in FF
- Residence time (LME) in FF
- BGE in XF
- PP rate in XF
- VCC in XF
- HC₅₀ value in EF

Independent 10% variation of each input parameter



SR max SR min



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Extreme values of possible variation range

- f_{exp} for countries exporting to multiple receiving LME: **null to total export**
- Sedimentation rate: 5% to 8% (Nixon et al., 1996)
- Denitrification rate: **30% to 52.7%** (Van Drecht et al., 2003 and Wollheim et al., 2008)
- Residence time: lower to upper archetype or -50%/+50% of used value
- BGE: 0.01 to 0.69 (del Giorgio & Cole, 1998)
- PP rates datasets show discrepancies between different sources: high uncertainty
- VCC is a model decision: **low uncertainty**





Key issues

Combining sensitivity and uncertainty







Weaknesses

- Dependency on third-party models (emissions, deposition)
- Dependency on the LCI model for the spatial aggregation of CF and NFs
- Unknown uncertainty associated with these 'input' models
- Low confidence on PP dataset
- No spatial differentiation for marine sedimentation and denitrification rates in the FF





Strengths

- Endpoint modelling
- Transparent and reproducible FFs, XFs, and EFs
- Spatially differentiated CFs
- High geographic applicability
- CFs and NFs for 233 Country-to-LME and 143 countries for 4 N-emission routes
- Global default CF and NF
- Key issues for data quality improvement identified





Thank you for your attention

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