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# Endpoint characterisation modelling for marine eutrophication in LCIA



Session track: Life cycle analysis (LCA) and sustainability Session LCAS02 – Increasing robustness in LCIA I Tue May 14 - Dochart room

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# **Marine Eutrophication**

*Ecosystem response to the availability of plant nutrients* 

- PP sustained by **nutrients** released from microbial and animal metabolism
- 2 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



## **Research question**

Drivers and goals

#### Considering that:

- ME impacts depend on the **fate processes** and on the **sensitivity** of the receiving ecosystems
- LCIA still lacks endpoint characterisation modelling
- Spatial differentiation is essential

#### Goals:

- Understand the fate processes affecting nitrogen loadings to coastal waters
- Estimate factors for the impact characterisation (CFs)
- Introducing spatial differentiation at a suitable scale



How can CFs for marine eutrophication be defined in a spatially differentiated LCIA endpoint model?



# The proposed method

Relates:

- Nitrogen loadings
- Phytoplankton biomass
- Biological response

#### **Components of the model framework:**

- Fate modelling:
  - River-N fate models (i.e. from anthropogenic emission sources to export to marine waters)
  - Marine-N fate modelling (i.e. fate of nitrogen in the marine compartment)

#### • Exposure modelling

(intermediate link from fate to effects, relating photic zone processes with bottom layer processes)

#### • Effect modelling

(includes the processes leading to impacts on biota)



## **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<sub>*j*</sub> is the **Exposure Factor** [kgO<sub>2</sub>/kgN] in receiving ecosystem j
- EF<sub>*j*</sub> is the **Effect Factor** (PAF·)[ $m^3/kgO_2$ ] in receiving ecosystem *j*



#### **Fate Factor**

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

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

Where:

- f<sub>exp i</sub> [dimensionless] is the fraction of the emitted N that reaches coastal marine waters (exported) calculated for each emission route i
- $\lambda_i$  [d<sup>-1</sup>] is the N-loss rate coefficient in receiving ecosystem j





## **River-N** fate modelling

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Fate modelling and export to marine coastal waters



## **Marine-N fate modelling**

#### Nitrogen losses ( $\lambda_i$ ) in the marine compartment may be caused by:

• **Denitrification**  $\approx$  30% (Van Drecht et al., 2003) (microbial mediated reduction of NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup> and NO into N<sub>2</sub> 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:

- High dynamics & exposure to regional currents: τ ≈ 3 mo
- Medium dynamics & exposure to local currents: τ ≈ 2 yr
- Low dynamics: τ ≈ 25 yr
- Very low dynamics or embayment: τ ≈ 90 yr



## Marine-N loss rate coefficient $(\lambda_i)$

Includes the 3 loss routes:

- Denitrification
- Advection
- Sedimentation

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

N-loss routes follow firstorder kinetics with a constant removal rate  $(\lambda_r)$ 

$$N_t = N_0 \cdot e^{-\lambda_r t}$$

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

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

From literature or archetypes to find  $\tau_j$  for LME *j* 

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



## **Exposure Factor (XF)** The $XF_i$ (unit: $kgO_2/kgN$ ) is estimated by:

$$XF_{j} = \frac{kgOM}{kgN} \times \frac{kgO_{2} \times (1 - BGE)}{kgOM} \times NIE_{j} \times VCC$$

$$OM: N \ ratio = \frac{M_{biomass}}{M_N} \approx 15.86 \ gOM/gN$$
  
after 106 CO<sub>2</sub> + 16 HNO<sub>3</sub> + H<sub>3</sub>PO<sub>4</sub> + 122 H<sub>2</sub>O  $\Rightarrow$  C<sub>106</sub>H<sub>263</sub>O<sub>110</sub>N<sub>16</sub>P + 138 O<sub>2</sub>

(photosynthesis)

$$O_{2}: OM \ ratio = \frac{M_{O_{2}}}{M_{biomass}} \approx 1.24 \ gO_{2}/gOM$$
  
after  $(CH_{2}O)_{106}(NH_{3})_{16}H_{3}PO_{4} + 138 \ O_{2} \Rightarrow 106 \ CO_{2} + 122 \ H_{2}O + 16 \ HNO_{3} + H_{3}PO_{4}$  (respiration)

**BGE** = 0.26 (del Giorgio & Cole, 1998) then: 
$$\frac{kgO_2 \times (1 - BGE)}{kgOM} \approx 0.92 \ gO_2/gOM$$

BGE is the amount of new bacterial biomass produced per unit organic C substrate assimilated

$$NIE_{j} = \frac{EmpN_{consumed}}{TheorN_{available}} \qquad EmpN_{consumed} = \frac{DIN}{DIN\ content\ in\ N_{tot}} \times M_{N} \times A_{LME} \quad \text{with}\ DIN = 10^{(\log PP - 2.332)/0.442} \text{ (Nixon et al., 1996)}$$
$$TheorN_{available} = PP \times M_{N}/M_{C} \times A_{LME}$$

Nitrogen Incorporation Efficiency expresses the environmental factors affecting PP rates

$$VCC = \frac{V_{photic \ habitat}}{V_{benthic \ zone}} = \frac{30}{0.3} = 100$$

Volume Correction Coefficient normalises different volume of photic zone above and benthic habitat at the bottom

## **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<sub>50</sub>) 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)

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## **Grouping EF into climate zones**

- Mean annual Sea Surface Temperature (maSST)
- Latitudinal distribution
- Köppen-Geiger climate classification system

									mgO <sub>2</sub> /L	kgO <sub>2</sub> /m <sup>3</sup>	PAF.m <sup>3</sup> /kgO
Climate zone	LME	taxa	n	α	β	Slope	Inters.	R <sup>2</sup>	HC50	mg/L	EF
Polar	11	20	20	0.220	0.344	2.632	4.371	0.924	1.661	1.66E-03	3.01E+02
Subpolar	7	33	33	0.207	0.541	2.408	4.460	0.954	1.611	1.61E-03	3.10E+02
Temperate	16	55	55	0.133	0.723	2.361	4.659	0.981	1.357	1.36E-03	3.68E+02
Subtropical	13	41	41	0.228	0.554	2.492	4.414	0.981	1.691	1.69E-03	2.96E+02
Tropical	17	19	19	0.165	0.247	2.932	4.495	0.914	1.461	1.46E-03	3.42E+02
Global	64	65	65	0.149	0.735	2.443	4.612	0.984	1.409	1.41E-03	3.55E+02



D	maSST 1957-2005	regression coeff.	Calculation: maSST 2005 = b × 2005 + a	Classification
ME name	b	а	Estimation mean annual SST 2005	Climate zon
Arctic Ocean	ice covere	d all year	.12	Polar
5 Beaufort Sea	0.0034	-8 1379	-1.2	Polar
1. Antarctic	0.0023	-5.7893	-1.2	Polar
6. Fast Siberian Sea	0.0075	-16.1415	-1.1	Polar
7. Laptev Sea	0.0065	-13.6953	-0.8	Polar
8. Kara Sea	0.0061	-12.8746	-0.5	Polar
4. Chukchi Sea	0.0118	-23.6389	-0.1	Polar
3. Hudson Bay	0.0120	-23.1076	1.0	Polar
8. West Greenland Shelf	0.0086	-16.2938	1.0	Polar
9. East Greenland Shelf	0.0104	-18.9583	1.9	Polar
0. Barents Sea	-0.0008	4.8359	3.3	Polar
2 Sea of Okhotsk	0.0100	-15 / 208	46	Subpolar
East Bering Sea	0.0100	-13 6712	51	Subpolar
3 West Bering Sea	0.0097	-14 3607	52	Subpolar
Newfoundland-Labrador Shelf	0.0157	-25.9772	5.6	Subpolar
9 Iceland Shelf	-0.0022	10 3775	60	Subpolar
3 Baltic Sea	0.0153	-22 3495	83	Subpolar
1. Norwegian Sea	0.0036	1.2815	8.6	Subpolar
	0.0007	42.4524		-
1. Oyashio Current	0.0097	-12.4524	7.0	Temperate
o Scotlari Shelf	0.0235	-58.7342	8.4	Temperate
Gulf of Alacka	-0.0030	12.2008	9.6	Tomperate
. Guit of Alaska	0.0078	-6.0887	9.6	Temperate
A Deterories Chalf	0.0179	-25.3213	10.5	Temperate
A. Patagonian Shen	0.0031	4.0785	10.8	Temperate
A Caltia Disease Chalf	0.0221	-31.7350	12.0	Temperate
A. Cellic-Biscay Shell	0.0085	-3.5225	13.1	Temperate
2 Black Sea	-0.0017	18 2366	14.9	Temperate
2 Southeast Australia	0.0017	-6.8315	14.9	Temperate
6 New Zealand Shelf	0.0100	10.8093	15.4	Temperate
8. Yellow Sea	0.0197	-24.1103	15.4	Temperate
3. Humboldt Current	0.0083	-0.1418	16.5	Temperate
5. Iberian Coastal	0.0162	-15.5848	17.0	Temperate
3. Southwest Australia	0.0086	0.0699	17.2	Temperate
California Compat	0.0005	4 22 47	17.4	Culturation
. California Current	0.0005	4.3347	17.4	Subtropical
9 Benguela Current	0.0054	0.0577	20.0	Subtropical
7 Canany Current	0.0004	2 4479	22.0	Subtropical
7 Fast China Sea	0.0000	-41 3278	22.0	Subtropical
4 West-Central Australia	0.0167	-11 1084	22.4	Subtropical
5. South Brazil Shelf	0.0228	-22.8069	22.9	Subtropical
9. Kuroshio Current	0.0132	-3.4566	23.0	Subtropical
1. East-Central Australia	0.0115	-0.0330	23.0	Subtropical
. Gulf of California	0.0254	-26,4000	24.5	Subtropical
. Southeast U.S. Continental Shelf	-0.0031	31.0589	24.8	Subtropical
0. Agulhas Current	0.0139	-2.4145	25.5	Subtropical
. Gulf of Mexico	0.0038	18.4183	26.1	Subtropical
0. Insular Pacific-Hawaiian	0.0006	23.6974	25.0	Tropical
0. Northeast Australia	0.0095	7,7313	25.0	Tropical
6. Fast Brazil Shelf	0.0116	3.9558	20.7	Tropical
1 Somali Coastal Current	0.0094	8 4143	27.3	Tropical
1. Pacific Central-American	0.0060	15.4948	27.5	Tropical
8. Guinea Current	0.0118	3.8046	27.6	Tropical
2. Arabian Sea	0.0085	10.5733	27.7	Tropical
2. Caribbean Sea	0.0005	26.7566	27.8	Tropical
5. Northwest Australia	0.0086	10.5848	27.8	Tropical
7. North Brazil Shelf	0.0044	19.0068	27.9	Tropical
6. South China Sea	0.0163	-4.5643	28.0	Tropical
3. Red Sea	0.0060	16.1768	28.1	Tropical
9. North Australia	0.0085	11.1456	28.2	Tropical
4. Bay of Bengal	0.0102	8.3154	28.7	Tropical
8. Indonesian Sea	0.0109	6.9714	28.7	Tropical
5. Gulf of Thailand	0.0082	12.3672	28.9	Tropical
7. Sulu-Celebes Sea	0.0126	3.6460	29.0	Tropical

Adapted from www.lme.noaa.gov

## Spatial differentiation of the model results

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Geographical distribution of the countries showing the Top10 (red) and Bottom10 (green) CFs (emissions to surface freshwater). **CF unit = ×10<sup>3</sup> PAF·m<sup>3</sup>·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 et al., 2007)

#### Tested input parameters:

0	$f_{exp}$	(in FF)
0	Sedimentation rate	(in FF)
•	Denitrification rate	(in FF)
0	Residence time (LME)	(in FF)
0	BGE	(in XF)
•	PP rate	(in XF)
•	VCC	(in XF)
•	HC <sub>50</sub> value	(in EF)

Independent 10% variation of each input parameter

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## **Uncertainty estimation**

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* 





## Data quality improvement

*Effort investment vs. return analysis* 

- Sed and Denitr rates high investment and low return
- VCC high investment and medium return
- BGE medium investment and low return
- Expanding the EC<sub>50</sub> dataset high investment and medium return
- RT high investment and medium return
- $f_{exp}$  (N-export splitting) medium investment and high return
- PP datasets **low** investment and **high** return



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**Increasing priority** 



#### 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

#### References:

- Nixon SW, Ammerman JW, Atkinson LP, et al. 1996. The fate of nitrogen and phosphorous at the land-sea margin of the North Atlantic Ocean. Biogeochemistry 35: 141-180.
- Van Drecht G, Bouwman AF, Knoop JM, Beusen AHW, Meinardi CR. 2003. Global modeling of the fate of nitrogen from point and nonpoint sources in soils, groundwater, and surface water. Global Biogeochemical Cycles 17(4), 1115.
- del Giorgio PA, Cole JJ. 1998. Bacterial growth efficiency in natural aquatic ecosystems. Annu. Rev. Ecol. Syst. 29: 503-541.
- Posthuma L, Suter II GW, Traas TP (eds.). 2002. Species Sensitivity Distributions in Ecotoxicology. Boca Raton FL: Lewis Publishers.
- Pennington DW, Payet J, Hauschild M. 1994. Aquatic ecotoxicological indicators in life-cycle assessment. Environmental Toxicology and Chemistry 23(7): 1796-1807.
- Vaquer-Sunyer R, Duarte CM. 2008. Thresholds of hypoxia for marine biodiversity. PNAS USA 105: 15452–57.
- Wollheim WM, Vörösmarty CJ, Bouwman AF, Green P, Harrison J, Linder E, Peterson BJ, Seitzinger SP, Syvitski JPM. 2008. Global N removal by freshwater aquatic systems using a spatially distributed, within-basin approach, Global Biogeochemical Cycles, 22, GB2026

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