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

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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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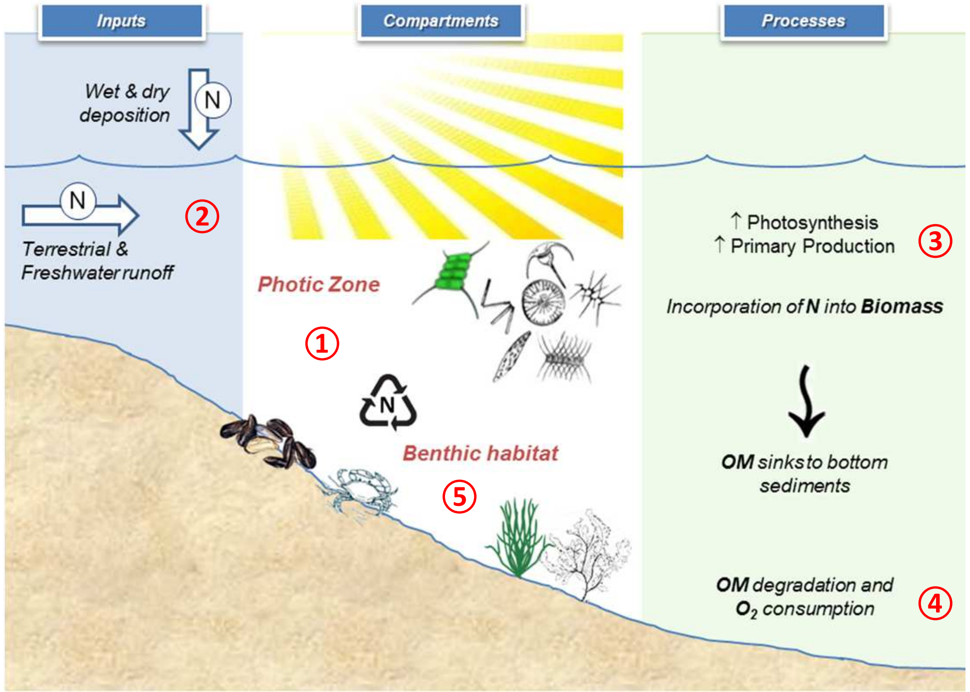
Marine Eutrophication

Ecosystem response to the availability of plant nutrients



① 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.

Life Cycle Assessment

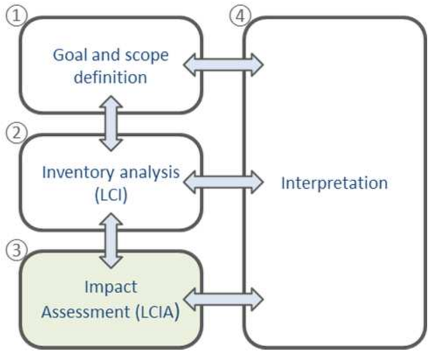
LCA and LCIA

Life Cycle Assessment (LCA)

- Environmental assessment tool
- Evaluates the environmental exchanges (technosphere-ecosphere)
- 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

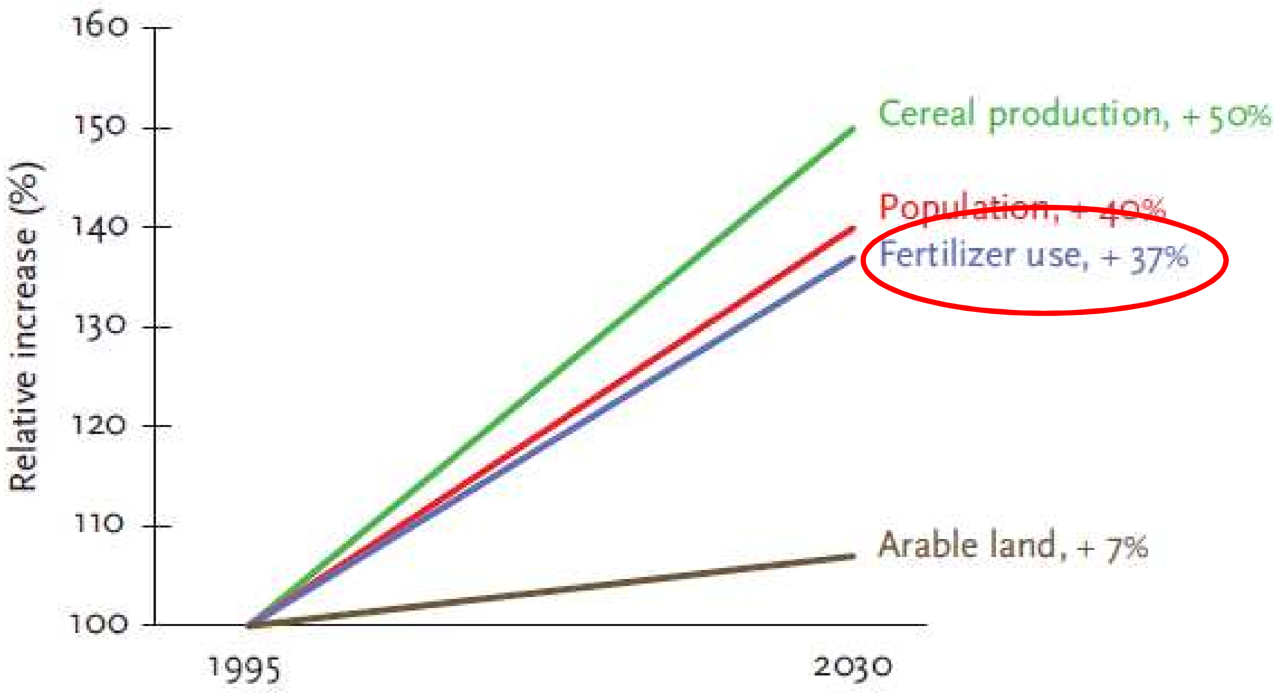


Future scenarios

Increase in food demand

Climatic-driven pressures

Increase in crops productivity



- More impacts
- New locations

- Management
- Legislation/regulations
- Best practices
- Guidelines

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

Drivers and goals

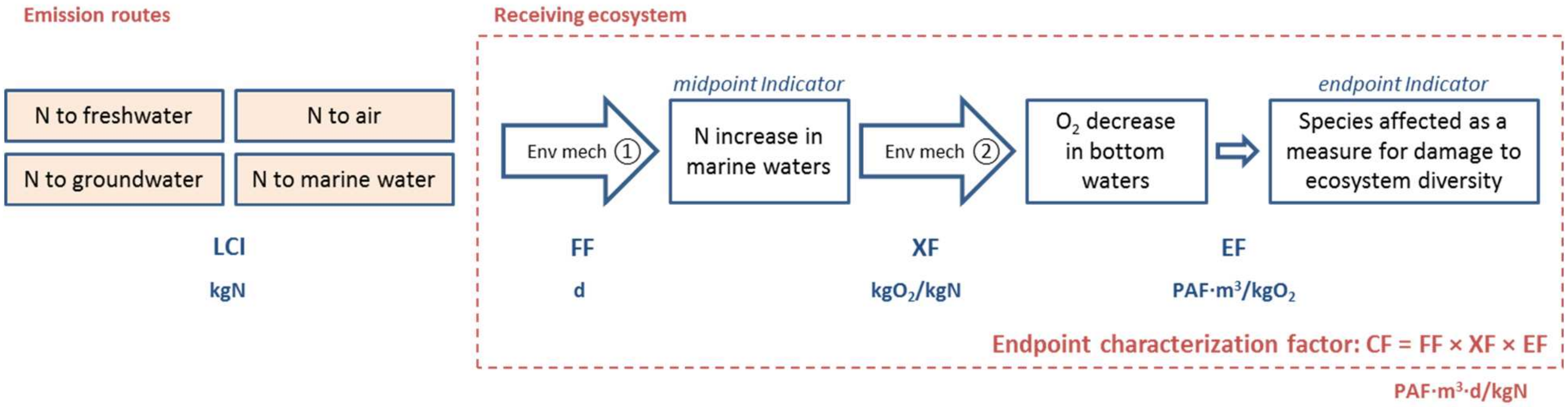
Research question

- 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·)[m^3·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_j is the **Exposure Factor** [kgO$_2$/kgN] in receiving ecosystem j
- EF_j 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:

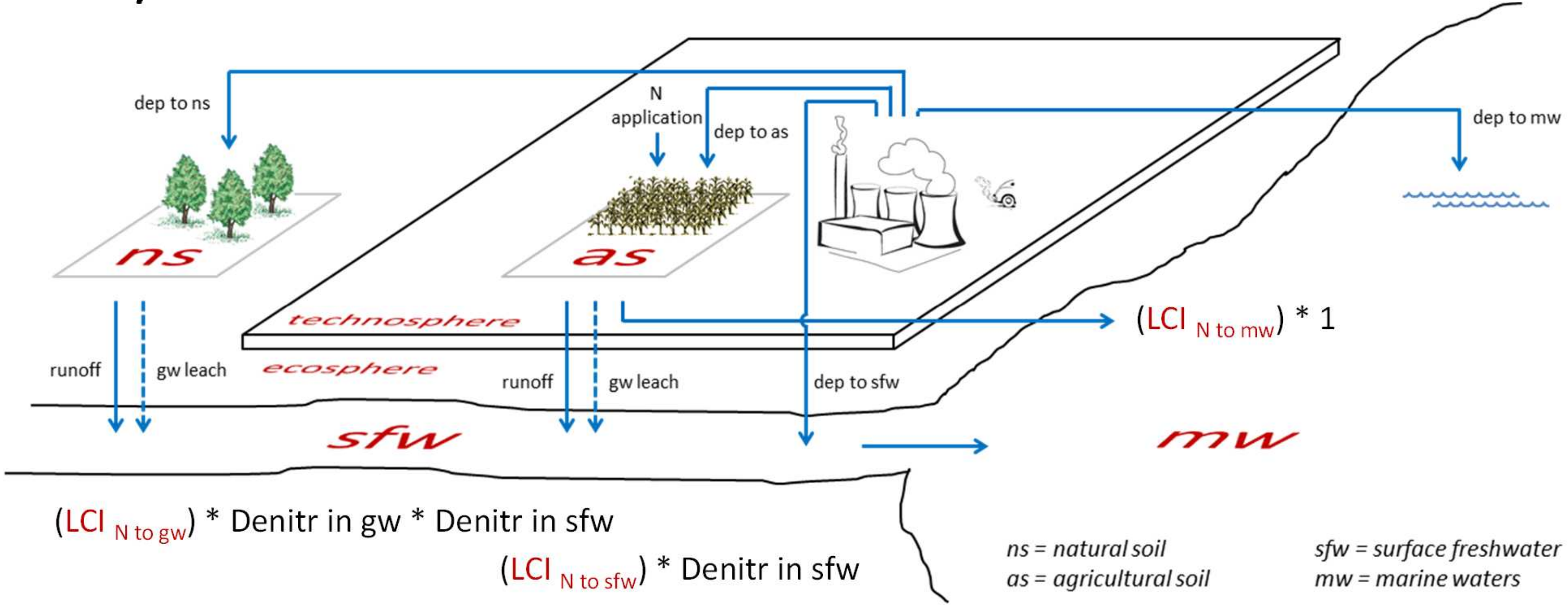
- $f_{\exp\ i}$ [dimensionless] is the fraction of the emitted N that reaches coastal marine waters (exported) calculated for each emission route i
- λ_j [d^{-1}] is the N-loss rate coefficient in receiving ecosystem j

$f_{exp\ i}$	***River-N fate***
λ_j	***Marine-N fate***

River-N fate modelling

Fate modelling and export to marine coastal waters

$$f_{\mathrm{exp}\ i} = \begin{array}{l} (\mathrm{LCI}_{\mathrm{N\ to\ air}}) * f_{dep}\ \text{to sea} * f_{dep}\ \text{to mw} + \\ (\mathrm{LCI}_{\mathrm{N\ to\ air}}) * f\ \text{to inland} * f_{dep}\ \text{to ns} * f_{leach}\ \text{from ns} * \text{Denitr in sfw} + \\ (\mathrm{LCI}_{\mathrm{N\ to\ air}}) * f\ \text{to inland} * f_{dep}\ \text{to as} * f_{leach}\ \text{from as} * \text{Denitr in sfw} + \\ (\mathrm{LCI}_{\mathrm{N\ to\ air}}) * f\ \text{to inland} * f_{dep}\ \text{to sfs} * \text{Denitr in sfw} \end{array}$$



$(\mathrm{LCI}_{\mathrm{N\ to\ mw}}) * 1$

$(\mathrm{LCI}_{\mathrm{N\ to\ gw}})$ * Denitr in gw * Denitr in sfw

$(\mathrm{LCI}_{\mathrm{N\ to\ sfw}})$ * Denitr in sfw

ns = natural soil
as = agricultural soil

sfw = surface freshwater
mw = marine waters

Marine-N fate modelling

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

- Denitrification ≈ 30% (Van Drecht et al., 2003)
  (microbial mediated reduction of NO_3^-*,* NO_2^- *and NO into* N_2 *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 (λ_j)

Includes the 3 loss routes:

- *Denitrification*
- *Advection*
- *Sedimentation*

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

N-loss routes follow first-order kinetics with a constant removal rate (λ_r)

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

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

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

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

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

Exposure Factor (XF)

The XF_j (unit: kgO_2/kgN) is estimated by:

$$XF_j = \frac{kgOM}{kgN} \times \frac{kgO_2 \times (1 - BGE)}{kgOM} \times NIE_j$$

after *(photosynthesis)*

after (   ) *(respiration)*

(del Giorgio & Cole, 1998) then: $\frac{(\quad)}{}$

Bacterial Growth Efficiency is the amount of new bacterial biomass produced per unit organic C substrate assimilated

with (Nixon et al., 1996)

Nitrogen Incorporation Efficiency expresses the environmental factors affecting PP rates *(ecosystem response)*

Effect Factor (EF)

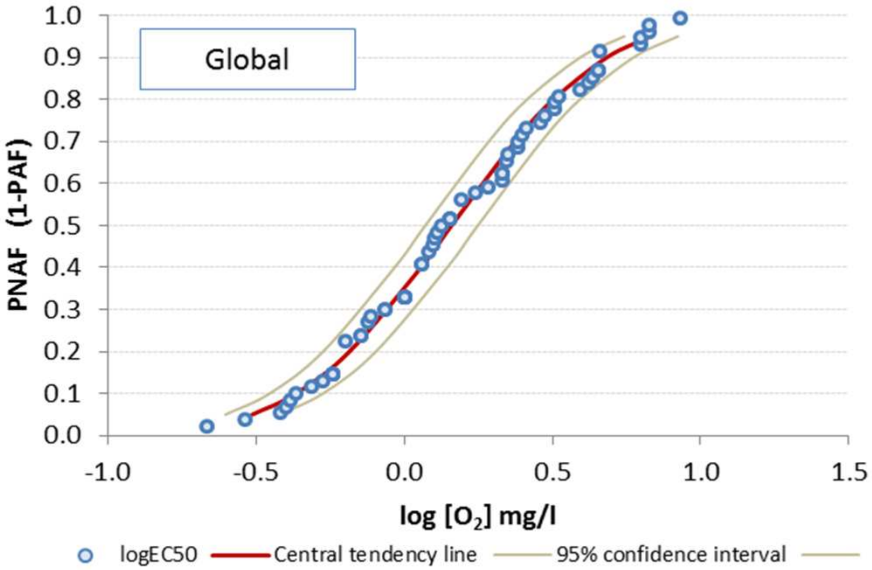
The EF_j (unit: $PAF \cdot m^3/kgO_2$ is estimated by the average gradient method (Pennington et al., 2004):

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

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

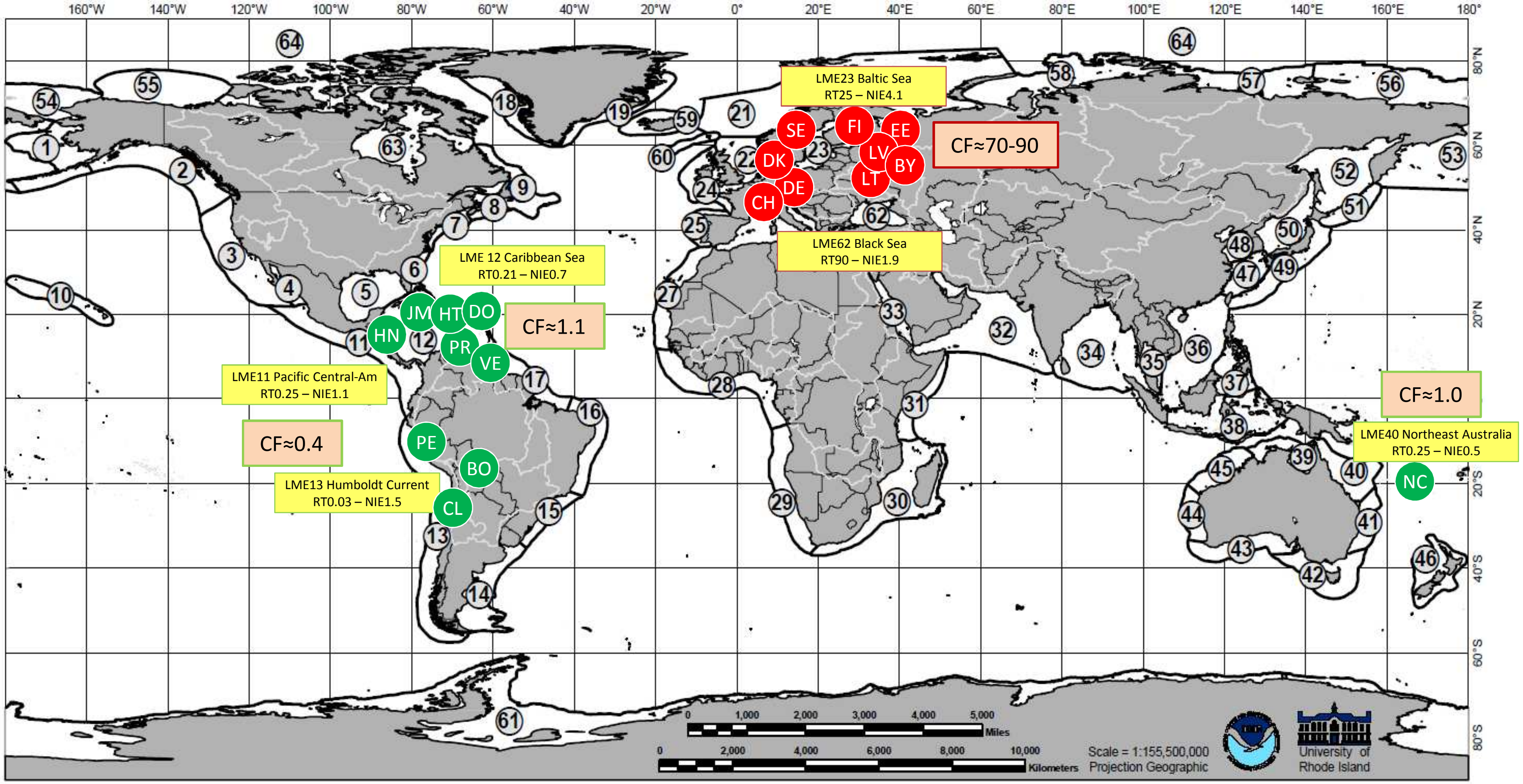
Species sensitivity to hypoxia (EC_{50}) from Vaquer-Sunyer & Duarte (2008)

- 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 = ×10^3 PAF·m^3·d/kgN**



LME23 Baltic Sea
RT25 – NIE4.1

CF≈70-90

LME62 Black Sea
RT90 – NIE1.9

LME 12 Caribbean Sea
RT0.21 – NIE0.7

CF≈1.1

LME11 Pacific Central-Am
RT0.25 – NIE1.1

CF≈0.4

LME13 Humboldt Current
RT0.03 – NIE1.5

CF≈1.0

LME40 Northeast Australia
RT0.25 – NIE0.5

Sensitivity analysis

Sensitivity Ratios (SR) were calculated by:

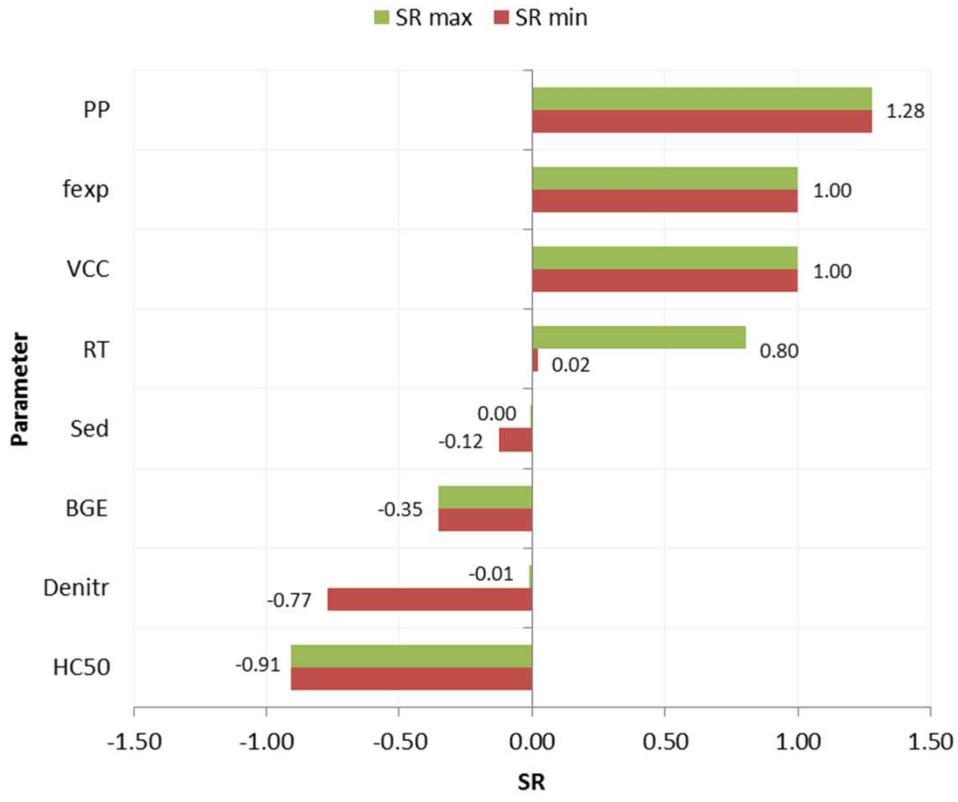
$$SR_X = \frac{(CF_{end} - CF_{start})/CF_{start}}{(X_{end} - X_{start})/X_{start}}$$

(Strandesen et al., 2007)

Tested input parameters:

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*
HC_{50} value	in *EF*

Independent 10% variation of each input parameter



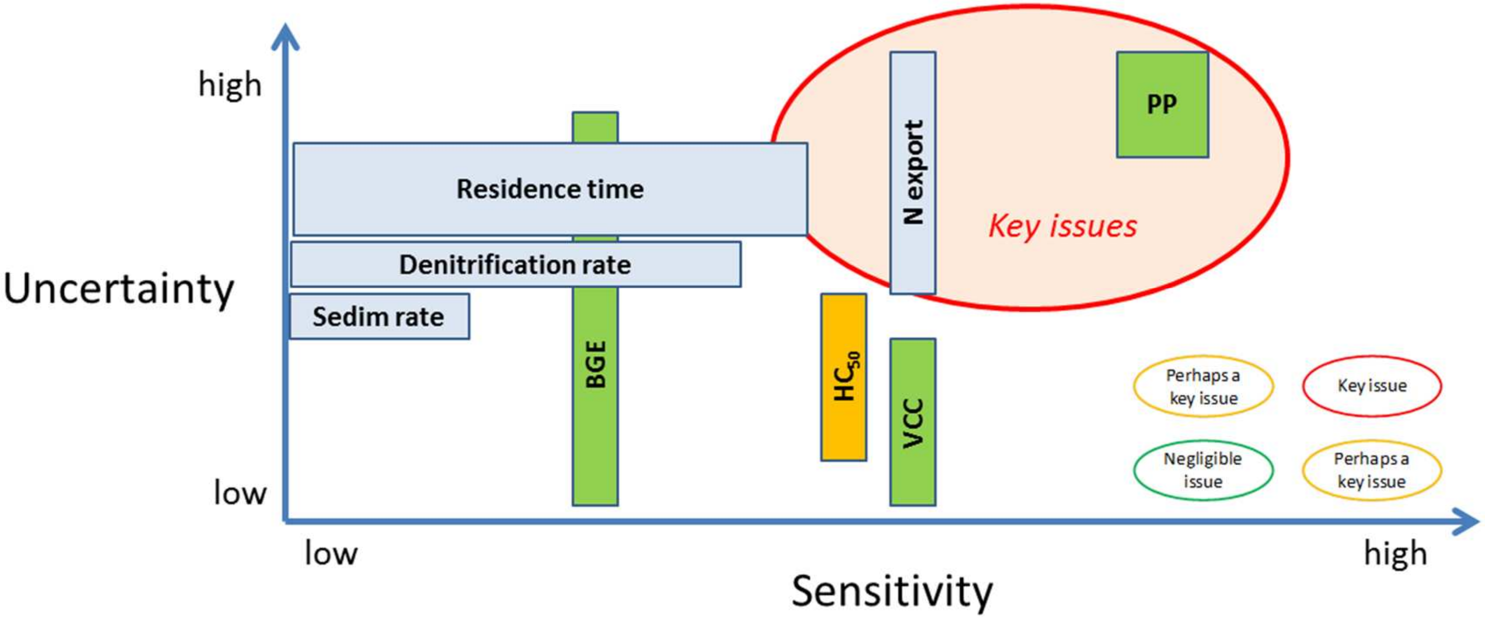
Uncertainty estimation

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



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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All at Sea?