Re-evaluation of primary production required for fish production: A new calculation framework

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Introduction

Specific primary production required for fish production (SPRR) is the amount of net primary production required to produce one unit of fish, which can be used to assess the impact of fishing on marine ecosystems.

Current approach:

$$SPPR=TE^{1-TL} \left[\frac{kgC\_NPP}{kgC\_biomass} \right] \quad [1]$$

TL: trophic level; TE: transfer efficiency

Ingestion (I_n) gC/m².year → $TL=n$ $TE=P_n/I_n$ → Production (P_n) gC/m².year
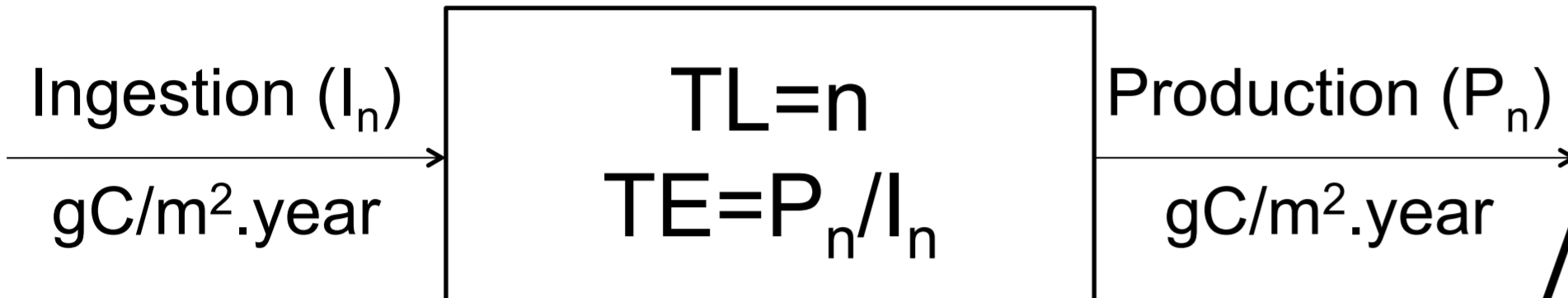
One TE value is used for all species and all ecosystems (e.g., typical TE=10%).

Limitations:

- TE is **ecosystem-specific** (ranges from 3.5 to 38.1%) [2].
- TE is **species-specific**.
- Current approach is valid for linear food chain but not for complex food web.

Goals: New calculation framework

- Use food web modelling to estimate complete material/ energy flows in the food webs.
- Calculate SPPR from food web flow matrix, without knowing TL and TE values.

→ More realistic way to assess fishing impact.

Materials and Methods

Calculation framework

Flow matrix ← Food web modelling ←
- Site-specific data
- Biological constraints
- Food web topology

Flow matrix → Transaction matrix $P=(p_{ij})_{nxn}$ → Normalized transaction matrix $A=(a_{ij})_{nxn}=(p_{ij}/q_j)_{nxn}$ → Total requirement matrix $L=(I-A)^{-1}$ → SPPR
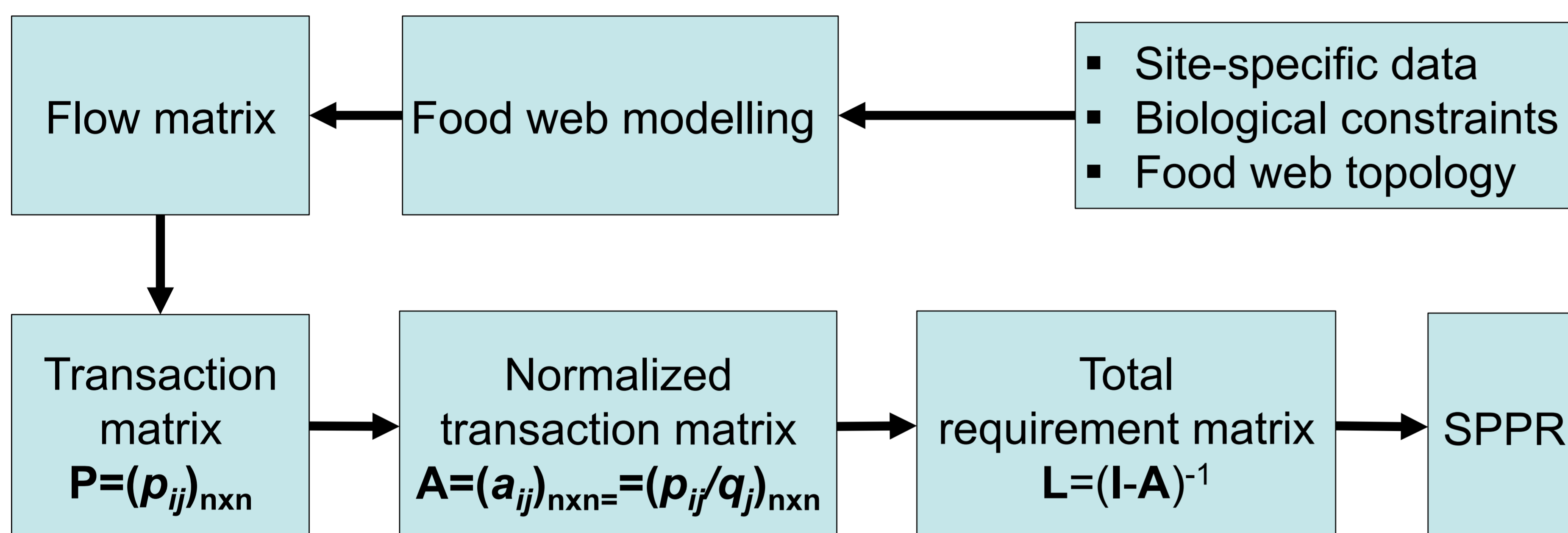
Fig. 1. Calculation framework scheme to quantify SPPR and re-evaluate trophic transfer efficiency from food web flow matrix. p_{ij}: flow from species i to species j; q_j: net production of species j (q_j is equal to ingestion minus sum of the respiration, excretion and egestion flows for consumer and equal net primary production for producer); I is the identity matrix. Each element L_{ij} of total requirement matrix L represents the amount of i directly or indirectly required to produced 1 unit of j.

Case study: Spring Barents Sea food web [3]

- Linear inverse modelling → estimate carbon flows in Southern Barents Sea food web in Spring in 1998.
- Markov chain Monte Carlo technique → sample 1000 possible food webs.
- New calculation framework → estimate SPPR for each food web realisation → uncertainty of environmental impact.
- Compare with current approach for environmental impact assessment of fish production (eq1).
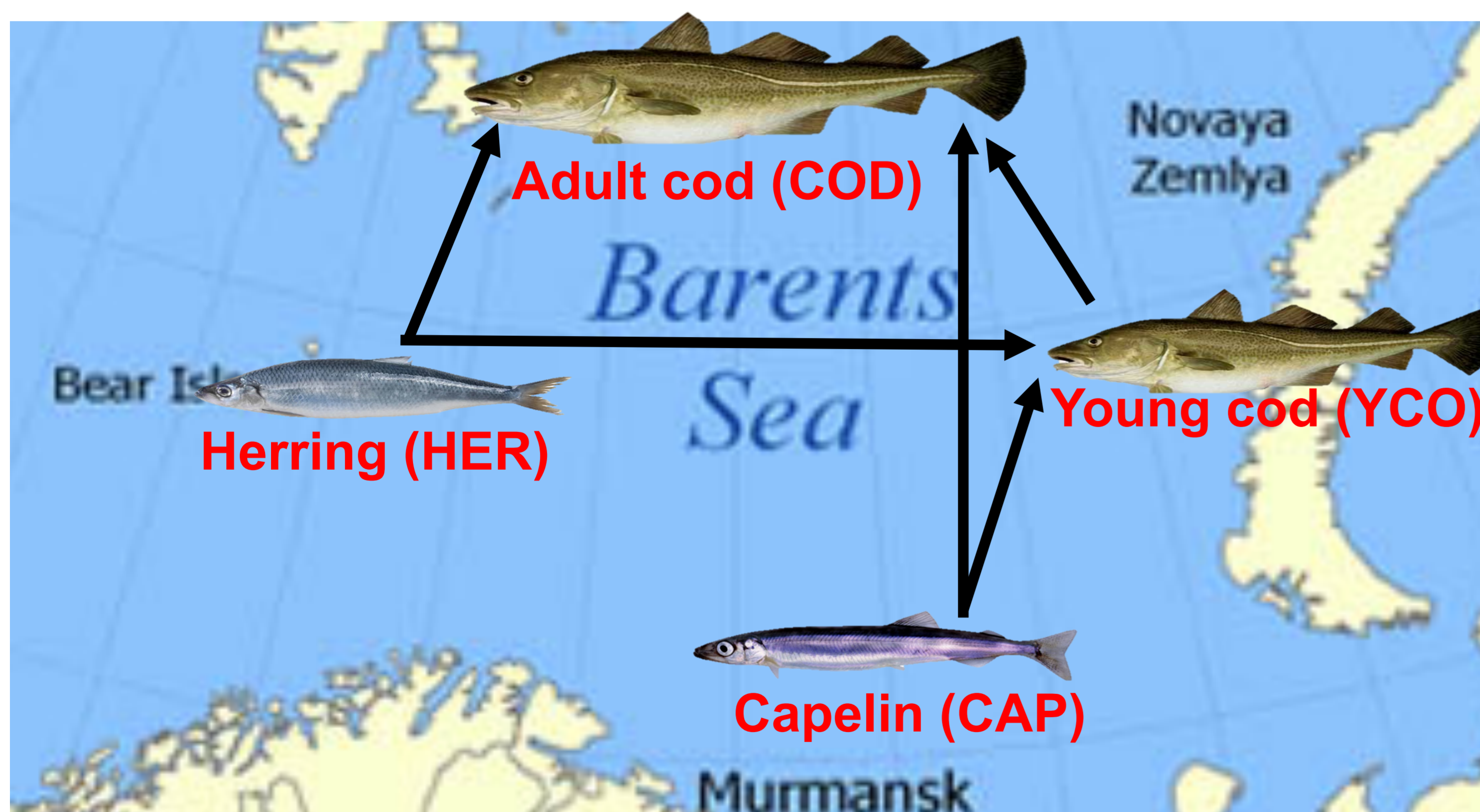
Results & Discussion

Fig. 2. Southern Barents Sea ecosystem with 4 main fish groups. The arrows represent the carbon flows between 4 fish groups, other carbon flows are not represented in the figure.

- SPPR calculated from the **new calculation framework** is 8 (CAP) to 20 (COD) times lower than from the **current approach** (TE=10%).
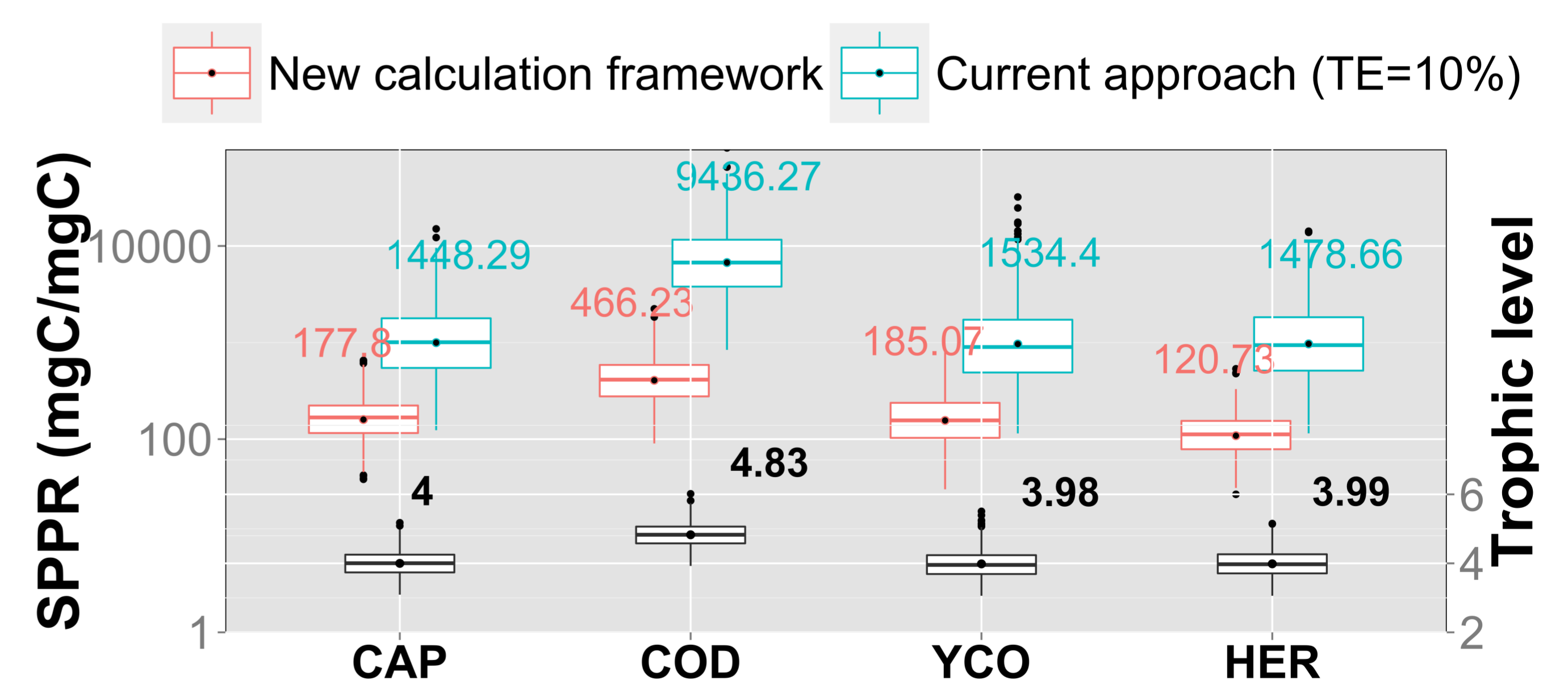

Fig. 3. Specific required primary production calculated from new calculation framework versus current approach (blue) with TE of 10% and estimated TL (black). The black dots and numbers indicate the mean values.

Conclusions

The new calculation framework:
- results in a more realistic way to quantify primary production required for fish production;
- does not rely on default values of trophic level and transfer efficiency.

References:
[1] Pauly, D and Christensen, V. Nature 1995; 374: 255-257; [2] Libralato et al. Marine Ecology Progress Series 2008; 355: 107-129; [3] De Laender et al. Marine Ecology Progress Series 2010; 398: 93-107