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Quantifying parameter sensitivity in Ecopath with Ecosim Ecotracer models using a new Python wrapper

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Abstract: Mercury is a pervasive global pollutant that poses significant risks to ecosystem health and human populations. One source of risk is through the consumption of contaminated fish. Regulatory bodies evaluating the impact of mercury in commercial fisheries require reliable predictive tools to assess these risks and inform potential management actions such as safe release limits for industry. The Ecopath with Ecosim (EwE) software, combined with the Ecotracer module, provides a suitable platform for this purpose given mercury transfer occurs through predator-prey relationships, following the structure of the food web (Christensen and Walters 2024; Walters and Christensen 2018).

The application of EwE models is constrained by high parametric uncertainty. Sophisticated EwE models can contain hundreds of parameters describing the physiology and behaviour of every species, yet they frequently suffer from a lack of empirical data to inform them, creating a plethora of knowledge gaps for modellers. Furthermore, researchers are limited to the sensitivity analysis routines implemented within the EwE software. Users can either create a handful of highly customised scenarios through the GUI or opt for large-scale scenario runs using the built-in sensitivity analysis tools, which offer less flexibility in terms of the types of sensitivity analysis and lack of support for parts of the model such as Ecotracer. While custom analysis features can be developed in R and used with EwE, they often require access to the source code and a visual basic interface. Understanding the uncertainty in mercury concentration predictions made by Ecotracer would be a significant step in allowing Ecotracer to be used by fishery managers.

To address these limitations, we developed "PyEwE", a Python interface that wraps the underlying .NET binaries of the EwE software. This creates a flexible programming interface, allowing researchers to leverage existing Python scientific libraries for sampling schemes, custom analyses, optimization routines, and parallelised model scenarios that are fully reproducible. Users of PyEwE can perform large-scale scenario runs but have complete control over the parameterisation of each scenario including control of Ecotracer parameters for each scenario which was not previously possible.

To quantify how input parameter variance drives model output variance, we conducted a global sensitivity analysis on an East Bass Strait model using PyEwE (Bulman et al. 2005). With the SALib library (Iwanaga et al. 2022), we used Saltelli sampling to calculate Sobol indices for both grouped (by functional group) and ungrouped parameter sets (Saltelli et al. 2010; Sobol′ 2001). This type of sampling and parallel execution is not available in the GUI. The grouped analysis revealed critical predator-prey interactions for contaminant transfer while demonstrating that parameters associated with low-accumulation functional groups were not significant drivers of contamination in higher trophic levels. The ungrouped Sobol total sensitivity indices identified migration parameterisation as highly influential on contaminant concentration in all modelled species. Furthermore, parameterisation of environmental contaminant flows, particularly the exchange rate of water in the study area, dominated contaminant concentrations in species with up to two degrees of separation from environmental contaminants (connected by absorption or predation).

An unplanned benefit of performing sensitivity analysis is the revelations into possibly unrealistic sensitivity or overly simplified components. The absence of observation data makes it difficult to understand whether a model is reliable and whilst sensitivity analysis is no replacement for model validation it can serve to identify deficiencies. Indeed, the sensitivity analysis revealed a lack of emigration and only immigration in one functional group explaining the extreme sensitivity to a single immigration concentration.

These findings, which are dependent on the structural accuracy of EwE models, offer direction for future research and support prioritisation of data collection efforts. The tool and the analysis shown can support the development of safe release for industrial activities, including gas pipeline decommissioning, helping Australia meet its obligations under the Minamata Convention (United Nations 2013). The PyEwE library, together with other Python tools and EwE, offers the functionality to support this analysis.

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