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Ecosampler: A new approach to assessing parameter uncertainty in Ecopath with Ecosim

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ABSTRACT

The widely used Ecopath with Ecosim (EwE) food web modelling approach has been extended with a new module to measure the impact of input parameter sensitivity on its results. Ecosampler records samples – alternate mass-balanced parameter sets for a food web model – from the built-in Monte Carlo routine, and replays these samples through all of EwE modules and any loaded plug-in. Via Ecosampler, output variation due to base input parameter sensitivity can be captured, of any computational component including the temporal module Ecosim, the spatial–temporal module Ecospace, and plug-ins such as Ecological Network Analysis, Value Chain, and Ecological Indicators.

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Software metadata

(executable) Software metadata description	*Please fill in this column*
Current software version	*Ecopath with Ecosim 6.6-Beta*
Permanent link to executables of this version	http://ecopath.org/download/ecopath-6-6-beta/ *(installer)*
Legal Software License	*GNU Lesser General Public License v2*
Computing platform / Operating System	*Microsoft Windows XP Service Pack 3 or newer*
Installation requirements & dependencies	*This executable requires Microsoft.NET Framework 4.5 or newer; Microsoft Office 2010 or newer OR Microsoft Access 2010 or newer database drivers.*
If available link to user manual–if formally published include a reference to the publication in the reference list	*The user manual is included in the installer of Ecosampler*
Support email for questions	development@ecopath.org

Code metadata

Code metadata description	*Please fill in this column*
Current code version	*V1*
Permanent link to code/repository used of this code version	https://github.com/ElsevierSoftwareX/SOFTX_2018_57
Legal Code License	*GNU Lesser General Public Licence v2*
Code versioning system used	*Apache Subversion (SVN)*
Software code languages, tools, and services used	*Microsoft Visual Studio Community Edition 2017, Visual Basic.Net, C#*
Compilation requirements, operating environments & dependencies	*Minimum requirements: Microsoft Windows XP Service Pack 3, .NET Framework 4.5, Visual Studio 2010. Although not needed for compilation, Microsoft Office 2010 or Microsoft Access 2010 database drivers are required to load standard EwE models into the compiled product*
If available Link to developer documentation/manual	http://sources.ecopath.org/trac/Ecopath/
Support email for questions	development@ecopath.org

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1. Introduction

"Ecopath with Ecosim" or EwE is a freely available and open-source food web modelling approach widely applied to assess the impact of human exploitation and environmental change on predominantly aquatic food webs. The EwE approach consists of a three computational modules: Ecopath, a mass-balance energy accounting model to capture relevant components, their interactions, and their exploitation in a food web; Ecosim, which applies the Ecopath assumptions across time; and Ecospace, which adds a spatial dimension to the temporal dynamics [1,2]. In addition, the EwE approach contains a range of analytical modules, and features a powerful plug-in system that allows third-part analytical tools to seamlessly integrate into the flow of EwE and its computational models [3].

A limitation of EwE has been the lack of facilities to measure the impact of parameter uncertainty on its predictions [4]. The ability of ecosystem models to reproduce observed trends and patterns in nature depends on a thorough understanding of ecosystem behaviour, and because this understanding is always incomplete, and models are necessary simplifications of reality, the parameterization of ecosystem models *de facto* suffers from uncertainty. By considering input parameter uncertainty, ranges of possible outcomes give a better understanding of the reliability of model predictions [1,5–7].

During its development history, the EwE feature set gained – and at times lost – tools that partially addressed this issue. A Monte Carlo engine was added to assess the impact of sensitivity in key Ecopath parameters on Ecosim predictions [1,6,8]. EcoRanger, which provided a Monte Carlo-like approach to find the best fitting Ecopath parameter set to a series of user-defined criteria [9], received criticism for making it too easy to 'fix' faulty models and was discontinued with the release of EwE version 6.0 [10]. Two distinct management strategy evaluation tools include Ecopath input parameter uncertainty when evaluating the impact of alternative fishing policies [3,11]. The stepwise fitting routine automates the process of testing ranges of hypotheses to find the best statistical fit to time series [12]. Last, the recently added Ecological Indicators (ECOIND) plug-in includes input parameter uncertainty on a range of ecological indicators [8]. However, to date the EwE approach is left wanting the means to explore the impact of parameter uncertainty on all of its predictions.

EwE models are being increasingly used for policy and management advice, such as the Roberts Bank terminal EIA [13] and the Louisiana Delta Management plan [14], and integration of the EwE approach into international assessment frameworks (e.g., [15]). Lacking an out-of-the box feature to perform system-wide input parameter sensitivity testing has led to the development of third party toolboxes such as DataReli [16] and ecopath_matlab—a MATLAB implementation of a partial feature set of EwE to assess the impact of input parameter uncertainty on ecological network indicators [5]. Consequently, it has become imperative that the EwE approach gains the native ability to provide insights into how parameter sensitivity can affect the predictions of any module of EwE [4,6,17,18].

We have built a new module to address these needs, Ecosampler, which we present in this paper. To illustrate its capabilities, we apply Ecosampler to a food web model of the Israeli Mediterranean continental shelf [19,20], and explore the impact of parameter uncertainty on key ecological indicators delivered by two external analytical plug-ins: Ecological Network Analysis and ECOIND.

2. Problems and background

The main challenge to developing a EwE-wide parameter uncertainty module is that the EwE approach is open-ended in scope. The EwE source code is free and open source, which means that anyone can use and extend the code within code license terms [10]. The code is modular, which allows programmers to replace or omit EwE building blocks, or to integrate EwE food web modelling logic into their own code, for addressing specific research questions [3]. The source code is highly extensible through the plug-in system, which allows programmers to connect any logic into the EwE execution flow without having to alter the EwE source code [3,10]. This flexibility, as shown in Fig. 1, has given the EwE desktop software significant new functionality through third-party plug-ins, while the EwE computational engines have been embedded in custom analytical code scripts [3,7,8,13,21]. The challenge was to define a model uncertainty framework that can address parameter uncertainty in existing and future module of EwE, in any existing and future plug-in, while supporting the modular structure of EwE.

A EwE-wide uncertainty assessment module needs to vary the Ecopath input parameter set. The built-in Monte Carlo routine varies Ecopath input parameters intervals in search of alternate mass-balanced models. The coefficient of variation can be entered, or can be obtained from data pedigree—a measure of confidence in the data source of each parameter [1]. Monte Carlo then assesses if alternate mass-balanced models, where all energy in the system is accounted for without requiring outside sinks or sources (ecotrophic efficiency values $<= 1$), yield a better statistical fit to observations in the temporal module Ecosim. The built-in Monte Carlo routine had two major limitations for our purposes: (1) it could not vary all Ecopath input parameters, and (2) finding alternate mass-balanced parameter sets for complex or tightly constrained models could be very time consuming task. Separating the Monte Carlo logic from Ecosim for building an uncertainty engine was not a feasible task. However, EwE already offered a series of plug-in points that expose the flow of the Monte Carlo routines to external code.

A EwE-wide uncertainty assessment module requires capturing outputs of all model routines, including those produced by existing and future plug-ins. To keep EwE open-ended in scope, the plug-in system does not pose restrictions to the workings of plug-ins, nor does it prescribe data formats for computed results. Centralized collection and analysis of an open-ended number of output formats is therefore an unrealistic option. However, EwE users typically consume the various outputs of EwE through custom written scripts in R, Matlab, Excel macros, etc., for further analysis. To facilitate this type of use, EwE already contains an auto-save system to control which core models, and which subscribed plug-ins, automatically write their results to file. The auto-save system thus offers a useful venue for capturing model outputs as it already ties in to common EwE workflows.

3. Software framework

Ecosampler was implemented as an extension to the EwE core using Microsoft Visual Basic .NET. Ecosampler operates in three separate modes: record, review, and run.

In record mode, Ecosampler listens to the execution of the built-in Monte Carlo routine. When Monte Carlo finds an alternate mass-balanced parameter set for the loaded model, Ecosampler intercepts the parameters variations made by Monte Carlo, and stores this parameter set in the EwE model database as a sample (Fig. 2).

In review mode, EwE software users can load samples, one at the time, into the Ecopath desktop software. Sample values and their impact on the various model components can be checked, and samples producing ecologically unrealistic results can be deleted.

In run mode, Ecosampler loads a number of samples, one at the time. For each sample, the default EwE output folder is rerouted to a unique folder, and its Ecopath parameter values are written

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