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A toolbox to evaluate data reliability for whole-ecosystem models: Application on the Bay of Biscay continental shelf food-web model

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ABSTRACT

Ecosystem models are always simplifications of reality and as such their application for ecosystem-based management requires standard validation. Here, the “DataReli” toolbox is proposed to evaluate the quality of the data used during the construction of ecosystem models, their coherence across trophic levels, and whether data limitations prevent the model long-term applications. This toolbox is the combination of three operational and complementary analyses: (i) the pedigree index to determine to what extent a model was calibrated on data of local origin; (ii) the graphical analysis known as PREBAL to assess whether a model respects some basic ecological and fisheries principles; and (iii) a sensitivity analysis to evaluate the robustness of model predictions to small variations in input data. The toolbox is delivered to potential users with main generic recommendations on how interpreting results conjointly and on which decisions to make about parameters' revisions or model uses' restrictions. (i) Corrections of parameters should be preferentially envisaged when modelling data-rich environments. (ii) For those models with an overall pedigree index above 0.4, a closer look at the pedigree routine, i.e. values by parameters and compartments, and the PREBAL analysis would help to prioritize parameters needing improvement. (ii)' For Ecopath models of no overall acceptable quality (overall pedigree index <0.4), we recommend stopping the DataReli procedure at this point. (iii) In terms of sensitivity analysis, marked responses of model predictions to small variations in the input values must preferentially lead to restrictions in the model applications compared to corrections of parameter estimates. A concrete application of the “DataReli” toolbox to the pre-existing Ecopath model of the Bay of Biscay continental shelf food web is presented. For the present case study, the general level of input data reliability is considered as satisfying with regard to the model applications.

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1. Introduction

To ensure the usability of ecosystem models in the growing context of ecosystem-based management (Browman et al., 2004), one must know their capabilities and limitations (i.e. unknowns and caveats). Model limitations are generally divided into uncertainties originating from the data used during model construction (Gardner and O'Neill, 1983; Lehuta et al., 2010; Kearney et al., 2013, i.e. their quality generally referring to their origin and their quantity) and those in relation to the model structure (Gardner et al., 1982; Fulton et al., 2003; Hill et al., 2007; Johnson et al., 2009, i.e. the number of compartments, the level of taxa aggregation into compartments and the marine domain targeted in the model (benthos, pelagos or the entire continuum)).

The use of Ecopath to build mass-balance food-web models (Christensen and Walters, 2004; Christensen et al., 2008) has increased over 20-fold in the last 15 years (Dame and Christian, 2006; Fulton, 2010). While structural uncertainty was rather seldom studied (e.g. Pinnegar et al., 2005), several methods are now

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available for this specific modelling software to address the issue of inherent uncertainties in the input data. Among these methods, some are implemented in the Ecopath software and used routinely while others are detailed in recent scientific publications (Kavanagh et al., 2004; Link, 2010; Niiranen et al., 2012). However, their application has not yet become as an integral part of the modelling process.

The more tests a model passes, the more confident modellers become in its predictions (Rykiel, 1996). In the present paper, we propose an ordered suite of complementary analyses covering various aspects of data properties related to their use in static ecosystem models such as Ecopath (Christensen and Walters, 2004; Christensen et al., 2008). We call these analyses the "DataReli" toolbox for "Data Reliability checking" toolbox. The analyses entering the DataReli toolbox were selected on three criteria: (i) their ease of implementation; (ii) their complementarity, i.e. they cover several integration levels (from single ecosystem components to whole ecosystem; and (iii) that they guarantee model long-term applications. The DataReli toolbox is thus conceptualized in the sense of fulfilling a list of basic prerequisites with regard to data reliability common to all ecosystem models and some more specific to the scope for which the model was designed. Three complementary analyses were chosen: (i) the pedigree index (Pauly et al., 2000), which is designed to evaluate whether a model is based on extensive field sampling performed within the boundaries of the system during specific dates; (ii) the "PREBAL" or prebalancing analysis (Link, 2010), which assesses whether data are coherent to the system level by respecting some basic laws, rules and principles of ecosystem ecology; (iii) a sensitivity analysis that determines the robustness of commonly derived model outputs, namely Mixed Trophic Impacts (MTIs) (Ulanowicz and Puccia, 1990), to small variations in input data values (Rochette et al., 2009). This sensitivity analysis is useful to strengthen identification of major connections (pairwise interactions between ecosystem components, and energy pathways) within a steady-state ecosystem.

The present study aims at presenting the DataReli toolbox and ensuring its full transferability to all future potential users through a concrete application to an existing Ecopath model. Input data reliability is assessed for the model of the French continental shelf of the Bay of Biscay food web (Lassalle et al., 2011). The model under study was developed for studying the ecological roles played by top predators and small pelagics in the continental shelf food web of the Bay of Biscay (Lassalle et al., 2012) and for ecosystem-based assessment of anthropogenic effects (Lassalle et al., 2014).

2. Materials and methods

2.1. Study area

The Bay of Biscay is a large gulf in the Northeast Atlantic located off the western coast of France and the northern coast of Spain, between 48.5° and 43.5° N and 8° and 3° W (Fig. 1). The ECOPATH model example for the Bay of Biscay was restricted to middle-depth continental shelf, between the 30-m and 150-m isobaths, in divisions VIII a and b of the International Council for the Exploration of the Sea (ICES; www.ices.dk). The surface area represented by the model was about 102,585 km^2.

2.2. The Ecopath method and the Bay of Biscay application

The mass-balance model of the French Bay of Biscay continental shelf food web was constructed using Ecopath with Ecosim 6 (EwE; Christensen and Walters, 2004; Christensen et al., 2008). Successive research programmes in this region led to the collection of a significant amount of local data on various aspects of the ecosystem. Combining this information through the construction of a EwE model helped to quantify flows between the different elements of this aquatic exploited ecosystem at a specific point in time. The Ecopath model was originally proposed by Polovina (1984) and has been combined with routines for network analysis (Ulanowicz, 1986). The parameterization of an Ecopath model is based on satisfying two "master" equations. The production equation describes the production term for each compartment (species or group of species with similar ecotrophic roles) included in the system:

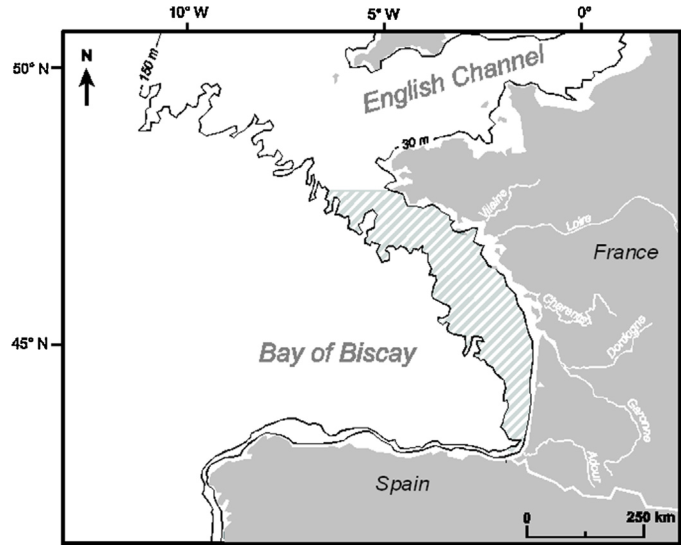

Fig. 1. Study area of the Bay of Biscay continental shelf and locations of the main rivers flowing into it. The shaded area corresponds to the French part of the continental shelf, and represents the spatial extent of the Ecopath model example.

$$\text{Production} = \text{fishery catch} + \text{predation mortality} + \text{net migration} + \text{biomass accumulation} + \text{other mortality}.$$

where "Other mortality" includes natural mortality factors such as mortality due to senescence, diseases, etc.

The consumption equation expresses the principle of conservation of matter within a compartment:

$$\text{Consumption} = \text{production} + \text{respiration} + \text{unassimilated food}.$$

The formal expressions of the above equations can be written as follows for a group i and its predator j:

$$B_i \times \left(\frac{P}{B}\right)_i = Y_i + \sum_j \left(B_j \times \left(\frac{Q}{B}\right)_j \times DC_{ji}\right) + Ex_i + Bacc_i + B_i(1 - EE_i) \times \left(\frac{P}{B}\right)_i \quad (1)$$

and

$$B_i \times \left(\frac{Q}{B}\right)_i = B_i \times \left(\frac{P}{B}\right)_i + R_i + U_i \quad (2)$$

where the main input parameters are biomass density (B, here in kg C km^{-2} or tonnes km^{-2}), production rate (P/B, year^{-1}), consumption rate (Q/B, year^{-1}), proportion of i in the diet of j (DC_{ji}; DC = diet composition), net migration rate (Ex, year^{-1}), biomass accumulation ($Bacc$, year^{-1}), total catch (Y; kg C km^{-2} year^{-1} or tonnes km^{-2} year^{-1}; fisheries data are not compulsory in Ecopath), respiration (R; kg C km^{-2} year^{-1} or tonnes km^{-2} year^{-1}), unassimilated food rate (U) and ecotrophic efficiency (EE; amount of species

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