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Global overview of the applications of the Ecopath with Ecosim modeling approach using the EcoBase models repository

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ABSTRACT

The 'Ecopath', later expanded to 'Ecopath with Ecosim' ('EwE'), modeling approach has been applied to hundreds of ecosystems around the world, since its first implementation in 1984. The 'EcoBase' model repository was developed to gather EwE models published worldwide. For the 433 unique models documented in EcoBase, we compiled, standardized, and analyzed all available metadata describing critical aspects of the models. We proposed a general description of the EwE applications and we analyzed their evolution over the last 30 years, based on the year of publication of the models. Then, we performed a correspondence analysis on the metadata to identify the main types of EwE models. Overall, most models were built to analyze ecosystem functioning and fisheries, principally in the Northern and Central Atlantic Ocean. During the first decade (1984–1993), most EwE applications were Ecopath models representing tropical marine systems and using simple food web representations to analyze trophic functioning only. Over the last two decades (1994–2014), EwE models were applied to study a wider variety of ecosystems, including polar regions and terrestrial systems, and a wider range of research topics , including pollution, aquaculture and Marine Protected Areas. The modeling practices also evolved toward Ecopath (but also Ecosim and Ecospace) models with larger spatial scales, shorter temporal scales, and more complex representations of the food web. In parallel, the numbers of both publications and modelers have steadily increased, while the proportion of journal articles presenting EwE-based studies has been growing. The correspondence analysis confirmed these trends and discriminated three types of models: the basic Ecopath models developed during the first decade, the average models developed over the last two decades using Ecopath and Ecosim routines and an intermediate number of groups, and the most elaborated models including Ecospace simulations and a high number of groups with multi-stanza. We concluded by discussing the challenges and potentials of the compilation and meta-analysis of EwE models, notably by using the EcoBase repository. This global overview showed that the usage of and interest for the EwE modeling approach in the scientific community had evolved and expended over the last three decades to support ecosystem-based fishery management.

1. Introduction

The Life Sciences have reached a new era, that of the 'Big New Biology' (Thessen and Patterson, 2011). Ecology is following a similar path, and has turned into a 'data-intensive science' (Kelling et al., 2009; Michener and Jones, 2012). Ecological studies are more and more based on data-driven methodologies, relying on large pre-existing datasets and allowing for new insights on complex or underlying phenomena at global scale (e.g., Christensen et al., 2009b). A popular example of open-access, digital and cross-disciplinary database in aquatic ecology is FishBase, the online encyclopedia of fishes (www.fishbase.org). However, extensive data sharing is still rare in Life Sciences, and ecology has not yet joined the other historical "big" sciences, such as oceanography, meteorology or astronomy, where massive data-sharing is the norm (Pauly, 1995; Edwards, 2010; Hampton et al., 2013). Although incentives for digitization of non-digital materials have

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been growing, existing repositories, such as FishBase, were estimated to represent less than 1% of the data in ecology (Reichman et al., 2011; Thessen and Patterson, 2011).

Data sharing is a required principle for independent verification and reuse (Vision, 2010), and published papers which make their data available are cited more frequently (Piwowar et al., 2007). Yet, the open-access principle of sharing information online for free has been increasingly applied to publications, but much less to data, mainly due to issues with recognition and sense of data ownership (Vision, 2010; Thessen and Patterson, 2011). Data sharing is not a tradition in ecology and faces multiple sociological and technological obstacles. Overall, new practices are needed to make data sharing fully part of the culture in Life Sciences (Pauly, 1988; Reichman et al., 2011; Thessen and Patterson, 2011; Dalgleish et al., 2012; Hampton et al., 2013). The two critical stages at which practices have to be improved to allow for data sharing are the very first, i.e., the collection of the data, and the very last, i.e., their publication. Most of the time, biological data are not being collected with reuse in mind and are then published in a narrative or summarized style in scientific articles (Vision, 2010; Thessen and Patterson, 2011). The actual data are meant to be provided in online supplements or upon individual requests sent to the authors, but these options often remain unreliable (Vision, 2010). Also, extensive data sharing may solve – at least in part – the problem of data loss, such as hard-copies or computer files in outmoded format (Zeller et al., 2005).

While facing the challenges of open data, ecology is more and more relying on modeling-based approaches to inform management. In aquatic ecology, the Ecopath with Ecosim (EwE) modeling approach has been widely applied to inform ecosystem-based management (e.g., Jarre-Teichmann, 1998; Plagányi and Butterworth, 2004; Christensen and Walters, 2011; Coll and Libralato, 2012), since its original development in the early 1980s (Polovina, 1984). EwE is commonly described as an ecosystem model, and more precisely corresponds to a quantitative, process-based and species-based model, representing trophic flows in the ecosystem. The EwE modeling approach was primarily developed as a tool-box to help fisheries management and answer 'what if' questions about policy that could not be addressed with single-species assessment models (Pauly et al., 2000; Christensen and Walters, 2004, 2011). Details on the core principles and equations of EwE can be found in the EwE user guide available online (Christensen et al., 2008). The EwE software is user-friendly, free (under the terms of the GNU General Public License) and downloadable online (www.ecopath.org). Thus, hundreds of EwE models representing aquatic (but also some terrestrial) ecosystems have been developed and published worldwide.

Building an EwE model require the collection, compilation and harmonization of various types of information: descriptive data on species abundance, diet composition and catch; computed data on species production, consumption and ecosystem properties; and simulation data on species biomass trends, after applying alternate scenarios (Christensen et al., 2008). By summarizing all available knowledge on the modeled ecosystems and deriving various system properties, EwE models help understanding the structure and functioning of ecosystems (Walters et al., 1997). Thus, EwE-based studies may be seen as important sources of information. On top of detailed information on the modeled species and food web, each EwE-based study also provides a general description of the modeled ecosystem, which represents critical information to reuse the model for performing meta-analyses. Several meta-analyses have been performed based on a selection of EwE models, and focusing, either on ecological and trophic concepts (e.g., Christensen and Pauly, 1993a; Gascuel et al., 2008; Arreguín-Sánchez, 2011), or on ecosystems and species of particular interest (e.g., Christensen, 1995; Christensen et al., 2003a,b; Pauly et al., 2009). However, only few meta-analyses have been using large collections (more than 50) of EwE models (e.g., Coll et al., 2012; Pikitch et al., 2012; Heymans et al., 2014). These meta-analyses were based on individual datasets since no comprehensive, open-access, and digital collection of EwE models was available, and this is why EcoBase was created. EcoBase is an online information repository of EwE models published worldwide in the scientific literature (see website at http://sirs.agrocampus-ouest.fr/EcoBase/).

In this study, we used EcoBase to compile available metadata on all the EwE models referenced in the repository. We analyzed the metadata to give a global overview of the applications of the EwE modeling approach in the scientific literature. We focused on some critical aspects: the general characteristics of the modeled ecosystems, the objectives of the EwE-based studies, the complexity and scope of the models, and the associated publication(s). First, we proposed a general description of the EwE applications published worldwide. Then, based on the year of publication of the models, we analyzed in detail the evolution of the EwE applications over the last three decades. Last, we performed a correspondence analysis on the metadata so as to formalize the relationships observed between some of the critical metadata and identify the main types of EwE models. We concluded with a discussion on the challenges and potentials of compiling metadata from EwE models and conducting meta-analyses, notably by using EcoBase. We intended to provide new insights on past, present and future usages of and interests for the EwE modeling approach in the scientific community.

2. Methods

2.1. Compilation of the models and publications

2.1.1. Compilation of 433 EwE models

The EcoBase project was initiated to support and stimulate data sharing and global meta-analyses using the EwE modeling approach. The EcoBase models repository was developed with the intention of making the models discoverable, accessible, and reusable to the scientific community. Details on the structure, usage and capabilities of EcoBase can be found in the report introducing EcoBase, which is available online (Colléter et al., 2013b). The main goals of EcoBase are to (i) provide a comprehensive and up-to-date list of published EwE models and EwE-based applications; (ii) compile and present information from the referenced EwE models; (iii) facilitate future meta-analyses based on EwE models.

In EcoBase, we completed an inventory of all EwE models published from 1984 to 2014 (Colléter et al., 2013b). Our inventory intended to be as exhaustive as possible, although some models may be missing, especially if they were published after October 2013 (date of the publication of the EcoBase repository). The EwE modeling approach and software consists of a suite of three sub-models (or routines): (i) Ecopath, a static and descriptive model, representing a mass-balanced snapshot of the food web; (ii) Ecosim, a dynamic and predictive model, producing time-dynamic simulations for exploring alternative scenarios, based on Ecopath; and (iii) Ecospace, a spatially-explicit version of Ecosim (Christensen and Pauly, 1992; Walters et al., 1997, 1999; Christensen and Walters, 2004). In EcoBase, 'EwE models' primarily designate Ecopath models, based on which Ecosim or Ecospace models may have been developed later on.

We extracted a list of 433 'unique' EwE models from the 571 models recorded in EcoBase, since several versions of the same model were recorded in some cases. Unique models were defined by the ecosystem they represented (i.e., the model area), the time period they covered (i.e., the model start and end years), and the author of the model (i.e., the first author on the reference of the model, commonly considered as the modeler who developed