A review of ecosystem modelling frameworks to support the development of integrated models for ecosystem management.

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Aim

The aim of this review was to assess how high-level modelling design decisions map to the effectiveness of models that are designed for ecosystem decision making and management.

Data collection

A rapid review following systematic review principles was conducted of the ecosystems modelling academic literature across the following disciplines: biology; ecology; economics; and systems management. Due to time constraints, we limited our literature search to journals appearing in Scopus and articles appearing in the last 20 years.

Our initial query returned over 1000 articles relating to biodiversity, modelling, and ecology or economics in agricultural or river systems. We then undertook a two stage sift process to identify studies which modelled systems employing an integrated biodiversity and economic approach. This process resulted in a total of 66 articles for detailed analysis.

The models in these studies were then characterised in terms of the approach taken to model development and their effectiveness. Model development was classified according to 9 factors: the mathematical approach used (model type); its intended purpose; whether the model described changes over time; the spatial scale; the level on which individual behaviour was described; how empirical data was used; the extent of stakeholder engagement; and the intended audience. Model effectiveness was assessed according to 4 main criteria: ease with which it could be applied to another related system; the effort required to use the model and the degree of confidence that can be placed in its outputs; whether it provides practical insights into the system; and whether the limitations of the model are clearly described.

Results

Overview of the data

Modelling approaches were distributed equally across three main categories: statistical models (28%), optimization models (34%), and simulation models (33%), with a small number of models (5%) making use of analytically derived results (mathematical models). A small majority of models (58%) were intended to provide a general description of the system rather than to provide guidance about a specific situation. There was a similarly small bias (56%) for models to capture a single static point in time rather than the dynamic behaviour of the system. A significant majority of studies (60%) presented a model that was developed specifically for the system as opposed to adapting (19%) or using an existing model (21%).

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Similar numbers of models considered large scale (national or regional, 39%) and intermediate scale (single ecosystem, 47%) systems, a relatively small number (14%) considered small, local scale systems. A significant majority of models (68%) tracked an aggregated description of the system state rather than modelling behaviour of its individual elements. Data was primarily used to determine model parameters (57% of studies) and secondarily to tune model behaviour (20%) or to check model outputs (23%). Stakeholder engagement was quite limited; 68% of studies had none, 22% had limited engagement, e.g. obtaining data sets, while only 10% extensively involved stakeholders in model development. Despite this, 79% of studies were directed at practitioners with only 21% being intended for an academic audience.

We concluded that the majority of models (90%) would be transferable though the amount of work to do so varied. In particular, while 42% of models could be transferred using readily available data, 32% and 26% would require some or considerable dedicated data collection respectively. 82% of the models used could be reproduced either using code provided or from the information provided in the study. However, only 1 could have been readily applied by a non-specialist. The majority of models (71%) relied on complex inputs, while outputs were generally more simple (68%). There was no clear bias in overall levels of certainty in inputs or outputs. 95% of studies provided examples of real world applications though only 67% provided specific actionable recommendations. The majority of studies (68%) gave an account of model limitations and 63% suggested ways in which the model could be improved.

Stand out observations

While it would seem that the majority of models used in the studies we reviewed could be used more widely, this does not appear to be common practice. It is more likely that a new model will be developed for a given study than that existing models will be used. Furthermore, several of the studies which built on existing models came from the research group that had developed the original model. There was only one study which explicitly developed another model that appeared in this body of literature, despite the fact that the majority of papers described ways in which the model could be improved. This suggests that considerable research resources may not be being applied effectively.

Moving on from this general point, we observe some differences in the modelling approaches depending on the focus of the study. In particular, ecological models tend to be based on simulation (56%) while there is a preference for optimization based approaches where the main discipline is economics (43%). Furthermore, simulation models were much more likely to be dynamic (79%) than static; whereas optimization models were evenly split between dynamic and static approaches. This might be a consequence of the focus on population dynamics in the ecological literature; whereas the economic literature is more focused on controllable systems. Regardless, these differences in approach will necessitate the synthesis of a common framework before truly integrated models for ecological-economic systems can be developed.

We found that the majority of model characteristics had only a limited effect on the transferability of a model; although we did note that simulation models had slightly lower data requirements than other types of model. Optimization models tended to provide the simplest outputs while statistical models produced the most complex. We also observe that data requirements drop as the model scale increases. This may appear counter-intuitive, but probably reflects differences in the level of detail that larger scale models seek to capture as compared to smaller scale models.

Conclusions

Making full use of the existing literature stands out as a major challenge to be addressed when developing models for ecological-economic systems. At present this literature appears to be relatively fragmented, with authors preferring to develop new models rather than building on existing ones. This does not appear to arise from a lack of openness in sharing model details, data, or code; though it may be that researchers struggle to identify useful approaches in the existing literature. We note that beyond the ecological-economic literature, there are several research areas in which specific model platforms have become the de facto standard. Examples include the climate change-economics literature (DICE/RICE) and the GTAP platform for global trade. While there is potential for development of such platforms in this area, e.g. NEVO, Bateman et al., it is clear that the community as a whole has yet to come to a consensus approach.

We should note that by limiting this review to Scopus and academic journals, we have excluded grey policy literature. Consequently, we have not captured how (or if) this academic research is applied in practice. Additionally, by including only studies that seek to specifically address a real world system, we exclude much of the theoretical modelling literature. Advances in modelling may arise more from this literature than the more application focused literature we have considered.