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Modelling how people and nature are intertwined

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Climate change adaptation, global food trade and urbanisation: all are examples of processes in which people and nature are closely intertwined. The state of nature drives human activities, while human activities change the state of nature. These human–nature, also social–ecological, interactions have always existed since early in the history of humankind and are a fundamental characteristic of life on Earth. Now in the Anthropocene – the acclaimed geological era in which human activity is the dominant influence on the environment – many social–ecological systems are under pressure (Raworth 2017). Human demand for land, water and natural resources is rapidly increasing while the state of natural areas that supply these is deteriorating due to human action, and as such limiting options for human activities in the future. Dealing with these growing demands and associated impacts is one of the grand challenges decision makers face worldwide (IPBES 2019).

Sustainability scientists aim to understand how social and ecological systems interact in order to better manage them. For example, models can help explore the feasibility of multiple development goals, understanding landscape complexity, and anticipating feedbacks in decision making (Liu et al. 2015, Kramer et al. 2017). In this vein, models can help to distil the key processes of the social–ecological system while studying them in a ‘virtual laboratory’.

Feedback interactions between people and the environment (A impacts B while B impacts A) are one of the properties of coupled social–ecological systems that sustainability scientists are trying to better understand. Currently, these feedbacks are rarely modelled, despite them being prominent in many social–ecological systems (Liu et al. 2015, see Fig. 1 for examples). Feedbacks are usually not included in models as it is considered technically and conceptually challenging. Instead, models typically focus on simulating one-way effects (A impacts B).

How much does it matter whether feedbacks between coupled social–ecological systems are modelled or not? This was the central question Synes et al. (2019) addressed in their recent study. The authors tested the benefits of simulating feedback responses between pollinator insects and decisions on farm land use intensity. Pollinators increase agricultural yield, yields influence farmers’ decisions about agricultural activities, and agricultural activities influence habitat suitability for pollinators. To simulate these

Figure 1. Examples of human–nature feedbacks in marine, urban and rural social–ecological systems: (over)fishing activities influencing fish populations and subsequent fishers’ strategies; real estate prices and urban green space development driving each other; and farmer decisions to increase crop yield influencing crop pollinator habitats, as modelled in Synes et al. (2019).

interactions, the authors used two agent-based models (models that can simulate the behaviour of individuals, in this case pollinators and farmers), which they applied to a hypothetical virtual landscape. They tested feedbacks between social and ecological systems by comparing changes in crop yield, pollinator populations and also clustering of land use types. The study showed that by capturing those feedbacks, the effects on both the social and ecological systems were amplified, revealing new system properties of the human–nature interactions.

Modelling coupled systems for sustainable environmental management

Modelling coupled systems requires an understanding of the key system elements and their interactions. To represent and explore the nature and effects of feedbacks, Synes et al. (2019) used and coupled two existing standalone agent-based models to represent the social and ecological system. Such sharing and re-using of existing models has many benefits. Besides an efficient use of research time, another benefit is that repeated testing and applying of a model to other contexts improves model performance over the long run (Schulze et al. 2017). Synes et al. (2019) coupled the two models so that the output of one became the input to the other in the next time step, thereby allowing for feedbacks between models. Coupled social–ecological systems can also be modelled by building a single comprehensive model which already includes social and ecological feedbacks (Voinov and Shugart 2013). For example, the coupled human and natural systems model named MIMES simultaneously captures simulated ecosystem services and their responses to multiple interacting environmental and human drivers (Bouman et al. 2015).

Regardless of the actual modelling approach, building models to represent coupled social–ecological systems comes

at a cost. First, while all models (coupled or not) simplify reality, strong simplifications in social–ecological models are often made regarding the social system (Schulze et al. 2017). This also holds true for Synes et al. (2019), who assume human decision-making is mainly based on ‘economic utility maximisation’, meaning that the model assumes decisions are driven by resource production and its economic use. This is a common social system simplification in models. Alternative behavioural theories which include, for instance, habits or errors in perception, are not yet very prominent in social–ecological models (Groeneveld et al. 2017). Second, temporal and spatial scales between the systems and models need to match. However, in reality, the interactions between social and ecological systems typically take place at different paces and spatial extents. For instance, a new international strategy to ensure sustainable fishing practices must be adapted to fit the local ecological circumstances and will influence the well-being of local fishers in the long run. While flagged as an important model consideration, differences in speed and spatial extent of farmers’ decisions and changes in pollinator populations were not explicitly taken into account in this work by Synes et al. Third, once the coupled social–ecological system is modelled, the output needs careful analysis and interpretation. A sensitivity analysis shows what choices regarding model settings and assumptions drive the outcomes of simulations. Such an analysis is needed for any model but is more challenging when coupled systems and feedbacks are simulated (Schulze et al. 2017). Multiple simulations, using different parameterisations of the ecological pollinator model, were run by Synes et al. (2019) to distil what settings had the largest effect on farmer decision making, crop yield and pollinator populations in their experimental design.

Despite these challenges, modelling coupled social–ecological systems brings new opportunities for environmental management. Models that do not capture feedback interactions between people and nature are leaving out key

processes and may not capture so-called ‘emergent properties’, i.e. those that appear only as a result of underlying interacting elements, as with the clustering of land uses (Grimm and Berger 2016). Other properties that could be missed are the detection of tipping points, or thresholds, such as maximum sustainable yield in agriculture, forestry and fisheries management. Through the use, re-use and validation of coupled systems models, we can understand the system better and hence better inform its management. Modelling the interactions between social and ecological elements is increasingly demanded as part of the evidence-based decision making (Verburg et al. 2016, Gissi et al. 2017). We see an important role for modelling coupled systems for testing possible outcomes of policy instruments in virtual laboratories. This would allow us to link knowledge captured in models on human behaviour and ecological processes to proposed policy instruments like subsidies, zoning or conservation strategies.

Currently, concepts to describe the relationships between people and nature are used in international to local decision making and policy negotiations. Common ones include: ecosystem services, landscape approaches, ecological and water footprints, planetary boundaries and cross-sectoral approaches (Raworth 2017, Reed et al. 2017, IPBES 2019). Modelling coupled socio-ecological systems can help to operationalize these concepts for decision making.

The future of modelling coupled systems for sustainability

To fully realise the potential of modelling coupled social-ecological systems to support decisions towards a sustainable society, we see and encourage five steps ahead.

1) Learn from methodological advances made in other disciplines. The work by Synes and colleagues is an example of how two agent-based models, developed by different scientific communities (social sciences and ecology) can enrich each other (Vincenot 2018). Similar opportunities could be found in applying methods to capture spatial patterns, developed for ecological studies, in applications to questions typically studied in the social sciences.

2) Make explicit model decisions regarding temporal and spatial issues. Adequately representing the scales of interaction not only depends on what processes are captured by a model, but also what environmental management question is addressed, i.e. determine what ‘granularity’ is relevant (Verburg et al. 2016).

3) Couple tested, generic models. Generic models can represent a wide range of species, systems and environments with only re-calibration or minor amendments (Grimm and Berger 2016). By re-using existing models, Synes et al. made a case that tested models can advance our understanding of the system.

4) Use ontologies: commonly agreed upon definitions of concepts and the relations among them. Transparency and

clarity of models is fundamental, especially when coupling them. To facilitate model interoperability and data and information exchange, researchers and students – as future scientists – need skills, tools and guidance for documenting models and using ontologies to facilitate this (Schulze et al. 2017).

5) Include feedbacks. Feedback representation is a growing research direction towards a next generation of social-ecological models (Robinson et al. 2018). The work of Synes and colleagues reminds us that we can only adequately find out how to best manage our environment if we acknowledge how strongly we are intertwined with nature.

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