Learning from uncertainty in lake ecosystem model scenarios

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Ecosystem-based management, (EBM) is an environmental management approach aimed at sustaining the ecosystem over time while securing the services humans want and need. It is not a new concept and its value and importance has long been recognized, however, its implementation has been slow. One of the challenges in applying EBM is the lack of confidence surrounding our understanding of the functioning of the ecosystem in question and the likely response given various possible management measures. Ecosystem models have been used to reduce this limitation and to provide insight into ecosystem functioning and relationships between internal processes and external forcing. They provide resource managers with the ability to examine the, ecological and economic, efficiency of the measures planned to achieve a predefined objective such as the Water Framework Directive “good status”.

The results of complex models, for example lake ecosystem models, often suffer from limitations due to various sources of error and uncertainty associated with the initial conditions, input data, model structure, validation data, etc. Perhaps one of the largest sources of uncertainty is associated with the calibrated parameter values. As a consequence of the parameter uncertainty, ecosystem models are often perceived as not sufficiently reliable as a management tool. Nevertheless, in such complex models, it is extremely difficult to independently quantify each of the sources of uncertainty and error, let alone their combined effect. In addition, quantifying the resulting predictive error is not trivial. Applying uncertainty analyses, which are often used with simpler models, can be prohibitively computationally intensive when applied to complex models and/or require a high level of quantitative skills that are not always readily available.

A multi-model ensemble modeling approach in which a given scenario is simulated with a series of models and the combined output is considered is popular among the climate change community. The use of an ensemble approach requires, however, multiple models. In practice, the existence of multiple models is rarely found for a given lake ecosystem. In cases, however, where a single model is available for a given ecosystem, a single-model ensemble approach can be used.

The application of an ensemble approach using a single model can provide resource managers with an assessment of the reliability of management scenarios output given the parameter uncertainty.

We examine this approach by applying a calibrated ecosystem model to Lake Kinneret, Israel, which due to its importance is intensively managed. One of the main concerns facing the resource managers is the increasingly frequent nuisance cyanobacteria blooms. Cyanobacteria blooms are indicators of an eutrophication process whereas nutrient loading (mainly nitrogen and phosphorus) is traditionally considered to be responsible for this process. Due to the importance and popular use of manipulation of nutrient loading as a prime lake management measure, we focus our scenarios on the impact of changes to nutrient loading on the ecosystem. We apply the single-model ensemble approach to study the impact of model parameter uncertainty in a complex lake ecosystem model on the results of management scenarios using and comparing the output to the calibrated model for the lake.

We use the 1-D hydrodynamic-ecological model, DYRESM-CAEDYM (DYCD) to study a series of management scenarios for Lake Kinneret. DYCD simulates the hydrodynamic and the biogeochemical dynamics of aquatic ecosystems and has been applied extensively to the lake. As the result of the large number of parameters in the model (>400) it suffers from a large degree of uncertainty that impacts model results and scenario outcome. In order to study the impact of model uncertainty on the outcome of a series of management scenarios (multiple levels of nutrient loading) we generated 2000 parameter vectors for each scenario based on the merging of results of a sensitivity analysis and the Hyper Latin Cube approach. For a number of major state variables we calculated key statistics in each scenario and examined the impact of the parameter space on the simulated trends and relationships between the management actions and the ecosystem variables.

The results indicated that parameter uncertainty did not alter, in most cases, the outcome of the scenarios and the expected trends and relationships between management actions and ecosystem variables modelled with the calibrated model. The analysis of the scenario results provided not only information on the impact of parameter uncertainty but additional insight into ecosystem functioning and relationships between internal processes and external forcing.