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Comparing strengths and weaknesses of three ecosystem services modelling tools in a diverse UK river catchment

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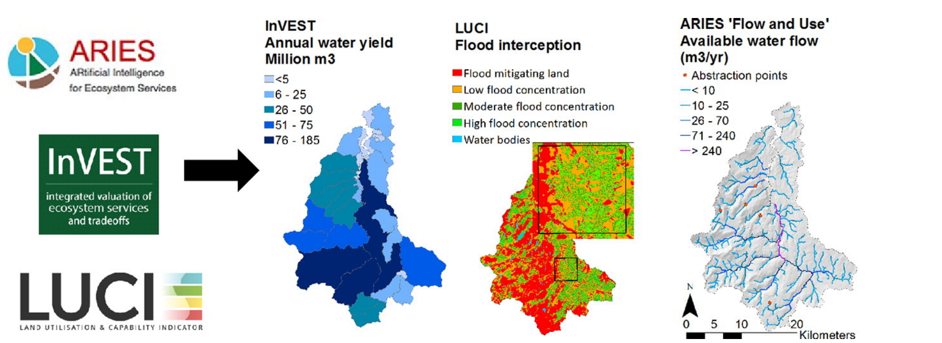
HIGHLIGHTS

- Ecosystem service decision support tools range in complexity and sophistication.
- We compared three spatial ecosystem service tools: ARIES, InVEST and LUCI.
- Models were run for water supply, carbon storage and nutrient retention services.
- All three tools performed similarly, but have different strengths.
- As each tool has unique features, choice of model depends on study question.

GRAPHICAL ABSTRACT



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ABSTRACT

Ecosystem services modelling tools can help land managers and policy makers evaluate the impacts of alternative management options or changes in land use on the delivery of ecosystem services. As the variety and complexity of these tools increases, there is a need for comparative studies across a range of settings, allowing users to make an informed choice. Using examples of provisioning and regulating services (water supply, carbon storage and nutrient retention), we compare three spatially explicit tools – LUCI (Land Utilisation and Capability Indicator), ARIES (Artificial Intelligence for Ecosystem Services) and InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs). Models were parameterised for the UK and applied to a temperate catchment with widely varying land use in North Wales. Although each tool provides quantitative mapped output, can be applied in different contexts, and can work at local or national scale, they differ in the approaches taken and underlying assumptions made. In this study, we focus on the wide range of outputs produced for each service and discuss the differences between each modelling tool. Model outputs were validated using empirical data for river flow, carbon and nutrient levels within the catchment. The sensitivity of the models to land-use change was tested using four scenarios of varying severity, evaluating the conversion of grassland habitat to woodland (0–30% of the landscape). We show that, while the modelling tools provide broadly comparable quantitative outputs, each has its own unique features and strengths. Therefore the choice of tool depends on the study question.

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1. Introduction

Ecosystem services modelling tools allow the quantification, spatial mapping, and in some cases economic valuation, of ecosystem services. The output from these tools can provide essential information for land managers and policy makers to evaluate the potential impact of alternative management options or land-use change on multiple services (Daily et al., 2009). Such tools are now being used around the world, at a range of spatial scales, to address a wide variety of policy and management questions. For example, they have been used to investigate the possible effects of climate change on water provisioning and erosion control in a Mediterranean basin (Bangash et al., 2013), to provide guidelines for water resource management in China (Fu et al., 2014), and to examine the potential impact of agricultural expansion on biodiversity and carbon storage in Brazil (Chaplin-Kramer et al., 2015).

Ecosystem service decision support tools range in complexity, with the simpler models requiring less user time and data inputs while the more complex models require more technical skill but can result in greater accuracy and utility. The simplest include spreadsheets (e.g. Ecosystem Services Review [ESR]; WRI, 2012), and mapping overlay tools based on land-cover based lookup tables (Burkhard et al., 2009). Intermediate complexity spatial tools provide information on the relative magnitude of service provision (e.g. SENCE; Vorstius and Spray, 2015), and the more complex tools allow spatial quantification and mapping of services, for example InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs; Sharp et al., 2015), LUCI (Land Utilisation and Capability Indicator; Jackson et al., 2013) and ARIES (Artificial Intelligence for Ecosystem Services; Villa et al., 2014). With an ever increasing variety of tools available, there are now a number of reviews and comparisons that help potential users make informed decisions on which tool might be appropriate for their needs. These typically focus on tool capabilities, ease of access/use, time requirements and generalisability (Nelson and Daily, 2010; Vigerstol and Aukema, 2011; Bagstad et al., 2013a; Drakou et al., 2015; Burgess et al., 2016). For example, model outputs from ARIES and InVEST for carbon storage, water and scenic viewshed services were compared for a semi-arid river basin in Arizona, USA, and northern Sonora, Mexico, under different management scenarios (Bagstad et al., 2013b). Vorstius and Spray (2015) investigated similarities in mapped outputs from three different tools in relation to service delivery at a local scale. Turner et al. (2016), focusing on methods to assess land degradation, briefly reviewed a range of decision support tools and other models whose outputs have been evaluated in the context of ecosystem services. There are also online toolkits available, for example, the National Ecosystem Approach Toolkit (NEAT; http://neat.ecosystemsknowledge.net/), providing guidance on selecting an appropriate modelling tool.

At first glance, many of the ecosystem services modelling tools appear to produce similar outputs; they can model multiple services, and are designed to be used for scenario analysis and decision-making. However, the approaches taken and underlying assumptions made for the models within each tool are often different, the appropriate resolution and scale of their application can vary and, since the models are in continuous development, reviews can become rapidly outdated. Therefore, there is an ongoing need for comparison studies that compare multiple models for the same service(s) and study site(s), along with a need to evaluate models in new biophysical settings. In particular, this paper demonstrates how three such tools differ, highlighting unique aspects and discussing their strengths and weaknesses, at a level of detail which is not met in most previous reviews.

In this paper we compare three spatially explicit ecosystem services modelling tools, using examples of provisioning and regulating services (water supply, carbon storage and nutrient retention). The models are parameterised for the UK and applied to a temperate catchment with widely varying altitude and land use in North Wales. While two of the tools have previously been compared (ARIES and InVEST) (e.g. Vigerstol and Aukema, 2011; Bagstad et al., 2013b), LUCI has not been evaluated in a tool comparison. Additionally, we focus on an aspect receiving little attention in previous reviews, i.e. that the modelling tools produce a range of different outputs for each 'service'; these differing outputs may inform the choice of tool for a particular application. Lastly, since ecosystem services modelling tools are often used to evaluate the impacts of land-use change, we assess their sensitivity to varying severities of land-use change (0–30% change of catchment area).

2. Material and methods

2.1. Study site

The Conwy catchment in North Wales, UK, is 580 km^2 in area (Fig. 1). It is a small catchment in global terms, but is characterised by a diverse range of elevation (0–1060 m), climate, geology and land uses. Predominantly rural, the land-use comprises sheep farming in the upland areas to the west and mixed dairy, beef and sheep farming in the lower areas to the east. The lowland flood plain area also contains some arable land. There is a large afforested area to the mid-west. Most of the sub-catchments contain some semi-natural woodland, including areas of riparian woodland. In the uplands to the south of the catchment lie extensive areas of blanket bog, protected under the European Natura 2000 biodiversity designation. More information can be found on the Conwy catchment in Emmett et al. (2016).

2.2. Modelling ecosystem services

We have chosen examples from both provisioning and regulating services, including those where the spatial context is important to the flow of services (water yield, nutrient retention) and where it is less directly important (carbon storage). We did not include a cultural service as ARIES and LUCI do not have readily available cultural models parameterised for the UK.

2.2.1. Overview of model approaches

ARIES, InVEST and LUCI were chosen as spatially explicit ecosystem services modelling tools that provide quantitative output, can be applied in different contexts, and can work at local or national scale, depending on the available data. InVEST combines land use and land cover (LULC) data with information on the supply (biophysical processes) and demand of ecosystem services to provide a service output value in biophysical or economic terms (Sharp et al., 2015). The models, written in Python, are available as stand-alone applications. LUCI is a decision support tool that can model ecosystem service condition and identify locations where interventions or changes in land use might deliver improvements in ecosystem services. Output maps are colour-coded for ease of interpretation: in default mode green is used to indicate good opportunity for changes, and red to mean "stop, don't make changes here". The models incorporate biophysical processes, applying topographical routing for hydrological and related services, and use lookup tables where appropriate, e.g. for carbon stock. The models are written in Python, and run in an ESRI GIS environment. LUCI has a unique, built-in trade-off tool, which allows the user to identify locations where there is potential for "win-wins", i.e., where multiple services might benefit from interventions, or where there may be a trade-off, with one service benefitting from interventions while another is reduced.

In contrast, ARIES was developed as an online platform to allow the building and integration of various kinds of models. This allows the most appropriate ecosystem services model to be assembled automatically from a library of modular components, driven by context-specific data and machine-processed ecosystem services knowledge (Villa et al., 2014). ARIES focuses on beneficiaries, probabilistic analysis, and spatio-temporal dynamics of flows and scale, aiming to distinguish between potential and actual benefits. While InVEST and LUCI focus on using known biophysical relationships (where possible) to model physical processes, ARIES, in addition to standard modelling approaches