Research article

Application of Integrated Modeling System to Ecosystem Services Evaluation

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Abstract In recent years, many case studies have been conducted on ecosystem service (ES) evaluation in both developed and developing regions. A method to integrate the ES evaluation has hitherto been undeveloped and a few systems been proposed for the same. Based on our previous studies on estimations of the potential supply of ES in both rural and urban areas, a modeling system capable of performing an integrated evaluation of ES is automatically applied into our study. A geographical and ecological information database of the ecosystem in Japan was connected, and an interface of an estimation model of the ecosystem services was connected to an integrated system. A system with a visible interface and clearly defined concepts and concept relationships, is helpful not only to researchers who are unfamiliar with GIS and modeling, but also to stakeholders and decision makers.

Keywords environmental planning, ecosystem services (ES), Geographical Information System (GIS), meta-modeling, semantic modeling

INTRODUCTION

The concept of ecosystem services (ES) refers to a variety of services ranging from highly related ecological functions (supporting and regulating services, e.g., material cycles inside ecosystems) to highly related human society functions (provisioning and cultural services, e.g. food production, logging, and recreation space provision).

Recently, many quantitative and spatial case studies on ES have been conducted using the geographical information system (GIS, e.g., Verhagen et al., 2015). Large projects on the assessment framework of ES, such as InVEST (Jackson et al., 2016), Oppla (Verweij et al., 2015), TESSA (Peh et al., 2013), and the Artificial Intelligence for Ecosystem Services (ARIES project, 2016), are also being conducted.

Rapid emergence of overwhelming volumes of data in recent years, for example the increasing number of elevation, landuse, and species occurrence databases, make choosing a suitable dataset for our study difficult. Many portal sites and meta-database projects for efficient database location are now being developed, e.g., KNB (The Knowledge Network for Biocomplexity), and OBIS (Ocean Biogeographic Information System). Despite great efforts to digitize data location, many researchers still search for files using browsers and download them individually, unzip, and convert them to a suitable format (file type, encodings, geographical projection, etc.), manually.

The existence of diverse methods of ES assessment in terms of aims and scopes presents a serious barrier to the sharing of ES studies, especially to the integration of various ES evaluations. For example, various methods of quantifying ES have been proposed: lookup table, statistical models explained by environmental variables, and mechanistic models based on ecology and earth sciences (Verhagen et al., 2015). The lookup table is fairly straightforward and transparent. However, its accuracy and its application are limited by its high dependency on location and disregard for the temporal and spatial continuity of ecosystems. Mechanistic models can perform highly accurate and detailed simulations; however, models developed by researchers or projects cannot be exchanged because highly specific ecosystem and ES concept terminologies are assigned.

Semantic modeling and semantic meta-modeling (Villa et al., 2014) are attractive methods in the big-data and divergence-model era. Based on machine-readable knowledge bases, such as unit systems, physical constants, formulae, and relationships between ES and landuse, a distributed database and model are automatically assembled to the requirements of a user.

OBJECTIVES

In this paper, the authors applied semantic modeling to our previous estimation method of urban ES (Ooba et al., 2015). A detailed description of the current situation of data-model rich ecology is given in the former section, where the needs of semantic modeling are discussed. In the next section, details of a trial application of the semantic modeling on urban ES assessment are given.

BACKGROUND OF SEMANTIC METHODOLOGY

Before the downsizing of digital electronic devices, measuring and observing field data such as geographical and ecological data was rather difficult in terms of accessing study areas, recording outside, and security. However, acquiring field data from various electric sensors, data loggers, wireless internet, remote sensing, global positioning system, etc. is much easier. Growing memory and bands of the networks governed by Moore's law results in relatively low-cost storage and transport of geographical and ecological data. Although the explosive availability of the data provides equal accessibility, new problems that have already been pointed out in the introduction section, still occur.

One of the solutions to this problem is the development of meta-databases. These systems need data annotations such as author names, data type, location and time of observation, and so on. For description method for the annotation, Dublin Core is commonly used and a related search engine for ecology has been developed, e.g., Morpho by the KNB project.

Statistical methods of computer modeling, including spatial analysis, have made marked progress with the growth of data availability. Free and commercial software for statistical modeling are well developed as they are not required to list software names. In addition, distributed data analysis frameworks are also available (e.g., Spark). It also mentions that the advancement of machine learning in this decade must be focused on.

It seems that the abundant data and models are not enough to address the concerns of policy makers and stakeholders regarding biodiversity, ecosystem, and ES. In addition to the diverse models of ES that are difficult to integrate, these models that assess and interpret ES do not meet the more practical needs of policy makers, stakeholders, and governmental and private planners (Urban and rural design, environmental planning, and ecosystem conservation).

Machine readable knowledge can solve this problem through machine reasoning (Villa, 2009; Villa et al., 2009, 2014). Ontology in computer science suggests an inference system based on sets of concepts and relationships among the concepts in a domain (e.g. disciplines of science or industrial sectors). For example, if a system holds an ontological engine and can access a knowledge base of the unit system, it appropriately converts from a unit (e.g., area, m2) to another unit (e.g., ha).

A system that operates databases and models using such ontological inference provides an integrated platform for the assessment of ES for specialists, as well as non-specialists, e.g., for aid in decision making regarding ecosystem conservation to keep ES from development. Non-specialists may not always understand the significance of the contribution of data and models to the success of a project, such as an environmental problem, in terms of accuracy and effectiveness as well as a specialist. However, the understanding of some concepts related to the environmental problem is simple enough that they can be shared by both non-specialists and specialists. Once an agreement on the ontology and the semantic modeling system to be used is established, discussions on the problem may benefit the data and models based on the system.

k.LAB software provides an integrated environment for the development of knowledge bases and data-model complexes, including automatic model selection (meta-modeling). This technology has been developed in conjunction with the ARIES project. Many studies have been conducted in the San Pedro River Basin, USA (Bagstad et al., 2016a), Puget Sound, Washington (Zank et al., 2016), the Southern Rocky Mountains (Bagstad et al., 2016b), and so on.

CASE STYDY

A fairly simple and transparent method was proposed for the spatial assessment of ES supply potential for a rapidly growing city in a developing country (Ooba et al., 2015, 2016; Kay et al., 2015). Integrated potential supply of ES can be estimated from a limited dataset (e.g. digital elevation map, DEM, and remote sensing image) and it can suggest the relative importance of green space inside a study area for the purpose of conserving ES supply. First, elevation and land cover map are obtained from remote sensing images or geographical maps. Indices related to each type of ES (supporting, regulating, provisioning, cultural, and habitat) are calculated using primary units or simple models related to a target type of land cover on a km-level grid. In the previous study (Ooba et al., 2014), these indices were collinear due to limited data-sources; one index that was not correlated to other indices was assigned to one type of ES category (Table 1). Finally, the ES indices are aggregated to an integrated index by ES weights estimated from results of internet surveys (Ooba et al., 2016).

Table 1 Methods used to estimate ecosystem services (see also Ooba et al., 2015)

Service category	Proxy variable	Basic units, method details*	Unit
Supporting	Carbon sequestration	3.09(W)	t/y ha
Provisioning	Food supply	2.98(A)	t/y ha
Regulating	Inverse of soil erosion coefficient	$S = 65.41\sin^2\theta + 4.56\sin\theta + 0.065$ C = 1 (R), 0.33(A), 0.0085(W)	-
Culture	Economic value of green space	Value per unit area as green belt area A(ha) $V = 3.0184A^{-0.437}$	10^6 JPY/y
Habitat	Continuity of green space	ArgGIS tool (Focal statistics) proximity as 2 km radius	-

** Land-use codes—R: Residential Area, A: Agricultural field, W: Vegetation mainly covered by wood plant*

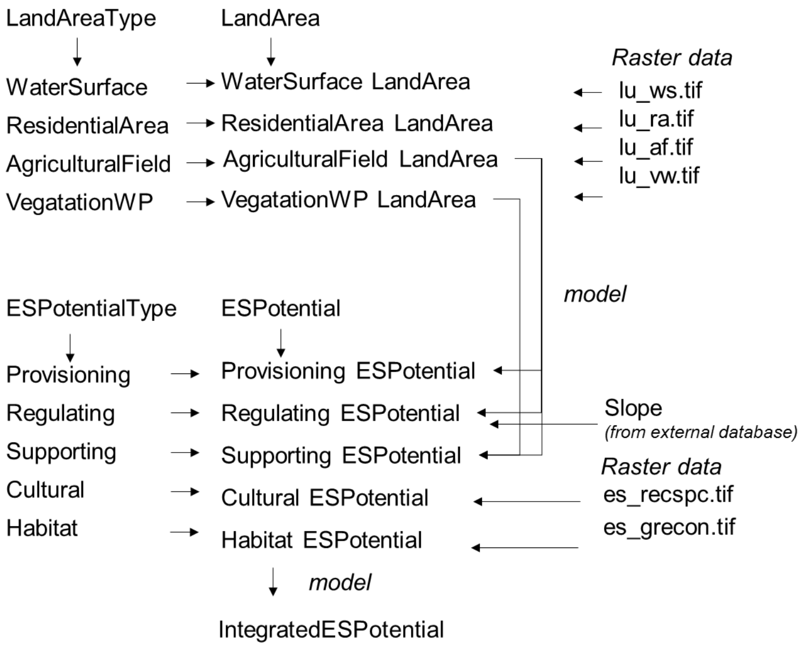

Fig. 1 Concepts and related attributes for the simple evaluation of ES supply potential

These manual operations by GIS were transplanted into a semantic modeling environment (k.LAB, ver. 0.9.8) based on ontology. Because there was no common knowledge base (ontology) that suited our purpose, we created a small, toy-level, ontology based on our method, for a trial assessment (Fig. 1). Two main concepts of land area and potential ES supply were asserted on a project in the system as "LandArea" and "ESPotential", and these concepts had their types described by the following attributes. "LandAreaType": WaterSurface, ResidentialArea, AgriculturalField, VegatationWP (Wood Plant); "ESPotentialType": Provisioning, Regulating, Supporting, Cultural, Habitat. In the next step, models that mention a multiple line statement are defined for file loading and calculating on the project. A study area is Nagoya City, Japan as the same as in the previous study, and then spatial context must be defined on the integrated system before model running.

In this study, due to somewhat complex spatial assessment calculation for Cultural and Habitat ESPotential, these raster files that had been prepared by GIS were loaded into the projects. DEM that an index of regulating services needs is obtained automatically from the standard knowledge base of k.LAB accessed to the default repository.

Results that is the same as the results of previous studies (Ooba el al., 2015). Relatively high potential supplies were exhibited in the area surrounding the city (agricultural fields and secondary forests).

The source code and data in this study will be open, and the k.LAB software can be used freely after a simple application in the integrated modeling project site (ARIES project, 2016).

CONCLUSION

Solving environmental problems requires collaborations between, not only biologists and ecologists, but also other scientists, engineers, environmental planners, and individuals from many other sectors. Vihervaara (2013) stressed the role of international and ecological monitoring networks, such as ILTER, for the assessment of biodiversity and ES, and the usefulness of the acquired data in the mitigation and adaptation of climate change. Integrated platforms for semantic modeling may enhance the potential of the data. Moreover, ES tools suitable for non-specialists under consensus on ecological concepts may provide new insight into regional planning from the perspectives of biodiversity and ES. Bagstad et al. (2014) mentioned that the semantic framework using hypothesis driven approaches or trusted process-based models is more confidential than statistical modeling from a reason of being able to validate of reasoning.

We have reported on the results of our toy program for the popups of popularization of semantic modeling in the Asia region; however, we can elaborated on more complex functions of the well-established k.LAB system. Many researchers have indicated more complicated usage of the system such as baysian model, watershed model, mechanistic model of ecosystem and so on, which have been researched in the ARIES project.

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