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Ecosystem Services Dependency Assessment and Management Database for Sectors of the Economy

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Several approaches exist for ecosystem services (ES) dependencies assessment. However, no assessment tool proposes concrete measures for creating sustainable dependencies on ES. Hence, this research introduces a method for proposing measures for making corporate ES dependencies more sustainable. ES dependencies algebra is based on the Ghosh inverse matrix as introduced in Eco-LCA (Zhang et al., 2010). Japanese national input-output (IO) tables for 108 aggregated economic sectors and ES related data were used to complete the method. The assessment results show each sector's dependency to each ES assessed in cumulative ES use. Exemplary results are shown as a case study on timber and agricultural products use. The most dependent sector on each ES was found to be the primary user of that ES. Therefore ES conservation methods implemented by the primary user were concluded to be more important than those implemented by the users further down the supply chain. This potential to manage dependencies more sustainably was studied by identifying best practices for primary users and other potential measures within each sector, and a knowledge database for potential solutions was created. This database was used to introduce solutions for better management according to ES dependency assessment results. The method can be further improved by expanding the database enabling stakeholders to examine sectors most dependent on each ES assessed and what potential these sectors have for better dependencies management.

Key Words : *ecosystem services, economic sectors, dependency assessment, input-output tables, knowledge database, Ghosh inverse matrix*

1. INTRODUCTION

(1) Trends in biodiversity and ecosystem services assessment

Since the Millennium Ecosystem Assessment (MA) in 2005[1)], ecosystem services have steadily gained wide-spread recognition culminating this year (2012) in the establishment of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)[2)]. IPBES can be considered the main organization in connecting biodiversity and ecosystem services science to policy-making, but in order to sustainably integrate human society and ecosystem services, aspects other than government policies, such as the relationships between corporations and ecosystem services, need to be considered in parallel.

Some of the major challenges in assessing the importance of ecosystem services lie in the private sector. Here, The Economics of Ecosystems & Biodiversity (TEEB) has taken a major role in analyzing the economic benefits of biodiversity and ecosystem services. Especially, the TEEB for Business report describes the risks and opportunities related to biodiversity loss and ecosystem decline[3)]. The report has proven its importance in initiating discussion on how to properly measure benefits from ecosystem services, but leaves plenty of opportunities for further research.

(2) Recent developments in ecosystem services dependency and impact assessment tools

Several approaches exist for assessing corporate dependencies and impacts on ecosystem services. A number of these assessment tools have been analyzed by Waage et al. [4] and include for example the Corporate Ecosystem Services Review (ESR) [5]. Other recent approaches include Life Cycle Impact Assessment Method based on Endpoint Modeling (LIME) [6] and a variation of Life Cycle Assessment called Eco-LCA developed by Zhang et al. in Ohio State University[7]. Of the published methods, all methods offer means to account for ecosystem services but they also are limited in scope. For example, ESR assesses a wide range of ecosystem services, but only qualitatively, LIME assesses only endpoint impacts on ecosystems, but not dependencies, and although Eco-LCA analyzes dependencies on ecosystem services quantitatively, it currently only considers a limited range of services. This situation creates research opportunities including aspects such as new variables for assessment, re-design of assessment frameworks, further research into natural and human systems interface transactions and including measures for improving the connections to ecosystem services into the assessment tools.

(3) Objective

Our research project has a long-term goal of developing ecosystem services assessment methods especially for industries. This paper discusses a recent approach of our project, and the general ideas of this approach are as follows.

The focus of our research is to develop a quantitative management decision support platform for industries to evaluate their relationships with ecosystem services and support facilitating symbiotic relationships between nature and industries. This platform consists of two modules, first being a dependency assessment module and the second an ecosystem services management solutions module. The dependency assessment module focuses on mathematically assessing benefits acquired from ecosystem services by industries. One such method is a new method that addresses gaps in ecosystem services assessment developed by Shaw et al.[8]. It is called Ecosystem Services Use (ESU) which is used to assess forest ecosystem services usage quantitatively for sectors of the Japanese economy.

The management solutions module provides ways to recommend sustainable ecosystem services management methods to industries. A conceptual module was first introduced by Matsui et al. in 2012[9], but the concrete methods of identifying and recommending solutions are still under development. This paper introduces our most recent approaches towards both of these modules.

This research adopts Shaw et al.'s approach of using ecosystem services as inputs to sectors of economy and assessing the sectors' dependence on these services by using national IO tables. However, whereas Shaw et al. concentrate on forest ecosystem services only, this research reviews ecosystem services on a broader range. Additionally, as opposed to the algebraic method based on Leontief inverse matrix used by Shaw et al., this research utilizes algebra for IO analysis based on the Ghosh inverse matrix method as introduced by Zhang et al. in Eco-LCA[7]. The reason for this is that Ghosh's method takes into account ecosystem services capacity limitations unlike Leontief's method as explained in more detail in section 2. (2).

This research builds on the methods created by Shaw et al. and Zhang et al., but in order to further close the gap between sectors of the economy and ecosystem services, assessing dependencies on a macro scale alone is inadequate. Current generalized tools do not provide solutions for better ecosystem services dependency management and hence sector specific management methods are investigated. Here, identifying and recommending concrete measures towards more sustainable dependence at a sector or where possible, even at a product level is needed for improved management and decision-making.

2. APPROACH

(1) Modules design

In order to achieve the above mentioned goals, identifying ecosystem services' current states and conservation needs is required. Furthermore, building a knowledge database of current states of ecosystem services, conservation needs and potential measures to address these needs is also necessary. This research addresses these requirements by first building a dependency assessment module for economic sectors' ecosystem services dependencies and second, identifying the ecosystem services' current states and conservation needs from MA[1] and other literature, and creating a knowledge database consisting of this information. In addition, potential measures to address these needs are identified by examination of environmental top-runner corporations and products. These potential measures are included into the knowledge database, and focus on products and services where possible.

Finally, these two modules are connected as follows. Ecosystem services current states and sectors' potential measures acquired from the knowledge database are connected to the dependency assessment results by embedding this information directly into the dependency assessment results. This procedure is further explained in 2. (4).

The scope of this research is kept to the Japanese economy and ecosystem services. The IO tables used represent the Japanese economy and to match this economic data, only domestically produced ecosystem services are considered. Imported resources (such as fossil fuels) are excluded for consistency.

The ultimate goal of this research is to provide a free tool for understanding economic sectors' ecosystem services dependencies, and studying sustainable management methodologies.

(2) Dependency assessment algebra

This research adopts mathematical methods for dependencies assessment from Eco-LCA[7]. Eco-LCA is an ecologically based life cycle assessment tool that focuses mostly on dependence on provisioning ecosystem services. The mathematical method adopted from Eco-LCA is a formula for cumulative resource use matrix. Vector $\boldsymbol{X}$ represents total economic activity of sectors of the economy as defined in the national IO tables. $\boldsymbol{X}$ can be displayed as

$$\boldsymbol{X} = \boldsymbol{Z}^{\boldsymbol{T}} + \boldsymbol{V} \qquad (1)$$

where $\boldsymbol{Z}$ is the IO transaction table and $\boldsymbol{V}$ is the vector of value added to each sector. Next, Ghosh matrix $\boldsymbol{G}$ is defined as

$$\boldsymbol{G} = \widehat{\boldsymbol{X}}^{-\boldsymbol{1}}\boldsymbol{Z} \qquad (2)$$

where $\widehat{\boldsymbol{X}}$ is the diagonalized matrix of the total economic activity vector $\boldsymbol{X}$ so that each x_i in $\boldsymbol{X}$ equal x_{ii} in $\widehat{\boldsymbol{X}}$. $\boldsymbol{G}$ is a normalized matrix where $g_{ij} = z_{ij}/x_i$ is the fraction of output from sector i to sector j. Using eq. 2, eq. 1 can be arranged to

$$\boldsymbol{X} = \boldsymbol{G}^{\boldsymbol{T}}\boldsymbol{X} + \boldsymbol{V} \qquad (3)$$

Using linear algebra, from eq. 3 cumulative resources use of sectors $\boldsymbol{X}_{ph}$ is acquired as

$$\boldsymbol{X}_{ph} = (\boldsymbol{I} - \boldsymbol{G}^{T})^{-1}\boldsymbol{V}_{ph} \qquad (4)$$

where $(\boldsymbol{I} - \boldsymbol{G}^{T})^{-1}$ is the Ghosh inverse matrix and $\boldsymbol{V}_{ph}$ is a matrix of resources entering relevant sectors. The notation *ph* is added to eq. 4 to display that physical flow is being used instead of monetary flow. $\boldsymbol{X}_{ph}$ is the matrix of sector i's cumulative use of ecosystem k. The unit of $\boldsymbol{X}_{ph}$ depends on the unit of the resource in $\boldsymbol{V}_{ph}$.

Ghosh inverse is a supply driven method unlike the more researched Leontief method, which is demand driven[10]. This is because in the Leontief method, resources input is done as the final demand of a relevant sector, whereas in the Ghosh method, resources enter as "value added" of a relevant sector. For this reason, in the Leontief method, supply is expected to grow in proportion to demand without any change in prices. This assumption does not suit many ecosystem services since they are considered limited, i.e. nature's capacity to facilitate human needs is limited. For example, sunlight per hectare of cropland cannot be increased, or the capacity to fix carbon for a certain plant species cannot be changed. Hence, the supply driven Ghosh inverse was chosen for this research. The term supply driven means that demand increases in proportion to the increase in supply. This suits limited ecosystem services better than Leontief method and allows us to study the impacts of a new value $\boldsymbol{V}_{ph}$ added to the economy.

The resources data is input to IO tables to the relevant sectors in the form of matrix $\boldsymbol{V}_{ph}$. For example, biomass power enters the table through the Electricity sector. The sector through which an ecosystem service enters the economy is called a primary user. Each sector's cumulative ecosystem service use is calculated with eq. 4. This enables investigating the sectors that are most responsible for the usage of a certain ecosystem service in terms of this cumulative use.

The dependency assessment results show the total cumulative ecosystem services use and cumulative use per sector. This allows normalization of results with regards to total cumulative use. Results are displayed in ecosystem services' original units and in shares of total use.

In our calculations, we assume that prices are homogenous and that ecosystem services distribution through the sectors of the economy is in proportion to IO transactions.

(3) Economy and ecosystem services input data

The Japanese national IO table of 2005 for 108 aggregated economy sectors provided by Ministry of Internal Affairs and Communications' Statistics Bureau[11] is used in this study. Ecosystem services input data were collected from various government and other data sources, which are displayed in Table 1. The data consist of ten different ecosystem services and supporting stocks, and flow services are further divided into provisioning and regulating services. The most recent data available was used.

(4) Compilation of dependency assessment results and knowledge database information

A spreadsheet based interface is being created to allow the user to adjust the graphical presentation of the results and knowledge database information according to their needs. The user chooses which ecosystem service they want to examine, and the extent to which they want to study dependent sectors and their potential management measures.

Table 1 Ecosystem services inputs, and supporting stocks

Ecosystem service/Stock	Unit	Source
Stock		
Cropland	ha	12)
Rangeland and pasture land	ha	12)
Urban land	ha	13)
Timberland	ha	14)
Flow		
Provisioning ES		
Agricultural products	t/y	15)
Timber	t/y	16)
Fish and related species	t/y	17) 18)
Water (Public supply)	t/y	19)
Biomass power	J/y	20)
Regulating ES		
C fixation (forest)	t/y	21) 22) 23)

Potential measures are acquired from the knowledge database and are displayed according to dependency assessment results as follows: The current state and possible conservation measures needed to secure sustainable usage of the ecosystem service studied and general best practices for sustainable usage of that resource are displayed with tool-tips and hyperlinks to further information at the user's demand. This information will be automatically linked from the knowledge database to dependency assessment results, and is displayed on demand within result figures similar to those shown in Figures 1 and 2. The sector names and ecosystem service figure titles function as hyperlinks to the knowledge database information.

3. AN EXAMPLE – AGRICULTURAL PRODUCTS AND TIMBER

Due to the extent of the results that can be achieved using this tool, an illustrative example on the dependency assessment results and knowledge database use is shown here.

(1) Dependency assessment

The dependency assessment results on agricultural products and timber provisioning for 108 sectors of the Japanese economy are shown here. Timber enters the economy through Forestry sector and agricultural products enter the economy through Cropland sector. For agricultural products, the data was acquired from the ministry of Agriculture, Forestry and Fisheries data[15] as 12.8Mt/y. Timber data was acquired from the Ministry of Agriculture, Forestry and Fisheries forest coverage data as well[16]. The annual timber provisioning is 10.1Mt/y. Agricultural products enter the economy through the Crop cultivation sector and timber enters the economy through the Forestry sector.

Fig. 1 shows the cumulative use of timber and agricultural products for top 20 user sectors obtained using eq. 4. The sectors are ordered by total dependency on these two ecosystem services. Fig. 2 shows a) the most dependent sectors on agricultural products and b) the most dependent sectors on timber. It shows normalized results for the sectors with greater than 5% cumulative use of the total use. Normalization was achieved by dividing each sector's use by total use.

Figures 1 and 2 show clearly that the primary user for each ecosystem service is the most dependent sector on those ecosystem services. The reason for this is that although intra-industry resource use is not large, the flow of ecosystem services back into the primary user sector is large due to their dependence on other sectors to continue production, as can be seen from eq. 4. Hence it can be inferred that primary sectors should carry the most responsibility when it comes to improving the management of these ecosystem services.

(2) Knowledge database use

An example of the information that is acquired from the knowledge database for agricultural products and timber use dependency assessment above is displayed here; the ecosystem services current states and conservation needs examined in this example and potential measures for primary users as well as other sectors for more sustainable use of these ecosystem services.

Note that the example of knowledge demonstrated below is general and narrative. Japanese ecosystem services specific, and sector specific knowledge for potential measures should be identified prior to tool publication.

a) Current states and conservation needs identification

Currently, agricultural land-use faces problems such as over-cultivation and land degradation, which lead to reduced crop productivity. This fact together with increased fertilizer usage results in soil acidification and hence poor land quality as explained by MA[1]. In order to use agricultural land more sustainably, increase the effectiveness of building up soil nutrients, and even increase biodiversity, the management measures explained in the following chapter are suggested.

According to MA, forests account for 50% of the world's terrestrial organic carbon stock. They are an important carbon sink and this is why slowing down forest loss and restoring forest cover are important aspects of conservation when it comes to timber use. Even though Japan has not recently suffered from forest loss, and has had stable forest coverage for over 50 years[24], returning forests to a more natural

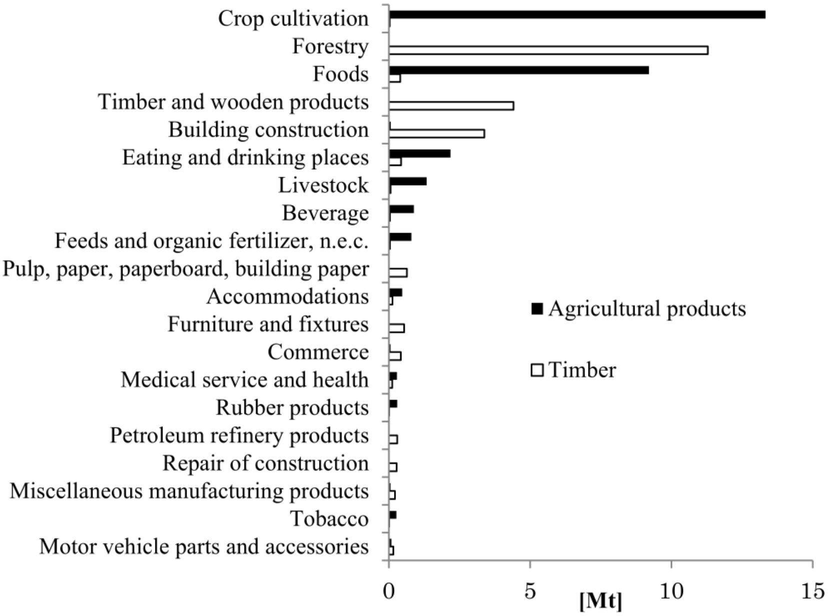

Fig. 1 Agricultural products and timber dependencies of top 20 dependent sectors

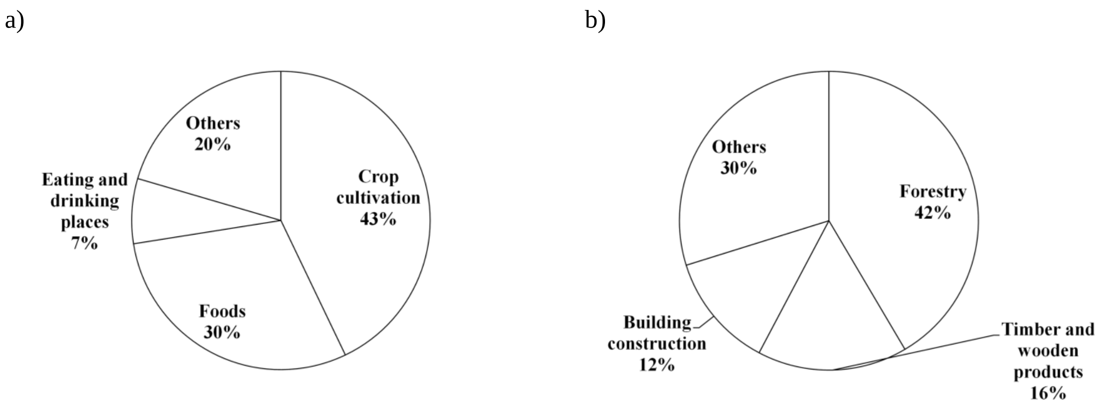

Fig. 2 Sectors with greater than 5% share of total ecosystem services use: a) agricultural products and b) timber

state is important for biodiversity. Planted forests can fix carbon faster than natural forests[1)], but carbon fixation tonnage per hectare should not compromise biodiversity as natural forests that have higher biodiversity have many qualities superior to planted forests, such as resilience to external disturbances[24)] and a wider variety of biological resources[1)].

b) Potential measures recommendation

As can be seen from Fig. 2, the most dependent sectors on each ecosystem service are the primary users. For this reason, the management measures for primary user sectors are of utmost importance.

Potential management methods for the Crop cultivation sector as a primary user of agricultural products are as follows: Crop rotation; i.e. cultivation of different crops in different years together with the introduction of agroforestry are examples of efficient measures in addressing crop land usage issues[1)] as described above. These measures increase the organic content and hence productivity of agricultural land. In addition, they facilitate reduction in use of chemical fertilizers which in turn increases the quality of agricultural land and reduces carbon emissions as production of fertilizers is a major source for carbon emissions for agricultural practices[25)].

Other sectors, namely indirect users of agricultural products, such as the ones shown in Fig. 2 a) can improve their management of this ecosystem service by demanding validations on the sustainability of primary users. One such method could be purchasing agricultural products labeled as Japan Agricultural Standard (JAS) organic agricultural products[26)].

In the case of timber, as can be seen from Fig. 2 b), Forestry as a primary user is clearly the largest consumer of timber from forest ecosystems. As stated above, forest loss, and in the case of Japan, biodiversity loss due to planted homogenous forests are some of the main issues for forests. A recognized method for primary users to show the sustainability of their forest management is to gain Forest Stewardship Council (FSC) certification for their products[27].

All other sectors using forestry products should demand sustainably managed forestry products by for example buying FSC certified products. This is true for the sectors most dependent on forestry products, such as Timber and wooden products in Fig. 2b as well as for end-users.

4. CONCLUSION

This paper has introduced a method of assessing ecosystem services dependencies for sectors of the economy and combining potential sustainable management measures with the assessment results. The research on an ecosystem services dependencies assessment tool and on ways to incorporate more sustainable ecosystem services management practices into the tool is important due to the fact that without tools to assess private sector's relationships to ecosystem services, policies concerning sustainable ecosystem use are hard to implement. Consequently, the largest movement within the ecosystem services assessment field currently relates to connecting science to policies. To this end, tools for assessing dependencies on ecosystem services and the ability to improve the connections between industry and nature need to be developed in parallel with policies. This research aims to do exactly this by providing the private sector with an effective decision making tool for sustainable use of ecosystem services.

Further research propositions include improving and expanding the knowledge database to include a more comprehensive collection of ecosystem services, as well as their current states and conservation needs, and management methods. This will be done exclusively for Japanese ecosystems where possible. In addition, improving the spreadsheet tool introduced in this research and developing a web-based tool is considered necessary. The latter proposition will concentrate on an intuitive user interface and easy understanding of nature-industry interactions for various stakeholders.

Furthermore, methods for comparing the extent of the dependencies on a variety of ecosystem services for a single sector should be examined. This would require unit aggregations in order to make resources and ecosystem services with different original units comparable. Once aggregated, the ecosystem services most depended upon could be examined for each sector and through using the knowledge database developed in this research, management of ecosystem services most relied on could be improved. For this to be possible, we encourage further discussion on aggregation methods and suitable aggregation units.

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