ONTOLOGY DEVELOPMENT FOR ECOSYSTEM SERVICES

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ABSTRACT

This study developed ES Ontology with purpose to cover the interoperability between classification frameworks and provide common understanding in ES concepts. The ES Ontology was developed using the Generic Ontology Development and top-down approach called as ESOnto. The study produced the conceptual design of ES which cover MA, TEEB, and CICES V5.1 classification frameworks, its interoperability and ES assessment and mapping. The ESOnto is visualised in Living Textbook and also available in the turtle language. It was evaluated using the user-based evaluation and task-based evaluation to check the usability, clarity and the coverage of the ontology.

Keywords: Ontology, Ecosystem Services, ESOnto, Task-based evaluation, User-based evaluation

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1. INTRODUCTION

1.1. Motivation and Problem Statement

Nature and human are not separable; nature plays an essential role in human life by providing basic needs such as air, water, food, shelter, recreational areas, warmth, and peace of mind; while human utilise, manage, and modify it to fit the society needs. As the human population grows, human activity induces problems in biophysical environments and environmental degradation such as global warming, ocean acidification (Wuebbles et al., 2017) and biodiversity loss (Ceballos et al., 2015; Ceballos, Ehrlich, & Dirzo, 2017; Pimm et al., 2014). Ecosystem services (ES) provide an analytical framework identifying the way nature contributes to human society while assessing the interaction among these two systems. The concept of ES was introduced in 1981, and since then, there has been an exponential rise of research and literature about it. The most recent definition of ES was defined in the Common International Classification of Ecosystem Services (CICES) 5.1 framework (2018) as "the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them" adapted from Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Based on the definition, ES is the intersection between social fields (human well-being) and environmental fields (ecosystem) which means "in the absence of people there are no services, and people often modify ecosystems to enhance the production of specific services"(Bennett, Peterson, & Gordon, 2009).

The concept of ES is evolving since Ehrlich & Ehrlich in 1981 initially defined ecosystem services and continued by recent activities and concept such as Millennium Ecosystem Assessment (MEA, 2005), The Economics of Ecosystem and Biodiversity (TEEB, 2008) and CICES V5.1 (2018) which add the complexity of ES. MEA provides a classification of ES as provisioning, regulating, cultural and supporting services (MA, 2005), TEEB has four classes like the MEA as provisioning, regulating, habitat, and cultural and amenity services (Fisher et al., 2010). TEEB updated the MEA by adding the economic value of the services. IPBES comes with broader concept of ES as values of nature, nature contribution to people and good quality of life (Díaz et al., 2015) and then CICES V5.1 which classification constructed based on MEA and TEEB but built for accounting. CICES V5.1 classified the ES into provisioning, regulating and cultural services and has five levels of hierarchy (Haines-Young & Potschin-Young, 2018). All these initiatives led to the generation to a series of different classification systems, terminologies and conceptual and methodological frameworks which can host a plurality of views.

Significant research has been carried out to quantify and assess the value of ES in order to understand how human activities change the ecosystem, how these changes affect the ES and impact of ES changes into human well-being (Milner-Gulland, 2012). According to that, hundreds of tools and dataset have been built in the last decade, from a simple excel sheet model (e.g., Ecosystem Service Assessment Tool/ESAT[1]) to a sophisticated software package (e.g., InVEST[2]). Every tool has its aim and function to support an ES quantification and assessment. Some are designed for assessment guideline such as (e.g., ValuES[3]), and the others are used to calculate the ES supply and ES value for decisions making (e.g., NEAT Tree[4], Co$ting Nature[5], InVEST, MESH[6]). Some of them are built for specific geographic

[1] http://www.safhandbook.net/assessment/visualize-consequences
[2] https://naturalcapitalproject.stanford.edu/invest
[3] http://www.aboutvalues.net/
[4] http://neat.ecosystemsknowledge.net/
[5] http://www.policysupport.org/costingnature
[6] http://www.naturalcapitalproject.org/mesh/

location (e.g. Letsmap do Brazil[7]) while others can be applied to any location in the world (e.g., MIMES[8], InVEST, ARIES[9]). Different approaches in methods, models and terminologies were used to build such systems (Bagstad, Semmens, Waage, & Winthrop, 2013; Drakou et al., 2015). This plurality of views and typologies accompanied by the lack of unified ontology for ecosystem services lead to a plurality of tools and quantification methods, non-interoperable dataset or tools, generating results that are often not comparable. Polasky, Tallis, & Reyers (2015) point out that it gives confusion to the practitioner and most of decision-makers do not have technical expertise to sort out these differences and decide the best approach to use.

At the same time, the ES community uses maps to identify relationships between different ecosystem services, ecosystem services and biodiversity, and to support planning and management decisions. Furthermore, it is used as a communication tool with stakeholders, visualise the locations of where valuable ecosystem services are produced and used. It also help to explain the relevance of ecosystem services to the public in their region (The Biodiversity Information System for Europe (BISE), 2018). ES mapping also delivers a clear explanation of ES and spatial planning (Galler, Hermes, Neuendorf, von Haaren, & Lovett, 2016). Although ES mapping offers excellent support, there are several bottlenecks encountered in the use of the maps for decision making and planning as described by Palomo et al. (2018) such as mapmaker and map user communication due to the lack of requirement assessments and nomenclatures and ontologies related to ES classification and terminology.

However, the standards of ecosystem service terminologies, methodologies and maps are not yet agreed upon. The differences in terminology need to be solved to make the practitioner and decision maker as the ES users understand what they got and how they can use the ES information. Moreover, in the absence of standard tools and terminology, the user of ES cannot combine information from different fields and difficult to understand the ES. Because of the scientific information is not interoperable, it is hard to deliver and provide better decision/policy to manage the environment and its services.

Here the ontology technology can take roles to bridge those differences and make it interoperable. Ontological representation of domain knowledge can provide a common understanding to solve the heterogeneity of knowledge management (Mankovskii et al., 2009a). It also can be used for integrating databases, provides interoperability between systems and specifies the interface to independent and knowledge-based services (Mankovskii et al., 2009b).

Martin-Clouaire (2018) defines the specification of an ontology as "a form of definitions of a representational vocabulary (classes, relations, and so forth) that provide meanings for the terms and formal constraints on their coherent use". Yew, Hassan, Zainal Abidin, Arshad, & Shariff (2015) mention the type of ontology as top-level/ upper ontology (foundation ontology), domain ontology (ontology for specific field), application ontology (terms and relation to support specific application) and presentation ontology (generated from domain ontology). A domain ontology specifies the concepts, relationships, and other distinction of a model in specific fields. The significant role of the domain ontology is to provide a standard or model of the domain and use it to communicate, study or solve problems.

This domain ontology provides the vocabularies and relation to build linked data. Linked data is "data published on the Web in such a way that it is machine-readable, its meaning is explicitly defined, it is linked to other external data sets, and can be linked to from external data sets"(Bizer, Heath, & Berners-Lee, 2009). It relies on Uniform Resource Identifier (URI) and Hypertext Transfer Protocol HTTP technology. The linked data relates several data in several web pages based on the URI which can make data can be discovered on linked sources based on semantics; ordered on suitability based on the context of use; and assembled into coherent, working scientific workflows (Villa, Balbi, Athanasiadis, &

[7] https://www.ufz.de/iwas-sachsen/index.php?en=19650
[8] http://www.afordablefutures.com/orientation-to-what-we-do/services/mimes
[9] http://aries.integratedmodelling.org/

Caracciolo, 2017). The interrelated dataset in the linked data can represent the interoperability between dataset in several web pages which can be held by creating the ontology as the fundamental component. There has been an ontological development in other domains such as the Gene Ontology in the medical domain which is used to standardise the representation of genes across species in different databases and vocabularies (Scheuermann, Ceusters, & Smith, 2009). The OBOE project assembles the semantics of observation and measurement in ecology (Madin, Bowers, Schildhauer, & Jones, 2008) and ENVO which is an ontology for life science disciplines (Buttigieg, Morrison, Smith, Mungall, & Lewis, 2013). Learning from the success of other domains' ontologies; this study developed a domain ontology for ES to bridge different standards of terminologies and methodologies in ES and also to communicate ES information.

1.2. Research Identification

1.2.1. Research Objectives

The main objective of this research is to develop an ontology for the domain of ES, in order to facilitate the communication of ES knowledge to its end-user and to facilitate interoperability between ES classification frameworks and information based on existing tools, datasets and models. This research will focus more on the geospatial aspect of ES and will consider the tools and dataset catalogue registered in the 'Bon-in-a-Box' toolbox[10] of GEO BON. The main objective is divided into three sub-objectives as follows to complete this study:

1. To explore and extract the knowledge of ES including the input and the output of ES tools, the classification method, the framework, and the terminologies used in the different tools and datasets.
2. To design and develop the domain ontology of ES based on the knowledge extracted from the ES tools, datasets and existing ES classification system.
3. To test and implement the domain ontology of ES against use cases which focus on geospatial aspect of the ontology.

1.2.2. Research Questions

1. To explore and extract the knowledge of ES including the input and the output of ES tools, the classification method, the framework, and the terminologies used in the different tools and datasets.
    a. What is the input, the process, and the output of ES tools and what is the type and format of the datasets available in the ES domain?
    b. What is the classification method, framework and terminologies used behind commonly used tool and dataset of ES?
    c. What are the relations between the input, the output, the classification, the framework and terminologies in the available dataset in the ES domain?
2. To design and develop the domain ontology of ES based on the knowledge extracted from the ES tools, datasets and existing ES classification system.
    a. What is the purpose and coverage of the ES Ontology?
    b. What are the classes and properties of the ES Ontology based on the knowledge extracted from the ES tools and datasets?
    c. How will the classes and properties be related to each other?
    d. What are the rules and constraints in the ES domain knowledge and how can they be implemented?
3. To test and implement the domain ontology of ES against use cases which focus on the geospatial aspect of the ontology.

[10] https://boninabox.GEO BON.org/

a. How to test the quality of ES Ontology?
b. Which relevant queries can be applied in ES Ontology to solve the use case?

1.3. Innovation

Although some first attempts were made to build ontologies for ES, these are rarely used or are designed to support the functionality of one specific tool or software (Villa et al., 2017; Werf et al., 2009; Martin-Clouaire, 2018). This study designed and developed a new domain ontology for ES called as ESOnto which covers interoperability between ES classification frameworks, ES assessment and quantification. The ES classification frameworks include MA, TEEB and CICES V5.1 and the ES assessment and quantification focus on the factor that affects the process. This study was taking account the role of the existing ES tools and data catalogues in 'Bon-in-a-Box', ES literature and consider the existing ontologies in order to ensure a broader use and applicability. The ES domain ontology developed in this study can be used for communicating the ES knowledge and interoperability between ES classification frameworks, standard of terminology and answering the ES competence questions.

1.4. Thesis Structure

The general structure and the content of the thesis are as follows:
Chapter 1 provides an introduction about the motivation of this study, the research objectives, research questions and the thesis structure.
Chapter 2 provides related works and knowledge about ecosystem services and ontology.
Chapter 3 provides information about the methodology used to build the ES Ontology. The methodology used the Generic Ontology Development which consists of the pre-development phase, development and post-development phase (Rajpathak & Chougule, 2011). The pre-development phase covers the process of defining the source of ES knowledge, the purpose and the coverage of the ES Ontology and extraction of information used to develop the ontology. The development phase covers the ES Ontology design, formalisation, visualisation and evaluation. The post-development phase covers the documentation of the ES Ontology.
Chapter 4 provides the result of the information extraction, ontology design, formalised ontology, its visualisation and the result of the ontology evaluation based on the user-based evaluation and task-based-evaluation and documentation.
Chapter 5 provides the discussion, conclusion and recommendation based on this study.
Appendix A provides the documentation of the ESOnto consist of the concepts and its definition and the relationships between concepts.
Appendix B provides the turtle files of the formalisation results
Appendix C provides the query results of the competence questions.
Appendix D provides the interoperability between MA, TEEB and CICES V5.1 classification framework.
Appendix E List of Bon-in-a-Box tools.

2. ECOSYSTEM SERVICES AND ONTOLOGY

This chapter provides information about existing related works about ecosystem services and ontology. Section 2.1 explains the component of ecosystem service, the interoperability problem in ES classification and terminology and the existing ontologies. Section 2.2 explains about existing classification frameworks and related works on ES assessment and mapping. Section 2.3 explains the ES data and tools. Section 2.3 what ontology is and its advantage. Section 2.5 explains on related works on the method of ontology development and evaluation.

2.1. Ecosystem Services and Relevant Ontologies

Ecosystem services are part of a social-ecological system due to the interactions between human well-being and ecosystem. The social-ecological system consists of social component or society or human well-being, the ecological component or ecosystem, ecosystem services and the driver of changes (Bennett et al., 2009). Gardner et al. (2013) described the interaction between the social component and the ecological component as ecosystem services and these interactions were affected by the driver of changes.

The definition of ecosystem service as interaction between human and ecosystem has been the subject of discussion, and it is essential because it will be the first point to communicate the concept of ecosystem services and used as an approach to describe the classification system /framework of ecosystem services (Fisher, Turner, & Morling, 2009). There are research and project which try to gather the terminology used in the ecosystem services research and practice. Wallace (2007) developed a classification system for ecosystem services assessment and compiled the terminology and definition used in the research. The European project of Operationalisation of Natural Capital and Ecosystem Services (OpenNESS) created a glossary which covers ES terminology with terminologies from MA, TEEB, the UK NEA, and Rubicode as the starting point (Potschin, Haines-Young, Heink, & Jax, 2014). La Notte et al. (2017) compiled and compared the definition of ecosystem services, ecosystem function and ecosystem process from several papers which proves that every paper has their definition to facilitate the ecosystem service accounting process. For example, Fisher et al. (2009) did not differentiate ecosystem goods from ecosystem services and did not define the definition of biophysical structure, ecosystem process, ecosystem function explicitly. Different from Fisher et al., Boyd and Banzhaf (2007) defined that the biophysical structure is equal to the ecosystem process, and ecosystem function is equal to ecosystem services. The different use and understanding about the terminology for different application and purpose create a bottleneck in the ES mapping process like stated by Palomo et al. (2018) as shown in Figure 1. They also mentioned that the nomenclature and ontology bottlenecks in ecosystem services classification and terminology were due to the lack of interoperability between the ES classification and the context of ES (the framework and the mapping context) and that the ES classification is one of many common challenges faced in ES mapping.

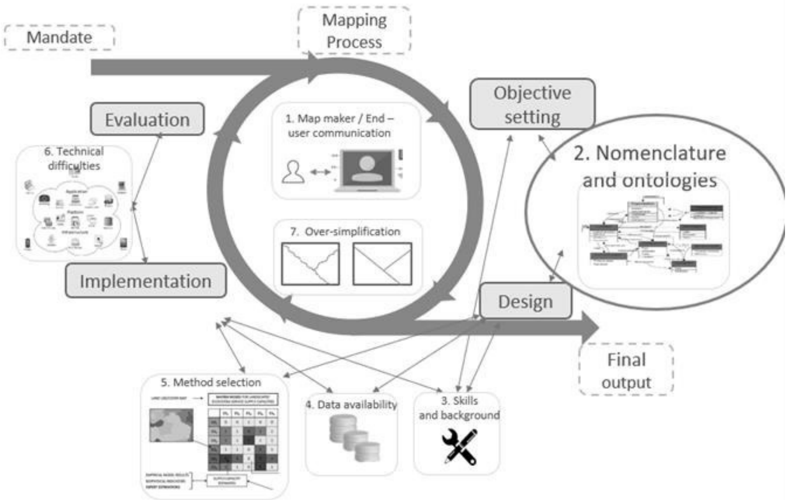


Figure 1 Bottlenecks in ecosystem services mapping. Source: (Palomo et al., 2018)

Moreover, there were different ecosystem service frameworks for different applications such as conceptual framework for EU wide ecosystem assessment (MAES, 2013) and MA conceptual frameworks which relate the ecosystem services with the constituents of well-being consist of security, basic material for good life, health, good social relations and freedom of choice and action (Capistrano, Samper K., Lee, & Raudsepp-Hearne, 2005). The other framework was Cascade framework which describes the relationship between the biodiversity, ecosystem function, ecosystem service and the benefits (Haines-Young & Potschin, 2010). Braat & de Groot (2012) improves the cascade frameworks by differentiating the goods and benefits. UK National Ecosystem Assessment (2009) has different frameworks which related the ES as part of the Ecosystem with goods, human well-being and drivers of change. These frameworks represent the ways people interpreted the ES which lead to different methods of assessment and mapping. The differences of assessment and mapping methods will produce different dataset and ES value.

Several studies have been conducted to solve the problem and to provide interoperability between dataset, models or software used in the ES domain. David Barton et al. (2016) developed OPPLA based on Bayesian Belief Network (BBN) to support the ES method selection. The BBN was structured as a classification model and was used as a model selection support or model description mode. The conceptual model covered and used term and hierarchy of the ES classification, scale, data availability, ES indicators and value which can be used as concepts in the ontology development for ES

Besides OPPLA, ARIES deploys the semantic web technology in its system using the k.IM language and k.Lab platform. It focuses on beneficiaries, probabilistic analysis, and spatiotemporal dynamics of flows and scale based on MEA Narrative (Villa et al., 2014). Its coverage and scale remain small only covering the information generated by the ARIES system (Villa et al., 2017). Despite the significant amount of effort put in the development of this language, for the time being, it is only used within this software. It does not cover the other classification of ES such as the TEEB, CICES and IPBES.

On the other hand, Martin-Clouaire (2018) designed an ontology for a part of ES that focuses on agroecosystem services. He considers the social-ecological system of agroecosystem services which consist of the dataset, the process, the stakeholder and their relation to the design of the ontology. He suggested considering that ontology enrichment will be needed as the experience and knowledge of ES and social-ecological systems grows.

As the part of social-ecological fields, there were related works such as the Socio-Ecological Research and Observation Ontology (SERONTO) and social-ecological system (SESs) ontology. As a core ontology, SERONTO was built by a Long-Term Biodiversity, Ecosystem, and Awareness Research Network (ALTER-Net) to integrate data from distributed data sources stored and collected at different locations within the European Union (Werf et al., 2009). SERONTO is an ontology about observations with its theoretical basis lying in statistical methodology which contains terms and concepts for describing and analysing 'raw' data from diverse origin. Still, due to it being developed using fundamental relationships among the elements of the system, its use in several applications has not yet been documented. Besides SERONTO, Frey & Cox in (2015) demonstrate the practical use of ontologies by transforming the SESs framework into an ontology.

Recently, Schmidt & Seppelt (2018) developed a systematic taxonomy of indicators representing the information demand on ES in different areas of governance and its application context in the decision making from existing online ES databases. They found that there is overlap in information supply and demand between databases, but it is challenging to discover and process due to limited interoperability of databases and missing semantic links of various terms and concepts in databases. They suggest adding knowledge representation systems such as ontologies to introduce logical inference rules as a prerequisite for automated reasoning and ease of information access.

Moreover, there are other ontologies developed to describe parts of what structures the ES concept covering the ecological or social field. The ontologies related to the environmental field that need to be considered on this research are OBOE project which assembles the semantics of observation and measurement in ecology (Madin et al., 2008), and ENVO which is an ontology for life science disciplines (Buttigieg et al., 2013). FOAF is an ontology describing the social system and in particular a person, their activities and their relationships with other people and objects that can be used in structured data ("The FOAF Project," 2015). These ontologies are an essential part of the way to build the ES Ontology. This study can utilise it as a reference so the ES Ontology will not be built from scratch.

2.2. Ecosystem Services Classification Systems

There were several studies try to group the ES serving different purposes, such as done by Costanza et al., (1997), MA (2005), Wallace (2007), TEEB (2010), Final Ecosystem Goods and Services Classification System or FEGS-CS (Boyd & Banzhaf, 2007), CICES V5.1 (Roy Haines-Young & Potschin, 2018). MA was the first to classify the ES into four categories: provisioning services, regulating services, supporting services and cultural services. TEEB followed this categorisation except for the supporting services was transform into the habitat services. FEGS-CS focused on the benefits and beneficiaries of ES and had a very different way to classify the ES. CICES V5.1 which become popular recently had the same classification with TEEB but merge the supporting and habitat services into regulating and maintenance services. MA and FEGS have different frameworks with TEEB and CICES V5.1 which using the cascade frameworks. However, the TEEB classification framework was adapted from MA and CICES V5.1 also adapted from IPBES and TEEB, so they were related one to another. Because of that, this study will cover the MA, TEEB and CICES V5.1 only.

The classification frameworks will affect the ES assessment and mapping process. Assess ES means to measure the state, quantity or value of the ES. ES is a function of complex interaction between the environment and the species, the variation of use and utilisation patterns by the beneficiaries (Fisher et al., 2009). Guidance will be needed to be able to assess and maps this complex interaction. These demands were recognised by Bagstad et al. (2013). Since then some guidance documents has been developed such as Best policy Guidance for the Integration of Biodiversity and Ecosystem Services in Standards (Secretariat of the CBD & UNEP-WCMC, 2012), the Guidance Manual for Assessing Ecosystem Services at Natura 2000 sites (McCarthy & Morling, 2014), ValuES (González-Jiménez et al., 2018) and Guidance in developing ES indicator (Brown et al., 2014). These guidance documents helped to understand the process of ES assessment.

The ES mapping research has grown and used to analyse the spatial distribution of ES at local, regional and global spatial scale (Maes et al., 2012). Those research mapping mentioned by Maes et al. (2012) were covered different aspect of ES such as the biodiversity, analyse the relationship between ecosystem services and others. Besides that, they also mentioned some gaps in the mapping of ES such as the availability of the data and consistent mapping approach. The consistent mapping approach problem can be solved if the map maker has the same understanding of ES with the ES user.

2.3. Data Source for Ecosystem Service Ontology Development.

Since the ES concept emerged, the amount of research and literature about it are increasing. Together with the increase of research there are also increase of the dataset and tools developed to analyse ES. GEO BON is Group on Earth Observations of Biodiversity Observation Network. GEO BON has developed the 'Bon-in-a-Box' (Biodiversity Observation Network in a Box) which is an online, customizable and continually updated portal of toolkit for biodiversity observations (Bon-in-a-Box, 2016). It delivers access to the latest biodiversity observation design, data management, analysis and reporting tools including the ES tools and dataset. Bon-in-a-Box list of tools was the main input for this research.

2.4. Ontological Concepts

The semantic web will enable people and computers to understand data on the web more efficiently. The World Wide Web Consortium (W3C) built technology stack for developing semantic web which enables people to build repositories on the web, build vocabularies and define rules for manage data on the web (Semantic Web - W3C, 2008). The layer of the semantic web technology stack is shown in Figure 2. The ontology is a part of it which intended to capture the knowledge of domain by defining vocabularies and the relationships among them(Ontologies - W3C, 2008).

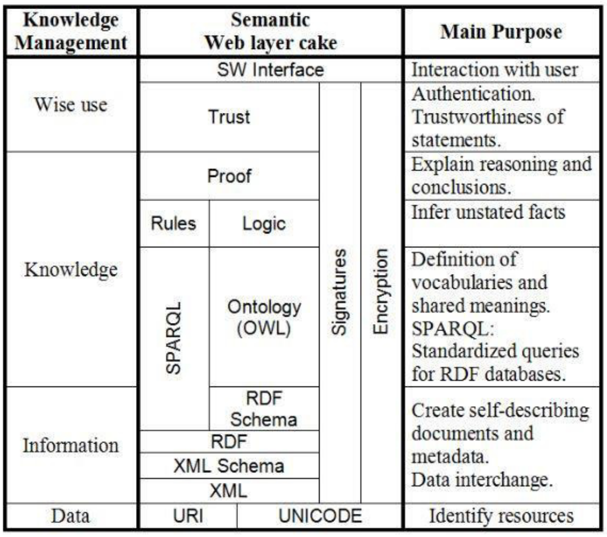


Figure 2 Semantic web building block. Source: adapted from (Koivunen & Miller, 2001)

Ontology enables sharing a common understanding of knowledge, enables reuse of domain knowledge, make domain assumption explicit, separates domain knowledge from operational knowledge and to analyse domain knowledge (Noy & McGuinness, 2001). Durán-Muñoz & Bautista-Zambrana (2017) mention that ontology has advantages like: it enables moving from one concept to another concept in the ontology structure; it has many entry points which can be traced and related to all of the associated concepts; Ontology connection enable discovery without requiring prior knowledge of the domain; it has the ability to represent structure, semi-structured and unstructured information; ontology also can match the concept of same idea (synonym).

Following is an example of the advantages of ontology about two databases that provide information about family, its members and address. The database A defines **family has member person** and defines the **address** for every person. The database B defines **family has member person** and lives in the same **address**. Ontology can integrate this information since ontology can relate several concepts shows in Figure 3 and give a common understanding about family, person and address.

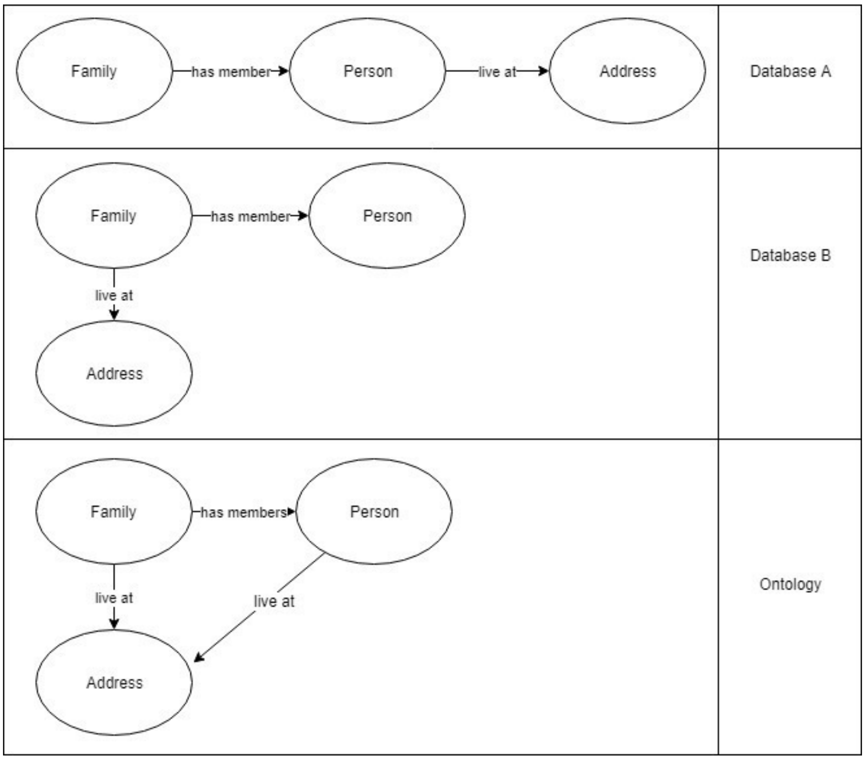


Figure 3 Comparison of conceptual model of database and Ontology

There were several applications which utilise semantic web and ontology behind it. For example, Wikipedia[11] with its semantic wiki, Google with Google Knowledge Graph[12] and Skyscanner[13] web application. In geospatial worlds, there is Open Street Map (OSM) with the OSMOnto (Kutz, Codescu, Couto Vale, & Mossakowski, 2014). Besides that, there were also some research about the use of ontology to model human navigator behaviour (Lamprecht et al., 2015) and the use of it for Internet of Things (Abreu, Velasquez, Pinto, Curado, & Monteiro, 2017; Hitz, Kessel, & Pfisterer, 2017; Patel, Pathak, Teixeira, & Issarny, 2011).

2.5. Methodological Framework for Ontology Development

There is some factors need to be considered as mention by Yew et al. (2015) to develop an ontology such as the ontology environment, the goal, the functional perspective, and the hierarchical perspective of the ontology. Fernández-López & Gómez-Pérez (2002) mentioned and compared six methodologies to develop ontology based on the IEEE standard (IEEE, 2006) proposed by the methodologies. It contains Cyc(D.B & R.V, 1990), TOVE (Grüninger & Fox, 1995), KACTUS (Kuzemin, Fastova, & Yanchevsky, 2014), METHONTOLOGY (Fernandez, Gomez-Perez, & Juristo, 1997), and Methodology for re-engineering ontologies (López, Pérez, & Amaya, 2000). Neither of them proposed pre-development processes and started with the development processes. Only METHONTOLOGY and Methodology for re-engineering ontologies which provides post-development. In 2011, Rajpathak & Chougule delivered Generic Ontology Development methodology which covers the pre-development, development and post-development processes as shown in Figure 4. The pre-development phase covers the steps to gather the specification document and to define the data source to build the ontology and knowledge acquisition. Then it is continued by creating the semantic structure (design ontology), ontology formalisation and ontology validation which is components of the development phase. In the post-development phase, the documentation of the ontology is prepared, and the ontology is maintained and updated if needed.

[11] https://www.wikipedia.org/
[12] https://googleblog.blogspot.com/2012/05/introducing-knowledge-graph-things-not.html
[13] skyscanner.net

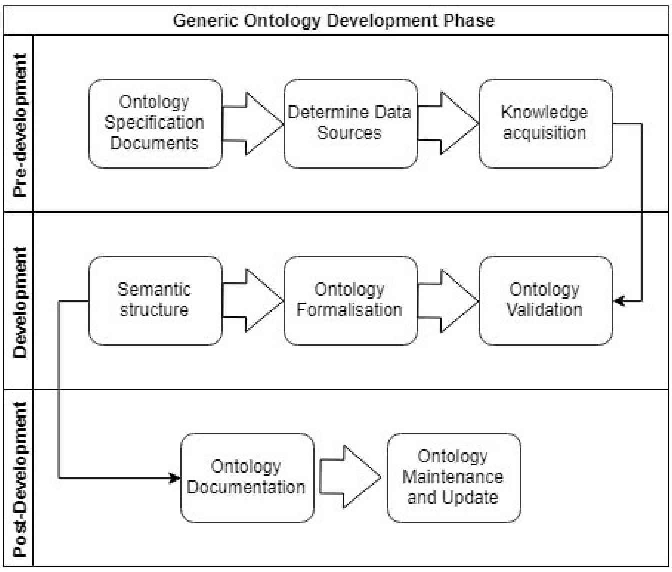


Figure 4 Generic Ontology Development phase. Source: adapted from (Rajpathak & Chougule,2011)

Beside the development methodology, in the design process there are three kinds of approaches which should be considered (Uschold & Gruninger, 1996):

1. Middle-out approach: Start the identification from the most relevant to the most abstract and to the most concrete concept. It is claimed to be more stable and more comfortable.
2. Top-down approach: Identify the abstract concepts first organised in a taxonomy.
3. Bottom-up approach: Identification starts with subclasses which are grouped into global classes.

A top-down approach enables to control the level of detail, but there is a possibility to have a less stable ontology. It starts with the general concept and builds the structure by specialisation (M. El Ghosh, H. Naja, H. Abdulrab, 2016). Therefore, the Generic Ontology Development and the top-down approach were used in this study.

3. DEVELOPMENT PROCESS OF ECOSYSTEM SERVICES ONTOLOGY

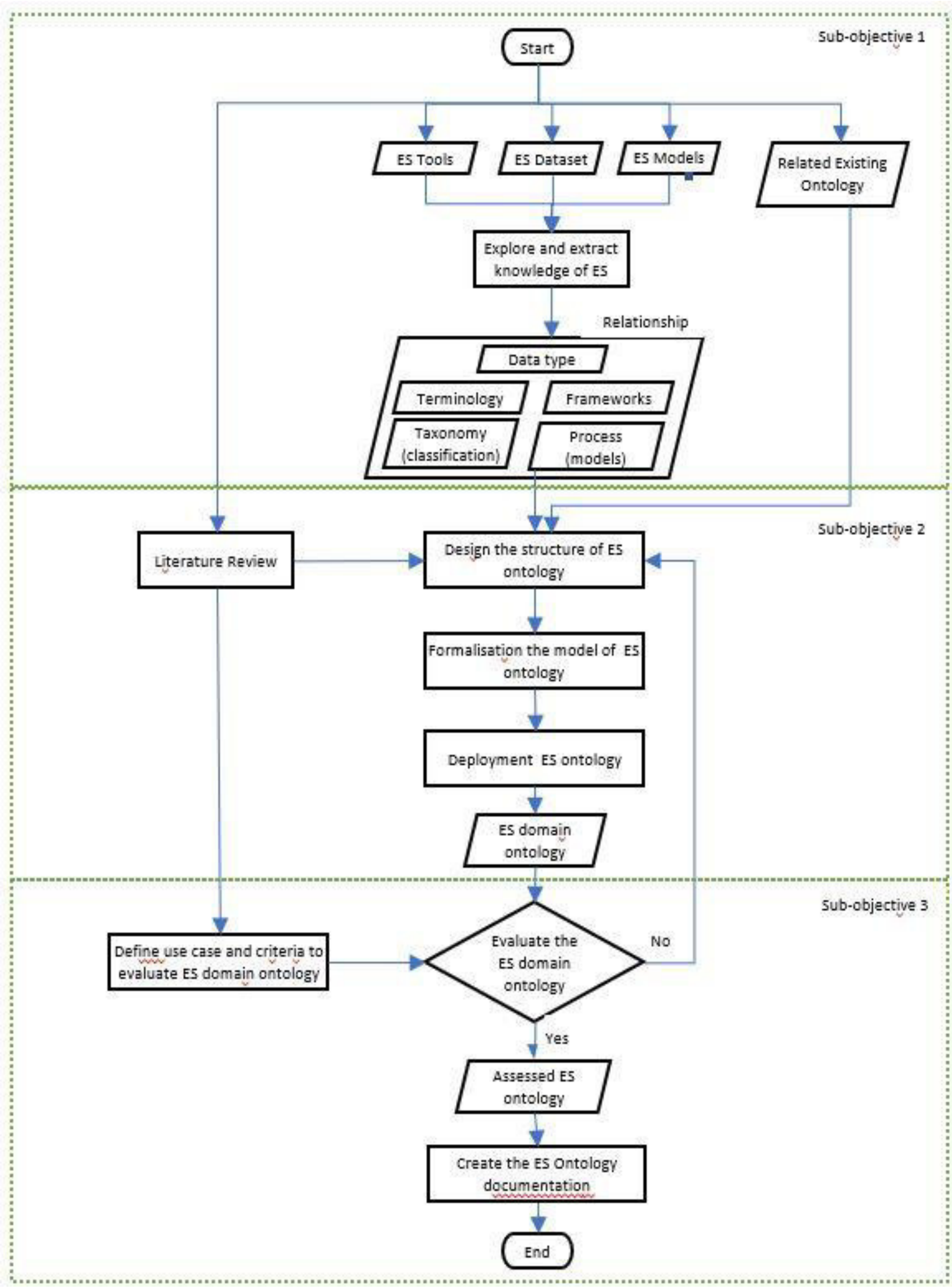


Figure 5 Workflow of ontology development for ecosystem services

The development of ES Ontology workflow shown in Figure 5 was adapted from the Generic Ontology Development method mentioned in Section 2.5. It consists of three sections based on the proposed sub-objectives. The first is to explore and extract the knowledge behind the tools and data catalogues of ES which covers the exploration and knowledge extraction from ES tools, dataset, models and related existing ontology (Section 3.1). The second is to design and develop the domain ontology of ES in Section which covers the process of defining the scope of the ontology, the ontology design, ontology formalisation and ontology deployment(Section 3.2), and the last section is to evaluate the developed domain ontology of ES which will cover the evaluation and documentation of ES Ontology (Section 3.2).

3.1. Knowledge Extraction of Ecosystem Services

The explore and extract knowledge of ecosystem service was started with defining the source of knowledge. In this study, we use the top-down strategy to build the ecosystem service ontology which starts from general concepts and build the structure by specialisation. The top-down approach also means using definition and part of existing ontologies (M. El Ghosh, H. Naja, H. Abdulrab, 2016) as mentioned in Section 2.5 and shown in Figure 6. Referring to the top-down strategy, the characteristic of the knowledge source should be documents which captured general information about ES such as standard documents, guidelines or books about ES, upper ontology, or domain ontology which related to ES. In this case, the Bon-in-a-Box provides a list of tools which consists of more than 300 tools and literature which also need to be selected. After that, the selected documents/literature, existing ontology and tools were explored, and the knowledge or information was extracted.

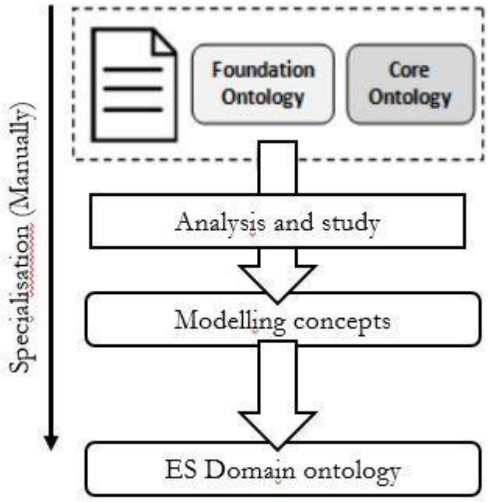


Figure 6 Top-down strategy. Source: (M. El Ghosh, H. Naja, H. Abdulrab, 2016)

The exploration of the tools was done by visiting the website and explore the user-manual or guideline documents of the tools. The information about the input, process and output of ecosystem service analysis were extracted. Then the information about classification, its hierarchy and the frameworks were mined from the standard documents/guidelines/books of ES. After that, the term gathered from the exploration process was used as the keywords to search the relationship with the existing ontologies. The definition and relation between the terms gathered from the extraction process also were explored and selected.

It is possible for a term in the ES domain to have several definitions depends on the applications and projects (La Notte et al., 2017). To select the most appropriate definition of a term, the definitions were compared and the best definition was chosen which describes the term with other concepts related to it or selected the most recent definitions.

3.2. Development Process of Ecosystem Services Ontology

There were four steps in the design and development of ecosystem services ontology. The first was to define the specification of the ES Ontology based on the literature review. This information will provide the boundary of the developed ontology. The second was to design the structure of the ontology and continued by ontology formalisation, and the last was ontology deployment.

3.2.1. Specification of ES Ontology

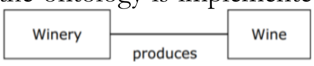
In this step, the ontology specification was defined. The specification provides the purpose of ontology development, the scope to see how many application domains can be formalised, the competency, the formality and the granularity of the ontology (Rajpathak & Chougule, 2011). This information was gathered from literature which mentioned the needs of ontology for ES domain. The competency of an ontology determined the types of algorithms can be developed by using the semantics included in an ontology. The formality of concepts and relations were determined by the formality and granularity of the ontology.

The granularity of ontology discourses different levels of an entity specification in the real world where leads to the coarse and fine-grained ontologies. Coarse ontology or high-level ontology represent general information and more shareable while a fine-grained ontology or low-level ontology has very detailed information, needs a very expressive language and should be used off-line. The low-level ontology should be created based on high-level ontologies (Fonseca, Egenhofer, Davis, & Câmara, 2002).

Based on dependence to the specific task, the ontologies are classified into four groups (Guarino, 1997):

- Top-level ontologies describe very general concepts such as BFO[14],Cyc[15], and Wordnet[16].
- Domain ontologies describe the vocabulary related to a generic domain such as ENVO[17] and OBO[18].
- Task ontologies describe a task or activity.
- Application ontologies describe concepts that depend on both a particular domain and a task, and usually a specialization of them.

Berners-Lee et al. (2006) agreed that ontology can be formal as a mathematical theory or informal as a natural language description of the world and the formality makes the ontology machine-readable and allows deeper reasoning over web resources. There were different levels of formality (Ojo & Janowski, 2005):

- Strongly informal: expressed in natural language (e.g. Wine is a product of winery).
- Semi-informal: the ontology is expressed using restricted and structured form of natural language in order to reduce ambiguity and to improve the clarity (e.g. Winery **produces** wine).
- Semi-formal: the ontology is implemented in an artificial and well-defined language. Following is the example: 

- Rigorously formal: the ontology is implemented using a semantically defined language that can represent logical properties of world elements and of their relationships. Below is the example:

```
<a:owl_objectproperty rdf:about="produces" rdfs:label="produces">
  <rdfs:range rdf:resource="Winery"/>
  <rdfs:domain rdf:resource="Wine"/>
</a:owl_objectproperty>
```

The ESOnto was built as a domain ontology and represented in the level of formality as semi-formal and rigorously.

14 http://basic-formal-ontology.org/
15 https://www.cyc.com/
16 http://wordnetweb.princeton.edu/perl/webwn
17 http://purl.obolibrary.org/obo/envo.owl
18 http://www.obofoundry.org/

3.2.2. Structure of the Ontology

The design of the ontology structure covered the process of creating the ontology components based on the extracted information from the exploration and extraction knowledge of ES. Lord (2010) and M. El Ghosh, H. Naja, H. Abdulrab (2016) mentioned that the components of ontology are the concept, relationship, individual or instance. The concept also called as class or type. A concept is the main component of ontology which represents a group of the individual which have the same characteristic. The individual or instance is the base unit or ground level object of ontology, and it can be a concrete object or abstract objects. The relationship represents interaction among individuals or concepts which also called as properties. The example in Figure 7 shows **Students** and **Course** as a concept, the **photogrammetry**, **remote sensing**, **spatial database** and **programming** are an individual and part of course concepts. **Ammy** and **Smith** are also individuals which parts of the student concept. The arrow line that connected circles (concepts and individuals) is called as relationships. In this example there are two relationships **is a** and **take.**

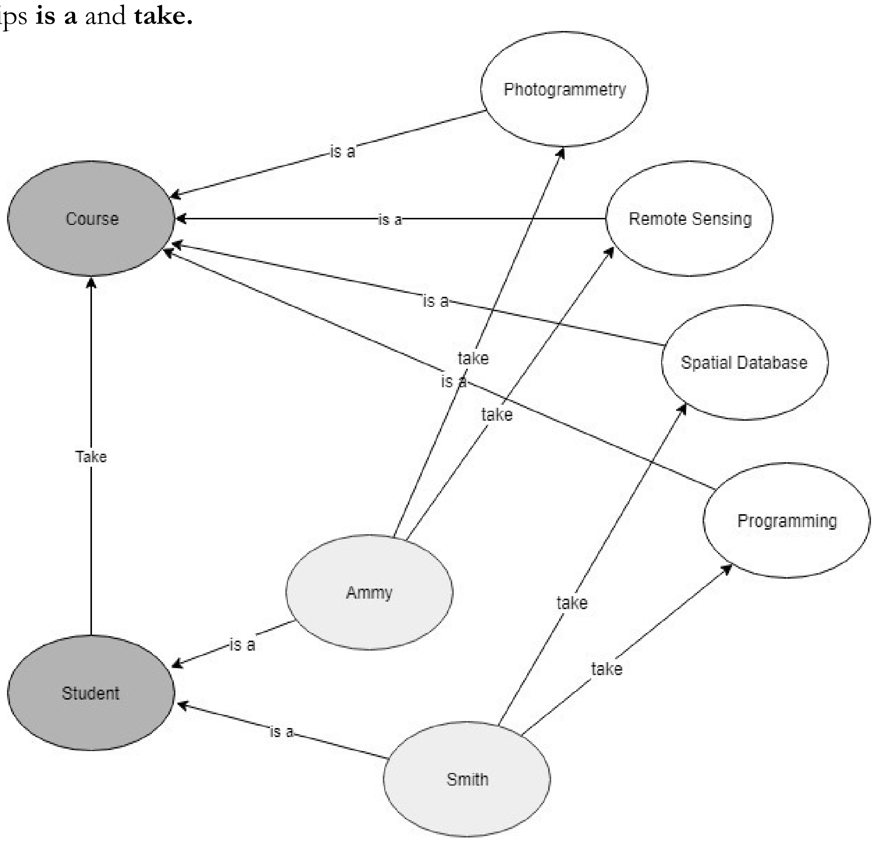


Figure 7 Example of the component of ontology. The dark grey circles are called concepts/class; the lines are the relationship; the white and the light grey circles are the individuals.

In the design steps, the concepts and the relationships of ES were defined and created to form a conceptual model. Bajwa (2011) mentioned the rules in the ontology design to be considered as follows: there is no correct way to model a domain because there are viable alternatives, ontology development is an iterative process, and the concepts of the ontology should be close to objects and relationships in the domain of interest.

3.2.3. Ontology Deployment

The ES Ontology developed in the previous step were deployed using the living textbook (LTB) web application[19] as a tool to visualise it. The concepts and relationship from the previous steps were built in this application. The LTB enables the ontology being accessed via web and being explored. It visualised the ontology by the interactive diagram (concept map) and the collaborative website (textbook) which described concepts (Augustijn, Lemmens, Verkroost, Ronzhin, & Walsh, 2018). The interface of LTB is

[19] https://ltb.itc.utwente.nl/

shown in Figure 8. The LTB provides functions to create the new concepts and relationships, link among concepts using relationships, and create explanation and external resources related to the concepts. The concepts and relationships of ES were created in LTB to build the ES Ontology. After that, the concept was linked to another concept using the relationship. The relationship needs to be defined carefully because there were two kinds of relationship in the LTB: incoming relations and outgoing relations.

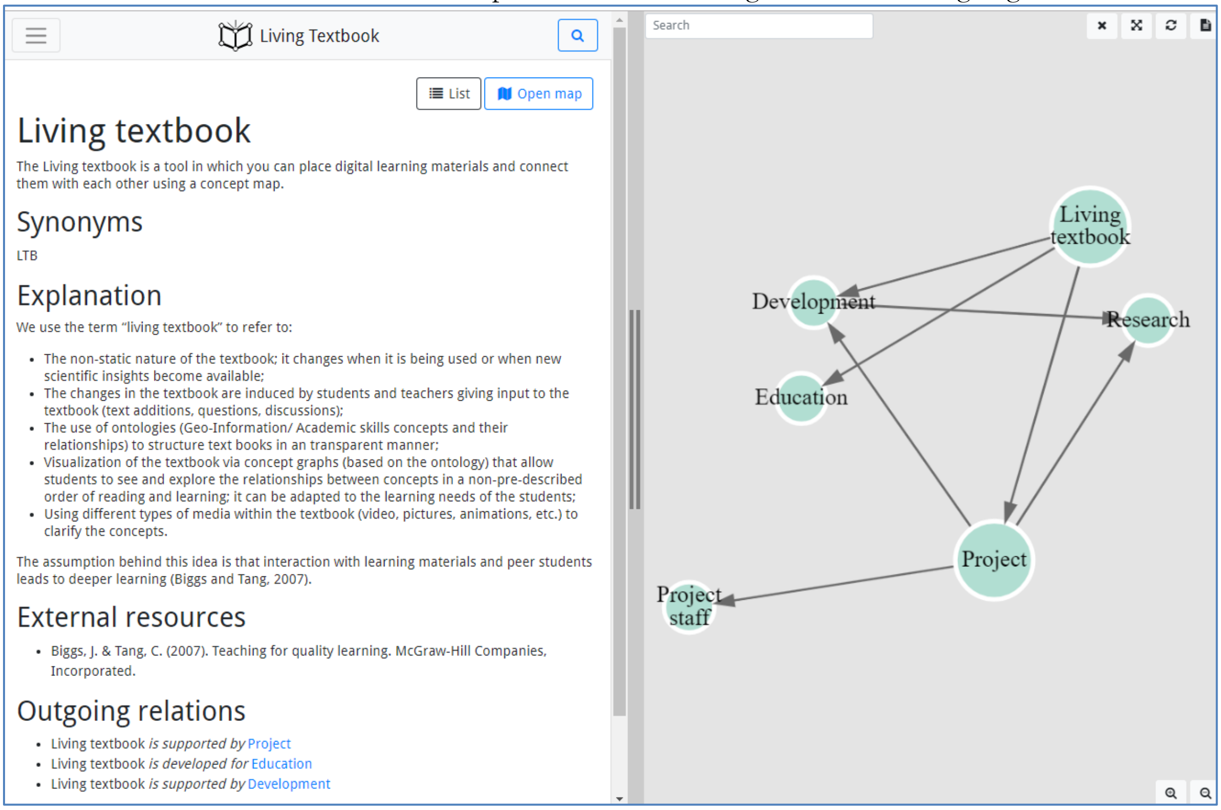


Figure 8 The interface of LTB web-applications. The right side is the interactive diagram, and the left side is the collaborative website(textbook). Source: (https://ltb.itc.utwente.nl/page/31/concept/4094)

3.2.4. Ontology Formalisation

Formalisation ontology is processed to link the individuals to the closest related concepts and define the relationships (Rajpathak & Chougule, 2011). The components of the ontology formalised in the form of triple. Triple is a sentence like and consist of subject, predicate and object. The triples are expressed in RDF that understandable by machines (RDF working group, 2014). One of the language to represents the triple is turtle. The advantage of turtle language is that it is straightforward and readable by human and machine (Beckett, Berners-Lee, Prud'hommeaux, & Carothers, 2008). The turtle language also enables the ontology to be queried using SPARQL which is an RDF query language to retrieve and manipulate data stored in RDF format.(The W3C SPARQL Working Group, 2013). The subject, predicate and object in the turtle are written based on their URI. Figure 9 represented an example of a simple turtle and mentioned that **spiderman** is the **enemyOf green-goblin.** To simplify the formalisation, the URL of URI was written as a prefix like shown in Figure 10. The grammar of turtle can be found in the RDF 1.1 Turtle documents[20] by W3C. In the formalisation step, the design of ES Ontology was transformed into turtle language.

```
<http://example.org/#spiderman>
<http://www.perceive.net/schemas/relationship/enemyOf>
<http://example.org/#green-goblin>.
```

Figure 9 Example of simple triple in turtle language. Source: Beckett et al. (2008)

[20] https://www.w3.org/TR/2014/REC-turtle-20140225/#sec-intro

```
@prefix ex: <http://example.org/>.
@prefix rel: <http://www.perceive.net/schemas/relationship/>.
@prefix foaf: <http://xmlns.com/foaf/0.1/> .

ex:#spiderman rel:enemyOf ex:#green-goblin;
              a foaf:Person ;    # in the context of the Marvel universe
              foaf:name "Green Goblin" .
```

Figure 10 Example of prefix applications. Source: (Beckett et al., 2008)

3.3. Evaluation of the Developed Ontology

Ontology can be evaluated based on the ontology correctness or ontology quality. Evaluation can be done using the following method: by comparing the ontology against a gold standard, data-driven evaluation, application or task-based evaluation, and user-based evaluation (Hlomani & Stacey, 2014). Comparing the ontology against a gold standard offers a way to evaluating ontology but has limitations because of the gold standard itself needs to be evaluated and it will be problematic to find the source of error whether it is the gold standards or the developed ontology (Hlomani & Stacey, 2014). Data-driven evaluation compares the ontology to existing data about the domain. One of the way to do it is by comparing concepts and relationships to text of documents about the domain ontology and analyse the results using probabilistic method (Brewster, Alani, Dasmahapatra, & Wilks, 2004). This method has limitation in the way it considers the domain knowledge to be constant which is different with reality (Hlomani & Stacey, 2014). In the task-based evaluation, the developed ontology is evaluated based in the context of actual software program or use case scenario and it may applicable in one application but not in another (Hlomani & Stacey, 2014). Like the other methods, the user-based evaluation also has difficulties in defining the objective standards of evaluation and the right users (Hlomani & Stacey, 2014). In the ES domain case, the gold standards and data-driven evaluation is hard to establish with the condition of different definition and approaches applied in the ES assessments which lead to the variety of ES data and the absent of standards. Therefore, the developed ES Ontology was evaluated using the task-based evaluation and user-based evaluation.

3.3.1. User-based Evaluation

User-based evaluation evaluated the ontology based on the user experience and intended to capture the subjective information about ontology (Hlomani & Stacey, 2014). In this research, the user-based evaluation was carried out using a questionnaire which intended to measure the usability of the ES Ontology (to measure whether the ontology helps the user understand the ES interoperability between classification frameworks and the valuation methods) and the clarity of the relationships. The questionnaire was divided into three parts; the first part is a true or false question about the concepts in ES Ontology. The second part asked the opinion of the ontology user to confirm the ability of the ES Ontology on helping the user in understanding ES domain study. The last part consists of questions which asked about the relationship used in the ES Ontology. The survey was conducted using Survey Monkey[21] as the survey platform and the participants need to explore the ESOnto and answer the first part of the survey based on the ESOnto. The second and third parts of the survey need to be answered based on user experience and opinion.

The participants of this survey were classified into three groups: expert user who is GEO BON member (ES working group), students of ITC who know ES before, and students of ITC who new to ES. The first and second part of the questionnaire were analysed without grouping the participants. However, the third part of the questionnaire which asked about the clarity of the relationships was analysed based on the group of participants. The weight of GEO BON member is 0.5 which is bigger than the other groups because of they are the expert of the domain, for students who knew ES is 0.3 and students who new to ES is 0.2.

[21] https://nl.surveymonkey.com/

3.3.2. Task-based Evaluation

The task-based evaluation evaluated the effectivity of an ontology in the context of an application which can be a software program or a use case scenario (Hlomani & Stacey, 2014). The use case scenario was design based on the interoperability of ecosystem frameworks and the valuation method of ecosystem services. This use case consists of competence questions which need to be answered using SPARQL queries.

3.3.2.1. Use-case scenario based on the MAES data

The first use case was based on the MAES data[22] of European Union Services. It contains information about the ES value in ton/year. ES of Europe were mapped per 10 km grid. Every grid has information about the value of food crop, fodder crop, textile crop and energy crop. All of them are calculated based on CICES classification frameworks. This data was intended to map and calculate the Total Ecosystem Service Value (TESV) of Europe (Maes, Zulian, & Barbosa, 2015). This use case was tried to capture the information of which subclass is affecting the value of the TESV and what is the interoperability between ecosystem services classification frameworks. The competence question needs to be answered as follows:

1. Which indicators used for provisioning service?
2. What are the class of the fodder crop ecosystem services in TEEB and MA classification frameworks?
3. Where is the location of the highest value of energy crop?
4. Which grid has the highest value of provisioning service? With the assumption that provisioning service value is equal with the sum of the provisioning service subclass value.

3.3.2.2. Use-case scenario based on the TEEB database

The second use case was using the TEEB database[23]. This database covers the ecosystem service value, type of ecosystem, location of observation, valuation methods and ES classification based on the TEEB classification frameworks (McVittie & Hussain, 2013). This use case was tried to communicate the methods and results of ES assessment based on the TEEB frameworks about the scale and value of ES. Below are the competence question needs to be answered:

1. Which valuation method they use to analyse the raw material ecosystem services?
2. What is the unit of the raw material ecosystem services value?
3. What is the scale of the map?

3.3.3. Ontology Documentation

The ontology documentation is necessary to provide documentation of a new ontology and to facilitate correct interpretation of the ontology structure for users (Rajpathak & Chougule, 2011). The ontology documentation consists of the list of concepts, definition and the source of definitions, the list of relationships and the link between concepts. It is presented in Appendix A.

[22] http://data.europa.eu/euodp/data/dataset/7e3f0681-5967-41f7-ae9b-87f1c3cfac4f
[23] http://www.teebweb.org/publication/tthe-economics-of-ecosystems-and-biodiversity-valuation-database-manual/

4. ECOSYSTEM SERVICE ONTOLOGY (ESONTO)

This chapter explains the result of the exploration and extraction of the knowledge source in section 4.1, the design of the ontology in section 4.2, the deployment of the ontology in LTB web application and formalisation results in section 4.3 and section 4.4. Besides that, the evaluation results of ESOnto is described in section 4.5.

4.1. Extracted Information from Ecosystem Service Resources

The ecosystem service ontology development was started by selecting the tools and dataset provided by Bon-in-a-Box, the literature and the existing ontologies. Table 1 shows some of the selected ES knowledge source used in this study. The tools give information about the input, process and output of ES analysis which later combined with the conceptualisation grabbed from the literature review. The literature gives information about the classification methods and frameworks which helps to construct the conceptual model for designing the ontology. The glossary and data catalogue were used to collect terms and definition which commonly used in ES.

Table 1 Some of ES knowledge source

No	Name	Type	Source
1	MA	Literature	https://www.millenniumassessment.org/en/index.html
2	TEEB	Literature	http://www.teebweb.org/
3	CICES V5.1	Literature	https://cices.eu/
4	MAES	Literature	https://biodiversity.europa.eu/maes
5	OpenNESS	Literature and glossary	http://www.openness-project.eu
6	Mapping Ecosystem Services (Burkhard & Maes, 2017)	Literature	
7	InVest	Tools	http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/
8	MESP	Tools	http://toolkit.grida.no/
9	ValuES	Tools	http://www.aboutvalues.net/
10	ESP-VT	Tools	http://esp-mapping.net/Home/
11	MESH	Tools	https://naturalcapitalproject.stanford.edu/mesh/
12	SWAT	Tools	http://swat.tamu.edu/

4.1.1. Explore the Literature

MA (2005) defines ES as "the benefits people obtain from ecosystems". The term service covers the product and its existence value (provisioning service and cultural service). MA divided ES into four classes: provisioning services, regulation services, cultural services and supporting services. The provisioning services are products obtained from an ecosystem such as food and fresh water. The regulating services are the benefit gained from ecosystem process regulation such as climate regulation and pollination. The cultural services are benefits which only can be felt because it is a nonmaterial benefit like the tourism which gives joy and spiritual or religious value in the ecosystem service components. The supporting services support the production process of another service, for example, is the soil formation which can support the production of food. The component included in every class is shown in Figure 11.

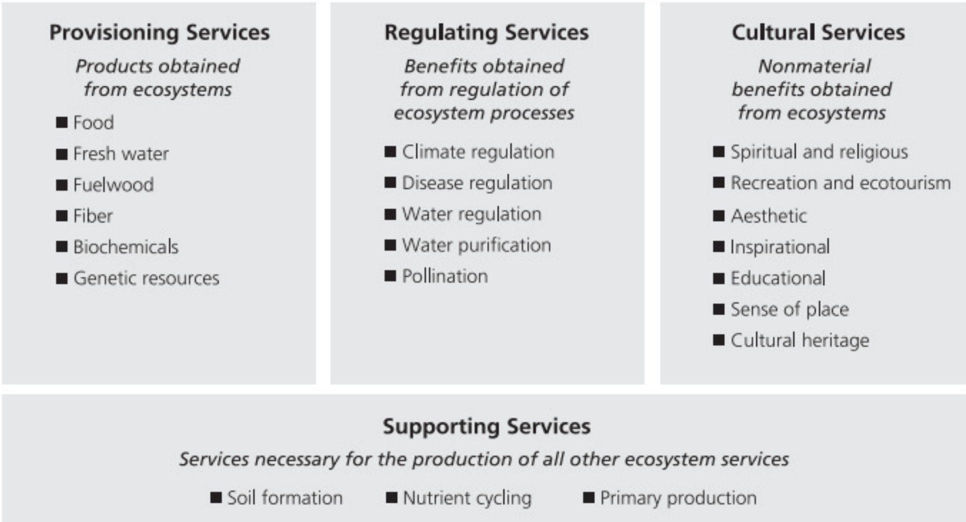


Figure 11 Millennium Ecosystem Assessment Classification. Source: (MA, 2005)

The definition of ES in TEEB (2010) is "the direct and indirect contributions of ecosystems to human well-being". Here the concept 'ecosystem goods and services' are synonymous with ES. TEEB was build based on MA classification frameworks, and it is divided into four classes as MA did, the difference is the supporting services in MA is called habitat and supporting services. Because they were built from the same frameworks the interoperability between MA and TEEB classification frameworks is not as complicated as the interoperability with CICES V5.1. It was released in 2018, and it was build based on the cascade conceptual framework. CICES V5.1 try to classify the final ES (the contribution of the ecosystem which most directly affects human well-being). For example, the final services of wood material as a building material is the volume of timber that ready to be cut from a woodland. The harvested timber is the concepts of goods and benefit, and the value for people is processed timber. The hierarchy of CICES V5.1 is different from MA and TEEB. It has five levels of hierarchy which are the section, division, group, class, and class type (Roy Haines-Young & Potschin, 2018) — represented by Figure 12 The section has three classes; the provisioning services, regulating and maintenance services, and cultural services.

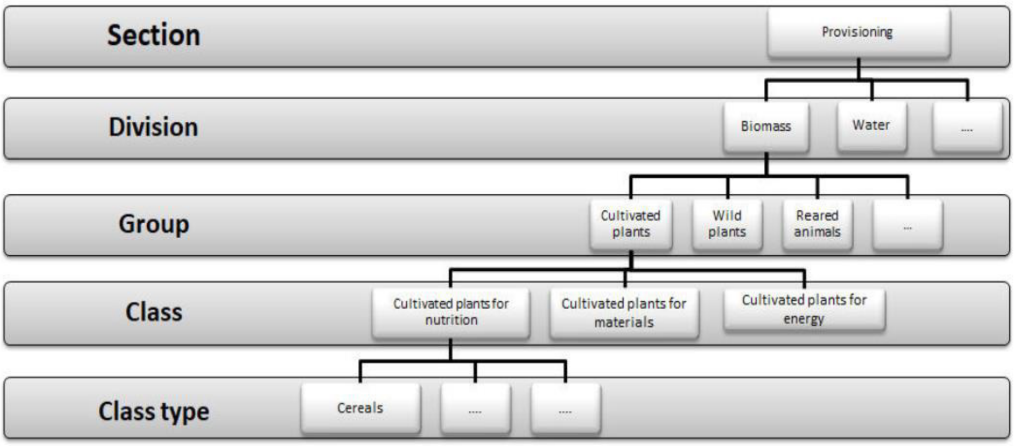


Figure 12 CICES V5.1 hierarchical structure represents the cultivated plants as part of the provisioning services. Source: (Roy Haines-Young & Potschin, 2018).

The interoperability between CICES V5.1, MA and TEEB are described in the spreadsheet document of CICES V5.1 from http://www.cices.eu/resource. It is comparing the subclass in MA and TEEB with the level of class at CICES V5.1. For example, the cultivated plants for nutrition in CICES V5.1 corresponds to the food provisioning services in MA and TEEB classification services. The example of interoperability between MA, TEEB and CICES V5.1 is visualised in Table 2 (the complete interoperability can be found in Appendix D).

Table 2 Interoperability between MA, TEEB and CICES V5.1.

CICES V5.1			MA	TEEB
Division	**Group**	**Class**		
Biomass	Cultivated terrestrial plants	Cultivated terrestrial plants grown for nutritional purposes	Food	Food
		Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials)	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
		Cultivated plants (including fungi, algae) grown as a source of energy	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
	Reared animals	Animals reared for nutritional purposes	Food	Food
		Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
		Animals reared to provide energy (including mechanical)	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources

MA, TEEB and CICES V5.1 used a conceptual framework as the reference of the classification frameworks. The MA conceptual framework consists of ecosystem services, human well-being, and the driver of change which can be direct or indirect (Capistrano et al., 2005). These components interact and can take place on any scale, using any technology and lifestyle which lead to the change of ecosystem services. TEEB and CICES V5.1 use cascade conceptual framework which consists of ecosystem structure, ecosystem function, ecosystem service, benefits and value (R. de Groot et al., 2010); Roy Haines-Young & Potschin, 2018). These components of the conceptual frameworks were adopted as the concepts in the ESOnto. Besides the conceptual framework, the hierarchy of classification frameworks of the MA, TEEB and CICES V5.1 and their interoperability information are captured as the typology of the ecosystem services.

Beside literature about classification frameworks, there is glossary provided by the OpenNESS. This glossary provides options of term definition related to ecosystem services. The definition of a concept was chosen by comparing the definition in the TEEB, CICES V5.1 and OpenNESS glossary like the example given in Table 3. After that, select the most appropriate definition which linked the concept with other concepts related to it. In this case, the ecosystem function definition from the OpenNESS glossary was chosen because it defined the relationship between ecosystem structure, ecosystem process and ecosystem services which were the concepts connected to ecosystem function. If the definition from that sources is not available or not properly defined by the source documents, then the definition is captured from journal article or papers.

Table 3 The example of the definition comparison from different sources.

Terms	TEEB	CICES V5.1	OpenNESS
Ecosystem Function	a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services	characteristics of the living system that come together to make something a service	The subset of the interactions between biophysical structures, and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services.

Furthermore, there is another kind of documents can be referred such as the guidelines to develop the ES indicators Brown et al. (2014). The guideline document shows step by step of how to assess ES. Assess ES means to measure the state, quantity or value of the ES. ES is a function of complex interaction between the environment and the species, the variation of use and utilisation patterns by the beneficiaries (Fisher et al., 2009). The ecosystem service indicator needs to be defined to assess and maps this complex interaction. The indicators will act as "information that effectively communicates the characteristics and trends of ecosystem services" (Brown et al., 2014). These indicators will help the policy makers to understand the condition of ES. Following is the step to develop an ES indicator mentioned by Brown et al. (2014) :

1. Identify the stakeholder and target audience includes the purpose of the assessment
2. Identify ES related to policy objectives and targets. In other word define the ES driver of change which can be policy, natural disaster, habitat conversion, climate change.
3. Determine the critical question and indicator use. The critical question is asking about what kind of ES provided by the habitat, where are the service production areas and the status of the services.
4. Develop a conceptual model. The major challenge in this step is developing the indicators and deciding what to measure. The ecosystem service indicator is divided into four types; supply, delivery, contribution to well-being and economic value.
5. Identify possible indicator
6. Gather and review the data.
   The spatial scale, temporal scale, baseline, operationality, validation, measurement units, spatial unit and the analysis process need to be considered.
7. Calculate indicators.
   The indicator can be directly got from the measurement (raw data), or it needs to be analysed from other data (derived data).
8. Communicate and interpret indicators. Indicators are working as communication tools to help people understand the complex interaction of ES. Indicators can be visualised using graph or map. The indicator map can identify spatial patterns, overlaps, gaps and facilitate decision making discussion (MAES, 2013)
9. Test and refine the indicators.
10. Develop a monitoring and reporting system.

The guideline above makes use some ES terms and concepts which can be identified such as the indicators, the driver of changes, the place of ES, the spatial and temporal scale, the measurement unit, spatial unit and the quantification method. Following are supporting information about the terms:

1. Indicators: information which communicates the trends, status and the change of ES. The indicator is representing the ES; for example, the amount of crop in an agriculture area can be an indicator of food provisioning services.

2. The driver of changes: Is the factor which affecting the change of ES which can be human interference such as policy and habitat conversion or nature as the driver such as disaster (volcano and earthquake) and climate change (Capistrano et al., 2005).
3. The place of ES refers to the place of ecosystem service which means the place where the service is being produced or where the service was utilised by human well-being. Place where the service is produced or called a service production area (SPA), the place where the benefit of the service was utilised by human well-being called as service benefiting area (SBA) (Fisher et al., 2009) and the service connecting area (SCA) which connected the SPA and SBA when they do not overlap or touched (Syrbe & Walz, 2012). The relation between SPA, SBA and SCA can be described using the geometry relationships as shown in Figure 13. There are only three possibilities of the relationship between SPA and SBA; SPA is equal with SBA (in situ), SPA is inside the SBA (omnidirectional), SBA is disjoint from SPA and connected by the connecting area (directional - slope dependent) and SBA overlap with the SPA with higher ranking directional effects (directional -without slope dependence).

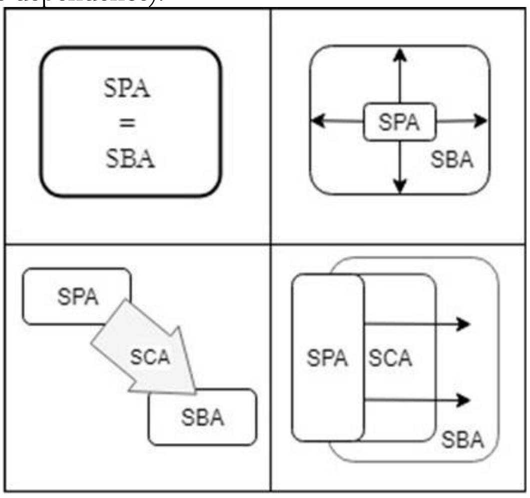


Figure 13 Spatial relationship between SPA, SBA and SCA. Source: (Syrbe & Walz, 2012)

4. Scale in ES refers to measurement and dimension in space and time which can be an extent, grain, size and resolution, but it also can refer to the level of organisation system (Rieb et al., 2017). Wu & Li (2006) define scale based on the dimension of scale (time, space and organisation levels), kinds of scale (intrinsic scale, observation scale, experimental scale, analysis/modelling scale and policy scale) and components of scale (grain, extent, coverage, spacing and cartographic scale). Zhang, Holzapfel, & Yuan (2013) mentioned that ES is dependent on scaling and the scale can be divided into the scale of observation, the scale of production, the scale of consumption and scale of management. These scales were represented in ecological scale, temporal scale and institutional scale (Hein, van Koppen, de Groot, & van Ierland, 2006).
5. The spatial unit can refer to single land use patches, smallest common geometry (grid), administrative unit, watersheds, or natural unit such as soil, geological or vegetation (Syrbe & Walz, 2012). The measurement unit can be an economic value or monetary unit such as the dollar, euro and it can be in another unit such as weight (ton/ha).
6. Quantification or valuation method defines as the methods used to measure the value of ES (Costanza et al., 1997). The value of ES can be identified as ecological value, socio-cultural value or Economic value which will bring different method to analyse(R. S. de Groot, Wilson, & Boumans, 2002).

4.1.2. Analysis of Ecosystem Service Tools and Dataset

The tools were divided into two: analysis tools and catalogue tools. The analysis tools provided information about how the ecosystem service was calculated, starting from the input, methods and the output. The information about the input, method, and output was gathered from the manual instruction or application development documents of the tools and datasets from Table 1. An easy way to gather the information was by creating a mind map about the tools. The example of mind mapping is shown in Figure 14. The information captured from the mind map is not the exact name of the input and output but the data type of the input and output data. For example, input of the carbon storage and sequestration model, is Carbon Pools, Land Use/Land Cover and the Economic Data. Input for the coastal blue carbon is Land Use/Land Cover, Carbon Pools, Transition matrics and Economic Value. That information can be classified as the economic data and non-economic data (Land Use/Land Cover, Carbon Pool, Transition Matrix) and can be represented as a table or map.

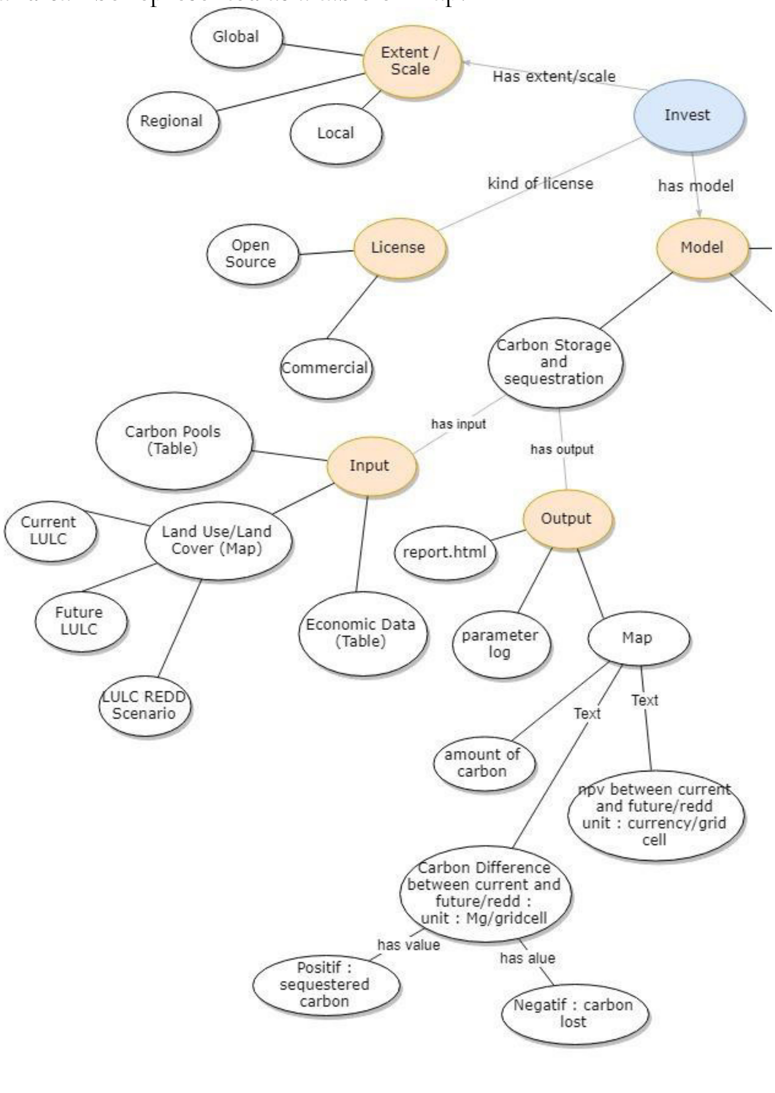


Figure 14 Mind mapping of InVEST

As seen in Table 4 the input of ecosystem service tools can vary, depends on what types of ecosystem services were calculated and the desired output. Taking InVEST and MESH as an example, the data (input and output) can be divided into economic data and non-economic data (the land use/ land cover and the thematic data). Different from InVEST and MESH, the input and output of SWAT do not include economic elements. In conclusion, the input data can then be classified into economic and non-economic data. All of them use modelling approaches to calculate the value ecosystem services.

Table 4 Information extracted from ES analysis tools

Tools	Frameworks	Input	Valuation method	Output
InVEST	Supply, Service and Value frameworks (The Natural Capital Project, 2017)	- Economic data (Table) - Land Use/Land Cover (Map) - Thematic data such as carbon pools, (Tabular/Map)	Modelling: - Forest carbon edge effect - Carbon storage and sequestration - Coastal blue carbon - Annual water yield - Nutrient delivery ratio - Sediment delivery ratio - Scenic quality provision - Recreation and Tourism - Wave Energy Production - Offshore Wind Energy Production - Marine finfish aquaculture production - Fisheries - Crop production - Seasonal water yield	ES value, Change of ES and result of a scenario (Map/Table). It can be economic value (with monetary unit) or non-economic value when calculating the supply.
MESH		From InVEST toolkit	Model-based on scenario (dynamics model)	Baseline Map scenario result map (Raster Map)
SWAT		watershed dimension, climate, hydrologic cycle, sediment, nutrients, pesticide, bacteria, water quality, plants, management, channel process, impoundment process (Table)	simulation based on terracing operation, tile drainage, contouring, filter strip, strip cropping, fire, ground waterways, plant parameter update	annual average crop values per hydrologic response unit (HRU) average basin values monthly and annual per HRU and sub-basin average basin values monthly and annual per HRU, water depth (Table)

Table 5 Extracted information from ES method toolkit and data catalogue

Tools	Search Parameter	Methods
MESP (method toolkit)	- Purpose - ES type - Target group	- Monetary - Non-Monetary
ValuES (method toolkit)	- Purpose - ES type - Target group	- Biophysical Assessment method - Monetary Valuation method - Social Valuation method - Frameworks and models for decision support
ESPVT	- Indicator - Location - Study Purpose - Duration - Purpose - ES Type - Biome - Spatial Scale	

Different information was gathered from the catalogue tools. The catalogue tools give information about ES concepts from the search parameter. Marine Ecosystem Service Partnership24 (MESP), ValuES25 and ESP-VT26 use the term purpose and ES type/class as advanced search parameter. There were other parameters in every tool as mentioned in Table 5. These parameters then were taken as a concept candidate. Beside the search parameter, MESP and ValuES classified the valuation method. MESP differentiate them into monetary and non-monetary method. ValuES differentiate them into biophysical assessment method, monetary valuation method, social valuation method and frameworks and model for decision support.

Table 6 Term gathered from pre-development step:

No	Term	Used	Expanded	Deleted	Description
1	ecosystem services	✓	✓		Used and expanded based on the ES type/classification (MA, TEEB, CICES V5.1)
2	human well-being	✓	✓		Used and expanded based on the institutional scale
3	driver of change	✓			Used
4	ecosystem structure	✓	✓		Expanded based on the ecosystem structure type. It also related to CICES V5.1 classification framework
5	ecosystem function	✓			Used
6	benefits	✓			Used
7	value	✓	✓		The term changed into “Ecosystem Service Value” and expanded by the properties which must have a measurement unit
8	economic data	✓			Used
9	non-economic data	✓			Used
10	valuation method	✓			Keep it general because there are some ways to classify the valuation methods
11	monetary			✓	Refer to valuation method (10)
12	non-monetary			✓	Refer to valuation method (10)
13	map	✓			Used
14	table	✓			Used
15	ES Type			✓	Refer to ecosystem service (1)
16	Target group			✓	Refer to Human well-being (2)
17	Location	✓	✓		Changed into “place” because place has wider coverage.
18	Indicator	✓			Used
19	Purpose			✓	deleted
20	Biome	✓	✓		Changed into “ecosystem”.
21	Spatial scale	✓	✓		Changed into “scale” because scale in ES are refer to spatial scale, ecological scale, institutional scale, observation scale and extension.

[24] https://marineecosystemservices.org/
[25] http://www.aboutvalues.net/
[26] http://esp-mapping.net/Home/

As a result, Table 6 shows the term gathered from the explore and extract knowledge of ecosystem services step and the selection results. Five terms were deleted because it was replaced by another term or not appropriate. The other terms were used as the starting point and then expanded based on the hierarchy or the typology and their properties.
These terms have connection one to another and it can be related one to another. The first relation is 'is generated by', for example, the ecosystem produces ecosystem function which produces the ecosystem service. The second relation is 'is represented by' such as map and table can represent the economic and non-economic data. The third relation is 'is affected by', for example, driver of change affects the ecosystem service.

4.1.3. Reusing Existing Ontologies

Reusing existing ontologies in developing a new ontology have advantages such as reduce the works and raise the quality of the new ontology because of the reused components have been evaluated (Lonsdale, Embley, Ding, Xu, & Hepp, 2010). There are ontologies which have been developed related to the ecosystem services mentioned in section 2.1. Some of them are domain ontologies such as ENVO, SERONTO and FOAF. This ontology may have overlap components with ecosystem services because ecosystem services are the domain which covers the relationship between environmental science and social science. Where ENVO is an environment ontology which also covers ecosystem and SERONTO and FOAF are ontologies which cover social science. Ontologies reuse consist of concept selection, relation retrieval and constraint discovery (Lonsdale et al., 2010). Before creating a new concept, we can check whether the concept exists in another ontology or not. To check the availability of a concept, ontology developer can use ontology lookup service[27] or linked open data[28]. Figure 15 shows the concept of the ecosystem in ENVO which cover the definition of the ecosystem, type of ecosystem and its relationship with the habitat and biome which can be used in the ecosystem service ontology.

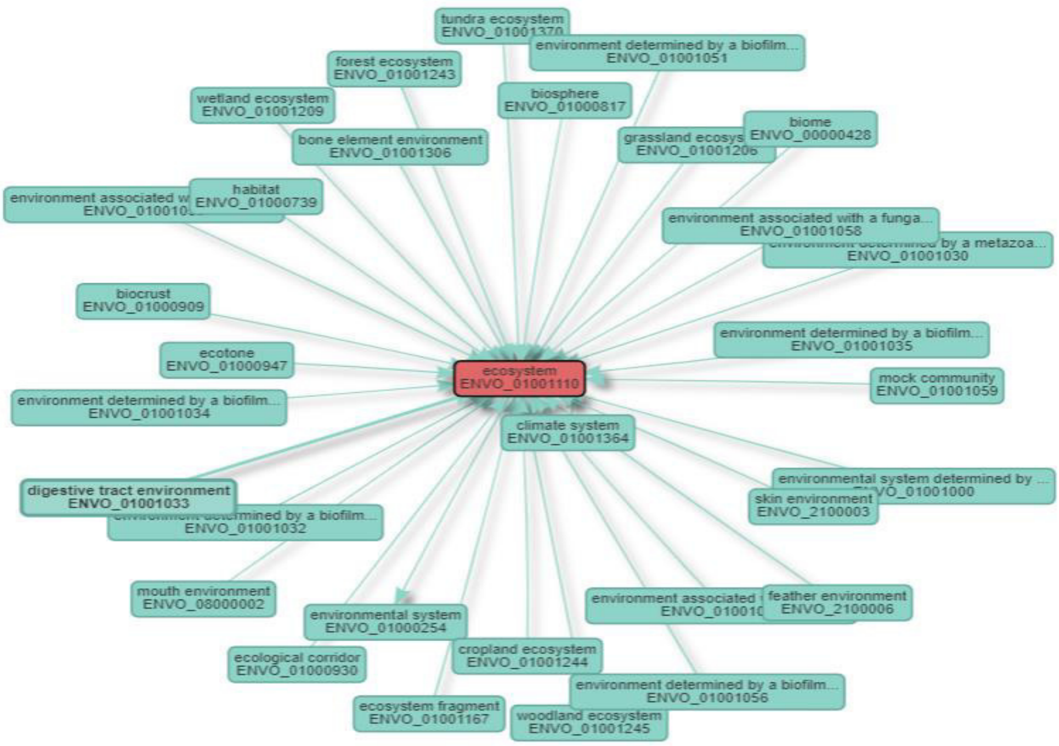


Figure 15 Visualisation of ecosystem concept in ENVO. Source: (https://www.ebi.ac.uk/ols/ontologies/envo/terms/graph?iri=http://purl.obolibrary.org/obo/ENVO_01001110)

[27] https://www.ebi.ac.uk/ols/index
[28] http://mappings.dbpedia.org/server/ontology/classes/

4.2. Conceptual Design of ESOnto

The term and relation from the previous step (Table 6) become the starting point to generate a conceptual model shown in Figure 16. This conceptual model was expanded based on the hierarchy of the ecosystem service classification frameworks (MA, TEEB and CICES V5.1). Besides that, the typology for place, scale, ecosystem structure, human well-being was added. This process generated 139 concepts (appendix A) and 11 relationships shown in Table 7.

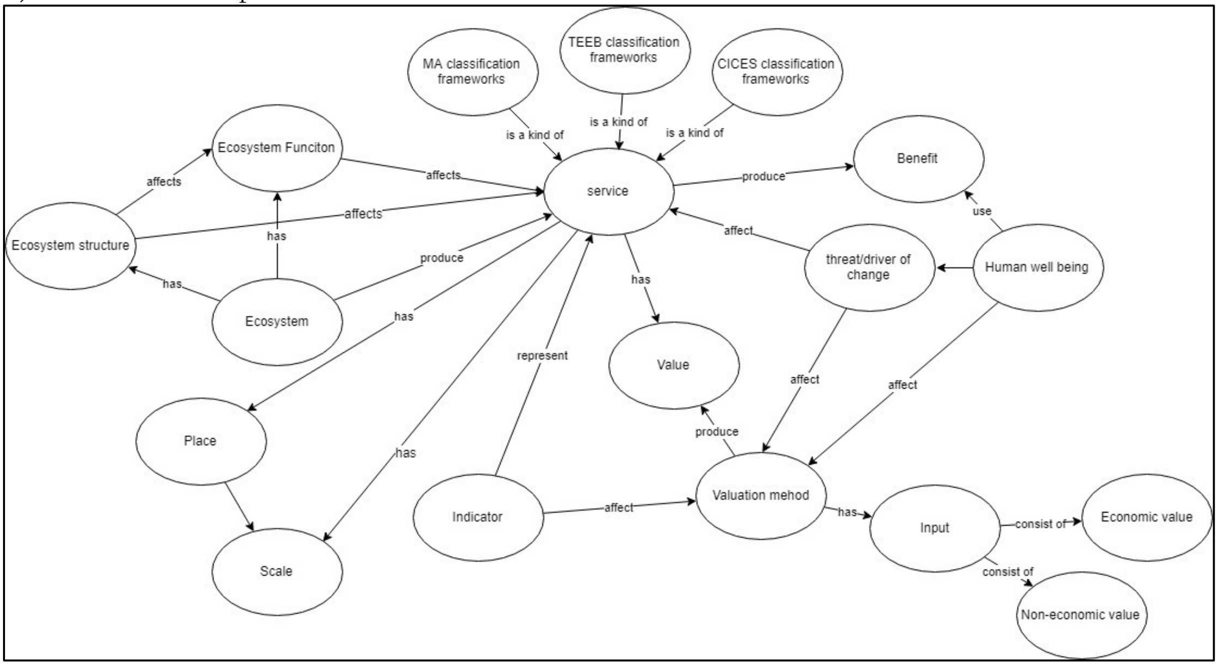


Figure 16 Simplification of the ES conceptualisation

Table 7 Relationships used in ESOnto

No	Relationships
1	is a kind of
2	is affected by
3	is generated by
4	is intended for
5	is known as
6	is located in
7	is part of
8	is properties of
9	is represented by
10	is retrieved by
11	is used by

4.3. Deployed Ontology

The conceptual model in section 4.2 was visualised using the LTB web application. In the LTB web application, the definition and the source of the concepts were written in the collaborative website. The LTB makes the ESOnto more attractive because of the visualisation of concepts map. The visualisation of the overall concepts and relationship of ESOnto in the LTB is shown in Figure 17 and the interface of concepts information and the concept map are shown in Figure 18.

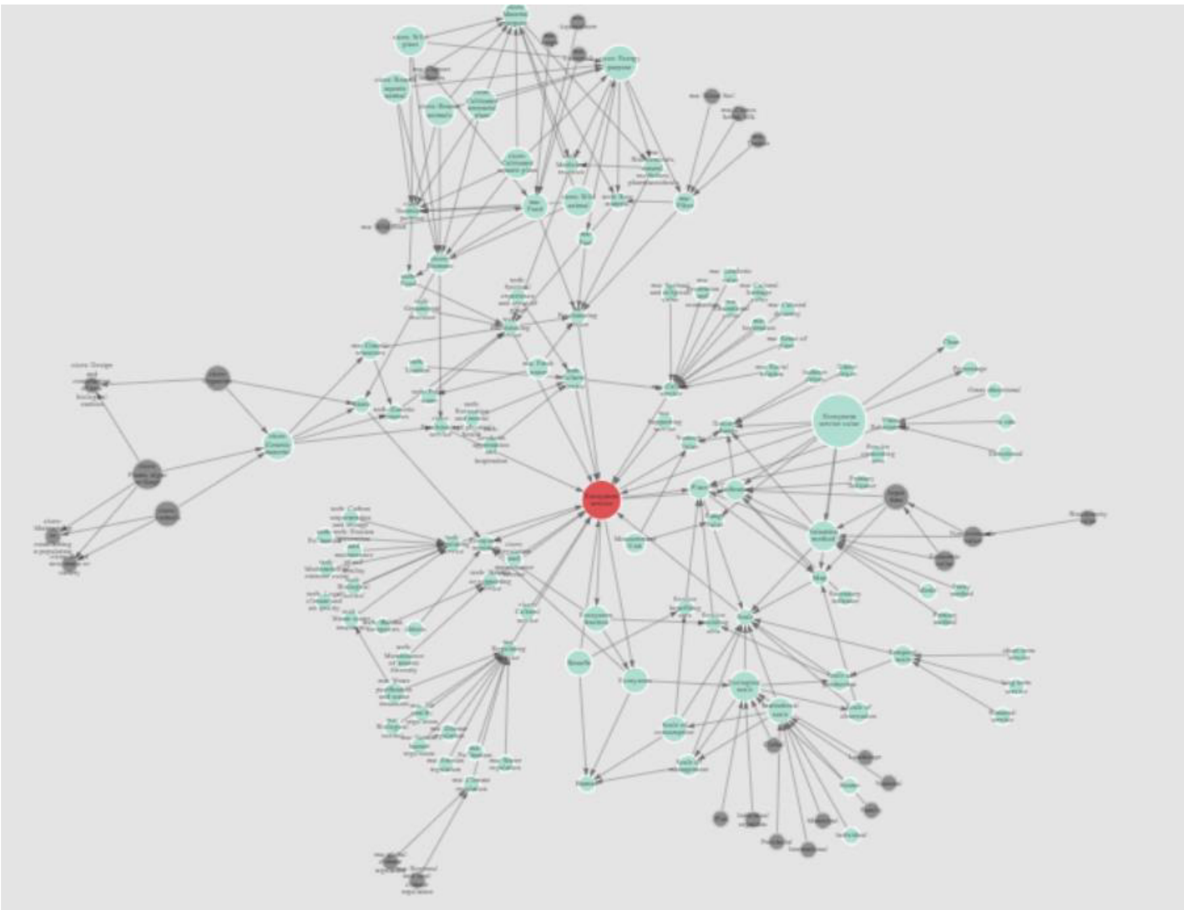


Figure 17 ESOnto concepts map

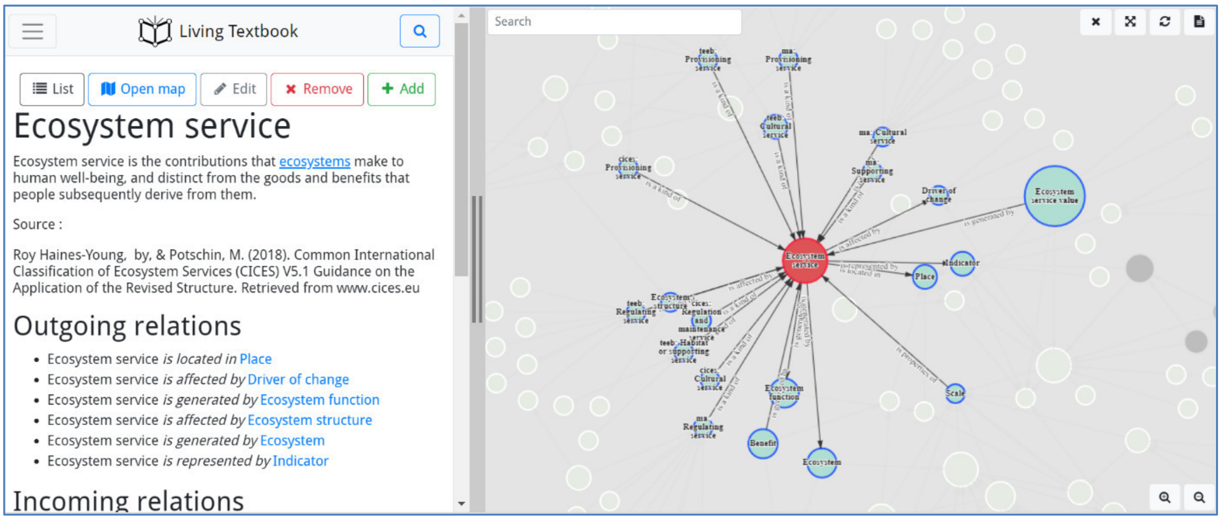


Figure 18 The visualisation of Ecosystem Service concept in LTB. The left part shows the definition, source of definition and the outgoing and incoming relations.

The concepts of ESOnto are shown by the circle; the arrows are showing the relationship between concepts. To read the ontology, it starts from the concept where the arrow began and ended where the end of the arrow. Example from Figure 19: **Ecosystem service value is generated by the ecosystem service; Ecosystem service is represented by Indicator; Ecosystem service is located in Place;** and **Ecosystem service is affected by Driver of change**. The ESOnto can be accessed in this link https://ltb.itc.utwente.nl/page/144/dashboard.

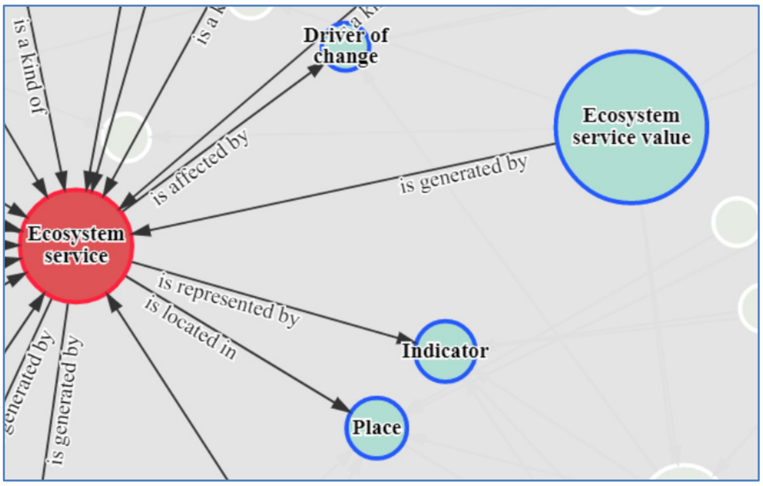


Figure 19 The relationships and concepts in the ESOnto

4.4. Formalised Ontology

The concepts and the relationships in previous results then formalised using turtle language. Only the ESOnto related to the use case was transformed into turtle language. Some existing ontology were used in the formalisation process as follows:

a. xsd: http://www.w3.org/2001/XMLSchema#
b. ENVO: http://purl.obolibrary.org/obo/ENVO_01001110
c. db: http://dbpedia.org/ontology

XML Schema (xsd) were used to define the type of value whether it is a string, decimal, integer or date. ENVO were used for the ecosystem and its classification part, and DBPedia were used to define the place of ecosystem services.

Figure 20 shows the example of formalisation using turtle from the TEEB Database. The prefix shows the ontologies used to formalise the TEEB database. Start from line 6 is the TEEB Database where it informed that **TEEB1** (code used to define an ecosystem service as individual) **is a Raw Material**, it is produced by **Ecosystem** of **Grassland** in (Service Production Area/**SPA**) of **Dutch Wadden Sea**. TEEB1 is generated using **direct market pricing** in **district** scale, and the **ES value** is **27 Euro/ha/yr**.

ECOSYSTEM			CASE STUDY LOCATION					
Biome	Ecosystem	ESSubservice	Country	Scale of research	Location Name	Valuation Method	Value	Unit
Select Biome	Select ecosystem	Select Subservice	Select a country	Select a region	Select an Income Group	Select a method	Query values	Select unit(s)
Grasslands	Temperate natural grasslands	Raw materials [unspecified]	Netherlands	Landscape / district	Dutch Wadden Sea, the Netherlan	Direct market pricing	27	EUR/ha/yr

```
1  @prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
2  @prefix ESOnto: <http://webprotege.stanford.edu/ayu#>.
3  @prefix ENVO: <http://purl.obolibrary.org/obo/ENVO_01001110#>.
4  @prefix db: <http://dbpedia.org/ontology/>.
5
6  ESOnto:TEEB1 a ESOnto:TEEBRawMaterial;
7                  ENVO:Ecosystem  ENVO:Grassland;
8                  db:Place "Netherlands";
9                  ESOnto:SPA  "Dutch Wadden Sea";
10                 ESOnto:ValuationMethod "Direct market pricing";
11                 ESOnto:ObservationScale "District";
12                 ESOnto:ESValue "27"^^xsd:decimal;
13                 ESOnto:MUnit  "Euro/ha/yr".
```

Figure 20 Formalisation code for TEEB Database.

Besides the data, the concept, and relationship also formalised as shown in Figure 21. This part of formalisation is describing the hierarchy of CICES V5.1 group of genetic material, and its interoperability with other classification frameworks. The complete turtle file for the MAES data and TEEB Dataset are shown in Appendix B

```
ESOnto:CICESDesignConstructNewBiologicalEntities    ESOnto:isKindOf            ESOnto:CICESGeneticMaterial;
                                                    ESOnto:EcosystemStructure  ESOnto:Biotic.
ESOnto:CICESBreedNewVariety                         ESOnto:isKindOf            ESOnto:CICESGeneticMaterial;
                                                    ESOnto:EcosystemStructure  ESOnto:Biotic.
ESOnto:CICESMaintainEstablishPopulation             ESOnto:isKindOf            ESOnto:CICESGeneticMaterial;
                                                    ESOnto:EcosystemStructure  ESOnto:Biotic.

ESOnto:CICESGeneticMaterial       ESOnto:isKindOf     ESOnto:CICESProvisioningService.
ESOnto:CICESBiomass               ESOnto:isKindOf     ESOnto:CICESProvisioningService.
ESOnto:CICESNutritionalPurpose    ESOnto:isKnownAs    ESOnto:MAFood,ESOnto:TEEBFood.
ESOnto:CICESMaterialPurpose       ESOnto:isKnownAs    ESOnto:MABiochemicalNaturalMedicinePharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource.
ESOnto:CICESEnergyPurpose         ESOnto:isKnownAs    ESOnto:MABiochemicalNaturalMedicinePharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource.
```

Figure 21 ESOnto formalisation

4.5. Evaluation of Ecosystem Service Ontology

This chapter will describe the result of ESOnto evaluation. The ESOnto was evaluated in two stages: through a user-based and task-based evaluation (see Section 3.3 for the description).

4.5.1. User-based Evaluation Results

Twenty-six participants participate in the user-based evaluation of the ESOnto. The user-based evaluation was done through an online survey in which participants explored the ontology through the LTB and answered the questions to assess their understanding of the ontology. The survey was estimated to take from eight to twenty minutes. Answers from participants who finished the survey in less than eight minutes were considered to be invalid. Furthermore, the incomplete answers were also considered as invalid. The incomplete answer refers to a case in which the participant only answers less than half of the survey questions. After the application of these criteria fourteen survey answers were considered as valid for this analysis, a number which was suitable for the requirements of this study.

Below is the question of the survey part I and part II which assessed the usability and level understanding of ES

Part I. True or false questions about ES

No	Statement
1	Ecosystem services are the contributions of human well-being to ecosystems
2	Medicinal resource (TEEB) is known as Biochemicals, natural, medicines, pharmaceuticals (MA).
3	Energy produced from wild plants (CICES) is a kind of Genetic material
4	Biomass (CICES) can be utilised as the source of food, the source of material and source of energy.
5	Ecosystem produces ecosystem services which generate benefit for human well-being
6	Water purification is a kind of provisioning service
7	The indicators of ecosystem services represent ecosystem service
8	Service providing area is a kind of place where ecosystem service is located
9	Ecosystem service is affected by the structure of an ecosystem
10	The place of ecosystem service is defined by the location of the production area and the benefit area

Part II. Do you agree or disagree with the following statement? 1(not agree) – 4(agree)

11. This ontology helps to understand the definition of ecosystem services.
12. This ontology helps to understand which factors are affecting the assessment of ecosystem service.

13. This ontology helps to understand the different classification frameworks of ecosystem services and the level of interoperability among them.

More than 70 percent of participants give the correct answer of the part I except for the first question about the definition of ES. The definition of ES in the first question was reversed from the written definition in ESOnto which might distract the participants. Despite that, the results of part I indicates that the user of ES can get information about ES in the ESOnto and it is supported by the results of the part II where 10 of 14 participants agreed that the ESOnto help them to understand the ES assessment and classification frameworks (Figure 22).

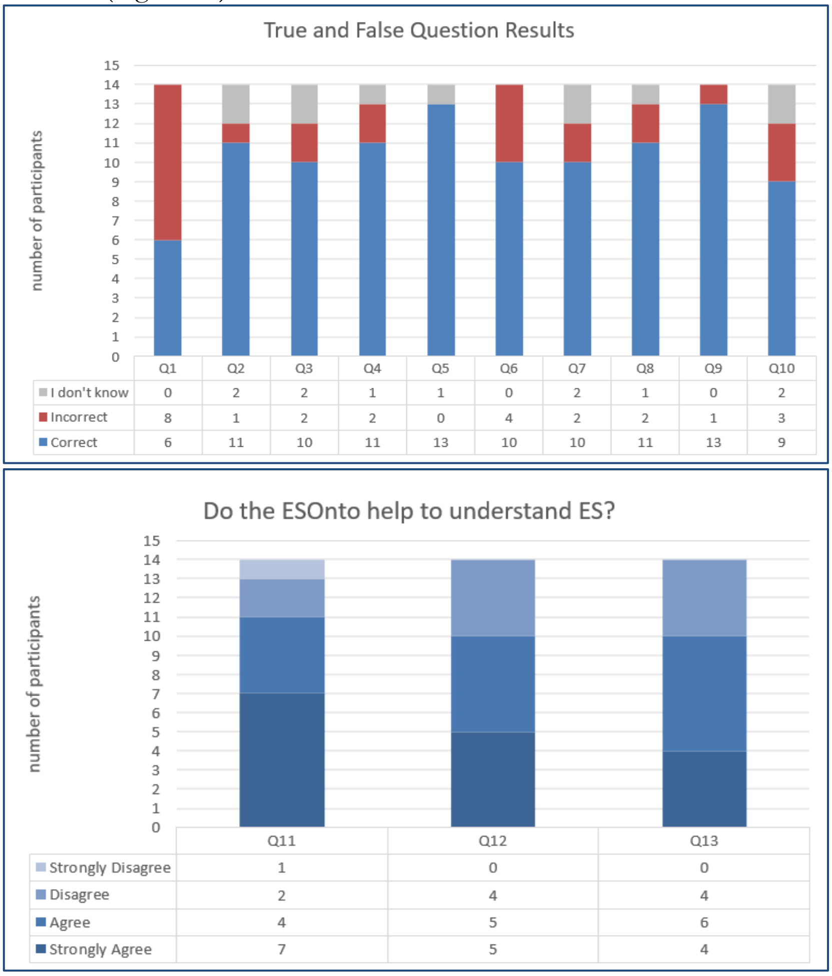
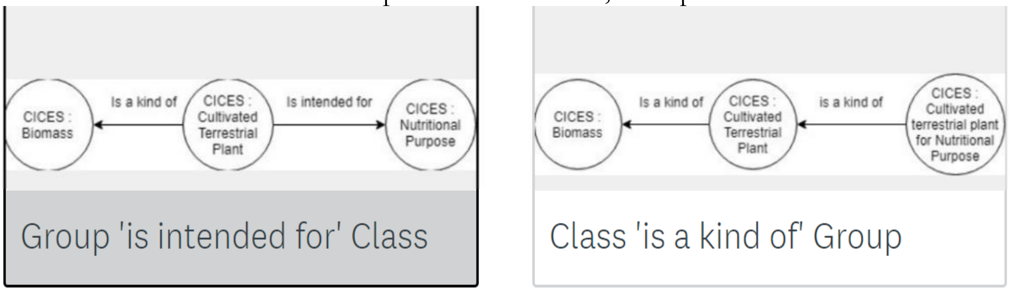


Figure 22 Upper graph: survey results of Part I. Lower graph: survey results of part II.

The survey results of part III were analysed based on the knowledge of the participants about ES. The first group is participants who encounter ES for the first time in this questionnaire. The second group is participants who are familiar with ES and the last is the Ecosystem Services working group of GEO BON. Refer to Section 3.3.1 the GEO BON member had the biggest weight factor followed by the participants who know ES and the participants who new to ES. The objective of these questions was asking about the clarity of the relationships used in the ESOnto. Below are the part III questions:

14. Which of the following words can best describe the interoperability between ecosystem service typologies:
    a. Is corresponding to
    b. Is known as
    c. Is same as
    d. Is equivalent to
    e. Other:.....

15. Which of the following relation types describe the best relationship between the valuation method of ecosystem service and the indicators of ecosystem service?
    a. Is affected by
    b. Is defined by
    c. Is measured by
    d. Other:.....
16. The hierarchy of CICES has four levels as following:1 Section (e.g. Provisioning), 2 Division (e.g. Biomass), 3 Group (e.g. Cultivated terrestrial plants for nutrition, materials or energy), 4 Class (e.g. Cultivated terrestrial plants grown for nutritional purposes). Which of the following choices which describe the best relationship between Division, Group and Class in CICES?



17. Which of the following action is needed to improve the ESOnto?
    a. Improve the definition of concept by adding explanation and example
    b. Improve the relationship type, so it is easier to understand
    c. No comments
    d. Other:.....

The result of part III is represented in Figure 23 and Figure 24. Most of the participants were select **is corresponding to** for presenting the interoperability of the classification frameworks. However, the GEO BON member select **is equivalent to** or **is same as**. The group who know ES select **is equivalent to**, so it is the most significant to replace **is known as** (the existing relationship for the ecosystem services interoperability). The question no 15 was about choosing the best relationship for describing the interaction between ecosystem service and the indicators, most of the GEO BON member select **is measured by**, the group who know ES select **is affected by** and **is measured by**, and the group who new to ES select **is affected by**. Compare to the number of the first, second and the third group and expertise level, **is measured by** can be a candidate to replace **is affected by** for relationship between the ecosystem service and indicators. For the question no 16 which asking the best relationship between group and class, most of the participants from three groups selected **class is a kind of group** which means it is better than the existing relationship in the ESOnto.

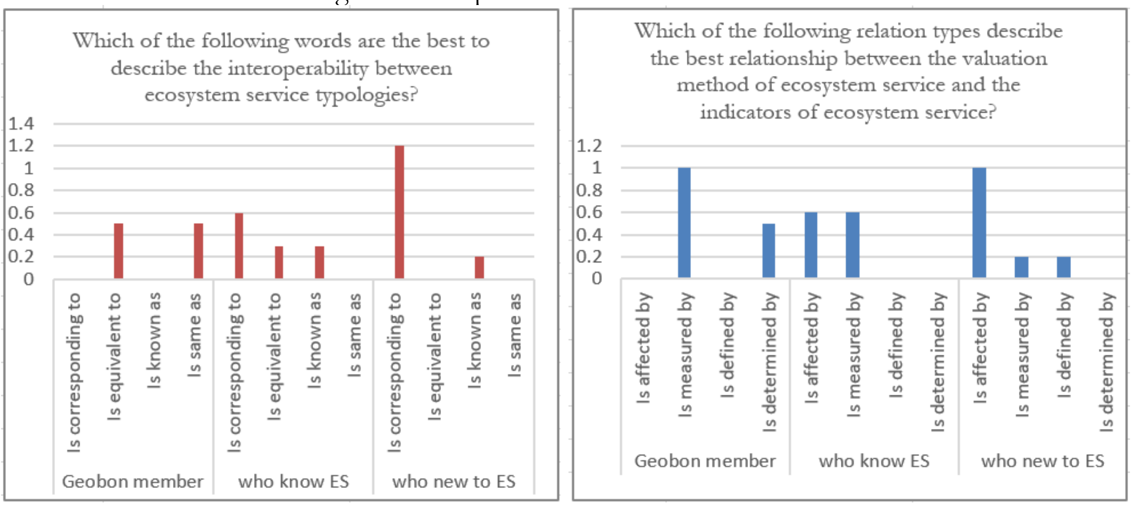


Figure 23 Survey results of Part III, question number 14 and 15.

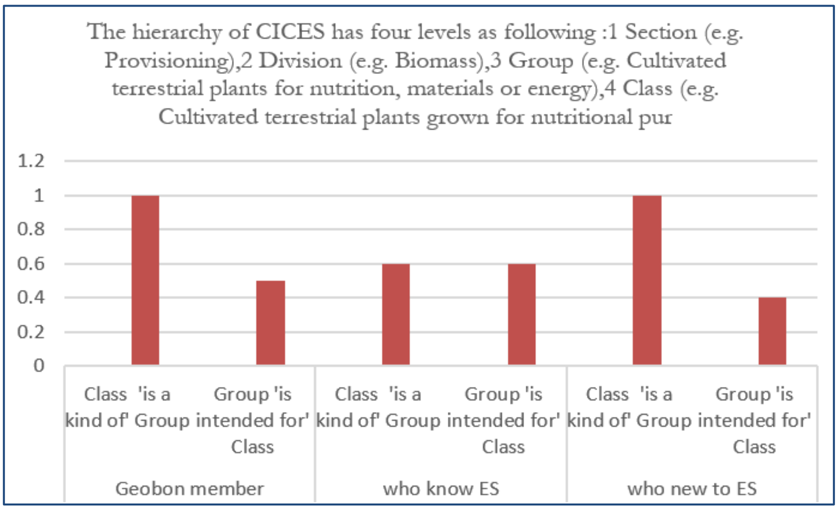


Figure 24 Survey results of part III, question number 16.

Based on part I and part II, the ESOnto was understandable and helped the user to grasp the knowledge about ES classification frameworks, its interoperability and the ES assessment process. Part III results prove that the existing relationships used in the ESOnto can be better by improving it using the survey results. Furthermore, there were suggestions from the survey participants as follows:

- Improve the definition of concept by adding explanation and example
- Improve the relationship type, so it is easier to understand
- replace the words "kind of" with "type of" because in everyday language, "kind of" is used to express doubt and people might be confused by this
- Add different layers for TEEB, MA and CICES that the user can (un)select
- This ontology is a very good and comprehensive synthesis. The interactive platform makes it more enjoyable to understand the terms and complexity of interactions. I think it can be a nice way to approach the study of ecosystem services through play.

4.5.2. Task-based Evaluation Results

The task-based evaluation was built based on the query from the competence question. The query from the competence question can be seen in Table 8. All of the queries are working well, and the result of the query can be seen in APPENDIX C.

Table 8 Translation of competence question ito queries.

No	Competence Question	Query	Concept used
1	Which indicators used for provisioning service?	SELECT ?ES1 ?ES2 ?Indicator WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator.} Group BY ?ES1 ?ES2 ?Indicator	**CICES Provisioning Service, its subclass** and **Indicator.**
2	What are the class of the fodder crop ecosystem services in TEEB and MA classification frameworks?	SELECT ?Indicator ?MATEEB WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator.	**CICES Provisioning Service, its subclass, MA Subclass, TEEB Subclass** and **Indicator.**

No	Competence Question	Query	Concept used
		?ES2 ESOnto:isKnownAs ?MATEEB. FILTER (?Indicator = ESOnto:foddercrop).} GROUP BY ?Indicator ?MATEEB	
3	Where is the location of the highest value of energy crop?	SELECT ?a ?ESV ?place WHERE {?a a ESOnto:energycrop; ESOnto:ESValue ?ESV; ESOnto:SPA ?place.} ORDER BY DESC (?ESV) LIMIT 1	**Ecosystem service value, Place, Service Providing Area (SPA), and Indicator (energy crop)**
4	Which grid has the highest value of provisioning service? With the assumption that provisioning service value is equal with the sum of the provisioning service subclass value.	SELECT SUM(?ESV) AS ?ESValue ?place WHERE { {SELECT distinct ?ES3 ?Indicator ?a WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator. ?a a ?Indicator}} ?a ESOnto:ESValue ?ESV; ESOnto:SPA ?place.} GROUP BY ?place ORDER BY DESC (?ESValue) limit 1	**Indicator, Ecosystem service value, Place, CICES: Provisioning Service and its subclass.**
5	Which valuation method is used to analyse the raw material ecosystem services?	SELECT ?VM WHERE {?a a ESOnto:TEEBRawMaterial; ESOnto:ValuationMethod ?VM.}	**Valuation method, TEEB: Raw Material**
6	What is the unit of the ecosystem services value?	SELECT ?b ?VUnit WHERE {?a a ?b; ESOnto:MUnit ?VUnit.} GROUP BY ?b ?VUnit	**Ecosystem services and Measurement unit**
7	What is the scale of the ES?	SELECT ?Scaletype ?ES ?scale WHERE {?Scaletype ESOnto:isKindOf ESOnto:Scale. ?ES ?Scaletype ?scale.}	**Scale, Scale type, Ecosystem service**

5. DISCUSSION AND CONCLUSION

The ontology development for ES proves that organised vocabularies (concepts) can support the communicating process and sharing a common knowledge about ES. Furthermore, it also supports the interoperability between ES classification frameworks. This chapter will discuss the overall works done in this thesis by taking into account the research objectives, methodology and results, answer to the research question and conclusion.

5.1. Discussion

The ontology of ES was built from three sources that fulfil the requirement to build ontology using the top-down approach. It consists of the Bon-in-a-Box list of tools, literature review and existing ontologies related to ES. The tools in Bon-in-a-Box list of tools can be divided into three kind of tools, the first is data analysis tools, the second is the catalogue tools and the thirds is the guidelines. Recall subsection 4.1 the data analysis tools can provide information about the input, process and output of ES. However, these tools do not always provide the information about the definition of the terminology, and the frameworks of ES for instance Co$ting Nature and WaterWorld. Furthermore, the specialisation process of the 'valuation method' concept is limited by the lack of the terminology information and framework.Jacobs et al. (2016) mentioned that there were diverse valuation methods and to integrate the ES Value more research is needed on the diverse purposes of valuation, ethical grounds and motivations of researchers. The 'valuation method' concept need further exploration later when the concept of the valuation become more concrete.

For the catalogue of tools, they provide important information about the concepts related to the ES. Based on the catalogue tools, the ES data were shared online. For instance, EUBON Europe biodiversity portal. These data were shared not in form of standard semantic web. This standard needs to be applied to enables the semantic web and linked data (Berners-Lee, 2006). In order to meet the standard, additional effort to convert the data into RDF data model was needed.

The guidelines describe the step by step of ES assessment and ES mapping process. In this study, eight ES guidelines that listed in the Bon-in-a-Box were used to extract information about the factor that influence the ES assessment and to confirm the concepts that gathered from the data analysis tools and catalogue tool. These guidelines were sufficient to confirm as they cover all the concepts gathered from the analysis and catalogue tools.

The extracted information from the three type of tools in Bon-in-a-Box were used to design the structure of the ontology that includes the concept of ES. It consists of concepts which affected the ES assessment. It also covered the interoperability between MA, TEEB and CICES V5.1 classification. Most of the ES data were acquired using the MA and TEEB, the interoperability information can be used to convert the ES data into CICES V5.1. MA and TEEB have two hierarchy level (class and subclass) and CICES V5.1 has five hierarchy level (section, division, group, class and class type). The subclass level of MA and TEEB have the same benefit are equivalent with the class level of CICES V5.1. The difference in the hierarchy level leads to condition that not all of the classes in CICES V5.1 can be represented in the MA and TEEB (Roy Haines-Young & Potschin, 2018). For example, the "non-aqueous natural abiotic ecosystem outputs" does not have equivalent class in MA and TEEB. In case other classification frameworks are added to the ontology such as the FEGS-CS, there is possibility of changes in the hierarchy and relationships type. Because the MA, TEEB and CICES V5.1 classified the ES based on the services while the FEGS-CS classified the ES based on the biological sphere and beneficiary (Geneletti et al., 2016).

The structure of the ontology was deployed using LTB web-applications. The LTB has advantages by providing a convenience way to build the visualisation of the ontology. It visualises the ES Ontology in an interactive user interface which provides the concepts map and information in the same page, also search function. To update the type of relationships the LTB user needs to update the link which use that type of relationships one by one. Beside that, it only can be accessed using University Twente accounts. However, the ESOnto can be deployed in other platforms.

After the deployment, the ES Ontology was formalised into RDF data model. The use case data which is in the excel format then converted to RDF data model using RDF Editor. The URI is needed as identifier of the data in the ES Ontology. The RDF data model is written using turtle language. The turtle language is straightforward and readable by human and machine compared to another syntax (Powell, 2015). Most of the user of this ontology are not familiar with the RDF data model. However, it needs to be applied in order to achieve the linked data. By using turtle language, the user can easily distinguish the components of ontology compare to another syntax. It also enables to retrieve and query the ES information.

The ESOnto was evaluated using two approaches; namely task-based evaluation and user-based evaluation. The task-based evaluation of the ontology measured the effectivity of the ESOnto. The task-based evaluation cover competence question related to interoperability between ES classification frameworks and aggregation of the ES value to the class of higher level based on the classification frameworks hierarchy. The evaluation result proves that the ESOnto can answer the competence question of the use case effectively refer to subsection 4.5.2. The user-based evaluation measured the usability and clarity of the ESOnto. The ESOnto succeed to communicate the knowledge of ES illustrated by around 70% of the participant agree that the ESOnto. It helps them to understand the ES Assessment, ES classification frameworks and its interoperability. The usability of the ontology is needed by the users to solve their problems using ontology (Baker & Cheung, 2007). The clarity of the relationships type needs to be improved based on the user-based evaluation results in subsection 4.5.1. The clarity can be achieved with more advanced evaluation using a peer-review based approach which allow the user to provide qualitative ratings on the ontology content for ontology evaluation (Supekar, 2005). Furthermore, the user-based evaluation has to consider on the issue of subjectivity as mentioned by Hlomani & Stacey (2014).

5.2. Conclusion

The development of ESOnto aims to serve interoperability between ecosystem classification frameworks and communicate information about ES domain. It achieved this by exploring the ecosystem service tools, data catalogue, literature and existing ontologies. The ESOnto is available in the turtle language which is readable by machine and is visualised in LTB which easier to understand by human. The user-based and task-based evaluation provide the usability, the clarity and the effectivity of the ESOnto. The ESOnto can be used for communicating the ES knowledge and interoperability between ES classification frameworks, standard of terminology and answering the ES competence questions.

However, there are some limitation and point to be improved in the next study as follows:

1. The use case in this study only used two dataset which was limited in the structure and information provided. So, it is recommended to test this ontology using bigger dataset from various source by developed the linked data of ES based on this study.
2. The ESOnto only cover MA, TEEB and CICES V5.1 and can be improved by adding the interoperability to other classification frameworks such as the FEGS-CS

5.3. Answering Research Questions

1. The input, the process, and the output of ES tools available in the ES domain

   The explored tools about ecosystem services had its frameworks and standards. The standard consists of ecosystem service terminologies, methodologies, tools and maps. This condition leads the input, and the output of the tools had its individual format and structured. It is almost impossible to combine data or use the output data as an input in different tool directly except the tools are made by the same institution or project. This characteristic also mentioned by Schmidt & Seppelt (2018) who analyse databases and conclude that all databases used individual standardisation concepts only a few provide documentation for archiving and retrieval of information across databases. These characteristics made the data discovery across different databases, and processing of information need significant effort and time.

2. The classification method, framework and terminologies.
   In the ecosystem service domain there were several classification methods and frameworks such mentioned in Section 2.2 and 4.1.1. Some of the classifications were created based on different frameworks but has same classification such as the MA and TEEB, there were also classification which used the same frameworks but has different classification such as TEEB, CICES V5.1 and FEGS-CS. But there were some concepts which used in all of the frameworks such as ecosystem service, ecosystem function and ecosystem structure and benefit. Even though, the definition of those concepts could be different such analysed by La Notte et al. (2017). In this study, the definition selection only based on the closest definition which linked the concept to other related concepts. The criteria of the definition selection can be improved to get more proper definition which will be used as the standard vocabularies in ES domain, besides that this study only covers MA, TEEB and CICES V5.1 classification frameworks so the ESOnto still open opportunity to be improved and expanded.
3. The relations between the input, the output, the classification, the framework and terminologies.
   Different terminologies and definition from the classification, frameworks, input data and output could be grouped into concepts which generate other concepts, concepts which affect the assessment of ES and concepts which represent and become properties of other concepts as mentioned in Section 4.1.2 .
4. Design and develop the domain ontology of ES
   The existing condition and characteristics of the ES Ontology was semi unstructured due to different standard of the data format, structure, data type, definition, classification and frameworks. Building the ES Ontology was challenging on defining the relationship for several typologies but needed to maintain the concistency of the relationship so it not only used by specific concepts but also can be used for different concepts. For example the valuation method was classified in several ways such done by Cord et al. (2017) which classify the valuation methods into bundles, trade-offs and synergies based on the relationship between ecosystem services. The valuation methods typology also can be defined based on the value characteristics whether it is economic value or non-economic value which used in ValuES. The Generic Ontology Development method and top-down strategy used in this study was very helpful to design the ES Ontology.
5. The purpose and coverage of the ES Ontology
   This ontology was intended to cover the interoperability problem caused by the classification frameworks. Besides that, the ES Ontology also built based on the cascade conceptual frameworks and ES assessment and mapping process.
6. The classes and properties of the ES Ontology.
   The classes and properties of the ES Ontology were built in coarse granularity. It captured the general concepts of the ES assessment and mapping based on the typology as shown in Appendix A and Section 4.2.
7. How will the classes and properties be related to each other?
   The classes are related based on their characteristics, whether it generates, affects, represent or properties of the other class. The relationships were presented in Section 4.2. and Appendix A parts the concepts and relationships
8. The rules and constraints in the ES domain.
   The interoperability relation between ecosystem services classification frameworks are going in one way. For example: CICES cultivated plants for nutritional purpose is known as MA food, but MA food not necessarily equal to the CICES cultivated plants for nutritional purpose. This rule was

implemented by the arrow of relationship is only going in one way. However, in LTB the two-way relationships were not possible because LTB only provide one-way relationships.

9. How to test the quality of ES Ontology?
   Hlomani & Stacey, (2014) mentioned four ways to evaluate ontology and also provides the metrics of the evaluation such as the accuracy, adaptability, clarity, cohesion, completeness, computational efficiency, conciseness, consistency, coupling and coverage. The evaluation of this study was measured the usability, clarity and coverage of the ESOnto. The user-based evaluation was used to measure the usability and clarity. The task-based evaluation was used to measure the coverage of the ESOnto base on the use case. The results of the usability were good as more than 70 percent participants can answer the true/false question about ES and the clarity of the relationship is not well defined as the participants choose different relationship to use in the ESOnto. The limitation of this evaluation because of limited participants in the survey.
10. Relevant queries can be applied in ES Ontology to solve the use case
    The use case and relevant query was composed base on the problem which solved by this ontology. The first is the interoperability problem, the query was developed to ask what the class of a certain ES is in different classification frameworks and aggregating ES service value into the higher class of ecosystem service. The second is about the communication problems, so the query was developed by asking about the ES Value, the Valuation methods, the indicators which used and the location.

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APPENDIX A THE DOCUMENTATION OF ESONTO

The concepts/terminology and its definition

No	Cconcepts	Definition	Source
1	Abiotic	Abiotic component of ecosystem includes basic inorganic elements and compounds, such as soil, water, oxygen, calcium carbonates, phosphates and a variety of organic compounds (by-products of organic activities or death). It also includes such physical factors and ingredients as moisture, wind currents and solar radiation.	(Monga, Radhika, & Sharma, 2017)
2	Benefit	The direct and indirect outputs from ecosystem that have been turned into goods or experiences that are no longer functionally connected to the systems from which they were derived. Benefits are things that can be valued either in monetary or social terms.	(Potschin et al., 2014)
3	Biome	A biome is an ecosystem to which resident ecological communities have evolved adaptations.	ENVO - http://purl.obolibrary.org/obo/ENVO_00000428
4	Biotic	The biotic components include all living organisms present in the environmental system.	(Monga et al., 2017)
5	Chart	A chart is a figure that displays the relationship among tabular numeric data, functions or some kinds of qualitative structures	http://semanticscience.org/resource/SIO_000904
6	cices: Animals		
7	cices: Biomass	The mass of tissues in living organisms in a population, ecosystem, or spatial unit derived by the fixation of energy though organic processes (Common usage & MA (2005)). The collection of plants or animals for nutrition, material and energy purposes.	(Potschin et al., 2014)
8	cices: Breed new strain or variety		
9	cices: Cultivated aquatic plant	Plants cultivated by in- situ aquaculture for nutrition, material and energy purpose	

No	Cconcepts	Definition	Source
10	cices: Cultivated terrestrial plant	cultivated terrestrial plant for nutrition, material and energy	
11	cices: Cultural service	All the non-material, and normally non-rival and non-consumptive, outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people.	(Roy Haines-Young & Potschin, 2018)
12	cices: Design and construction of new biological entities		
13	cices: Energy purpose	used as source of energy	
14	cices: Genetic material	The collection of materials for the establishment of maintenance of new stands or population of plants or animals, the use of plants and animals at the whole organism level for breeding purposes, and gene extraction. The collection of materials, such as seeds or spores, for reproduction is therefore excluded from the other classes dealing with 'materials'. It should also be noted that the service 'maintenance of nursery populations', which is under the regulating and maintenance section of CICES is distinct from the collection of materials for establishing or maintaining a population.	(Roy Haines-Young & Potschin, 2018)
15	cices: Maintaining or establishing a population		
16	cices: Material purpose		
17	cices: Nutritional purpose	The ecological contribution that can be harvested and used as raw material for the production of food.	(Roy Haines-Young & Potschin, 2018)
18	cices: Organism		
19	cices: Plants, algae or fungi		
20	cices: Provisioning service	This Section covers all nutritional, non-nutritional material and energetic outputs from living systems as well as abiotic outputs (including water)	(Roy Haines-Young & Potschin, 2018)
21	cices: Reared animals	reared animal for nutrition, material and energy	

No	Cconcepts	Definition	Source
22	cices: Reared aquatic animal	reared aquatic animal for nutrition, material and energy	
23	cices: Regulation and maintenance service	All the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort, together with abiotic equivalents.	(Roy Haines-Young & Potschin, 2018)
24	cices: Wild animal	**wild** animal (terrestrial and aquatic) for nutrition, materials or energy	
25	cices: Wild plant	**wild** plant (terrestrial and aquatic) for nutrition, materials or energy	
26	Direct driver	A direct driver unequivocally influences ecosystem processes. Source:	(Nelson, 2005)
27	Directional	Where the service provision benefits a specific location due to the flow direction.	(Fisher et al., 2009)
28	Driver of change	Driver is any natural or humaninduced factor that directly or indirectly causes a change in an ecosystem. A direct driver unequivocally influences ecosystem processes. An indirect driver operates more diffusely, by altering one or more direct drivers.	(Nelson, 2005)
29	Ecological scale	The spatial scale of ecosystem process or hierarchy of ecology.	(Hein et al., 2006)
30	Economic value	Value based on currency. Example: price of carbon based on the landuse in euro.	
31	Ecosystem	An environmental system which includes both living and non-living components.	ENVO : http://purl.obolibrary.org/obo/ENVO_01001110 https://en.wikipedia.org/wiki/Ecosystem
32	Ecosystem function	The subset of the interactions between biophysical structures, and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services.	(Potschin et al., 2014)
33	Ecosystem service	Ecosystem service is the contributions that ecosystems make to human well-being, and distinct from the goods and benefits that people subsequently derive from them.	(Roy Haines-Young & Potschin, 2018)
34	Ecosystem service value	Ecosystem values are measures of how important Ecosystem services are to human well being. Economists measure the value by estimating the amount people are willing to pay to preserve or enhance the services. However some services of ecosystems like wildlife vieweing, climate change regulation are not traded in markets so people's willingness to pay may not be clearly defined. This does not mean that the services have no value, or cannot be valued in monetary terms.	https://www.ecosystemvaluation.org/1-02.htm

No	Cconcepts	Definition	Source
35	Ecosystem structure	A static characteristic of an ecosystem that is measured as a stock or volume of material or energy, or the composition and distribution of biophysical elements.	(Potschin et al., 2014)
36	Family	A group of people related by common descent, a lineage	http://dbpedia.org/ontology/Family
37	Global Scale	has dimension more than 1.000.000 km2	(Hein et al., 2006)
38	Human	An agent (eg. person, group, software or physical artifact).	FOAF - http://xmlns.com/foaf/spec/#term_Agent
39	Indicator	Information based on measured data used to represent a particular attribute, characteristic, or property of a system.	(Millennium Ecosystem Assessment Board, 2005)
40	Indirect driver	An indirect driver operates more diffusely, by altering one or more direct drivers.	(Nelson, 2005)
41	Individual	a person	
42	Individual organism	has dimension less than 1 km2	(Hein et al., 2006)
43	Input data		
44	In-situ	Where the services are provided and the benefits are realized in the same location.	(Fisher et al., 2009)
45	Institutional scale	Hierarchy of socio-economic system.	(Hein et al., 2006)
46	International		
47	Landscape	has dimension 10.000- 1.000.000 km2	(Hein et al., 2006)
48	long-term service	decades	
49	ma: Aesthetic value	Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, "scenic drives," and the selection of housing locations.	(Millennium Ecosystem Assessment Board, 2005)
50	ma: Air quality regulation	Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.	(Millennium Ecosystem Assessment Board, 2005)
51	ma: Aquaculture		
52	ma: Biochemicals, natural, medicines, pharmaceuticals	Biochemicals, natural medicines, and pharmaceuticals. Many medicines, biocides, food additives such as alginates, and biological materials are derived from ecosystems.	(Millennium Ecosystem Assessment Board, 2005)
53	ma: Biological control	Ecosystem changes affect the prevalence of crop and livestock pests and diseases.	(Millennium Ecosystem Assessment Board, 2005)
54	ma: Capture fisheries		

No	Cconcepts	Definition	Source
55	ma: Climate regulation	Ecosystems influence climate both locally and globally	(Millennium Ecosystem Assessment Board, 2005)
56	ma: Cotton, hemp, silk		
57	ma: crops		
58	ma: Cultural diversity	The diversity of ecosystems is one factor influencing the diversity of cultures.	(Millennium Ecosystem Assessment Board, 2005)
59	ma: Cultural heritage value	Many societies place high value on the maintenance of either historically important landscapes ("cultural landscapes") or culturally significant species.	(Millennium Ecosystem Assessment Board, 2005)
60	ma: Cultural service	Cultural services are the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences.	(Capistrano et al., 2005)
61	ma: Disease regulation	Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.	(Millennium Ecosystem Assessment Board, 2005)
62	ma: Educational value	Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.	(Millennium Ecosystem Assessment Board, 2005)
63	ma: Erosion regulation	Vegetative cover plays an important role in soil retention and the prevention of landslides.	(Millennium Ecosystem Assessment Board, 2005)
64	ma: Fiber	Materials such as wood, jute, hemp, silk, and many other products derived from ecosystems.	(Millennium Ecosystem Assessment Board, 2005)
65	ma: Food	This includes the vast range of food products derived from plants, animals, and microbes.	(Millennium Ecosystem Assessment Board, 2005)
66	ma: Fresh water	Fresh water is another example of linkages between categories—in this case, between provisioning and regulating services.	(Millennium Ecosystem Assessment Board, 2005)
67	ma: Fuel	Wood, dung, and other biological materials serve as sources of energy.	(Millennium Ecosystem Assessment Board, 2005)
68	ma: Genetic resources	This includes the genes and genetic information used for animal and plant breeding and biotechnology.	(Millennium Ecosystem Assessment Board, 2005)
69	ma: global climate regulation		
70	ma: Inspiration	Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising.	(Millennium Ecosystem Assessment Board, 2005)
71	ma: Livestock		

No	Cconcepts	Definition	Source
72	ma: Natural hazard regulation	The presence of coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves.	(Millennium Ecosystem Assessment Board, 2005)
73	ma: Pollination	Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators.	(Millennium Ecosystem Assessment Board, 2005)
74	ma: Provisioning service	Provisioning services are the products people obtain from ecosystems, such as food, fuel, fiber, fresh water, and genetic resources.	(Capistrano et al., 2005)
75	ma: Recreation and ecotourism	Recreation and ecotourism. People often choose where to spend their leisure time based in part on the characteristics of the natural or cultivated landscapes in a particular area.	(Millennium Ecosystem Assessment Board, 2005)
76	ma: Regional and local climate regulation		
77	ma: Regulating service	Regulating services are the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification.	(Capistrano et al., 2005)
78	ma: Sense of place	Many people value the "sense of place" that is associated with recognized features of their environment, including aspects of the ecosystem.	(Millennium Ecosystem Assessment Board, 2005)
79	ma: Social relation	Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.	(Millennium Ecosystem Assessment Board, 2005)
80	ma: Spritual and religious value	Many religions attach spiritual and religious values to ecosystems or their components.	(Millennium Ecosystem Assessment Board, 2005)
81	ma: Supporting service	Supporting services are those that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation.	(Capistrano et al., 2005)
82	ma: Timber		
83	ma: Water purification and waste treatment	Ecosystems can be a source of impurities in fresh water but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems.	(Millennium Ecosystem Assessment Board, 2005)

No	Cconcepts	Definition	Source
84	ma: Water regulation	The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.	(Millennium Ecosystem Assessment Board, 2005)
85	ma: Wild food		
86	ma: Wood fuel		
87	Map	Map is a representation, usually on a flat surface, as of the features of an area of the earth or a portion of theheavens, showing them in their respective forms, sizes, and relationships according to some conventionof representation.	https://www.dictionary.com/browse/map
88	Measurement Unit	Measurement **unit** of ecosystem service value which can be in economic value (monetary **unit**) or in other **unit**.	Author
89	Model	This method using process models in which indicators are used as variables in the equation.	(Egoh, Drakou, Willemen, Maes, & Dunbar, 2012)
90	Municipal		
91	National		
92	Non-economic value	The value is not based on money. Example: number of species, supply value, biodiversity value.	Author
93	Numeric Value	Information in the form of a numeral contained in a data field.	http://purl.obolibrary.org/obo/NCIT_C81274
94	Omni-directional	Where the services are provided in one location but benefit the surrounding landscape without directional bias.	(Fisher et al., 2009)
95	Percentage	A fraction or ratio with 100 understood as the denominator.	http://purl.obolibrary.org/obo/NCIT_C25613
96	Place	Immobiles things or location.	http://dbpedia.org/ontology/Place
97	Place Relationship	The relationship between service providing area and service benefiting area. They can be realted based on the geometry relationship or the supply and use quantity of the services.	Author
98	Plot Scale	has dimension less than 1 km2	(Hein et al., 2006)
99	Primary Indicator	Primary indicators are reflecting the proxy used to measure ecosystem service.	(Egoh et al., 2012)
100	Primary method	Primary method use collection of primary data through direct observations.	(Egoh et al., 2012)

No	Cconcepts	Definition	Source
101	Provincial		
102	Proxy method	proxy methods in which a single or combined indicators are used to define ES, such as composite indicators	(Egoh et al., 2012)
103	Range value	**Range** value is the difference between the lowest and highest numerical values; the limits or scale of variation.	
104	Scale	Scale refers to measurements and dimensions in space and time (i.e. extent, grain, size and resolution), but has also referred to the level of organisation of a system. Scale can be the spatial or temporal dimension of an object or process (e.g. size of area or length of time), characterized by both grain and extent (Peterson and Parker, 1998). The grain is the finest level of spatial resolution possible with a given data set (e.g. pixel size for raster data). The extent is the size of the study area or the duration of time under consideration.	(Peterson & Parker, 1998)
105	Scale of consumption	The spatial and temporal scale of Service benefiting area. The beneficiary of ecosystem service can be classified into a hierarchy of socioeconomic institutions (Becker and Ostrom, 1995; O'Riordan et al., 1998), which ranges from the lowest institutional level, such as individuals and households, to higher level such as communities or municipalities, then to states or provinces, to nation, and the world. Stakeholders at each scale pay attention to the ecosystem service in which they have an interest and their utilization of ecosystem service likewise may vary greatly.	(Zhang et al., 2013)

No	Cconcepts	Definition	Source
106	Scale of management	The scale on ecosystem management and conservation plans. The interests that humans obtain from an ecosystem are highly related to its spatial and temporal scales. Ecosystem management should be in accordance with the characteristics of the ecosystem. Ecosystem valuation results at a global scale are unable to meet the need of the policy making for a nation or a region. It is critical to make decisions on landscape level conservation and management plans and ecosystem management at an appropriate institutional scale and implement ecosystem conservation and landuse planning (Tacconi, 2000). Separating ecosystem services into distinct scales is important in allocating interests appropriately to the stakeholders.	(Zhang et al., 2013)
107	Scale of observation	The scale of the boundaries areas for the ecosystem assessment. Defining the ecosystem boundaries based on easily identified physical boundaries, such as a lake or a stream, often is inadequate to address the complexity of natural systems within the question being addressed. However, some ecosystem processes or features coincide with the physical boundaries of certain area. It is challenging to define ecosystem boundaries since highly mobile organisms and constituents interact at multiple spatial and temporal scales.	(Zhang et al., 2013)
108	Scale of production	The spatial and temporal extent of service providing area. In terms of temporal dimension, ecosystem service can be divided into long-term service (decades), seasonal service (year) and short-term service (hours). In terms of spatial dimension, ecosystem service can be considered as global service or regional service.	(Zhang et al., 2013)
109	Seasonal service	year	
110	Secondary indicator	Secondary indicators provide the necessary information used to compose the Primary Indicator.	(Egoh et al., 2012)
111	Service benefiting area	Location of the service demands or where the benefits of ecosystem are required.	(Syrbe & Walz, 2012)
112	Service connecting area	The area of intervening space when service providing area and service benefit area are not contiguous.	(Syrbe & Walz, 2012)
113	Service providing area	The spatial units that are the source of landscape services.	(Fisher et al., 2009)
114	short-term service	Hours	

No	Cconcepts	Definition	Source
115	teeb : Waste-water treatment	Ecosystems such as wetlands filter both human and animal waste and act as a natural buffer to the surrounding environment. Through the biological activity of microorganisms in the soil, most waste is broken down. Thereby pathogens (disease causing microbes) are eliminated, and the level of nutrients and pollution is reduced.	(Elmqvist et al., 2010)
116	teeb: Aesthetic apprecation and inspiration	Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and the natural environment have been intimately related throughout human history. Biodiversity, ecosystems and natural landscapes have been the source of inspiration for much of our art, culture and increasingly for science.	(Elmqvist et al., 2010)
117	teeb: Biological control	Ecosystems are important for regulating pests and vector borne diseases that attack plants, animals and people. Ecosystems regulate pests and diseases through the activities of predators and parasites. Birds, bats, flies, wasps, frogs and fungi all act as natural controls.	(Elmqvist et al., 2010)
118	teeb: Carbon sequestration and storage	Ecosystems regulate the global climate by storing and sequestering greenhouse gases. As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues. In this way forest ecosystems are carbon stores. Biodiversity also plays an important role by improving the capacity of ecosystems to adapt to the effects of climate change.	(Elmqvist et al., 2010)
119	teeb: Cultural service	The nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values. (MA, 2005a)	(Elmqvist et al., 2010)
120	teeb: Erosion prevention and maintenance of soil fertility	Soil erosion is a key factor in the process of land degradation and desertification. Vegetation cover provides a vital regulating service by preventing soil erosion. Soil fertility is essential for plant growth and agriculture and well functioning ecosystems supply the soil with nutrients required to support plant growth.	(Elmqvist et al., 2010)
121	teeb: Food	Ecosystems provide the conditions for growing food. Food comes principally from managed agro-ecosystems but marine and freshwater systems or forests also provide food for human consumption. Wild foods from forests are often underestimated.	(Elmqvist et al., 2010)

No	Cconcepts	Definition	Source
122	teeb: Fresh water	Ecosystems play a vital role in the global hydrological cycle, as they regulate the flow and purification of water. Vegetation and forests influence the quantity of water available locally.	(Elmqvist et al., 2010)
123	teeb: Genetic resources	Genetic resources is important in support of improved breeding programs (e.g. for crop plants, farm animals, fisheries and aquaculture), with a wide range of objectives for increasing yield, resistance to disease, optimization of nutritional value, and adaptation to local environment and climate change.	(Elmqvist et al., 2010)
124	teeb: Habitat for species	Habitats provide everything that an individual plant or animal needs to survive: food; water; and shelter. Each ecosystem provides different habitats that can be essential for a species' lifecycle. Migratory species including birds, fish, mammals and insects all depend upon different ecosystems during their movements.	(Elmqvist et al., 2010)
125	teeb: Habitat or supporting service	The importance of ecosystems to provide living space for resident and migratory species (thus maintaining the gene pool and nursery service).	(Elmqvist et al., 2010)
126	teeb: Local climate and air quality	Trees provide shade whilst forests influence rainfall and water availability both locally and regionally. Trees or other plants also play an important role in regulating air quality by removing pollutants from the atmosphere.	(Elmqvist et al., 2010)
127	teeb: Maintenance of genetic diversity	Genetic diversity is the variety of genes between and within species populations. Genetic diversity distinguishes different breeds or races from each other thus providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock. Some habitats have an exceptionally high number of species which makes them more genetically diverse than others and are known as 'biodiversity hotspots'.	(Elmqvist et al., 2010)
128	teeb: Medicinal resource	Ecosystems and biodiversity provide many plants used as traditional medicines as well as providing the raw materials for the pharmaceutical industry. All ecosystems are a potential source of medicinal resources.	(Elmqvist et al., 2010)

No	Cconcepts	Definition	Source
129	teeb: Moderation of extreme event	Extreme weather events or natural hazards include floods, storms, tsunamis, avalanches and landslides. Ecosystems and living organisms create buffers against natural disasters, thereby preventing possible damage. For example, wetlands can soak up flood water whilst trees can stabilize slopes. Coral reefs and mangroves help protect coastlines from storm damage.	(Elmqvist et al., 2010)
130	teeb: Ornamental resource	Biodiversity has played an iconic, ornamental role throughout the development of human society. Uses of plant and animal parts, especially plumage of birds, have been important in conferring individual status, position and influence. Ornamental plants are typically grown for the display of their flowers but other common ornamental features include leaves, scent, fruit, stem and bark. Considerable exploration effort, and some of the rationale of the voyages of discovery, was underpinned by the search for and transfer of species to be enjoyed in parks, gardens, private greenhouses and zoos by wealthy members of societies less endowed with biodiversity.	(Elmqvist et al., 2010)
131	teeb: Pollination	Insects and wind pollinate plants and trees which is essential for the development of fruits, vegetables and seeds. Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats. Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee (Klein et al. 2007).	(Elmqvist et al., 2010)
132	teeb: Provisioning service	Provisioning Services are ecosystem service that describe the material or energy outputs from ecosystems. They include food, water and other resources.	(Elmqvist et al., 2010)
133	teeb: Raw material	Ecosystem provide a great diversity of materials for construction and fuel including wood, biofuels and plant oils that are directly derived from wild and cultivated plant species.	(Elmqvist et al., 2010)
134	teeb: Recreation and mental and physical health	Walking and playing sports in green space is not only a good form of physical exercise but also lets people relax. The role that green space plays in maintaining mental and physical health is increasingly being recognized, despite difficulties of measurement.	(Elmqvist et al., 2010)

No	Cconcepts	Definition	Source
135	teeb: Regulating service	Regulating Services are the services that ecosytems provide by acting as regulators eg. regulating the quality of air and soil or by providing flood and disease control.	(Elmqvist et al., 2010)
136	teeb: Spiritual experience and sense of place	In many parts of the world natural features such as specific forests, caves or mountains are considered sacred or have a religious meaning. Nature is a common element of all major religions and traditional knowledge, and associated customs are important for creating a sense of belonging.	(Elmqvist et al., 2010)
137	teeb: Tourism	Ecosystems and biodiversity play an important role for many kinds of tourism which in turn provides considerable economic benefits and is a vital source of income for many countries. In 2008 global earnings from tourism summed up to US$ 944 billion. Cultural and eco-tourism can also educate people about the importance of biological diversity.	(Elmqvist et al., 2010)
138	Temporal scale	Relating to time or limited by time.	NCIT - http://purl.obolibrary.org/obo/NCIT_C73990
139	Valuation method	It is methods used to estimate both the market and non-market components of the value of ecosystem service.	(Costanza et al., 1997)

The statistic information of ESOnto

Statistics item	**Total concepts**	**Without any (text) content**	**Without definition**	**Without prior knowledge**	**Without learning outcomes**	**excel.sheet.general-concept-statistics.no-relations**	**More than 5 relations**	**More than 10 relations**
Count	139	24	24	139	139	0	23	5

The relationships used in ESOnto

Number of relationships per type	**Number of relationships**
Relationship "is a kind of"	117
Relationship "is part of"	2
Relationship "is affected by"	14
Relationship "is intended for"	24
Relationship "is generated by"	5
Relationship "is retrieved by"	1
Relationship "is represented by"	12
Relationship "is used by"	6
Relationship "is located in"	3
Relationship "is known as"	17
Relationship "is properties of"	11

The concepts and its relationships

Concept	**Outgoing relations**			
Abiotic	* is part of Ecosystem structure			
Benefit	* is generated by Ecosystem service	* is located in Service benefiting area	* is used by Human	
Biome	* is a kind of Ecological scale			
Biotic	* is part of Ecosystem structure			
Biotic	cices: Genetic material is a kind of *	cices: Biomass is a kind of *	cices: Organism is a kind of *	
Chart	Ecosystem service value is represented by *			

Concept	Outgoing relations			
cices: Animals	* is intended for cices: Breed new strain or variety	* is intended for cices: Maintaining or establishing a population	* is a kind of cices: Genetic material	
cices: Biomass	* is a kind of Biotic	* is a kind of cices: Provisioning service		
cices: Biomass	cices: Cultivated aquatic plant is a kind of *	cices: Cultivated terrestrial plant is a kind of *	cices: Reared animals is a kind of *	cices: Reared aquatic animal is a kind of *
cices: Biomass	cices: Wild animal is a kind of *	cices: Wild plant is a kind of *		
cices: Breed new strain or variety	cices: Animals is intended for *	cices: Plants, algae or fungi is intended for *		
cices: Cultivated aquatic plant	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
cices: Cultivated terrestrial plant	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
cices: Cultural service	* is a kind of Ecosystem service			
cices: Design and construction of new biological entities	cices: Organism is intended for *	cices: Plants, algae or fungi is intended for *		
cices: Energy purpose	* is a kind of ma: Fiber	* is a kind of ma: Fuel	* is known as ma: Biochemicals, natural, medicines, pharmaceuticals	* is known as teeb: Medicinal resource
cices: Energy purpose	* is known as teeb: Raw material			

Concept	**Outgoing relations**			
cices: Energy purpose	cices: Cultivated aquatic plant is intended for *	cices: Cultivated terrestrial plant is intended for *	cices: Reared animals is intended for *	cices: Reared aquatic animal is intended for *
cices: Energy purpose	cices: Wild animal is intended for *	cices: Wild plant is intended for *		
cices: Genetic material	* is a kind of Biotic	* is known as ma: Genetic resources	* is a kind of cices: Provisioning service	* is known as teeb: Genetic resources
cices: Genetic material	cices: Animals is a kind of *	cices: Organism is a kind of *	cices: Plants, algae or fungi is a kind of *	
cices: Maintaining or establishing a population	cices: Animals is intended for *	cices: Plants, algae or fungi is intended for *		
cices: Material purpose	* is known as ma: Biochemicals, natural, medicines, pharmaceuticals	* is known as teeb: Medicinal resource	* is known as teeb: Raw material	
cices: Material purpose	cices: Cultivated aquatic plant is intended for *	cices: Cultivated terrestrial plant is intended for *	cices: Reared animals is intended for *	cices: Reared aquatic animal is intended for *
cices: Material purpose	cices: Wild animal is intended for *	cices: Wild plant is intended for *		
cices: Nutritional purpose	* is known as teeb: Food			
cices: Nutritional purpose	cices: Cultivated aquatic plant is intended for *	ma: Food is known as *	cices: Cultivated terrestrial plant is intended for *	cices: Reared animals is intended for *
cices: Nutritional purpose	cices: Reared aquatic animal is intended for *	cices: Wild animal is intended for *	cices: Wild plant is intended for *	

Concept	**Outgoing relations**			
cices: Organism	* is a kind of Biotic	* is a kind of cices: Genetic material	* is intended for cices: Design and construction of new biological entities	
cices: Plants, algae or fungi	* is a kind of cices: Genetic material	* is intended for cices: Breed new strain or variety	* is intended for cices: Design and construction of new biological entities	* is intended for cices: Maintaining or establishing a population
cices: Provisioning service	* is a kind of Ecosystem service			
cices: Provisioning service	cices: Genetic material is a kind of *	cices: Biomass is a kind of *		
cices: Reared animals	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
cices: Reared aquatic animal	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
cices: Regulation and maintenance service	* is a kind of Ecosystem service			
cices: Wild animal	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
cices: Wild plant	* is intended for cices: Material purpose	* is intended for cices: Nutritional purpose	* is a kind of cices: Biomass	* is intended for cices: Energy purpose
Direct driver	* is a kind of Driver of change			
Directional	* is a kind of Place Relationship			
Driver of change	Direct driver is a kind of *	Indirect driver is a kind of *	Indicator is affected by *	Ecosystem service value is affected by *
Driver of change	Ecosystem service is affected by *	Valuation method is affected by *		

Concept	**Outgoing relations**			
Ecological scale	* is properties of Scale of production	* is a kind of Scale	* is properties of Scale of management	* is properties of Scale of observation
Ecological scale	Biome is a kind of *	Plot Scale is a kind of *	Global Scale is a kind of *	Individual organism is a kind of *
Ecological scale	Ecosystem is a kind of *	Landscape is a kind of *		
Economic value	* is a kind of Input data	* is used by Valuation method		
Ecosystem	* is represented by Ecosystem structure	* is a kind of Ecological scale	* is affected by Human	
Ecosystem	Ecosystem service is generated by *	Ecosystem function is generated by *		
Ecosystem function	* is affected by Ecosystem structure	* is located in Service providing area	* is generated by Ecosystem	
Ecosystem function	Ecosystem service is generated by *			
Ecosystem service	* is affected by Driver of change	* is generated by Ecosystem function	* is located in Place	* is affected by Ecosystem structure
Ecosystem service	* is generated by Ecosystem	* is represented by Indicator		
Ecosystem service	cices: Cultural service is a kind of *	Benefit is generated by *	Scale is properties of *	cices: Provisioning service is a kind of *
Ecosystem service	cices: Regulation and maintenance service is a kind of *	ma: Cultural service is a kind of *	ma: Provisioning service is a kind of *	ma: Regulating service is a kind of *
Ecosystem service	ma: Supporting service is a kind of *	teeb: Cultural service is a kind of *	teeb: Habitat or supporting service is a kind of *	teeb: Provisioning service is a kind of *
Ecosystem service	teeb: Regulating service is a kind of *	Ecosystem service value is generated by *		

Concept	**Outgoing relations**			
Ecosystem service value	* is affected by Driver of change	* is represented by Map	* is generated by Ecosystem service	* is retrieved by Valuation method
Ecosystem service value	* is affected by Indicator	* is represented by Chart	* is represented by Numeric Value	* is represented by Percentage
Ecosystem service value	* is represented by Range value			
Ecosystem structure	Abiotic is part of *	Biotic is part of *	Ecosystem service is affected by *	Ecosystem function is affected by *
Ecosystem structure	Ecosystem is represented by *			
Family	* is a kind of Institutional scale			
Global Scale	* is a kind of Ecological scale			
Human	Ecosystem is affected by *	Scale of consumption is affected by *	Benefit is used by *	Scale of management is affected by *
Indicator	* is affected by Driver of change	* is represented by Map		
Indicator	Primary Indicator is a kind of *	Ecosystem service value is affected by *	Ecosystem service is represented by *	Valuation method is affected by *
Indicator	Secondary indicator is a kind of *	Input data is affected by *		
Indirect driver	* is a kind of Driver of change			
Individual	* is a kind of Institutional scale			
Individual organism	* is a kind of Ecological scale			

Concept	**Outgoing relations**			
Input data	* is affected by Indicator	* is represented by Map	* is used by Valuation method	
Input data	Non-economic value is a kind of *	Economic value is a kind of *		
In-situ	* is a kind of Place Relationship			
Institutional scale	* is properties of Scale of consumption	* is a kind of Scale	* is properties of Scale of management	
Institutional scale	Individual is a kind of *	Municipal is a kind of *	Provincial is a kind of *	National is a kind of *
Institutional scale	International is a kind of *	Family is a kind of *		
International	* is a kind of Institutional scale			
Landscape	* is a kind of Ecological scale			
long-term service	* is a kind of Temporal scale			
ma: Aesthetic value	* is a kind of ma: Cultural service			
ma: Air quality regulation	* is a kind of ma: Regulating service			
ma: Aquaculture	* is a kind of ma: Food			
ma: Biochemicals, natural, medicines, pharmaceuticals	* is a kind of ma: Provisioning service	* is known as teeb: Medicinal resource		
ma: Biochemicals, natural, medicines, pharmaceuticals	cices: Energy purpose is known as *	cices: Material purpose is known as *		
ma: Biological control	* is a kind of ma: Regulating service			
ma: Capture fisheries	* is a kind of ma: Food			

Concept	**Outgoing relations**			
ma: Climate regulation	* is a kind of ma: Regulating service			
ma: Climate regulation	ma: global climate regulation is a kind of *	ma: Regional and local climate regulation is a kind of *		
ma: Cotton, hemp, silk	* is a kind of ma: Fiber			
ma: crops	* is a kind of ma: Food			
ma: Cultural diversity	* is a kind of ma: Cultural service			
ma: Cultural heritage value	* is a kind of ma: Cultural service			
ma: Cultural service	* is a kind of Ecosystem service			
ma: Cultural service	ma: Aesthetic value is a kind of *	ma: Cultural diversity is a kind of *	ma: Cultural heritage value is a kind of *	ma: Educational value is a kind of *
ma: Cultural service	ma: Inspiration is a kind of *	ma: Recreation and ecotourism is a kind of *	ma: Sense of place is a kind of *	ma: Social relation is a kind of *
ma: Cultural service	ma: Spritual and religious value is a kind of *	teeb: Cultural service is known as *		
ma: Disease regulation	* is a kind of ma: Regulating service			
ma: Educational value	* is a kind of ma: Cultural service			
ma: Erosion regulation	* is a kind of ma: Regulating service			
ma: Fiber	* is a kind of ma: Provisioning service	* is known as teeb: Raw material		

Concept	**Outgoing relations**			
ma: Fiber	ma: Cotton, hemp, silk is a kind of *	cices: Energy purpose is a kind of *	ma: Timber is a kind of *	ma: Wood fuel is a kind of *
ma: Food	* is a kind of ma: Provisioning service	* is known as cices: Nutritional purpose	* is known as teeb: Food	
ma: Food	ma: Aquaculture is a kind of *	ma: Capture fisheries is a kind of *	ma: crops is a kind of *	ma: Livestock is a kind of *
ma: Food	ma: Wild food is a kind of *			
ma: Fresh water	* is a kind of ma: Provisioning service	* is known as teeb: Fresh water		
ma: Fuel	* is a kind of ma: Provisioning service			
ma: Fuel	cices: Energy purpose is a kind of *			
ma: Genetic resources	* is a kind of ma: Provisioning service	* is known as teeb: Genetic resources		
ma: Genetic resources	cices: Genetic material is known as *			
ma: global climate regulation	* is a kind of ma: Climate regulation			
ma: Inspiration	* is a kind of ma: Cultural service			
ma: Livestock	* is a kind of ma: Food			
ma: Natural hazard regulation	* is a kind of ma: Regulating service			
ma: Pollination	* is a kind of ma: Regulating service			
ma: Provisioning service	* is a kind of Ecosystem service			

Concept	**Outgoing relations**			
ma: Provisioning service	ma: Biochemicals, natural, medicines, pharmaceuticals is a kind of *	ma: Fiber is a kind of *	ma: Fuel is a kind of *	ma: Genetic resources is a kind of *
ma: Provisioning service	ma: Food is a kind of *	ma: Fresh water is a kind of *		
ma: Recreation and ecotourism	* is a kind of ma: Cultural service			
ma: Regional and local climate regulation	* is a kind of ma: Climate regulation			
ma: Regulating service	* is a kind of Ecosystem service			
ma: Regulating service	ma: Air quality regulation is a kind of *	ma: Climate regulation is a kind of *	ma: Water regulation is a kind of *	ma: Erosion regulation is a kind of *
ma: Regulating service	ma: Biological control is a kind of *	ma: Pollination is a kind of *	ma: Natural hazard regulation is a kind of *	ma: Disease regulation is a kind of *
ma: Regulating service	ma: Water purification and waste treatment is a kind of *			
ma: Sense of place	* is a kind of ma: Cultural service			
ma: Social relation	* is a kind of ma: Cultural service			
ma: Spritual and religious value	* is a kind of ma: Cultural service			
ma: Supporting service	* is a kind of Ecosystem service			
ma: Timber	* is a kind of ma: Fiber			

Concept	**Outgoing relations**			
ma: Water purification and waste treatment	* is a kind of ma: Regulating service	* is known as teeb : Waste-water treatment		
ma: Water regulation	* is a kind of ma: Regulating service			
ma: Wild food	* is a kind of ma: Food			
ma: Wood fuel	* is a kind of ma: Fiber			
Map	* is represented by Scale			
Map	Ecosystem service value is represented by *	Place is represented by *	Scale of observation is properties of *	Indicator is represented by *
Map	Input data is represented by *			
Measurement Unit	* is used by Numeric Value	* is used by Range value		
Model	* is a kind of Valuation method			
Municipal	* is a kind of Institutional scale			
National	* is a kind of Institutional scale			
Non-economic value	* is a kind of Input data	* is used by Valuation method		
Numeric Value	Measurement Unit is used by *	Ecosystem service value is represented by *		
Omni-directional	* is a kind of Place Relationship			
Percentage	Ecosystem service value is represented by *			
Place	* is represented by Map	* is represented by Scale		

Concept	Outgoing relations			
Place	Service benefiting area is a kind of *	Place Relationship is properties of *	Service connecting area is a kind of *	Service providing area is a kind of *
Place	Valuation method is affected by *	Ecosystem service is located in *		
Place Relationship	* is properties of Place			
Place Relationship	Directional is a kind of *	In-situ is a kind of *	Omni-directional is a kind of *	
Plot Scale	* is a kind of Ecological scale			
Primary Indicator	* is a kind of Indicator			
Primary method	* is a kind of Valuation method			
Provincial	* is a kind of Institutional scale			
Proxy method	* is a kind of Valuation method			
Range value	Measurement Unit is used by *	Ecosystem service value is represented by *		
Scale	* is properties of Ecosystem service			
Scale	Ecological scale is a kind of *	Institutional scale is a kind of *	Scale of consumption is a kind of *	Scale of management is a kind of *
Scale	Map is represented by *	Place is represented by *		
Scale	Scale of observation is a kind of *	Scale of production is a kind of *	Temporal scale is a kind of *	Valuation method is affected by *
Scale of consumption	* is a kind of Scale	* is affected by Human	* is properties of Service benefiting area	

Concept	**Outgoing relations**			
Scale of consumption	Institutional scale is properties of *			
Scale of management	* is affected by Human	* is a kind of Scale		
Scale of management	Institutional scale is properties of *	Ecological scale is properties of *		
Scale of observation	* is a kind of Scale	* is properties of Map		
Scale of observation	Ecological scale is properties of *			
Scale of production	* is a kind of Scale	* is properties of Service providing area		
Scale of production	Ecological scale is properties of *	Temporal scale is properties of *		
Seasonal service	* is a kind of Temporal scale			
Secondary indicator	* is a kind of Indicator			
Service benefiting area	* is a kind of Place			
Service benefiting area	Scale of consumption is properties of *	Benefit is located in *		
Service connecting area	* is a kind of Place			
Service providing area	* is a kind of Place			
Service providing area	Ecosystem function is located in *	Scale of production is properties of *		
short-term service	* is a kind of Temporal scale			
teeb : Waste-water treatment	* is a kind of teeb: Regulating service			
teeb : Waste-water treatment	ma: Water purification and waste treatment is known as *			

Concept	**Outgoing relations**			
teeb: Aesthetic apprecation and inspiration	* is a kind of teeb: Cultural service			
teeb: Biological control	* is a kind of teeb: Regulating service			
teeb: Carbon sequestration and storage	* is a kind of teeb: Regulating service			
teeb: Cultural service	* is known as ma: Cultural service	* is a kind of Ecosystem service		
teeb: Cultural service	teeb: Aesthetic apprecation and inspiration is a kind of *	teeb: Recreation and mental and physical health is a kind of *	teeb: Spiritual experience and sense of place is a kind of *	teeb: Tourism is a kind of *
teeb: Erosion prevention and maintenance of soil fertility	* is a kind of teeb: Regulating service			
teeb: Food	* is a kind of teeb: Provisioning service			
teeb: Food	cices: Nutritional purpose is known as *	ma: Food is known as *		
teeb: Fresh water	* is a kind of teeb: Provisioning service			
teeb: Fresh water	ma: Fresh water is known as *			
teeb: Genetic resources	* is a kind of teeb: Provisioning service			
teeb: Genetic resources	cices: Genetic material is known as *	ma: Genetic resources is known as *		
teeb: Habitat for species	* is a kind of teeb: Habitat or supporting service			

Concept	**Outgoing relations**			
teeb: Habitat or supporting service	* is a kind of Ecosystem service			
teeb: Habitat or supporting service	teeb: Habitat for species is a kind of *	teeb: Maintenance of genetic diversity is a kind of *		
teeb: Local climate and air quality	* is a kind of teeb: Regulating service			
teeb: Maintenance of genetic diversity	* is a kind of teeb: Habitat or supporting service			
teeb: Medicinal resource	* is a kind of teeb: Provisioning service			
teeb: Medicinal resource	cices: Material purpose is known as *	ma: Biochemicals, natural, medicines, pharmaceuticals is known as *	cices: Energy purpose is known as *	
teeb: Moderation of extreme event	* is a kind of teeb: Regulating service			
teeb: Ornamental resource	* is a kind of teeb: Provisioning service			
teeb: Pollination	* is a kind of teeb: Regulating service			
teeb: Provisioning service	* is a kind of Ecosystem service			
teeb: Provisioning service	teeb: Food is a kind of *	teeb: Medicinal resource is a kind of *	teeb: Raw material is a kind of *	teeb: Fresh water is a kind of *
teeb: Provisioning service	teeb: Genetic resources is a kind of *	teeb: Ornamental resource is a kind of *		

Concept	Outgoing relations			
teeb: Raw material	* is a kind of teeb: Provisioning service			
teeb: Raw material	cices: Material purpose is known as *	ma: Fiber is known as *	cices: Energy purpose is known as *	
teeb: Recreation and mental and physical health	* is a kind of teeb: Cultural service			
teeb: Regulating service	* is a kind of Ecosystem service			
teeb: Regulating service	teeb : Waste-water treatment is a kind of *	teeb: Biological control is a kind of *	teeb: Carbon sequestration and storage is a kind of *	teeb: Erosion prevention and maintenance of soil fertility is a kind of *
teeb: Regulating service	teeb: Local climate and air quality is a kind of *	teeb: Moderation of extreme event is a kind of *	teeb: Pollination is a kind of *	
teeb: Spiritual experience and sense of place	* is a kind of teeb: Cultural service			
teeb: Tourism	* is a kind of teeb: Cultural service			
Temporal scale	* is properties of Scale of production	* is a kind of Scale		
Temporal scale	Seasonal service is a kind of *	short-term service is a kind of *	long-term service is a kind of *	
Valuation method	* is affected by Driver of change	* is affected by Scale	* is affected by Indicator	* is affected by Place
Valuation method	Economic value is used by *	Input data is used by *	Non-economic value is used by *	
Valuation method	Model is a kind of *	Primary method is a kind of *	Proxy method is a kind of *	Ecosystem service value is retrieved by *

APPENDIX B TURTLE FILE OF ESONTO

MAES Data

@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@prefix geo: <http://www.opengis.net/ont/geosparql#>.
@prefix ESOnto: <http://webprotege.stanford.edu/ayu#>.

ESOnto:CICESNutritionalPurpose ESOnto:isKindOf ESOnto:CICESBiomass;
ESOnto:EcosystemStructure ESOnto:Biotic.
ESOnto:CICESEnergyPurpose ESOnto:isKindOf ESOnto:CICESBiomass;
ESOnto:EcosystemStructure ESOnto:Biotic.
ESOnto:CICESMaterialPurpose ESOnto:isKindOf ESOnto:CICESBiomass;
ESOnto:EcosystemStructure ESOnto:Biotic.

ESOnto:CICESDesignConstructNewBiologicalEntities ESOnto:isKindOf ESOnto:CICESGe
neticMaterial;
ESOnto:EcosystemStructure ESOnto:Biotic.
ESOnto:CICESBreedNewVariety ESOnto:isKindOf ESOnto:CICESGeneticM
aterial;
ESOnto:EcosystemStructure ESOnto:Biotic.
ESOnto:CICESMaintainEstablishPopulation ESOnto:isKindOf ESOnto:CICESGenet
icMaterial;
ESOnto:EcosystemStructure ESOnto:Biotic.

ESOnto:CICESGeneticMaterial ESOnto:isKindOf ESOnto:CICESProvisioningService.
ESOnto:CICESBiomass ESOnto:isKindOf ESOnto:CICESProvisioningService.
ESOnto:CICESNutritionalPurpose ESOnto:isKnownAs ESOnto:MAFood,ESOnto:TEEBFood
.
ESOnto:CICESMaterialPurpose ESOnto:isKnownAs ESOnto:MABiochemicalNaturalMedicine
Pharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource, ESOnto:TEE
BRawMaterial.
ESOnto:CICESEnergyPurpose ESOnto:isKnownAs ESOnto:MABiochemicalNaturalMedicin
ePharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource, ESOnto:TE
EBRawMaterial.

ESOnto:MAFood ESOnto:isKindOf ESOnto:MAProvisioningService.
ESOnto:MABiochemicalNaturalMedicinePharmaceuticals ESOnto:isKindOf ESOnto:MAProvisioningS
ervice.
ESOnto:MAFiber ESOnto:isKindOf ESOnto:MAProvisioningService.
ESOnto:MAFuel ESOnto:isKindOf ESOnto:MAProvisioningService.

```
ESOnto:TEEBFood                    ESOnto:isKindOf ESOnto:TEEBProvisioningService.
ESOnto:TEEBMedicinalResource       ESOnto:isKindOf ESOnto:TEEBProvisioningService.
ESOnto:TEEBRawMaterial             ESOnto:isKindOf ESOnto:TEEBProvisioningService.

ESOnto:MAProvisioningServis     ESOnto:isKindOf        ESOnto:EcosystemService.
ESOnto:TEEBProvisioningServis   ESOnto:isKindOf        ESOnto:EcosystemService.
ESOnto:CICESProvisioningServis  ESOnto:isKindOf        ESOnto:EcosystemService.
ESOnto:ESValue                  ESOnto:isgeneratedby   ESOnto:EcosystemService.
ESOnto:Observationalscale       ESOnto:isKindOf        ESOnto:Scale.
ESOnto:ProductionScale          ESOnto:isKindOf        ESOnto:Scale.
ESOnto:BenefitScale             ESOnto:isKindOf        ESOnto:Scale.
ESOnto:ESValue                  ESOnto:isRepresentedBy ESOnto:Indicator.

ESOnto:CICESNP1 a ESOnto:CICESNutritionalPurpose;
                ESOnto:Indicator     ESOnto:foodcrop, ESOnto:foddercrop.
ESOnto:CICESEP1 a ESOnto:CICESEnergyPurpose;
                ESOnto:Indicator     ESOnto:energycrop, ESOnto:textilecrop.


#Foodcrop
ESOnto:foodcrop1  a    ESOnto:foodcrop;
        ESOnto:SPA "10kmE395N327"^^xsd:string;
        ESOnto:Observationscale "10km";
        ESOnto:ESValue "7.39384"^^xsd:decimal;
        ESOnto:MUnit "ton/year".

ESOnto:foodcrop2  a    ESOnto:foodcrop;
        ESOnto:SPA "10kmE395N328"^^xsd:string;
        ESOnto:Observationscale "10km";
        ESOnto:ESValue "9.21015"^^xsd:decimal;
        ESOnto:MUnit "ton/year".

ESOnto:foodcrop3  a    ESOnto:foodcrop;
        ESOnto:SPA "10kmE395N329"^^xsd:string;
        ESOnto:Observationscale "10km";
        ESOnto:ESValue "6.54996"^^xsd:decimal;
        ESOnto:MUnit "ton/year".

ESOnto:foodcrop4  a    ESOnto:foodcrop;
        ESOnto:SPA "10kmE395N330"^^xsd:string;
        ESOnto:Observationscale "10km".

ESOnto:foodcrop5  a    ESOnto:foodcrop;
        ESOnto:SPA "10kmE396N327"^^xsd:string;
        ESOnto:Observationscale "10km";
        ESOnto:ESValue "13.98004"^^xsd:decimal;
        ESOnto:MUnit "ton/year".
```

```
ESOnto:foodcrop6  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE396N328"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "19.2076"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop7  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE396N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "27.47504"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop8  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE396N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "94.96227"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop9  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE397N327"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "2.10891"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop10  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE397N328"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "119.58414"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop11  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE397N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "78.61202"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop12  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE397N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "98.97304"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foodcrop13  a     ESOnto:foodcrop;
                  ESOnto:SPA "10kmE398N327"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "4.88411"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".
```

```
ESOnto:foodcrop14  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE398N328"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "12.15981"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foodcrop15  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE398N329"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "48.92246"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foodcrop16  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE398N330"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "92.25722"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foodcrop17  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE399N328"^^xsd:string;
                    ESOnto:Observationscale "10km"
                    .

ESOnto:foodcrop18  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE399N329"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "73.09526"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foodcrop19  a     ESOnto:foodcrop;
                    ESOnto:SPA "10kmE399N330"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "51.97356"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

#Foddercrop
ESOnto:foddercrop1  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE395N327"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "13.7589"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop2  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE395N328"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "17.13882"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".
```

```
ESOnto:foddercrop3  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE395N329"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "12.18856"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop4  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE395N330"^^xsd:string;
                    ESOnto:Observationscale "10km"
                    .

ESOnto:foddercrop5  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE396N327"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "26.01491"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop6  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE396N328"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "35.74266"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop7  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE396N329"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "51.12722"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop8  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE396N330"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "176.71158"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop9  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE397N327"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "3.92439"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".

ESOnto:foddercrop10  a     ESOnto:foddercrop;
                    ESOnto:SPA "10kmE397N328"^^xsd:string;
                    ESOnto:Observationscale "10km";
                    ESOnto:ESValue "222.52945"^^xsd:decimal;
                    ESOnto:MUnit "ton/year".
```

```
ESOnto:foddercrop11  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE397N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "146.28603"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop12  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE397N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "184.17505"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop13  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE398N327"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "9.08865"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop14  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE398N328"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "22.62772"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop15  a  ESOnto:foddercrop;
                  ESOnto:SPA "10kmE398N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "91.03789"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop16  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE398N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "171.67786"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop17  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE399N328"^^xsd:string;
                  ESOnto:Observationscale "10km"
                  .

ESOnto:foddercrop18  a     ESOnto:foddercrop;
                  ESOnto:SPA "10kmE399N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "136.02012"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:foddercrop19  a  ESOnto:foddercrop;
```

```
                ESOnto:SPA "10kmE399N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "96.71556"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

#Energycrop
ESOnto:energycrop1  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE395N327"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.54565"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop2  a   ESOnto:energycrop;
                ESOnto:SPA "10kmE395N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.67969"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop3  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE395N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.48337"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop4  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE395N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                .

ESOnto:energycrop5  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE396N327"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "1.0317"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop6  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE396N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "1.41748"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop7  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE396N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "2.0276"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop8  a    ESOnto:energycrop;
```

```
                ESOnto:SPA "10kmE396N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "7.00803"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop9  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE397N327"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.15563"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop10  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE397N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "8.82508"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop11  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE397N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "5.80141"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop12  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE397N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "7.30402"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop13  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE398N327"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.36043"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop14  a    ESOnto:energycrop;
                ESOnto:SPA "10kmE398N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.89737"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop15  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE398N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "3.61038"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop16  a    ESOnto:energycrop;
```

```
                ESOnto:SPA "10kmE398N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "6.8084"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop17  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE399N328"^^xsd:string;
                ESOnto:Observationscale "10km"
                .

ESOnto:energycrop18  a     ESOnto:energycrop;
                ESOnto:SPA "10kmE399N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "5.39429"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:energycrop19  a  ESOnto:energycrop;
                ESOnto:SPA "10kmE399N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "3.83555"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

#Textilecrop
ESOnto:textilecrop1  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE395N327"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.00487"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop2  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE395N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.00607"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop3  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE395N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.00431"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop4  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE395N330"^^xsd:string;
                ESOnto:Observationscale "10km"
                .

ESOnto:textilecrop5  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE396N327"^^xsd:string;
```

```
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.00921"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop6  a     ESOnto:textilecrop;
                  ESOnto:SPA "10kmE396N328"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.01266"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop7  a     ESOnto:textilecrop;
                  ESOnto:SPA "10kmE396N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.01811"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop8  a     ESOnto:textilecrop;
                  ESOnto:SPA "10kmE396N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.06259"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop9  a     ESOnto:textilecrop;
                  ESOnto:SPA "10kmE397N327"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.00139"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop10  a  ESOnto:textilecrop;
                  ESOnto:SPA "10kmE397N328"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.07882"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop11  a     ESOnto:textilecrop;
                  ESOnto:SPA "10kmE397N329"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.05181"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop12  a  ESOnto:textilecrop;
                  ESOnto:SPA "10kmE397N330"^^xsd:string;
                  ESOnto:Observationscale "10km";
                  ESOnto:ESValue "0.06524"^^xsd:decimal;
                  ESOnto:MUnit "ton/year".

ESOnto:textilecrop13  a  ESOnto:textilecrop;
                  ESOnto:SPA "10kmE398N327"^^xsd:string;
```

```
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.00321"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop14  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE398N328"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.00801"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop15  a  ESOnto:textilecrop;
                ESOnto:SPA "10kmE398N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.03224"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop16  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE398N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.06081"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop17  a  ESOnto:textilecrop;
                ESOnto:SPA "10kmE399N328"^^xsd:string;
                ESOnto:Observationscale "10km"
                .

ESOnto:textilecrop18  a     ESOnto:textilecrop;
                ESOnto:SPA "10kmE399N329"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.04818"^^xsd:decimal;
                ESOnto:MUnit "ton/year".

ESOnto:textilecrop19  a  ESOnto:textilecrop;
                ESOnto:SPA "10kmE399N330"^^xsd:string;
                ESOnto:Observationscale "10km";
                ESOnto:ESValue "0.03426"^^xsd:decimal;
                ESOnto:MUnit "ton/year".
```

TEEB Data

```
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/>.
@prefix xsd: <http://www.w3.org/2001/XMLSchema#>.
@prefix ESOnto: <http://webprotege.stanford.edu/ayu#>.
@prefix ENVO: <http://purl.obolibrary.org/obo/ENVO_01001110#>.
@prefix db: <http://dbpedia.org/ontology/>.

ESOnto:CICESNutritionalPurpose    ESOnto:isKindOf    ESOnto:CICESBiomass;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.
ESOnto:CICESEnergyPurpose    ESOnto:isKindOf    ESOnto:CICESBiomass;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.
ESOnto:CICESMaterialPurpose    ESOnto:isKindOf    ESOnto:CICESBiomass;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.

ESOnto:CICESDesignConstructNewBiologicalEntities    ESOnto:isKindOf ESOnto:CICESGeneticMat
erial;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.
ESOnto:CICESBreedNewVariety    ESOnto:isKindOf ESOnto:CICESGeneticMaterial;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.
ESOnto:CICESMaintainEstablishPopulation    ESOnto:isKindOf ESOnto:CICESGeneticMaterial;
                    ESOnto:EcosystemStructure    ESOnto:Biotic.

ESOnto:CICESGeneticMaterial    ESOnto:isKindOf    ESOnto:CICESProvisioningService.
ESOnto:CICESBiomass    ESOnto:isKindOf    ESOnto:CICESProvisioningService.
ESOnto:CICESNutritionalPurpose    ESOnto:isKnownAs    ESOnto:MAFood,ESOnto:TEEBFood
.
ESOnto:CICESMaterialPurpose    ESOnto:isKnownAs    ESOnto:MABiochemicalNaturalMedicine
Pharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource, ESOnto:TEE
BRawMaterial.
ESOnto:CICESEnergyPurpose    ESOnto:isKnownAs    ESOnto:MABiochemicalNaturalMedicin
ePharmaceuticals, ESOnto:MAFiber, ESOnto:MAFuel, ESOnto:TEEBMedicinalResource, ESOnto:TE
EBRawMaterial.

ESOnto:MAFood    ESOnto:isKindOf ESOnto:MAProvisioningService.
ESOnto:MABiochemicalNaturalMedicinePharmaceuticals ESOnto:isKindOf ESOnto:MAProvisioningS
ervice.
ESOnto:MAFiber    ESOnto:isKindOf ESOnto:MAProvisioningService.
ESOnto:MAFuel    ESOnto:isKindOf ESOnto:MAProvisioningService.

ESOnto:TEEBFood    ESOnto:isKindOf ESOnto:TEEBProvisioningService.
ESOnto:TEEBMedicinalResource    ESOnto:isKindOf ESOnto:TEEBProvisioningService.
ESOnto:TEEBRawMaterial    ESOnto:isKindOf ESOnto:TEEBProvisioningService.

ESOnto:TEEB1 a ESOnto:TEEBRawMaterial;
        ENVO:Ecosystem    ENVO:Grassland;
        db:Place "Netherlands";
```

```
        ESOnto:SPA     "Dutch Wadden Sea";
        ESOnto:ValuationMethod "Direct market pricing";
        ESOnto:ObservationScale    "District";
        ESOnto:ESValue "27"^^xsd:decimal;
        ESOnto:MUnit  "Euro/ha/yr".

ESOnto:TEEB2 a ESOnto:TEEBRawMaterial;
        ENVO:Ecosystem     ENVO:Woodland;
        db:Place "Southern Europe";
        ESOnto:SPA     "Northern Mediterranean region";
        ESOnto:ValuationMethod "Direct market pricing";
        ESOnto:ObservationScale     "Region";
        ESOnto:ESValue "67.5"^^xsd:decimal;
        ESOnto:MUnit   "Euro/ha/yr".

ESOnto:TEEB3 a ESOnto:TEEBRawMaterial;
        ENVO:Ecosystem     ENVO:Woodland;
        db:Place "Southern Europe";
        ESOnto:SPA     "Northern Mediterranean region";
        ESOnto:ValuationMethod "Benefit Transfer";
        ESOnto:ObservationScale     "Region";
        ESOnto:ESValue "41"^^xsd:decimal;
        ESOnto:MUnit   "Euro/ha/yr".

ESOnto:TEEB4 a ESOnto:TEEBProvisioningService;
        ENVO:Ecosystem     ENVO:Wetland;
        db:Place "Europe";
        ESOnto:SPA     "Danube floodplains";
        ESOnto:ValuationMethod "Benefit Transfer";
        ESOnto:ObservationScale     "Region";
        ESOnto:ESValue "61"^^xsd:decimal;
        ESOnto:MUnit   "Euro/ha/yr".

ESOnto:TEEB5 a ESOnto:TEEBFood;
        ENVO:Ecosystem     ENVO:Estuarie;
        db:Place "Netherlands";
        ESOnto:SPA     "Dutch Wadden Sea";
        ESOnto:ValuationMethod "Direct market pricing";
        ESOnto:ObservationScale     "Region";
        ESOnto:ESValue "450"^^xsd:decimal;
        ESOnto:MUnit   "USD/ha/yr".

ESOnto:ObservationScale ESOnto:isKindOf        ESOnto:Scale.
ESOnto:ProductionScale ESOnto:isKindOf        ESOnto:Scale.
ESOnto:BenefitScale ESOnto:isKindOf        ESOnto:Scale.
ESOnto:CICESEP1 a ESOnto:CICESEnergyPurpose;
                ESOnto:Indicator        ESOnto:energycrop, ESOnto:textilecrop.
```

APPENDIX C QUERY RESULTS OF THE COMPETENCE QUESTIONS

The answers of competence questions based on query:

No	Competence Question	Query	Results
1	Which indicators used for provisioning service?	SELECT ?ES1 ?ES2 ?Indicator WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator.} Group BY ?ES1 ?ES2 ?Indicator	ES1 | ES2 | Indicator ESOnto:CICESBiomass | ESOnto:CICESNutritionalPurpose | ESOnto:foodcrop ESOnto:CICESBiomass | ESOnto:CICESNutritionalPurpose | ESOnto:foddercrop ESOnto:CICESBiomass | ESOnto:CICESEnergyPurpose | ESOnto:textilecrop ESOnto:CICESBiomass | ESOnto:CICESEnergyPurpose | ESOnto:energycrop
2	What are the class of the fodder crop ecosystem services in TEEB and MA classification frameworks?	SELECT ?Indicator ?MATEEB WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator. ?ES2 ESOnto:isKnownAs ?MATEEB. FILTER (?Indicator = ESOnto:foddercrop).} GROUP BY ?Indicator ?MATEEB	Indicator | MATEEB ESOnto:foddercrop | ESOnto:MAFood ESOnto:foddercrop | ESOnto:TEEBFood
3	Where is the location of the highest value of energy crop?	SELECT ?a ?ESV ?place WHERE {?a a ESOnto:energycrop; ESOnto:ESValue ?ESV; ESOnto:SPA ?place.} ORDER BY DESC (?ESV) LIMIT 1	a | ESV | place ESOnto:energycrop10 | 8.82508 | "10kmE397N328"^^xsd:string

No	Competence Question	Query	Results
4	Which grid has the highest value of provisioning service? With the assumption that provisioning service value is equal with the sum of the provisioning service subclass value.	SELECT SUM(?ESV) AS ?ESValue ?place WHERE { {SELECT distinct ?ES3 ?Indicator ?a WHERE {?ES1 ESOnto:isKindOf ESOnto:CICESProvisioningService. ?ES2 ESOnto:isKindOf ?ES1. ?ES3 a ?ES2; ESOnto:Indicator ?Indicator. ?a a ?Indicator}} ?a ESOnto:ESValue ?ESV; ESOnto:SPA ?place.} GROUP BY ?place ORDER BY DESC (?ESValue) limit 1	ESValue | place "351,01749"^^xsd:decimal | "10kmE397N328"^^xsd:string
5	Which valuation method they use to analyse the raw material ecosystem services?	SELECT ?VM WHERE {?a a ESOnto:TEEBRawMaterial; ESOnto:ValuationMethod ?VM.}	a | VM ESOnto:TEEB1 | "Direct market pricing" ESOnto:TEEB3 | "Benefit Transfer" ESOnto:TEEB2 | "Direct market pricing"

<table>
<tr><th>No</th><th>Competence Question</th><th>Query</th><th>Results</th></tr>
<tr><td>6</td><td>What are the unit of the ecosystem services value?</td><td>SELECT ?b ?VUnit
WHERE {?a a ?b; ESOnto:MUnit ?VUnit.}
GROUP BY ?b ?VUnit</td><td><table>
<tr><th>b</th><th>VUnit</th></tr>
<tr><td>ESOnto:TEEBRawMaterial</td><td>"Euro/ha/yr"</td></tr>
<tr><td>ESOnto:TEEBProvisioningService</td><td>"Euro/ha/yr"</td></tr>
<tr><td>ESOnto:TEEBFood</td><td>"USD/ha/yr"</td></tr>
<tr><td>ESOnto:foodcrop</td><td>"ton/year"</td></tr>
<tr><td>ESOnto:foddercrop</td><td>"ton/year"</td></tr>
<tr><td>ESOnto:energycrop</td><td>"ton/year"</td></tr>
<tr><td>ESOnto:textilecrop</td><td>"ton/year"</td></tr>
</table></td></tr>
<tr><td>7</td><td>What is the scale of the ES?</td><td>SELECT ?Scaletype ?ES ?scale
WHERE {?Scaletype ESOnto:isKindOf ESOnto:Scale.
?ES ?Scaletype ?scale.}</td><td><table>
<tr><th>Scaletype</th><th>ES</th><th>scale</th></tr>
<tr><td>ESOnto:ObservationScale</td><td>ESOnto:TEEB1</td><td>"District"</td></tr>
<tr><td>ESOnto:ObservationScale</td><td>ESOnto:TEEB2</td><td>"Region"</td></tr>
<tr><td>ESOnto:ObservationScale</td><td>ESOnto:TEEB3</td><td>"Region"</td></tr>
<tr><td>ESOnto:ObservationScale</td><td>ESOnto:TEEB4</td><td>"Region"</td></tr>
<tr><td>ESOnto:ObservationScale</td><td>ESOnto:TEEB5</td><td>"Region"</td></tr>
</table></td></tr>
</table>

APPENDIX D THE INTEROPERABILITY BETWEEN MA, TEEB AND CICES V5.1

The interoperability information between MA, TEEB and CICES V5.1[29] (Roy Haines-Young & Potschin, 2018).

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources

[29] https://cices.eu/content/uploads/sites/8/2018/03/Finalised-V5.1_18032018.xlsx

CICES V5.1				MA	TEEB
Section	Division	Group	Class		
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	nutritional purposes	Food	Food
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Materials purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Energy purpose	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	maintaining or establishing a population	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	breed new strains or varieties	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	design and construction of new biological entities	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	maintaining or establishing a population	Genetic materials	Genetic materials

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals	breed new strains or varieties	Genetic materials	Genetic materials
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from organisms	design and construction of new biological entities	Genetic materials	Genetic materials
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Smell reduction	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Noise attenuation	Water purification and water treatment, air quality regulation?	Water purification and water treatment, air quality regulation?

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	Water purification and water treatment, air quality regulation?	Water purification and water treatment, air quality regulation?
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	Erosion regulation	Erosion prevention
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	Erosion regulation	Erosion prevention
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	Water regulation	Regulation of water flows, regulation of extreme events
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Wind protection	Natural hazard regulation	Regulation of water flows, regulation of extreme events
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Fire protection	Natural hazard regulation?	Regulation of water flows, regulation of extreme events?
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	Pollination	Pollination
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	No equivalent	Biological control

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	No equivalent	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	Pest regulation	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	Disease regulation	Biological control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality	Soil formation (supporting service)	Maintenance of soil fertility
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	Soil formation (supporting service)	Maintenance of soil fertility
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	Water regulation	Water
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	Water regulation	Water
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	Atmospheric regulation	Climate regulation
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	Atmospheric regulation	Climate regulation

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions	Recreation and ecotourism	Recreation and ecotourism
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions	Recreation and ecotourism	Recreation and ecotourism
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	Knowledge systems and educational values, cultural diversity, aesthetic values	Information and cognitive development
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	Knowledge systems and educational values, cultural diversity, aesthetic values	Information and cognitive development
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information

CICES V5.1				MA	TEEB
Section	Division	Group	Class		
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	Spiritual and religious values	Inspiration for culture, art and design, aesthetic information
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	No equivalent	No equivalent

CICES V5.1				MA	TEEB
Section	Division	Group	Class		
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	No equivalent	No equivalent
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	Water	Water
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	Water	Water
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	Water	Water
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	Water	Water
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking	Water	Water
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as a material (non-drinking purposes)	Water	Water
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy	Ground water (and subsurface) used as an energy source	Water	Water
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for nutritional purposes	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem	Mineral substances used for nutrition,	Mineral substances used for material purposes	No equivalent	No equivalent

CICES V5.1				MA	TEEB
Section	Division	Group	Class		
	outputs	materials or energy			
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for as an energy source	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances or ecosystem properties used for nutritional purposes	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Non-mineral substances used for materials	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Wind energy	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Solar energy	No equivalent	No equivalent
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy	Geothermal	No equivalent	No equivalent

CICES V5.1				MA	TEEB
Section	Division	Group	Class		
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by freshwater and marine ecosystems	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Dilution by atmosphere	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes	Mediation by other chemical or physical means (e.g. via Filtration, sequestration, storage or accumulation)	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Mediation of nuisances by abiotic structures or processes	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Liquid flows	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Gaseous flows	No equivalent	No equivalent
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Maintenance of physical, chemical, abiotic conditions	Maintenance and regulation by inorganic natural chemical and physical processes	No equivalent	No equivalent

CICES V5.1				MA	TEEB
Section	**Division**	**Group**	**Class**		
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Physical and experiential interactions with natural abiotic components of the environment	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions	No equivalent	No equivalent
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Intellectual and representative interactions with abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable intellectual interactions	No equivalent	No equivalent
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions	No equivalent	No equivalent
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Other abiotic characteristics that have a non-use value	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value	No equivalent	No equivalent

APPENDIX E LIST OF BON-IN-A-BOX TOOLS

ID inter	TOOL NAME	Web Link	Institute	Type
75	TEAM Forest Carbon Calculator	http://www.teamnetwork.org/gridsphere/gridsphere?cid=carbonApp	Center for Applied Biodiversity Science, Conservation International.	Data Analysis Tool
116	InVEST	http://www.naturalcapitalproject.org/InVEST.html	Stanford University and the University of Minnesota, The Nature Conservancy, and the World Wildlife Fund.	Data Analysis Tool
251	TESSA - Toolkit for Ecosystem Service at Sitebased AssessmenT	http://tessa.tools/	Anglia Ruskin University, BirdLife International, Royal Society for the Protection of Birds (RSPB), Tropical Biology Association, UNEP-WCMC, University of Cambridge and University of Southampton.	Guidelines
89	GEONETCast	http://www.earthobservations.org/activity.php?id=58 http://www.eumetsat.int/website/home/Data/DataDelivery/EUMETCast/GEONETCast/index.html	China Meteorological Administration (CMA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO) and EUMETSAT.	Catalogue Tool
ES3	Ecosystem Service Valuation Toolkit	http://esvaluation.org/	EARTH ECONOMICS	-
ES4	ARIES (Artificial Intelligence for Ecosystem Services)	http://ariesonline.org/	Basque Center for Climate Change	Data Analysis Tool

ID inter	TOOL NAME	Web Link	Institute	Type
ES5	MIMES (Multi-scale Integrated Models of Ecosystem Services)	http://www.afordablefutures.com/services/mimes	Accounting FOR Desirable Futures LLC (AFORDable Futures)	Data Analysis Tool
ES6	EVRI - Environmental valuation reference inventory	https://www.evri.ca/en/content/about-evri	Environment Canada	Catalogue Tool
ES7	Catalogue of Assessments on Biodiversity and Ecosystem Services	http://catalog.ipbes.net/	IPBES UNEP-WCMC	Catalogue Tool
ES8	Marine Ecosystem Service partnership database (MESP)	www.marineecosystemservices.org/databases	Duke University; University of Brest	Catalogue Tool
ES10	The Ecosystem Services Partnership Visualization tool	http://esp-mapping.net/Home/	Joint Research Centre, European Comission	Catalogue Tool
ES12	National Ecosystem Approach Toolkit NEAT	http://neat.ecosystemsknowledge.net/	UNEP-WCMC, LWEC, UK.	Guidelines
ES13	ValuES	http://www.aboutvalues.net/	GIZ – UFZ – CSF	Guidelines
ES17	MESH - Mapping Ecosystem Services to Human well-being	http://www.naturalcapitalproject.org/mesh/	Biodiversity International / CGIAR / The Natural Capital Project	Data Analysis Tool
ES19	Corporate Ecosystem Services Review (ESR)	http://www.wri.org/publication/corporate-ecosystem-services-review	World Business Council for Sustainable Development Meridian Institute World Resource Institute	Guidelines
ES20	ASSESSING SOCIO-ECONOMIC BENEFITS OF NATURA 2000	http://ec.europa.eu/environment/nature/natura2000/financing/docs/benefits_toolkit.pdf	Institute of European Environmental Policy (IEEP)	Guidelines

ID inter	TOOL NAME	Web Link	Institute	Type
ES22	Ecosystem Services Partnership ESP	http://es-partnership.org/	Environmental Systems Analysis Group (Wageningen University, the Netherlands)	Guidelines and Catalogue Tools
ES23	Soil and water assessment tool -SWAT	http://swat.tamu.edu/	USDA Agricultural Research Service (USDA-ARS) Texas A&M AgriLife Research (The Texas A&M University System)	Data Analysis Tool
ES25	Co$ting Nature	http://www.policysupport.org/costingnature	Kings College LondonAMBIOTEKUNEP-WCMC	Data Analysis Tool
ES27	EcoMetrix	http://www.ecometrixsolutions.com/ecometrix.html	EcoMetrix Solution Group	Data Analysis Tool
239	SMART	http://www.smartconservationsoftware.org/	Zoological Society of London	Data Analysis Tool
	BioScore 2.0	http://www.bioscore.eu/aboutBioScore2.html	PBL - Netherlands Environmental Assessment Agency Wageningen Environmental Research (Alterra)	Data Analysis Tool
	EU BON Biodiversity Portal	http://biodiversity.eubon.eu/home	Museum für Naturkunde - Leibniz Institute for Evolution and Biodiversity Science	Catalogue Tool
N12	ILRI Tools Portal	http://data.ilri.org/tools/	CGIAR	Catalogue Tool

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N14	OPAL Offset Portfolio Analyzer and Locator	http://www.naturalcapitalproject.org/software/#opal	Natural Capital Project, Stanford University The Nature Conservancy (TNC) WWF Institute of the Environment, University of Minnesota	Data Analysis Tool
N15	LUCI (Land Utilisation and Capability Indicator)	http://www.lucitools.org/		Data Analysis Tool
N16	The Guidance Manual for "The Economics of Ecosystems and Biodiversity" (TEEB) Country Studies	http://www.teebweb.org/resources/guidance-manual-for-teeb-country-studies/	UNEP UFZ GIZ IEEP	Guideline
N17	ESII TOOL The Ecosystem Services Identification & Inventory Tool	http://www.esiitool.com/	The Nature Conservancy Dow Chemical company EcoMetrix Solutions Group.	Data Analysis Tool
N18	Policy support tools and methodologies for scenario analysis and modelling of biodiversity and ecosystem services based on a fast track assessment and a guide	http://www.ipbes.net/work-programme/scenarios-and-modelling	IPBES	Guideline
	WaterWorld	www.policysupport.org/waterworld	Kings College London AMBIOTEK	Data Analysis Tool