Report on the use of CICES to identify and characterise the biophysical, social and monetary dimensions of ES assessments

Deliverable D4.2

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Preface

Mapping and Assessment of Ecosystems and their Services (MAES) are core to the EU Biodiversity (BD) Strategy 2020. Specifically, Action 5 sets the requirement for an EU-wide knowledge base developed by Member States designed to be: a primary data source for developing Europe's green infrastructure; a resource to identify areas for ecosystem restoration; and, a baseline against which the goal of 'no net loss of BD and ecosystem services (ES)' can be evaluated.

In response to these requirements, ESMERALDA (Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking) aims to deliver a flexible methodology to provide the building blocks for pan-European and regional assessments. The work will support the timely delivery of EU member states in relation to Action 5 of the BD Strategy, supporting the needs of assessments in relation to the requirements for planning, agriculture, climate, water and nature policy. This methodology will build on existing ES projects and databases (e.g. MAES, OpenNESS, OPERAs, national studies), the Millennium Assessment (MA), IPBES and TEEB. ESMERALDA will identify relevant stakeholders and take stock of their requirements at EU, national and regional levels.

The objective of ESMERALDA is to share experience through an active process of dialogue and knowledge co-creation that will enable participants to achieve the Action 5 aims. The mapping approach proposed will integrate biophysical, social and economic assessment techniques.

The six work packages of ESMERALDA are organised through four strands (see Figure P1), namely policy, research, application and networking, which reflect the main objectives of EMSERALDA.

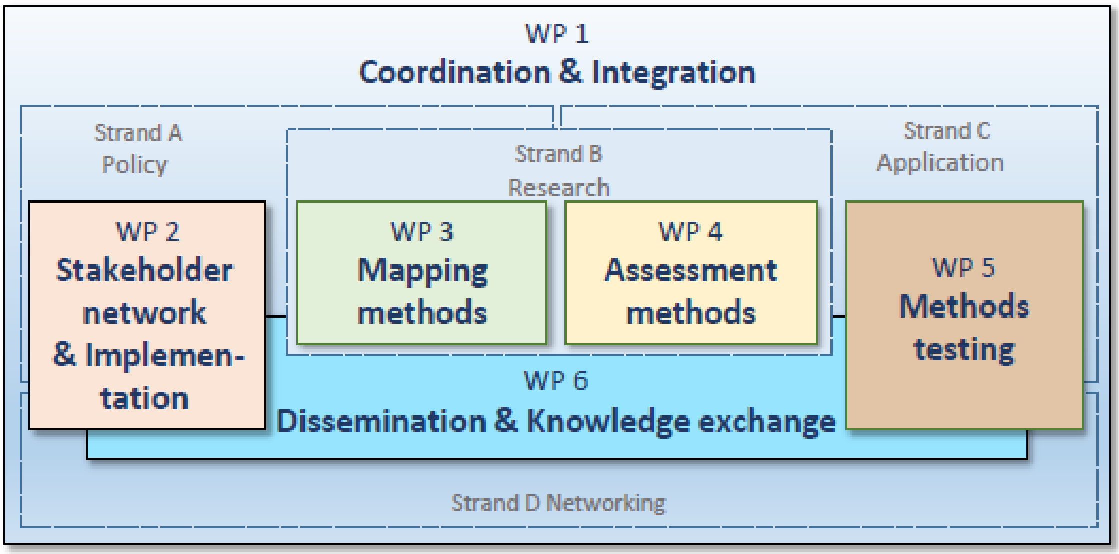

Figure P1: ESMERALDA components and their interrelations and integration within its four strands.

This report sits within work package WP4 "Assessment Methods" as specified in the Description of Action for ESMERALDA (2015).

Acknowledgements

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Summary

The aim of this Deliverable is to report on the use of the Common International Classification of Ecosystem Services (CICES) to characterise the biophysical, social and economic methods of ecosystem assessments, and to identify how it can be further developed to support the needs of the user community.

A first draft of this Deliverable was made available in 2016 and used to shape discussion in the various ESMERALDA workshops that took place during 2016-17. The objective of these meetings was to test a first version of the methodology for mapping and assessment of ecosystem services, and so close engagement with this work was necessary to ensure that the development and use of CICES was eventually integrated into the wider outcomes of ESMERALDA. This final Deliverable, prepared at the end of the Project, now describes both the preliminary work and the further developments that have taken place.

CICES V4.3 was developed in the context of work on the revision of the System of Environmental and Economic Accounting (SEEA) that is being led by the United Nations Statistical Division (UNSD). However, it has also been used widely in ecosystem services research for designing indicators, mapping and for valuation. In the EU, it is being used as the basis of the mapping work that is being done in support of Action 5 of the EU Biodiversity Strategy to 2020, under the MAES Programme.

This report describes the structure and conceptual underpinning of CICES V4.3, and reviews the challenges that arise in designing a classification system of this kind. These challenges include the problem of scope, the extent to which 'final ecosystem services' can be defined operationally, and how benefits and uses of services can be distinguished from services so that assessments can be based on sound quantitative data. The review of CICES draws on a review of the published literature and a survey of users. The conclusions drawn from this review were both extended and tested through two workshops with the user community in 2016.

The results of our work show that there is an extensive and established user base for CICES V4.3, and that it has a number of advantages for users in terms of its hierarchical structure, logic and coverage, as well as the potential it offers as a standard. The review has identified some shortcomings, however, many of which can be overcome by the development of guidelines and the provision of examples of different applications. These shortcomings, nevertheless, also point to the need to revise the present structure of the Classification, especially in the area of cultural ecosystem services.

A systematic review of the wider ecosystem service literature has provided further insights into the ways in which CICES might be improved. This work has looked at whether the CICES classes are to narrow or too broad, and whether there is a need to provide better guidance at sub-class (Class-type level). Taken in conjunction with the other work discussed here, the review demonstrates that CICES V4.3 could nevertheless serve as an effective indicator framework, and that this function should also be supported in any revision.

On the basis of the work done in ESMERALDA and in the wider user community, CICES V4.3 has been revised during 2017 on the basis of parallel work supported by the European Environment Agency. The outcome of the revision process (Version 5.1) are described also here together with the implications for ESMERALDA with its focus on the role of mapping in integrated assessment. The key recommendations we make are:

- That just as V4.3 of CICES has been tested for its coverage and completeness, effort should now be made to critically examine the structure of the new CICES version V5.1.
- The extent to which CICES 5.1 can support the clear description of the way ecosystem services are defined and measured should be examined and its use as a reference system based on concept matching techniques further explored.
- That the CICES 5.1 'indicator' and 'methods' library developed out of the work done in ESMERALDA should be published and used to facilitate the transfer of knowledge within the context of the MAES Process.
- That future work should look at how CICES 5.1 can link to the ways we classify and characterise the condition of ecosystems, so that we can better understand the biophysical underpinnings of ecosystem services.
- Future work should also look at the way we describe and classify benefits and beneficiaries, so that we can better document how people depend on or engage with nature over space and time.
- That the relationship between CICES V5.1 and other classification systems is tested and its reference function developed further.

The work in ESMERALDA Task 4.1 and subsequently this Deliverable resulted wholly or contributed partly in the following publications (title pages including abstracts are to be found in Appendix 8):

Czúcz, B.; Arany, I.; Potschin, M.; Bereczki, K.; Kertész, M.; Kiss, M.; Aszalós, R. and R. Haines-Young (2018): Where concepts meet the real world: a systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services 29* (2018) 145–157. https://doi.org/10.1016/j.ecoser.2017.11.018

Czúcz, B.; Arany, I.; Potschin-Young, M.; Bereczki, K.; Kertész, M.; Kiss, M.; Vári, A.; Aszalós, R. and R. Haines-Young: Ecosystem service indicators along the cascade: mapping and assessment of capacity, actual use and benefits (in preparation)

Haines-Young, R. and M. Potschin-Young (2018): Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief. One Ecosystem 3: e27108. https://doi.org/10.3897/oneeco.3.e27108

Potschin-Young, M.; Burkhard, B.; Czúcz, B. and F. Santos-Martín (2018): Glossary of ecosystem services mapping and assessment terminology. One Ecosystem 3: e27110. https://doi.org/10.3897/oneeco.3.e27110

Santos-Martín, F.; Viinikka, A.; Monomen, L.; Brander, L.; Vihervaara, P.; Liekens, I. and M. Potschin-Young (2018): Creating an operational database for Ecosystems Services Mapping and Assessment Methods. One Ecosystem 3: e26719 https://doi:10.3897/oneeco.3.e26719

1. Introduction

1.1. Background

Categorising and describing Ecosystem Services (ES) is the basis of any attempt to measure, map or value them; in other words, to undertake an ecosystem assessment of some kind. It is the basis of being transparent in what we do, so that we can communicate our findings to others, or test what they conclude. In this Deliverable we examine the role of the *Common International Classification of Ecosystem Services* (CICES) to support this categorisation and communication process. In particular we examine how it can contribute to the development of *integrated assessment frameworks*, which is one of the key outcomes of WP4 of the ESMERALDA Project.

A critical review of CICES has been especially important within ESMERALDA because the classification has been adopted as part of the framework for the overall MAES Initiative (Maes et al., 2013. The experience gained has helped to develop guidelines so that CICES might be used more effectively in the future and informed the revision process that has resulted in the publication of CICES V5.1 in January 2018.

1.2. Aim of the Deliverable

The aim of this Deliverable is to report on the use of CICES and to link it to the biophysical, social and economic methods of ecosystem assessments classified in ESMERALDA.

To do so, the Deliverable draws on the experience gained in developing CICES V4.3 and uses it to reflect on the difficulty of designing a classification system that is simple and transparent to use, but which also fulfils the crucial needs of integrated assessment by addressing cross-scale issues and linking up analyses across the biophysical, social and economic methods. A particular question that is explored concerns whether CICES in its old (V4.3) or updated form (V5.1) is able to provide a multi-purpose classification, able to support ecosystem service mapping, valuation and accounting needs, as well as deliberative and participatory work with stakeholders.

1.3. Structure of the Deliverable report

The structure and status of CICES are described in Part 2 of this Deliverable, which also sets out the conceptual basis of the classification. In Part 3, we describe the work that has been undertaken in the internal consultation process of ESMERALDA on the biophysical, social and economic methods of mapping and assessment, and the lessons for the use of CICES that can be drawn from it. This work draws on material from two workshops held as part of the ESMERALDA Project during 2016, and focussed on the version of CICES that has been used most widely until now (V4.3).

One of the key contributions made by CICES that are identified in Parts 2 and 3 is that CICES can serve as a framework for the development of indicators. However, it is recognised that it cannot encompass all relevant knowledge of the broad field of ES mapping and assessment. Thus, the lessons from the internal consultation process were complemented by a systematic review exercise presented in Part 4 of this report. This work allowed a more detailed exploration of issues and the identification of a range of metrics that might be used by the MAES community in their work; the outcome have provided an input into the development of a ‘CICES-consistent indicator library’ that can be used in mapping and assessment work.

2. CICES Structure and Applications

2.1. History and current context

A number of different typologies or ways of classifying ecosystem services are available, including those used in the Millennium Ecosystem Assessment (MA) and The Economics of Ecosystems and Biodiversity (TEEB), and a number of national assessments, such as those in the UK and Spain. An alternative framing of the idea of ecosystem services as nature's benefits or contributions to people has been put forward by Diaz et al. (2018), on the basis of work done as part of IPBES. The problem with them is that they all approach the classification problem in different ways, and so they are not always easy to compare.

In order to try to partly overcome this 'translation problem', the *Common International Classification of Ecosystem Services* (CICES) was proposed in 2009 and revised in 2013 (Haines-Young and Potschin 2013; Potschin and Haines-Young, 2016). It was designed to help people measure, map and assess ecosystem services, which were defined as the contributions that ecosystems make to human well-being. This version, 4.3, is the one that has been most widely used. Although it was developed in the context of work on the revision of the System of Environmental and Economic Accounting (SEEA) that has been led by the United Nations Statistical Division (UNSD), it has also been used in ecosystem services research for designing ES indicators, ES mapping and for ES valuation. In the EU it is being used as the basis of the mapping work that is being done support of Action 5 of the EU Biodiversity Strategy to 2020, under the MAES Programme (see: http://biodiversity.europa.eu/maes). It was also proposed as the basis for INCA, a project of the European Commission to develop natural capital accounts.

Version of CICES (V4.3) was published at the beginning of 2013. It has therefore been timely to gather information on how it has been used and the issues associated with its application. This was done both through the ESMERALDA Project and also through the independent work being led by the European Environment Agency as part of its input to the MAES process itself, and the development of ecosystem accounting methods with partners such as the UNSD. These efforts to gain an insight into this collective experience were informed by two workshops organised through the auspices of ESMERALDA, and the survey of CICES users undertaken for the EEA. The workshops and the questionnaire were deigned to identify the kinds of guidance that people might need in using CICES, and to look at whether any changes in the CICES structure might be required to make it more useful. A further issue that was explored was to understand better any requirements for CICES to be linked to other classification systems for habitats or ecosystems on the one hand, and benefits and beneficiaries on the other. The results of these wider consultations are summarised below Report and the ways they shaped the subsequent development of CICES are described.

2.2. CICES Structure

The full classification (V4.3) is provided in full in Appendix 1, and summarised at the class level in Table 1. The hierarchical structure CICES is illustrated in Figure 1.

In CICES, provisioning ecosystem services are the material and energetic outputs from ecosystems from which goods and products are derived. The regulating ecosystem services category includes all the ways in which ecosystems can mediate the environment in which people live or depend on in

Table 1: Correspondences between CICES V4.3 Classes the typologies of the MA and TEEB.

CICES v4.3 Class		MA	TEEB
1.1.1.1	Cultivated crops	Food	Food
1.1.1.2	Reared animals and their outputs		
1.1.1.3	Wild plants, algae and their outputs		
1.1.1.4	Wild animals and their outputs		
1.1.1.5	Plants and algae from in-situ aquaculture		
1.1.1.6	Animals from in-situ aquaculture		
1.1.2.1	Surface water for drinking	Water	Water
1.1.2.2	Ground water for drinking		
1.2.1.1	Fibres and other materials from plants, algae and animals for direct use or processing	Fibre, Timber, Ornamental, Biochemical	Raw materials, medicinal resources
1.2.1.2	Materials from plants, algae and animals for agricultural use		
1.2.1.3	Genetic materials from all biota	Genetic materials	Genetic materials
1.2.2.1	Surface water for non-drinking purposes	Water	Water
1.2.2.2	Ground water for non-drinking purposes		
1.3.1.1	Plant-based resources	Fibre	Fuels and fibres
1.3.1.2	Animal-based resources		
1.3.2.1	Animal-based energy		
2.1.1.1	Bio-remediation by micro-organisms, algae, plants, and animals	Water purification and water treatment, air quality regulation	Waste treatment (water purification), air quality regulation
2.1.1.2	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals		
2.1.2.1	Filtration/sequestration/storage/accumulation by ecosystems		
2.1.2.2	Dilution by atmosphere, freshwater and marine ecosystems		
2.1.2.3	Mediation of smell/noise/visual impacts		
2.2.1.1	Mass stabilisation and control of erosion rates	Erosion regulation	Erosion prevention
2.2.1.2	Buffering and attenuation of mass flows		
2.2.2.1	Hydrological cycle and water flow maintenance	Water regulation	Regulation of water flows, regulation of extreme events
2.2.2.2	Flood protection	Natural hazard regulation	
2.2.3.1	Storm protection		
2.2.3.2	Ventilation and transpiration	Air quality regulation	Air quality regulation
2.3.1.1	Pollination and seed dispersal	Pollination	Pollination
2.3.1.2	Maintaining nursery populations and habitats		
2.3.2.1	Pest control	Pest regulation	Biological control
2.3.2.2	Disease control	Disease regulation	
2.3.3.1	Weathering processes	Soil formation (supporting ES)	Maintenance of soil fertility
2.3.3.2	Decomposition and fixing processes		
2.3.4.1	Chemical condition of freshwaters	Water regulation	Water
2.3.4.2	Chemical condition of salt waters		
2.3.5.1	Global climate regulation by reduction of greenhouse gas concentrations	Atmospheric regulation	Climate regulation
2.3.5.2	Micro and regional climate regulation	Air quality regulation	Air quality regulation
3.1.1.1	Experiential use of plants, animals and land-/seascapes in different environmental settings	Recreation and ecotourism	Recreation and tourism
3.1.1.2	Physical use of land-/seascapes in different environmental settings		
3.1.2.1	Scientific	Knowledge systems and educational values, cultural diversity, aesthetic values	Inspiration for culture, art and design, aesthetic information
3.1.2.2	Educational		
3.1.2.3	Heritage, cultural		
3.1.2.4	Entertainment		
3.1.2.5	Aesthetic		
3.2.1.1	Symbolic	Spiritual and religious values	Information and cognitive development
3.2.1.2	Sacred and/or religious		
3.2.2.1	Existence		
3.2.2.2	Bequest		

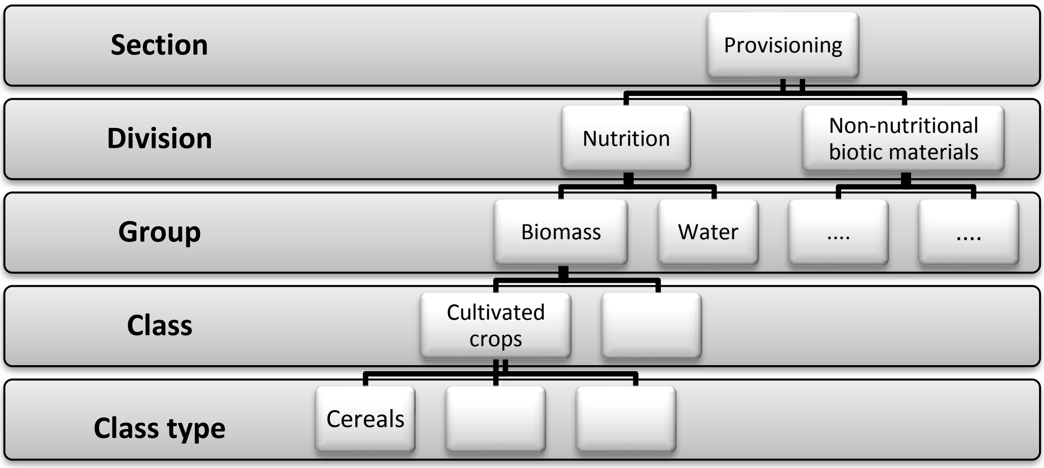


Figure 1: The hierachical structure of CICES (Potschin and Haines-Young, 2016a).

some way, and benefit from them in terms of their health or security, for example. Finally, the cultural ecosystem services category identified all the non-material characteristics of ecosystems that contribute to, or are important for people's mental or intellectual well-being. As Figure 1 shows, CICES is hierarchical in structure, splitting these major 'sections' successively into 'divisions', 'groups' and 'classes'.

The hierarchical structure was designed to deal with the fact that in assessing ES different people were working at different thematic and spatial scales; with this kind of structure it was intended that users could go down to the most appropriate level of detail that they required, but then group or combine results when making comparisons or more generalised reports. In designing CICES V4.3, there was also an attempt to make it more comprehensive than the classifications used by the MA or TEEB, and to include categories such as biomass-based energy that were not explicitly included in these typologies. The broader range of categories at the detailed class level was intended to enable translations between different systems to be made; a simple prototype tool for helping people cross reference some of the more widely used classification systems has, for example, been developed[1]. Table 1 also shows the equivalences between CICES and the MA and TEEB categories.

In order to build a generally applicable classification system, the higher categories in CICES were intended to be exhaustive, in the sense that they were sufficiently general to cover all the things that people recognise as ecosystem services in the broadest sense. It was recognised from the outset, however, that the system also ought to be open-ended to allow users to nest what was particularly relevant to them into the system at some level. Thus, the class types were not specified; instead the assumption was that, given the general structure, users could place the specific things that they were measuring or interested into one of the existing classes.

2.3. Conceptual framing and its implications for integrated ecosystem assessments

CICES is not an arbitrary classification – but is underpinned by a conceptual framework (Figure 2) known as the 'ES cascade model' (Potschin and Haines-Young, 2016). A review of the cascade is necessary to understand the context in which CICES is set, in relating to the needs of integrated

[1] See: http://openness.hugin.com/example/cices

assessment, and the other tools that need to be developed and used alongside CICES to make a full assessment.

Many people work with the definition of ecosystem services used in the MA, which describes them simply as 'the benefits that ecosystems provide to people' (MA, 2005). Others, however, follow the definition of TEEB, which views them as 'the direct and indirect *contributions* of ecosystems to human well-being' (De Groot et al., 2010). If we read these definitions carefully then it is clear that they are quite different in terms of what they take services to be: according to TEEB, services give rise to benefits, whereas in the MA they are the same thing. To add to this confusion we might note that both categorisations take the ideas of 'services' and 'goods' to be synonymous. For example, in the UK National Ecosystem Assessment (UK NEA) (Mace et al., 2011), 'goods' and 'benefits' are taken to be identical, representing categories of things that people assign value to; they are taken to be quite distinct from services, which are seen as the ecosystem outputs from which goods and benefits are derived (Mace et al., 2012).

Do these differences in the way we categorise ecosystem services, goods and benefits really matter? We suggest it depends on one's perspective. Some have argued that one of the important characteristics of the field of ecosystem services is that many different disciplines have come together to explore the insights that the concept offers for understanding the relationships between nature and society. It is this diversity that explains the different approaches that people have taken to categorising ecosystem services. They have also argued that the multiple interpretations that people bring to the concept are especially important, because it is a 'boundary object', that is an idea that can be adapted to represent different perspectives while retaining some sense of continuity across these different viewpoints (Abson et al., 2014).

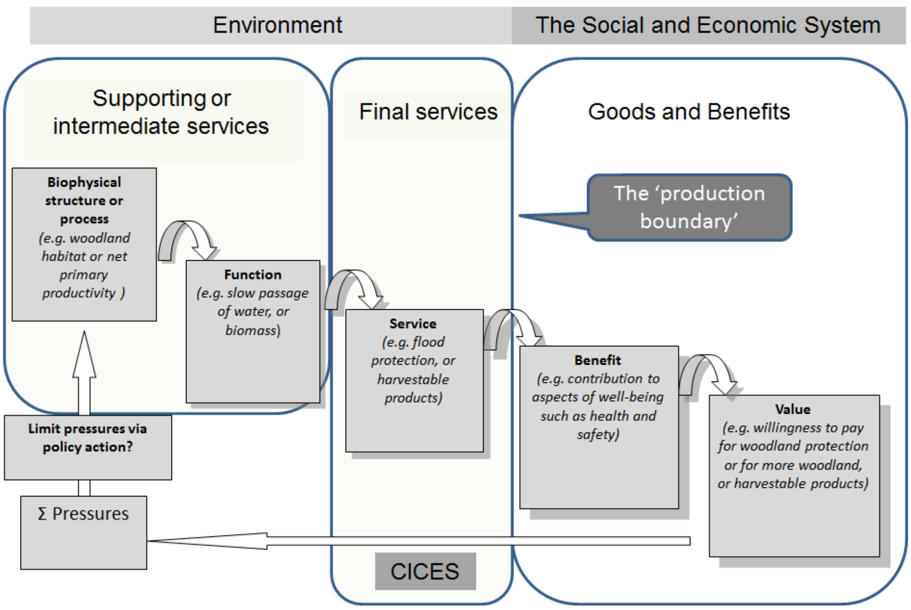


Figure 2 The cascade model (Potschin and Haines-Young, 2016a).

Boundary objects are especially important in multi- or trans-disciplinary situations, because they create the space in which novel discussions and research interactions can occur. The dynamic, multi-faceted nature of the ecosystem service community is certainly part of its fascination. However, these 'boundary objects' are not useful when it comes to the problem of naming, describing and measuring things apparently as fundamental as 'ecosystem services'. When we start to think about this issue, then we start to appreciate the alternative perspective on the problem of whether the differences in the way differences in the way we categorise ecosystem services, goods and benefits really matters.

The links between people and nature are, however, complex, and so it is hardly surprising that people have defined ecosystem services in different ways. Some think of ES as the benefits that nature provides to people, like security and the basic material we need for a good life. Others view ES as the contributions that ecosystem make to such things. For the moment it is sufficient to note that despite differences in the way ES are defined most commentators agree that there is some kind of 'pathway' that goes from ecological structures and processes at one end through to the well-being of people at the other (Figure 2). This idea can be represented in terms of what we call the 'cascade model'. It is a way of expanding thinking about ecosystems to include people, in which it might be described as a 'socio-ecological system'. Finding out how these socio-ecological systems work and how we can act to sustain them are core issues in the field of ecosystem services. The task not only involves the study of ecology, but also such things as the social practices, governance and institutional structures, technology and, most importantly, the things people value.

To see something of the way socio-ecological systems work it is useful to 'unpack' the cascade model to see how the elements are related. Ecosystem services are at the centre of the cascade model, which seeks to show how the biophysical elements of the socio-ecological system are connected to the socio-economic ones; ecosystem services are at the interface between people and nature.

The 'ecosystem' is represented by the ecological structures and processes to the far left of the diagram. Often we simply use some label for a habitat type, such as woodland or grassland, as a catch-all to denote this box, but there is no reason why we cannot also refer to ecological processes, such as 'primary productivity' as something that can also occupy this part of the diagram. In either case, given the complexity of most ecosystems, when we want to start to understand how they benefit people, then it is helpful to start by identifying those properties and characteristics of the system that are potentially useful to people. This is where the idea of a 'function' enters into the discussion. In terms of the cascade model, these are taken to be the 'subset' characteristics or behaviours that an ecosystem has that determines or 'underpins' its capacity to deliver an ecosystem service. Some people call these underpinning elements 'supporting' and 'intermediate' services, depending on how closely connected they are to the final service outputs; we believe, however, this terminology deflects attention away from the important characteristics and behaviours of an ecosystem that generate different services. Thus, using our terminology for one of the examples in Figure 2, the primary productivity of a woodland (i.e. an ecological structure) generates a standing crop of biomass (i.e. a functional characteristic of the woodland), parts of which can be harvested (as a 'provisioning' service).

In the cascade it is envisaged that services contribute to human well-being through the benefits that they support; for example by improving the health and safety of people or by securing their livelihoods. Services are therefore the various ecosystem stocks and flows that directly contribute to some kind of benefit through human agency. The difference between a service and a benefit in the cascade model is that benefits are the things that change well-being and which people assign value to; they are therefore synonymous with 'goods' and 'products'. The cascade model suggests that it is on the basis of changes in the values of the benefits that people make judgements about the kinds of intervention they might make to protect or enhance the supply of ecosystem services; this is indicated by the feedback arrow at the base of the diagram. The important thing to note about 'values' is that they can be expressed in many ways; for example, alongside monetary values people can express the importance they attach to the benefits using moral, aesthetic and spiritual criteria.

Despite the simplicity of the cascade model it is useful in highlighting a defining characteristic of an ecosystem service, namely that they are, in some sense, final outputs from an ecosystem. They are 'final', in that they are still connected to the ecological structures and processes that gave rise to them, and final in the sense that these links are broken or transformed through some human interaction necessary to realise a benefit. Often this intervention can take the form of some physical action such as harvesting the useful parts of a crop. The interaction might also be non-material and more passive involving, for example, by enjoying the reduction or regulation of some kind of risk (flood risk is the example shown in Figure 2), or the intellectual or spiritual significance of nature in a particular cultural context. Thus, services are at the point where the 'production boundary' is crossed between the biophysical and the socio-economic parts of the socio-ecological system.

Although Figure 2 places CICES at the interface between the biophysical and socio-economic components of the 'socio-ecological system', it is important to note that measurement and ultimately assessments of the status of those services may not be confined to this central part of the diagram. While a key task is to identify appropriate metrics that can be used to quantify each service, it might well be the case that measures of structure and process, ecological function, benefit and value are also needed, or can be used instead as proxies to find out what is going on. The extent to which CICES therefore provides both a rigorous framework for assessing services and a thematic list of ecosystem outputs that need to be explored in some way through a variety of different types of measures is a question that will be explored in Chapter 4 of this Deliverable report.

2.4. Current status of CICES

Given that the (until now) most widely used version of CICES was released in 2013 (V4.3), there has been sufficient time for people to apply the framework and to report on their experience. Thus the 2016 Survey of CICES users identified a number of publications and a more extended literature review has identified others; at the time of the draft Deliverable 4.2 report for ESMERALDA, the body of peer-reviewed literature that underpins CICES V4.3 exceeded 40 publications.

In relation to the status of CICES and its role in ESMERALDA, it is important to note that V4.3 formed part of the mapping framework proposed to support the EU's Biodiversity Strategy to 2020 (MAES 2014; see also Maes et al. 2012). The second report of the Mapping and Assessment of Ecosystem Services (MAES) Working Group used the CICES classes to identify a range of indicators that can be used for mapping and assessment purposes[2]. This approach was further tested in Maes et al. (2016), who identified several issues in using CICES as a common framework for indicators across different ecosystems. The ways in which CICES classes could be assigned to ecosystem types was also examined and alternative approaches for handling ground water, for example, were discussed.

[2] see also: http://biodiversity.europa.eu/maes/#ESTAB (accessed 30/01/2016)

The use of CICES as a template for indicator development has also been taken up more widely in the literature. It has, for example, been used as the basis for the German TEEB study (Naturkapital Deutschland – TEEB DE, 2014) as well as the German National Ecosystem Assessment screening study, NEA-D (Albert et al., 2014). It has also been refined at the most detailed class level to meet the requirements of the ecosystem assessment in Belgium (Turkelboom et al., 2013). Mononen et al. (2015) used CICES to develop an indicator framework at the national scale in Finland, and Kostrzewski et al. (2014) described how it was used to help define metrics that could form part of the Integrated Environmental Monitoring Programme in Poland. Kosenius et al. (2013) described other work in Finland on forests, peatlands, agricultural lands, and freshwaters, and found that - when defining indicators - the classification developed in CICES was useful because "it divides ecosystem services to concrete and at least to some extent measurable categories" (Kosenius et al., 2013, p.26).

While being useful in their own right, the studies that have used CICES V4.3 as an indicator framework are valuable more generally because they provide evidence on the extent to which the classification captures the full range of services; key design criteria for CICES have been that, for at least in the upper levels of the hierarchy, the categories should be 'comprehensive' and 'complete' (Haines-Young and Potschin, 2013). A key conclusion that one may take from a review of the papers cited above is that no key gaps were identified; the comprehensive nature of CICES V4.3 is a particular point emphasised by Grizzetti et al. (2015) in their guidelines developed through the MARS (Managing Aquatic ecosystems and water Resources under multiples Stress) Project. Arovuori & Saastamoinen (2014) have also supported the comprehensive nature of the classification. These and other studies (e.g. Stępniewska, 2014; Mizgajski, 2012) also indicate the versatility of the overall structure of the classification. However there has been no systematic analysis on the practical usefulness of CICES as an indicator template so far, and so this gap has been addressed in ESMERALDA (Milestone 20; see also Part 4 of this Deliverable); we report on this work in Chapter 6 of this deliverable.

In terms of flexibility and being able to construct reporting categories appropriate to different types of application, the value of the hierarchical structure of CICES has been noted in a number of studies. In their work on ecosystem services in tourism and recreation, for example, Kulczyk et al. (2014) showed how the categories at the Division level could be used to report on different dimensions of tourism and recreation, and that "common classifications" such CICES, allow "easy communication and comparisons within different contexts" (Kulczyk et al., 2014. p. 87). By contrast, Helfenstein and Kienast, (2014) used the hierarchical structure in a more flexible way in their analysis of ecosystem service state and trends at regional to national levels in Switzerland. These researchers used CICES to define eight categories of ecosystem services: provisioning services, biodiversity, water regulation, cultural services, climate regulation, soil preservation, mitigation of natural hazards, and air quality regulation. They found it "more practical" to use various levels in the CICES hierarchy than to adhere to one, but noted that "their entirety, our selected ecosystem services cover all CICES classes except disease control and ones pertaining to marine ecosystems" (Helfenstein and Kienast, 2014, p. 12).

Although the upper levels in the CICES hierarchy are designed to be complete and comprehensive, flexibility in dealing with locally or application-specific ecosystem services was built into the system by allowing users to define categories that were relevant to them at the 'class type' level. Categories at the sub-class level would 'inherit' the general properties of the hierarchical levels above, but then have specific names and definitions specific to the place or type of application involved. The work of Saastamoinen (2014) has described how this can be done in relation to the work in Finland on peatlands, agricultural lands, and freshwaters; Alahuhta et al. (2013) considers the specific case of freshwaters in more detail. The creation of policy-relevant sub-classes using CICES, as part of a broader mapping and ecosystem assessment done in the context of MAES, is also illustrated by the work in Ireland, described by Medcalf et al. (2016).

While the applications of CICES suggest that the CICES V4.3 framework has been appropriate for many uses, it is also clear that we need to think carefully about how such systems can be developed. For example, the work of Armstrong et al. (2012) and Liquete et al. (2013) suggested that it may need to be adapted to ensure that it is suitable for the assessment of marine and coastal ecosystems, or integrated more closely with typologies for describing underlying ecosystem functions. It is the case that marine interests were probably under-represented in the consultations that led to version 4.3, and that in marine situations many of the services that are meaningful in a terrestrial context, do not apply. Winkler and Nicholas (2016) have identified terminological issues relating to the way CICES deals with cultural ecosystem services, based on their study of ecosystem services in vineyard landscapes in England and California.

A particular issue relating to the way categories in CICES are famed relates to the extent to which they unambiguously represent ‘final services’. This is an issue that will be explored in section 2.5 of this Report. In the context of this review of the published literature, it is interesting to note the work of Liquete et al. (2016). These researchers examined the link between ecosystem services and biodiversity, with a view to understanding whether the “maintenance of nursery populations and habitats” can be regarded as a final service in marine ecosystems, or an intermediate one. Their conclusion is that it can be regarded as a final service when it can be linked to a concrete human benefit, but that it is not when used with indicators of general biodiversity or ecosystem condition. In short, their conclusion suggests that in defining final services, ‘context matters’. Other work that also suggests this conclusion includes that of Saarikoski et al. (2015), who looked at a range of definitional issues through the lens of the boreal forests. The implication of such work is that better guidance on how the notion of a ‘final ecosystem service’ can be applied using CICES is probably required.

A key task in any indicator mapping or account application is the ability to assign services to particular ecosystem types that can be used as some kind of mapping of accounting unit. Our review of the available literature suggested that making such assignments have been relatively unproblematic, in so far as there is little reference to any significant issues. The hierarchical structure of the classification appears to allow some adjustment of the generality of the categories from CICES used to represent services to the geographical scale of the investigation; fundamentally, flexibility is achieved by using different metrics to represent the services, the choice being dependent on such factors as data available, selected methods and analytical context. They key point here is that the definitions of the CICES classes are sufficiently broad to allow ‘interpretation’, but sufficiently specific to ensure that ultimately people in different studies ‘measure the same thing’.

Although CICES was designed with accounting applications in mind, the ability to use the classification structure to build appropriate and meaningful reporting and analytical units for more general kinds of work, is perhaps one of its major contribution to the wider ES community. A particular feature of many of the published studies has also been the extent to which CICES can help make an *integrated* assessment of some kind. Within the ESMERALDA project, we took 'integrated' to mean a number of things. At the most basic level it entails making an assessment of an *individual service* based on the interrelationships between the biophysical, social and monetary dimensions that affect supply and demand, and therefore to bridge the different elements of the cascade and communicate the result in a holistic way. In addition, it is also fundamentally taken to imply an assessment that is able to look at and communicate the *relationships between services* (or within 'bundles' of services) so that patterns of 'trade-off' and 'synergy' can be identified, as well as the factors that drive ecosystem change. Finally, an integrated assessment is one that can bring together and represent at different spatial and temporal scales.

Examples of published work involving CICES that has facilitated an integrated approach therefore take various forms. Santos-Martín et al. (2013) have used CICES to examine the relationships between ecosystems and human well-being in Spain. The Classification has been used as the basis for developing or comparing indicators of ecosystem service supply and demand; this type of work includes that of Castro et al. (2014), Kosenius et al. (2013), von Haaren et al. (2014) and Tenerelli et al. (2016). The latter used CICES as a way of categorising crowd-sourced indicators, derived from 'go-sources images', for cultural ecosystem services for mountain ecosystems.

The use of CICES in relation to the analysis of the drivers of ecosystem change, is illustrated by work such as that of Maes et al. (2015) who examined how current patterns of land use change impacted upon on the aggregated provision of eight ecosystem services at the regional scale of the European Union, measured by the so-called 'Total Ecosystem Services Index' (TESI8). Vidal-Abarca et al. (2014) have used the Driver-Pressure-State-Impact-Response (DPSIR) framework alongside CICES to examine fluvial ecosystems and social systems in Spain. The assessment of green infrastructure based on the analysis of ecological networks and ecosystem services represented by CICES has been described by Liquete et al. (2015). Elsewhere, Bürgi et al. (2015) have used CICES in a historical context to examine how ecosystem service output had changed for a Swiss landscape since about 1900. The classification framework was used to code the reports from archive sources about whether things that we would now regard as ecosystem services were documented as important in past periods, with a view to understanding what this can tell us about scenarios of future change.

The uses of CICES to undertake ES trade-off and marginal change analyses at European scales is illustrated by the work of Haines-Young et al. (2012), who used scenarios to explore how the functional and geographical linkages between services would play out under a range of future conditions. A more extensive trade-off analysis based on current information was done by Lee and Lautenbach (2016), who have undertaken a quantitative review of relationships between ecosystem services in the context of multi-functional land systems. They used CICES to analyse 67 case studies that studied 476 pairwise combinations of ecosystem services, seeking to find evidence for "trade-off", "synergy" or "no-effect". They found that synergistic relationships were most frequently observed between different regulating services and between different cultural services, whereas the relationship between regulating and provisioning services tended to be one of trade-off. What is of particular interest in terms of understanding the contribution of CICES, however, is that the hierarchal structure was a valuable characteristic of the system, both in terms of making a comparative study and of analysing cross-scale patterns.

Despite the fact that CICES was initially developed to address accounting needs, there are relatively few published studies that describe these types of application. However, the potential has been discussed. Liquete et al. (2013), for example, undertook a systematic review of literature on marine and coastal ecosystem services (MCES), and concluded that by using the general structure of CICES, an integrated MCES classification for marine and coastal ecosystems could be created that could be linked with the framework of the UN System of Environmental-Economic Accounts (SEEA) and with standard product and activity classifications, such as the International Standard Industrial Classification of All Economic Activities, the Central Products Classification, and the Classification of Individual Consumption by Purpose. This they thought it would be valuable for making progress in the context of these ecosystems. Schröter et al. (2014) have also sought to explore the accounting applications through their work in Telemark, Norway. The argued that to take accounting applications forward, there is a requirement for clarity of concepts for monitoring purposes, accuracy and appropriateness of indicators at broad spatial scales, given limitations of data, and the spatial explicitness of ecosystem services. Their work illustrated that using CICES as a framework, a set of spatial modelling methods could be combined that enable the analysis of the capacity and flow of ecosystem services at a broad scale, and that these metrics could be allocated to relevant spatial units to meet the needs of ecosystem accounting.

Our review of recent literature suggests that while CICES V4.3 clearly works for many purposes, given the importance of categorising ecosystem services in clear and transparent ways, the development of this and other systems needs to be reviewed constantly as our needs and concepts evolve. They are essential tools for our mapping and assessment work. Crossman et al. (2013) for example, have suggested that a classification, such as CICES, might form as part of a more general systematic approach or 'blueprint' for mapping and modelling ecosystem services. Busch et al. (2012) have also argued that it is important to develop classification systems, such as CICES, that are 'geographically and hierarchically consistent' so that we can make comparisons between regions, and integrate detailed local studies into a broader geographical understandings.

2.5. Challenges

Socio-ecological systems are, of course, more complex than Figure 1 suggests, especially when seeking to understand the balance between the capacity of ecosystems to supply a service and the demand for it. However, this simple diagram helps us understand that all the different elements of the cascade need to be considered if we want to appreciate what an ecosystem service really is and how it connects people and nature. We need to map and measure indicators across the entire pathway to build up a complete picture. The left hand side of the cascade captures the important elements that determine the capacity of ecosystem to supply services, while the right hand side aspects of the demand for them. And understanding the balance between them is at the heart of the contemporary sustainability debate, and key to our understanding of the way people and nature are linked. Current experience suggests there are a number of challenges around the problem of classifying ecosystem services; we can reflect upon them by reference to CICES V4.3.

Experience in trying to work with CICES V4.3 across different application areas has demonstrated how difficult it is to categorise 'final ecosystem services' in a uniform and unambiguous way. Final services, according to Boyd and Banzhaf (2007), are the 'end-products of nature'; they argue that it is important to define them clearly to avoid the problem of 'double counting' when we value. More formally, these authors suggest they 'are components of nature, directly enjoyed, consumed, or used to yield human well-being'. The implication is that we should avoid trying to value the processes or ecosystem components that underpin them, not because they are unimportant, but because their value is already embodied in this final output.

The difficulty of this idea of final services posed when working on CICES has been that it is clear that, to some extent, what constitutes a final service is context-dependent. Take the case of the regulating service categorised in CICES as 'pollination'. On the face of it, it looks like a thing that has more of an underpinning or supporting role rather than being a 'final service'. However, on closer scrutiny the answer is 'it depends'; certainly pollination is an important input to a number of provisioning services such as fruit production. However, encouraging pollinator species in our gardens, whether they benefit us by pollinating our fruit or not, can also be regarded as a final service. In this context, pollinators are another iconic group of species that we want to conserve or encourage, like farmland birds, for example. Also, in a horticultural situation it might be useful think of pollination as a final service in some analyses, say where the contribution of natural pollinators is supplemented by the artificial introduction of pollinators by farmers, and we seek to understand precisely what the scale of the contribution from the ecosystem is. The point here, in relation to CICES is that the list of services in the classification are more a set of potential or *putative* final services and whether they are or are not has to be determined by the circumstances in which the classification is being applied. There probably is no definitive list of things that we can unambiguously categorise as 'final services'. Any future version of CICES or any associated guidance would have to help people navigate some of these issues when they seek to describe and measure ecosystem services.

As CICES was intended as an overarching classification scheme, trying to encompass all domains of nature and society, creating a universally appropriate and consistent hierarchy structure is a considerable challenge. There are clearly an infinite number of diverse interactions between nature and society, and it is not trivial to find appropriate organizing principles and levels of detail across all major scientific domains affected. Furthermore, in many domains there is no 'natural order' among the potential dimensions (e.g. a provisioning service can be used for nutrition, material or energy; can be plant-based, animal-based or abiotic; can be cultivated or come from the wild; etc.). Fortunately, the lack of a predetermined 'natural order' also means that any sensible classification system can be sufficient, and be used in various practical assessment contexts.

A second related challenge in designing CICES, has concerned the scope of the classification. During the consultation processes that gave rise to CICES there was considerable debate about whether abiotic ecosystem outputs like wind or hydropower, or minerals like salt, should be categorised as 'ecosystem services'. In the end, the augment that the category 'ecosystem services' should be restricted to those ecosystem outputs that were dependent on living processes won the day. The telling point was that a key feature of the concept was that it helps make the case for the importance of biodiversity, and to include other things that are not dependent on living processes would dilute it. The problem is, of course, has been that these abiotic ecosystem outputs are not unimportant, and discussion of them has often involved trade-offs etc., and in any case lay people often do not see the different between these products of nature and those dependent on biodiversity.

The point about scope that can be illustrated from the example of CICES is that to some extent these kinds of decision are arbitrary, and have to be guided by the kinds of problem that people want to apply the system too. The arbitrary nature of these decisions is illustrated, for example, by the place of water in CICES V4.3. Water is indeed an abiotic ecosystem output – but it is included in the classification as a provisioning service. Water quantity and quality of water can be regulated by living processes and these kinds of thing ought to feature somewhere in the classification. However, strictly speaking, living processes do not 'produce' water, and so it should probably be excluded from the classification as a provisioning service. Those consulted when V4.3 was developed felt it was, nevertheless, too important to be excluded.

One of the final challenges that we encountered in designing CICES V4.3 was related to the difficulty that people have in distinguishing services and benefits. The distinction is a difficult one to make because it involves deciding where the 'end-product of nature' is transformed into a good, a product or a benefit as a result of human action of some kind. Take the case of crops standing in a field. In CICES V4.3 these would be regarded as a final ecosystem service because they are still connected to the ecological processes associated with the farmed landscape that produced them. That crop can then be turned into a product by harvesting it. While many ecosystem service applications also regard crops in a field as examples of a provisioning service, this is at odds with those developing accounting applications who argue that outputs from ago-ecosystems represent a form of 'co-production' by people and nature, and that the contribution of nature is already built into the value of the crop. They argue that the final service in this situation is nutrient cycling and the other ecological properties of the system that make copping possible. Thus, according to the concepts underpinning the System of Integrated Environmental and Economic Accounts (SEEA), outputs like crops, plantation timber, and aquaculture, are considered benefits produced as a combination of final ecosystem services and human inputs; according to the way national accounts are constructed only things whose growth is dependent on 'natural processes' can be categories as an 'ecosystem service'.

The difficulty that the strict SEEA formulation in the 'Central Framework' seems to pose is that at a time when we are seeking to make sure that the value of nature is fully taken into account, the criterion of reliance on 'natural processes' would seem to exclude much of what goes on across the majority of landscapes, not only in Europe but also elsewhere. Agro-ecosystems my not be natural, but they do still depend on ecological processes, and so it is this dependency or connection that perhaps we should emphasise and take account of. The challenge for valuation is to disentangle these two types of input. To do so we argue that cultivated crops and reared animals should be fully recorded in physical terms so that judgements about the contribution and value of different inputs can be made in a transparent way. Given the difficulties of disentangling the contributions of ecosystems and human-derived capital, it is proposed in CICES that we follow the 'harvest approach'[3] described in the SEEA EEA guidelines, which takes the measurement of ecosystem services as equivalent to the amount of the crop that is harvested, irrespective of the extent of management in its growth. The SEA-EEA guidelines suggest that:

[3] As opposed to the second approach recognizes the extent of management of growth by defining some crops as natural and others as cultivated, following the logic underpinning the determination of the SNA production boundary (SEEA-EEA, para 3.25.

> "…..*it may be appropriate to apply the harvest approach for cultivated crops and other plants, based on the assumption that the various flows, such as pollination, nutrients from the soil, and water, that constitute inputs into the growth of the mature crop are in fixed proportion to the quantities of harvested product*" (SEEA EEA para 3.30).

The way that the SEEA attempts to categorise ecosystem services is legitimate and rational, given its perspective and aims. The point we want to make in noting the issue is that classification systems inevitably depend on the ways the groups involved view the world; the paradigms that they inhabit. Reflecting on the design of CICES V4.3 we concluded that we need to be much clearer developing a terminology that distinguishes services from the benefits that are associated with them in different situations, and that probably we need a more comprehensive system for categorising benefits as well as services. The example of the 'FEGS' system developed by the US-EPA (Landers et al., 2016) suggests that there may be scope in looking at the way services, benefits and beneficiaries are aligned in different classification systems, so that a more complete picture can be established. Since it is clear that the 'end-products of nature' can give rise to multiple benefits, and that different groups may value in different ways, future categorisation systems probably need to be much more sophisticated in the way they help us to conceptualise these things.

These challenges provided the backdrop for the work undertaken in ESMERALDA on CICES and how it could support integration of the biophysical, social and monetary dimensions of ecosystem assessments. Much of this was progressed through workshops that brought together members of the consortium and others working on these topics. The outcomes are discussed in the next part of the Deliverable report.

3. Characterising the biophysical, social and economic methods with CICES

3.1. Introduction

As part of the on-going work of ESMERALDA, a number of meetings were held during 2016, with consortium members and others, on the general issue of integrated mapping and assessment in MAES, and on the use of CICES. The work on CICES was also undertaken in collaboration with the European Environment Agency (EEA), in conjunction with an on-going initiative to examine the case for revising CICES V4.3. This section of section of the Deliverable describes outcomes of these workshops.

3.2. Customisation of CICES across Member States

A workshop on the ‘

customisation of CICES’ was held at European Environment Agency between 25th and 26th February 2016; it formed Milestone 19 of ESMERALDA (see Potschin and Haines-Young, 2016b). The aim of the ‘Copenhagen Workshop’ was to take stock of the experience gained in using the current version of CICES V4.3 for accounting, mapping and assessment, and to advise on the objectives for any future revision and the development of guidelines to help people apply it effectively within the context of ESMERALDA and the EU MAES process. The workshop drew on interim results from consultation on CICES that was due to be completed in April 2016 (see below).

The workshop was organised by University of Nottingham (WP4 leader on Ecosystems Service Assessment Methods) and hosted by the European Environment Agency. Eighteen experts from ten different European countries attended the meeting; they included members of the ESMERALDA consortium as well as members of the wider ecosystem service community; all had experience in using CICES or had worked on classification issues.

The workshop focused on two main areas for discussion. The first sought to draw on the experience of using CICES by those attending the meeting, and to reflect on some interim results from the on-going survey of CICES applications. The second looked at CICES as an indicator framework and some of the key messages that can be taken forward in developing guidelines for using the current or revised version of the classification in the future.

3.2.1. Using CICES for mapping and assessment methods

The key points that emerged from the discussion around the issues of using CICES for mapping and assessment methods were that there was a need for better guidance in using CICES (both in its current form and especially if there is a revision). It was suggested that any guidance could usefully be provided (for example in the form of a MAES report) and that future work within the ESMERALDA project could inform and test the development of these guidelines.

In terms of ***provisioning services*** it was noted that in using CICES many people start at the class level rather using the groupings at the higher levels in the hierarchy, and so there should be some attempt to make the descriptors less abstract at an early stage. It was also suggested that it should be recognised that the classification is used in different domains and so there should be some attempt to reflect this in potential alternative terminologies; for example there might be scientific descriptors as well and more popular terms as equivalents. A numerical coding for all services in the CICES hierarchy was also recommended as useful.

For ***regulation and maintenance services***, it was noted that it might be useful to make guidance context- (biome) specific, by for example, providing guidance for marine applications, or by including examples of services for different biomes. In the context of marine ecosystems it was argued that assessments are often best made at the group level and so better guidance was needed here, especially in relation to the distinction between 'intermediate' and 'final' services. It was concluded, however, that for marine context there should be no attempt to remove services that are potentially 'intermediate' from the CICES class list, even if the goal is to focus on 'final services'. Their inclusion is considered necessary to ensure comprehensive coverage in all types of application (see Potschin et al. 2017 for more detailed discussion of the concept of intermediate services).

In relation to ***cultural services***, it was agreed that there was a pressing need to clarify the terminology in relation to the service/benefit distinction. It was also agreed that the cultural dimension of all services needed to be explained as part of clarifying what cultural services actually are. In terms of suggestions for revision people felt that the split between physical and intellectual services at the group level was unclear, and that some other formulation such as 'proximal' and 'remote' interactions might be more helpful; scale might provide another potential approach to differentiating cultural services. In terms of definitions it was suggested that it might be worth stressing that these kinds of service ***shape*** our cultural environment, and so descriptors might try to capture the more 'active' or 'doing' aspects.

3.2.2. Using CICES as an indicator framework

The discussions also focussed on reviewing the ways in which CICES has being used to create indicator frameworks or metrics that could be used in mapping and assessment, and accounting. The workshop drew on the results of the case study analysis that was undertaken within ESMERALDA (Santos-Martin et al. 2016) hat looked at around 60 applications. The analysis found that not only did methodologies of mapping and assessment vary across Member States, but also that knowledge of the ecosystem service concept and the way they are classified also differed. However, in terms of the classification system used, CICES was the most frequently applied. Regional scale applications were also the most common. In terms of the focus of the studies, the majority (49%) looked at the biophysical dimension and on the capacity of ecosystems to supply services. Within provisioning services, the top three were cultivated crops, fibres and other materials and ground water. For regulating and maintenance services, the most common were global climate regulation, flood protection and filtration/sequestration. Within the cultural services section, the most frequently assessed were aesthetic, physical use of landscape and seascapes, and heritage. A key conclusion to emerge was that while a range of indicators based on CICES 4.3 that were identified, only few could be used for reporting under Action 5 of the EU Biodiversity Strategy, and that further work was needed to ensure better coverage.

Further background for the discussions on indicators was provided by reviews of studies in Finland and Germany. Subsequent discussions confirmed the earlier conclusion that there was a need for revision of the current version of CICES, or at least the clarification of terms etc. so that it can be applied more easily. It was felt however, that the role of CICES as a translator should be maintained and strengthened, and that perhaps it could also help translate between application contexts as well as between ecosystem service classification systems. The idea of 'application masks' was suggested as an option in relation to this. It was recommended that 'CICES masks' that could be applied in different biomes (e.g. marine) as well as different types of application (e.g. accounting, assessment etc.).

In terms of using CICES as an indicator framework, it was confirmed that while ecosystem services are the focus, indicators across the range of variables included in the ES cascade, for example, would be needed in different applications; their relation to the CICES classes could be clarified. Such an approach is illustrated by the work of Mononen et al. (2015). It was felt that there was a particular need to help people to differentiate or to assess ecosystem service supply and demand metrics. However, it was suggested that if indicators are suggested alongside the CICES classes, they should not be used as part of the definition. CICES should not be presented as a 'comprehensive indicator framework'; rather people should be able to apply CICES independently of any suggested metrics.

A key point that emerged from the discussion on indicators was that while CICES V4.3 can support a variety of different tasks (accounting, assessment, communication, scoping), given that its origins lie in the EU/EEA accounting work and the UN System of Environmental-Economic Accounting Experimental Ecosystem Accounts (SEEA EEA), any revision should ensure that as a minimum those needed are fulfilled. There was some concern that the focus on accounting might make CICES too restrictive and undermine its multi-purpose use. However, it was stressed that accounting is much more than monetary valuation, and that applications linked to biophysical and social measures can be supported, and this could be emphasised in any set of future guidelines.

3.2.3. Conclusions from 'Customisation of CICES'

A key message to emerge from the workshop was the need to provide guidelines to users of CICES. In many respects, some of the current problems of application arise from the lack of guidelines for V4.3. . The recommendation was that rather than developing the guidelines ***after*** the revision process had been completed, the development of guidelines should be seen as ***part of*** that processes of revision. In this way issues could be identified early on and strategies for overcoming them presented in a more transparent way. It was recommended that the work undertaken by the EEA and ESMERALDA in the short term should provide a 'road-map' for the development of these guidelines. Although the guidelines might eventually be published as a MAES Report, it was felt that web-based support was probably also needed.

3.3. CICES User Survey 2016

As part of the wider work surrounding the development of CICES in the context of experimental ecosystem accounting, a survey of people using CICES or concerned with ecosystem service classification was undertaken in the first quarter of 2016[4] (Haines-Young, 2016). The aim was to draw on the body of experience that has been built up since the release of V4.3 in 2013, and to identify where its strengths and weaknesses are, and potentially how the structure might be improved. People who had not used CICES but who had used other classification systems were also encouraged to complete the survey. Altogether, 327 people attempted the questionnaire from which there were 222 useable responses, in the sense that they provided answers to some or all of

[4] see also www.cices.eu

the questions posed in the main body of the survey; 125 (59%) recoded that they were CICES users and 87 (41%) that they were not.

A clear message that emerges from the questionnaire was that there appeared to be an established user-base for CICES; much broader than had, for example, been anticipated in the workshop on customisation (Section 3.2 above). In terms of application area, the majority of users selected 'mapping and ecosystem assessment' (77%), followed by 'valuation' (37%) and 'the development of indicators' (35%); only 19% selected environmental accounting[5]. The responses of people using CICES confirmed that its key advantages were its logic, the flexible hierarchical structure, its comprehensive coverage and the potential that it offered as a standard. While users also identified difficulties in working with the classification, the comments suggest that many of these could potentially be overcome by providing better guidance and examples. The kinds of issue that these examples need to illustrate include the links to underlying structures, processes and functions, and the links to benefits and beneficiaries. It seems apparent that whether or not formal classifications of benefits and beneficiaries are developed in the future, these examples could serve to help users of CICES in the short to medium term. The important analytical issues that need to be considered include the problem of 'double counting' and how to handle it in the classification, and how the classification might support the analysis of 'trade-offs'.

The results of the Survey confirmed the findings of the 'Copenhagen Workshop', namely that the classification of cultural ecosystem services in version 4.3 of CICES is an area of concern. Also echoed were the findings that for the marine sector, that a better explanation of that constituted a final service in different types of environment might be necessary. A conclusion to emerge from the analysis of responses was that to support the wider range of uses, it would be advantageous for any future version to have a less technical set of descriptors and service names that could be used with non-experts during, say, a participatory process. While it seems unlikely that a 'lay version' of the classification could replace the more technical one (given the need for better definitions suggested by a number of respondents), the ability to have consistent but customised naming conventions that suit a wider range of applications would seem useful. The approach could also be used to cross-reference service categories that make more sense in the context of specific ecosystem types, such as marine.

In terms of developing CICES further it emerged that there was a majority of respondents in favour of better integrating the classification of abiotic ecosystem outputs into the system. Making a link to classifications of benefits and beneficiaries was also strongly emphasised. At the time of the workshop the process of revising CICES V4.3 was on-going and it was agreed with the EEA that recommendations for modifying the structure of CICES and any draft guidelines could be examined by the ESMERALDA consortium, so that they can be made as operationally robust as possible. It was suggested that this strategy could support that part of the ESMERALDA work programme concerned with is testing analytical methods across a range of different case studies.

[5] The survey identified nearly 40 published papers and links to other sources describing work based on CICES; many of these have been used in the literature review presented in Part 2. They also provide a useful starting point for developing a set of examples around which strategies for handling analytical and conceptual issues can be described.

3.4. Flexible methods for ecosystem service mapping and assessing

The ESMERALDA workshop on 'flexible methods' held in Nottingham between 14th-15th April 2016 ('Nottingham Workshop') was designed to address a much wider range of issues than the those relating to CICES (see Potschin et al., 2016c), nevertheless less its outcomes are highly relevant in the context of the current Deliverable and so are discussed here. The ambition was to understand how the 'flexible methods' identified in the Project built towards the creation of a suite of integrated assessment tools and concepts that can be used by EU Member States to fulfil the requirements of the MAES Process. A robust system for classifying ecosystem services was seen as an important part of this process.

The specific aims of the 'Nottingham Workshop' were to develop a common understanding within ESMERALDA on methods for mapping and assessing ecosystem services and how these could be assigned to the 'tiered approach'. It was also designed to identify the relationships between ecosystem services, ecosystems, scales and specific methods and the potential linkages between methods across the biophysical, social, and economic domains. The extent to which the current or future versions of CICES can be used to support and operationalise these various methods was one of the key points in the discussions.

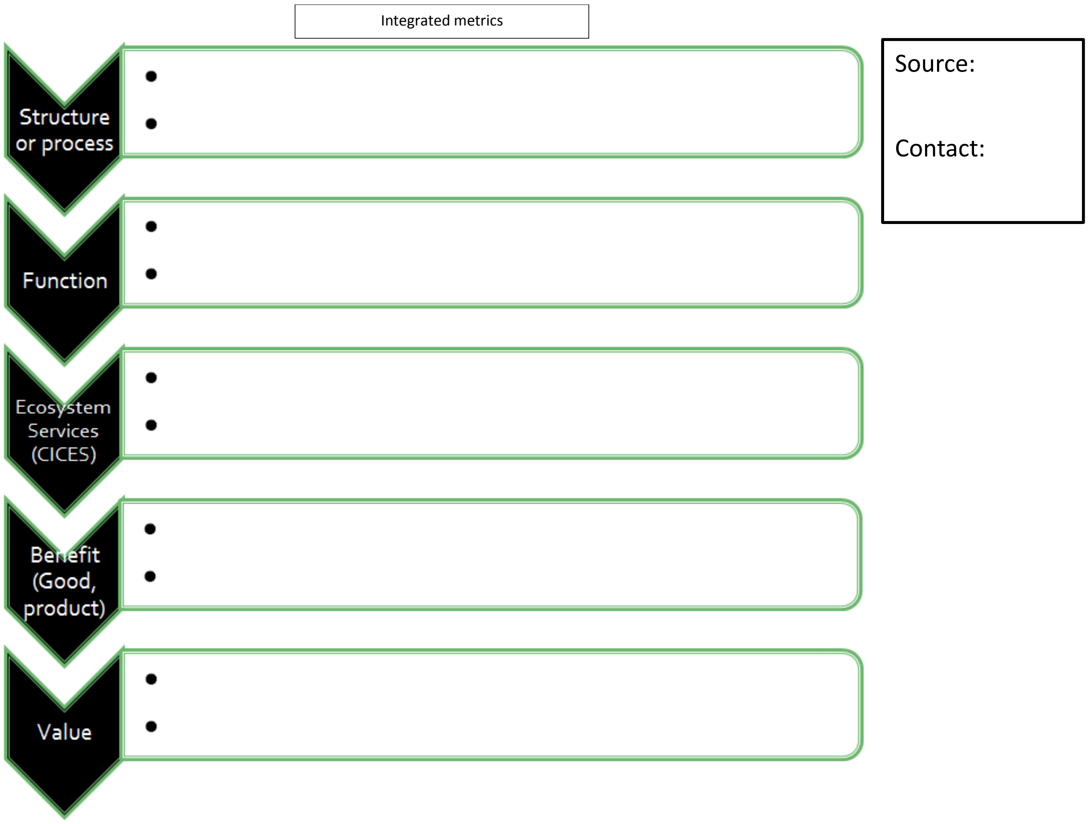


Figure 3: Template used to collect information on integrated CICES metrics at the workshop

3.4.1. Ecosystem services and their quantification

The workshop began with an introductory session on ecosystem services and their quantification, and in particular how CICES V4.3 can be used to help identify what potentially is being measured. The issue is especially important because experience suggests that often 'ecosystem service flows' cannot be measured directly, but instead characterised by using proxies that give insights into the capacity of ecosystems to supply services, or the demand for, or use of, services by people. The discussions therefore examined the extent to which CICES can provide a framework that can be used to capture different sorts of metrics and how they relate to each other in an 'integrated assessment'.

It was generally agreed that, taken together, the cascade model and CICES provide one basis for 'quantifying' and 'qualifying' ecosystem services. Quantification is clearly a pre-requisite for developing metrics or indicators that can be used both for mapping and ecosystem accounting. The idea of 'qualification' was emphasised to highlight the fact that the cascade and the classification itself provide a set of concepts and descriptors that can be used to engage stakeholders in discussions about ecosystem services. It was noted and accepted that while CICES V4.3 is not the only 'entry-point' for mapping and assessment, it can provide a way of making comparisons and cross-references. We later implemented and further elaborated the idea of using CICES as a tool for synthesis and comparison across studies in the systematic review in Chapter 4 (see also Czúcz et al., 2018).

To help people to use CICES it was suggested that links to 'real indicators' were needed; an exercise undertaken in the break-out session identified a number of examples that could be used in this context. The template used is shown in Figure 3, and the results tabulated in Appendix 2. The aim of the exercise was not so much to identify 'relevant' indicators for the services that were suggested by the participants, but to examine if and how they could be seen as *integrated* measures across all the elements of the ES cascade, in the sense that they all measured different aspects of the *same* service, and hence could be used to triangulate the judgements made about its status and trends. The workshop identified 28 examples that were used as the starting point of further ESMERALDA work (Santos-Martin et al., 2018a; 2018b).

In reviewing the examples, participants reported that in general it was possible to think of integrated measures across the biophysical, social and economic dimensions of the ES cascade, but that most of the examples were at the V4.3 class level; in the future is was suggested that it may be useful also provide to illustrations of how metrics and indicators could be constructed at the division and group levels. Such examples could be used to illustrate how these upper levels in the classification can be used to define more aggregated types of metric that can also be used in mapping and assessment work. The need for better guidance and examples was highlighted through an example involving the use of CICES to classify 'purification'. Experience suggests that the category is too complex to be assessed at the class level, and that perhaps mapping needed to be done using more aggregated metrics for representing categories at the group or division level. It was also recognised, however, that for some applications, further flexibility could also be highlighted by showing how sub-classes could be added below the class level to better take account of local issues (see also Chapter 4 & Czúcz et al., 2018).

The participants recommended that guidance should be developed to better communicate flexibility for applications, for example by providing a wider range of names for services at the class level so that the classification can be adapted to local needs. A future version of CICES might also be translated into other languages, and in this context resources might need to be found to harmonise the translated names and descriptors. The need to tailor CICES so that it can better be used to assess the variety of ES associated with both terrestrial and marine ecosystems was also considered. It was suggested, for example, that customised versions could be developed for specific habitats/ecosystems (e.g. urban) or more general set of 'biophysical classes'.

While it was acknowledged that CICES can help users simplify the complexity around defining and measuring ecosystem services, it was also pointed out that understanding the supply and demand side is not always 'linear', and can become complex when you have to incorporate all the ES cascade components into the assessment. In terms of helping people pursue 'an ecosystem approach' it was argued that this might limit its use if we really are aiming to provide information for decision making; a particular issue identified was to ensure that there was consistency between legal and administrative requirements and measures at different levels of the ecosystem service cascade.

Further complexity in the application of CICES was noted because some felt that certain CICES categories were "inherently inseparable", such as 'timber' and 'fuelwood', or mediation at the 'species' and 'ecosystem' level. Other difficulties were identified around those services that are simply 'closely related' such as 'honey' and 'pollination', or where one service was provided by a number of species (i.e. multiple ecological 'structures', in terms of the ES cascade model). The extent to which the issue of the level of 'human input' needed to be considered when defining an ecosystem service was also discussed using the example of where ecological pest control was used, but based on an introduced species.

Participants felt that either better guidance on how to handle these issues was needed or the structure of the classification might need to be modified. It was suggested that other complexities that also needed to be considered were those relating to how to handle temporal fluctuations in ES, related say to timber provision and flood control at different levels of the ES cascade; it was suggested that some of these difficulties might be resolved by clarifying how the capacity to supply a service and the actual provision relate to each other, and what these two characteristics mean in terms of developing metrics for assessment purposes. These proposals were further picked up in Chapter 4 (see 4.2.6 & Czúcz et al., in prep).

The discussion noted a number of other issues that might be addressed in providing guidance for those using CICES in the context of ESMERALDA. The difficulties of classifying cultural ecosystem services at the division, group and class levels were suggested as especially problematic. Help where proxies (such as species abundance) are used as indicator for ES (or habitat quality) might also be needed so that people have sufficient ecological information to be able to apply or to interpret metrics appropriately.

The need to assess ecosystem services as bundles was recognised as a particular problem for CICES and some participants felt that the 'cross linkages' between some of the services in the classification were not covered particularly well. The example given was the cultural dimension of some provisioning services such as hunting or collecting wild plant food. These kinds of situation, it was pointed out, open up the danger of 'double counting' especially where the distinction between services and benefits is not sufficiently well made. This was illustrated by reference to the case of marine ecosystems that provide nursery habitats, a regulating service, but also food as a provisioning service through fish stocks. A further example was that of mapping ecosystems services associated with forests, where there was an overlap between timber provisioning and the regulation of climate through carbon sequestration.

The breakout sessions generated a number of examples that could be used in any future guidance to illustrate how metrics can be used to characterise the different cascade elements. The examples showed how proxy measures at the function or structure and process level relate to a service, or how a suite of measures that can be used to make a more robust assessment of status and trends. This material was used both as an input into the guidelines being developed for the revised version of CICES and as an input into the development of the 'library of CICES-consistent indicators' that was being developed as part of ESMERALDA Milestone 20 (see Chapter 4.2.5).

3.4.2. Biophysical, social and economic methods

After the initial session, the Nottingham Workshop focussed more generally on the identification of a suite of 'flexible methods' that could be '*applied in all EU members states, including the outermost regions, marine areas and specific biomes'* (ESMERALDA Objective 5, DoA, p. 8). Despite such a broad methodological focus, the outcomes were nevertheless relevant to this discussion on CICES. On the one hand, they potentially allowed guidance to be extended to identify what methods have or can be used for the measurement of specific indicators. On the other, the discussions identified what the different methods are *measuring* in terms of a particular service.

The Nottingham Workshop attempted to gain an overview of what methods, models and tools are currently being applied in case study work by ESMERALDA partners. The aim was to identify what the advantages, disadvantages and problems were with different methods, and what the reach of the different applications was. To do this, a series of matrices were defined that could be used to record the information provided by participants. The information recorded in the methods matrix is shown in Table 2 All examples were cross-referenced to CICES classes, and the links between these classes, ecosystem types, methods and metrics could then be traced.

Table 2: Fields used to define 'methods matrix'

	Field
1	Example application
2	Name of reporter
3	Location
4	Ecosystem Type(s)
5	Ecosystem Service(s) (CICES V4.3 Class)
6	Scale (local, national, …)
7	Method(s)
8	Variable (used to measure ES)
9	Strength of method
10	Weakness of method
11	Tier 1-3
12	Links to biophysical methods
13	Links to social methods
14	Links to economic methods
15	Comments

Using this matrix the breakout sessions considered biophysical, social and economic methods and this enabled 150 examples to be documented. The material was further refined after the workshop and later checked by the participants who provided it (Santos-Martin, 2018a; 2018b)

In order to identify the expertise available within the consortium, a further matrix was created, this time cross tabulating the CICES V4.3 classes with the 'mapping tiers' that have been used to characterise the work in ESMERALDA. This matrix has also undergone further elaboration since the workshop and is reported as part of WP3 (see Weibel et al. (2018) for more information on the 'tier work' within ESMERALDA).

The documentation and guidance on methods that has been developed from these materials is presented as part of the final Deliverables from WP3. In the final report from WP3 (Deliverable D3.4) we focus only on how these fit together to enable an integrated assessment to be made. At the stage of the workshop a number of initial conclusions could be drawn in relation to CICES V4.3 that has informed subsequent work.

First, that participants found it relatively easy to cross reference their work to the different categories in CICES V4.3, even though they may not have used the classification initially for their work. The value of CICES as framework for making comparisons and standardising results therefore appeared to be supported. Second, that there is a significant body of case study information that can be drawn upon to develop future guidance that covers a range of biophysical, social and economic applications. Moreover, there appeared to be good coverage of the major ecosystem or habitat types found in Europe. Third, there is a prospect that the on-going work on CICES-consistent indicators and metrics can be underpinned by guidance on what methods are available for quantification. A particular area where it was agreed that further work was needed was on the links between methods, especially between those dealing with the biophysical and economic aspects of mapping and assessment. It was acknowledged that, while the linkages between socio-cultural and economic assessment also need to be explored, preliminary results suggest that this appears to be less challenging. The workshop confirmed, however, that in all areas operational progress continued to be limited by data availability and data quality issues.

4. CICES: Understanding the practitioners' perspective

As part of the ESMERALDA work Programme, a systematic review on ecosystem service indicators was undertaken and presented as Milestone 20 (MS20, CICES consistent library of indicators for biophysical, social and economic dimensions). Part of this was subsequently published as a paper by Czúcz et al. (2018). Much of this work is relevant to this discussion on the role and structure of CICES, and so the findings of this work are considered in detail. The systematic review reflected to and provided insights on many of the design issues identified in the workshops and consultation, such as consistency and the optimal level of resolution in the classification. Critically, however, it did so from a practical perspective. The aim of the systematic review was to examine the extent to which CICES 4.3 conformed to the current practice, and to determine whether there are:

- any CICES V4.3 classes that are indistinguishable from a practical assessment perspective, and hence to determine whether the classes are too narrow;
- any CICES V4.3 classes that where the practice distinguishes subtypes, and hence to determine whether the classes are too broad; and,
- any ecosystem services identified in the assessment literature that are not covered by CICES V4.3, and hence better understand its claim to be 'comprehensive'.

We also characterized the ES indicators found in the papers using several of their measurable characteristics in order to document current practices surrounding their use. By linking practical ES indicators to CICES classes and further key attributes in this paper we therefore explored:

- the consistency of the ES type categories in the light of their practical implementation as indicators;
- the relative position of indicators / ES types in the assessment framework and geographical space; and
- the characteristics of the metrics / units in which the indicator is measured.

This pragmatic and systematic analysis therefore responded to and complemented the more participatory approaches summarised in Part 3 of this Report.

4.1. The systematic review approach

It can be expected that papers in the peer-reviewed ecosystem service research literature provide examples of work that is both practically effective and scientifically sound, and to represent the pool of available methods and common forms of assessment. Published ES studies therefore represent an important resource for developing a comprehensive overview of the current 'state of the art'. In this Deliverable report we present the most CICES-relevant findings from the systematic review described and initially discussed in the ESMERALDA Milestone report MS20 ("CICES consistent library of indicators for biophysical, social and economic dimensions") and Czúcz et al. (2018).

The systematic review was based on a so-called concept matching approach that attempted to bridge the gap between studies using incompatible classification systems. This approach was designed to provide useful overviews and comparisons between different studies by matching the detailed definitions / descriptions of the studies ES to CICES classes instead of relying on just the short ES names used by these papers. This approach was partly inspired by the participatory discussions on CICES, and was similar to the method followed by Malinga et al. (2015) and Englund et al. (2017), who also matched the ES in the published studies to one of the relatively comprehensive global classification systems in their systematic reviews. This analysis matches the ES type definitions of the selected typology to what the studies actually did, even if this sometimes contradicts to what they claim to have done. The ambition was to eliminate ambiguities created by the incompatibilities between the different typologies, and therefore develop a robust and well-structured overview of what is being researched and how the work is being done. Furthermore, by matching a 'theory driven' classification system such as CICES V4.3 with real-world applications (i.e. to policy-oriented mapping and assessment studies) was possible to 'test' the classification system for its comprehensiveness and any hidden inconsistencies.

Thus the systematic review focussed on the individual ecosystem service metrics (indicators) used in the published literature, and constructed a database describing their use. In order to make a detailed analysis of the material a small number of non-preferentially selected papers were identified. The number was limited by using a set of strict inclusion/exclusion criteria so that a deeper analysis could be made of them (cf. Malinga et al., 2015). Following Crossman et al. (2013) and Englund et al. (2017), the selection was based on other recent systematic reviews of ecosystem service indicators and took the papers that they identified as the starting point for the analysis. Thus, the list of papers selected by Boerema et al. (2017) was used as a starting point; these authors performed a relatively comprehensive systematic literature search and identified 405 peer reviewed papers. For the purposes of the systematic review done in ESMERALDA the selection was narrowed to those studies related to Europe (n = 121) to meet the remit of ESMERALDA. The 121 papers were further screened using criteria relating to the centrality of the ES concept in the study, quantification, and compatibility to assessment logic. Papers were not excluded on the basis of whether they made explicit reference to CICES V4.3 or not, because this was not considered relevant given the concept matching approach used in the analysis; if only papers using CICES were included this would also introduce an unfair bias. Altogether, 85 papers met the selection criteria (Appendix 6).

If a paper was selected for review, all ES indicators 'quantified' in the paper were recorded as separate entries in a review template. It is important to note that the term 'quantification' was interpreted in a way that was consistent with usage in the natural sciences (Stevens, 1946), i.e. services "scored" on an ordinal or binary scale were still included. If there was more than one indicator for the same service, each one was recorded separately. If two papers used exactly the same approach and methods to measure a service, each was considered individually and were treated as representing two distinct data items. The analysis of indicators was taken further by documenting the units in which they were quantified (e.g. mass, length, area, energy, score, money, etc.) and any normalisation to unit area, time or population.

To extract information from the papers used in the different studies reviewers were asked to read the definitions of the indicators and the underlying ecosystem service provided in the paper, and link them to the classes in CICES V4.3, taking care to follow the original logic and intentions of the authors. All CICES 4.3 classes that matched or partially matched the definition or interpretation of the indicator used by the authors were noted; most papers seemed to work at the equivalent of the CICES class level Thus in the case of a specific paper, a single service (CICES class) could be assessed by several indicators, and a single indicator could represent several CICES classes at the same time (i.e. there could be 'many to many' relationships).For example, if in a study, an ES was assessed both in biophysical units and in monetary terms, then this was recorded as two data items. Thus, in the case of a specific paper, a single service (CICES V4.3 class) could be assessed by several indicators, and a single indicator could represent several CICES V4.3 classes. The aim was to use linkages between indicators and CICES classes ('one-to-one' or 'one-to-many') to assess the 'goodness of fit' of the CICES classes. To achieve this we defined the 'exclusivity' of an indicator as a binary metric distinguishing indicators that represent just a single CICES class ('exclusive'), and ones that cover several different classes ('non-exclusive'). We considered that wherever a large number of non-exclusive indicators are identified then this suggests that the underlying CICES classes are 'overspecified' or too detailed for practical purposes. On the other hand, if classes were associated with predominantly exclusive indicators, then this might suggest that the level of thematic resolution in CICES is appropriate in operational terms.

Of the 85 papers selected for analysis, 21% involved ecosystem service mapping and 48% assessments. The remainder were mainly concerned with indicator development. From these papers 439 ES indicators were identified. None of the studies reviewed referred to CICES explicitly, so all the links between CICES V4.3 classes and the indicators assessed were to be established by the reviewers. In the 50 mapping and assessment papers 328 indicators were found. As mapping and assessment activities are primarily motivated by policy applications, these indicators are particularly relevant for policy or decision-making contexts. Thus, both of these two sets of papers (called henceforth 'all studies' and 'mapping and assessment studies' respectively) serve as valid and distinct 'statistical populations'; in what follows we discuss and summarise the results for both of them separately.

4.2. Results

4.2.1. Similarities and overlaps between CICES V4.3 classes

To study the similarities and overlaps between CICES V4.3 classes, we used a simple similarity metric (Jaccard, 1912) which measured the proportion of 'shared indicators' among all indicators for a CICES class to all pairs of CICES classes. The similarity values indicated the degree to which any pair of CICES classes is handled jointly; a very high similarity scores is a sign that the pair in question is effectively indistinguishable. To visualize and analyse the similarity patterns, we applied simple hierarchical clustering (single link) and forced network graphs in R (algorithms *hclust* in base R & *forceNetwork* in package networkD3, Gandrud et al., 2016). The results are shown in Figures 4 and 5. Only those 39 CICES classes that were covered by at least 5 different papers were included in the analysis. We identified clusters of CICES classes at a predefined cut-off level of 0.5, which is the middle of the similarity range; this separates class clusters dominated by pairwise similarities from isolated classes which have no 'dominantly similar' kins. To simplify the discussion of the results, we have made use of the four-digit CICES V4.3 class notation, which is introduced in Table 1 and Appendix 1.

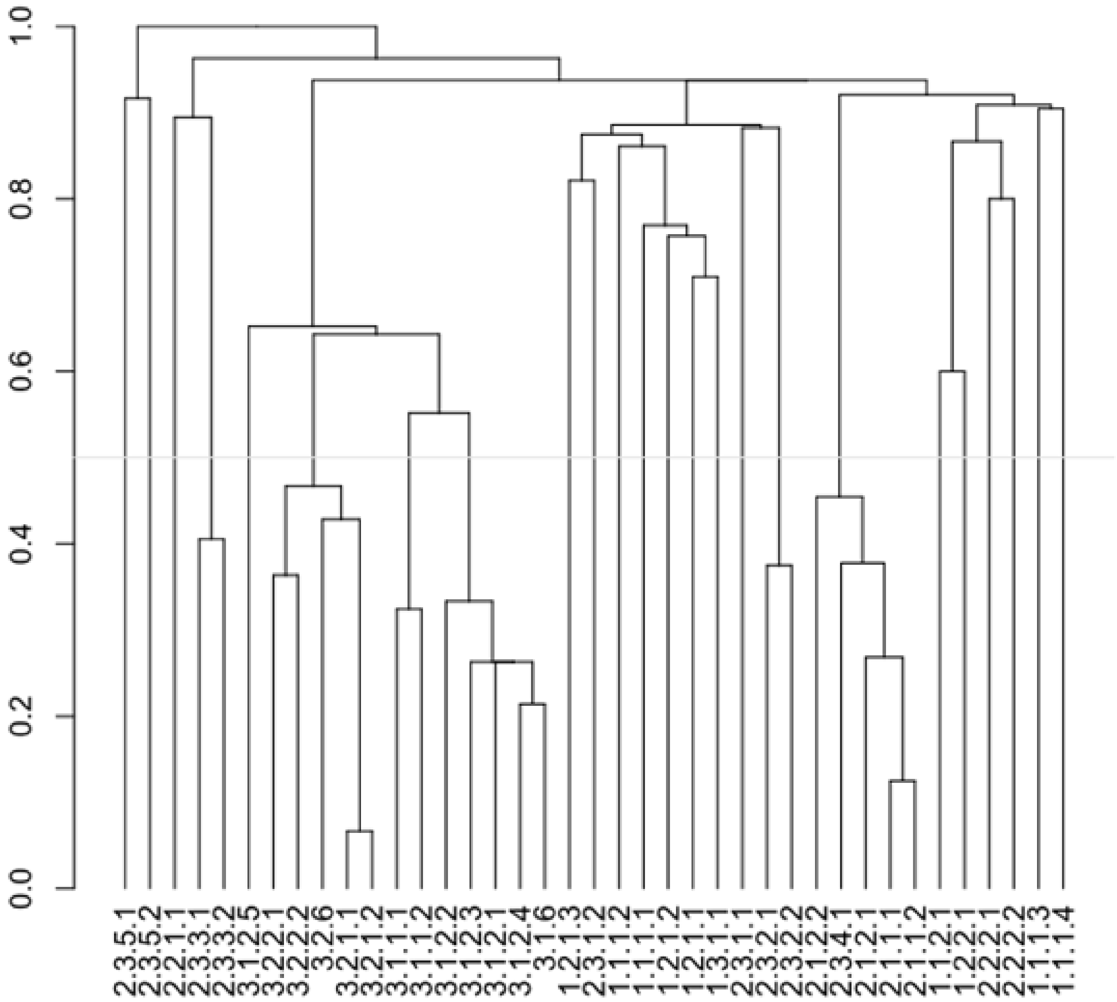
The CICES V4.3 class with the highest proportion of exclusive indicators is 2.3.5.1 (global climate regulation, where 89% of the indicators are of this type) (Table 3). This therefore seems to be the most well-defined and least ambiguous ecosystem service for practical assessments. Other relatively clear and frequently assessed CICES classes include 2.3.1.1 (pollination and seed dispersal, 83%), 2.3.5.2 (local climate, 71%), 2.2.2.2 (flood protection, 64%), 2.2.1.1 (erosion control, 53%), 1.1.1.4

(wild animals and their outputs, 53%), and 1.1.1.1 (cultivated crops, 50%). Not surprisingly, the CICES classes with a lowest 'degree of exclusivity' are the ones involved in the clusters.

Altogether 226 of the 440 indicators identified are exclusive indicators (51%). However, if we merge all the classes in the clusters (i.e. consider indicators that refer to several classes in a single cluster as 'exclusive') then the ratio of exclusive indicators rises to 68%. If we consider the fraction of exclusive indicators as a metric characterising how much a class captures real analytical situations, then most CICES V4.3 classes seem to perform poorly, with only 6 (13%) of the original classes, and 9 (26%) of the merged classes being assessed with dedicated indicators at least half of the time. On the other hand, more than 60% of the CICES V4.3 classes have been assessed at least once with specific methods and indicators, which means that for around two-thirds of the classes there are applied contexts where the underlying distinctions make sense. And if we consider the few clusters of overlapping classes identified in Table 3 jointly, then these figures improve to more than 75%. Regulating services tend to be the most 'unambiguous', and cultural services the most 'elusive'. To provide further insights on the use of indicators, in the discussion that follows we use these clusters as reporting units, rather than the CICES classes that were found to belong to them.

Table 3: The most frequent ecosystem services (CICES V4.3 classes and clusters) in all reviewed mapping and assessment studies, and their major characteristics. For more detailed breakdown see Appendix 3.

	NP N of papers	**NI** N of ind.	**EI** % of exclusive ind.	**AN** % of area normed	**TN** % of time normed	**PN** % of population normed	**PC** % of percentages	**SC** % of scores	**MO** % of monetized
	85	440	68%	48%	36%	2%	22%	27%	20%
2.3.5.1: Global climate regulation by greenhouse gas reduction	27	38	89%	76%	58%	0%	9%	12%	15%
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	26	44	45%	27%	18%	7%	0%	64%	33%
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	25	38	45%	24%	34%	8%	4%	42%	46%
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	24	48	75%	52%	46%	0%	38%	23%	20%
2.3.1.1: Pollination and seed dispersal	22	47	83%	66%	38%	0%	29%	10%	12%
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	20	26	31%	31%	31%	12%	6%	59%	53%
1.1.1.1: Cultivated crops	18	28	50%	54%	50%	0%	5%	23%	27%
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	18	30	40%	20%	23%	10%	5%	55%	50%
2.3.1.2: Maintaining nursery populations and habitats	14	23	43%	35%	22%	4%	25%	30%	15%
1.2.1.1: Fibres and other materials for direct use or processing	12	26	8%	58%	42%	0%	6%	41%	53%
2.2.2.2: Flood protection	12	14	64%	14%	36%	21%	9%	45%	27%
C: Maintenance of soil fertility (2.3.3.1, 2.3.3.2)	12	37	84%	32%	41%	0%	58%	9%	12%
1.2.1.2: Materials from plants, algae and animals for agricultural use	11	20	25%	75%	55%	0%	19%	25%	25%
2.2.1.1: Mass stabilisation and control of erosion rates	11	15	53%	47%	47%	0%	0%	25%	25%
1.1.1.2: Reared animals and their outputs	10	13	46%	38%	46%	0%	10%	40%	30%
1.1.1.4: Wild animals and their outputs	10	17	53%	24%	29%	0%	0%	44%	89%
2.2.2.1: Hydrological cycle and water flow maintenance	10	11	45%	64%	45%	0%	22%	22%	22%
2.3.5.2: Micro and regional climate regulation	10	14	71%	64%	29%	0%	15%	31%	8%
B: Pest and disease control services (2.3.2.1, 2.3.2.2)	10	16	50%	56%	31%	0%	14%	29%	14%



Key: NP: number of pertinent papers (which address the given ES); NI: number of pertinent indicators (which address the given ES); SI: ratio of 'solo' indicators (which only pertain to the given ES exclusively); MCL: mean estimated cascade level of the pertinent indicators according to scale shown in Figure 2; MP: ratio of indicators mapped (used for producing maps in the study); MA: mean anchor: ratio of mapped indicators (MP*NI) anchored at the beneficiaries; AN: ratio of indicators that were normed to unit area (/ha, /km2); TN: ratio of indicators that were normed to time (/year); PN: ratio of indicators that were normed to population (/person, /household); PC: ratio of indicators expressed as percentage (a ratio or a composition); SC: ratio of score-type (ordinal scale dimensionless) indicators (as percentage of biophysical and social indicators); MO: ratio of monetized indicators (percentage of biophysical and social indicators that were also expressed as monetary indicators).

Figure 4: A hierarchical clustering (single link method) of the CICES V4.3 classes based on their use similarities (the fraction of shared indicators in the published study, see text). The selected similarity level (s=0.5) for the discussion of groups is indicated with a grey horizontal line. A key to the four-digit abbreviation of the CICES classes can be found in Table 1 and Appendix 1.

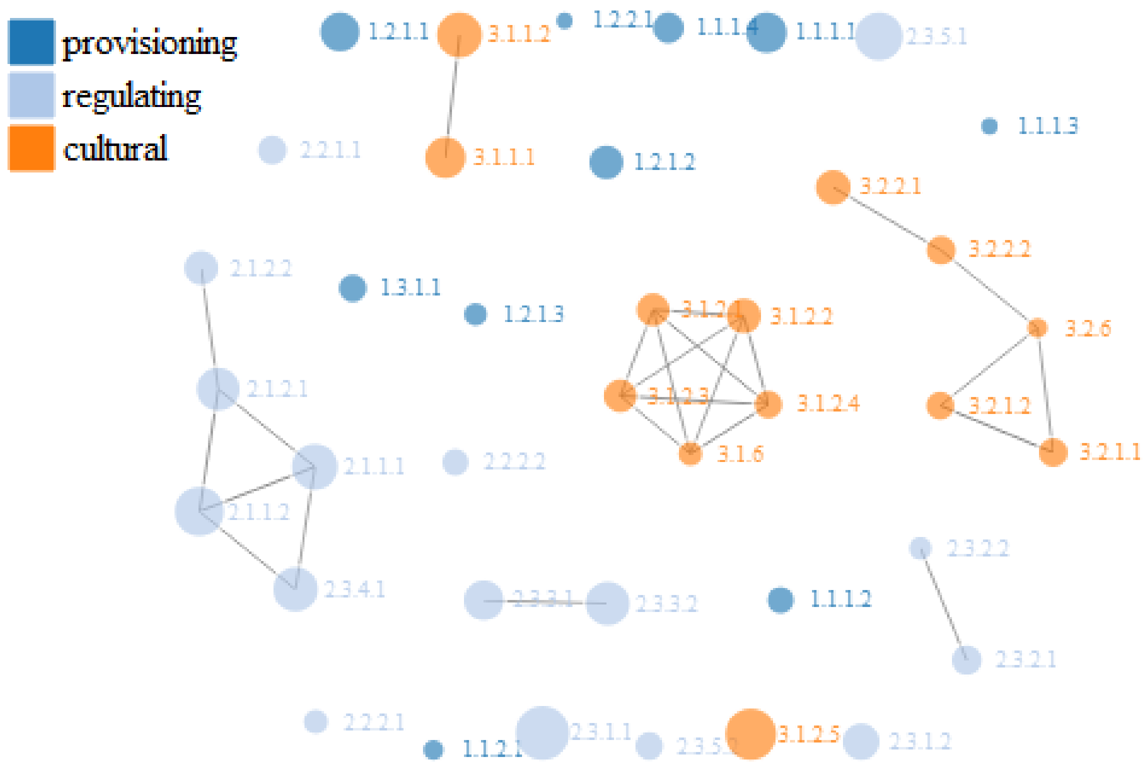


Figure 5: A graphical visualization of the links between the different CICES V4.3 classes at the selected similarity threshold (s=0.5). A key to the four-digit abbreviation of the CICES classes can be found in Table 1 and Appendix 1.

Figures 4 and 5 identify the clusters of CICES V4.3 classes that appeared to be strongly interlinked, these and the implications that follow from them were as follows:

- ***Bio-remediation and water quality maintenance services*** (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1[6]): were found to be frequently assessed together under different names (e.g. nutrient retention: Grossmann et al., 2012; Boerema et al., 2014, potential risk of pesticide residues: Bjorklund et al. 1999, waste treatment and water purification: Calvet-Mir et al., 2012; Trepel, 2010). This link identified was perhaps not surprising because most of these indicators try to capture the ecosystem's ability to buffer the harms that intensive agriculture poses to surface and ground water. Since bioremediation is meant to denote the processing of waste the implication of this finding is perhaps that guidance is required on how to separate this class from those relating to water quality regulation.

- ***Pest and disease control services*** (2.3.2.1, 2.3.2.2): these services were also frequently assessed jointly, because the ecological factors that support them (e.g. diverse and healthy ecosystems) are broadly similar, especially in the context of agricultural pests and human (or animal) diseases (Plieninger et al., 2012). Thus, this distinction between pests and diseases

[6] For coding on CICES classes see Appendix 1.

may be seen as somewhat arbitrary, even though in cases when an assessment focusses on a single pest/ disease species of high socio-economic relevance, this distinction might be justified in any future revision.

- ***Maintenance of soil fertility*** (2.3.3.1, 2.3.3.2): from a practical perspective it appeared to be difficult to separate the physical (inorganic) and biological (organic) components of soil formation processes, and so some reorganisation of the classes may seem necessary here given that few published studies distinguished them.

- ***Recreational (experiential and physical) use of land-/seascapes in different environmental settings*** (3.1.1.1, 3.1.1.2): It seemed that most of the studies did not appear to distinguish the experiential from the physical use of settings in the context of recreation.

- ***Intellectual representational interactions with nature*** (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4, 3.1.6): This group encompasses all scientific, educational and historical aspects of nature being our information host and heritage-keeper. It did not include aesthetic beauty (3.1.2.5) which was one of the most common cultural ES in assessments, typically addressed on its own; as a result, it was well-separated from all the other cultural services. On the other hand the group also included one of the experimental abiotic CICES classes (3.1.6: physical use of caves) which was also assessed frequently enough to be included into this analysis.

- ***Spiritual, symbolic and inherent values of nature*** (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2, 3.2.6): All non-use values seemed to be grouped here. As abiotic elements of the natural environment may also have very similar spiritual or symbolic significance (sacred rocks, mountains, historical places), there is the case in any revision for a similar abiotic CICES class covering this theme.

There were also other groups of services that showed some level of overlap (e.g. 1.1.2.1 & 1.2.2.1: water for nutrition and agriculture; 1.2.1.1, 1.3.1.1: wood for fibre/timber and fuel), which suggested that the current hierarchy levels for provisioning in CICES V4.3 may not match the way people think. The perception that the 'intended use' (nutrition, material, energy) comes largely at the class level in the classification hierarchy has already emerged several times during the CICES discussions, and these results seem to support this point.

4.2.2. Potential gaps in CICES V4.3

As part of the systematic review, three indicators were encountered that could be considered as ecosystem services but which were hard to fit into the categories of CICES 4.3. These and the implications drawn were as follows:

- ***Maintenance of traditional ecological knowledge*** (Calvet-Mir et al., 2012)**:** According to Calvet-Mir et al. (and partly to Derak and Cortina, 2014) the capacity of a traditional landscape that it can contribute to the preservation of endangered knowledge forms can be considered as an ecosystem service. With some flexibility this ecosystem service can be considered to be included into 3.1.2.3 (cultural heritage), just the examples provided need to be a bit broader to exceed the role of ecosystems as a physical container. An alternative strategy for any revision is that scientific knowledge category is expanded to also include traditional forms of knowledge.

- ***Creation and maintenance of social relations*** (Calvet-Mir et al., 2012, Plieninger et al., 2013): Some ecosystems, like parks or community gardens are places for creating and enhancing social networks. This non-material contribution of ecosystems to human well-being can be important in some contexts like urban assessments. Whether it can be accommodated into an existing class, or regarded more as an aggregate measure of benefits (contribution to well-being) of other cultural ES needs to be considered in any revision.

- ***Fire protection*** (Scholz and Uzomah, 2013): This regulating service, is actually the antagonist of a disservice (fire), which can be exerted by ecosystem components that can help to reduce fire risks (e.g. by reducing the build-up of litter). Even though this regulating service can be extremely important in some arid regions, we did not manage to find a place for it in CICES, and so this might be considered in any future revision or guidance.

4.2.3. Resolution at the class-type level

As part of the systematic review, the reviewers were also asked to note where they found that the indicator clearly corresponded to a specific class-type within CICES; in designing the classification class-types were intended to be flexible in the sense that they could be specified by the user as the needs of their study dictated. Any finding that published papers used a finer grain resolution than the CICES class does not necessarily imply the need to modify the classification but it does provide an insight into where guidance and examples may be useful to help people apply the system. The findings are shown in Table 4.

Table 4: CICES classes where assessment practice sees general 'sub-types' (i.e. the indicators in the published studies only partly cover the "scope" of the CICES class, and so might be regarded as Class-types)

CICES class		**Proposed subtypes**
1.1.1.4	Wild animals and their outputs	fish, game, shellfish
1.2.1.1	Fibres and other materials from plants, algae and animals for direct use or processing	cultivated, wild
1.2.1.2	Materials from plants, algae and animals for agricultural use	cultivated, wild
1.2.1.3	Genetic materials from all biota	medicinal
2.1.2.3	Mediation of smell/noise/visual impacts	noise mediation
2.2.2.2	Flood protection	coastal protection
2.3.1.1	Pollination and seed dispersal	pollination, seed dispersal
2.3.5.2	Micro and regional climate regulation	air quality, microclimate

Table 5: The most frequent (NP≥10) ecosystem services (CICES V4.3 classes and clusters) in the reviewed mapping and assessment studies, and their major characteristics. For more detailed breakdown see Appendix 4.

	NP N of papers	NI N of ind.	EI % of exclusive ind.	AN % of area normed	TN % of time normed	PN % of population normed	PC % of percentages	SC % of scores	MO % of monetized
All ecosystem services and indicators reviewed	50	328	62%	39%	31%	2%	18%	34%	20%
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	22	34	50%	21%	32%	9%	4%	42%	42%
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	20	44	75%	48%	43%	0%	39%	25%	22%
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	19	35	43%	23%	14%	9%	0%	63%	30%
2.3.5.1: Global climate regulation by greenhouse gas reduction	18	26	85%	69%	50%	0%	0%	17%	13%
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	17	22	36%	27%	27%	14%	7%	60%	47%
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	15	27	41%	19%	22%	11%	0%	56%	50%
1.1.1.1: Cultivated crops	14	23	52%	43%	52%	0%	6%	28%	28%
1.2.1.1: Fibres and other materials for direct use or processing	11	22	9%	50%	32%	0%	7%	47%	47%
2.2.2.2: Flood protection	11	13	62%	15%	38%	15%	9%	45%	18%
2.3.1.1: Pollination and seed dispersal	11	18	56%	33%	22%	0%	13%	27%	20%
2.3.1.2: Maintaining nursery populations and habitats	10	18	33%	22%	17%	6%	27%	40%	20%

Key: NP: number of pertinent papers (which address the given ES); NI: number of pertinent indicators (which address the given ES); EI: ratio of 'exclusive' indicators (which only pertain to the given ES exclusively); AN: ratio of indicators that were normalised to unit area (/ha, /km2); TN: ratio of indicators that were normalised to time (/year); PN: ratio of indicators that were normalised to population (/person, /household); PC: ratio of indicators expressed as percentage (a ratio or a composition); SC: ratio of score-type (ordinal scale dimensionless) indicators (as percentage of biophysical and social indicators); MO: ratio of monetised indicators (percentage of biophysical and social indicators that were also expressed as monetary indicators).

4.2.4. The most frequently studied CICES classes and clusters

The 'popularity' of the different ES in assessments was considered of practical interest in the review of CICES, and so a statistical overview of frequency of analysis was used to identify policy or research priorities, as well as potential knowledge gaps or selection biases. The results are summarised in Tables 3 and 5 and Appendices 3-4, which show respectively the results for all studies and those for mapping and assessment only. In both cases, only CICES classes and class clusters that were studied in at least 10 papers were considered. In the discussion that follows the clusters identified in Table 3 are used as reporting units instead of the original CICES classes that were found to be thematically overlapping. The rate of exclusive indicators was also recalculated. Thus, an indicator which refers to a single cluster would still be considered an exclusive indicator. This caused the number of exclusive indicators to increase considerably to 300 (68%, Table 3).

The first four most frequently cited CICES classes are the same irrespective of whether we consider all studies or only those dealing with mapping and assessment (Tables 3 and 5). Nevertheless, their order is different in the two cases: 2.3.5.1 (global climate regulation) is the service most studied among all papers, followed by 3.1.2.5 (aesthetic), cluster D (recreation), and A (bio-remediation). In the case of mapping and assessment studies, the order was recreation, bio-remediation, aesthetic and climate.

In addition to the most frequently studied CICES classes, the list of most neglected CICES classes is also interesting and relevant. There were three CICES classes that did not occur in any studies: 1.1.1.5 (plants and algae from in-situ aquaculture), 1.3.2.1 (animal-based energy), and 2.2.3.2 (natural or planted vegetation that enables air ventilation). Furthermore, there are seven more CICES classes that were represented in less than 5% of all studies (2.2.1.2: Buffering and attenuation of mass flows, 1.1.1.6: Animals from in-situ aquaculture, 1.1.2.2: Ground water for drinking, 2.2.3.1: Storm protection, 2.3.4.2: Chemical condition of salt waters, 1.2.2.2: Ground water for non-drinking purposes, 1.3.1.2: Animal-based energy sources).

There can be many reasons behind the 'popularity' of a specific ES type in published studies, or, vice versa, an apparent lack of interest therein. Such reasons can include perceptions on biological or social relevance, overt user preferences, and unconscious selection biases, which might favour or disregard certain ES types. Biological and social relevance are obviously location-specific, thus our results should only be considered indicative for Europe, the region represented by the studies reviewed. However, geographical relevance is not the only factor in play, and a direct attribution of the observed frequency patterns to any of the factors is largely impossible. Nonetheless, there can be some plausible reasons behind these patterns. Based on an overview of the papers reviewed these include:

- the *perceived relevance* of the services in the study context;
- the *availability of data and methods*;
- the *availability of existing information* for decision makers;
- the *'agenda' of the scientists*; and,
- ease of understanding and *communicability*.

Not surprisingly, the *perceived relevance of services* is a key selection criterion in most of the studies, specifically for those limiting their focus to a particular ecosystem type, or a special study context (e.g. Lehmann et al., 2014; Larondelle and Haase, 2013). To ensure this, assessments are often advised to base the selection of ES on participatory approaches exploring the perceived importance of 'candidate' services among target stakeholders (e.g. TEEB, 2012; Martinez-Harms et al., 2015; Förster et al., 2015). A further obvious motivation for the selection of specific services is *available data and methods*. This was frequently mentioned in the reviewed studies (e.g. Larondelle and Haase, 2012), along with accumulated research experience (e.g. Zorilla-Miras et al., 2014; Ford et al. 2012). The *availability of pre-existing information* for decision makers can also influence the selection of services for the study: services being recognised as already well-represented in policy-oriented information streams are less often the focus of assessment (thereby avoiding duplication of effort, e.g. Crossman et al., 2013). The *scientists' wish to influence the policy agenda*, can also be an important overt, hidden or even unconscious element in the process of service selection. This is no surprise if we consider that the primary motivation of the biodiversity conservation sector to champion the policy integration of the ES concept is of a similar nature: to generate convincing (utilitarian) arguments for the other sectors that support nature and biodiversity conservation (Balvanera et al., 2001; Chan et al., 2006). This might favour the selection of ES that are more closely related to biodiversity and natural ecosystems. A further type of agenda bias is the publication pressure on scientists, which might favour what is novel and interesting instead of what would really be policy-relevant (Olander et al., 2017). In our review, the papers classified as 'indicator development' are expected to be more affected by this bias than the mapping and assessment papers. And finally, the *ease of understanding and communicability* can also be an important factor for ES selection, especially in highly participative studies (Derak and Cortina, 2014; Mavsar et al., 2013).

It is not possible to 'test' these different possibilities in a statistical sense using the papers we have reviewed. However, all of these considerations can influence the selection of ES in a specific study and can potentially be seen as unexpected patterns in the occurrence frequency of the different CICES classes. For example, somewhat surprisingly we can see that cultural and regulating services are much more frequently assessed than the more tangible provisioning services. The list of the first 11 most studied CICES classes in Table 5 contains five regulating, all four cultural and just two provisioning classes or clusters. The popularity of regulating services is in line with the results of several previous systematic reviews (Egoh et al., 2012; Martinez-Harms and Balvanera, 2012; Malinga et al., 2015). The order of cultural and provisioning services in our study, however, is the opposite of the order found by Moringa et al. (2015) which can probably be explained by the fact that cultural ecosystem services are much more frequently studied in non-spatial assessments, a study-type that was excluded from the review of Moringa et al. (2015), which focused exclusively on mapping studies.

The dominance of regulating services can probably be best explained by a mixture of the *information availability* and the *agenda* arguments, but the former seems to be stronger, as it can explain all 5 regulating ES whereas the latter seem only to favour two of them (2.3.1.1: pollination, 2.3.1.2: nursery populations). The large number of cultural services seems also to favour the *information availability* argument, but in this case the *communicability* and the *availability of methods* arguments can also play a role. Climate regulation (2.3.5.1) can also be more easily assessed, because there are many elaborated methods for modelling 'carbon sequestration' (Backéus et al., 2005; Wang et al., 2017), which is generally perceived a good indicator for this service. The low number of studies on provisioning services, which usually are relatively *easily understandable and communicable,* also suggests that probably this consideration plays a weaker role in ES selection in most of the other cases.

Comparing the order of the ES in Tables 3 and 5 there seems to be a tendency for the more 'ecological', biodiversity-related services like 2.3.1.1 (pollination) and 2.3.1.2 (nursery populations) to be more frequently studied in non-assessment studies (i.e. field surveys and experiments with an ES focus). This seems to be in line with 'conventional wisdom', which suggests that the major motive for studying ecosystem services is to collect arguments for preserving biodiversity. These studies can probably be seen as method development aiming to bridge this perceived gap. On the other hand, the reduced prevalence of the biodiversity-related ES among mapping and assessment studies seems to suggest that these types of assessments are less influenced by these scientific agendas.

4.2.5. Units and dimensions

According to measurement theory (Stevens, 1946), every variable quantified in a scientific way should have a clear scale, unit and a detailed 'measurement protocol'. Without these necessary 'accessories', we can never talk about comparable measurements, we may then provide just arbitrary figures. Unit, scale and a clear protocol are also indispensable components in ES indicators (Czúcz and Arany, 2016), and the ES community clearly has some work to do here (Boerema et al., 2017). As a contribution to the fulfilment of these tasks, we provide an overview on some of the measurement aspects of biophysical and social ES indicators used in ES studies.

Appendix 5 is a list of all of the biophysical and social ES indicators used to quantify the CICES classes. It shows for each ES the different biophysical or social parameters that were quantified along with the physical dimensions used in the studies. Key aspects of the indicators reviewed are summarised in Tables 3 and 5. The results are structured according to whether the indicators were normalised to time, unit area or population, what the share of ordinal-scale ratings (scores) was, the frequency of monetary indicators, and the use of percentage values as a 'measurand'.

There are several provisioning services (1.1.1.1: cultivated crops, 1.2.1.2: materials for agriculture, 1.3.1.1: biofuels, and 1.2.2.1: non-drinking water), as well as regulating ES 2.3.5.1 (global climate regulation), that are predominantly reported using time-normalised units: rates (quantity /unit time) and fluxes (quantity /unit area /unit time). On the other hand, there are also many services (most typically cultural, and regulating ES, like 3.1.2.5: aesthetic, cluster E: intellectual, and 2.3.1.2: nursery), which are rarely assessed in terms of time-normalised indicators. Normalisation to unit area is a relatively common practice for indicators of several regulating and provisioning ES (especially 2.3.5.1: global climate, 2.3.1.1: pollination, and 1.2.1.2: materials for agriculture). On the other hand, indicators for cultural ES, as well as regulating ES 2.2.2.2 (flood protection) are seldom normalised to unit area. Normalising physical quantities to human population was rare, and could be found in only 2% of all indicators. This type of normalisation is most common in the case of cultural ES, as well as regulating ES 2.2.2.2 (flood protection).

We also assessed the frequency of indicators expressed as percentages or ratios, which turned to be 22% on average, with a high representation of percentage-type indicators in the case of CICES cluster C (soil fertility).

Except for cluster D (recreation), scores seem to represent the typical means of quantification for all other cultural services. Scores are also relatively popular in the case of two seldom assessed provisioning services (1.1.1.3: wild plants and 1.2.1.3: genetic materials). However, there are examples of scores being used for all ES, although this seems to be rarer for regulating services such as 2.3.5.1: global climate, 2.3.1.1: pollination and C: soil fertility. Conversely, for all of the frequently assessed ES there are viable options for quantification other than scores.

Altogether 20% of the ES indicators were quantified using economic values, and we can also see that in the case of all ES that are frequently reported (i.e. in more than 5 papers) there were studies that addressed their monetary dimension. However, not all ES are equally popular subjects for monetisation, and there are only a few CICES classes that were monetized in more than half of the papers reviewed: cluster F (spiritual, symbolic and inherent values of nature), 1.2.1.1 (fibres and other materials for direct use or processing), and particularly 1.1.1.4 (wild animals and their outputs). The latter was reported in monetary terms in almost 90% of the assessments where this service was included. All cultural services were above average in terms of monetisation, as well as several provisioning ES (1.1.1.2: reared animals, 1.1.1.3: wild plants, 1.1.2.1 / 1.2.2.1: surface water, and 1.3.1.1: biofuel plants). On the other hand, most regulating services were rarely monetised.

ES indicators can be expressed either as stocks (volumes) or flows/rates (the change of stocks per unit time). According to theoretical considerations, flows better comply with the ES concept, whereas stock quantities would seem to fit better to other describing ecosystem state, condition or natural capital (Costanza and Daly, 1992). Of course, due to the complexity of socio-ecological systems, there are several 'stock-like' parameters that are associated with (and thus potentially good indicators of) flow-like processes, and vice versa. The practice illustrated by the reviewed papers shows that rates were more commonly used for describing provisioning and certain regulating services (2.3.5.1: global climate regulation). This is perhaps not surprising because most provisioning services effectively constitute material flows, as well as the changes in greenhouse gas concentrations responsible for global climate regulation. It is actually more surprising that not all papers use time-normalised indicators in these cases, which actually suggests a bad indicator choice or poor documentation. Mixing stocks and flows, for example if carbon stocks are used for assessing 2.3.5.1 (climate regulation), can be seen as a major design flaw (Boyd and Banzhaf, 2007; Boerema et al., 2017).

As with time-normalisation, area-normalisation also seems to be an issue in indicator selection and documentation for ES assessments. Since early discussions of the ES concept, most studies consider the quantity of the services provided to be proportional to the quantity of the ecosystems that provide them. This approach is implicit in many quantification methods ranging from benefit transfer (Richardson et al., 2015) to matrix approaches (Jacobs et al., 2015). It implies that all studies that seek to compare the ES flows from different areas need to normalise their indicators with respect to unit area. According to conceptual considerations, except for simple non-spatial assessments (which convey only a single overall number for each ES in the study area), every ES study, and particularly mapping studies should take care to report their indicators as area-normalised quantities (i.e. densities, fluxes). Good practice would mean that all ES that are assessed in extensive physical quantities (ones that can be added or subtracted, like mass, volume, the number of anything) should be measured as the flux (quantity /time /area) of that quantity.

In addition to time and area there are several further options for normalising ES units, and so a third, less typical option can be considered, namely expressing quantities as some unit of human population. This approach makes most sense for non-score type indicators that characterise ES from the side of the benefits received by human society. In the studies reviewed, the few cases that used this type of normalisation involved cultural ES, as well as regulating ES 2.2.2.2 (flood protection). Population-normalisation might be an important technical step in making existing indicators 'benefit-relevant' (Olander et al., 2017).

While many physical quantities (e.g. soil or atmospheric composition data) are expressed by default as percentages, a transformation to percentages can be also be a conscious strategy to enhance the usefulness of the indicators. Rebasing diverse indicators to a common [e.g. 0-1] scale (also called 'normalisation' in many papers) is an accepted way of reducing complexity and establishing commensurability, especially for comparing alternatives in a local decision context (Busch et al., 2012; Wright et al., 2017). However, in other use cases, careless rebasing may also cause problems by compromising transferability except when the basis (the benchmark value of the denominator of the transformation) is meaningful in broader spatial and temporal contexts (e.g. ecological or policy thresholds, Wright et al., 2017).

Indicators expressed on ordinal scales as scores can be an effective way to integrate stakeholder knowledge into ES assessments, and can be especially useful for ES for which no good biophysical measures exist. Such indicators, furthermore, can be designed to be inherently commensurable within a single study, thus eliminating the necessity of rebasing. Stakeholder or expert scoring, often termed 'qualitative approach' is also good at providing a general overview, indicating trends and identifying trade-offs, but is typically too context-specific to be transferable because it lacks explicitness and accountability (Busch et al., 2012). This seems to be the case for all cultural services except recreation, for which there are many other real-life options from recreation opportunities mapping to travel statistics analysis. Some provisioning ES (1.1.1.3: wild plants and 1.2.1.3: genetic materials) seem to share this preference for score-type metrics. Based on our experience in the review we think that this is related to the role that traditional or hybrid knowledge systems play in these ES (Perera et al., 2012; Jacobs et al., 2015). Expert scores seem to be a natural choice for integrating these non-scientific forms of knowledge into an assessment. However, the flexibility in the expert/stakeholder scoring approach can also make room for lack of rigour in the form of combining unrelated or loosely related services in a single question. The strong negative correlation between *EI* (exclusive indicators) and *SC* (scores) in our results (Tables 3 and 5) may, in fact, indicate such an effect.

Assessing ecosystem services in economic terms is often a goal. In theory stocks and flows at all levels of the cascade can be valued economically (La Notte et al., 2015). Economic (or monetary) valuation, however, seems not to be equally common for all ecosystem service types (Tables 3 and 5). In a specific assessment there can be many considerations behind the decision which services to 'monetise'. This decision situation follows a very similar logic to the decision on which ES to include at all in the assessment (see Section 3.2). Nevertheless, in many cases the 'mandate' of the study predetermines decisions about monetisation, with some ES and decision situations being inherently inappropriate for such treatment (McCauley, 2006). In our results for specific ES types a departure from the overall ratio of monetised indicators may suggest the influence of similar considerations to the ones discussed in Section 3.2 (e.g. *methods availability*, *lack of information,* or *ease of understanding*). For example, in the case of 'wild products' (1.1.1.4: wild animals, 1.1.1.3: wild plants; but partly also 1.2.1.1: fibres and other materials, 1.1.2.1 / 1.2.2.1: surface water, and 1.3.1.1: biofuel plants) there are easily accessible and understandable market price-based methods, and the monetisation of these ES can be further motivated by the partial lack of these services from traditional accounting systems (*availability of information*). This is especially true for wild animals (mainly fish, game and shellfish in the studies reviewed), which can be a key component of subsistence systems or tourism industries in many parts of the world, but may still go 'under the radar' of traditional economic accounts (Schulp et al., 2014). In the case of cultural services, *methods availability* (especially travel cost, contingent valuation and choice modelling methods, see van Berkel and Verburg, 2014; or Brander and Crossman 2017), and *lack of information* can also be seen as factors favouring monetisation. However, the fact that the monetisation ratio of these services is clearly higher in all studies than in the mapping and assessment studies alone (cf. Appendix 3 & 4) testifies to the need for an intensive methods development *agenda* for the monetisation of cultural ES. The is an apparent lack of interest in the set of reviewed papers in monetising regulating services except for the use of hedonic pricing for 2.2.2.2 (flood regulation), and market prices for 2.3.5.1 (global climate regulation). Despite there being a relatively straightforward valuation technique for of 2.3.5.1 (global climate), namely emission markets, the lack of monetised assessment probably reflects the fact that the focus of generally on biophysical modelling. As this service is often assessed by natural scientists, and that the last step (multiplying carbon volumes with prices) seems trivial, the lack of interest in translating the biophysical quantities into monetary ones might be understandable.

4.2.6. Ecosystem service indicators along the cascade

As part of the systematic review, the ecosystem service cascade model was used as a way of characterising the conceptual focus of the indicators reviewed. The cascade is appropriate because it is the conceptual framework on which CICES was constructed.

In our literature review many studies were not clear about what aspect of ecosystem service output is being considered, whether that be supply or demand, or more specifically analysis of capacities (for potentially available quantities/flows) or actual use (quantities / flows that were really consumed / enjoyed). However, the systematic review undertaken as part of ESMERALDA enabled this kind of analysis to be made by recognising that the conceptual model can be used as an indicator framework and used to highlight the focus of the work being considered (Czúcz and Arany, 2016). Indeed, linking indicators to the different components of the cascade can be considered as a crucial step in operationalizing the ES concept (Czúcz and Arany, 2016); such analysis has enabled the extent to which people use proxy indicators for services in those situations where more direct measurement is difficult or impossible, how the indicators used have been placed along the ES cascade and how they are referenced spatially.

Mapping studies and the 'mapped' indicators in them are particularly relevant in the MAES context. In the case of mapping studies it is, for example, important to understand how the ES assessed are linked to spatial locations (via some 'spatial anchor'). Conceptually, there are two main options for establishing this link: services can either be linked to the locations where they were produced (source ecosystems), or to the locations where they eventually get used (beneficiaries). Both approaches can be logical choices depending on context: studies which discuss sustainability thresholds inevitably need to map services at their source ecosystems, whereas a mapping of 'ES use' arguably requires a demand-anchor. Nevertheless, there has so far been relatively little agreement or guidance on which one to choose in a particular mapping context. This final part of the analysis of the user perspective was therefore focussed on these issues.

To note the position of the indicators along the cascade conceptual framework a simplified version was used in which the value box was eliminated (Figure 6). The modification reflected the fact that monetary and other values are themselves a specific type of indicator which can be assigned to several other levels of the cascade (cf. La Notte et al., 2015). Thus during the systematic review analysts were asked to assign cascade levels to each indicator, interpreting the indicators according to the short definitions in Figure 6. Initial experience suggested that it was not always easy to assign a specific cascade level to an indicator and in such cases the reviewers could add multiple levels to indicate uncertainties.

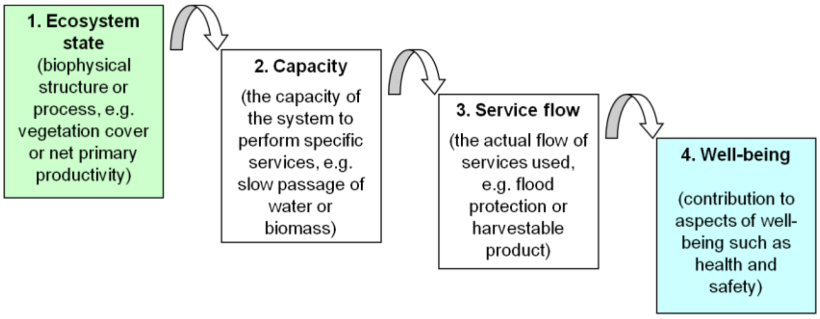


Figure 6: The ES 'cascade model', as an indicator template based on La Notte et al. (2015) and Czúcz and Arany (2016) (adapted from Haines-Young and Potschin, 2010 and Potschin and Haines-Young, 2011; and see discussion Section 2.3, this document).

To characterize the 'position' of a group of indicators on the cascade model, we used the arithmetic mean of the numeric IDs given in Figure 6 (1: ecosystem state, 2: capacity, 3: actual use, 4: benefits, see Figure 2). Indicators with multiple cascade levels assigned were represented by a single number (their own mean) in this calculation. Even though calculating an average of values over an ordinal scale is not valid statistically, this hidden conversion to an interval scale that assumes 'equal steps' between the levels is frequently used in practice (e.g. school grading systems) so we have employed it here. An indicator that scores low along the four-grade scale means that the ES in question is perceived to be more to do with the 'ecological underpinning' of the service. On the other hand, an ES which is assessed mostly by indicators positioned closer to the 'end of the cascade' (i.e. higher cascade level scores) takes effect closer to society (i.e. assess more as a benefit).

Some of the indicators were used to produce maps in the studies we reviewed. In these cases it reviewers were asked to identify whether the maps assigned ('anchored') the indicator values spatially to their source ecosystems, or destination (consumer, beneficiary) communities. For the sake of simplicity, we have referred to this property of the mapped indicators as the 'spatial anchor'. There are a many examples for both source-anchored and beneficiary-anchored mapping studies in the literature, but so far, no review or guidance material has touched on this subject. To characterize groups of indicators we also defined a 'mean anchor' as the ratio of mapped indicators anchored at the beneficiaries (assuming that an anchor at sources is coded with a 0, and an anchor at beneficiaries is coded with an 1).

The *mean cascade levels* (*MCL*) of the most frequently assessed CICES classes are summarized in Table 6. Furthermore, the cascade level spectrum for the most important CICES classes is shown in individual bar charts in Figure 7. The mean cascade level of all ES indicators reviewed is 2.44, close to the middle of the cascade, which corresponds to 2.5. Services with a relatively low cascade level includes mostly regulating services, like cluster A (bio-remediation), 2.3.1.2 (nursery), and cluster C (soil fertility); whereas cultural services and a few provisioning ES (e.g. 1.2.1.1: Fibres and other materials for direct use or processing, 1.1.1.4: Wild animals and their outputs) could be characterised with relatively high MCL values.

Table 6: Mean cascade levels for most frequently assessed CICES classes or clusters in mapping and assessment studies.

	NP N of papers	NI N of ind.	MCL Mean casc. level
All ecosystem services and indicators reviewed	50	328	2.44
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	22	34	2.91
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	20	44	2.13
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	19	35	2.85
2.3.5.1: Global climate regulation by greenhouse gas reduction	18	26	2.46
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	17	22	2.87
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	15	27	3.01
1.1.1.1: Cultivated crops	14	23	2.64
1.2.1.1: Fibres and other materials for direct use or processing	11	22	2.79
2.2.2.2: Flood protection	11	13	2.50
2.3.1.1: Pollination and seed dispersal	11	18	2.38
2.3.1.2: Maintaining nursery populations and habitats	10	18	2.33

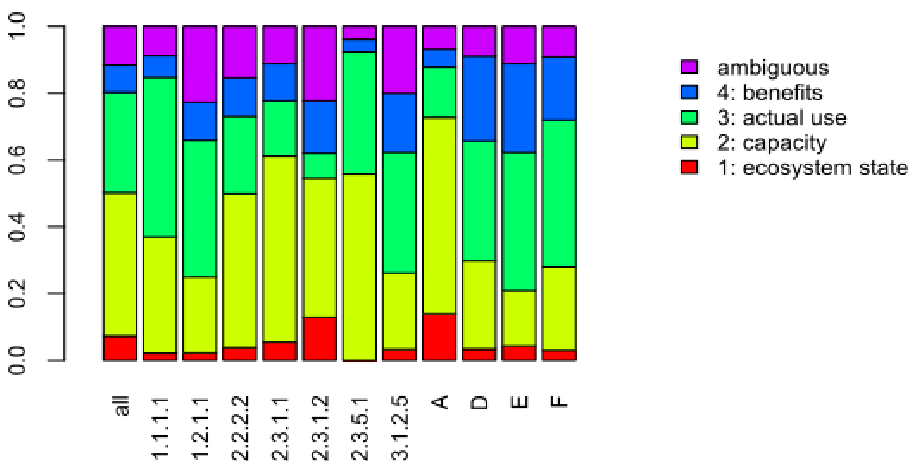


Figure 7. The cascade level spectrum for the most important CICES classes in ecosystem services mapping and assessment papers.

Among the 328 indicators identified in the set of mapping and assessment studies, there were only 125 (38%) that were actually mapped. The percentage of mapped indicators varies between the different ES, with 2.1.2.3 (smell/noise/visual mediation), 2.3.5.2 (microclimate), 1.1.1.3 (wild plants), cluster B (pest control), and 3.1.2.5 (aesthetic) being the most popular. Considering the spatial anchor, we have found that both approaches (mapping at sources / beneficiaries) were used in the mapping studies. Most of the mapping papers seem to follow the source-anchor strategy: 95% of the papers link all of their ES to the source ecosystems. The few indicators linked to beneficiaries mostly comprise cultural ES (D: recreation, F: spiritual) and climate regulation (2.3.5.1: global, and 2.3.5.2: local). The proportion of source-anchored, beneficiary-anchored, and no-mapping studies among the indicators for the most frequent CICES classes in the mapping and assessment studies (Table 3) can be more closely examined in Figure 8. The proportion of beneficiary-anchored indicators is the highest in the case of cluster D (‘recreation’ made up roughly one third of the indicators).

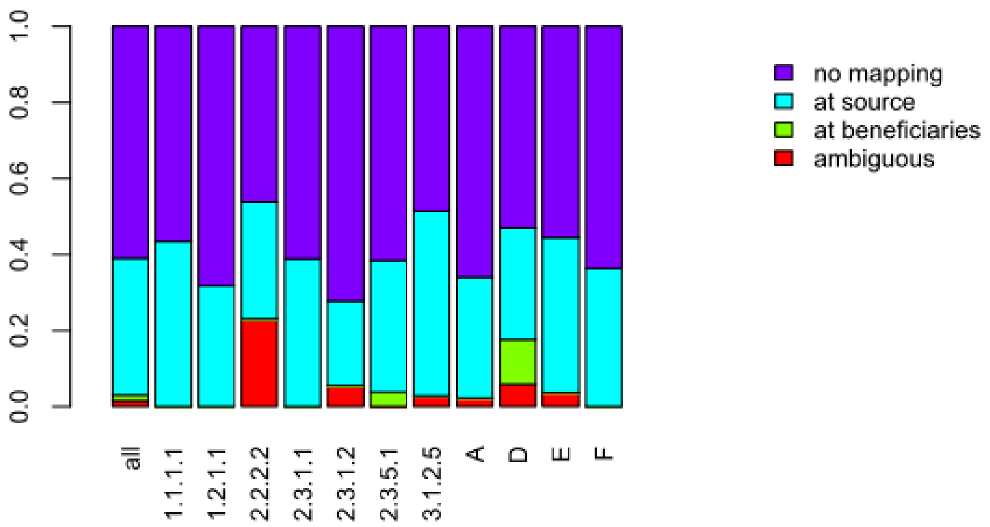


Figure 8. The distribution of spatial anchor for the most important CICES classes in mapping and assessment papers

4.3. The user perspective: summary and conclusions

The aim of this work on the user perspective was to link the ecosystem services studied in published papers to a common ES typology (CICES) by a concept matching systematic review exercise in order to:

- gain a critical appraisal of CICES based on the pattern how CICES classes are represented in practical assessments, thus providing constructive feedbacks for CICES development; and,
- create a reliable statistical overview of the ES studied in the selected set of papers, which highlights good and bad practices surrounding the selection and quantification of the ES.

In relation to CICES we conclude that despite a few concerns with gaps in the coverage and the distinctiveness of the categories, the system as a whole is reasonably comprehensive and capable of being used operationally. The gaps and overlaps identified were taken into account and addressed during the CICES revision process leading to CICES V5.1 (see Chapter 5).

In addition to highlighting that cultural and regulating services are more often considered than provisioning ones, we made a detailed analysis of the relative frequencies of all CICES classes in practical ES studies and provided a number of potential explanations for the patterns observed. We also provided a quantitative overview of several little studied aspects of ES indicator use identified in the papers reviewed. This has allowed us to comment critically on the wider literature of ecosystem service indicators. Specifically, our systematic review suggests that:

- There is considerable variation in how different studies interpret the same ecosystem service, and the units and dimensions of the indicators reported frequently do not match the character of the ES assessed (stocks vs. flows, a lack of normalisation to time and area).

- Approaches to quantification involving scores are widely used, but most frequently for cultural ES and some regulating services (e.g. flood protection).

- Monetisation is most frequently done for some cultural and provisioning ES. Most regulating services were relatively rarely monetised (including ones, like global climate regulation, for which appropriate techniques would be relatively easily available).

- Mapping studies are not consistent in the way they link indicators to spatial locations. This aspect of indicator use (spatial anchor) should therefore be handled more carefully and described explicitly in future studies.

The findings emphasise the importance of appropriate method choice and documentation for ES studies. Notably, all ES studies should include a clear description of the indicandum (the phenomenon thing indicated), the units and scales of indicators, as well as all relevant methodological details, any assumptions and systemic considerations. We therefore support the conclusions of Boerema et al. (2017, p. 368) in recommending that all ES studies “should have a clear section in their methods stating exactly which ES they measured, and how they did this”. Only through a systematic and consistent approach to indicator development and use will it be possible to compare and build on the results of ecosystem assessments. In the case of assessments, which are principally social processes, anything that improves the internal consistency, clarity and communicability of the process is likely to improve the chances of success (Scholes et al., 2017). While CICES offers one part of the conceptual framework that is required, transparency in the way ES and their indicators are selected, defined, presented and measured is also essential to future progress.

5. The revision of CICES V4.3

5.1. Introduction

The work in ESMERALDA has provided an opportunity to examine the experience gained in using Versions 4.3 of CICES and reflect on the feedback received in order to support the revision process. In this Part of the Deliverable D4.2 report, we will focus on the revision itself, and how developed out of the different strands of work; in particular we highlight the contribution of the work in ESMERALDA. The role of the new version, and CICES in general, in helping to identify and characterise the biophysical, social and monetary dimensions of ecosystem service assessments will be considered in Part 6.

As described in this document, CICES-related the work in ESMERALDA principally comprised a series of workshops (Chapters 2 and 3) and the systematic review of indicators using it as an analytical framework (Chapter 4). These efforts took place in parallel with other independent initiatives led by the European Environment Agency and its partners, which included a meeting hosted by the United Nations Statistical Division (UNSD), in New York, in June 2016 as part of their work on developing the *System of Environmental Economic Accounting* (SEEA). The work with the UNSD led to a further meeting in Wageningen, in November 2016, co-organised between the EEA, US-EPA and UNSD. The outcomes of this meeting are summarised in Rhodes et al. (2018).

As a result of all the work undertaken in 2016 and 2017, proposals for a revision of CICES V4.3 were made. The suggested structure for 'Version 5' were circulated to members of the EU KIP INCA project, and international experts attending the:

- The 23rd Meeting London Group on Environmental Accounting, October 2017; and,
- The 2nd Meeting of the SEEA-EEA Technical Committee in November 2017

As a result of the input and comments received a final, revised version of CICES (Version 5.1) was released in January 2018. The new version can be accessed via the CICES website[7], together with the associated guidance document (Haines-Young and Potschin 2018).

5.2. The development of CICES V5.1

The revision of CICES represented by V5.1 basically clarifies the way specific ecosystem services are defined and extends the scope of the classification. Specifically, the structure has been modified to help people aggregate service categories more easily for reporting purposes when no-end use is known.

In developing the revision for V5.1, the key findings from the work in ESMERALDA were that the hierarchical structure should be retained to enable people to use the classification at different thematic and spatial scales. The systematic review confirmed that in relation to biotic ecosystem outputs CICES was comprehensive, in that most services independently identified in the literature could be accommodated at class level. However, the wider consultations in ESMERALDA also confirmed that while there was strong support for retaining the focus on the outputs of ecosystem arising from living processes, there was a requirement for developing a related approach for abiotic outputs.

[7] www.cices.eu

The problem with excluding abiotic ecosystem outputs from CICES V4.3 was that in practical situations, especially when dealing with non-experts, stakeholders see the distinction as fairly arbitrary, and things like wind power, salt and snow are all seen as useful things that 'nature' can provide. The workshop recommendations and the 2018 User Survey suggested that the boundary between biotic and abiotic ecosystem services is difficult to define in practice and that some extension of CICES was therefore necessary. The status of 'water' was highlighted as a particular issue. Insofar as it is not directly produced by living systems, it is difficult to see water as an ecosystem service similar to those based on biomass (or 'biodiversity' more generally). However, the MA, TEEB and IPBES have conventionally regarded it as an ecosystem service; it was therefore included as such in CICES V4.3, despite the ambiguity.

When CICES V4.3 was released, a rudimentary table of abiotic ecosystem outputs was provided using the same classification logic as for those ecosystem services that depend on living systems (and water), except that only three hierarchical levels were used. One of the design aims identified for the revised version of CICES was to ensure better coherence between the natural science understanding of the world as a geo-physical system and the focus of CICES on defining outputs from living systems as ecosystem services. As a consequence, water was included under abiotic outputs in CICES V5.1 because hydrological cycles are mainly driven by geo-physical processes. As a result, a more detailed structure for classifying abiotic outputs was developed that was more closely aligned with that used for biotic outputs. The approach adopted for V5.1 is broadly consistent with the approach suggested by van der Meulen et al. (2016), although their suggestion for the inclusion of carrier services (relating, for example, to the use of rivers for transport) was not been taken up. It is considered that 'space', per se, is not an ecosystem service and is better covered in land accounting systems (such as the SEEA Central Framework which seeks to document both the stock of different land types and their uses). The approach used in developing CICES V5.1 followed the EU MAES process, and hence thinking in ESMERALDA, which has taken 'natural capital' to include all natural resources that human society draws upon, i.e. both earth's ecosystems and the underpinning geo-physical systems (Figure 9).

Figure 9 makes a distinction between ecosystem capital and abiotic resources, although for some cases there is no clear-cut boundary between biotic and abiotic components. However, this distinction helps to identify and classify different types of natural capital, which is important in the context of developing a natural capital accounting approach; ten Brink (2015) provides further detailed discussion of the concept of natural capital that and the approach taken in the revision of CICES is consistent with this.

While the development of a parallel classification for abiotic ecosystem outputs and the 'relocation' of water were identified as major changes to the structure of CICES, the consultations, workshops survey and systematic review suggested that many of the other features of V4.3 should be retained. In addition to retaining the hierarchical structure, it was decided to retain the focus on 'final' services, and develop the ability to provide a read-across to other classification or typological systems that deal with ecosystem services. It was also clear that the primary, three-fold distinction between provisioning, regulating and cultural services should be retained.

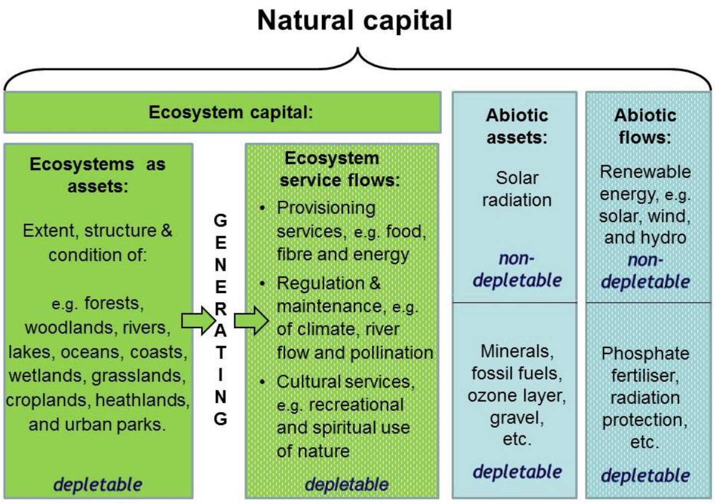


Figure 9: Components of natural capital, developed from the natural capital figure in the EU MAES report on Mapping and Assessment of Ecosystems and their Services (European Commission, 2013).

The need to be clear about the distinction between ecosystem services and their associated benefits was, nevertheless, one of the key tasks identified by the user community that was tackled in the revision of CICES. To emphasise the 'purposeful' nature of ecosystem service, in V5.1 the definition of each service is now made up of two parts, one describing the biophysical output from the ecosystem (i.e. *what the ecosystem does*) and the other describing the contribution it makes some benefit (i.e. *how that output is used or enjoyed by people*). Thus, for example, the service 'Wild animals (terrestrial and aquatic) for used nutrition' would be defined using this two-part approach as:

- 'non-domesticated, wild animal species and their outputs .....
- that can be harvested and used as a raw material for the production of food'.

Similarly, the service of 'pest control' would be 'the reduction by biological interactions of the incidence of species… that damage or reduce the output of food, material or energy from ecosystems, or their cultural importance, by the consumption of biomass or the spreading of disease'.

In developing the two-part definition structure the ambition in V5.1 was to clarify the terminology surrounding the ecosystem service terms used in CICES, which was one of the major points identified in the consultation leading up to this release. Feedback suggested, however, that there was a need for simplicity in terminology, especially when using the classification with non-expert audiences. Thus, to complement the complexity that is required for technical clarity, the revision has included simpler descriptors that can be used as a short-hand for each service. For instance, while the 'simpler version' of CICES might have the category of 'disease control' it is now underpinned by the definition 'The reduction by biological interactions of the incidence of species [….] that prevent or reduce the output of food, material or energy from ecosystems, or their cultural importance, by the consumption of biomass or the spreading of disease'. These simpler terms can be used flexibly and cross-referenced to the more tightly defined underpinning class in CICES.

The requirement that CICES can be used both for ecosystem accounting as well as mapping and assessment meant that it needed to follow the methodological principles set out in the *UNSD Handbook on Experimental Ecosystem Accounting* (SEEA EEA). These relate primarily to two aspects: (a) the question of the economic production boundary; and (b) the need to identify beneficiaries for a final ecosystem service to exist in the sense defined by the SEEA.

The concept of the 'economic production boundary', i.e. the point beyond which activities and natural outputs are already recorded in national accounting systems was a particular issue that was discussed in the consultations on CICES. The approach adopted in the revision follows V4.3, in that a fundamental characteristic of final services seen as being their connection to the underlying ecosystem functions, processes and structures that generate them. On the 'supply side' of the cascade, the idea of 'function' is used to highlight those characteristics of the living system that come together to make something a service. The production boundary is crossed once that connection is broken (or re-established in the case of waste-related services) by harvest or other activity. This approach has implications for the way cultivated crops and animals are treated in accounts and is discussed below.

The identification of beneficiaries that make concrete use of putative final ecosystem services is a second key concern of ecosystem accounting; the requirement arises from the need to develop supply and use accounts for ecosystem services, and has been discussed extensively in the SEEA guidance. In the revised version of CICS the 'use clause' in the definition and the 'example benefit' in provided that can be taken as partial guidance for identifying potential beneficiaries. However, a key assumption underpinning CICES us that services can be identified independently of specific ecosystems or beneficiary groups. The consultations on the revision identified that in making assumption there is a fundamental difference in the approach with other systems in terms of how ecosystem services are defined. FEGS-CS and NESCS, for example, frame each ES as a conjunction of an ecological end-product from an ecological asset, with a specific use by a specific user or beneficiary (see for example discussion by Landers et al, 2016).

For CICES users the task of identifying beneficiaries mainly relies on knowledge of, and research on, individuals or groups deriving some benefit (or dis-benefit) in each application. For the purpose of ecosystem accounting statistical classifications, such as the Statistical Classification of Economic Activities in the European Community (NACE), can help to identify key beneficiary categories.

An understanding of the application context is particularly important when using CICES V5.1 for analytical purposes. While this is key to identifying relevant beneficiary groups, it is also fundamental to identifying what actually constitutes a final ecosystem service.

Thus, while CICES seeks to provide a classification of final services, the listing should be regarded as providing a classification of *potential* or *putative* final services. In any application it is up to the user to decide whether in a particular context, the service is to be regarded as final or not, or whether the particular ecosystem property or behaviour is regarded as having a more 'intermediate' status and could thus better be described via an assessment of ecosystem condition.

In some of the literature on ecosystem services, flows that have an intermediate status are sometimes described as 'intermediate services', which operate alongside more basic ecological structures and processes, or 'supporting services', to underpin the output of final services. CICES does not attempt to identify or classify all the things that play this underpinning role, and indeed this guidance avoids the use of the terms 'intermediate' and 'supporting services' entirely (see Potschin-Young et al. 2017 for more extensive discussion). This is not to say that these kinds of thing are unimportant, rather that they are not regarded as services. These could be better documented in other ecosystem accounts of the structures, processes and functions that give rise to services. For mapping studies, researchers simply need to be clear about the status of the thing(s) being mapped.

In CICES these underpinning elements ultimately determine the capacity of the ecosystem to deliver particular services that can be represented by concepts other than that of a service, say in terms of measures of ecosystem condition. The term intermediate service is only used to refer to intra-ecosystem service flows, that is where the 'final' output from one ecosystem supports another. Examples, include situations where natural pollinators in cultivate ecosystems depend on surrounding semi-natural habitats. Here pollination would be an intermediate service provided by the semi-natural system to the cultivated one. For situations where pollination is supported by processes or species living entirely within an ecosystem, then pollination would not normally be regarded as a final service, but rather part of the 'functional' underpinning of the ecosystem. Thus, application context matters.

5.3. The structure of CICES V5.1

A summary of the biotic and abiotic ecosystem outputs defined by CICES V5.1 is shown in Tables 7 and 8. For ease of review only the three top levels in the hierarchy are shown; the structure to class level is provided in Appendix 7, which also shows the coding system used. The full classification with all definitions and examples can be downloaded as a spreadsheet from the CICES website.

As Tables 7 and 8 show, although the hierarchical structure of CICES V4.3 was retained, it was modified in response to the need to deal with accounting situations where no end-use is known. Clearly the same issue may arise in other mapping and assessment studies. The general approach and the way the system works for cultivated crops is illustrated in Figure 10. Here cultivated crops at Goup level has no end-use associated with it; this category is subsequently disaggregated at class level as 'Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes' which is defined as 'the ecological contribution to the growth of cultivated, land-based crops that can be harvested and used as raw material for the production of food'. This can be represented as 'cereals' at class type level). Similar disaggregation can be made for crops are used for materials or energy.

Thus, given the need to aggregate and report on services where information on end-use was not available the new categories 'biomass' 'water' and 'non-aqueous natural abiotic ecosystem outputs' were used in the revision to make the distinction between types of provisioning output at Division level. As a consequence the biomass-based set, the Groups for cultivated plants, reared and wild animals etc. covered all end-uses (except genetic) whether it was for nutrition, materials or energy. The new class structure is the point at which the specific type of end use can be employed to make an assignment to a category of service. This change is in line with the lessons from the consultation process (Chapter 3) and the systematic review (Chapter 4.2.1).

When referencing services by means of the coding system devised for V5.1 (see Appendix 7) it is suggested that use is made of the Group level for reporting purposes, with the three-digit code used to refer to the category being considered and an 'X' to denote no assignment at Class level. Thus, the Group 'Cultivated terrestrial plants for nutrition, materials or energy' could be denoted as 1.1.1.X.

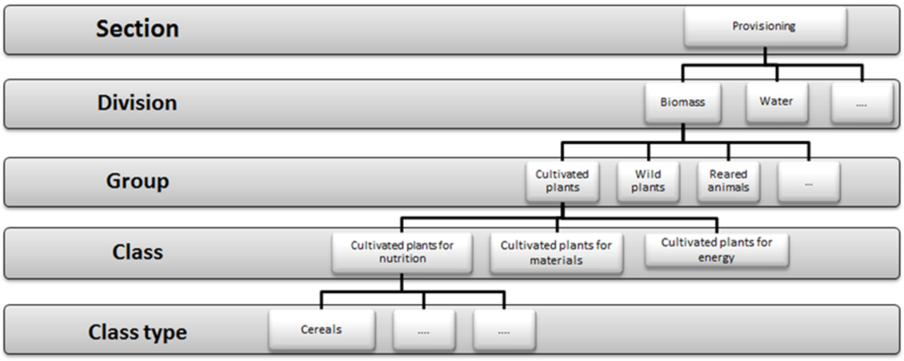


Figure 10: The hierarchical structure of CICES V5.1, illustrated with reference to a provisioning service 'cultivated plants'.

Table 7: Overview of revised structure of CICES (V5.1) for biotic ecosystem services (upper three levels in the classification only). Water is included to indicate correspondence to V4.3, but see Table 8.

BIOTIC ecosystem outputs		
Section	**Division**	**Group**
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals
Provisioning (Biotic)	Other types of provisioning service from biotic sources	Other
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions
Regulation & Maintenance (Biotic)	Other types of regulation and maintenance service by living processes	Other
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
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
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
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
Cultural (Biotic)	Other characteristics of living systems that have cultural significance	Other

Table 8: Overview of revised structure of CICES (V5.1) for abiotic ecosystem services (upper three levels in the classification only); we suggest that water related categories are classified here (cf Table 7)

ABIOTIC ecosystem outputs		
Section	**Division**	**Group**
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Maintenance of physical, chemical, abiotic conditions
Regulation & Maintenance (Abiotic)	Other type of regulation and maintenance service by abiotic processes	Other
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
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
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
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
Cultural (Abiotic)	Other abiotic characteristics of nature that have cultural significance	Other

Where measurement units permit aggregation to Group and Division levels in the CICES hierarchy, aggregation is also possible. For example, in the case of water, if no distinction is needed between surface and ground sources in terms of drinking water then volumes extracted, say, can be reported at Group level and coded as 4.1. [1,2].1. Where any ambiguity might arise in terms of the way users combine categories for reporting purposes, then it is suggested that 'bracketing' provides an appropriate notation to show the way categories are aggregated.

Although these reporting issues arising from aggregation and disaggregation are important, it is important to make the distinction between the use of the classification to *define* ecosystem services, and the use of the classification as a set of *reporting or analytical categories*. The consultation and survey on the use of V4.3 revealed that users had employed CICES in both ways. In using CICES V5.1, it is therefore important that users recognise that these two perspectives on the classification exist, and be clear how they are therefore using it. While CICES is primarily a *defining* system, it is efficient and simpler if the services can be reported using the same structure. However, if it makes sense for reporting purposes to aggregate or combine Classes etc., users are free to do so. In that case, it is advised that the CICES Classes and codes are used to denote what 'customised' categories have been created.

In addition to the problem of reporting when no end use is known, a further feature to note in the revised structure for CICES is the way Classes within the Groups for Cultivated Plants and Reared Animals are defined. In V4.3 these were seen as problematic in accounting applications because of the significant human input needed for their production. Some argued that instead, ecosystem processes that enable crop and animal growth, such as nutrient cycling, should be recognised as the relevant ecosystem contributions. In order to reflect this position, the definitions for these classes refer to the *ecological contribution* to the provision of nutrition, material and energy output.

However, the consultation and literature review for CICES 4.3 also identified that that many ecosystem service applications outside accounting take the volume of crop before harvest, or the number of reared animals grazed, as the final service because it is difficult disaggregate the contribution that ecological and economic production systems make to the final output. A similar observation was made by Czúcz et al. (2018).

That many provisioning services are a form of 'co-production' by people and nature means that services are often complex and difficult to disentangle, and may only be measurable using proxies of various kinds. Thus, in V5.1, while the definitions of provision services involving cultivated plants and reared animals follows the framing used by the SEEA, which views them in terms of the contribution of nature, in practical terms V5.1 acknowledges that operationally it might only be possible to follow the so-called 'harvest approach' also discussed in the SEEA EEA Guidance.

The harvest approach of the SEEA EEA Guidance recognises the difficulty of identifying the contribution of ecological processes, and suggests that the harvested amount is taken as the final output and an agreed proportion is attributed to the ecosystem and to the economic production system. Thus, in V5.1, we define the services for cultivated plants and reared animals as the contributions that ecosystem make to their production but recognise that they may be quantified using proxy measures such as volumes of harvest biomass. If disaggregation of the 'co-production' is needed, then this is perhaps best done in monetary or energetic terms, for example, and external to any classification structure such as CICES.

In addition to the nutritional Classes for cultivated plants and reared animals, the same definitional structure is adopted for materials and from plant and animal sources (1.1.1.2 & 1.1.3.2) and energy derived from these same sources (1.1.3.3 & 1.1.4.3). Again, it is assumed that the matter of the scale of the contribution that ecosystems make is to be settled outside the classification structure.

The alignment between the definitions of ecosystem services and the metrics used to characterise them is a key issue for accounting, mapping and assessment. As has been argued in Part 4 of this Deliverable report, users should be careful to clearly state how they have framed the particular services that are the focus of their work, and what proxies are used to assess them. In addition to the modifications made to the way provisioning services are defined, V5.1 also clarified the way cultural services should be handled.

Although it is recognised that *all* services can have a cultural dimension or significance, on the basis of the feedback received, Cultural services were retained at Section level in V5.1 as a way of identifying the intangible ecosystem outputs that enable a range of experiential and intellectual activities. In defining them, however, the approach adopted in V5.1 was to identify the characteristics of ecosystems that enable cultural benefits to be generated or enjoyed. This approach was adopted to be consistent with the approach suggested for 'recreational services in the SEEA-EEA guidance.

Thus, in applying the classification of cultural services it is important now to make a distinction between (a) *what* people do or feel in cultural terms, and (b) the *properties* of the ecosystem that enable, facilitate or support those activities or feelings. By way of illustration, in V5.1 a recreational activity, such as walking, is not regarded as an ecosystem service, but rather a benefit or 'cultural good'. The service provided by the ecosystem is the *opportunity* or characteristics of the environmental setting or location that enables that activity and determines its quality for people.

For cultural services the Division level spits those characteristics of living systems that are experienced either 'in-situ' or 'remotely' (i.e. Divisions: 'Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting' vs 'Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting'). The Direct interactions are divided at Group level between those enabling physical or active engagement with the living environment or those enabling more passive or intellectual interactions. The latter cover ecosystem characteristics that enable scientific investigation, education and training and interactions that relate to culture, heritage, and aesthetic experiences. The Indirect interactions at Group level includes classes that relate to ecosystem characteristics that underpin symbolic and religious meaning, entertainment, and things which are important to people by their very existence or their presumed importance to future generations. All of these classes were present in V4.3; the ordering and hence coding has been changed in V5.1 for greater consistency.

As noted in part 4 of this Deliverable report, the work on indicators done in ESMERALDA suggested that 'maintenance of traditional ecological knowledge' and 'creation and maintenance of social relations' are two potential gaps in the structure of CICES at the Class level for cultural services. To meet these points, in V5.1, the Class relating to scientific knowledge (3.1.2.1) has been extended to include opportunities to generate traditional knowledge. A Class relating to social relations has not been included, however, as it relates to outcomes within the social system and has more to do with the views taken of conflicts, trade-offs and values etc.. Moreover, good social relations are not exclusively cultural issues, but can be determined by factors relating to the sufficiency of provisioning outputs or impacts of different actors on regulating services, for example.

Despite all the changes that have been made in the revised version of CICES, it remains fully compatible with V4.3 and there is detailed documentation on what has been done. The Tables in Appendix 7 show the correspondence between the classes in the different versions. In making the revision, it was also recognised that people may use other ways of naming ecosystem services in their work. As a result, in the revision there was a need to retain and develop CICES as a 'reference system'. Thus, the full downloadable version of CICES 5.1 provides cross-walks to the classifications used in the Millennium Assessment (MA), The Economics of Ecosystems and Biodiversity (TEEB), and IPBES, with its concept of nature's benefits (or contributions) to people. Current work is also exploring how cross-references can be made between CICES and the FEGS-CS and NESCS systems used by the US EPA (see Rhodes et al., 2018).

6. Using CICES to identify and characterise the biophysical, social and monetary dimensions of ES assessments

6.1. Introduction

The aim of Deliverable has been to review and document the experience gained in developing and applying CICES with a view to better understanding how it can support integrated assessments. The goal has been to use this experience to reflect on the extent to which it provides a classification system that is simple and transparent, and which fulfils the need to take account of the biophysical, social and economic dimensions of mapping and assessment at different spatial and temporal scales.

The idea of 'integrated assessment' is the focus of other work streams within ESMERALDA and will be reported separately as part of Deliverable 4.8 (Potschin-Young (Ed), 2018). In this final part of this Deliverable D4.2 we use what has been achieved but only discuss the role of ecosystem classification systems in general and CICES in particular. Deliverable 4.8 should be referred to for a more general discussion of the framework.

6.2. The role of CICES in ecosystem assessment

At an early stage in ESMERALDA it has become clear that the notion of what constitutes an integrated ecosystem assessment had a number of interpretations. For the purposes of this Deliverable it was felt that these interpretations needed to be explored to better understand the context in which ES classification systems, and indeed measurements based on them, were set. We use as the basis of this discussion the diagram developed in ESMERALDA Deliverable 4.8 (Potschin-Young (Ed), 2018) that was the outcome of consultations across the ESMERALDA consortium (Figure 11).

It has been broadly agreed within ESMERALDA that assessments should be seen as a 'social' or 'transdisciplinary' process which involves the analysis and review of information derived from research. The purpose of such assessments is to help people in a position of responsibility to evaluate possible actions or think about a problem; for MAES this clearly relates to the EU Biodiversity strategy 2020. Thus, assessment is taken to mean assembling, summarising, organising, interpreting, and possibly reconciling pieces of existing knowledge so as to communicate them in ways that are relevant and helpful to an intelligent but inexpert decision-maker (see also ESMERALDA Glossary, published as Potschin-Young et al., 2018).

Fundamentally, in any assessment of ecosystem services scientific evidence must be translated into information that is understandable for policy and decision making, e.g. through maps, indicators, narratives and graphs. However, for such assessments to be *integrated*, they must additionally link data and information on biophysical and socio-economic components of a socio-economic system not just with each other, but also with the societal and policy contexts in which the socio-ecological system is embedded. Ultimately the assessment must enable decision makers to examine changes in biodiversity and ecosystem services against specific and measurable policy goals. This process of integration can therefore occur at many points in the process shown in Figure 11.

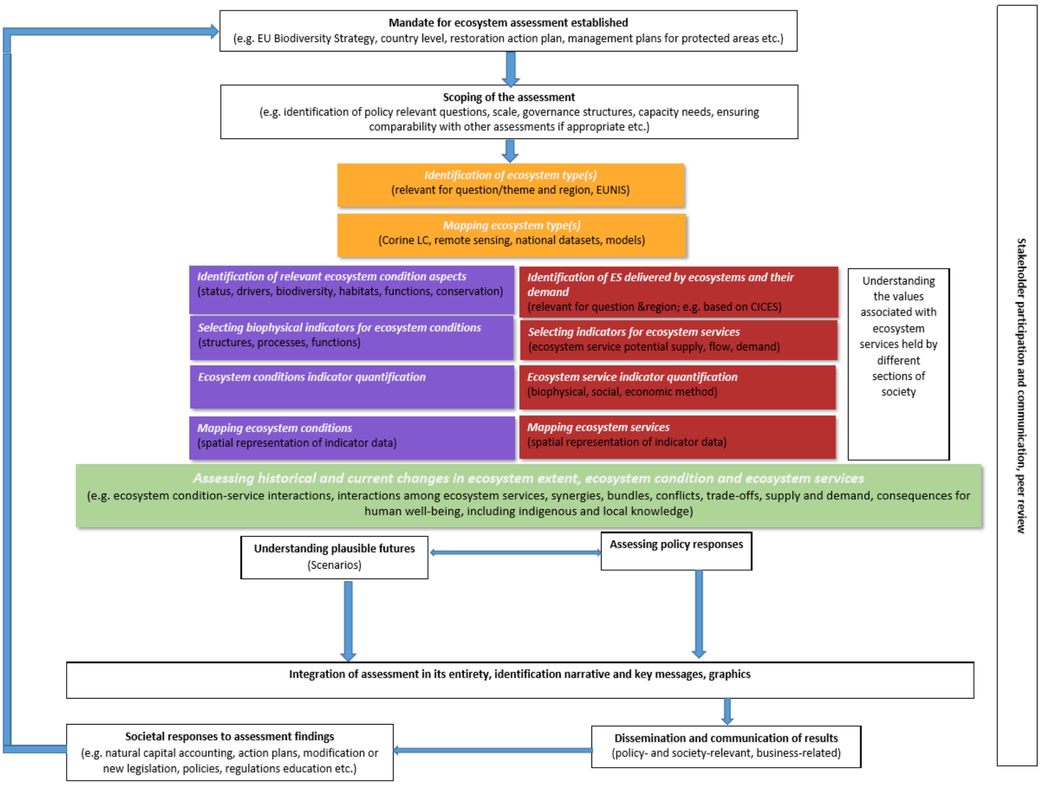


Figure 11: Towards an IEA framework in ESMERALDA drafted by Brown, C.; Potschin, M. and R. Haines-Young (2017) based on Burkard et al. (2016) and Maes, J. et al. (2014) 2nd Maes report – Final framework following consultation within the ESMERALDA Consortium.

For example, as Figure 11 suggests, stakeholder engagement is essential throughout the whole assessment process. Assessments of the kind that concern ESMERALDA are often deliberative in character, and may in fact involve a number of iterative cycles in order that different perspectives are coherently brought together. Given the ambition that common understandings and actions, it is essential that ideas converge during the assessment process and that all parties eventually come to 'talk about the same thing'. This is where classifications such as CICES can clearly make a significant contribution to the notion of *integrated* assessment.

The consultations and literature review presented here suggest that CICES was been relatively successful in providing a common assessment framework across a number of studies. It was concluded, however, that one key feature needed to be developed in V5.1 in order to better support engagement with non-expert stakeholders in assessment work, namely the development of simple descriptors for service types that can be used alongside technical definitions. As Chapter 4 of this report and Czúcz et al. (2018) have shown, studies often provide poor or only partial descriptions of the services they examine, and sometimes do not specify what classification framework they are using. The ability the cross-reference analytical categories to a common nomenclature would clearly help to improve the consistency, clarity and communicability of findings. CICES has been shown to be comprehensive in its coverage and the classes sufficiently well specified to support concept-matching approaches. The new feature in V5.1 which includes 'simple' names alongside a more systematic and uniform defining convention will, we suggest, further improve the ability of CICES to provide a reference framework that can integrate different perspectives and approaches.

In addition to the integration of different user perspectives or needs, the reference function of CICES has other benefits. By being sufficiently flexible and comprehensive to serve as a reference system, other classifications can be benchmarked against it. This is essential because assessments often involve using evidence from other studies conducted elsewhere, and it is important that knowledge transfer can take place with a minimum of ambiguity. Value transfer methods used in the assessment of the economic dimension of ecosystem services, for example, generally have such a requirement, and the detailed and consistent definitions can also make it easier to use CICES in future concept-matching exercises (Czúcz et al., 2018) even in the absence of appropriate crosswalks.

Although access to a consistent classification framework is implicit in the integrated framework, the linkage between many of the elements shown in Figure 11 is unclear. This is especially important in relation to the need to identify indicators of condition and ecosystem service. Indeed, the better alignment between thinking about ecosystem services and the condition of the ecosystems that underpin them has been one of the key concerns of ESMERALDA. Progress in this area is essential if the goals of the EU 2020 Biodiversity Strategy are to be achieved, because it deals with how measures of ecosystem state or integrity can be used to understand the impacts on ecosystem service output.

While guidance on the links between CICES and systems for classifying ecosystems is essential, as the framework shown in Figure 11 suggests (purple boxes), a key feature of the ESMERALDA framework is the need to characterise ecosystem condition, in terms of the functional status of ecosystems and their underlying ecological structures and dynamics. Although CICES does not provide a classification of the kind of measures used to characterise condition, the conceptual framework on which it is based (cascade model) does offer a way of defining them, in terms of ecosystem function, and of cross-referencing to specific ecosystem services.

The concept of ecosystem condition and how to measure it is still an active area of debate. However, the focus of thinking is sufficiently well-aligned with ideas about the functional characteristics that underpin ecosystem services to suggest that they are largely congruent. Thus, the term 'condition' could be used to refer to general descriptors of the status of an ecosystem (e.g. vegetation cover and stratification, functional diversity), whereas 'capacity' measures are used more specifically to denote the functional characteristics of the system that underpins the supply of a particular ecosystem service. **If changes in ecosystem condition are to be mapped or documented in ecosystem accounts, and assessments more generally, then a clear link to the implications for specific ecosystem services is likely to be required if robust and credible analyses are to be made.** The current structure of CICES V5.1 provides a framework in which this kind of analysis might be attempted (cf. Czúcz et al., 2017). This approach might be especially useful in the context of making the framework in Figure 11 'operational', because while it appears to highlight the links between ecosystem condition and ecosystem services, these links are not defined in detail, and it is assumed that the analysis of services and condition can proceed in parallel. In practice it is likely that a good deal of iteration between the left and right-hand boxes dealing with services and condition would be necessary.

Although work within any ecosystem assessment might deal directly with the analysis of ecosystem condition, efforts might also include taking account of work done on other similar ecosystems in other locations. A common classification system, or a way of cross-referencing different approaches, can clearly also facilitate the exchange of information and the sharing of experience. The same kind of requirement might also arise at the stage of scoping an assessment (see Figure 11, top centre), when users explore whether they need to examine whether particular problems identified elsewhere apply in their geographical area.

Efficient knowledge transfer is therefore essential if ecosystem assessments are to be successful. Thus in addition to ensuring that it provides a comprehensive and well defined set of service categories, the use of the system for transferring knowledge has been further developed in the revision of V5.1, by extending the cross-walk feature to the typology proposed for IPBES. At the same time, the ability shown by V4.3 to translate the ecosystem service categories used for the MA and TEEB has been retained.

While thinking about ecosystem condition has a central place alongside ecosystem services in Figure 11, the importance of this linkage should not overshadow the fact that while alignment between these two areas is an essential part of 'integration', For any system of ecosystem service classification to be successful, it must also be capable of being integrated with many other types of classification. It must, for example, be capable of being used alongside the classification systems used for identifying and mapping different types of ecosystems (orange boxes, Figure 11), as well as beneficiaries.

The investigation of the performance of CICES that has been reported in Part 4 found no evidence of any limitation in respect of the lack of any explicit link to specific ecosystems or beneficiary groups. This is important because other approaches to classifying ecosystem services, e.g. FEGS-CS and NESCS, stress the dependency of any delimitation of an ecosystem service on the link to a specific ecosystem type and/or beneficiary group (see Rhodes et al. 2018). CICES does not make this assumption. As the review of Czúcz et al. (2018) showed, services from a very wide range of studies from different ecosystems could successfully be assigned to a CICES class. While this the systematic review was confined to European studies, there was no indication from the analysis that a similar conclusion could not be drawn if an even wider range of studies were considered.

Despite the assumption that the CICES categories apply across all ecosystems and beneficiary groups, the extent to which CICES might be 'customised' for specific ecosystem types was an issue that arose in the consultation, particularly in relation to marine ecosystems. The issue was identified in the review of CICES V4.3 reported by Royo Gelabert (2016) which argued that some classes were not relevant to the marine situation and the naming convention was often in appropriate. Although the option of customisation was explored during the revision process, for the final version of V5.1 it was decided not to provide a customised approach. Instead an attempt was made to make the terminology used to denote the Classes in V5.1 sufficiently generic to cover the V4.3 Classes seen as 'relevant' in the marine work described by the Royo Gelabert (2016) study. Thus, customisation of class names and definitions seemed unnecessary. Indeed, it was concluded that if such an approach was adopted and extended to a number of different ecosystems, then the multiplication of different terminologies would probably lead to confusion.

The juxtaposition of ecosystem condition and services in Figure 11 and the prominent place of the two in the diagram clearly emphasise the importance of the biophysical underpinnings of any ecosystem assessment. However, it should be emphasised that integrated assessments seek to bring information together not only from the biophysical domain but also from the social and economic realms. The reference to the values associated with different ecosystem services is, in fact, shown on the right-hand side of the Figure. An understanding of social and economic values is also an implicit requirement of resolving the issues of conflicts and trade-offs highlighted in the grey box shown in Figure 11, dealing with analysis of the historical perspective. The analysis of values also needs to be made explicit by clear and unambiguous cross-reference to specific ecosystem services.

6.3. Conclusions and recommendations

An important message that has emerged from the work reported here is that CICES can be used as an effective indicator framework across the biophysical, social and economic dimensions of ecosystem assessments. It can do this because, while it defines services in a reasonably precise way, it does not specify *how* they should be measured or *which* specific metrics should be applied. Thus, the classification provides an 'entry point' for the process of integration in any assessment process by allowing a series of measurements to be considered and reviewed critically in terms of how they characterise or represent a specific service.

The development and need for a 'CICES consistent' indicator library has been discussed in Part 4 of this Deliverable. It was suggested that in developing such a library there is no intention to dictate which metrics are to be used for which service, but rather to provide examples of how people have quantified the services so that the experience can be shared with others and comparisons made. While the focus of any indicator library must be on the services themselves, the work presented in Part 4 suggests that it would be most useful to also cross-reference the library to metrics for *all* of the elements of the cascade, as had been done, for example, by Mononen et al. (2014). The approach is useful in the sense that it helps users understand where and how proxy measures can be used in an ecosystem assessment. Integration of indicators across the ecosystem service cascade is also a way of more fully understanding issues relating to supply and demand, and hence the overall status of the service in the context of questions about sustainability. In part 4 of this Deliverable report, the analysis was taken further and it was shown that while in general most studies developed indicators close to the centre of the cascade (i.e. were 'service-focussed'), regulating services tended to be examined in terms of biophysical measures relating to ecosystem structure, process and function, while cultural services and some provisioning were assessed more in terms of associated benefits and values.

If an indicator library is to be effective in supporting integrated assessment, it must not only describe *what* has been measured in different studies, but ideally also *how* the work was undertaken. While the individual details can be found in the associated references, it is important to note the specific contribution that ESMERALDA has made in this area in its review and classification of biophysical, social and economic methods for assessment. The database that has been created within the project is described in Santos-Martin et al. (2018a) and can be approached via the ESMERALDA MAES Explorer (http://www.maes-explorer.eu/). Although time constraints have meant that currently methods have been cross-referenced with the services measured using CICES V4.3, the ambition is to extend this kind of work and in the future reference to the structure of V5.1 should be made.

It is often said that you cannot manage what you cannot measure. It follows, of course, that you also have to know precisely *what* is being measured. And this is where classification systems are important. They help us define what we mean and communicate what we have found. Both are important in the context of integrated assessment

The need for robust and relevant tools for classification is especially important in the field of ecosystem services (Polasky et al., 2015). To make progress we have to bring together perspectives from different disciplines and ensure that we are talking about the same things. More fundamentally, to support evidence-based policy making, we must be able to review and transfer knowledge to different situations in ways that are clear and unambiguous. The *Common International Classification of Ecosystem Services*, CICES, has been developed to do just that. In this Deliverable report we have shown how it can support analysis of the biophysical, social and economic domains of ecosystem assessment. In order to take this kind of work further, the following recommendations can be made:

- **That just as V4.3 of CICES has been tested for its coverage and completeness, effort should now be made to critically examine the structure of V5.1.** This is especially important in the context of the extension to include abiotic ecosystem outputs in the same classification structure as that used for those based on living systems. It is also important in the context to the on-going work in relation to the conceptual and practical work associated with the development of ecosystem accounting methods (the next phase of MAES in EU member states) and understanding the relationship to the IPBES concept of 'nature's benefits (or contributions) to people'.
- **All ecosystem service studies should include a clear description of the way services are defined and measured, the units and scale of indicators used, and all relevant methodological details and assumptions** (cf Czúcz et al., 2018; Boerema et al., 2017; Scholes et al., 2017). As has been emphasised in Part 4 of this Deliverable report, only through a systematic and consistent approach to indicator development is it possible to compare and build on the results of ecosystem assessments. The extent to which CICES 5.1 can support the clear description of the way services are defined and measured should be examined and its use as a reference system based on concept matching techniques further explored.
- **That the a CICES 5.1 'indicator' and 'methods' library be developed out of the work done in ESMERALDA be published, and used to facilitate the transfer of knowledge within the context of the MAES Process.** It is important to stress that in undertaking this work there is no claim that CICES (and the underpinning cascade model) represents the only way of looking at ecosystem services, but that by virtue of its development as a cross-reference tool to other classification systems, it provides a foundation on which knowledge exchange rapidly can be built. It is recommended that the ESMERALDA MAES Methods Explorer and the methods database behind it will be fully cross-referenced to CICES 5.1 as well as V4.3, and that these tools are linked explicitly to the CICES consistent indicator library.

- **That future work should look at how CICES 5.1 can link to the ways we classify and characterise the condition of ecosystems, so that we can better understand the biophysical underpinnings of ecosystem services.** Although some of the work on ecosystem condition is likely to focus on broad measures of ecosystem integrity (e.g. ecosystem productivity) and assume these capture the general ability of the system to deliver services, for many management or policy needs this work will also have to consider the links to specific ecosystem services. An alignment between the use of condition measures and the service categories covered by CICES V5.1 would be a helpful next step towards developing integrated mapping and assessment approaches.
- **Future work should also look at the way we describe and classify benefits and beneficiaries, so that we can better document how people depend on or engage with nature over space and time.** Some of this work has begun in EU-funded projects such as OpenNESS and indeed ESMERALDA, and further insights will emerge from the wider use of the classification in the other work in the EU on natural capital and ecosystem services accounting (e.g. the new EU Coordination and Support Action MAIA to be started in autumn 2018 and which can build directly on ESMERALDA outcomes). Overall, we need to develop better ways of measuring the value of ecosystems to different individuals and groups, and documenting the costs of depletion to them in clear and unambiguous ways if we are to effectively inform policy and investment decisions.
- **That the relationship between CICES V5.1 and other classification systems is tested and its reference function developed further.** Two areas of on-going work are especially interesting. First the work by the US-EPA which is now bringing together the FEGS-CS and NESCS systems for documenting ecosystem services, both of which depend on identifying tight ecosystem-output-benefit-beneficiary relationships (Landers et al. 2016). Although preliminary work suggests that CICES classes can in many be cross-reference to FEGS-CS categories, the relationship to any new unified US-EPA structure needs to be explored. Second, although a cross-walk between CICES V5.1 classes and the IPBES Reporting Categories for Nature's Benefits to People (see Diaz et al. 2018) has been made, the role of ecosystem service classifications in this apparently novel framework is unclear.

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Appendix 1: The CICES V4.3 Coding system

CICES V4.3				
Section	Division	Group	Class	Code
1. Provisioning	1. Nutrition	1. Biomass	1. Cultivated crops	1.1.1.1
			2. Reared animals and their outputs	1.1.1.2
			3. Wild plants, algae and their outputs	1.1.1.3
			4. Wild animals and their outputs	1.1.1.4
			5. Plants and algae from in-situ aquaculture	1.1.1.5
			6. Animals from in-situ aquaculture	1.1.1.6
		2. Water	1. Surface water for drinking	1.1.2.1
			2. Ground water for drinking	1.1.2.2
	2. Materials	1. Biomass	1. Fibres and other materials from plants, algae and animals for direct use or processing	1.2.1.1
			2. Materials from plants, algae and animals for agricultural use	1.2.1.2
			3. Genetic materials from all biota	1.2.1.3
		2. Water	1. Surface water for non-drinking purposes	1.2.2.1
			2. Ground water for non-drinking purposes	1.2.2.2
	3. Energy	1. Biomass-based energy sources	1.Plant-based resources	1.3.1.1
			2. Animal-based resources	1.3.1.2
		2. Mechanical energy	1. Animal-based energy	1.3.2.1
2. Regulation & Maintenance	1. Mediation of waste, toxics and other nuisances	1. Mediation by biota	1. Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1
			2. Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2
		2. Mediation by ecosystems	1. Filtration/sequestration/storage/accumulation by ecosystems	2.1.2.1
			2. Dilution by atmosphere, freshwater and marine ecosystems	2.1.2.2
			3. Mediation of smell/noise/visual impacts	2.1.2.3
	2. Mediation of flows	1. Mass flows	1. Mass stabilisation and control of erosion rates	2.2.1.1
			2. Buffering and attenuation of mass flows	2.2.1.2
		2. Liquid flows	1. Hydrological cycle and water flow maintenance	2.2.2.1
			2. Flood protection	2.2.2.2
		3. Gaseous / air flows	1. Storm protection	2.2.3.1
			2. Ventilation and transpiration	2.2.3.2
	3. Maintenance of physical, chemical, biological conditions	1. Lifecycle maintenance, habitat and gene pool protection	1. Pollination and seed dispersal	2.3.1.1
			2. Maintaining nursery populations and habitats	2.3.1.2
		2. Pest and disease control	1. Pest control	2.3.2.1
			2. Disease control	2.3.2.2
		3. Soil formation and composition	1. Weathering processes	2.3.3.1
			2. Decomposition and fixing processes	2.3.3.2
		4. Water conditions	1. Chemical condition of freshwaters	2.3.4.1
			2. Chemical condition of salt waters	2.3.4.2
		5. Atmospheric composition and climate regulation	1. Global climate regulation by reduction of greenhouse gas concentrations	2.3.5.1
			2. Micro and regional climate regulation	2.3.5.2

Coding system for CICES classes, cont.

CICES V4.3				
Section	Division	Group	Class	Code
3. Cultural	1. Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	1. Physical and experiential interactions	1. Experiential use of plants, animals and land-/seascapes in different environmental settings	3.1.1.1
			2. Physical use of land-/seascapes in different environmental settings	3.1.1.2
		2 Intellectual and representative interactions	1. Scientific	3.1.2.1
			2. Educational	3.1.2.2
			3. Heritage, cultural	3.1.2.3
			4. Entertainment	3.1.2.4
			5. Aesthetic	3.1.2.5
	2. Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	3. Spiritual and/or emblematic	1. Symbolic	3.2.3.1
			2. Sacred and/or religious	3.2.3.2
		4. Other cultural outputs	1. Existence	3.2.4.1
			2. Bequest	3.2.4.2

A complementary coding system for the CICES groups in the experimental "Accompanying classification of abiotic outputs from natural systems" in CICES v4.3 as used in Chapter 4:

Abiotic mineral nutrition (e.g. salt)	1.1.6
Abiotic non-mineral nutrition (e.g. sunlight)	1.1.7
Abiotic metallic materials (e.g. metal ores)	1.2.6
Abiotic non-metallic materials (e.g. minerals, aggregates, pigments, building materials (mud/clay))	1.2.7
Abiotic renewable energy (e.g. wind, waves, hydropower)	1.3.6
Abiotic non-renewable energy (e.g. coal, oil, gas)	1.3.7
Abiotic mediation of waste (e.g. atmospheric dispersion and dilution; adsorption and sequestration of waters in sediments; screening by natural physical structures)	2.1.6
Abiotic mediation of flows (e.g. protection by sand and mud flats; topographic control of wind erosion)	2.2.6
Abiotic maintenance of conditions (e.g. land and sea breezes; snow)	2.3.6
Abiotic cultural: physical & intellectual interactions (e.g. caves)	3.1.6
Abiotic cultural: spiritual & emblematic interactions (e.g. sacred rocks or spaces)	3.2.6

Appendix 2: Outcome summary of CICES break out groups at 'Nottingham Workshop'

No.	Source	Contact	CICES Code	Structure/Process	Function	Service	Good/Benefit	Value	Comment
1		Mihai Adamescu	1.1.2.1. and 2.3.4.1	* Water Cycle/Eutrophication	*Water purification/water * N-concentration/ N/P ration	* chemical condition of (regulating and Maintenance and provisioning service (1.1.2.1) * Freshwater (2.3.4.1)	Drinking Water	Water costs	* how to estimate the costs? * who has to pay
2	Nedkov (2012)	Stoyan Nedkov	2.2.2.2.	Water cycle	Water distribution function of the different ecosystems in the river basin	flood protection	mitigation of the flood by reducing the water quantity during peak flow events	avoided costs of potential damages caused by floods	Mapping of flood regulation ES
3	Papiz in preparation	Stoyan Nedkov	2.1.2.1	water cycle	dilution of pollutants in river water and the soils in the floodplain	filtration of freshwater/water purification	clean water/drinking water		
4	Mapping ecosystem services at Eu scale (published in ecosystem services, issue 1)	Joachim Maes	2.1.2.1	* river network (Map) * nitrogen uptake, denitrification, burial	Nitrogen removal (ton N/ha/year) (assuming sustainability)	Nitrogen removed (ton N/km/years) (actual removal)	increased water quality (% improvement)	avoided replacement cost (€) of Nitrogen removal by constructed wetlands	filtration/storage/accumulation if ecosystems --> water purification (self purifying capacity of water bodies) --> use Nitrogen as indicator

5	Zulian et al. in Land	Joachim Maes		* species distribution (maps) * presence, absence visitation rate and flight distance	pollination potential (dimensionless between 0-1)		% crop deficit (% of yield that would be foregone if no wild pollinators are present)	value of crops due to pollination	
6	??	David Vackar	3.2.4.1	Biodiversity	trophic chains (flows)	Existence	existence value	existence value (based e.g. on choice experiment mobility etc.)	
7	Vagious	David Vackar	2.3.5.1	photosynthesis	net primary production (WDU, measurements - ORUL datasets	global climate regulation by reduction of GHG concentration	carbon storage in ecosystems	marginal abatement cost (MAC) (contribution of ecosystems to Co2 reduction and reduction of climate change cost)	
8	VITO	Steven Broekx	3.1.1.2	* available green area nearby * time distribution	* time distribution activities/attractions *spent time in area, walking/biking	* physical use of landscape	* well-being * health	*avoided heath costs * expenditures local restaurants * willingness to pay * travel costs	

9	VITO	Steven Broekx	2.2.1.1	rainfall intensity * elevation	* soil run-off * sedimentation	coastal erosion	* fertile soil, soil maintenance * sediment transport (?)	* avoided dredging * agricultural productivity * avoided damage flooding mid streams	
10	SONNAR	Katie Medcalf	1.1.1.4/2.3.1.1	flowering plants which support pollination	pollination	* Wild animals and their outputs * Wild animals and their outputs	honey	food	
11	Ireland Project	Katie Medcalf	2.3.5.1	peat with active sphagnum layer	carbon sequestration	Global climate regulation by reduction of greenhouse gas concentrations	climate stability	carbon accounting	
12	BEF-LV	Kristina Veidemane	3.1.1.1			cultural services, bird monitoring	recreation potential	visitor xxx? * WTP	
13	BEF-LV	Kristina Veidemane	2.2.1.1	accumulation and erosion of the material/sediment flow along the coastal process, formation of dunes		mass stabilization and control of erosion rates	stable coastal areas, no loss of land	potential loss of property, loss of beach	coastal ecosystems --> dunes, metrices = accumulated volume of sediments m3/m2 of dune area
14	OpenNESS Hungarian CS "Kiskunsag"	Balint Czucz		The following properties of the ecosystem: * floral abundance * floral diversity * temporal continuity if flowering *	nectar provision	honey harvest (locations of hives) --> number of families/m2	honey		

15	Niraj-MAES	Balint Czucz	1.1.1.3, 1.2.1.1. (wild)	*different ecosystems (natural, semi-natural) w collected species * biodiversity (species), ecosystem state (degradation/naturalness)	* the growth of collected species (capacity, pot supply)	*Wild plants, algae and their outputs *Fibres and other materials from plants, algae and animals for direct use or processing	local products	* income * health (medical plants) * sustenance of traditional knowledge	
16	ESP 2015	Philip Roche	2.2.1.1	* De??? --> storage, shape length * vegetation cover * rainfall	* stabilisation of soil * reduction of kinetic rain drops energy	Erosion control	* preservation of soils * reduction of rivers sediments * risk reduction		use of RUSLE model
17	TRENTO Urban case study	Chiara Cortinovis		soil cover (type of vegetation) and canopy coverage (vegetation height, etc.)	shading and evapotranspiration	microclimate regulation (cooling) [+ other regulating ES as provided by urban ecosystems]	number of people (and vulnerable people) in each class of cooling effect --> metric used to compare alternatives		
18	VITO	Inge Liekens		*different ;landscapes/ecosystems * land use	*naturalness * diversity	attractiveness of the landscape	number of visitors (based on attraction, facilities, …)	WTP/Visit	recreational value
19	Studies in USVI Bonaire ?	Pieter van Beukering		corals reefs providing hard 3 D structure in coastal waters	energy buffer function for waves	coastal protection in coastal zones	avoided damage from flooding to houses and infrastructure	number of properties x real estate values x probability of flood events	

20	Campagne, C.S. et al. (2015) The sea grass Posidania oceanica: Ecosystem services identification an economic evaluation of goods and benefit. Marine Pollution Bulletin	Sylvie Campagne				* coastline erosion protection *decrease of wave power and current * stabilization /consolidation of seabeds by sediment deposition	protection from coastal erosion	economic value in €/ha/year	* it is a particular example --> more details see
21		Paulo Borges			regulating and Maintenance	* maintaining nursery populations and habitats * flood control * water regulation/provision	* safety * water * gene pool	funds given to remove invasive plants	Island example, indicator of naturalness (based in spatial distribution of eudemonic species)
22	PhD thesis research	Zbig Szkop		urban forest (urban trees)	absorption of pollutant	* regulating services * improving air quality	* cleaner air (better air quality) * micro climate regulation	* money spent on medical care (healing people form lung problems) --> 20€ per tree * avoided costs	
23	TEEB-DE	Sven-Erik Rabe (ETH)	1.1.1.1	area of agricultural cropland	indicator - agr-environmental yield potential * natural yield capability	Cultivated crops (indicator yield index)			

24	biodiversity.fi/ecosystem services	Petteri Vihervaara/Laura M.	2.3.5.1 also usable for 1.3.1.1	ha of forest class (mapping --> statistical behind)	C sequestration rate (modelled)	(Biomass) Carbon storage [tons/ha] --> comparability IPCC accounting rules	climate regulation (expert evaluation) --> vague to measure	increased security, avoided costs, market price --> "expected to rise!" (by Head of World Bank 12.4.16)	
25	Patagonian case od OpenNESS	Graciela Rusch		area grassland cover	primary productivity	cattle, grazing pressure	meat, identity of being a cattle farmer	Pesos, money, Realising the importance of identity	
26	SH=study (in work)	Felix Mueller	2.1.1.1, 2.1.1.2, 2.1.2.1., 2.1.2.2., 2.2.1.1., 2.3.4.1, but also crop production	biotic structure, vegetation composition, land use, input, fertilization, storage leaking, runoff	all sub processes of nitrogen cycle, linked with energy and water	nutrient retention, indicated by nitrogen	* clean drinking water (ground water) * reduced eutrophication	*water cleaning plant demand, respective waste water treatment costs for respective nutrient amount	CICES should be a Lego box, --> simplify complexity, not suitable to many recent management problems
27	Urban Maes for Poland	Damiam Lowicki	2.2.2.1	the share of green urban areas	rainfall catching	Hydrological cycle and water flow maintenance	water retention, infiltration	avoid costs of water infrastructure	
28	ESP 2015 conference	Philip Roche	1.2.1.1.	forest area, tree density, tree structure, photosynthesis	* primary production * NPP	wood biomass	* timber * industry grade wood biomass		

Appendix 3: The main properties of indicators used to characterise the different ES in the reviewed studies (all studies)

Explanation:

NP: number of pertinent papers (which address the given ES)

NI: number of pertinent indicators (which address the given ES)

EI: ratio of 'exclusive' indicators (which only pertain to the given ES exclusively), among all pertinent indicators (*NI*)

AN: ratio of indicators that were normalised to unit area (/ha, /km2)

TN: ratio of indicators that were normalised to time (/year)

PN: ratio of indicators that were normalised to population (/person, /household)

PC: ratio of indicators expressed as percentage (a rate or a composition)

SC: ratio of score-type (ordinal scale dimensionless) indicators (as percentage of biophysical and social indicators)

MO: ratio of monetised indicators (percentage of biophysical and social indicators that were also expressed as monetary indicators)

Table cells with percentage values are colour coded from red (0%) to blue (100%)

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
All ecosystem services and indicators reviewed	85	440	68%	48%	36%	2%	22%	27%	20%
2.3.5.1: Global climate regulation by greenhouse gas reduction	27	38	89%	76%	58%	0%	9%	12%	15%
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	26	44	45%	27% `	18%	7%	0%	64%	33%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	25	38	45%	24%	34%	8%	4%	42%	46%
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	24	48	75%	52%	46%	0%	38%	23%	20%
2.3.1.1: Pollination and seed dispersal	22	47	83%	66%	38%	0%	29%	10%	12%
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	20	26	31%	31%	31%	12%	6%	59%	53%
1.1.1.1: Cultivated crops	18	28	50%	54%	50%	0%	5%	23%	27%
E: Intellectual and representation al interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	18	30	40%	20%	23%	10%	5%	55%	50%
2.3.1.2: Maintaining nursery populations and habitats	14	23	43%	35%	22%	4%	25%	30%	15%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.2.1.1: Fibres and other materials for direct use or processing	12	26	8%	58%	42%	0%	6%	41%	53%
2.2.2.2: Flood protection	12	14	64%	14%	36%	21%	9%	45%	27%
C: Maintenance of soil fertility (2.3.3.1, 2.3.3.2)	12	37	84%	32%	41%	0%	58%	9%	12%
1.2.1.2: Materials from plants, algae and animals for agricultural use	11	20	25%	75%	55%	0%	19%	25%	25%
2.2.1.1: Mass stabilisation and control of erosion rates	11	15	53%	47%	47%	0%	0%	25%	25%
1.1.1.2: Reared animals and their outputs	10	13	46%	38%	46%	0%	10%	40%	30%
1.1.1.4: Wild animals and their outputs	10	17	53%	24%	29%	0%	0%	44%	89%
2.2.2.1: Hydrological cycle and water flow maintenance	10	11	45%	64%	45%	0%	22%	22%	22%
2.3.5.2: Micro and regional climate regulation	10	14	71%	64%	29%	0%	15%	31%	8%
B: Pest and disease control services (2.3.2.1, 2.3.2.2)	10	16	50%	56%	31%	0%	14%	29%	14%
1.3.1.1: Plant-based resources	9	14	21%	64%	57%	0%	10%	20%	40%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.1.2.1: Surface water for drinking	7	8	0%	63%	25%	0%	33%	17%	33%
1.1.1.3: Wild plants, algae and their outputs	6	6	17%	67%	33%	0%	25%	50%	50%
1.2.1.3: Genetic materials from all biota	5	10	10%	10%	10%	10%	33%	67%	11%
1.2.2.1: Surface water for non-drinking purposes	5	6	33%	50%	67%	0%	25%	0%	50%
2.1.2.3: Mediation of smell/noise/visual impacts	4	6	33%	17%	33%	0%	33%	33%	0%
2.2.1.2: Buffering and attenuation of mass flows	3	3	0%	67%	67%	0%	0%	0%	50%
1.1.1.6: Animals from in-situ aquaculture	2	3	33%	0%	33%	0%	0%	50%	50%
1.1.2.2: Ground water for drinking	2	2	0%	50%	0%	0%	50%	0%	0%
2.2.3.1: Storm protection	2	3	67%	33%	33%	0%	0%	50%	50%
2.3.4.2: Chemical condition of salt waters	2	2	0%	100%	100%	0%	0%	0%	100%
1.2.2.2: Ground water for non-drinking purposes	1	1	0%	100%	0%	0%	0%	0%	0%
1.3.1.2: Animal-based resources	1	4	0%	50%	50%	0%	0%	0%	100%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.1.1.5: Plants and algae from in-situ aquaculture	0	0	NA	NA	NA	NA	NA	NA	NA
1.3.2.1: Animal-based energy	0	0	NA	NA	NA	NA	NA	NA	NA
2.2.3.2: Ventilation and transpiration	0	0	NA	NA	NA	NA	NA	NA	NA

Appendix 4: The main properties of indicators used to characterise the different ES in the mapping and assessment studies reviewed

Explanation:

NP: number of pertinent papers (which address the given ES)

NI: number of pertinent indicators (which address the given ES)

EI: ratio of 'exclusive' indicators (which only pertain to the given ES exclusively), among all pertinent indicators (*NI*)

AN: ratio of indicators that were normalised to unit area (/ha, /km2)

TN: ratio of indicators that were normalised to time (/year)

PN: ratio of indicators that were normalised to population (/person, /household)

PC: ratio of indicators expressed as percentage (a rate or a composition)

SC: ratio of score-type (ordinal scale dimensionless) indicators (as percentage of biophysical and social indicators)

MO: ratio of monetised indicators (percentage of biophysical and social indicators that were also expressed as monetary indicators)

Table cells with percentage values are colour coded from red (0%) to blue (100%)

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
All ecosystem services and indicators reviewed	50	328	62%	39%	31%	2%	18%	34%	20%
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	22	34	50%	21%	32%	9%	4%	42%	42%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	20	44	75%	48%	43%	0%	39%	25%	22%
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	19	35	43%	23%	14%	9%	0%	63%	30%
2.3.5.1: Global climate regulation by greenhouse gas reduction	18	26	85%	69%	50%	0%	0%	17%	13%
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	17	22	36%	27%	27%	14%	7%	60%	47%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	15	27	41%	19%	22%	11%	0%	56%	50%
1.1.1.1: Cultivated crops	14	23	52%	43%	52%	0%	6%	28%	28%
1.2.1.1: Fibres and other materials for direct use or processing	11	22	9%	50%	32%	0%	7%	47%	47%
2.2.2.2: Flood protection	11	13	62%	15%	38%	15%	9%	45%	18%
2.3.1.1: Pollination and seed dispersal	11	18	56%	33%	22%	0%	13%	27%	20%
2.3.1.2: Maintaining nursery populations and habitats	10	18	33%	22%	17%	6%	27%	40%	20%
1.1.1.2: Reared animals and their outputs	9	12	50%	33%	50%	0%	11%	44%	33%
1.1.1.4: Wild animals and their outputs	9	15	47%	27%	33%	0%	0%	50%	88%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.2.1.2: Materials from plants, algae and animals for agricultural use	9	15	13%	67%	47%	0%	23%	31%	15%
2.2.1.1: Mass stabilisation and control of erosion rates	9	12	42%	33%	33%	0%	0%	30%	20%
2.2.2.1: Hydrological cycle and water flow maintenance	8	8	25%	50%	25%	0%	29%	29%	14%
2.3.5.2: Micro and regional climate regulation	8	12	67%	58%	25%	0%	18%	36%	9%
C: Maintenance of soil fertility (2.3.3.1, 2.3.3.2)	8	18	67%	33%	44%	0%	41%	18%	6%
1.3.1.1: Plant-based resources	7	9	0%	56%	44%	0%	14%	29%	29%
B: Pest and disease control services (2.3.2.1, 2.3.2.2)	7	12	33%	50%	17%	0%	18%	36%	9%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.1.1.3: Wild plants, algae and their outputs	6	6	17%	67%	33%	0%	25%	50%	50%
1.1.2.1: Surface water for drinking	6	7	0%	57%	29%	0%	20%	20%	40%
1.2.1.3: Genetic materials from all biota	4	9	11%	0%	11%	11%	25%	75%	13%
1.2.2.1: Surface water for non-drinking purposes	4	5	40%	40%	80%	0%	0%	0%	67%
2.1.2.3: Mediation of smell/noise/ visual impacts	4	6	33%	17%	33%	0%	33%	33%	0%
2.2.1.2: Buffering and attenuation of mass flows	3	3	0%	67%	67%	0%	0%	0%	50%
1.1.1.6: Animals from in-situ aquaculture	2	3	33%	0%	33%	0%	0%	50%	50%
1.1.2.2: Ground water for drinking	2	2	0%	50%	0%	0%	50%	0%	0%
1.2.2.2: Ground water for non-drinking purposes	1	1	0%	100%	0%	0%	0%	0%	0%

CICES v4.3 class	N of papers (NP)	N of ind. (NI)	% of exclu-sive ind. (EI)	% of area nor-med (AN)	% of time nor-med (TN)	% of popu-lation nor-med (PN)	% of per-cent-ages (PC)	% of sco-res (SC)	% of mone-tised ind. (MO)
1.3.1.2: Animal-based resources	1	4	0%	50%	50%	0%	0%	0%	100%
2.2.3.1: Storm protection	1	1	0%	0%	0%	0%	0%	100%	0%
2.3.4.2: Chemical condition of salt waters	1	1	0%	100%	100%	0%	NA	NA	Inf
1.1.1.5: Plants and algae from in-situ aquaculture	0	0	NA	NA	NA	NA	NA	NA	NA
1.3.2.1: Animal-based energy	0	0	NA	NA	NA	NA	NA	NA	NA
2.2.3.2: Ventilation and transpiration	0	0	NA	NA	NA	NA	NA	NA	NA

Appendix 5: The units and dimensions of ES indicators in the reviewed studies

Key to the physical dimensions:

m: mass (kg, g, mg… or concentration)
l, l^2, l^3: length (m, cm, km…), area (m^2, ha…), and volume (m^3, ml…)
t: time (hour, year…)
p: population unit (persons, households)
n: number (of something)
T: temperature (°C, K)
E: energy (J, MJ)
C: electrolytic conductivity (mS)
0: dimensionless unit (typically a mathematical index measured on a continuous scale)

CICES 4.3 class	Units and dimensions
2.3.5.1: Global climate regulation by greenhouse gas reduction	different C pools [m, ml^{-2}, $ml^{-2}t^{-1}$, mt^{-1}]; CO_2 or CO_2 equivalent [ml^{-2}, $ml^{-2}t^{-1}$, mt^{-1}]; N_2O [$ml^{-2}t^{-1}$]; natural forest area [l^2]; score
3.1.2.5: Aesthetic value, sense of place, artistic inspiration	employment [n]; enterprises [n]; flower colours spectrum [0]; hotspot density [nl^{-2}]; score; tourists [nt^{-1}]
D: Recreational (experiential and physical) use of land-/seascapes (3.1.1.1, 3.1.1.2)	accessible area [l^2]; employment [n]; enterprises [n]; hotspot density [nl^{-2}]; recreational areas [l^2]; score; tourists / visits [n, nt^{-1}]; urban green area [l^2, l^2p^{-1}]
A: Bio-remediation and water quality maintenance services (2.1.1.1, 2.1.1.2, 2.1.2.1, 2.1.2.2, 2.3.4.1)	C (mainly dissolved organic carbon, DOC) [m, mt^{-1}]; distance (from natural or disturbed habitats) [l]; functional microbial activity (FMA) [0]; mineralization rate [mt^{-1}]; N, $NO3^-$ [m, $ml^{-2}t^{-1}$, mt^{-1}]; nutrients [m]; P [m, $ml^{-2}t^{-1}$, mt^{-1}]; pollutants [?, $ml^{-2}t^{-1}$]; score; suspended solids (SS) [m]; tree cover [l^2]; wells below threshold [n]
2.3.1.1: Pollination and seed dispersal	additional preserved species [n]; alien species [n]; crop yield [mt^{-1}]; dispersed seedlings [n]; distance (from natural or disturbed habitats) [l]; flower area [l^2]; flower species number [$nl^{-2}t^{-1}$, n] [n]; flower visitation [n]; fruit set [n]; good habitat area [l^2]; highly cultivated land area [l^2]; hives [n]; landscape index [l^{-1}]; nectar energy [$El^{-2}t^{-1}$]; nectar water [$ml^{-2}t^{-1}$]; nectar yield [lt^{-1}]; pollen grains [n]; pollination demand [0]; score; seed set [m, n]; tree & hedge cover [l^2]; useful species abundance [n]; useful species number [n]
F: Spiritual, symbolic and inherent values of nature (3.2.1.1, 3.2.1.2, 3.2.2.1, 3.2.2.2)	frequently visited area [l^2]; hotspot density [nl^{-2}]; score; emblematic species [nt^{-1}]; visitors [n]
1.1.1.1: Cultivated crops	crop & by-product [$ml^{-2}t^{-1}$]; crop energy [El^{-2}, $El^{-2}t^{-1}$]; crop growth [m]; crop yield [m, ml^{-2}, $ml^{-2}t^{-1}$, mt^{-1}]; cropland area [l^2]; employment [n]; enterprises [n]; score
E: Intellectual and representational interactions with nature (3.1.2.1, 3.1.2.2, 3.1.2.3, 3.1.2.4)	employment [n]; enterprises [n]; hotspot density [nl^{-2}]; score; tourists [nt^{-1}]; useful species abundance [n, l^2]; volunteering initiatives [n]
2.3.1.2: Maintaining nursery populations and habitats	additional preserved species [n]; alien species [n]; extinct species [n]; juvenile abundance [nl^{-2}]; landscape index [0]; nursery area [l^2]; rare species abundance [n]; rare species number [nl^{-2}]; score; sediment [l, $ml^{-2}t^{-1}$]; useful species abundance [n]; useful species number [n]

1.2.1.1: Fibres and other materials for direct use or processing	crop & by-product [$ml^{-2}t^{-1}$]; crop yield [m, ml^{-2}]; fish yield [m]; livestock units; score; water [ml^{-2}]; wood growth [$ml^{-2}t^{-1}$]; wood stock [ml^{-2}]; wood yield [lt^{-1}, $ml^{-2}t^{-1}$]
2.2.2.2: Flood protection	landscape index [0]; reduced flood risk area [l^2, l^2p^{-1}]; score; settlement area [l^2]; storage and permeability capacity [0]; water [lt^{-1}]
C: Maintenance of soil fertility (2.3.3.1, 2.3.3.2)	C pools [m, $ml^{-2}t^{-1}$]; conductivity [Cl^{-1}]; crop growth [mt^{-1}]; decomposition rate [mt^{-1}]; detritivore feeding rate [mt^{-1}]; fine roots [nt^{-1}]; mineralization rate [m, mt^{-1}]; N [m, $ml^{-2}t^{-1}$, mt^{-1}]; $NO3^-$ [ml^{-2}]; P [m]; score; sediment [l^3]; sedimentation cone area [l^2]; soil organic carbon (SOC) [m]; topsoil turned over by earthworms [$ml^{-2}t^{-1}$]; useful species abundance [m]; water holding capacity [l^3]; yield loss [m]
1.2.1.2: Materials from plants, algae and animals for agricultural use	crop & by-product [$ml^{-2}t^{-1}$]; crop energy [$El^{-2}t^{-1}$]; crop growth [m]; crop yield [m, ml^{-2}, $ml^{-2}t^{-1}$]; dry matter [ml^{-2}]; fodder yield [$ml^{-2}t^{-1}$]; score; unit of forage (UF) [$l^{-2}t^{-1}$]; useful species number [n]
2.2.1.1: Mass stabilisation and control of erosion rates	landscape index [0]; score; sediment [l^3, lt^{-1}, $ml^{-2}t^{-1}$]; sedimentation cone area [l^2]; soil eroded [m, $ml^{-2}t^{-1}$]
1.1.1.2: Reared animals and their outputs	crop energy [El^{-2}, $El^{-2}t^{-1}$]; grazing land area [l^2]; livestock units; meat & dairy [m, $ml^{-2}t^{-1}$]; score
1.1.1.4: Wild animals and their outputs	employment [n]; enterprises [n]; fish yield [m, mt^{-1}]; score
2.2.2.1: Hydrological cycle and water flow maintenance	groundwater level [l]; index [0]; score; water [lt^{-1}, ml^{-2}, $ml^{-2}t^{-1}$]; water holding capacity [lt^{-1}]
2.3.5.2: Micro and regional climate regulation	biomass [l]; dry deposition velocity [$l\ t^{-2}$]; evapotranspiration [l^3]; natural forest area [l^2]; NH3 [ml^{-2}]; potential evapotranspiration (PET) [lt^{-1}]; score; shadow area [l^2]; surface emissivity [0]; temperature [T]
B: Pest and disease control services (2.3.2.1, 2.3.2.2)	alien species [n]; distance (from natural or disturbed habitats) [l]; fallen seeds [n]; landscape index [l^{-1}]; score; tree & hedge cover[l^2]; useful species abundance [n]; useful species number [n, nt^{-1}]
1.3.1.1: Plant-based resources	crop growth [m]; crop yield [m]; score; wood growth [$ml^{-2}t^{-1}$]; wood stock [ml^{-2}]; wood yield [$ml^{-2}t^{-1}$]
1.1.2.1: Surface water for drinking	groundwater level [l]; score; specific discharge [l]; water [ml^{-2}, mt^{-1}]; wells below threshold [n]
1.1.1.3: Wild plants, algae and their outputs	hotspot density [nl^{-2}]; score; useful species number [n]
1.2.1.3: Genetic materials from all biota	extinct species [n]; rare species abundance [n]; rare species [n]; score
1.2.2.1: Surface water for non-drinking purposes	groundwater level [l]; specific discharge [l]; water [l^3, mt^{-1}]
2.1.2.3: Mediation of smell/noise/visual impacts	C [mt^{-1}]; functional microbial activity (FMA) [0]; hotspot density [nl^{-2}]; N [mt^{-1}]; score
2.2.1.2: Buffering and attenuation of mass flows	landscape index [0]; sediment [lt^{-1}]
1.1.1.6: Animals from in-situ aquaculture	fish yield [mt^{-1}]; score
1.1.2.2: Ground water for drinking	groundwater level [l]; wells below threshold [n]
2.2.3.1: Storm protection	score
2.3.4.2: Chemical condition of salt waters	pollutants [$ml^{-2}t^{-1}$]
1.2.2.2: Ground water for non-drinking purposes	groundwater level [l]
1.3.1.2: Animal-based resources	fish yield [m]; livestock units; money

Appendix 6: List of the studies reviewed

Aitkenhead, M. J., Albanito, F., Jones, M. B., & Black, H. I. J. (2011). Development and testing of a process-based model (MOSES) for simulating soil processes, functions and ecosystem services. Ecological Modelling, 222(20–22), 3795–3810. http://doi.org/10.1016/j.ecolmodel.2011.09.014

Anastácio, P. M., Marques, B., & Lillebø, A. I. (2013). Modeling the effect of temperature, solar radiation and salinity on Bolboschoenus maritimus sequestration of mercury. Ecological Modelling, 256, 31–42. http://doi.org/10.1016/j.ecolmodel.2013.02.013

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Appendix 7: Overview of CICES V5.1

(see CICES V5.1 **spreadsheet for full details**, download from www.cices.eu**)**

Provisioning

Filter	Section	Division	Group	Class	Code	Class type	V4.3 Equivalent	Code(4.3)
CICES	**Provisioning (Biotic)**	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes	1.1.1.1	*Crops by amount, type (e.g. cereals, root crops, soft fruit, etc.)*	*Cultivated crops*	*1.1.1.1*
CICES	**Provisioning (Biotic)**	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated plants (including fungi, algae) grown for material purposes (excluding genetic materials)	1.1.1.2	*Material by amount, type, use, media (land, soil, freshwater, marine)*	*Fibres and other materials from plants, algae and animals for direct use or processing*	*1.2.1.1*
CICES	**Provisioning (Biotic)**	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	Cultivated plants (including fungi, algae) grown as a source of energy	1.1.1.3	*By amount, type, source*	*Plant-based resources*	*1.3.1.1*
CICES	**Provisioning (Biotic)**	Biomass	Cultivated aqutic plants for nutrition, materials or energy	Cultivativaed plants grown for nutritional purposes by in- situ aquaculture	1.1.2.1	*Plants, algae by amount, type*	*Plants and algae from in-situ aquaculture*	*1.1.1.5*
CICES	**Provisioning (Biotic)**	Biomass	Cultivated aqutic plants for nutrition, materials or energy	Cultivativaed plants grown for material purposes by in- situ aquaculture (excluding genetic materials)	1.1.2.2	*Plants, algae by amount, type*	*Plants and algae from in-situ aquaculture*	*1.1.1.5*
CICES	**Provisioning (Biotic)**	Biomass	Cultivated aqutic plants for nutrition, materials or energy	Cultivativaed plands grown as a source of energy by in-situ aquaculture	1.1.2.3	*Plants, algae by amount, type*	*Plants and algae from in-situ aquaculture*	*1.1.1.5*
CICES	**Provisioning (Biotic)**	Biomass	Reared animals for nutrition, materials or energy	Animals reared to provide nutrition	1.1.3.1	*Animals, products by amount, type (e.g. beef, dairy)*	*Reared animals and their outputs*	*1.1.1.2*
CICES	**Provisioning (Biotic)**	Biomass	Reared animals for nutrition, materials or energy	Animals reared to provide materials (excluding genetic materials)	1.1.3.2	*Material by amount, type, use, media (land, soil, freshwater, marine)*	*Materials from plants, algae and animals for agricultural use*	*1.2.1.2*
CICES	**Provisioning (Biotic)**	Biomass	Reared animals for nutrition, materials or energy	Animals reared to provide energy (including mechanical)	1.1.3.3	*By amount, type, source*	*Animal-based resources*	*1.3.1.2*
CICES	**Provisioning (Biotic)**	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Animals by amount, type*	*Animals from in-situ aquaculture*	*1.1.1.6*
CICES	**Provisioning (Biotic)**	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for material purposes (excluding genetic materials)	1.1.4.2	*Animals by amount, type*	*Animals from in-situ aquaculture*	*1.1.1.6*
CICES	**Provisioning (Biotic)**	Biomass	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Animals by amount, type*	*Animals from in-situ aquaculture*	*1.1.1.6*
CICES	**Provisioning (Biotic)**	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic) used for nutrition	1.1.5.1	*Plants, algae by amount, type*	*Wild plants, algae and their outputs*	*1.1.1.3*
CICES	**Provisioning (Biotic)**	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic) used for materials (excluding genetic materials)	1.1.5.2	*Plants, algae by amount, type*	*Wild plants, algae and their outputs*	*1.1.1.3*
CICES	**Provisioning (Biotic)**	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic) used for energy	1.1.5.3	*Material by type/source*	*Not recognised in V4.3*	*N/A*
CICES	**Provisioning (Biotic)**	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) for used nutrition	1.1.6.1	*Animals by amount, type*	*Wild animals and their outputs*	*1.1.1.4*
CICES	**Provisioning (Biotic)**	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) for used materials (excluding genetic materials)	1.1.6.2	*Material by type/source*	*Not recognised in V4.3*	*N/A*
CICES	**Provisioning (Biotic)**	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) for as a source of energy	1.1.6.3	*By amount, type, source*	*Not recognised in V4.3*	*N/A*
CICES	**Provisioning (Biotic)**	Biomass	Genetic material from all biotia (including seed, spore or gamete production)	Genetic material from plants, algae or fungi	1.1.7.1	*Material by amount, type*	*Genetic materials from all biota*	*1.2.1.3*
CICES	**Provisioning (Biotic)**	Biomass	Genetic material from all biotia (including seed, spore or gamete production)	Genetic material from animals	1.1.7.2	*Material by amount, type*	*Genetic materials from all biota*	*1.2.1.3*
CICES	**Provisioning (Biotic)**	Biomass	Other types of provisioning service from biotic sources	Other	1.1.X.X	*Use nested codes to allocate other provisioning services from living systems*	*Not recognised in V4.3*	*N/A*

Provisioning (Water – also included in abiotic Table)

Filter	Section	Division	Group	Class	Code	Class type	V4.3 Equivalent	Code(4.3)
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	*By amount, type, source*	*Surface water for drinking*	*1.1.2.1*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	*By amount & source*	*Surface water for non-drinking purposes*	*1.2.2.1*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	*By amount, type, source*	*Not recognised in V4.3*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	4.1.1.4	*By amount, type, source*	*Not recognised in V4.3*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water for drinking	4.2.2.1	*By amount, type, source*	*Ground water for drinking*	*1.1.2.2*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water used as a material (non-drinking purposes)	4.2.2.2	*By amount & source*	*Ground water as source of energy*	*1.2.2.2*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water used as an energy source	4.2.2.3	*By amount & source*	*Ground water for non-drinking purposes*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Other aqueous ecosystem outputs	Other	4.2.3.X	*Use nested codes to allocate other provisioning services from living systems to appropriate Divisions/Groups*	*Not recognised in V4.3*	*N/A*

Regulation and Maintenance

Filter	Section	Division	Group	Class	Code	Class type	V4.3 Equivalent	Code(4.3)
CICES	**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	2.1.1.1	*By type of living system or by waste or subsistence type*	*Bio-remediation by micro-organisms, algae, plants, and animals*	*2.1.1.1*
CICES	**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	2.1.1.2	*By type of living system, or by water or substance type*	*Filtration/sequestration/storage/accumulation by micro-organisms, algae,*	*2.1.1.2*
CICES	**Regulation & Maintenance (Biotic)**	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	By type of living system	*Mediation of smell/noise/visual impacts*	*2.1.2.3*
CICES	**Regulation & Maintenance (Biotic)**	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Noise attenuation	2.1.2.2	By type of living system	*Mediation of smell/noise/visual impacts*	*2.1.2.3*
CICES	**Regulation & Maintenance (Biotic)**	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	By type of living system	*Mediation of smell/noise/visual impacts*	*2.1.2.3*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*By reduction in risk, area protected*	*Mass stabilisation and control of erosion rates*	*2.2.1.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	*By reduction in risk, area protected*	*Buffering and attenuation of mass flows*	*2.2.1.2*
CICES	**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)	2.2.1.3	*By depth/volumes*	*Hydrological cycle and water flow maintenance*	*2.2.2.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Storm protection	2.2.1.4	*By reduction in risk, area protected*	*Storm protection*	*2.2.3.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Fire protection	2.2.1.5	*By reduction in risk, area protected*	*Not recognised in V4.3*	*N/A*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*By amount and pollinator*	*Pollination and seed dispersal*	*2.3.1.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*By amount and dispersal agent*	*Pollination and seed dispersal*	*2.3.1.1*
CICES	**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)	2.2.2.3	*By amount and source*	*Maintaining nursery populations and habitats*	*2.3.1.2*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Pest and disease control	Pest control (including invasive species)	2.2.3.1	*By reduction in incidence, risk, area protected by type of living system*	*Pest control*	*2.3.2.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Pest and disease control	Disease control	2.2.3.2	*By reduction in incidence, risk, area protected by type of living system*	*Disease control*	*2.3.2.2*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Weathering processes and their effect on soil quality	2.2.4.1	*By amount/concentration and source*	*Weathering processes*	*2.3.3.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Regulation of soil quality	Decomposition and fixing processes and their effect on soil quality	2.2.4.2	*By amount/concentration and source*	*Decomposition and fixing processes*	*2.3.3.2*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	2.2.5.1	*By type of living system*	*Chemical condition of freshwaters*	*2.3.4.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	*By type of living system*	*Chemical condition of salt waters*	*2.3.4.2*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere	2.2.6.1	*By contribution of type of living system to amount, concentration or climatic parameter*	*Global climate regulation by reduction of greenhouse gas concentrations*	*2.3.5.1*
CICES	**Regulation & Maintenance (Biotic)**	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*By contribution of type of living system to amount, concentration or climatic parameter*	*Micro and regional climate regulation*	*2.3.5.2*
CICES	**Regulation & Maintenance (Biotic)**	Other type of regulation and maintenance service by living processes	Other	Other	2.3.X.X	Use nested codes to allocate other regulating and maintenance services from living systems to appropriate Divisions/Groups	*Not recognised in V4.3*	*N/A*

Cultural

Filter	Section	Division	Group	Class	Code	Class type	V4.3 Equivalent	Code(4.3)
CICES	**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	3.1.1.1	*By type of living system or environmental setting*	*Experiential use of plants, animals and land-/seascapes in different environmental settings*	*3.1.1.1*
CICES	**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	3.1.1.2	*By type of living system or environmental setting*	*Physical use of land-/seascapes in different environmental settings*	*3.1.1.2*
CICES	**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	3.1.2.1	*By type of living system or environmental setting*	*Scientific*	*3.1.2.1*
CICES	**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	3.1.2.2	*By type of living system or environmental setting*	*Educational*	*3.1.2.2*
CICES	**Cultural (Biotic)**	Direct, in-situ and outdoor interactions with living systems that depend on presence in the	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*By type of living system or environmental setting*	*Heritage, cultural*	*3.1.2.3*
CICES	**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	3.1.2.4	*By type of living system or environmental setting*	*Aesthetic*	*3.1.2.5*
CICES	**Cultural (Biotic)**	Indirect, remote, often indoor interactions with living systems that do not require presence in the	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*By type of living system or environmental setting*	*Symbolic*	*3.2.1.1*
CICES	**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	3.2.1.2	*By type of living system or environmental setting*	*Sacred and/or religious*	*3.2.1.2*
CICES	**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	3.2.1.3	*By type of living system or environmental setting*	*Entertainment*	*3.1.2.4*
CICES	**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	3.2.2.1	*By type of living system or environmental setting*	*Existence*	*3.2.2.1*
CICES	**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 bequest value	3.2.2.2	*By type of living system or environmental setting*	*Bequest*	*3.2.2.2*

Abiotic extension

Note water is also included in the main CICES table (see text); for completeness it is also included here.

Filter	Section	Division	Group	Class	Code	Class type	V4.3 Equivalent	Code(4.3)
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Surface water for drinking	4.2.1.1	*By amount, type, source*	*Surface water for drinking*	*1.1.2.1*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Surface water used as a material (non-drinking purposes)	4.2.1.2	*By amount & source*	*Surface water for non-drinking purposes*	*1.2.2.1*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Freshwater surface water used as an energy source	4.2.1.3	*By amount, type, source*	*Not recognised in V4.3*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Surface water used for nutrition, materials or energy	Coastal and marine water used as energy source	4.1.1.4	*By amount, type, source*	*Not recognised in V4.3*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water for drinking	4.2.2.1	*By amount, type, source*	*Ground water for drinking*	*1.1.2.2*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water used as a material (non-drinking purposes)	4.2.2.2	*By amount & source*	*Ground water as source of energy*	*1.2.2.2*
CICES Extended	**Provisioning (Abiotic)**	Water	Ground water for used for nutrition, materials or energy	Ground water used as an energy source	4.2.2.3	*By amount & source*	*Ground water for non-drinking purposes*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Water	Other aqueous ecosystem outputs	Other	4.2.3.X	*Use nested codes to allocate other provisioning services from living systems to appropriate*	*Not recognised in V4.3*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for nutrition	4.3.1.1	*Amount by type*	*Minerals*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy	Mineral substances used for material purposes	4.3.1.2	*Amount by type*	*Solid*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or	Mineral substances used for as an energy source	4.3.1.3	*Amount by type*	*N/A*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosysem properties used for nutrition, materials or	Non-mineral substances or ecosysem properties used for nutrition	4.3.2.1	*Amount by type*	*Non-mineral*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosysem properties used for nutrition, materials or	Non-mineral substances used for materials	4.3.2.2	*Amount by type*	*Gas*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosysem properties used for nutrition, materials or energy	Wind energy	4.3.2.3	*Amount by type*	*Wind*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosysem properties used for nutrition, materials or energy	Solar energy	4.3.2.4	*Amount by type*	*Solar*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosysem properties used for nutrition, materials or	Geothermal	4.3.2.5	*Amount by type*	*Geo-thermal*	*N/A*
CICES Extended	**Provisioning (Abiotic)**	Non-aqueous natural abiotic ecosystem outputs	Other mineral or non-mineral substances or ecosysem properties used for nutrition, materials or	Other	4.3.2.6	*Use nested codes to allocate other provisioning services from living systems to appropriate Divisions/Groups*	*Not recognised in V4.3*	*N/A*
CICES Extended	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	5.1.1.1	*Amount by type*	*Dilution by freshwater and marine ecosystems*	*N/A*
CICES Extended	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	5.1.1.2	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	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, storageor accumulation)	5.1.1.3	*Amount by type*	*Mediation of waste, toxics and other nuisances, by natural chemical and physical*	*N/A*
CICES Extended	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	5.1.2.1	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Mass flows	5.2.1.1	*Amount by type*	*Mediation of flows by natural abiotic structures*	*N/A*
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Liquid flows	5.2.1.2	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Gaseous flows	5.2.1.3	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	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	5.2.2.1	*Amount by type*	*Maintenance of physical, chemical, abiotic conditions*	*N/A*
CICES Extended	Regulation & Maintenance (Abiotic)	Other type of regulation and maintenance service by abiotic processes	Other	Other	5.3.X.X	Use nested codes to allocate other regulating services from living systems to appropriate Divisions/Groups	*Not recognised in V4.3*	*N/A*
CICES Extended	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	6.1.1.1	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	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	6.1.2.1	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	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	6.2.1.1	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	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 or bequest value	6.2.2.1	*Amount by type*	*Not recognised in V4.3*	*N/A*
CICES Extended	Cultural (Abiotic)	Other abiotic characteristics of nature that have cultural significance	Other	Other	6.3.X.X	*Use nested codes to allocate other provisioning services from living systems to appropriate Divisions/Groups*	*Not recognised in V4.3*	*N/A*

Appendix 8: Publications derived from the work in Task 4.1, respectively this deliverable:

Czúcz, B.; Arany, I.; Potschin, M.; Bereczki, K.; Kertész, M.; Kiss, M.; Aszalós, R. and R. Haines-Young (2018): Where concepts meet the real world: a systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services 29* (2018) 145–157. https://doi.org/10.1016/j.ecoser.2017.11.018

Czúcz, B.; Arany, I.; Potschin-Young, M.; Bereczki, K.; Kertész, M.; Kiss, M.; Vári, A.; Aszalós, R. and R. Haines-Young: Ecosystem service indicators along the cascade: mapping and assessment of capacity, actual use and benefits (in preparation)

Haines-Young, R. and M. Potschin-Young (2018): Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief. *One Ecosystem* 3: e27108. https://doi.org/10.3897/oneeco.3.e27108

Potschin-Young, M.; Burkhard, B.; Czúcz, B. and F. Santos-Martín (2018): Glossary of ecosystem services mapping and assessment terminology. *One Ecosystem* 3: e27110. https://doi.org/10.3897/oneeco.3.e27110

Santos-Martín, F.; Viinikka, A.; Monomen, L.; Brander, L.; Vihervaara, P.; Liekens, I. and M. Potschin-Young (2018): Creating an operational database for Ecosystems Services Mapping and Assessment Methods. *One Ecosystem* 3: e26719. doi: 10.3897/oneeco.3.e26719

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Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES

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CICES

ABSTRACT

We present a 'concept matching' systematic review linking the classes of the Common International Classification for Ecosystem Services (CICES, v4.3) to the ways scientists define and apply ES indicators in published studies. With the dual aim of creating an overview how the different services are measured in the studies, and determining if CICES provides an appropriate structure to accommodate the ES assessed in the practical literature, we reviewed 85 scientific papers from which 440 indicators were identified. Almost all CICES classes were represented, with cultural and some regulating (e.g. global climate regulation, pollination) ES being the most frequently considered. The four most frequently studied CICES classes (or class clusters) were *global climate regulation*, *aesthetic beauty*, *recreation*, and *bioremediation*. Regulating and cultural services were more often assessed than provisioning services. Normalisation to unit area and time was common for indicators of several regulating and provisioning ES. Scores were most frequently used for cultural ES (except *recreation*) and some regulating services (e.g. *flood protection*). Altogether 20% of the ES indicators were quantified as an economic value, and monetisation is most frequently done for cultural and provisioning ES. Few regulating services, on the other hand, were monetised (including ones, like *global climate regulation*, for which appropriate techniques are relatively easily available). The work enabled a library of indicators to be compiled and made available. The findings can be used to help improve CICES so that it can provide a more robust and comprehensive framework for ecosystem assessments.

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Policy Brief

Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief

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Abstract

The Common International Classification of Ecosystem Services (CICES) is widely used for mapping, ecosystem assessment, and natural capital ecosystem accounting. On the basis of the experience gained in using it since the first version was published in 2013, it has been updated for version 5.1. This policy brief summarises what has been done and how the classification can be used.

Keywords

CICES, ecosystem service classification, MAES, ESMERALDA, KIP-INCA

 Print

Glossary of ecosystem services mapping and assessment terminology

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Abstract

Mapping and assessment of ecosystems and their services (MAES) is a key EU initiative to synthesize vital environmental information and facilitate balanced policy decisions. As MAES integrates across many scientific and policy domains the development of a common language and shared concepts is essential. Here we present a comprehensive MAES Glossary that was compiled in the ESMERALDA project; it is based on the integration of several previous glossaries and a wide-ranging consultation process. While there are several ecosystem services glossaries available as from EU supported work such as Oppla, OpenNESS, and ecosystem services related handbooks, the new material presented here focusses on mapping and assessment of ecosystem services and therefore more directly supports the MAES process.

Keywords

Ecosystems, Ecosystem Services, Mapping, Assessment, Terminology, ESMERALDA, OpenNESS, EU Biodiversity Strategy

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Research Article

Creating an operational database for Ecosystems Services Mapping and Assessment Methods

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Abstract

Identifying and applying the appropriate method for ecosystem services mapping and assessment is not trivial. To provide guidance in this task, this paper describes the creation of a database for existing studies on mapping and assessing ecosystems and their services, which records relevant information to the ecosystem studies (e.g. methods used, the scale, ecosystem type, ecosystem service categories) and other relevant attributes that need to be considered. This database, therefore, forms the basis for an online ecosystem service 'methods finder'. Our results provide an overview of the database itself (883 entries until April 2018) and the consultation within the ESMERALDA consortium that shaped its development, as well as providing an overview of the final mapping and assessment methods describing their spatial distribution. This work helps identify the main gaps and opportunities for alignment and development of commonalities in analytical approach amongst the individual Member States. The results illustrate the different conditions,