Ref. Ares(2017)1116679 - 02/03/2017

Tools for Assessment and Planning of Aquaculture Sustainability

SHORT TITLE:	**TAPAS**
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TOPIC:	**H2020- SFS-11b-2015**
PROJECT NUMBER:	**678396**

DELIVERABLE: 4.2

Final report on framework for assessment of ecosystems services provided by European Aquaculture

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History of changes:

Ver	Date	Changes	Author
1	23.02.2017	First draft	NIVA
2	28.02.2017	Comments from partners incorporated into text	UM, UN, MI, ABT
3	28.02.2017	Final draft	NIVA
4	01.03.2017	QA	UOS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 678396

Refer to this document as:

Dale T, Seifert-Dähnn I, Chen W, Marin A, Casserly J & Bardócz T (2017). Final report on framework for assessment of ecosystems services provided by European Aquaculture. EU H2020 TAPAS Deliverable 4.2. Report. 48pp

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programme under grant agreement No 678396

SUMMARY

This report presents an approach to the assessment of ES related to aquaculture and represents a background document and a departure point for building a general framework for assessment of ecosystems services in the TAPAS (Tools for Assessment and Planning of Aquaculture Sustainability) project. TAPAS is an H2020 research project running from 2016 to 2020 (www.tapas-h2020.eu). TAPAS aims to promote the sustainability of European aquaculture and alleviate bottlenecks by providing tools for key stakeholders at local, national and EU level. In TAPAS we aim to assess the combined environmental and social impacts of aquaculture and the economic instruments, management tools and farm practices that will support and incentivize the sustainable development of aquaculture. We adopt an ecosystem services approach, which takes into account benefits (from provisioning, regulating, supporting and cultural services) humans derive from freshwater and marine ecosystems, and how aquaculture influence these.

The report is a formal requirement of Deliverable 4.2, submitted in Month 12 of the project. It provides a foundation for the work that will be conducted in Work Package 4 " Ecosystem Services and Societal models ". The development of the framework will continue throughout the lifetime of the TAPAS project

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1. Aims and objectives

In the Description of Work (DoW) the aims and objectives for task 4.1. were as follows:

“The key objective is to draft a general framework to assess the ecosystems services (ES) provided (and required) by European Aquaculture. The most obvious and important ES provided by aquaculture is the provisioning of e.g. food, feeds, fibre. The provisioning services are also the most easily valued, since aquaculture commodities are traded in well established markets. However, aquaculture, particularly extractive aquaculture such as shellfish and macroalgae, also produce ES other than provisioning (e.g. nutrient removal, turbidity reduction, habitat provision and carbon sequestration) and several of these do not have established markets and are far more difficult to quantify. There is no “one approach fits all” for the assessment of ES, and the approach taken will depend on issues such as type of political/management/regulatory decisions the ES assessment is intended to inform, data availability and scale. Under this task we will develop a general framework for the assessment of ecosystems serviced provided by as well as required the main segments (extensive aquaculture of fin-fish and extractive aquaculture of mussel and seaweeds) of European aquaculture.

We will build on recently developed frameworks (e.g. VALMER and/or UK National Ecosystems Assessment), and through a “fitness for purpose” literature review of existing tools and models suggest a suite of alternatives suitable for the main segments of European Aquaculture. The framework will be refined through expert and stakeholder workshops.”

The aim of Deliverable 4.2. was to suggest an approach to the assessment of ES related to aquaculture and draft a general framework based on the work done at this stage in the project. Deliverable 4.2 will act as a departure point for the further development of the various constituent of a framework, and discussion grounds for expert and stakeholder workshops to be arranged throughout TAPAS. Finally, Deliverable 4.2 aims to create the backbone of a structure that can be incorporated into the TAPAS Smart tool.

2. Introduction

Aquaculture is the fastest growing food production system in the world. The industry has grown at a steady 8-10% over the past 30 years, and this is set to continue. A milestone was reached in 2014 when the aquaculture sector’s contribution to the supply of fish for human consumption surpassed that of wild-caught fish for the first time (FAO 2016). Within EU the productions have been more or less constant since 2000 (FAO 2016), but there has been a significant growth in some European countries outside EU such as Norway and Turkey (see table).

There are concerns that the fast growth of aquaculture can incur negative environmental and social impacts, and in several areas the debate is highly polarized (Bostock et al. 2010). The controversy ultimately stems from different perceptions of what the financial, social and environmental costs and benefits actually would be at various development trajectories of the

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aquaculture industry, as well as from concerns about the true sustainability of these development trajectories (Baulcomb et al. 2013).

Discussing the environmental and social impacts of “aquaculture”, is largely unhelpful when it comes to resolving debates about the sustainability of present and future aquaculture activity. “Aquaculture” is an umbrella term that encompasses a large number of species and production systems embedded in different environmental, social, economic and cultural contexts, each of which will have its own set of environmental and social impacts that are worth considering explicitly and systematically (Bostock et al. 2010).

The concept of ecosystem services can help to facilitate the assessment of the sustainability of aquaculture by making the link between humans and the environment explicit. Despite this, however, there has been little research that frames the environmental and social debates surrounding aquaculture in the context of ecosystem services (Baulcomb et al. 2013).

3. Background

3.1 European aquaculture

3.1.1 Overview

The total aquaculture production within EU was 1.26 million tons in 2014. Including the production by the EEA countries Norway and Iceland, and the production of Turkey the total aquaculture production in Europe was 2.84 million tons in 2014.

In 2014 the three largest aquaculture producers among EU Member States were Spain, the United Kingdom and France, which together accounted for more than half (55 %) of total EU-28 aquaculture production. However, the EEA country Norway is by far the biggest European producer with a higher total production than EU-28 together (Table 1).

Table 1 Aquaculture production in Europe in the period 2004-2014 in ‘000 tons. Source: Eurostat (online data codes: fish_aq_q and fish_aq_2a)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
EU-28 (2)	1 325	1 278	1 297	1 319	1 272	1 318	1 272	1 249	1 225	1 183	1 270
Norway	637	662	709	830	848	962	1 020	1 145	1 321	1 248	1 332
Spain	297	221	294	284	252	268	254	274	267	226	285
Turkey	94	120	129	140	:	:	:	189	212	233	234
United Kingdom (4)	207	173	172	174	180	197	201	199	206	203	215
France	243	245	238	238	238	236	203	194	205	200	200
Italy	118	181	174	181	158	162	154	164	137	141	149
Greece	97	106	113	113	115	122	121	111	109	114	104
Netherlands	79	71	42	53	47	56	67	44	46	47	63
Poland	35	38	36	35	37	37	37	26	33	31	36
Denmark	43	39	28	31	37	34	32	32	34	32	34
Ireland	58	60	53	53	45	47	46	44	34	33	29
Germany	57	45	38	45	44	40	41	39	27	25	26
Czech Republic	19	20	20	20	20	20	20	21	21	19	20
Hungary	13	14	15	16	15	14	14	16	15	14	15
Croatia	10	11	14	13	16	16	16	17	14	14	14
Finland	13	14	13	13	13	14	12	11	13	14	13
Sweden	6	6	8	5	8	9	11	13	14	13	13
Portugal	7	7	8	7	7	7	8	9	10	10	11
Romania	8	7	9	10	12	13	9	8	10	10	11
Malta	1	5	7	9	7	6	7	4	7	9	9
Iceland	9	8	9	5	5	5	5	5	7	7	8

Bulgaria	2	3	3	4	7	8	8	7	7	6	7
Cyprus	2	2	4	3	4	3	4	5	4	5	5
Austria	2	2	3	3	2	2	2	3	3	3	3
Lithuania	3	2	2	3	3	3	3	3	3	4	3
Slovenia	2	1	1	1	1	1	1	1	1	1	1
Slovakia	1	1	1	1	1	1	1	1	1	1	1
Estonia (³)	0	1	1	1	0	1	1	0	1	1	1
Latvia	1	1	1	1	1	1	1	1	1	1	1
Belgium	1	0	0	0	0	1	1	0	0	0	0
Luxembourg	:	:	:	:	:	:	:	:	:	:	:

(¹) Excluding production from hatcheries and nurseries, fish eggs for human consumption, ornamental and aquarium species.

(²) Differences between the EU-28 totals and the sums for the EU Member States are due to rounding.

(³) 2011: break in series.

(⁴) 2014: break in series.

Although over 100 species groups are farmed in Europe, production is dominated by Atlantic salmon (55% of production tonnage), mussels (15%), rainbow trout (13%), sea-bass (5%), sea-bream (4%), Pacific oyster (3%), and carp (2%).

3.1.2 Segments of European aquaculture

Aquaculture in Europe takes a variety of forms along several axes. It takes place in fresh water, brackish water, and sea water. Marine aquaculture is carried out in a range from sheltered bays to exposed open coast. Culture systems range from extensive to intensive depending on the stocking density of the culture organisms, the level of inputs (e.g. feeds provided), and the degree of management. European aquaculture is carried out in natural settings such as lakes and ponds or in tanks of various types. Tank aquaculture range from full flow-through systems to recirculation systems with high degree of water re-use. Aquaculture companies range from small traditionally ran family owned businesses to large multinational industrial companies listed on stock markets around the world.

In the following section we have briefly described the various segments of European aquaculture. Here we describe "segment" as production techniques/systems and environment rather than referring to species. This is because the same species may be farmed using several different methods and because it is the production method/system and surrounding ecosystem rather than species that will be linked to ecosystems services-and disservices. We have modified the illustration of aquaculture methods used in EU, and use this as a summary of the various segments of aquaculture and the corresponding aquatic ecosystem Figure 1

Marine and brackish water aquaculture

European marine and brackish water aquaculture consists of fin-fish, shellfish, and algae. Marine and brackish water aquaculture systems in Europe are operated *extensive, semi-intensive* and *intensive*.

Extensive and *semi intensive* brackish aquaculture is still carried out in lagoons and coastal ponds in parts of Europe, and is an analogy to extensive and semi intensive freshwater systems. *Extensive* marine water aquaculture is mainly shellfish farming-(and algae). Shellfish farming is primarily based on spat collected in the wild and the grow-out phase is depend on nutrients provided by the environment. Different techniques can be used, including bottom farming, "off-bottom" farming (tables and wooden posts) and floating systems such as rafts and longlines. Bottom farming is carried out in shallow areas while rafts and longlines can be used in open sea or estuarine environments. Rafts are solid floating platforms supporting the farmed shellfish, while longlines are floating lines anchored at both ends, on which shellfish are suspended (either directly or on dropper lines). Typical examples of species produced by the above described methods are mussels, oysters, and clams.

There is still some land based intensive pond production of sea bass and bream as well as mullet and the fingerlings are produced in land based hatcheries. However, the largest fraction of European brackish and marine water aquaculture is *intensive* production carried out in marine cages. In marine cage culture, fish are reared in cages anchored to the seabed. On the surface the cages have a rectangular or circular floating framework, either made of plastic or steel. The surface structure is supporting a large net bag hanging in the water. In many cases a farm site contains several cages moored together. The cages often carry walkways for boat access and workspace. In some cases, a barge is connected to the cages, and this barge carry feeds tanks, storage, and accommodation.

In cage cultures the water flows freely in and out of the cages, the openness of the system makes the fish exposed to external influences (i.e. pollution events or physical impact) as well as exposing the adjacent environment to the stock, and the fish farm effluents. In Europe marine cages culture are widely used for rearing finfish, mainly salmon, trout, sea bass and sea bream.

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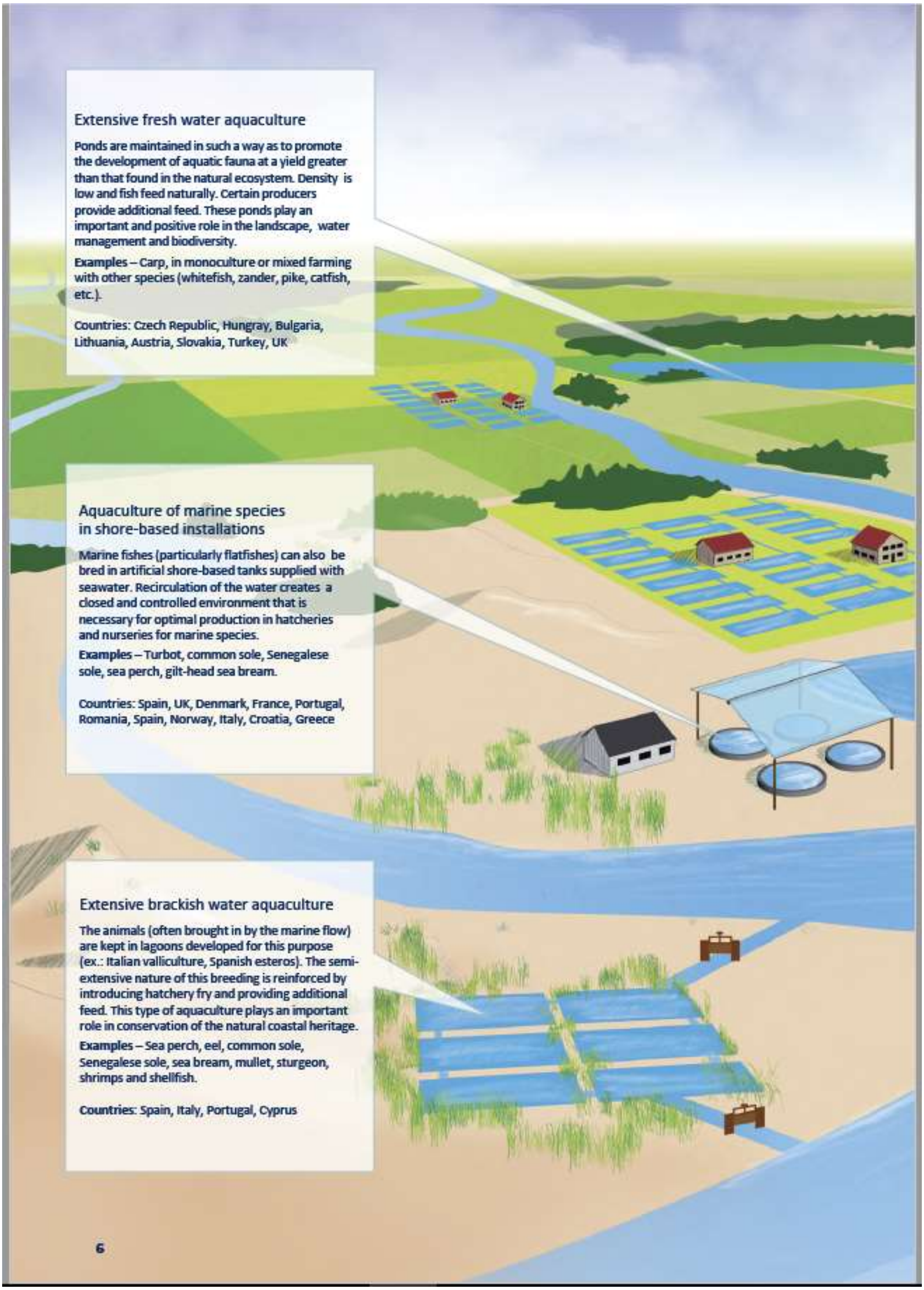

Extensive fresh water aquaculture

Ponds are maintained in such a way as to promote the development of aquatic fauna at a yield greater than that found in the natural ecosystem. Density is low and fish feed naturally. Certain producers provide additional feed. These ponds play an important and positive role in the landscape, water management and biodiversity.

Examples – Carp, in monoculture or mixed farming with other species (whitefish, zander, pike, catfish, etc.).

Countries: Czech Republic, Hungray, Bulgaria, Lithuania, Austria, Slovakia, Turkey, UK

Aquaculture of marine species in shore-based installations

Marine fishes (particularly flatfishes) can also be bred in artificial shore-based tanks supplied with seawater. Recirculation of the water creates a closed and controlled environment that is necessary for optimal production in hatcheries and nurseries for marine species.

Examples – Turbot, common sole, Senegalese sole, sea perch, gilt-head sea bream.

Countries: Spain, UK, Denmark, France, Portugal, Romania, Spain, Norway, Italy, Croatia, Greece

Extensive brackish water aquaculture

The animals (often brought in by the marine flow) are kept in lagoons developed for this purpose (ex.: Italian valliculture, Spanish esteros). The semi-extensive nature of this breeding is reinforced by introducing hatchery fry and providing additional feed. This type of aquaculture plays an important role in conservation of the natural coastal heritage.

Examples – Sea perch, eel, common sole, Senegalese sole, sea bream, mullet, sturgeon, shrimps and shellfish.

Countries: Spain, Italy, Portugal, Cyprus

Intensive fresh water aquaculture

In intensive systems, fish are bred in tanks until they reach marketable size, or they reach a size where they are transferred to other systems such as cages. There are two techniques: continuous flow (river water enters tanks upstream and leaves downstream) and recirculation (the water remains in a closed circuit and is recycled and 'recirculated' in the tanks). There is also cage aquaculture.

Examples – Rainbow trout, Atlantic salmon, eel, catfish, sturgeon, tilapia, etc.

Countries: UK, Ireland, Czech Republic, Norway, Denmark, Bulgaria, Estonia, Spain, Croatia, Italy, Cyprus, Lithuania, Hungary, Poland, Portugal, Romania, Slovakia, Finland, Sweden,

Marine cage aquaculture (intensive)

The fish are kept in cages anchored to the seabed and maintained on the surface by means of a floating framework. This form of aquaculture is practiced both in sheltered and more exposed zones near shore, but more sophisticated techniques (submersible cages, remote monitoring, automatic feeding, etc.) may make it possible to move further from shore.

Examples – Atlantic salmon, sea perch, sea bream, meagre, tuna, etc

Countries: UK, Ireland, Spain, Greece, Malta, Turkey, Croatia, Denmark

Shellfish farming (extensive)

Shellfish farming is based either on the collection of wild spat or hatchery spat, which feed on nutrients provided by environment (filter-feeding animals) . Oyster and mussel farming use a wide range of techniques: bottom-farming, on tables, wooden posts, ropes, etc.

Examples – Oysters, mussels, clams and abalones

Countries: UK, Ireland, Netherlands, Germany, France, Italy, Greece, Spain, Portugal, Cyprus, Bulgaria, Sweden, Denmark

Figure 1 Modification of the fact sheet on aquaculture methods presented in the EU commission page on Aquaculture (https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/2012-aquaculture-techniques_en.pdf)

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Freshwater aquaculture

In European freshwater aquaculture systems mainly fin-fish are produced. Freshwater aquaculture systems in Europe are operated both *extensive, semi-intensive* and *intensive*.

Extensive freshwater fish farming is practiced across the whole Europe, and is particularly common in Central and Eastern Europe. The farming is carried out in Earth ponds (mainly artificial but often built hundreds of years ago). According to the traditional technology, juvenile production is usually carried out in the same ponds, where the adult spawning process occurs naturally. The fish production in the ponds is achieved essentially from the natural and renewable resources of the pond, where the higher yield of fish compared to the natural ecosystems is based on the optimization of the pond's trophic web. Every winter, the ponds are cleaned and fertilized to stimulate aquatic vegetation and consequently increase the abundance of organisms form the base of the aquatic food web. Production in extensive farms is generally low (less than 1 t/ha/y). Typical species produced in extensive systems are carp, catfish and pike.

In *semi-intensive* freshwater aquaculture systems, the production of the pond is increased compared to extensive production by adding supplementary feed allowing for higher stocking density and production per hectare. Furthermore, in semi-intensive systems egg incubation, hatching and larval rearing is often carried out in controlled facilities and juvenile fish are subsequently stocked in the ponds. Typical species produced in semi-intensive freshwater systems are, common carp, amur, bighead carp, tench, roach, pike and perch, sold for human consumption and restocking sport fishing ponds or rivers.

In *intensive* freshwater systems, fish are bred in high density in various types of tanks until they reach marketable size. In intensive systems the farmed organism relies on provided (formulated) feeds only. There are principally two techniques in use: flow-through and recirculation (RAS). In flow-through systems river or lake water either flows by gravity or is pumped through the farm with minimal treatment of effluent waters. Water is not recirculated and treated within the farming operation. In some cases, incoming water may be filtered (and sterilised) and effluents filtered sterilized and nitrogen wastes removed. In recirculation systems water is reused many times, by passing the water through treatment processes to remove waste and to restore water quality. Typical species grown in intensive freshwater systems are rainbow trout, eel and African catfish. The smolt production of salmon is also in many cases carried out in intensive freshwater systems.

Another system that, at least in Europe, is operated *intensive* is freshwater cage culture. The bulk of freshwater cage culture is an integrated part of the production of Atlantic salmon and rainbow trout. Here the freshwater cage culture is an intermediate step between the land based rearing of fingerlings (see above) and the grow-out period carried out in sea cages. In addition, there is a smaller production of trout and Arctic charr for the table or for re-stocking of rivers and lakes for fishery purposes.

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Integrated systems

Innovative systems have been developed to increase the productivity and reduce the environmental impacts of aquaculture by combining different types of production. The concept of "integration" implies that byproducts from on type of production (e.g. nutrients from fin-fish) becomes inputs to another (e.g macroalgae or vegetables). We chose to include this type of aquaculture in this description of segment in European aquaculture because it has received much attention among researchers and regulators. These concepts have, however, almost no commercial uptake in Europe,

One concept that has received much interest is Integrated multi-trophic aquaculture (**IMTA**). This includes combining organisms from different trophic levels of an ecosystem (e.g. fish, shellfish, algae) in the same water body, so that the byproducts of one become the inputs of another. The most common combination is fed aquaculture (e.g., fin-fish, shrimp) with inorganic extractive (e.g., macroalgae) and organic extractive (e.g., shellfish) aquaculture. Such systems can be used to recycle waste nutrients from higher trophic-level species into the production of lower trophic-level crops of commercial value. IMTA may reduce the environmental impacts directly through the uptake of dissolved nutrients by primary producers (e.g. macroalgae) and of particulate nutrients by suspension feeders (e.g. mussels), and through removing the nutrients from the location.

Aquaponics refers to any system that combines aquaculture (usually fish in aquarium-like structures) with hydroponics (cultivating plants in water) in recirculating systems. Nutrients generated by the fish are absorbed by plants cultured in enriched water. Fish provide most of the nutrients required for plant nutrition. More technically, the water from an aquaculture system is fed to a hydroponic system where fish waste is broken down by nitrification bacteria into nitrates and nitrites, which are again utilized by the plants as nutrients. The water is then often recirculated back to the aquaculture system.

3.2 The ecosystem services (ESS) approach

The literature on ecosystems services has grown quickly during the last decade. This section is not trying to give a comprehensive review of this literature but aims to provide background information that can be used as a starting point for the development of the ecosystem services approach to be used in TAPAS

3.2.1. History and background

The definition of ecosystems service (ESS) has evolved over the years, and the definition is still being discussed with additional view-points and arguments both from ecology and economics (Braat & de Groot 2012). A recent and widely used definition is from the TEEB where "ecosystem services are the direct and indirect contributions of ecosystems to human well-being" (TEEB et al. 2012, Braat & de Groot 2012).

The origins of the modern concept of ecosystem services (ESS) are to be found in the late 1970s, and the original purpose was to design a pedagogical concept that would help to raise the public

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interest in environmental problems, in particular the public interest in biodiversity conservation. It continues throughout the 1980s in the sustainable development debate, and into the 1990s with a mainstreaming of ecosystem services in the scientific literature (Costanza & Daly, 1992, Daily, 1997). In this period there was an increased focus on methods to estimate the economic value of ecosystems services. The paper "The value of the worlds ecosystems services and natural capital" by Costanza et al. (1997) is often considered a milestone, where the authors made an estimate the total value on the worlds ecosystems. For decision-making the strengths of ESS approach is among other things that it is interdisciplinary and meaningful both to social sciences and natural sciences, and furthermore that the ESS approach provides a possibility to analyze the interactions and trade-offs between environmental conservation and economic development.

The Millennium Ecosystem Assessment (MA, 2005)[1] served to define and popularize the concept and has contributed to several other major international initiatives such as The Economics of Ecosystems and Biodiversity (TEEB)[2] and the recently established Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES)[3]. The MEA has also stimulated national assessments in many countries such as e.g the UK (UK NEA 2011)[4]

3.2.2. Conceptual frameworks

In the Millennium Ecosystem Assessment (MA)(2005) ecosystem assessments is described as a "social process" through which scientific evidence about the causes of ecosystem change and their consequences for human well-being are identified, so that appropriate management and policy options can be developed to support decision-makers. In ecosystems services assessments researchers, resource managers, decision makers and various stakeholders are brought together for joint problem solving, and shared vision or common reference point. A shared perspective of how things should be approached and what outcomes are required is essential (see Jahn et al. 2012; Hauck et al. 2013, Potschin & Haines-Young 2016).

Conceptual frameworks can provide a shared language and a common set of relationships and definitions, which have proved to be effective in supporting of collaborative and comparative work, hence the development of conceptual frameworks has received considerable attention over recent years. There are presently several frameworks that all have merit in particular situations (e.g. review by Dick et al. 2014), but there is no common framework that "fits all" types of ecosystems services assessments. One conceptual framework of ecosystem services assessment commonly utilized at the present is the ecosystems services cascade model (proposed by Haines-Young & Potschin 2010)(used e.g. by Maes et al. 2012, Liquete et al. 2013, Sprangenberg et al. 2014, Felipe Lucia et al. 2015, Mongruel et al. 2015). The ecosystems services cascade model (Figure 2) links natural systems to elements of human well-being, following a pattern that resembles a production chain with a flow from ecological structures and processes generated by ecosystems, to the services and benefits eventually derived by

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[1] Millennium Ecosystem Assessement (MEA)- http://www.millenniumassessment.org/en/index.html
[2] The Economics of Ecosystems and Biodiversity (TEEB)- http://www.teebweb.org/
[3] Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBS)- http://www.ipbes.net/
[4] UK National ecosystems assessment (UK NEA)-http://uknea.unep wcmc.org/Home/tabid/38/Default.aspx

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humans. Ecosystem services play a pivotal role in the cascade, which constitutes them as distinct from the functional characteristics of the ecosystems that make them useful, and the benefits that people ultimately enjoy. A defining feature of services is that they are, in some sense, the final outputs from an ecosystem (Potschin & Haines-Young, 2016).

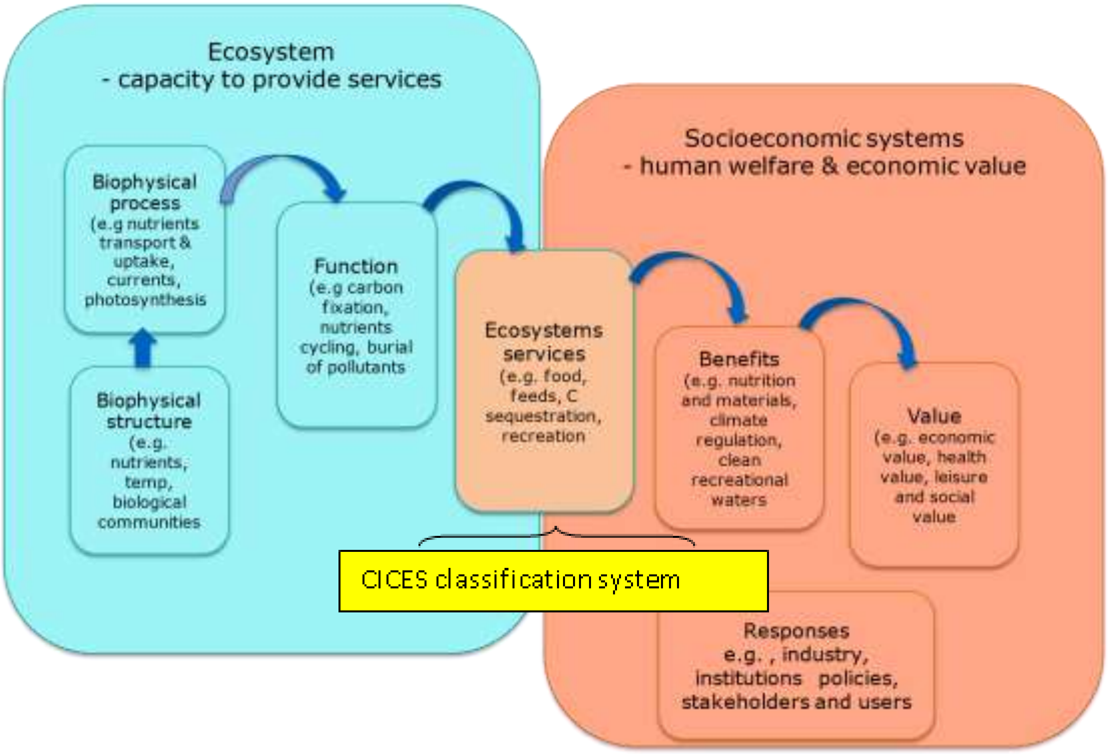

Figure 2. The Ecosystem Services cascade framework, showing the combination of natural (blue) and social (orange) sciences. (Modified from Haines-Young & Potschin, 2010).

If one accepts that ecosystem assessments are social processes then it follows that conceptual frameworks cannot simply be taken 'off the shelf'; the collaborative effort in choosing/modifying already existing frameworks or building one is a step that all participants working on an assessment must go through to understand each other (Axelsson et al. 2013, Potschin & Haines-Young 2016).

In this process Potschin & Haines-Young (2016) suggest that it is worth reflecting on the different types of purpose a conceptual framework aims to fill and use this as a guideline to build and efficiently use a conceptual framework, and Potschin & Haines-Young (2016) refers to the preliminary documentation of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (United Nations, 2012) that propose that conceptual frameworks could be viewed as having four purposes:

- tools to make complex systems as simple as they need to be for their intended purpose;
- providing support to structure and prioritize work;

- helping to clarify and focus thinking about complex relationships, supporting communication across disciplines, knowledge systems and between science and policy; and,
- allowing buy-in from a variety of stakeholders by involving them in the development of the framework, and thus increase policy relevance.

3.2.3. Ecosystems services classification

During recent decades there have been a growing body ecosystem services classifications in the literature, each with their own advantages and drawbacks. The Millennium Ecosystem Assessment (MA) classification of ecosystem services is perhaps the most cited (MA 2005). In the MA four different ecosystems services are distinguished: provisioning services, regulating services, cultural services and supporting services Figure 3. However, the classification in the MA has also been criticized among other things for the absence of hierarchy within the classification that makes ecosystem service valuation difficult (Wallace, 2007; Fisher& Turner, 2008) as leads to double counting of services (Boyd & Banzhaf, 2007).

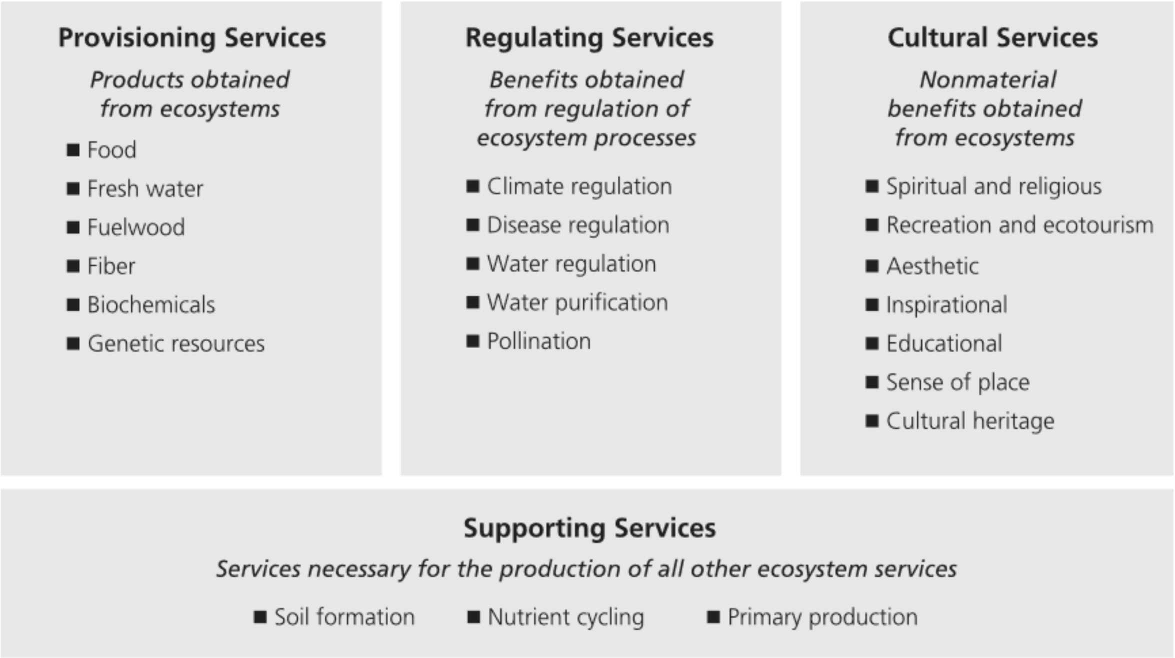

Figure 3 The conceptual framework for ecosystems services in the Millennium Ecosystems Assessment

A number of ecosystem service classifications have subsequently been developed (e.g., Fisher et al., 2009, de Groot et al., 2010 (TEEB), Balmford et al. 2011, Mace et al. 2011, Liquete et al., 2013, Turner et al., 2014). Common for all of them is that they aim to provide clear distinction between ecosystem services (also known as final services), the functions that generate those services (also called intermediate services) and the benefits derived from the services. Where the boundaries are placed between services, functions and benefits varies with classification (Hattam et al. 2015). The inclusion of abiotic components of ecosystems into ecosystem services classifications has also complicated the process of developing consistency in classification. One

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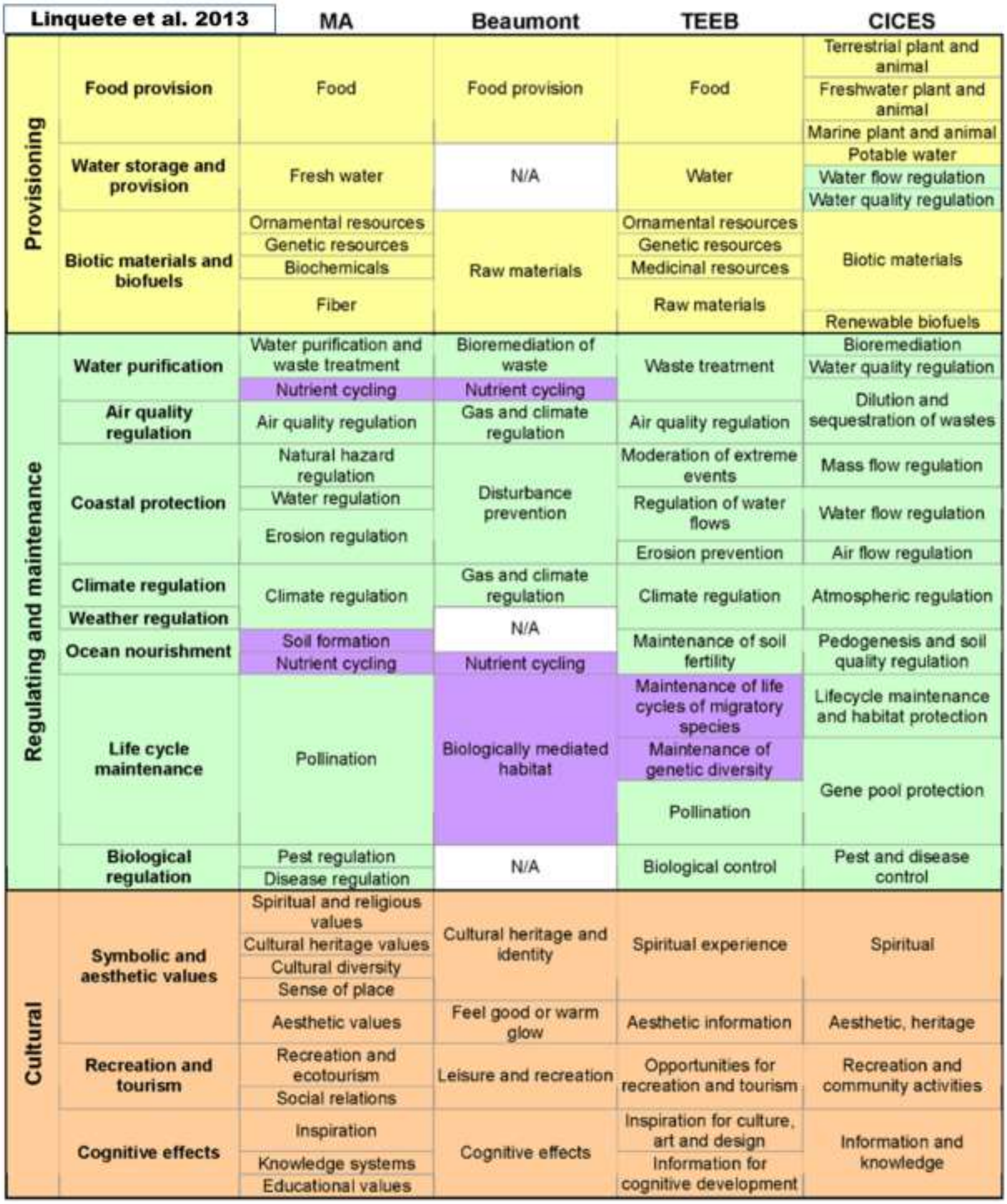
recent framework that has been designed to meet some of these challenges is the Common International Classification of Ecosystem Services (CICES), proposed by the European Environment Agency (Maes et al. 2014). Liquete et al. (2013) carried out a systematic review that highlighted the need of an improved ecosystem service classification for marine and coastal systems, and proposed their own classifications with definitions and links related to previous classifications. Table 2 is taken from Liquete et al. (2013) and illustrate differences among some of the commonly used classification frameworks.

Table 2 Differences and similarities in selected classification frameworks. From Liquete et al. 2013.



Linquete et al. 2013		MA	Beaumont	TEEB	CICES
Provisioning	**Food provision**	Food	Food provision	Food	Terrestrial plant and animal Freshwater plant and animal Marine plant and animal
	Water storage and provision	Fresh water	N/A	Water	Potable water Water flow regulation Water quality regulation
	Biotic materials and biofuels	Ornamental resources Genetic resources Biochemicals Fiber	Raw materials	Ornamental resources Genetic resources Medicinal resources Raw materials	Biotic materials Renewable biofuels
Regulating and maintenance	**Water purification**	Water purification and waste treatment Nutrient cycling	Bioremediation of waste Nutrient cycling	Waste treatment	Bioremediation Water quality regulation Dilution and sequestration of wastes
	Air quality regulation	Air quality regulation	Gas and climate regulation	Air quality regulation	
	Coastal protection	Natural hazard regulation Water regulation Erosion regulation	Disturbance prevention	Moderation of extreme events Regulation of water flows Erosion prevention	Mass flow regulation Water flow regulation Air flow regulation
	Climate regulation	Climate regulation	Gas and climate regulation	Climate regulation	Atmospheric regulation
	Weather regulation		N/A		
	Ocean nourishment	Soil formation Nutrient cycling	Nutrient cycling	Maintenance of soil fertility	Pedogenesis and soil quality regulation
	Life cycle maintenance	Pollination	Biologically mediated habitat	Maintenance of life cycles of migratory species Maintenance of genetic diversity Pollination	Lifecycle maintenance and habitat protection Gene pool protection
	Biological regulation	Pest regulation Disease regulation	N/A	Biological control	Pest and disease control
Cultural	**Symbolic and aesthetic values**	Spiritual and religious values Cultural heritage values Cultural diversity Sense of place Aesthetic values	Cultural heritage and identity Feel good or warm glow	Spiritual experience Aesthetic information	Spiritual Aesthetic, heritage
	Recreation and tourism	Recreation and ecotourism Social relations	Leisure and recreation	Opportunities for recreation and tourism	Recreation and community activities
	Cognitive effects	Inspiration Knowledge systems Educational values	Cognitive effects	Inspiration for culture, art and design Information for cognitive development	Information and knowledge

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As with the conceptual frameworks, some argue that the most appropriate classification system in any given case should be chosen based on its fit-for-purpose (e.g. Spangenberg and Settele, 2010, Heink et al. 2016), i.e. whether the ecosystem service analysis intends to focus more on ecological systems or on socio-economic systems. Also when it comes to classification the purpose of the assessment is important. Fisher et al. (2009) emphasize the importance of the "decision context" meaning the approach taken where the purpose is, for example, to promote understanding and to educate a larger public might be different to the approach taken if the purpose is to compare cost–benefit analysis to be used in environmental decision-making.

3.2.4. Ecosystem service indicators

Indicators are depictions of system qualities, quantities, or states, which are not directly accessible by the observer. Indicators are useful for supporting management activities as well as contributing to studies aiming to model and value changes in ecosystem service provision (Niemeijer & de Groot, 2008). Ecosystems services indicators can be of two main types –firstly, 'measures of key ecosystem properties reflecting changes in ecosystem services and can provide information on the direction and possible magnitude of the impact or response of an ecosystem to stress' (van den Belt & Costanza, 2011). Secondly an indicator can be a quantitative value (like a benchmark) against which change is measured and where the value to be exceeded is incorporated in a statutory or policy instrument, where compliance with it is judged by monitoring (McLusky & Elliott, 2004).

Indicators can both reflect state and/or performance of the ecosystem (the blue part of Figure 2), and the ecosystem natural capital stocks and the flow of ecosystem services of significant value (benefits) to human society (the yellow part of Figure 2).

Aubry & Elliott (2006) suggest environmental indicators should have three basic functions:

- *to simplify:* amongst the diverse components of an ecosystem, a few indicators are needed according to their perceived relevance for characterising the overall state of the ecosystem
- *to quantify:* the indicator is compared with reference values considered to be characteristic of either 'pristine' or heavily impacted ecosystems to determine changes from reference or expected conditions and
- *to communicate:* with stakeholders and policy makers, by promoting information exchange and comparison of spatial and temporal patterns.

In the literature there are several suggestions on what attributes a good indicator should have, and several of these attributes are mentioned by several authors. According to van Oudenhoven et al. (2012), Kandziora et al. (2013) good indicators should communicate information of high "scientific correctness" and high "practical applicability", This is summarized in Müller et al. (2016), where the table below was presented (Table 3).

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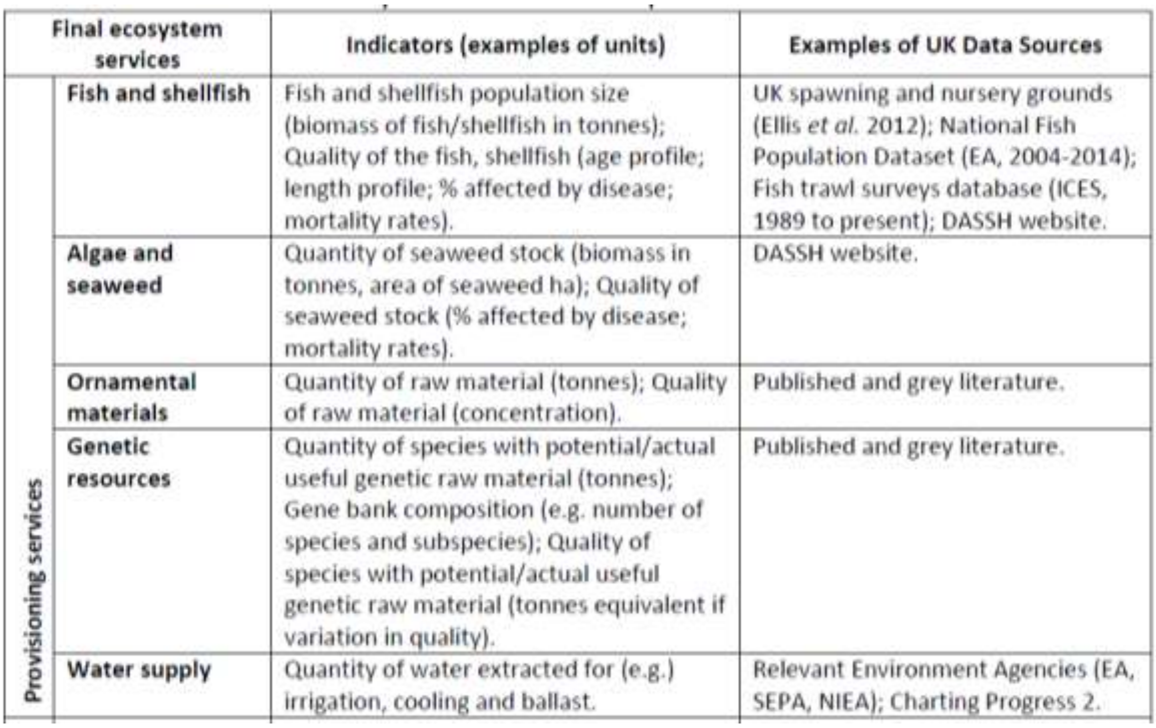
Table 3. Attributes of indicator quality. Source. Müller & Wiggering 2004, Müller et al. 2016.

Scientific correctness	**Practical applicability**
A clear representation of the indicandum	A high political relevance concerning management options
A clear proof of relevant cause–effect relations	Direct relationship to respective management actions
An optimal sensitivity of the representation	A high comprehensibility and public transparency
A high transparency of the derivation strategy	Strong acceptability by users/stakeholders
A high validity, accuracy, precision, representativeness	An orientation towards (quantitative) environmental targets
An optimal degree of aggregation	A capacity to communicate information clearly
An appropriate measurability and high data availability	A link with information on the normative loadings in the applied indicators systems
A good fulfilment of statistical requirements	A relationship to long–term trends and applicability for early warning purposes

Others refer to the SMART principles (Doran 1981) which suggests that in order to be operational, valuable and successful, the management of the environment requires indicators which are Specific, Measurable, Achievable-Appropriate-Attainable, Realistic- Results focused-Relevant, and Time bounded-Timely (e.g. Turner et al. (2014) (UK NEA))

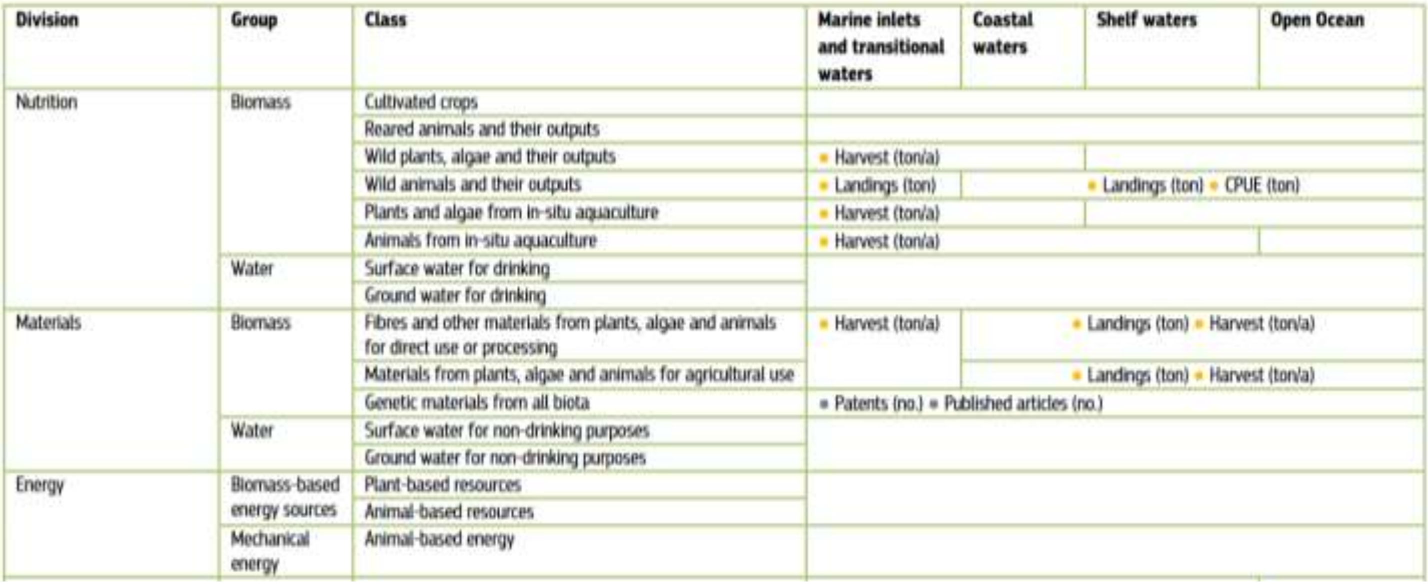
There are already several sources of ecosystems services indicator systems available. Among others, lists of ecosystems services indicators are proposed in UNEP-WCMC (2011), Kandziora et al. 2013, Liquete et al. 2013, Brown et al. 2014, Turner et al. 2014 (UK NEA), Maes et al. 2016, (MAES). The table below (Table 4) show an example of final provisional ecosystem services from coastal and marine areas and their corresponding indicators taken from UK NEA (small section of table 4.6. Turner et al. 2014). Table 5 provides another example of the indicators for marine provisioning services per CICES/MAES (Maes et al. 2016).

Table 4 Example of indicators of final ecosystems services in coastal and marine areas



Final ecosystem services		**Indicators (examples of units)**	**Examples of UK Data Sources**
Provisioning services	**Fish and shellfish**	Fish and shellfish population size (biomass of fish/shellfish in tonnes); Quality of the fish, shellfish (age profile; length profile; % affected by disease; mortality rates).	UK spawning and nursery grounds (Ellis *et al.* 2012); National Fish Population Dataset (EA, 2004-2014); Fish trawl surveys database (ICES, 1989 to present); DASSH website.
	Algae and seaweed	Quantity of seaweed stock (biomass in tonnes, area of seaweed ha); Quality of seaweed stock (% affected by disease; mortality rates).	DASSH website.
	Ornamental materials	Quantity of raw material (tonnes); Quality of raw material (concentration).	Published and grey literature.
	Genetic resources	Quantity of species with potential/actual useful genetic raw material (tonnes); Gene bank composition (e.g. number of species and subspecies); Quality of species with potential/actual useful genetic raw material (tonnes equivalent if variation in quality).	Published and grey literature.
	Water supply	Quantity of water extracted for (e.g.) irrigation, cooling and ballast.	Relevant Environment Agencies (EA, SEPA, NIEA); Charting Progress 2.

Table 5 Example of indicators for marine ecosystems



Division	**Group**	**Class**	**Marine inlets and transitional waters**	**Coastal waters**	**Shelf waters**	**Open Ocean**
Nutrition	Biomass	Cultivated crops				
		Reared animals and their outputs				
		Wild plants, algae and their outputs	▪ Harvest (ton/a)			
		Wild animals and their outputs	▪ Landings (ton)		▪ Landings (ton) ▪ CPUE (ton)	
		Plants and algae from in-situ aquaculture	▪ Harvest (ton/a)			
		Animals from in-situ aquaculture	▪ Harvest (ton/a)			
	Water	Surface water for drinking				
		Ground water for drinking				
Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	▪ Harvest (ton/a)	▪ Landings (ton) ▪ Harvest (ton/a)		
		Materials from plants, algae and animals for agricultural use		▪ Landings (ton) ▪ Harvest (ton/a)		
		Genetic materials from all biota	▪ Patents (no.) ▪ Published articles (no.)			
	Water	Surface water for non-drinking purposes				
		Ground water for non-drinking purposes				
Energy	Biomass-based energy sources	Plant-based resources				
		Animal-based resources				
	Mechanical energy	Animal-based energy				

3.2.5 Ecosystem service valuation

Economic valuation is a useful method to measure the contribution of ecosystem services to human well-being and welfare. Even if valuation has its own limits, ecosystem valuation is important to show some of the major economic values associated with such goods and services – and the heavy losses that occur when ecosystems changes (TEEB, 2010).

Ecosystem values can be estimated and expressed in both monetary or non-monetary terms (UNET-WCMC, 2011). Ecosystem services such as provision services and culture services can now be valued in the monetary terms. While other types of ecosystem services such as biodiversity are difficult to be valued in monetary term (TEEM, 2010). For example, nature has an intrinsic value that is independent of the use or enjoyment people have of it. There has been a fast growing literature on marine ecosystem valuation. For example, UNEP-WCMC (2011) describes various valuation methods and applications suitable for marine and coastal ecosystem services. Beaudoin and Pendleton (2012) highlights areas of ocean and coastal management for which a better understanding of the economic value of marine ecosystem services could improve the critical marine resources management and thus improve ocean governance. Koundouri et al. (2015) developed a framework for assessing the marine and coastal ecosystem services, which Chen et al (2014) applied to estimate both use-value and non-use value related to marine ecosystem service changes. Total Economic Value (TEV) has been mentioned in various literatures including UNEP-WCMC (2011), Koundouri et al. (2015) and Mace et al. 2011. TEV estimates the aggregate social costs and benefits of changes in ecosystem services. The TEV includes directly use value and indirectly use value (regulating services). Direct use value is related to economic benefits and costs for market goods including provision services and cultural services. The indirectly use value for example is relevant to regulating services.

The definition of different values can be found below (MERMAID, 2013) (Figure 4):

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Direct use value: The use of the area in either a consumptive manner, e.g. industrial water abstraction or in a non-consumptive manner, e.g. tourism;

Indirect use value: The role of the area in providing or supporting key (ecosystem) services, e.g. nutrient cycling, habitat provision, climate regulation; and

Option value: Not associated with current use of the area but the benefit of keeping open the option to make use of the area's resources in the future. A related concept is quasi-option value, which arises through avoiding or delaying irreversible decisions, where technological and knowledge improvements can alter the optimal management of a natural resource.

Non-use value is associated with benefits derived simply from the knowledge that the natural resources and aspects of the natural environment are maintained, i.e., it is not associated with any use of a resource. Non-use value can be split into three parts:

- Altruistic value: Derived from knowing that contemporaries can enjoy the goods and services related to the area;
- Bequest value: Associated with the knowledge that the area as a resource will be passed on to future generations; and
- Existence value: Derived simply from the satisfaction of knowing that the area continues to exist, regardless of use made of it by oneself or others now or in the future.

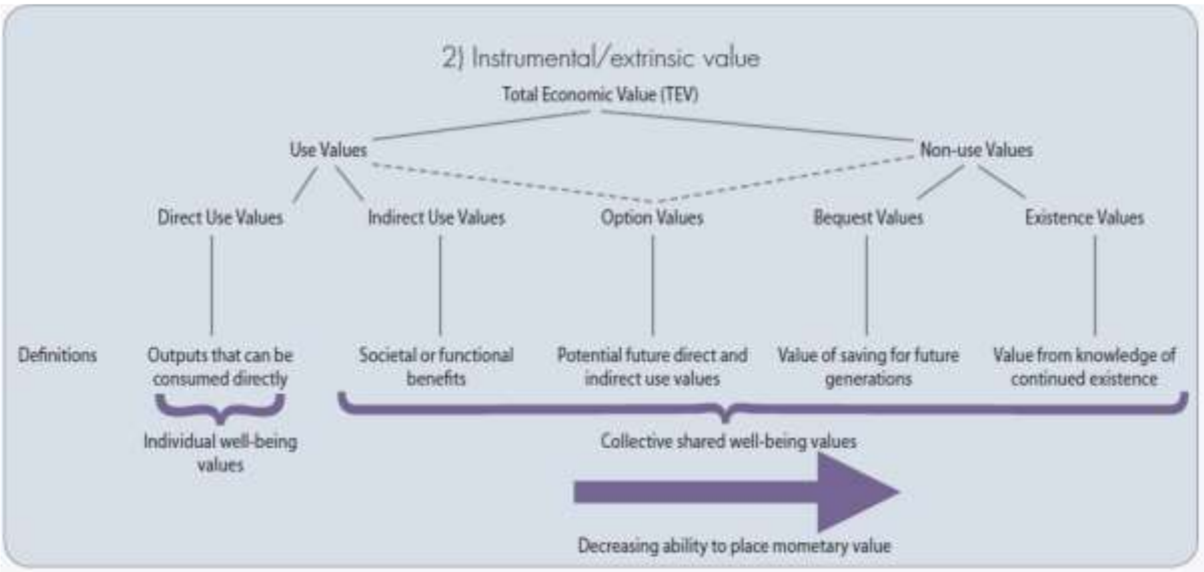

Figure 4 The TEV framework is summarized in Mace et al. (2011).

3.3 ES and aquaculture

Aquaculture represent, to varying degrees, systems engineered by humans, and therefore have some similarity to agriculture systems. Because the concept of ecosystem services is derived from the idea that humans benefit in a variety of ways from healthy, functioning natural ecosystems (Daily, 1997), Baulcom et al. (2013) puts forth the argument that aquaculture systems should not be equated with natural systems, and that they should instead be considered as a human constructs capable of augmenting or undermining the provision of a suite of ecosystem services by the surrounding environment (Baulcom et al 2013).

Given the definition of ES, aquaculture itself is considered as a provisioning service as its purpose is to provide humans with seafood. At the same time aquaculture can also be considered as a pressure, which alters the delivery of other important ES in comparison to a status without aquaculture. Hence, assessments of both the aquaculture systems and its impacts on ecosystem services should extend beyond a simple quantification of the amount of food produced by any given aquaculture system.

While the impact itself occurs in the ecosystem by changing biophysical processes or ecosystem functions (left blue box in Figure 2), the changes in ES occur in the socio-economic system (right orange box in Figure 2). The magnitude of the impact depends on the ecosystem itself, the aquaculture segment and farming practices, but also on socio-economic determinants such as the importance of affected ES, the demand of it and the method used to determine the value of these ES.

At this stage we have not taken any decision regarding final classification system to use in the TAPAS project. Regardless of which classification system TAPAS that will be selected, a starting point could be to look at the ES put forward in different classification systems and select the ES that has relevance for aquaculture. At this stage we have started to draft an overview of aquaculture relevant services, where the table below (Table 6) provides a short general definition of the different ecosystem services (with reference to earlier chapters) and describes its general relevance for aquaculture. Green indicate anticipated augmentation of ES, red indicates anticipated undermining ES and pink indicate that it is not relevant to aquaculture at this stage.

Table 6 Classification of ecosystem services, which can be potentially affected by aquaculture; source: adapted from Mongruel et al. (2015), based on Vigerstol et al. (2011), Liquete et al. (2013).

Type of ES	**Main type of output or process**	**General definition**	**Relevance for aquaculture**
Provisioning services	Food provision	The provision of biomass for human consumption and the conditions to grow it. It mostly relates to cropping, animal husbandry and fisheries.	Aquaculture itself can be considered as an enhancement of the food provision service.
	Water storage and provision	The provision of water for human consumption and other uses (e.g. industrial cooling processes).	Certain types of aquaculture require abstraction of fresh- or saltwater.
	Biotic materials, biofuels and genetic resources	The provision of biomass or biotic elements for non-food purposes e.g. medicinal use (drugs, cosmetics), ornamental use (corals, shells), biomass for energy (algal lipids, whale oil, biogas	Aquaculture of macro- of microalgae for energy production and as input for producing cosmetics and pharmaceuticals.

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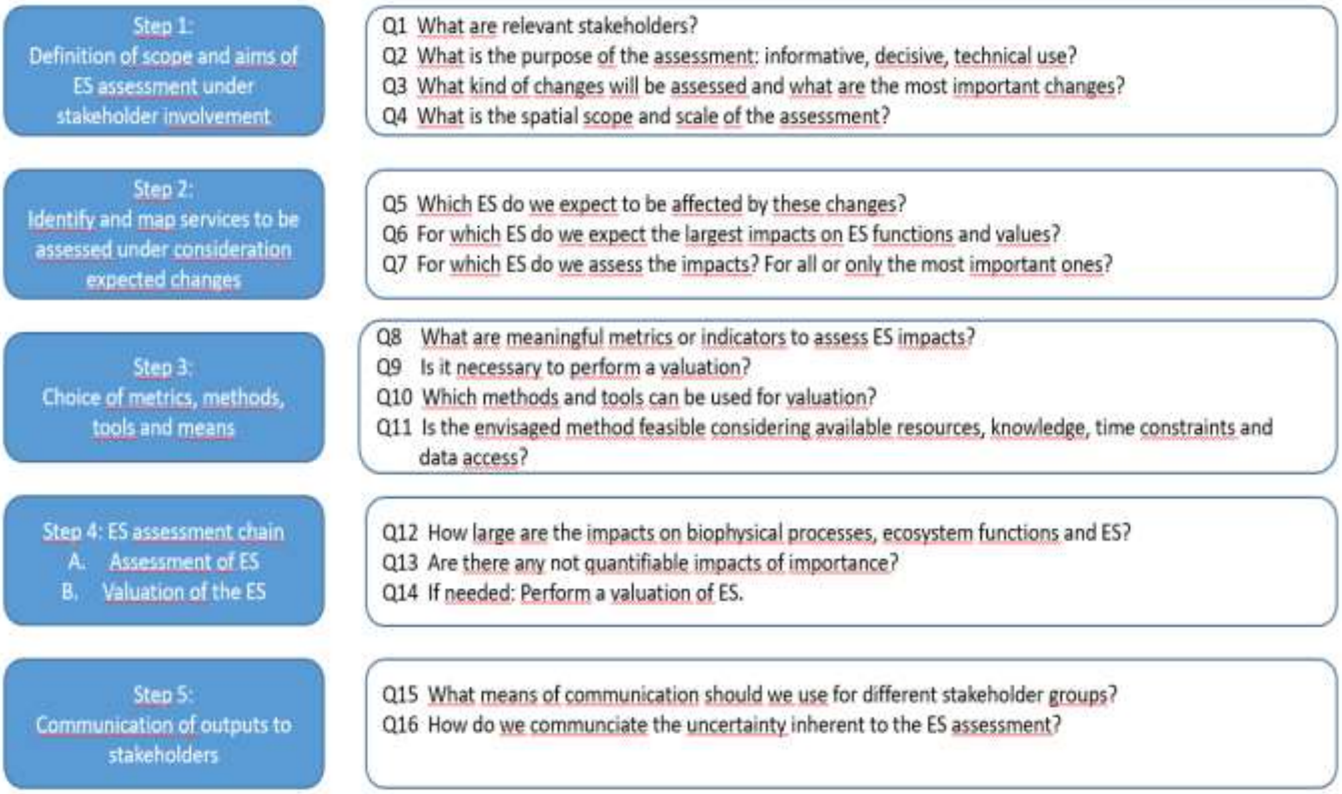
		production), other products (leather, fertilizer, cloth).	Jewelry and other decoration (shells from shellfish) Fertilizer and building materials (lime from shellfish) The escape of farmed species poses a threat to the genetic resources of its wild counterparts (e.g. salmon escape).
Regulating services	Water purification	Biochemical and physicochemical processes involved in the removal of wastes and pollutants from the aquatic environment.	Aquaculture of extractive species can increase water purification.
	Air quality regulation	Regulation of air pollutants concentration in the lower atmosphere.	Not relevant
	Coastal protection	Protection against floods, droughts, hurricanes and other extreme events. Also, erosion prevention in the coast.	Decline of seagrasses meadows (eg. Posidonia oceanica in the Mediterranean Sea) due to nutrient release Protection of coastlines from storm surges and waves, and prevent coastal erosion
	Climate regulation	Regulation of greenhouse and climate active gases. The most common proxies are the uptake, storage and sequestration of carbon dioxide.	Microalgae, seaweed (microalgae) and shellfish aquaculture contributes to CO_2 storage and sequestration. Decline of seagrasses meadows (eg. Posidonia oceanica in the Mediterranean Sea) due to nutrient release
	Weather regulation	Influence of ecosystems and habitats on the local weather conditions such as thermoregulation and relative humidity.	Not relevant.
	Biological regulation and pest control	Biological control of pests mostly linked to the protection of crops and animal production that may affect commercial activities and human health.	As organisms are kept in high densities in aquaculture it is easier for diseases to spread, especially if not artificial pest control is on place. Aquaculture organisms provide an increased number of hosts for parasites that is also found on wild counterparts (e.g. salmon lice). The use og antibiotics and
Cultural services	Symbolic and aesthetic value	Exaltation of senses and emotions by landscapes, habitats or species.	Both an enhancement as well as a degradation of aesthetic values are possible, depending on the type of aquaculture and how the farm is embedded in its surroundings.
	Recreation and tourism	Opportunities that the natural environment provide for relaxation and amusement.	Angling in farm ponds or artificially stocked ponds can have a high touristic value. Escaped farmed fish is of interests for some anglers, since they are easy to catch Escaped fish in rivers are considered a nuisance lowering the value of the original river angling

			There is a spatial competition with tourist development due to a loss of aesthetic landscape value and bath water quality. The fish net pens occupy an important amount of sea space, which normally degrades the aesthetic value of the seascape or landscape.
	Cognitive effects	Trigger of mental processes like knowing, developing, perceiving, or being aware resulting from natural landscapes or living organisms.	Increase awareness around food production and how we depend on healthy aquatic ecosystems.
			Farmers are on alert of any change of water quality.
Supporting	Biodiversity & Habitat provision		“Open” aquaculture systems may attract e.g. wild organism due to the availability of food and substrate and by this improve the local biodiversity.
			“Open” aquaculture systems may attract e.g. wild organism due to the availability of food and create disequilibrium of natural populations
			Waster release from aquaculture reduces benthic biodiversity- sea grass beds etc.
			Aquaculture of non-native species may reduce local biodiversity
			Aquaculture of native endangered species can increase local biodiversity
	Nutrient cycling	Maintaining the cycle of nutrients such as nitrogen and phosphorus by biological and physical processes.	Intensive aquaculture can locally increase nutrient loads in aquatic systems.
			Intensive aquaculture can locally improve nutrient supply in oligotrophic environment and contribute to the restoration of damaged reef ecosystems.
			Shellfish feeding enhances bacterial denitrification, sedimentation rates and speed the sequestration of nutrients. Shellfish repackage phytoplankton biomass and make it available to benthic deposit feeders (benthic-pelagic coupling). Nutrients are removed when shellfish are harvested
	Life cycle maintenance	Biological and physical support to facilitate the healthy and diverse reproduction of species.	The physical structure aquaculture installations provides habitat (artificial reef) and supports a diverse assemblage of fish, invertebrates and benthic organisms.
			Artificial “nursery habitat” for stock that are released into freshwater for fishery enhancement

In chapter 4 we split this table into impacts on ES relevant for the European aquaculture segments presented in Figure 1.

4. TAPAS operational framework for ES assessment

Based on already existing guidelines DEFRA 2007, Everand & Waters 2013, McCarthy & Morling 2014,) and recently developed frameworks for ES assessment (Tinch & Mathieu 2011, Turner et al. 2014, Mongruel et al. 2015), the TAPAS operational framework incorporates the steps as suggested in the VALMER triage-process for determining the scope and selection of methods Mongruel et al. (2015). In addition, it is expanded by an ES assessment step and a communication step (see Figure 5), steps 4 and 5 respectively. The final version of this operation framework is intended to be incorporated into TAPAS Smart.



Step 1: Definition of scope and aims of ES assessment under stakeholder involvement	Q1 What are relevant stakeholders? Q2 What is the purpose of the assessment: informative, decisive, technical use? Q3 What kind of changes will be assessed and what are the most important changes? Q4 What is the spatial scope and scale of the assessment?
Step 2: Identify and map services to be assessed under consideration expected changes	Q5 Which ES do we expect to be affected by these changes? Q6 For which ES do we expect the largest impacts on ES functions and values? Q7 For which ES do we assess the impacts? For all or only the most important ones?
Step 3: Choice of metrics, methods, tools and means	Q8 What are meaningful metrics or indicators to assess ES impacts? Q9 Is it necessary to perform a valuation? Q10 Which methods and tools can be used for valuation? Q11 Is the envisaged method feasible considering available resources, knowledge, time constraints and data access?
Step 4: ES assessment chain A. Assessment of ES B. Valuation of the ES	Q12 How large are the impacts on biophysical processes, ecosystem functions and ES? Q13 Are there any not quantifiable impacts of importance? Q14 If needed: Perform a valuation of ES.
Step 5: Communication of outputs to stakeholders	Q15 What means of communication should we use for different stakeholder groups? Q16 How do we communciate the uncertainty inherent to the ES assessment?

Figure 5 Suggestions for a TAPAS operational framework for ES assessment

4.1 General principles

At this stage of the development of the TAPAS operational framework, the text in this chapter is a literal representation from chapter 4.1 in Mongruel et al. 2015. The stepwise approach in Mongruel et al. 2015 is clearly described and make a very good departure point for developing a TAPAS operational framework (guidelines).

4.1.1. Assessment process and stakeholder engagement

Work in partnership

It is important to engage as early as possible with the decision makers who will use the valuation information. Decision makers are defined as those with responsibility for initiating

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actions and so, depending on the context, may be, for example, national officials developing policy, or local organizations implementing awareness campaigns. Stakeholders are defined as those with an interest in the issue: decision makers will be a subset of the stakeholder group.

All the responsibility for applying valuation data does not lie with the decision maker; deciding whether valuation is what is needed to answer the management question (and how results can and should be used) should be a joint process between the decision maker and those undertaking the valuation, and should include a written agreement to detail the requirements and expectations of both parties. A personal relationship should be built with the decision makers through frequent communication.

Use social science methods

Stakeholder engagement can take a number of forms, including providing information to them, re-questing that they share data and knowledge, or through their active participation throughout the project. Social science has developed methodologies and tools for engaging with stakeholders, and the best practice should be applied. When ES valuation is carried out for a research project, it should be clear when the research project is expected to feed existing stakeholder forums and when stake-holder groups must be convened in the context of the research project.

Communicate appropriately

Communicating the concepts of ecosystem services and valuation will require different techniques and tools depending on the target audience.

4.1.2. Assessment content

Decide upon the management issue to be addressed

The requirements of the stakeholders are central to the process, but it is also important to consider what is actually needed to inform management decisions, and also what, practically, can be under-taken in terms of valuation. The approach and methods for ES assessment may differ depending on the stage of the management process at which valuation is needed.

Define the scope of ecosystem service valuation

There are many contexts in which ecosystem service valuation is worthwhile, including in illuminating people's dependency on the environment in order to build collective understanding, which may, in the long term, affect perceptions of public policy. However, the objective of assessment may concern more immediate, management-driven change.

Develop realistic and coherent scenarios of ecosystem service change

The management scenarios considered as part of the valuation process should address multiple policies in a coherent manner. The type of scenario (whether comparing alternative management actions or building visions of alternative futures) will depend on the context and stakeholder perspective. When assessing change in ecosystem services due to management actions, the cross-effects of various thematic policies should be considered (for instance the cross-effects of the Water Framework Directive and the Marine Strategy Framework Directive

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for coastal ecosystems). The current state of the regulation which affects ecosystem services should be explicitly taken into account in order to estimate the effects of a marginal change in environmental or sectoral policies.

Explore and quantify ecosystem service metrics that are meaningful

Value can be expressed in a number of metrics (e.g. monetary, output, use and cultural measures), and a monetary value may not always be meaningful to the stakeholder. Also, a monetary value may not have the greatest impact: if passive use is the only value available, the issue may be better ad-dressed by natural science or conservation arguments rather than valuation. It is difficult to predict a priori how different individuals or stakeholder groups will react to different metrics, as it will depend on their motivation. VALMER should discuss possible metrics, and where appropriate consider testing metrics using focus groups or other social science methods. To date, that has not been any systematic assessment of which metrics are preferred by particular people or in particular situations so this must be assessed on a case by case basis. Similarly, preferences for aggregate values or for narrative descriptions will also vary from stakeholder to stakeholder.

Tailor valuation outputs to the audience

The need to communicate appropriately with stakeholders continues throughout the process. The output required by stakeholders and decision makers will vary between individuals and situations. There is no single magic bullet that will work for everyone. There is a place for both headline figures (to make a point in a short time) and narratives that provide broader qualitative assessments. As a general rule, outputs should be clear, concise, and short. However, whatever the format of the out-put, it is essential that strong supporting evidence is also available: decision makers will have to defend actions enacted on the basis of the valuation. Uncertainty within the valuation must also be communicated effectively, and guidelines for doing so already exist: for example, the categories and definitions used by the Intergovernmental Panel on Climate Change.

Publish on the whole approach

Few examples exist within the peer-reviewed literature that detail how valuation has actually been used in practice. In general, studies refer to how valuation results could or might be used. It is there-fore important to publish details of how the work has been applied.

4.1.3. Science needs for valuation

Consider different scales

The scale of the valuation should consider the extent of the socio-economic system impacted, the scales of the ecological functions that support the service being considered, and the sensitivity of the valuation method used and how these relate to the scale of the proposed management action.

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Avoid unnecessary complexity

Initially, simpler scenarios of ecosystem change, and more straightforward models, will help researchers and stakeholders develop familiarity and expertise in ecosystem service valuation. Keeping complexity to a minimum will also help to mitigate uncertainty, and generate more robust outputs. Initial valuation efforts should focus on direct relationships between management action and changes in ecosystems, ecosystem services and values. As VALMER valuations better quantify ecosystem service values (and changes in values), it will become clear where a better understanding of complexity may be needed.

Create new primary data

Empirical studies are essential for the continued improvement of the ecosystem service valuation discipline as a whole. Where socio-economic data is unavailable for a case study site, the aim should be to create new data rather than applying benefits transfer. Data that already exists from similar sites and situations may have some value nonetheless, in providing an indication of likely empirical results and directing specific data collection needs.

Address natural science issues

Natural scientists do not fully understand the complex linkages between ecological processes and the ecosystem services they generate, or the impact that management actions will have on processes and services. These data gaps restrict what can be attempted in terms of ecosystem service assessment, valuation and management. Biophysical modelling is therefore an important area of work on which to focus. Data gaps also arise due to the traditional separation of the relevant disciplines: natural scientist concentrate on functions and processes, while economists and other social scientists focus on people, with minimal overlap. This needs to be addressed if ecosystem service valuation is to become truly interdisciplinary.

Make knowledge gaps and uncertainty explicit

In order to avoid too much additional research in ecology or economics, the focus should not be on accuracy of data in each field but on developing data that are appropriate for integrated assessment: coupled biophysical and human models have the potential to be useful tools in this process. Another way to overcome the lack of knowledge is to follow an iterative process between the global under-standing of ES and the focus on key ecological processes or social issues. Face-to-face discussions involving natural and social scientists during which the specific ES are discussed from both the eco-logical and economic perspectives are useful in improving mutual understanding, exploring linkages and identifying data gaps. Where significant uncertainty remains, assumptions made and confidence assessments should be included as an integral part of the ES valuation outputs.

Be aware of context dependency

Economists understand that benefit transfer methods must be undertaken with caution, but may have less appreciation of the context dependency of ecological patterns and processes. However, the same procedures for data transposition apply. Where natural science data is not available for a case study site, any attempt to use natural science data from another area should only be undertaken after careful consideration of the biogeochemical parameters of both the case study site and the area from which the data was obtained.

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4.2. Description of the TAPAS operational framework

The aim of step 1 is to set the frame for the ES assessment by identifying relevant stakeholders to cooperate with, defining the purpose of the assessment, delineating the spatial scope and decide on the changes to be taken into consideration. Step 2 can be considered as screening of affected ES given the changes to be considered as agreed on in step 1. The aim is to find out where the largest impacts on ES can be expected and if it necessary to do an assessment of all ES affected or limit the assessment to the most important ones. This information can guide the decision in step 3 on which metrics, methods and tools should be used for the assessment. Step 4 consists of the assessment itself and is split in an analysis of the biogeochemical impacts in the ecosystem and the valuation. Step 5 deals with the communication of methods, results and uncertainties to different stakeholder groups. The guiding questions relating to each step are in more detailed described in the following.

4.2.1 Step 1: Definition of scope and aims of ES assessment under stakeholder involvement

Q1 What are relevant stakeholders?

This first questions aims to identify key stakeholder, which are relevant for our problem. Basically all people interested in the issue are stakeholders. In practice this group may be too large to work with, so it can be necessary to split them into subgroups. Such groups may national officials developing policies, local environmental organizations running awareness campaigns or aquaculture business in the area. For working in partnership it must be judged from case to case if it makes more sense to have meetings including representatives from all stakeholder groups (e.g. when the aim is to find a consensus) or if the groups should be met separately (e.g. when we need to find out the interests of each group). However, all stakeholders should be given the opportunity to inform themselves about the assessment process. (see also below Step 5, Communications with stakeholders)

Q2 What is the purpose of the assessment: informative, decisive, technical use?

This question relates to the operational needs of the stakeholders who envisage using a marine ES assessment. Following the classification by Laurans et al. 2013, three types of purposes for ES assessment can be distinguished: 1) informative uses, 2) decisive uses and 3) technical uses. Examples of informative uses include: to improve and integrate knowledge about the benefits to society derived from ecosystems, to explore possible changes in the ecosystems due to human or other pressures, to provide initial diagnosis for marine management, to raise awareness of particularly issues or of the value of the marine environment more generally. Examples of decisive uses include: to compare operational management options, to facilitate trade-offs, and to search ways for increasing welfare of concerned populations. Examples of technical use include: to design a new marine and coastal policy, to design management options, to assess different aquaculture farming practices, to generate the background data for the development of market-based instruments (e.g. taxes. Charges, fees, subsidies, incentives) Tinch & Mathieu 2011, Mongruel et al. 2015.

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In this stage it should be openly discussed with the stakeholders if an ES assessment approach is the appropriate method to reach their target or if other methods should be used instead or in addition.

Q3 What kind of changes will be assessed and what are the most important changes?

As mentioned before ES assessments are used to compare two or more different situations. These different situations can arise due to changes in policy (e.g. other regulations for aquaculture business), changes in farming practices (e.g. multi-trophic farming instead of cultivating single species), changes in global natural conditions (e.g. climate change), changes in local natural conditions (e.g. changes in water quality due to other factors than aquaculture). It is important to determine what kind of changes should be assessed and if it makes eventually sense to assess several changes in combination (e.g. climate change und changes in farming practices). When several change scenarios should be assessed and there is a danger that this will exceed the available budget, a prioritizing should be made. This can be done by either asking the stakeholders to give a score (high, moderate, low priority) as suggested by Mongruel et al. (2015) or by trying to roughly estimate what change would probably have the largest impact on ES.

Q4 What is the spatial scope and scale of the assessment?

This questions aims to come to a demarcation of the ES assessment in time (time horizon to be considered) and space (geographic demarcation). It must be determined what ecosystems will be affected by the changes taken into consideration.

4.2.2 Step 2: Identify and map services to be assessed under consideration expected changes

Q5 Which ES do we expect to be affected by these changes?

Given certain changes this questions aims to identify which ES will probably be affected. This information can be determined by screening literature and talking to experts and stakeholders.

Q6 For which ES do we expect the largest impacts on ES functions and values?

After identifying affected ES we are interested in getting a good "guesstimate" for which ES functions and values we probably expect the largest impacts. We must consider both the ES functions as well as the value sphere as not only large changes in ES functions will lead to large impacts. Also small changes in functions of an ES with a high value can lead to large impacts. At this stage it would be enough if estimates are based on expert knowledge.

Q7 For which ES do we assess the impacts? For all or only the most important ones??

A complete ES assessment aims to assess the total economic values of an ecosystem by summing up all positive and negative impacts on affected ES. This is often a very resource intensive process and resource constraints can make it necessary to limit the assessment to the most important ES. Here the information from Q6 can be used to come up with a ranking of the importance of affected ES. Then the ES assessment should start with the most important one. Stakeholders should be involved in this process as the also none-quantifiable ES may be of high importance for them and should not be overlooked.

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4.2.3 Step 3: Choice of metrics, methods, tools and means

Q8 What are meaningful metrics or indicators to assess ES impacts?

Ecosystem service indicators should be developed to meet the needs of the end users.

It is therefore strongly recommended that all relevant stakeholders are consulted as early in the indicator development/selection process as possible (Brown et al. 2014). The process of finding meaningful indicators and metrics can be to develop new ones adapted to our case, or maybe more likely be a process of selecting relevant indicators from indicators used in other assessments. There are several guidelines and papers on how to develop indicators (e.g Brown et al. 2014) and there are several sources where lists of already defined indicators are provided (see section 3.2.4).

In the context of the TAPAS project we suggest that the first step is to develop a list of indicators for the various segments of aquaculture described in section 2.1.2. This implies that we will make lists of indicators for both marine, brackish and freshwaters. In the classification system of CICES/MAES (Maes et al. 2014, 2016) there are also indicators suggested for terrestrial agro-ecosystems such as grass land and croplands, and some of these indicators might also have relevance in the context of aquaculture.

For each case study, indicators can be selected from these list by the study site team together with end-users and stakeholders

Q9 Is it necessary to perform a valuation?

Valuation is the last step in ES assessment. Its aim is to convert all impacts on different ES into the same unit, usually a monetary metrics, to make them better comparable and allow for summation (e.g. positive versus negative impacts). Converting the impacts on ES in value units is not free from criticism (CIT) as the results depend on the chosen valuation method and thus add uncertainty to them. So, "deciding whether valuation is what is needed to answer the management question (and how results can and should be used) should be a joint process between the decision maker and those undertaking the valuation, and should include a written agreement to detail the requirements and expectations of both parties" [Mongruel, 2015 #653].

Valuation is essential, when the results will be used in a cost-benefit analysis. It is non-essential when the results should e.g. support decision on biodiversity conservation measures. In this case it is more useful to look at biological or ecological indicators representing e.g. biodiversity targets.

Q10 Which methods and tools can be used for valuation?

There are different methods and tools in the literature to value the ecosystem services which have been widely applied to the marine ecosystem services valuation. These methods include market technique methodology, non-market valuation, appraisal methods and the methods that combines socio-ecological sides such as system dynamic models, Bayesian belief networks and

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INVEST program. We will describe the basic idea of each method in this section and then provide a table which illustrates which methods and tools could be used for evaluating which type of ecosystem services.

Market-based techniques

Market-based prices

Some environmental goods and services are traded in the market, either as input in the production of goods and services, or as substitutes or alternative resources. As a result, the market gives the goods and services a price. The price reflects the resource costs, and the balance between supply and demand. The market does not necessarily consider all the costs and benefits of the traded goods and services. Market-based techniques use the market-based prices, and governments usually correct market distortions by implementing a tax or subsidy. It is necessary to estimate both the demand and supply curve when using market-based techniques. (UNEP-WCMC, 2011)

Production functions

This method is a tool to find out "how changes in some ecosystem function affect production of another good or service which is a traded resource, or which can be valued using another technique" (UNEP-WCMC, 2011). Scientific data or knowledge is necessary to estimate the production function. The data collection process can be demanding.

Avoided costs

The avoided costs technique estimates the costs incurred if the ecosystem services are no longer available. As an example, the method is used to value wetlands flood protection, by estimating the costs of damages on buildings and infrastructure if a flood occurs without the protection from wetlands (UNEP-WCMC, 2011).

Replacement costs

The replacement costs methods estimate the cost of replacing an ecosystem function by human-engineered alternatives (UNEP-WCMC, 2011). For example, replacement costs are the costs of building purification facilities to replace wetlands.

Expenditure measures

Both locals and tourists can enjoy some recreational activities supported by the ecosystems. Magnificent waterfalls, wild nature in national parks, surfing, snorkeling, fishing and hunting are some of the sought ecosystem services. As a result, local communities may benefit from tourism, as it enables additional jobs such as equipment rentals and guides. In addition, "direct expenditure will lead to additional indirect spending" (UNEP-WCMC, 2011). The whole economy in the area benefits from these recreational activities. The reason why exactly this area is attractive can be a combination of different characteristics of the area. Expenditure measures cannot be used as an only tool to estimate the value of the ecosystem services, but can be an important decision making tool.

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Revealed preference techniques

Travel costs

The travel cost method is based on the actual behavior of people. ”It is used to value the recreational benefits of environmental resources such as forests, national parks, wildlife reserves, and sites offering fishing and hunting opportunities.” (Perman et al., 2011)

Using the travel cost method, questions to be asked are;

- How far do people travel to experience recreational activities?
- How often do people travel to experience them?

With this knowledge, you can estimate the value based on costs and time of traveling.

Hedonic prices

The hedonic price method is commonly used technique to estimate the value of certain environmental characteristics. Hedonic prices can be used on properties and on wages. To estimate the value, one compares houses with identical specifications except for the location. The value of the environmental characteristics is the difference in housing prices with regards to location.

Random utility model

The random utility model is a type of revealed preferences. It assumes that an individual is utility maximizing. By looking at the individual repeated choices, the random utility model can estimate the value for various characteristics. This is a model that is widely used to estimate the value of recreational fishing, because it reveals the preferences the individual has when it comes to weather, type of fish, water quality, the number of fish caught and fish size. It can also be used to estimate the value of other recreational activities.

Stated preferences

Contingent valuation

Contingent valuation uses surveys to ask “a representative sample of the population about their willingness to pay (WTP) and willingness to accept (WTA) for ecosystem services” (Perman et al., 2011). This method can estimate both use values and non-use values, which is a huge advantage. A disadvantage with this method is that people tends to overestimate their WTP.

Choice experiment

Choice experiment attempts to model the preference of individuals via revealed or stated preference on several different scenarios. The method also involves survey which presents different alternatives with detailed gain and costs for each alternatives. The respondents of the survey shall elect their desired alternative and their preference then will be compiled and integrated (Perman et al., 2011).

Value transfer

“Value transfer means using information regarding economic value from one site as a proxy estimate for economic value in another site.” (UNEP-WCMC, 2011)

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There are mainly two ways to transfer value, unit transfer and value function transfer. An estimated value from one location, applied directly on another location, is called unit transfer (UNEP-WCMC, 2011). Generally, the estimated value consists of several characteristics, each of which has its value. As locations rarely are exactly like, it would be better estimation if we make use of the characteristics that location holds. Value function transfer assumes different characteristics affect the value of the two sites in a mirrored way and thereafter projects the potential value for the new location based on the characteristics of the new site.

Appraisal methods

Cost benefit analysis

A cost-benefit analysis compares benefits and costs of a project (or option). It usually involves comparison between alternatives. In principle we should include all the relevant costs and benefits in the calculation. Non-monetary costs and benefits should be converted to monetary term to be used in the calculation. The alternative with the highest net benefit should be the preferred alternative. This is a commonly used method in health economics and in public infrastructure development. In environmental economics, lots of focus has been shifted to social cost and benefits analysis.

Cost effectiveness analysis

Cost-effectiveness analysis seeks to find the alternative which is the most cost-efficient to produce a specific outcome. It has been widely used in evaluating measures to change the environmental quality and ecosystem services. A cost-effectiveness ratio or effectiveness-cost ratio is being used. The most cost effective measures will usually be chosen. The method usually applies when the benefit side is difficult to evaluate. The drawback for this method lies in the same part that it does not consider the benefit side of the measures.

Multi-criteria analysis

Multi-criteria analysis is a collective term for analyses using criteria to evaluate different options (UNEP-WCMC, 2011). The criteria are weighted or ranked, according to their importance. Each option is evaluated against the criteria. Then one score is summed up for each option. The option with highest score is the preferred option. Thus, multi-criteria analysis is a useful tool for decision making.

Ecosystem accounting

Ecosystem accounting is a “coherent and integrated approach to assess the environment through the measurement of ecosystems and the flows of services from ecosystems into economic and other human activity.” (UN SEEA, 2014). The approach goes beyond ecosystem analysis by linking the ecosystems to economic and other human activities.

Ecosystem accounting includes the contribution of ecosystems to standard measures of economic activity, such as gross domestic product (GDP) and national income as well as assessment of ecosystems services that are commonly unpriced and not considered in national-level economic reporting and analysis (UN SEEA, 2014). Ecosystem accounting assesses both expected ecosystem service flows and changes in ecosystem assets. Ecosystem assets are assessed in both physical terms and monetary term (Gundersen et al. 2016, Mongruel et al 2015).

Cross methods

Bayesian belief networks

The Bayesian belief network model is “a graphical model that incorporates probabilistic relationships among variables of interest” (Heckerman, 1997). The variables can be directly linked or indirectly linked through other variables. “When a Bayesian belief network model is compiled, results are therefore presented in the form of probability distributions rather than single values” (Newton, 2009). Therefore, this type of modeling is suited to get an overview over complex relationships, such as in the case of ecosystem along with how ecosystem may be affected according to the probability of occurrence of different situations.

System dynamic modelling

System dynamic modelling examines the interactions between different variables in a system. Ecosystems are known to be complex. If one variable changes, it can have a huge effect on other variables in the ecosystem and henceforth ecosystem services. (Mongruel et al. 2015). The latest development in the modelling regime has tried to couple the natural science models with socioeconomic model thus provides a more integrated analysis of a dynamic natural-social system.

Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)

“InVEST is a suite of software models used to map and value the goods and services, which has been developed by the Natural Capital Project at the Stanford University” (Mongruel et al. 2015). “InVest uses maps as information sources, and return results in either biophysical terms or economic terms” (Natural Capital Project, n.d.). InVEST is suitable to estimate changes in ecosystems and its related value, since it is based on production functions for ecosystems (Natural Capital Project, n.d.).

Q11 Is the envisaged method feasible considering available resources, knowledge, time constraints and data access?

Once you have decided on metrics, methods and tools to be used, you should ask yourself if the use of these is feasible given your available budget, knowledge and manpower, data access and eventual time constraints. Primary data collection is always more resource consuming than the use of secondary data sets, but trade-offs are also possible in terms of accuracy and uncertainty or by taking only into account the most important ES. If the chosen methods are not feasible it must be decided on alternative methods and tools.

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4.2.4 Step 4: ES assessment chain

Q12 How large are the impacts on biophysical processes, ecosystem functions and ES?

After defining the scope and frame of assessment and selecting appropriate methods for ES assessment, the actual assessment of ES can begin. An ES assessment usually follows an assessment chain as illustrated in Figure 6. Following the TAPAS operational framework we already determined what kind of changes we will consider (Q3) and what kind of ES will be assess (Q7). In all parts of the chain, we should quantify the changes as far as possible and feasible with the methods we decided to use. Not or difficulty quantifiable impacts should be described qualitatively.

The first chain link is to quantify the changes in the system we expect and classified as being important (Q3). In the next two boxes the impacts on ES are quantified by determining the changes in ecosystem functions. Often an impact on final ES (i.e. ES of direct use for humans) is preceded by a change in intermediate ES (i.e. supporting or some regulating services). Depending on the scope of the assessment for this step ecosystem models can be used (e.g. Atlantis) and a valuation step can be added (see Q14) or ES assessment models (e.g. InVEST, ARIES) covering the ecosystems of relevance are applicable (for a comparison of models see Bagstad et al. 2013).

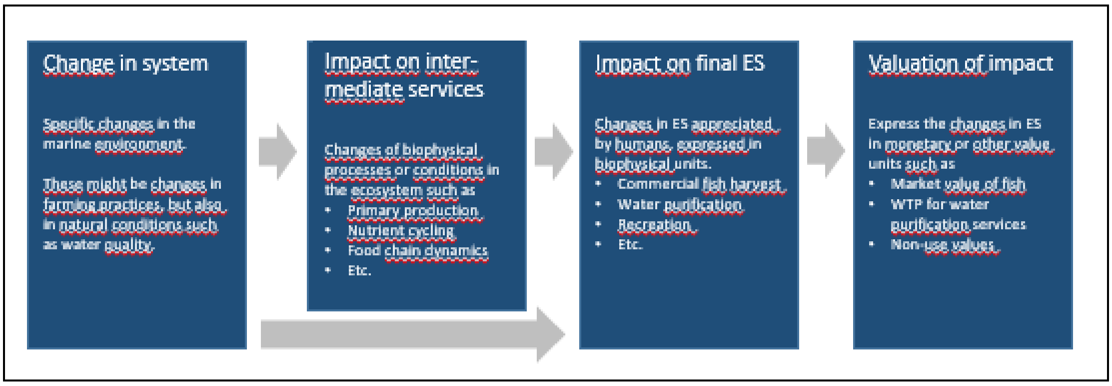

Figure 6 ES assessment chain, source: UNEP-WCMC, 2011 adapted

Q13 Are there any not quantifiable impacts of importance?

If there are any impacts on ES, which are considered to be important by the stakeholders, but are not quantifiable (e.g. cultural services), these ES should be described in qualitative terms.

Q14 If needed: Perform a valuation of ES.

When it was decided that a valuation step is necessary (Q9) and which methods to use (Q10&Q11) a valuation of the ES impacts should be done.

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4.2.5 Step5: Communication of outputs to stakeholders

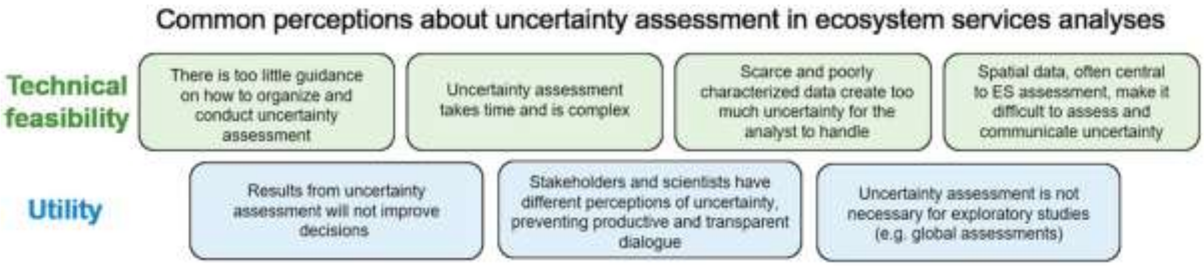
The importance of stakeholder involvement is already addressed several places in this document. This section is focusing on the communication of outputs to stakeholders

Q15 What means of communication should we use for different stakeholder groups?

At this stage it is not possible to describe the means of communication that will be used in TAPAS. For the TAPAS framework we will develop some guidelines on how to approach the stakeholder communication that could eg include topics such as how to develop a stakeholder involvement plans.

Q16 How do we communicate the uncertainty inherent to the ES assessment?

There is uncertainty inherent to ES assessments related to the complexity of the natural system, respondents' preferences and technical problems play essential roles (e.g. Hou et al. 2013). Some authors have pointed out that ecosystem services (ES) analyses are increasingly used to address societal challenges, but too often are not accompanied by uncertainty assessment (see review Hamel & Bryant 2017). Although some ES assessments have a theoretical focus, most studies are conducted with some claim to decision-relevance. In a recent survey, Nahuelhual et al. (2015) report that 82% of ecosystem service mapping studies cite a decision-making purpose. Omitting the communication of uncertainties could lead to overlooking important management possibilities, thus providing misleading decision-support information (Grêt-Regamay et al. 2013, Jacobs et al. 2013). The lack of uncertainty assessments may have several reasons (Figure 7). According to Hamel & Bryant (2017) some analysts maintain that uncertainty assessment will not be well-received by decision makers and stakeholders, for two distinct reasons: i) decision makers and stakeholders don't care about the nuances "they just want to know the answer" or ii) honest presentation of uncertainty is challenging since stakeholders come from widely varying backgrounds and may interpret the implications of uncertainty differently, and even "overreact" to the prevalence of uncertainty and erroneously discount even the legitimate finding.



There is too little guidance on how to organize and conduct uncertainty assessment

Uncertainty assessment takes time and is complex

Scarce and poorly characterized data create too much uncertainty for the analyst to handle

Spatial data, often central to ES assessment, make it difficult to assess and communicate uncertainty

Results from uncertainty assessment will not improve decisions

Stakeholders and scientists have different perceptions of uncertainty, preventing productive and transparent dialogue

Uncertainty assessment is not necessary for exploratory studies (e.g. global assessments)

Figure 7 Graphic summary of Hamel & Bryant (2017)'s study on uncertainty assessments

In their paper "Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions" Ruckelhouse et al. (2015) conclude that communicating uncertainty in useful and transparent ways remains challenging, but highly recommend to clearly and honestly report the degree of uncertainty.

This is a very important issue that must be addressed in the TAPAS framework, however, at this stage we cannot describe how uncertainty will be dealt with and communicated in the TAPAS framework and this will be an area for open discussions.

4.3. Sources of data

The final TAPAS framework should have a list with links to data sources from European aquaculture producing countries (see also see sub-chapter Q11).

4.4 Glossary -terms and definitions

The final TAPAS framework will include a glossary with terms and definitions.

5. Assessment of the impacts on ES imposed by different segments of European Aquaculture

This section is a starting point for listing the ES impacted by the various segments of European Aquaculture (see figure 1). At this stage no attempt has been done summarize the potential impacts on ES in a coherent way. Therefore, there might be some differences in how the ES and impacts are described for the different segments. There might also be differences between descriptions in this section and descriptions used in Table 6.

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5.1 ESS and marine cage aquaculture

Marine cage aquaculture (intensive)

The fish are kept in cages anchored to the seabed and maintained on the surface by means of a floating framework. This form of aquaculture is practiced both in sheltered and more exposed zones near shore, but more sophisticated techniques (submersible cages, remote monitoring, automatic feeding, etc.) may make it possible to move further from shore.

Examples – Atlantic salmon, sea perch, sea bream, meagre, tuna, etc

Countries: UK, Ireland, Spain, Greece, Malta, Turkey, Croatia, Denmark

5.1.1. Which habitats and ecosystems might be affected by the farming?

Marine habitats such as pelagic water column, littoral rock and other hard substrate, littoral sediment, infralittoral rock and other hard substrate, circalittoral rock and other hard substrate, sublittoral sediments, deep-sea bed (e.g. Norwegian fjords), seabirds communities, Coastal habitats characterized by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliff, strandlines characterized by terrestrial invertebrates and moist and wet coastal dune slacks and dune-slack pools.

5.2.1. Which ecosystem services might be affected?

ES main category	ES sub category	Description of changes in ES
Provisioning	Food provision	Harvest of fish biomass from in-situ aquaculture
	Water storage and provision	
	Biotic materials and biofuels	
Regulating	Water purification	
	Air quality regulation	
	Coastal protection	Protection of coastlines from storm surges and waves
	Climate regulation	
	Weather regulation	
	Biological regulation and pest control	Escape of farmed fish

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Cultural	Symbolic and aesthetic value	Both an enhancement as well as a degradation of aesthetic values and the attractiveness for tourists are possible
	Recreation and tourism	Both an enhancement as well as a degradation of aesthetic values and the attractiveness for tourists are possible)
	Cognitive effects	Educational
Supporting	Biodiversity & Habitat provision	Increase local biodiversity because marine cages may function as “artificial reefs” attracting various organism (e.g. birds and fish). Decrease local biodiversity by waste release (e.g reduced benthic biodiversity, smothering of sea grass beds and corals)
	Nutrient cycling	
	Life cycle maintenance habitat and gene pool protection	

5.2 ESS and marine shellfish aquaculture

Shellfish farming (extensive)

Shellfish farming is based either on the collection of wild spat or hatchery spat, which feed on nutrients provided by environment (filter-feeding animals) . Oyster and mussel farming use a wide range of techniques: bottom-farming, on tables, wooden posts, ropes, etc.

Examples – Oysters, mussels, clams and abalones

Countries: UK, Ireland, Netherlands, Germany, France, Italy, Greece, Spain, Portugal, Cyprus, Bulgaria, Sweden, Denmark

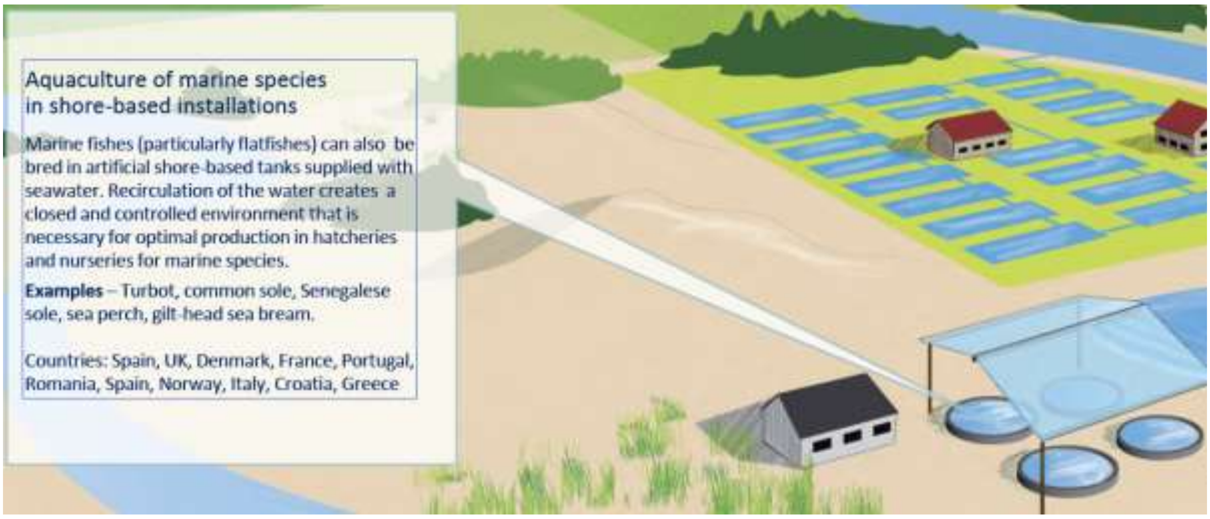
5.2.1. Which habitats and ecosystems might be affected by the farming?

Marine habitats such pelagic water column, littoral rock and other hard substrate, littoral sediment, infralittoral rock and other hard substrate, circalittoral rock and other hard substrate, sublittoral sediments, seabirds communities. Coastal habitats characterized by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliff, strandlines characterised by terrestrial invertebrates and moist and wet coastal dune slacks and dune-slack pools.

5.2.2. Which ecosystem services might be affected?

ES main category	ES sub category	Description of changes in ES
Provisioning	Food provision	Harvest of mussel biomass from in-situ aquaculture
	Water storage and provision	Not relevant
	Biotic materials and biofuels	Harvest of Non-food products such as oil and meal for industrial production of animal feeds. Harvest of fertilizer and building materials (lime) Harvest of materials for Jewelry and other decoration (shells, pearls)
Regulating	Water purification	Shellfish filter sea water: Water quality maintenance (Reduce turbidity, Denitrification, Bacterial biomass removal)
	Air quality regulation	Not relevant
	Coastal protection	Protection of coastlines from storm surges and waves
	Climate regulation	Not relevant
	Micro climate regulation	
	Biological regulation and pest control	Control of fish pathogens, biological control on the spread of water born human diseases
Cultural	Symbolic and aesthetic value	Both an enhancement as well as a degradation of aesthetic values and the attractiveness
	Recreation and tourism	Both an enhancement as well as a degradation of aesthetic values and the attractiveness for tourists are possible
	Cognitive effects	
Supporting	Biodiversity & Habitat provision	Increase local biodiversity because: Shellfish farm may function as “artificial reefs” attracting various organism (e.g. birds and fish). Provide three-dimensional habitats in soft bottom areas Provide substrate/habitat for marine invertebrates
	Nutrient cycling	Benthic-pelagic coupling
	Life cycle maintenance	Nursery habitat

5.3 ESS and aquaculture of marine species in shore based installations



Aquaculture of marine species in shore-based installations

Marine fishes (particularly flatfishes) can also be bred in artificial shore-based tanks supplied with seawater. Recirculation of the water creates a closed and controlled environment that is necessary for optimal production in hatcheries and nurseries for marine species.

Examples – Turbot, common sole, Senegalese sole, sea perch, gilt-head sea bream.

Countries: Spain, UK, Denmark, France, Portugal, Romania, Spain, Norway, Italy, Croatia, Greece

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5.3.1. Which habitats and ecosystems might be affected by the farming?

Depending on where the outlet is put, but might include marine habitats such pelagic water column, littoral rock and other hard substrate, littoral sediment, infralittoral rock and other hard substrate, circalittoral rock and other hard substrate, sublittoral sediments, (sea)birds communities. Coastal habitats characterized by their proximity to the sea, including coastal dunes and wooded coastal dunes, beaches and cliff, strandlines characterised by terrestrial invertebrates and moist and wet coastal dune slacks and dune-slack pools.

5.3.2. Which ecosystem services might be affected?

ES main category	**ES sub category**	**Description**
Provisioning	Food provision	Harvest of farmed species
	Water storage and provision	Even though farming needs salt seawater, the amount of needed is marginal compare to seawater availability. So the ecosystem services will not be affected significantly by the farming practice.
	Biotic materials and biofuels	
Regulating	Water purification	
	Air quality regulation	
	Coastal protection	
	Climate regulation	
	Weather regulation	
	Biological regulation and pest control	Escape of farmed fish
Cultural	Symbolic and aesthetic value	Aesthetic value mainly onshore and the pipeline for transportation of seawater will be affected by the infrastructure
	Recreation and tourism	Recreational value will be improved if angling or the other activities such fish watching is developed in the regions
	Cognitive effects	Educational
Supporting	Biodiversity & Habitat provision	Not relevant.
	Nutrient cycling	Not relevant
	Life cycle maintenance	Not relevant

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5.4 ESS and extensive brackish water aquaculture

Extensive brackish water aquaculture

The animals (often brought in by the marine flow) are kept in lagoons developed for this purpose (ex.: Italian valliculture, Spanish esteros). The semi-extensive nature of this breeding is reinforced by introducing hatchery fry and providing additional feed. This type of aquaculture plays an important role in conservation of the natural coastal heritage.

Examples – Sea perch, eel, common sole, Senegalese sole, sea bream, mullet, sturgeon, shrimps and shellfish.

Countries: Spain, Italy, Portugal, Cyprus

5.4.1. Which habitats and ecosystems might be affected by the farming?

Coastal wetlands, adjacent coastal areas when the water is not recycled, tidal areas, fully submerged zones.

5.4.2. Which ecosystem services might be affected?

ES main category	ES sub category	Description of changes in ES
Provisioning	Food provision	The aquaculture production can be increased by farming practices (i.e. by adding fish fodder, fertilizing primary production, introducing hatchery fry), but this often happens for a trade-off with other services i.e. regulating services.
	Water storage and provision	If fresh- or saltwater is extracted to be used in artificial brackish water ponds, this service is reduced.
	Biotic materials and biofuels	In principle also non-food products may be grown in brackish water aquaculture, such as seaweed. And shells from shellfish might be used for other purposes too e.g. ornamental use.
Regulating	Water purification	Brackish wetlands are able to absorb nutrients from land-based runoff, but also nutrients excreted by farmed fish. The degree of absorption can be increased by aquaculture, but depends on the species farmed and on farming practices. E.g. Shellfish such as mussels filter the sea water and help to reduce turbidity, contribute to denitrification and can remove bacterial biomass.
	Air quality regulation	
	Coastal protection	Shellfish can stabilize the seashore.
	Climate regulation	CO_2 binding by shellfish and water plants. Amount of CO_2 uptakes depends on species and farming practices. But in comparison with other systems brackish water aquaculture must be considered only a weak carbon sink.

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	Weather regulation	Local change in microclimate if artificial brackish water ponds are created or wetlands are restored by the aquaculture activity.
	Biological regulation and pest control	Escape of farmed species, can disrupt wild ecosystems.
Cultural	Symbolic and aesthetic value	Both an enhancement as well as a degradation of aesthetic values and the attractiveness are possible, depending on the type of farming.
	Recreation and tourism	Both an enhancement as well as a degradation of recreational values are possible dependent in the type of farming. If managed extensive or semi-intensive systems of brackish water aquaculture are able to increase wetlands biodiversity and e.g. attract additional bird species (e.g. Veta La Palma, SW Spain).
	Cognitive effects	Probably most relevant for the local community, but might also be exploited by a broader public e.g. when creating a nature center next to a sustainable driven brackish water aquaculture facility.
Supporting	Biodiversity & Habitat provision	Extensive and semi-intensive systems may attract birds due to the additional fish available and thus improve the local habitat for them and increase birds biodiversity. Intensive systems may have the opposite effect. Farmed shellfish may increase 3-dimensional habitat provided.
	Nutrient cycling	Decrease in increase of nutrient load to the ecosystem by brackish water aquaculture is possible.
	Life cycle maintenance	Habitat provisioning for mobile fish, invertebrate and epibenthic fauna. Diversification of landscape (synergies among habitats). Both positively impacted by shellfish aquaculture. Brackish wetlands also provide a habitat for lots of bird species, such as ducks, waders, gooses and flamingo's

5.5 ESS and extensive and intensive freshwater culture

Intensive fresh water aquaculture

In intensive systems, fish are bred in tanks until they reach marketable size, or they reach a size where they are transferred to other systems such as cages. There are two techniques: continuous flow (river water enters tanks upstream and leaves downstream) and recirculation
(the water remains in a closed circuit and is recycled and 'recirculated' in the tanks). There is also cage aquaculture.

Examples – Rainbow trout, Atlantic salmon, eel, catfish, sturgeon, tilapia, etc.

Countries: UK, Ireland, Czech Republic, Norway, Denmark, Bulgaria, Estonia, Spain, Croatia, Italy, Cyprus, Lithuania, Hungary, Poland, Portugal, Romania, Slovakia, Finland, Sweden,

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Extensive fresh water aquaculture

Ponds are maintained in such a way as to promote the development of aquatic fauna at a yield greater than that found in the natural ecosystem. Density is low and fish feed naturally. Certain producers provide additional feed. These ponds play an important and positive role in the landscape, water management and biodiversity.

Examples – Carp, in monoculture or mixed farming with other species (whitefish, zander, pike, catfish, etc.).

Countries: Czech Republic, Hungray, Bulgaria, Lithuania, Austria, Slovakia, Turkey, UK

5.5.1 Which habitats and ecosystems might be affected by the farming?

Freshwater aquatic systems that are providing or receiving water from intensive tank systems. These are ponds, (artificial) lakes, rivers or streams. Adjacent terrestrial ecosystems and wetlands might also be also affected e.g. by influx of water of changed quality (e.g. elevated nutrient levels). Recirculation systems with proper water treatment are not expected to have any impacts on ecosystems as the water is circuited. In continuous flow systems farming practices (extensive or intensive) will affect the conditions in the system itself, but also downstream. In the following we therefore only considered continuous flow systems.

5.5.2 Which ecosystem services might be affected?

ES main category	ES sub category	Description of changes in ES
Provisioning	Food provision	In intensive aquaculture production the production of fish is increased by optimizing the living conditions for them e.g. by adding additional fodder or pharmaceuticals. If the fish fodder is not consumed completely in the aquaculture system, also an increase in fish biomass can be expected downstream from the facility.
	Water storage and provision	When creating more ponds or dammed lakes, flood peaks could be flattened out by temporarily storing water in them.
	Biotic materials and biofuels	In principle also non-food products may be grown in intensive freshwater aquaculture.
Regulating	Water purification	Water quality downstream the aquaculture facility will be influenced by the farming activity. Depending on farming practices an increase or decrease of nutrients and organic matter (from fish fodder but also from fish excreta) can be expected [Gál, 2016 #673].
	Air quality regulation	

	Coastal protection	
	Climate regulation	Nutrient inputs into the system can enhance algal growth and thus increase the CO2 uptake.
	Weather regulation	Local change in microclimate if artificial ponds are created or wetlands are restored by the aquaculture activity.
	Biological regulation and pest control	Escape of farmed species, can disrupt wild ecosystems.
Cultural	Symbolic and aesthetic value	Both an enhancement as well as a degradation of aesthetic values and the attractiveness are possible dependent in the type of farming.
	Recreation and tourism	Both an enhancement as well as a degradation of aesthetic values and the attractiveness for tourists are possible. Farm might e.g. attract tourists for fishing.
	Cognitive effects	Probably most relevant for the local community, but might also be exploited by a broader public e.g. when creating a nature center or when the facility is linked to some cultural heritage sites.
Supporting	Biodiversity & Habitat provision	Surrounding ecosystem might be affected by feeding, e.g. by attracting birds. In downstream ecosystems changes in water quality might affect the biodiversity in these systems.
	Nutrient cycling	Decrease in increase of nutrient load to the downstream ecosystem is possible.
	Life cycle maintenance	Intensive freshwater aquaculture might serve as “nursery habitat” for fish that is afterwards released into other freshwater ponds.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 678396

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