HyMoCARES Project

WPT1. Ecosystem Services (ES) assessment framework

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CONTENTS

1 Introduction

This report presents the definitions and systematics of ecosystem services (ES) developed in the HyMoCARES project on the basis of existing literature and results of previous EU and national projects. The report is a precondition to elaborate output T.1.1 “HyMoCARES methodological framework for the assessment of Ecosystem Services provided by Alpine rivers”.

This report outlines the HyMoCARES perspective on ES, which focuses on the ES that are supplied to significant extent by Alpine rivers, and explains and clarifies its development and specificities. After a short introduction to the ES concept, we present in brief the state of the art based on the literature analyzed for this report, a detailed list of ES with descriptions and the rationales of our definitions, followed by a summary on suitable data that may be used as indicators for the assessment of ES.

1.1 The ES concept

The ecosystem services are defined as "direct and indirect contribution made by ecosystems to human welfare" (TEEB, 2015). Many studies (e.g., TEEB, 2015; MEA, 2005; Costanza et al., 1997) have been conducted to provide information on these services, and to investigate how they connect ecosystems with society and the well-being of human populations (Haines-Young and Potschin, 2013). Historically ES have been divided in four groups: provisioning, regulating, cultural and supporting services (MEA, 2005). However, with this early definition of ES confusion may arise about the distinction of ecological processes and services that generate a benefit for humans (Haines-Young and Potschin, 2010).

The cascade model defined in Haines-Young and Potschin (2010) helps to clarify the concept (see Fig. 1). This model path flows from landscape structure or processes to function or capacities to services and finally to benefits. Thus, an ecosystem yields the potential to deliver a service, which is in turn defined only if it contributes to human well-being. In a management perspective, the services provided should be evaluated, but also the processes and functions which yield that service should be understood and considered in management practice. The ecosystem services concept enables to assess and predict the effects of policies and related management practices on resources provided by ecosystems, to quantify trade-offs among several services used by humans, and may be very suitable in communication processes and stakeholder analysis (Diehl et al., 2015). Recently, the concept has been increasingly included in the impact assessment of development plans and policies (Geneletti, 2013), thus requiring the development of quantitative predictive tools to assess ecosystem services, especially for the management of water resources (Grizzetti et al., 2016).

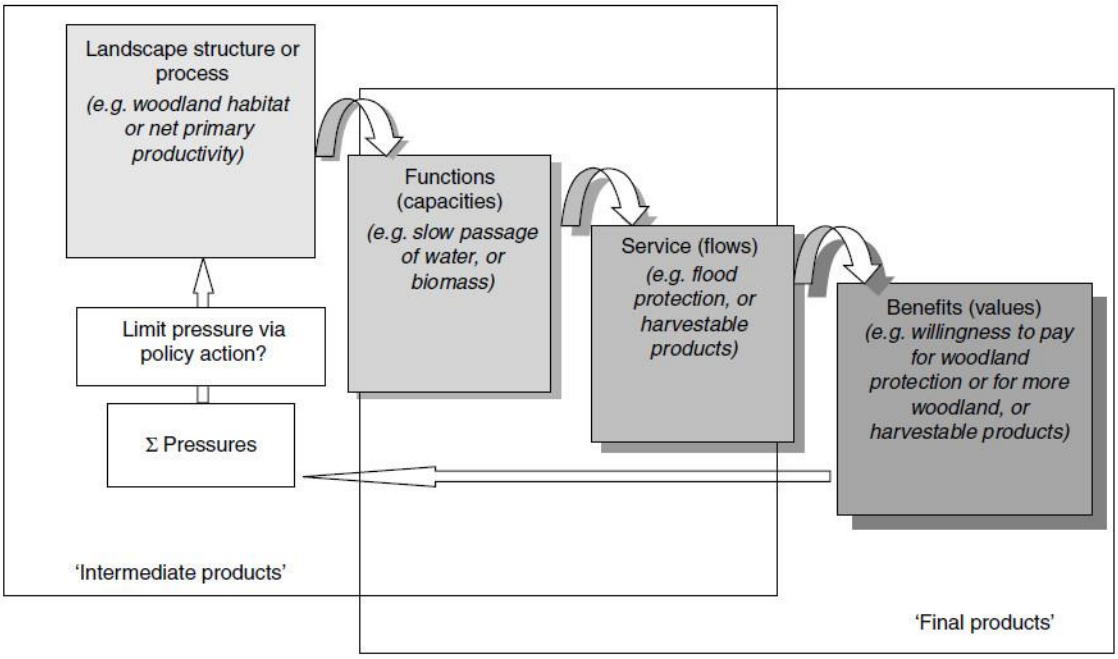

Fig. 1. Cascade model describing the relationship between biodiversity, ecosystem function and human well-being. From Haines and Potschin (2010).

So far, there is no published review available focusing specifically on ES provided by rivers and floodplains (cf. Posthumus et al. 2010). Hence, HyMoCARES needed to conduct a literature search on available case studies of rivers and floodplains, which are relatively few compared to terrestrial ecosystems. On the other hand, terrestrial approaches usually also include aquatic ecosystems (e.g. rivers) due to their extraordinarily high ES provisioning capacity, but they don't consider the specificities of aquatic and / or semi-terrestrial systems in an appropriate way, as the spatial scales, the temporal dynamics as well as the longitudinal and lateral connectivity that are particularly important in rivers and floodplains.

1.2 Literature analysis

In order to identify relevant ES in rivers and floodplains, several classification approaches were first compared and evaluated, whereby a comprehensive list of ES relevant to river corridors could be produced. Although approaches to the classification of individual ES groups are comparable, the assessment of the various ES provided an aquatic ecosystem presents the challenge, as approaches from several technical and functional domains have to be considered. This requires an analysis of various conceptual approaches for the identification of indicators and their data requirements. Since the Millennium Ecosystem Assessment (MA, 2005), the ES concept per se, the ES classification systems, the methods for recording as well as aspects of implementation have been continuously developed further. An approach of adapting the ES concept specifically according to the type of ecosystems and of a given study stands in contrast to the requirements for a more uniform design of studies (Crossman et al., 2013, Seppelt et al., 2012). These questions are currently also addressed in the international initiatives MAES (Mapping and Assessment of Ecosystems and their Services) and CICES (Common International Classification of Ecosystem Services), with the aim that future individual case studies on ES will be more comparable through a more uniform approach. Therefore, the studies prepared in this context serve as a starting point for the approach in HyMoCARES, in particular the currently ongoing EU project MARS (Managing Aquatic Ecosystems and Water Resources under Multiple Stress) (Grizzetti et al., 2015). Following the CICES classification, the REFORM project has produced a list of ES provided by rivers in different river types and at the different scales (Vermaat et al., 2013). The RESI “River Ecosystem Service Index” project (see Fig. 2) is a German national project funded by the government which aims to study ecosystem services provided by rivers and their floodplains and presents several interfaces with the first WP of HyMoCARES project.

Fig. 2. Illustration of the various ecosystem services provided by rivers and floodplains (source: G. Costea, IGB Berlin, modified after www.csir.co.za/nre/ecosystems/ProEcoServ.html).

The HyMoCARES approach considers rivers and floodplains a unit, i.e. as elements of a river corridor with temporally changing location of the river channel. Accordingly, both the aquatic and terrestrial ecological functions must be taken into account when determining the ES as well as the indicators. This means, for example, that both the products from fisheries and agriculture have to be considered in the resource supply module.

In the following a brief overview of the various classification systems based on Beichler et al. (2016a) is provided as well as a motivation of the HyMoCARES approach. Some of these studies presented in Tab. 1 are not focused on aquatic ecosystems, but they are pivotal for the ES concept and selection. Thereby, one of the most important and controversial point is the subdivision of the ES into the main groups "provision services", "regulatory services", "cultural services" and "supporting services", as was proposed in the Millenium Ecosystem Assessment (MA, 2005) and it has been already debated in several studies. In particular, the ES group "Supporting services" has been seen critically, because it describes the underlying characteristics of the ecosystem rather than the actually used ES. The other main groups are well-established and are also included in the standardized CICES classification (Haines-Young and Potschin, 2013): Provisioning Services, Regulating and Maintenance Services and Cultural Services. Compared to MA (2005), CICES does not include "supporting services" to avoid double counting.

The subdivisions into ES groups differ between these studies on the basis of the assignment within the main groups, and these are amended by introducing additional groups. For example, "Habitat" according to CICES is classified as an ES within the main group "Regulating and Maintenance", in other studies it is named as an own main group (de Groot et al., 2010; Posthumus et al., 2010; Scholz et al., 2012). Posthumus et al. (2010) supplemented the main group "carrier", where e.g. transport or the temporary intake of water has been considered as an ES. Burkhard et al. (2012) suggested the additional main group "integrity" which focuses on the status of the ecosystem: "*Ecological integrity means the preservation of non-specific ecological risks that are the general disturbances of the self-organizing capacity of ecological systems*". This main group "integrity" and contained ES (such as exergy, heterogeneity) has already been used in the context of floodplain ecosystems (Clerici et al., 2014). In CICES, a separate main group for services resulting from the use of abiotic material is proposed, since these are not related to processes in the ecosystem (Grizzetti et al., 2015, Haines-Young and Potschin, 2013). In this main group, for example, sunlight, mining products as well as renewable abiotic energy resources such as wind, waves and hydropower were classified.

A completely different approach to the classification of the main groups of ES, in particular with reference to peculiarities of aquatic systems has been described in Turner et al. (2008) with the groups hydrological services, biogeochemical services and ecological services. In the majority of the projects and studies, the cultural ES are taken over from the CICES classification (e.g., Grizzetti et al., 2015, Maes et al., 2014). More possible additions to CICES relating specifically to cultural ES, namely "Option, employment, material, social capital & cohesion" have been proposed by Bark et al., 2015.

Selected important properties of each considered study are summarized in Table 2, as the number of ES covered in the study, how the study classifies the supporting ES, if potential ES or actually used ES are considered. Since HyMoCARES focuses on hydromorphological management of river corridors, we also report how each study considers hydropower and navigation, which are two of the most relevant and severe human activities for river ecosystems, and which are often not considered as ES.

Tab. 1. Overview of the studies considered for the comparison of the ES classification (adapted from Beichler et al., 2016a).

Study reference	Title and project acronyms	Focus
CICES after Haines-Young & Potschin (2013)	Common International Classification of Ecosystem Services (CICES) Version 4.3.	International standardized ES classification
Bark et al. (2015)	Operationalizing the ecosystem services approach in water planning: a case study of indigenous cultural values from the Murray–Darling Basin, Australia.	Aquatic and semiaquatic, cultural ES from Chan et al. ,2012
Clerici et al. (2014)	Land-cover change dynamics and insights into ecosystem services in European stream riparian zones.	Aquatic and semiaquatic based on Burkhard et al. (2012)
de Groot et al.(2010)	Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making.	Extensive ES list
Egoh et al. (2012)	Indicators for mapping ecosystem services: a review	Extensive ES list
Grizzetti et al. (2015)	Cook-book for water ecosystem service assessment and valuation (MARS)	Extensive ES list, aquatic, semiaquatic
Haines-Young & Potschin (2014)	Typology/Classification of Ecosystem Services. (OpenNESS Ecosystem Services Reference Book, Vol. 2)	Extensive ES list comparison among MA, TEEB, CICES
Keeler et al. (2012)	Linking water quality and well-being for improved assessment and valuation of ecosystem services.	Aquatic
Liquete et al. (2013)	Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review.	Aquatic, semiaquatic
Maes et al. (2014)	Mapping and Assessment of Ecosystems and their Services (MAES) Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020	Extensive ES list
Posthumus et al. (2010)	A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England.	Aquatic, semiaquatic
Scholz et al.(2012)	Ökosystemfunktionen von Flussauen. Analyse und Bewertung von Hochwasserretention, Nährstoffrückhalt, Kohlenstoffvorrat, Treibhausgasemissionen und Habitatfunktion.	Aquatic, semiaquatic
Turner (2008)	Valuing Ecosystem Services: The Case of Multi-functional Wetlands.	Aquatic, semiaquatic

Tab. 2. Relevant characteristic of the studies considered for HyMoCARES list.

Study reference	Number of ES	Scale	Classification of habitat and/or supporting ES	Potentially offered or actually used ES	Hydropower and navigation
CICES after Haines-Young & Potschin (2013)	59 (10 abiotic outputs)	Global	Regulating and maintenance services	Links services to benefits and goods that are valued by people; classifies services and not benefits	Hydropower as abiotic ecosystem output; navigation not considered
Bark et al. (2015)	8 (cultural services)	Local (Murray River Basin, Australia)		Actual use of ES locally assessed	Hydropower and navigation not directly targeted
Clerici et al. (2014)	28	European	Habitat as part of the ecosystem structure and processes , ecological integrity	Potential ES capacity affected by change in land use; recreational services not considered due to local bias	Hydropower and navigation not directly targeted
de Groot et al.(2010)	23	Global	Habitat or supporting services	Links services to benefits and goods that are valued by people	Hydropower and navigation not directly targeted
Egoh et al. (2012)	20	Multiple scales	Habitat or supporting services	Case studies	Hydropower as a service; navigation not considered
Grizzetti et al. (2015)	19	Multiple scales	Regulating and maintenance services	Links services to benefits and goods that are valued by people; classifies services and not benefits	Considered as abiotic environmental services
Haines-Young & Potschin (2014)	59 (10 abiotic outputs)	Global	Regulating and maintenance services	Links services to benefits and goods that are valued by people; classifies services and not benefits	Hydropower as abiotic ecosystem output; navigation not considered
Keeler et al. (2012)	14	Global study applied at local scale		Require to identify the beneficiaries	Hydropower and navigation as ES
Liquete et al. (2013)	14	Case studies	Regulating and maintenance services	Links services to benefits and goods that are valued by people	Hydropower is not an ES; navigation not considered

Maes et al. (2014)	48	Case studies	Regulating and maintenance services	Links services to benefits and goods that are valued by people; classifies services and not benefits	Hydropower and navigation are not ES
Posthumus et al. (2010)	14	Local (Beckingham Marshes, England)	Habitat provision as separate service	Both potential and used	Hydropower and navigation not directly targeted
Scholz et al.(2012)	4	/	Habitat protection as separate service	/	Hydropower and navigation not directly targeted
Turner (2008)	10		Habitat as ecological service		Hydropower as ES; recreational navigation as ES

2 Adaptation of the CICES classification

Several national and international projects studying ES have been concluded in recent years or are in progress. A specific project about ES provided by rivers and floodplains is the 'River Ecosystem Service Index (RESI) project (www.resi-project.info) coordinated by the Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) Berlin. RESI is a German national project funded by the BMBF funding program "Regional Water Resources Management for Sustainable Protection of Waters in Germany (ReWaM)". RESI aims to evaluate and visualize actual and potential services provided to human well-being by rivers and their floodplains.

The RESI classification (see Tab. 3, Beichler et al. 2016a; Beichler et al. 2016b) is based on the main grouping of CICES in provisioning (orange), regulating (green) and cultural (blue) services. In addition, the group "basic functions" is added, which are primarily related to the structures and processes of river systems, which are not defined here as ES, even though they have been categorized as "Supporting services" in the MA (2005). The basic use of the CICES classification by RESI, which constitutes the basis for most of recent works, allows to facilitate the comparison of the RESI ES list with the output of other projects. The basic differences in relation to individual subgroups of ES are briefly summarized below. In Tab. 4 we provided the suggested data sources for the evaluation of each ES.

Tab. 3. ES classification proposed for the RESI project (Beichler et al. 2016a).

Main group	Subgroup	Ecosystem service	Description
Provisioning	Nutrition	Cultivated crops	Agricultural products for consumers
		Plant resources for agricultural use	Plants used to feed farm animals as a basis to produce e.g. milk and meat
		Wild animals and fish (consumptive)	
		Surface water for drinking purpose	
		Ground water for drinking purpose	
	Resources	Fibers and other resources from plants for direct use or for processing	Wood from forest and plantations
		Water for non-drinking purposes in industry and agriculture (surface and ground water)	Water for cooling or irrigation purposes
	Biomass-based energy resources	Plant-based resources from agriculture, short rotation coppice, forestry	(Wood) Biomass from agriculture or forestry as a resource for energy production
Regulation & Maintenance	Retention (Self-purification)	Retention of organic C	• (Temporary) Retention of organic C by uptake into stationary biomass (e.g. assimilation by mussels or biofilm) or by deposition as sediments • Permanent removal of organic C by respiration • Microbial degradation of organic pollutants
		Retention of N	• (Temporary) Retention of organic N by uptake into stationary biomass (e.g. assimilation by mussels or macrophytes) or by deposition as sediments • (Temporary) Retention of inorganic N by uptake into pelagic biomass (assimilation by phytoplankton, zooplankton) • Permanent removal of N by denitrification in river channel or floodplain contributing to self-purification
		Retention of P	• (Temporary) Retention of P by uptake into stationary biomass (e.g. assimilation by mussels or biofilm) or by deposition as sediments • (Temporary) Retention of P by uptake into pelagic biomass (assimilation by phytoplankton, zooplankton)
	Global climate regulation	Reduction of greenhouse gas emission / carbon sequestration	• Reducing anoxic ways of C degradation (leading to CH4 emissions) • Reducing incomplete anoxic ways of N degradation (leading to N_2O emission) • Retention of CO2 by uptake into biomass by biotic assimilation enabling sequestration of C by a) temporary retention by growth of biomass in river channels and banks (e.g. phytoplankton, annual macrophytes) (with partial trade-off with eutrophication) and b)

			retention in live or dead biomass of floodplain vegetation and soils
	Extreme discharge mitigation	Flood risk mitigation	Mitigation of flood discharge and lowering of flood peak by inundation of floodplain areas (retention effect) and high roughness of natural river channels (delay effect, which is also broadening the flood wave)
		Drought risk mitigation	Mitigation of drought effects on river flow by a) inflow from floodplain aquifers or b) stabilization of river water level by hydraulic roughness of river channel, which is in some river types additionally increased at low flow by dense growth of aquatic macrophytes.
	Drainage	Drainage capability	Possibility for water to be drained from an area into a stream channel following a natural slope of the ground
	Sediments (incl. suspended)	Bed load equilibrium and control of channel incision	Adjustment of local surplus or lack of sediment due to erosion or incision or sedimentation (in river channels, floodplains, river mouths, beaches)
		Soil formation in floodplains	Sediment-induced soil formation, which is enhanced by sedimentation of suspended particles during floods
	local climate regulation	Temperature regulation/Cooling (water bodies and ground)	Cooling effect due to evapotranspiration in summer
		Provisioning of habitat	Availability of habitats in typical functional and structural quality, which is used by typical biotic communities of rivers and floodplains, and may then partially be used by humans
Cultural	Scenery	Aesthetics of landscape	Aesthetics of landscape as characterized by its diversity, specificity and naturalness
		Natural and cultural heritage	Entirety of all physical objects (as memorials, species), as well as notional and cultural reflection of physical goods of nature, and informal cultural forms of expression.
	Emotional and intellectual interactions with riverine ecosystem	Unspecific interactions with riverine ecosystem	Experience of animals, plants and landscapes during activities (e.g. hiking, biking) for recreational purpose
		Education and Science	Use of river ecosystems for popular or scientific excursions , nature trails, research objects etc. which are relating to river ecosystems
	Recreation and tourism: activities related to Water	water-related activities	Swimming, un-motorized boating, motorized boating (e.g. cruise tours) and fishing as specific water related activities with recreational purpose
Basic functions	Hydrologic balance / Water regime	Discharge and discharge dynamics	Discharge and discharge dynamics, as determined by the catchment and upstream channel sections
		Connectivity with aquifers	Hydrological or hydraulic Interaction between river and groundwater

	Morphology	Physical structure of river channel and floodplain	Physical structure of river channel and floodplain as a result of hydromorphological processes
Usage of abiotic natural capital		Hydropower	
		Navigation	

Tab. 4. ES classification with suggested data source (adapted from Beichler et al., 2016b).

Main group	**Subgroup**	**Ecosystem service**	**Data source**
Provisioning	Nutrition	Cultivated crops	CORINE land cover (http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012), digital topographic maps, EU ecosystem mapping MAES; agricultural statistics; increase of crop production due to fertilized should be deduced from this
		Plant resources for agricultural use	See above
		Wild animals and fish (consumptive)	See above
		Surface water for drinking purpose	See above
		Ground water for drinking purpose	See above
	Resources	Fibers and other resources from plants for direct use or for processing	See above
		Water for non-drinking purposes in industry and agriculture (surface and ground water)	Water protection zones, drinking water suppliers, aquifers acc. EU Water Framework Directive
	Biomass-based energy resources	Plant-based resources from agriculture, short rotation coppice, forestry	Corine land cover, digital topographic maps, EU ecosystem mapping MAES; agricultural statistics
Regulation & Maintenance	Retention (Self-purification)	Retention of organic C	Modelling of nutrient retention by MONERIS model; use of physical habitat quality of river channel as a proxy
		Retention of N	See above
		Retention of P	See above
	Global climate regulation	Reduction of greenhouse gas emission / carbon sequestration	Presence of soil types with high organic content, peat mires, plant growth productivity
	Extreme discharge mitigation	Flood risk mitigation	Presence of active floodplain area based on maps elaborated for the EU Flood Risk Directive; Presence of artificial impoundments and reservoirs
		Drought risk mitigation	Presence of aquifers in the floodplain, non-existing incision of river channel; artificial reduction of river flow due to human activities
	Drainage	Drainage capability	Presence of stream channels

	Sediments (incl. suspended)	Bed load equilibrium and control of channel incision	Presence of dams upstream; Data on the temporal evolution of the altitude of the river bed, known trends of river channel incision or aggradation
		Soil formation in floodplains	Presence of active floodplain area based on maps elaborated for the EU Flood Risk Directive
	Micro and regional climate regulation	Regulating temperature/Cooling (water bodies and ground)	Estimated biomass in respective ecosystem type
		Provisioning of habitat	Natura 2000 areas and their conservation status, nature protection zones, biotope mapping, national park, special protection area, physical habitat mapping of river channels, ecological status of river sections according to WFD
Cultural	Scenery	Aesthetics of landscape	Landscape protection area, viewpoints, density of hiking trails and promenades, absence of noise (from roads, railways, airports etc.), artificial constructions in concrete, iron etc.; aesthetic preferences of local residents, stakeholders and tourists
		Natural and cultural heritage	Diversity of natural/typical landscape structures
	Emotional and intellectual interactions with riverine ecosystem	Unspecific interactions with riverine ecosystem	Stakeholder surveys, frequency of pictures on Panoramio, Flickr etc.; frequency of occurrence in popular publications
		Education and Science	Frequency of occurrence in scientific and educational publications
		water-related activities	Informal or designated bank areas for various water sports Number of fishing licenses
Basic functions	Hydrologic balance / Water regime	Discharge and discharge dynamics	Shape of flood wave and peak
		Connectivity with aquifers	Open aquifer directly neighboring the river channel
	Morphology	Physical structure of river channel and floodplain	Physical habitat mapping
Usage of abiotic natural capital		Hydropower	
		Navigation	

Provisioning ecosystem services

In comparison with CICES and other classifications, in RESI adjustments for the main group of the provisioning services have been made. Within the subgroup "food", no wild plants, algae or in-situ aquaculture are considered because of their low relevance in river landscapes (Beichler et al., 2016a). In addition, the classes "reared animals and their outputs" and "material from plants for agricultural use" are brought together in RESI. The reason is that the growing fodder plants (as the performance of the terrestrial ecosystem) only provide an intermediate output as input for the production of the final and human demand. The inclusion of feed (field crop, permanent grassland) and animal products (milk, meat, wool) produced would lead to a double counting of the ES. Within the subgroup "raw materials", the vegetable raw materials in agriculture are no longer recorded for the same former reason. Animal raw materials (in the form of organic fertilizers) represent a further ES, for which reliable data are hardly available, since the collection and utilization is subject to considerable uncertainties, particularly with regard to the spatial reference of the morphological floodplain. Organic fertilizers are used as a raw material in plant production (and would be classified as ES here), but can also be a burden on the ecosystem due to the nutrient input. Their origin and application areas are sometimes spatially widely separated. Within the category of vegetable raw materials for processing only wood is covered, since industrial plant cultivation on agricultural land is neither relevant to Germany nor to morphological floodplains. Furthermore, RESI does not distinguish between groundwater and surface water as a source of industrial water.

Regulatory ecosystem services

The main group of regulatory services is divided in the CICES classification into actors or mediators. In the RESI, no grouping takes place with regard to these actors, but according to the types of substances (C, N, P, THG). However, since the material cycles of C, N, and P are closely related, potential overlaps, feedbacks, and tradeoffs are possible. For example, the retention / accumulation of organic C in sediments also promote the removal of N by denitrification. On the other hand, a certain proportion of N_2O is generated during denitrification, which contributes to greenhouse gas emissions. In rivers, due to the often faster succession of assimilation (by phytoplankton) and mineralization, and due to the further transport of this biomass in the water column (pelagial), there is a fundamental difference with floodplains, in which the retention of C, N and P by incorporation into biomass occurs usually on a long-term and local basis. In the RESI, further ES and subgroups such as noise / odor / visual disturbances, air and gas mass movements, pest and disease control are not included as they have been considered less relevant to rivers and floodplains. Water quality is already indirectly assessed as ES via the retention of nutrients. With regard to the application in river floodplains, flood regulation is introduced as a regulative service. Drainage capacity stands for the possibility of the water to run off with natural slope until the river channel which is ensured by the natural water bodies ("receiving waters") as a service of the floodplain and river. This avoids the need of artificial lifting which is often necessary in artificially drained lowlands.

The concept of "flood protection" has been modified by CICES in "flood risk mitigation" in order to avoid the anthropogenic concept of protection and to emphasize the performance of natural flow regulation (Mehl et al., 2013). Functionally linked with this is the regulation of low flows which is also an important service. These services are based on processes of hydrological and eco-morphological self-regulation, e.g. balance of low water events by flow from the aquifer (damping of the discharge drop) or the damping of the water level at low water by increasing macrophytes growth and morphological structures (narrower "low water channel").

The RESI ES "habitat provision" was defined analogously to the maintenance of life cycles, habitats and gene pools according to CICES. The conservation of species and habitats is aimed at all species and habitats (preservation of biodiversity as a separate value) in RESI, not only on used and beneficial species. Therefore, RESI does not distinguish between the CICES classes “pollination and seed dispersal” and “maintaining of nursery populations and habitats”.

The habitat provisioning and conservation has a controversial position in ES classifications: in some studies, it is considered as a main ES group (De Groot et al., 2010; Posthumus et al., 2010; Scholz et al., 2012), while in other studies it is part of the "basic function" and not as part of the regulatory services (Grizzetti et al., 2015; Haines-Young and Potschin, 2013; Liquete et al., 2013). The ES Habitat Provision (which also includes the provision of species) takes a special position within RESI as it is the basis for biodiversity and thus also for a number of other ES (Scholz et al., 2012). The separate definition of this ES thus may help to avoid possible double counts of other habitat-related ES in the final synthesis.

Cultural ecosystem services

In the main group of cultural ES, many aspects of the CICES classification have been adopted. The ES "landscape aesthetics" is defined by the characteristics, variety, individuality and naturalness. Landscape aesthetics contribute to human well-being through inspiration, identity and a sense of place, and, in addition to CICES, it has also been cited as a cultural achievement for other national and international ES classifications (Bark et al., 2015; Grizzetti et al., 2015). According to the CICES class, the cultural ecosystem performance "nature and culture heritage" comprises legally protected areas (for example nature reserves) and monuments which are preserved for future generations. The classes "experiencing animals, plants and landscapes", the "Recreation and Tourism" are regarded in RESI as further cultural ecosystem services, as in many other international ES classifications (Russi et al., 2013; MEA 2005; Grizzetti et al., 2015; Egoh et al., 2012; Posthumus et al., 2010). “Recreation and tourism" is the possibility to conduct recreational activities (MEA 2005). The CICES class "use of landscapes for hiking, sports fishing, etc." is used in RESI as the group water-related activities. This includes activities for the purpose of recreation in rivers or floodplains and includes bathing, recreational boating, fishing and natural observation (Bark et al., 2015; Plieninger et al., 2013; Vermaat et al., 2013).

The three CICES classes "education", "nature education" and "science" are combined in RESI into "education and science". This ES describes possibilities of formal or informal further education and training (MA 2005). The area "spiritual, symbolic meaning of living creatures, living spaces and landscapes" with the four CICES classes symbolic meaning, spiritual meaning, existence value and legacy of future generations is not considered in the RESI as an independent ES class, due to the risk of double counting.

Basic functions

The main group of the basic functions contains such processes in river systems and floodplains, which represent a prerequisite for many ES but are not defined directly as ES. These basic functions are mostly generated by the abiotic, physical environment, i.e. which are supported by organisms only to a minor extent. For example, ephemeral rivers in deserts show that the hydraulics and morphometry of rivers are mostly shaped by abiotic mechanisms. Hence, the approach of this ES classification is similar to that of the "supporting services" of the MA (2005) and of the "integrity" (Burkhard et al., 2012), but is specifically designed for use in rivers and floodplains. Differing from this classification, in CICES the water balance (also in the sense of the EU-WFD, see Mehl et al., 2015) is classified into the group of regulative ES. However, in the context of RESI, this category has been treated only separately to prevent double counting.

Usage of abiotic natural capital

In addition to the ES groups, navigation and hydropower are listed, which are included in some ES classification studies, too. For example, in the MEA (2005), hydropower and transport are part of the supply chain. According to other studies, the availability of water for the purpose of hydropower and shipping is an achievement of aquatic ecosystems (Febria et al., 2015; Keeler et al., 2012; Vigerstol and Aukema, 2011). The question of whether hydropower and navigation can be defined as ES has not yet been conclusively clarified in the international context. In the RESI project, they are listed as uses in the ES list as abiotic use order to take them into account when assessing and weighing up measures.

In Alpine rivers, navigation is absent. Hydropower makes use of the hydrological features of Alpine rivers which are mostly shaped by physical processes, as water discharge, hydraulics, precipitation, storage, and evaporation. These processes are part of the water cycle driven by the sun, with only minor interference of Alpine ecosystems. Consequently, the human use of the hydrological cycle by hydropower plants is not defined in HyMoCARES as the use of an ecosystem service, but rather as the use of abiotic natural capital.

3 HyMoCARES Ecosystem Services list

Based on the considerations about riverine ecosystem services delineated above, a classification scheme and list of 18 ES provided by Alpine river corridors has been developed for the HyMoCARES project (Tab. 5).

The classification presents some differences compared with the classification proposed in RESI, which are outlined in the following paragraphs. The HyMoCARES classification was developed having in mind the overall cause-effect relationships framework. For this reason, some relevant ES, which have likely influence on other ES, were considered functions or processes and moved to an upper level following the scheme presented in Fig. 1.

The ES ***"Cultivated crops"*** has been proposed to be removed by some partners in HyMoCARES. Crop production in floodplains benefits from (former) river ecosystems through both abiotic and biotic functions: abiotic functions are for example the creation of flat floodplain areas by river dynamics with high groundwater levels, clay accumulation, high air humidity, and resulting mitigation of temperature extremes; and biotic functions are the production organic matter and nutrients accumulated in floodplains during river floods (supported by various biota). The river corridor and floodplain coincide often with the entire width of the valley in Alpine areas due to physical, geographical and geological reasons. Thus the presence of cultivation could be not only a result of river processes, which shape and influence the entire landscape, but a consequence of other external factors (e.g., climate, solar radiation, geographical features). "Cultivated crops" is at some extent a river ES, which in addition is fundamental to assess, thus finally we decided to include it in the HyMoCARES list. However, this service has to be assessed differently for each management action: in case of increase of flooding frequency due to a management action, the risk and damages for agriculture are included in the flood risk mitigation, as stated in the Flood Directive and double counting has to be avoided.

Accordingly with the new CICES classification (Haines-Young and Potschin, 2018), we decide to split the service "***Water for non-drinking purposes in industry and agriculture (surface and ground water)"*** in two services, clearly separating surface water from groundwater. The new services name "***Surface water for non-drinking purposes in industry and agriculture"*** and ***"Ground water for non-drinking purposes in industry and agriculture".*** The hydromorphological processes that sustain these services are very different, supporting the decision to divide in two services.

The ES "***Wild animals and fish (consumptive)***" has been removed in the HyMoCARES list because it is considered as not important in the Alpine area. Wild animals and fish in this area are fundamental for recreational reasons, but they are not used as food primary source. C, P and N retention has been considered as a single service for the sake of simplicity. The new ES is named "***Retention of nutrients***" following the classification of Grizzetti et al., 2015. However, at the indicator level the mentioned nutrients have to be estimated separately, due to different retention mechanisms. The "***Drainage capability***" has been considered as a property and a function of the morphology more than an ES itself.

It has been suggested by some partners to consider "***Bed load equilibrium as ecosystem"*** as ecosystem service or environmental service because channel incision is a real cost for agencies. These costs affect human well-being negatively, as it may be not used any more e.g. to finance other needs of citizens. Hence, a river which still has an equilibrated sediment budget may be seen as directly contributing to human well-being. In the HyMoCARES perspective, the ES "***Bed load equilibrium and control of channel incision***" has been considered as a function of both the sediment supply and the river morphology and removed.

It was debated if the ES "***Soil formation in floodplains***" could be a double counting of the agricultural services. Soil formation is important not only for the agriculture but it contributes to the maintenance of biogeochemical conditions of soil, nutrient storage and soil structure (Haines-Young and Potschin, 2013). However, the temporal scale of the restoration actions is often too short to have an effect on this ES, and we decided to not consider it in the framework.

Concerning the ES "***Habitat-related services***", the HyMoCARES partners had intense discussions and debates. Physical habitat represents in general fundamental for the supply of several ES and has to be considered in the cascade model a process or a function. Nursery and maintenance habitat for rare species has been proposed by some HyMoCARES partners to be included in the Natural and Cultural Heritage because they see the existence of these species as a cultural service. The proposed ES "habitat provision" in the RESI project already subsumes several services that might otherwise need to be reconsidered such as "maintenance of life cycles, habitats and gene pool protection", "pollination and seed dispersal", "maintaining of nursey populations and habitats", "genetic materials from all biota".

On the other hand, habitat provisioning for species (especially key or umbrella species) represents a proxy of the biodiversity, which is fundamental to sustain a healthy habitat and which also contributes to human well-being. Therefore, habitat quality has been included as an ES in previous studies on ES provided by floodplains (Posthumus et al 2010, Rouquette et al. 2011). If river corridors provide diverse habitats which sustain a high biodiversity, human well-being not only benefits through cultural services, but also through other services for adjacent agricultural and urban areas, as pollination by various wild pollinating insects and the regulation of the abundance of biotic pests (fungi, insects, rodents). For example, the intense apple production in the Adige valley system not only depends on pollination by domestic bees but also on pollination by wild insects (www.apfel-pinklady.com/de/bienen-eine-kostenlose-dienstleistung-des-okosystems), as domestic bees are not active at temporary temperatures below 10°C, and also may prefer visiting other flowers over the apple tree flowers (www.kohl.bz.it/de/die-bestaeubung-der-apfelbluete.html).

Including 'habitat provisioning' as an ES into the HyMoCARES list might support the objectives of HyMoCARES, as this would i) ensure the compatibility of HyMoCARES with ongoing efforts to assess ES at global level by use if the CICES ES list (which includes the ES 'Maintaining nursery populations and habitats') and at European level through the MAES program, and ii) assist stakeholders to justify, visualize and communicate the success of any river restoration projects by the use of the HyMoCARES ES list, as such projects usually include an improvement of water-related habitats as a key objective. The assessment of the ES 'habitat provisioning' may be based on the presence of protected areas in the river floodplain, as e.g. Natura 2000 areas or protected forest, on the results of physical habitat or vegetation mapping (if available), and/or by the known occurrence of plant or animal target species (e.g., species included in Bird and Habitat Directive lists as the *Salmo trutta marmoratus* or *Salmo marmoratus*).

At the indicators level, habitat will be quantified using different techniques and we will discuss if it must be considered an ES in the next meetings. The ES "***Natural and cultural heritage***" has been moved from the "Scenery" subgroup of the RESI list to the subgroup of the "Intellectual services". The ES "Unspecific interactions with riverine ecosystem" has been removed because we could include these services in other services.

We decided to consider all the '***basic functions***' of the RESI list as processes or functions that influence many ES and remove it from the list

We included the "***Sediments for construction***" as abiotic material provisioning, and with that we added sand and gravel mining which has been an important and impacting activity in the Alps. It is forbidden now in most of the partner countries, but not in each of them (e.g., Slovenia, Germany but also in other countries).

Tab. 5. ES classification scheme of the HyMoCARES project. For a complete description please see **ANNEX 1**.

Main group	Subgroup	Ecosystem service
Provisioning	**Nutrition**	Cultivated crops
		Plant resources for agricultural use - Pasture
		Surface water for drinking purpose
		Ground water for drinking purpose
	Resources	Fibers and other resources from plants for direct use or for processing - Resources related to the riparian forests, wood
		Surface water for non-drinking purposes in industry and agriculture
		Ground water for non-drinking purposes in industry and agriculture
	Biomass-based energy resources	Plant-based resources from agriculture, short rotation coppice, forestry
Regulation & Maintenance	**Retention (Self-purification)**	Retention of nutrients
	Global climate regulation	Reduction of greenhouse gas emission / carbon sequestration
	Flood and drought risk mitigation	Flood risk mitigation (flooding and risk related to morphological dynamics of rivers)
		Drought risk mitigation
	Micro and regional climate regulation	Regulating temperature/Cooling (water bodies and ground)
	Habitat-related services	Habitat-related services
Cultural	**Scenery**	Aesthetics of landscape
	Emotional and intel-lectual interactions	Natural and cultural heritage of the river and floodplain ecosystem
		Education, Science
	Water-related activities	Water-related activities
Usage of abiotic natural capital		Hydropower
		Navigation

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ANNEX 1: HyMoCARES ES LIST

Table 6: Complete list of HyMoCARES considered in ES with description and data source.

Main group	Subgroup	Ecosystem service	Description	Data source (partial)
Provisioning	**Nutrition**	Cultivated crops	Agricultural products for consumers	CORINE land cover (http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012), digital topographic maps, EU ecosystem mapping MAES; agricultural statistics; increase of crop production due to fertilized should be deduced from this
		Plant resources for agricultural use - Pasture	Plants used to feed farm animals as a basis to produce e.g. milk and meat	See above
		Surface water for drinking purpose		Water protection zones, drinking water suppliers, aquifers acc. EU Water Framework Directive
		Ground water for drinking purpose		See above
	Resources	Fibers and other resources from plants for direct use or for processing - Resources related to the riparian forests, wood	Wood from forest and plantations	CORINE land cover (http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012), digital topographic maps, EU ecosystem mapping MAES; agricultural statistics;

				increase of crop production due to fertilized should be deduced from this
		Surface water for non-drinking purposes in industry and agriculture (surface and ground water)	Surface water for e.g. cooling or irrigation purposes	Water protection zones, drinking water suppliers, aquifers acc. EU Water Framework Directive
		Groundwater for non-drinking purposes in industry and agriculture (surface and ground water)	Groundwater for e.g. cooling or irrigation purposes	Water protection zones, drinking water suppliers, aquifers acc. EU Water Framework Directive
	Biomass-based energy resources	Plant-based resources from agriculture, short rotation coppice, forestry	(Wood) Biomass from agriculture or forestry as a resource for energy production	Corine land cover, digital topographic maps, EU ecosystem mapping MAES; agricultural statistics
Regulation & Maintenance	**Retention (Self-purification)**	Self-purification	• (Temporary) Retention of organic C, N and P by uptake into stationary biomass (e.g. assimilation by mussels or biofilm) or by deposition as sediments • Permanent removal of organic C, N and P by respiration • Microbial degradation of organic pollutants	Modelling of nutrient retention by MONERIS model; use of physical habitat quality of river channel as a proxy

	Global climate regulation	Reduction of greenhouse gas emission / carbon sequestration	• Reducing anoxic ways of C degradation (leading to CH4 emissions) • Reducing incomplete anoxic ways of N degradation (leading to N_2O emission) • Retention of CO2 by uptake into biomass by biotic assimilation enabling sequestration of C by a) temporary retention by growth of biomass in river channels and banks (e.g. phytoplankton, annual macrophytes) (with partial trade-off with eutrophication) and b) retention in live or dead biomass of floodplain vegetation and soil	Presence of soil types with high organic content, peat mires, plant growth productivity
	Extreme discharge mitigation	Flood risk mitigation (flooding and risk related to morphological dynamics of rivers)	Mitigation of flood discharge and lowering of flood peak by inundation of floodplain areas (retention effect) and high roughness of natural river channels (delay effect, which is also broadening the flood wave)	Presence of active floodplain area based on maps elaborated for the EU Flood Risk Directive; Presence of artificial impoundments and reservoirs
		Drought risk mitigation	Mitigation of drought effects on river flow by a) inflow from	Presence of aquifers in the floodplain, non-existing incision of river channel; artificial

			floodplain aquifers or b) stabilization of river water level by hydraulic roughness of river channel, which is in some river types additionally increased at low flow by dense growth of aquatic macrophytes.	reduction of river flow due to hydropower use
	Micro and regional climate regulation	Regulating temperature/Cooling (water bodies and ground)	Cooling effect due to evapotranspiration in summer	Estimated biomass in respective ecosystem type
	Habitat-related services	Habitat related services	Availability of habitats in typical functional and structural quality, which is used by typical biotic communities of rivers and floodplains, and may then partially be used by humans	Natura 2000 areas and their conservation status, nature protection zones, biotope mapping, national park, special protection area, physical habitat mapping of river channels, ecological status of river sections according to WFD, habitat modelling
Cultural	**Scenery**	Aesthetics of landscape	Aesthetics of landscape as characterized by its diversity, specificity and naturalness	Landscape protection area, viewpoints, density of hiking trails and promenades, absence of noise (from roads, railways, airports etc), artificial constructions in concrete, iron etc.; aesthetic preferences of local residents, stakeholders and tourists
	Emotional and intel-lectual interactions	Natural and cultural heritage of the river and floodplain ecosystem	Entirety of all physical objects (as memorials, species), as well as notional and cultural reflection of physical goods of nature, and informal cultural forms of expression	Diversity of natural/typical landscape structures

		Education, Science	Use of river ecosystems for popular or scientific excursions , nature trails, research objects etc. which are relating to river ecosystems	Frequency of occurrence in scientific and educational publications
	Water-related activities	Water-related activities	Swimming, un-motorized boating, motorized boating (e.g. cruise tours) and fishing as specific water related activities with recreational purpose	Informal or designated bank areas for various water sports Number of fishing licenses
Usage of abiotic natural capital		Hydropower		
		Navigation		
		Sediments for construction		