Preparatory Phase for the pan-European Research Infrastructure DANUBIUS–RI
"The International Centre for advanced studies on river-sea systems"

Working Document on

Research Needs in River-Sea Systems, Actors and Events for Science Developments, relevant for the Innovation Process of DANUBIUS-RI

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EXECUTIVE SUMMARY

DANUBIUS-RI (International Centre for Advanced Studies on River-Sea Systems) is an initiative to develop a pan-European distributed Research Infrastructure (RI), which supports interdisciplinary research on River-Sea Systems, comprising rivers and their catchments, transitional waters, such as estuaries and deltas, as well as adjacent coastal seas. DANUBIUS-RI aims to enable research using a systems-based approach to overcome disciplinary, regional and national boundaries, in order to better understand environmental processes and system dynamics, to maintain ecosystem functioning and thus to sustain valuable ecosystem services. In 2016, DANUBIUS-RI entered the Roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). The RI will provide access to a range of River-Sea Systems, facilities, data and expertise, and will enable interdisciplinary research, knowledge exchange, education and training. DANUBIUS-PP (Preparatory Phase) is a three-year, European Commission funded H2020 project that seeks to achieve the legal, financial and technical maturity required for the successful implementation, operation and further development of DANUBIUS-RI (www.danubius-pp.eu).

Rivers and seas have been modified progressively over the past 12,000 years with environmental consequences, which are cumulative and pervasive. The effects are ubiquitous: with fundamental changes in the movement of water and sediment from catchments to coasts, and widespread consequences, such as pollution and eutrophication. This jeopardises the continued provision of key ecosystem services by River-Sea Systems. New approaches to Research and Innovation (R&I) are needed, which provide interdisciplinary opportunities for holistic visions that recognises the multi-faceted links within River-Sea Systems. This requires, *inter alia*, linking natural and human processes, as well as linking freshwater, transitional water and coastal water processes within River-Sea Systems to enhance process and system understanding, to provide the basis for sustainable adaptive management, and the development of informed environmental policies and regulations. The pressures of past and present human activities on River-Sea Systems, have led to changes in the ecosystem state of European River-Sea Systems. However, there are difficulties in identifying how society can best respond to these changes. Targeted, adaptive management actions are needed, which should be inclusive (i.e. with stakeholder and public engagement) and informed by science. The vision of DANUBIUS-RI is to provide a pan-European RI to address these challenges with a research infrastructure that spans rivers and seas, to ‘make River-Sea Systems work’.

This deliverable summarises current research needs in European River-Sea Systems. It is a working document, which will be further developed into the Science and Innovation Agenda for DANUBIUS-RI. The Science and Innovation Agenda will be published at the conclusion of DANUBIUS-PP in

2019. The deliverable draws upon a review of the academic literature, expert consultations and discussions. It uses the Driver – Pressure – State – Impact – Response (DPSIR) conceptual framework to investigate overarching research challenges in European River-Sea Systems. In this way, four overarching and interrelated challenges in River-Sea Systems have been identified that will guide the development of DANUBIUS-RI through the preparatory phase towards implementation:

- Climate Change
- Water Sufficiency
- Sediments and their Management
- Ecosystem Health

Climate change is contributing to an intensification of the hydrological cycle and an increase in the frequency of extreme events (e.g. floods and droughts), with effects that are exacerbated in coastal areas by sea level rise, and land subsidence. Inevitably, there will be considerable social and economic impacts on agriculture, on urban and peri-urban areas, on communications and transport, as well as on industry and business. Hence, long-term mitigation and adaptation will be crucial to maintaining key ecosystem services currently provided by River-Sea Systems. This, in turn, requires greater holistic understanding of River-Sea Systems, particularly in our ability to attribute 'cause and effect', recognising how River-Sea Systems are evolving in response to a variety of 'drivers' at different spatial and temporal scales.

Water is an essential resource, and DANUBIUS-RI considers the challenge of **water sufficiency** as being how to ensure continued water availability for both anthropogenic and environmental needs. It embraces both quantity and quality, of both surface water and groundwater, along the continuum from catchment to coast. The challenge of water sufficiency lies in addressing problems, such as eutrophication and hypoxia, pollution, salinization, changes in river (and tidal river) regime and sea level in the context of increasing water abstraction, river regulation, and changing catchment land-use. Individually and collectively, these drivers and pressures affect the hydrogeomorphology of rivers, which have been increasingly isolated from their floodplains, and modified by extensive engineering. In some parts of Europe, the potential for increasing coastal flooding is of concern, while there are general questions about how an increasingly scarce resource (water) can be allocated equitably between different uses.

The continued functioning of River-Sea Systems is also dependent upon maintaining **sediment** movement through catchment to coast. River-Sea Systems are characterised by the routing of sediment from source to sink through erosion, deposition and remobilisation. 'Natural' rivers persist in a state of dynamic equilibrium. However, catchment, river and coastal management significantly affect the movement of sediment through modified rivers, estuaries and deltas, and coastal seas. This threatens the continued availability of sediment, which is itself a resource: whether for sustaining farmland, or enhancing flood protection (via aggradation of floodplains, deltas and coasts). Sediment dynamics is also key to safeguarding the morphological dynamics of River-Sea Systems, which are essential for biodiversity conservation. Erosion and sedimentation occur over different scales, and holistic approaches for research on River-Sea Systems are required to deliver integrated sediment management plans, which are supported by key stakeholders at different levels.

River-Sea Systems are complex and heterogeneous, and encompass diverse habitats in freshwater, semi-terrestrial and semi-aquatic (i.e. floodplains), transitional (deltas, estuaries) and coastal environments. **Healthy ecosystems** are those that are resilient, stable and sustainable, and maintaining their organisation over time. Biodiversity in different spatial and temporal scales is a key element for ecosystem structure and functioning, underpinning the provision of key ecosystem services (such as fish production, habitat provision, flood and storm protection). Ecosystem health is threatened e.g. by habitat fragmentation and loss, insufficient water and sediment quantity and quality, overfishing and invasive species. Across Europe, lateral connectivity between rivers and floodplains has been lost in many cases by river regulation due to navigation and flood protection, while longitudinal connectivity has been affected (e.g. through dam construction for hydropower and reservoirs). These changes, which occur mostly in the catchments and headwaters, endanger highly productive and biodiverse environments further downstream, in estuaries, deltas and coastal seas. A key challenge is to determine how changing ecosystem structure and function will affect ecosystem health and the provision of ecosystem services in the future. It is also unclear how River-Sea Systems will evolve, given the multiple and interacting pressures, as well as the rates at which some of these systems are changing.

The four challenges *Climate Change*, *Water Sufficiency*, *Sediments and their Management*, and *Ecosystem Health* summarised here are interrelated. However, they highlight the importance of interdisciplinary R&I at different temporal and spatial scales across the River-Sea continuum. The vision of DANUBIUS-RI is to provide a distributed RI for observation, experimentation and modelling in a range of European River-Sea Systems that addresses this need by

- enabling interdisciplinary research along River-Sea continuum,
- integrating existing knowledge and providing new interdisciplinary knowledge,
- using standardised methods and providing access to comparable data,
- strengthening regional, national and international collaborations,
- engaging decision makers, stakeholders and the public(s),
- training early career scientists.

PREAMBLE

This deliverable (D) 2.2 is a “working document on research needs in River-Sea Systems, actors and events for science developments, relevant for the innovation process of DANUBIUS-RI”, which will be updated over the next months. Together with D2.3 (draft) and D2.4 (final) “review report on environmental, societal and policy challenges in River-Sea Systems and emerging research and legislation needs”, it will form the basis for developing the Science and Innovation Agenda of DANUBIUS-RI. The upcoming D2.5 (draft) and D2.6 (final) deliverables will provide the “strategic Science and Innovation Agenda underpinning the technical and organizational design of DANUBIUS-RI” and will be published in November 2018 (confidential) and 2019 (public), respectively.

In the following, chapter 1 introduces the mission and vision of DANUBIUS-RI, chapter 2 provides an overview of research needs in River-Sea Systems, and chapter 3 looks towards DANUBIUS-RI’s Science and Innovation Agenda. The identified research needs have been clustered around the following four overarching, interrelated challenges: *Climate Change*, *Water Sufficiency*, *Sediments and their Management*, as well as *Ecosystem Health*. These challenges and their associated research needs are further described in sub-chapters 2.1 to 2.4. Due to their interrelations, there are several cross-cutting issues, which are affected by climate change and which are in turn affecting water sufficiency, sediments and their management, as well as ecosystem health. Cross-cutting issues are for example changes in hydro- and morphodynamics, eutrophication and pollution.

1. Introduction

River-Sea Systems comprise rivers and their catchments, estuaries, deltas and lagoons, as well as their adjacent coastal seas (Figure 1). As such, River-Sea Systems cover freshwater, transitional and coastal waters, including semi-aquatic and semi-terrestrial environments, such as floodplains. The extent of a River-Sea System is defined by the surface-water (or groundwater) boundary and the marine boundary, which is more variable. It is defined by the extent of riverine influence on individual parameters of interest.

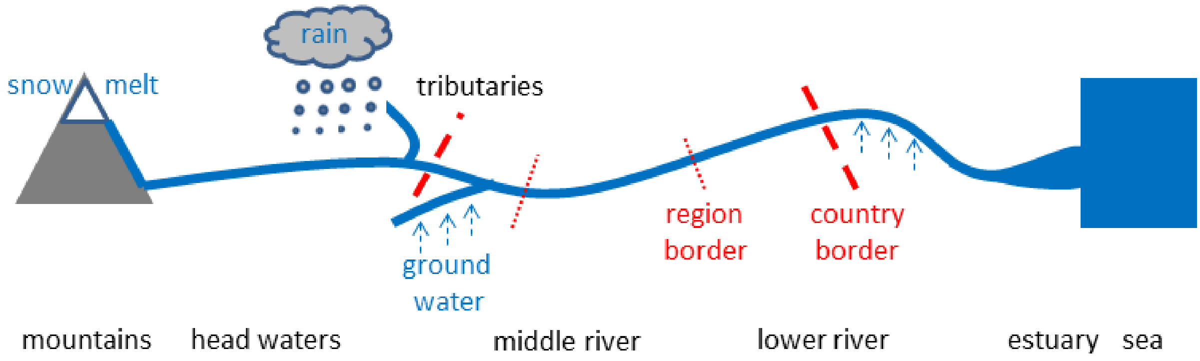

Figure 1 DANUBIUS-RI's conceptualized view of a River-Sea Continuum (Jos Brils, Deltares)

River-Sea Systems provide ecosystem services that are fundamental to societal wellbeing. However, these systems face compounding pressures: from climate change and human drivers, such as urbanisation, energy generation, waterborne transport, agriculture and fisheries at different spatial (local, national and global) and temporal (seasons to centuries) scales. The resulting changes in the structure and the functioning of River-Sea Systems lead to the decrease or loss of ecosystem services. This poses a number of societal challenges, for example, eutrophication, hypoxia, pollution, changes in hydrology, sediment transport and morphology, loss of biodiversity and sea level rise. Without counteraction towards sustainable development, these pressures and respective changes are likely to increase in future with implications throughout the River-Sea continuum and with uncertain consequences for the resilience of River-Sea Systems. The state of European River-Sea Systems is a dynamic product of interacting environmental and socio-economic processes. Given this complexity, holistic understanding and management of these systems requires new approaches to interdisciplinary Research & Innovation (R&I) at a number of levels.

At present, research facilities devoted to rivers and seas are fragmented with a paucity of R&I facilities spanning freshwater and marine systems. This is problematic given the scale of current and emerging environmental problems confronting River-Sea Systems that require: (1) new approaches to observe, understand, and model the environment; and (2) enhanced links between academic communities, policy, industry, business, and the public to improve the management of these vulnerable environments. A holistic and integrated approach is needed for effective implementation of key environmental policies and to address key current and emerging environmental and societal challenges related to River-Sea Systems[1].

DANUBIUS-RI is an initiative to develop a pan-European distributed research infrastructure (RI) dedicated to R&I in River-Sea Systems. In 2016, the RI was accepted on the roadmap of the European Strategy Forum on Research Infrastructures (ESFRI). It will comprise facilities, resources and services to enable R&I spanning the River-Sea continuum. By facilitating interdisciplinary R&I, crossing disciplinary, political and geographical boundaries, engaging stakeholders and the public(s), DANUBIUS-RI aims to achieve a step-change in process and system understanding, and finally management of River-Sea Systems.

DANUBIUS-RI's *mission* is to achieve a better understanding of how River-Sea Systems function and how these social-ecological systems are evolving under multiple and interacting pressures. For example, how are River-Sea Systems changing due to natural and human pressures? How are processes in the catchment and headwaters affecting transitional and coastal waters further downstream, and *vice versa*? How can we distinguish human-induced changes from those driven by natural processes? This is essential for developing effective measures. Can we identify tipping points in River-Sea System functioning? How can we better characterise River-Sea Systems (e.g. using state-of-the-art Earth Observation or citizen science)? How can we predict short- and long-term changes in River-Sea Systems and how can we manage River-Sea Systems sustainably?

DANUBIUS-RI's *vision* is that this mission will be implemented by long-term provision of top-level research facilities, for example in a wide range of Supersites ('living labs') in selected European River-Sea Systems, facilitating the execution of cutting-edge environmental research. Furthermore, DANUBIUS-RI's mission will be achieved by being a 'one-stop shop' for knowledge exchange, access to harmonised data, and a platform for interdisciplinary research, education and training (DANUBIUS-PP, 2016). DANUBIUS-RI aims to develop and facilitate holistic and integrative research approaches to enhance process and system understanding, and thus achieve a step-change. This can only be achieved by studying River-Sea Systems as a continuum, to provide scientifically informed information to enable better-informed and holistically engaged environmental

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[1] Illustrated by the large number of sectorial European policies related to River-Sea Systems: the Water Framework Directive (WFD), the Flood Directive(FD), the Urban Waste Water Treatment Directive (UWWTD), the Marine Strategy Framework Directive (MSFD), the Maritime Spatial Planning Directive (MSPD), the Nitrate Directive (ND) and the Habitats Directive (HD).

protection of River-Sea Systems, to mitigate human impacts and maintain their ecosystem functioning, and thus their capacity to provide ecosystem services.

DANUBIUS-RI will also contribute to the scientific basis for informing environmental policymaking. A better scientific understanding of the functioning or River-Sea Systems can facilitate the joint implementation of existing European environmental policies, e.g. the Water Framework Directive, Marine Strategy Framework Directive, Floods Directive, and Habitats Directive. This is essential to reconcile intensive human use and environmental protection in River-Sea Systems, and requires holistic approaches to R&I to deliver enhanced process and system understanding. That understanding will also support the achievement of many of the United Nations' Agenda 2030 Sustainable Development Goals (SDGs) of which two - 'Clean Water & Sanitation' (SDG 6) and 'Life below Water' (SDG 14) explicitly emphasize the role of water for humans and nature (UN, 2015).

Furthermore, DANUBIUS-RI will build on the knowledge of past and present program initiatives and research projects related to the advanced studies of River-Sea Systems to develop the Science and Innovation Agenda of DANUBIUS-RI, to build collaborations and to integrate DANUBIUS-RI with other initiatives. *Relevant actors and events* for the science developments of DANUBIUS-RI are listed in *Annex I*.

However, how to identify tangible and achievable ways to facilitate R&I on River-Sea Systems that can help in providing solutions to current and emerging challenges? This provides the wider context in which to develop a research infrastructure in European River-Sea Systems and the framework that enables collaborations on interdisciplinary projects that address key challenges extending across the freshwater-marine continuum.

2. Research & Innovation to address Challenges in River-Sea Systems

In this chapter, we summarize the current key environmental and socio-economic challenges in River-Sea Systems before outlining the research required to address these challenges in the following sub-chapters. River-Sea Systems represent complex social-ecological systems (SES) and complex adaptive systems (Gibbs and Cole, 2008), in which:

- a large numbers of components undergo an array of simultaneous nonlinear interactions;
- the behaviour of the whole system feeds back to its individual components, thereby modifying their behaviour;
- the interactions evolve over time as the components adapt in an attempt to persist as part of the wider environment that includes the other components of the whole system.

Due to this complexity, the Driver – Pressure – State Change – Impact – Response (DPSIR) conceptual framework (Figure 2) has been used to identify challenges and related R&I needs in River-Sea Systems. An introduction into the DPSIR conceptual framework is provided in *Annex II: Methodology of Driver-Pressure-State-Impact-Response (DPSIR) Framework*. This approach links cause-effect relationships among the five categories (D, P, S, I and R) and has been successfully applied in other studies (e.g. LOICZ Science Plan, FP7 projects ELME & KNOWSEAS) to analyse and assess social-ecological problems in aquatic systems (Gari *et al*., 2015).

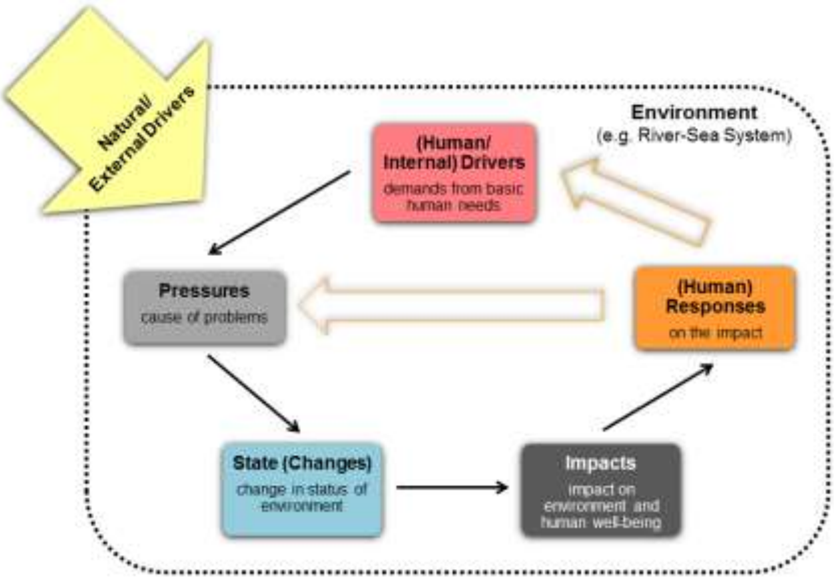


Figure 2 DPSIR conceptual framework illustrating the difference between external and internal drivers in relation to the systems boundary (dotted line). Also shown are feedback loops: e.g. indicating human response to reduce negative effects of pressures or adaptive management of drivers (adopted after Gregory et al., 2013).

This analysis included a literature review and input from the DANUBIUS-PP project partners to identify the key challenges in River-Sea Systems - globally and regionally, in the DANUBIUS-RI Supersites. In order to identify cause-effect relationships in River-Sea Systems and to derive related challenges and R&I needs, a causal chain analysis was performed for selected DANUBIUS-RI Supersites (*see Annex III: Research Needs in Selected Supersites*). We further developed DANUBIUS-RI's view on current and anticipated challenges, and related R&I needs in River-Sea-Systems during a workshop with representatives of each work package in DANUBIUS-PP, as well as representatives of Nodes and Supersites. Figure 3 shows a graphical presentation of the application of the DPSIR analysis to River-Sea Systems in Europe.

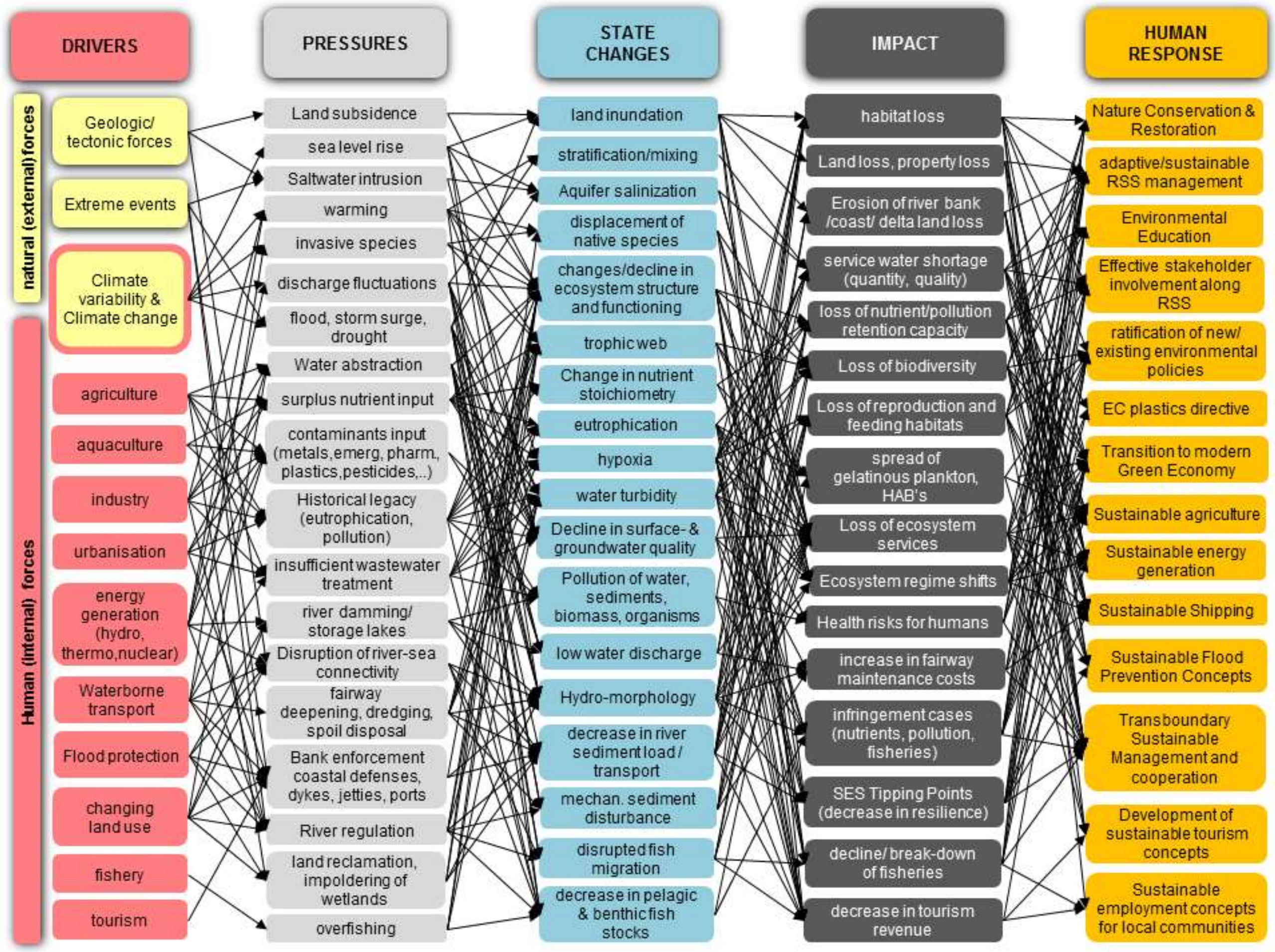


Figure 3 Example of the DPSIR conceptual framework applied to European River-Sea Systems

Natural (external) drivers are geologic and tectonic forces, climate variability and extreme events. Human (internal) drivers include climate change, agriculture, aquaculture, fisheries, energy generation, urbanization, waterborne transport, industry and tourism. The pressures resulting from past and present human activities cause a wide range of ecosystem state changes, which have multiple impacts on River-Sea Systems and thus ecosystem services provision. They represent important challenges for society and the environment. For example, what are effective human responses (management, regulation) to combat or mitigate the impacts, either by addressing the drivers directly or by mitigating the pressures? To achieve the necessary integration of academic and practical knowledge, appropriate strategies based upon dialogue, models, products, visions and/or common metrics must be developed (Hirsch Hadorn et al., 2010, see also *3. Outlook – Towards DANUBIUS-RI's Science and Innovation Agenda*).

As an intermediate step in developing DANUBIUS-RI's Science and Innovation Agenda, the R&I challenges that were addressed in the DPSIR Supersite analyses were clustered during the workshop mentioned above. Thus, four overarching challenges in River-Sea Systems were identified (Figure 4):

- Cumulative Effects of Climate Change and Increasing Human Use
- Water Sufficiency
- Sediments and their Management
- Ecosystem Health

DANUBIUS-RI conceives *Water Sufficiency* as the challenge of ensuring continued water availability for both anthropogenic and environmental needs. It includes water of sufficient quantity as well as quality of both surface waters and groundwater along the freshwater-marine continuum to maintain ecosystem functioning and to provide ecosystem services. *Sediments and their Management* is also cross-cutting issue, with links to, and possible consequences for, many different sectors, regulatory interests and management requirements. *Ecosystem Health* links the biophysical understanding of how natural River-Sea Systems function with societal goals and human values.

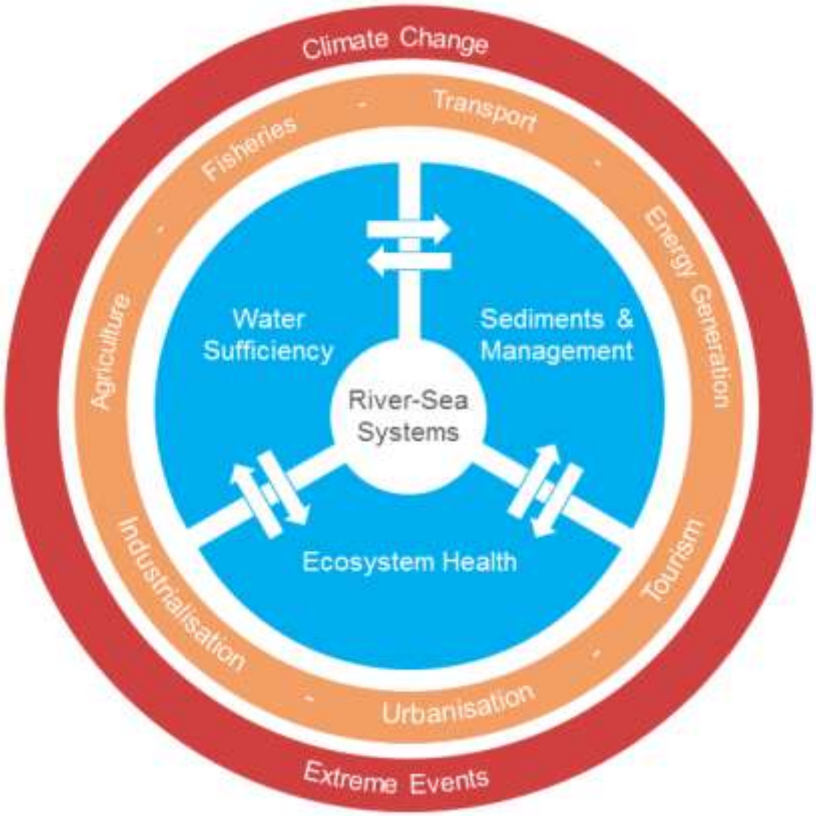


Figure 4 External (Climate Change and Extreme Events) and internal drivers (Fisheries, Transport, etc.) resulting from basic human needs cause cumulative effects on River-Sea Systems. DANUBIUS-RI identified overarching challenges related to Water Sufficiency, Sediments and their Management, and Ecosystem Health.

2.1 Cumulative Effects of Climate Change and Increasing Human Use

Over the period 1880 to 2012, global mean temperature has increased by an estimated 0.8˚C (IPCC, 2013). This increase is largely attributed to greenhouse gas emissions since the industrial revolution (IPCC, 2013). Each of the last three decades has been successively warmer than any preceding decade since 1850. In the northern hemisphere, 1983-2012 is thought to have been the warmest 30-year period of the last 1400 years (IPCC, 2013). The effects of climate change will be particularly marked for the water cycle in general and in River-Sea Systems in particular (Bates et al., 2008), e.g. due to sea level rise and land inundation, and increasing frequency and intensity of extreme events. There will be considerable socio-economic impacts, for example on agriculture, communications, transport, utilities, infrastructures, industry and business (Field et al., 2014, Brown, 2016). Long-term mitigation and adaptation will be crucial to maintain River-Sea Systems for human well-being. Hence, an integrated view on water, ecosystem health and environmental flows is essential to devise sustainable agricultural and economic systems that will allow us to decelerate climate change, protect us from extremes whilst at the same time, adapting to the unavoidable (UN-Water, 2017a).

The functioning of River-Sea Systems is defined by the interplay of the two big groups of drivers and their consequences: climate change and basic human needs (internal drivers). A clear distinction between climate and human drivers is crucial for effective mitigation programmes or to prevent unwanted effects, due to differences in control of the drivers and the efficacy of the measures adopted (KDM, 2007). Anthropogenic trends in climate change are superimposed on natural, low-frequency climate variability (e.g. decadal or multi-decadal climate oscillations like North Atlantic Oscillation), which complicates a clear distinction. Climate change and internal human drivers act over different temporal and spatial scales. Humans can only mitigate the effects and impacts of natural forces like climate variability, extreme events and that of geologic forces (e.g., land subsidence and earthquake-mediated tsunamis), but cannot intervene with the natural drivers directly. In the long-term, reduction of greenhouse gas emissions will take effect on climate change. However, in the short-term human responses also have to focus on reducing the negative effects of associated pressures, e.g. sea level rise and changing precipitation patterns. In contrast, human drivers associated with ever-increasing human activities in River-Sea Systems operate on shorter temporal and smaller spatial scales. Therefore, adaptive management of the drivers can prevent undesired state changes and impacts on environment and human well-being.

CUMULATIVE EFFECTS OF CLIMATE CHANGE AND INCREASING HUMAN USE:
Selected Research Needs & Questions

DRIVERS

- How can we distinguish between natural variability, climate change and human drivers defining altogether the evolution of River-Sea Systems?
- How can we efficiently differentiate between the various human drivers?
- How do the individual drivers affect the fluxes, cycles and budgets of water and dissolved and particulate matter in River-Sea Systems?
- To which extent and why are individual River-Sea Systems behaving differently?

PRESSURES

- How will sea level rise, warming, shifting seasons and changing precipitation patterns affect key attributes of River-Sea Systems, like discharge regime, tidal patterns, suspended matter and sediment dynamics, benthic-pelagic coupling, biological productivity and biodiversity?
- In which way, and to what extent are climate change induced pressures coinciding with other human pressures, like pollution or nutrient loading? How are they affecting each other?

STATE CHANGES

- What are the best indicators to represent the complex drivers and associated pressures qualitatively and quantitatively?
- How are processes and changes in the headwaters affecting those further along the River-Sea continuum and in various types of River-Sea Systems? What are respective timescales?
- How are changes in coastal seas influencing River-Sea Systems further upstream (e.g. sea level rise)?

IMPACTS

- How resilient are River-Sea Systems to increasing pressures, e.g. depending on their climate zone, range of human alteration, maturity of social processes?
- What are the ranges of climate and human induced changes to which River-Sea Systems are able to adapt while maintaining ecosystem functioning and services?
- What are the key thresholds for the functioning of these social-ecological systems?

HUMAN RESPONSES

- What recommendations for policymaking can be derived from enhanced process and system understanding?
- Which challenges in River-Sea Systems can be solved technically, which need a change of regulation/policy and which require changes in human perception and behavior? How could all these measures be integrated effectively in adaptive management strategies?
- What are efficient decision-making instruments to choose the best options to manage the system to create and maintain conditions for sustainable growth and eco-innovation for jobs and economic development, for sustainable living, housing and working?
- How can we better observe and predict process and system dynamics? What infrastructure is required?

2.1.1 Extreme Events

Water-related extreme events such as floods, storm surges, strong short-term fluctuations in river discharges and severe droughts are natural phenomena, however, they are projected to increase in intensity and frequency due to climate change (IPCC, 2013). Extreme events are short-term events, with the potential to severely modify coastal and riverine dynamics. They turn into disasters with wider societal impacts when humans are affected, due to increasing settlement density close to rivers and coasts and the increasing intensity of use. Water-related disasters pose both direct impacts (e.g. damage to buildings, crops and infrastructure, loss of life and property) and indirect impacts (e.g. losses in productivity and livelihoods, increased investment risk, indebtedness and human health impacts) (UN-Water, 2017b).

EXTREME EVENTS: Selected Research Needs & Questions

DRIVERS

- What are the reasons that make extreme events more severe with regard to their consequences for humans and nature?
- How are flood protection measures (e.g. dyke construction, reduction of floodplains) affecting flood regime (inland waters) and development of flooding (incl. coastal)?
- How are extreme events (low flow & floods) interacting with water-quality issues (e.g. eutrophication, hypoxia, contaminants)?

PRESSURES

- What are the mechanisms triggering extreme events (e.g. floods, droughts, storm surges, tsunamis), which may develop into disasters at different scales?

STATE CHANGES

- How are extreme events influencing the linkages between individual components of River-Sea Systems?
- How are extreme events influencing the evolution of River-Sea Systems?
- How are extreme events changing the hydromorphological conditions of River-Sea Systems (reversibly/irreversibly)?

IMPACTS

- For how long are "footprints" of extreme events visible (memory effects)? Which components return to pre-extreme event conditions? How long does it take? How are they influencing ecosystem functioning?
- How are extreme events influencing the chemical and ecological status of River-Sea Systems?
- How resilient are ecosystem functions and services to extremes events?

HUMAN RESPONSES

- How can we identify sustainable disaster prevention and mitigation concepts (e.g. maintaining lateral floodplain - river connections, quantifying the ecosystem services provided by River-Sea Systems in relation to climate change, protection measures for urban areas, sewerage systems)?
- What are adequate management strategies against droughts in River-Sea Systems (e.g. considering the ambiguous effects of water storage in the headwaters)?

2.2 Water Sufficiency

Water is an essential natural resource. The geology in the source area and the catchment determines largely the chemical composition of the water. The human drivers of agriculture, urbanisation, industry, energy generation, water-borne transport, changing land use and associated pressures such as channelization, dams and reservoirs, water abstraction, insufficient waste-water treatment, nutrient loading and pollution are transforming River-Sea Systems and the quantity and quality of water and sediment transported to the sea. Climate change pressures, such as increasing temperatures, floods and invasive species, are additional stressors (see *2.1 Cumulative Effects of Climate Change and Increasing Human Use*).

Water sufficiency addresses water quantity and quality, and takes into account water and dissolved, colloidal and solid matter fluxes. To achieve water sufficiency, we have to address challenges including eutrophication and hypoxia, pollution by organic and inorganic contaminants, changes in river and coastal flow regime and morphology, water abstraction and salinization, to avoid a decline in ecosystem structure and functioning, and thus ecosystem services, such as nutrient and pollution retention and transformation capacity. However, phenomena like eutrophication, pollution or hydromorphological changes must be addressed as cross-cutting issues. They are the result of complex interactions between water, morphological structures (riverbed, banks/coasts, floodplains/marshes), sediment and biota.

2.2.1 Changes in Hydro- and Morphodynamics

Future projections indicate that the demand for water, food and energy will increase significantly over forthcoming decades under the pressures of population growth, economic development, urbanization and climate change (UN-Water, 2013). Agriculture (incl. crops and livestock), fisheries, aquaculture and forestry, is both a cause and a victim of water scarcity. It accounts for an estimated 70 per cent of global water withdrawals, while competition with other sectors for water is increasing[2]. This will increase the pressure on future water resources availability. To combat the impact of both land use change and climate change on catchment hydrology and river flow, solutions are needed to increase the current water retention capacity of individual catchments, and optimize catchment drainage (e.g. restoring wetlands and forests, increasing groundwater recharge).

Hydro- and Morphodynamics of River-Sea Systems have been significantly altered in the past by river regulation and water abstraction due to agriculture, energy generation, waterborne transport, flood protection, and industrial production. On one hand, storm-surge and flood protection measures, like dykes provide essential protection for local populations, and navigable rivers provide valuable

[2] www.fao.org/land-water/overview/WASAG

transport links and associated employment. On the other hand, river regulation, and excessive water abstraction for industry and agriculture have multiple adverse consequences with respect to society and environment (Blackbourn, 2006). These adverse consequences include increasing water shortages, changes in water residence time, changes in dissolved and particulate matter and the loss of biodiversity. The disconnection of floodplains from rivers and drainage of wetlands causes negative environmental feedbacks. This may result in fundamental shifts in the structure and functioning of freshwater, transitional water and coastal ecosystems, as well as associated semi-aquatic and semi-terrestrial ecosystems affecting ecosystem services and thus society.

The deepening of navigation channels in estuaries and their regular maintenance through dredging and the relocation of dredged material may result in increases in water turbidity, i.e. shifting of, and increase in turbidity zones, and amplifying the tidal ranges in estuaries downstream (Winterwerp et al., 2013). The loss of intertidal areas has reduced their resilience to further engineering works (e.g., increase in hydraulic pressure due to deepening), with the loss of accommodation space for suspended fine sediment (Winterwerp et al., 2013). In addition, continued deepening of navigation channels in estuaries results in sediment displacement, which has a profound influence on nutrient uptake capacity diminishing the resilience of estuaries to further impacts. Embankments prevent natural gradients from land to sea, which has also impacts on salt marshes, for example in the Wadden Sea (De Brouwer et al., 2001).

Flow manipulations hinder channel development, drain floodplain wetlands, reduce floodplain productivity, decrease dynamism of deltas, and may cause extensive modification of aquatic communities (Nilsson et al., 2005). Reservoirs are needed for drinking water storage, energy production and irrigation. However, dams also fragment aquatic habitats, impeding not only the movement of species but also the delivery of nutrients and sediments downstream. Similar to that of sediments, the distribution and accumulation of contaminants in River-Sea Systems is modified by dam obstruction and reservoir retention (Lehner et al., 2011). These and other effects have been directly linked to the loss of populations and entire species of freshwater fish (Nilsson et al., 2005). Hydromorphological modifications may lead to excess sedimentation (e.g. in artificial lakes or shallow water zones) or erosion (e.g. sediment starving rivers downstream of a dam and coastal beach erosion). This also causes degradation of aquatic habitat quality including: 1) changes in coarse material load/deposition needed for spawning (e.g. salmon), applications to organism burrowing (fine vs coarse fractions); 2) changes in fine material load – i.e. decrease/increase of turbidity and related light availability and light quality, temperature, trapping/releasing of contaminants (see also *2.4 Ecosystem Health*).

CHANGES IN HYDRO- & MORPHODYNAMICS: Selected Research Needs & Questions

DRIVERS

- What are the key features determining the catchment hydrology (flow regime, natural water resources availability)?
- What is the impact of land use changes on flow regime and morphology (e.g. role of wetlands and forests?
- How might further river regulation affect the flow regime, the water and sediment balance and the morphology of River-Sea Systems?
- What is the role of groundwater in maintaining river base flow?

PRESSURES

- What are the effects of retention measures in the catchment on the river flow regime?
- How do morphodynamic changes affect hydrodynamics, suspended sediment distribution and transport in estuaries (including upstream transport)?
- Which processes cause the transition to hyperturbid estuaries? What are the effects of deepening, narrowing and dredging?

STATE CHANGES

- How can we effectively assess the influence of hydroengineering on:
  - hydro- and morphodynamics (incl. tidal patterns), turbidity zones and suspended particulate matter segregation, turnover processes of dissolved and particular matter?
  - nutrients and oxygen dynamics?
  - release of contaminants from sediments?
- What are the combined effects of flow regulation and climate change on the seasonality of water discharge? What are the implications for the functioning of wetland ecosystems (deltas, estuaries, lagoons)?
- How are the fast dynamics of suspended particulate matter (SPM) in the water column and the slow dynamics of the bottom pool interacting to determine estuarine turbidity maxima (ETM) locations and variability, and what processes govern the mobile bottom pool dynamics?
- What are the fractions of fluvial and marine SPM classes in ETMs, and what are the transport mechanisms to bring marine SPM from the shelf sea into the estuary?

IMPACTS

- How are hydroengineering measures influencing aquatic and riverbank ecosystem structure and functioning, as well as aquatic biodiversity and habitat availability?
- How effective are natural retention measures ("nature-based solutions") in mitigating extreme river flow events?
- What processes trigger the transition from normal to hyperturbid estuaries, and how much does the transition depend on direct human invention, such as deepening or narrowing?

HUMAN RESPONSE

- How can we assess the sustainability of hydro-engineering measures?
- Is the "building with nature" concept an option to harmonize ecosystem health and the provision of ecosystem services?
- How effective are natural retention measures (nature-based solutions) in the catchment in increasing water resource availability?
- How do restoration projects influence the River-Sea System?
- What are effective measures against anthropogenically increased turbidity in estuaries?

2.2.2 Eutrophication & Hypoxia

Eutrophication is a major challenge in many River-Sea Systems globally. Mainly due to an excessive use of fertilizers in arable farming and extensive livestock farming in catchments (Carstensen et al., 2012), and point source inputs from wastewater treatment and industry, River-Sea Systems receive surplus nutrients (N, P) leading to extensive algal blooms, both in rivers and in coastal seas. Decomposition of the algal biomass and zooplankton excretions leads to surplus oxygen demand and often to subsequent hypoxia, with widespread consequences e.g. fish kills (Steckbauer et al., 2011, Hilton et al., 2006). Excessive nutrient input from rivers in combination with supporting climate conditions can lead to major algal blooms e.g. River Thames (Moorhouse et al., 2018, Bowes et al., 2016) and Elbe (Hardenbicker et al., 2014). This has caused severe eutrophication and hypoxia events in a number of receiving seas in the 1970s to 1990s, e.g. in the Black Sea, Baltic Sea, and Northern Adriatic Sea (Diaz and Rosenberg, 2008, Friedrich et al., 2014) with dramatic consequences for the functioning of coastal pelagic and benthic ecosystems (Zhang et al., 2010).

Insufficient treatment of industrial and urban wastewater from a growing human population represent additional source for excess nutrients in many regions. P inputs in Europe have decreased in recent decades primarily due to the implementation of the EU's Urban Wastewater Treatment Directive (EEC, 1991) resulting in improved wastewater treatment (Foy, 2007), and a ban on the use phosphates in many detergents in many industrialized countries. However, N inputs continue to increase globally (Battye et al., 2017) and are more difficult to manage given their mainly diffuse origin (Howarth et al., 2011). Furthermore, wetland drainage reduces the natural ability of catchments to remove excess nutrients, aggravating eutrophication issues (Hansen et al., 2018).

In many regions, climate change may also lead to higher water temperatures, the increased flow of freshwater and nutrients to coastal waters, and stronger stratification, intensifying coastal eutrophication and increasing the development of hypoxia (Rabalais et al., 2009). Climate change further reduces ecosystem resilience and can act as a trigger towards tipping points of ecosystem states (e.g., (Oguz and Gilbert, 2007). Hence, the nutrient balance in River-Sea Systems is crucial for the functioning of these ecosystems.

EUTROPHICATION & HYPOXIA: Selected Research Needs & Questions

DRIVERS

- What are the sources, pathways and transformations of nutrients into/in River-Sea Systems? How can they be traced and quantified?
- How are extreme events influencing nutrient and oxygen dynamics, sediment and suspended particulate matter dynamics?

PRESSURES

- How are global change processes such as increasing human population, urbanization or migration affecting nutrient loading of surface and groundwaters?
- What is the contribution of past eutrophication (in sediments) to present nutrient budgets and thus fueling eutrophication?
- How is regular dredging of navigation channels influencing the nutrient retention capacity?

STATE CHANGES

- What are the interactions and feedbacks between changes in habitats, food webs, and bio-geochemical transformations?
- What are the consequences of changed N/P/(Si) ratios on ecosystem structure and functioning and the carrying capacity in the riverine, estuarine and coastal environments?
- What is the contribution of bank, floodplain and marsh vegetation to nutrient budgets and sediment dynamics and budget?
- How are eutrophication, hypoxia and warming interacting? What are cumulative effects?

IMPACTS

- How are processes and changes in the catchment/headwaters impacting the ecosystem state downstream, in estuaries/deltas and coastal seas?
- What are the linkages between eutrophication, fisheries and climate change for the spread of gelatinous plankton and harmful algal blooms in coastal seas?

HUMAN RESPONSES

- How can societal change contribute to combating surplus nutrient inputs and which tools will be most efficient?
- Which gaps need to be closed and which links must be created in the different relevant regulations (e.g., WFD, FD, MSFD, MSPD, ND, HD, Natura 2000) for a coherent nutrient policy?
- How long does it take for measures in the catchment to take effect in adjacent coastal seas? e.g. sewage treatment plant improvements and reduction measures on fertilizers and manure in agriculture and aquaculture
- What would be reasonable nutrient thresholds in the headwaters, catchment and groundwater bodies to comply with EU regulation downstream in the estuary and coastal sea?
- How can baselines for tolerable eutrophication levels in River-Sea Systems be assessed across diverse River-Seas Systems?
- How can we improve nutrient retention in the River-Sea continuum?

2.2.3 Pollution incl. Emerging Pollutants

In this context, the terms ‘pollutant’ and ‘contaminant’ refer to organic and inorganic dissolved, colloidal and particulate substances of anthropogenic origin other than nutrients that have undesirable effects on ecosystem and human health. Significant amounts and a wide range of different pollutants enter River-Sea Systems, challenging water and sediment quality for humans and nature. Attention is needed both to address unresolved contamination problems due to ‘well-known’ pollutants, such as metals and metalloids or persistent organic compounds (these are often present in European waters as legacies of the past in sediments; they are regularly monitored and strongly regulated) and due to emerging pollutants, which are currently neither regularly monitored nor regulated but which are causing growing concern. Prominent examples of this heterogeneous (in terms of composition, structure, origin, distribution between water, sediment and biota, and effects) group are functionalized nanoparticles and microplastics, multi-resistant pathogenic germs, substances from pesticides, flame retardants, anti-fouling substances and pharmaceuticals.

Contaminants may threaten groundwater resources and thus drinking water. They affect wildlife communities via different modes of action which can be related to the molecular, sub-organism or organism level (*see also 2.4 Ecosystem Health*). The more complex the level, the more difficult it will be for organisms to compensate the adverse effects. If compensation mechanisms fail, core functions like reproduction will be disturbed which in turn will negatively affect the community level. Some pollutants have a bio-magnification potential across trophic levels. Bioaccumulation in the food chain of those harmful substances poses a danger for the ecosystem and for humans themselves (Heydebreck et al., 2015, Schäfer et al., 2015, Vink, 2009). In general, pollution along with eutrophication leads to a substantial decrease in water and sediment quality (*see* also *2.3 Sediments and their Management*).

POLLUTION INCL. EMERGING POLLUTANTS: Selected Research Needs & Questions

DRIVERS

- What are the sources, pathways and transformations of pollutants into/in River-Sea Systems? How can they be traced and quantified?
- How do extreme events influence the dynamics of dissolved and particle-bound contaminants?

PRESSURES

- What are the implications of global trends, such as increasing urbanization and industrialization in River-Sea Systems, for the release of pollutants?
- What are catchment-specific substance and risk patterns of organic and inorganic contaminants (along gradients of human use), plastics, antibiotics and pharmaceuticals? What triggers their remobilization, pathways and damage potential along the River-Sea System?
- What is the contribution of pollution to the degradation of River-Sea Systems compared to other pressures, e.g., eutrophication, invasive species, river regulation, water abstraction?
- What are pollutant baseline patterns from (river) source to sea and how variable are they over time?
- What is the environmental fate of pollutants, including emerging pollutants and (micro) plastics, from the emitter to the sea? How are they emitted, distributed and transformed in the environment?
- How relevant is the contribution of past pollution on present water quality?

STATE CHANGES

- What are the effects of emerging contaminants on biota? How are they transferred in the food chain and how can we better display synergistic effects in the future? How are contaminants transformed during their passage through the system?
- Are changes in distribution patterns of contaminants linked to their toxicity?
- How significant is mechanical sediment disturbance for the release, change in speciation and biomagnification of contaminants from sediments?
- What are the effects of climate change, land use change, and hydroengineering measures on distribution patterns of pollutants? What is the influence on pathways and harmful effects?

IMPACTS

- How are pollutants affecting the integrity of aquatic communities including biodiversity, as well as ecosystem functioning and services?
- What is the impact of pollutants in combination with other stressors on organisms, ecosystem functioning and services?

HUMAN RESPONSES

- Which measures beyond the Water Framework Directive etc. are needed to protect in a sustainable manner River-Sea Systems from pollution?
- How can we enable a high living standard whilst guaranteeing healthy River-Sea Systems?
- How can the efficiency of environmental quality assessments be increased to evaluate and secure water quality?
- Which target and non-target methods for the detection of emerging contaminants deliver the potential to describe the complete chemical budget of the respective water bodies?
- What will future strategies of risk assessment of anthropogenic compounds look like, in order to avoid costly harm reduction and repair measures? How will future concepts for water pollution control in River-Sea Systems look like?

2.3 Sediments and their Management

Natural river basins are continuously evolving and adapting. Erosion, sediment transport and sedimentation have been key factors for landscape development, the genesis and degradation of soils, water quality, the evolution of aquatic habitats and the formation of river deltas for geological eras. Sediment is an intrinsic part of River-Sea Systems like soil and (ground)water. River-born sediment originates from the weathering of rocks and their minerals, organic material and soils in upstream catchment, and from river bank erosion and other instream sources. The type of the river (i.e. whether alluvial, bedrock or a mixture of both) determines whether the water of the River-Sea System is turbid or clear by nature. As flow velocities decline in lowland areas, transported sediment settles on the river bed and banks, and in floodplains during flooding. The permeability of the river bed sediments determines to a large extent the rate of water movement between rivers and underlying alluvial aquifers, and hence, has an important role for floodplain ecosystem characteristics and groundwater formation.

At the mouth of most rivers, the remaining sediment is deposited within the estuary or delta and transported into the coastal sea, determining their sedimentary composition and, hence, benthic habitat types. The formation and decline of deltas and estuaries is intrinsically linked to the river and catchment sediment regime. The growth of modern deltas has been accelerated by changes in catchment land use (deforestation and agriculture), and increasing soil erosion, which have increased sediment transport (Maselli and Trincardi, 2013, Giosan et al., 2012). Sediment routing from source to sink through erosion, deposition and remobilisation can take periods of time ranging from several days up to several thousand years, introducing a historical component to River-Sea Systems (Hoffmann, 2015). Natural river hydro- and morphodynamics maintain a dynamic equilibrium, regulating small variations in water-flow and sedimentation by resuspension and resettlement. In estuaries, sediment transport occurs both downstream and upstream, mixing fluvial and marine sediment because of tidal currents (Salomons and Brils, 2004). Sediment forms habitats for benthic flora, fauna and microbial communities, while microbial turnover processes organic matter and recycles nutrients. Sediment also acts as a nutrient sink (e.g., burial, N-loss via denitrification and anammox; (Engstrom et al., 2005). Sediment dynamics and gradients (wet-dry and fresh-salt) form favourable conditions for a large biodiversity, from the river headwaters to the coastal zone.

Both small and substantial changes in sediment distribution, erosion, deposition, and transport are natural and necessary processes in aquatic ecosystems. Sediment dynamics are a prerequisite for morphodynamics, which provide ecologically important habitats e.g. for fish and benthic invertebrates at various life stages. The magnitudes of the sediment loads transported by rivers have important implications for system functioning; for example through their influence on material fluxes, geochemical cycling, water quality, channel morphology, delta development, and the aquatic ecosystems and habitats supported by the river.

Sediment is also a resource; humans utilise sediment in river systems as fertile farmland and as a source of construction material (Salomons and Brils, 2004). Sands are "now being extracted at a rate far greater than their renewal," as outlined in a UNEP report (Peduzzi, 2014). Sand must be considered as a particularly scarce resource. Sand is required to let foreshore areas grow in order to cope with rising sea levels. Sediment also plays a crucial role in goods and services provided by freshwater and marine ecosystems. Ecosystem goods and services may be affected by changes in sediment quality and quantity (*see 2.3.1 Sediment Quality & Quantity*): e.g. nutrient cycling, habitat substrate, resource, energy dissipation in the hydrological cycle, soil formation in inundation areas and delta regions, beach nourishment, and recreation (SedNet, 2017). In estuarine environments, increased suspended sediment concentrations can be an important reason for not achieving good ecological status.

2.3.1 Sediment Quality & Quantity

Sediment regime refers to the maintenance of sediment quantity and quality in River-Sea Systems. Common challenges regarding the sediment regime include erosion/deposition and transport of associated pollutants, as well as sediment retention due to river regulation. Sediment is closely linked to water quality issues, as sediments accumulate contaminants and nutrients, depending on particle reactivity, affinity to organic or lithogenic material and redox conditions (see also *2.2.3 Pollution*). Hence, the sediment record often provides an environmental archive of changing industrial and agricultural practices. Where water quality is improving, the legacy of past disturbances is usually present after several hundred years in sediments at the river bed, behind dams, in lakes, estuaries, seas and in the floodplains of many River-Sea Systems. Contaminated sediments in many River-Sea Systems represent a global problem because they may be eroded (e.g. due to flooding and channel bank erosion) or disturbed, due to dredging, and transported further downstream (Burton and Johnston, 2010, Chapman and Wang, 2001, Dagnino et al., 2013, Salomons and Brils, 2004).

In River-Sea Systems with human activities (pressures), sediment dynamics are often altered compared to the natural status. Erosion and sedimentation processes interact with human interventions in the sediment regime, like deepening of navigation channels, dredging for maintenance, damming for energy generation or drinking water reservoirs. Syvitski et al., 2005 showed that about 26% of the global sediment transit is trapped in reservoirs. Walling, 2006 estimates the total loss of worldwide reservoir volume due to sedimentation at a rate of 0.5 to 1 per cent per annum. Reservoir lakes behind dams are estimated to intercept > 40% of global sediment transport (Vörösmarty et al., 2003) and >50% of large river systems are affected by dams (Nilsson et al., 2005). These interceptions may result in either a sediment surplus or shortage. A surplus of sediment causes reservoir siltation with negative effects on hydropower production and water storage. It restricts navigation of waterways and might lead to increasing estuarine turbidity resulting in declining ecosystem health. A shortage of sediment due to river regulation and sediment retention behind dams causes coastal erosion and retreating or drowning deltas (McCarney-Castle et al., 2012). It causes incision of river beds and degradation of channel morphology with impacts on river habitat (e.g. a lack of suitable spawning habitat) and floodplain groundwater, stability of infrastructure and navigability. This phenomenon of drowning deltas will be further amplified by sea level rise.

Sediment transport and hydromorphology are closely interrelated; the latter is a central aspect of the status of a river under the Water Framework Directive. Hydromorphological characteristics of the river influence the sediment regime and are crucial for the diversity of habitats and biota (Bábek et al., 2008, Collins et al., 2011, Langhammer, 2010, see also *2.4 Ecosystem Health*).

2.3.2 Sediment Management

Where human activities interfere with sediment quantity or quality, sediment management becomes necessary. Since sediment is transported through the river basin to the sea, adverse environmental effects can occur not only locally but also at points far from the original source of contamination. This is especially true when contaminated sediments are "diluted" with pristine sediments and with higher biological activity, as is well known for the bio-methylation of metals and metalloids, e.g. mercury. Remediation and protection measures therefore need to be integrated into river basin management plans. To ensure that management is effective, we need better understanding of the underlying processes of remobilization, phase transfer, and bio-availability of contaminants and their transport, particularly under extreme conditions. Action is also needed, not only on source control, but also to deal with 'legacy' contamination. This is especially important in areas where contaminated sediment is likely to be remobilized during extreme events (e.g. floods), not least because such events are likely to become more frequent in many River-Sea Systems due to climate change (SedNet, 2014).

If we are to manage sediment for environmental objectives (e.g. for maintaining habitats) and/or for the needs of society (e.g. dredging for maintaining navigation), this should be undertaken with a full awareness of the impacts on nature and society in the River-Sea System. Coherent conceptual models, numeric models and information systems at River-Sea System scale (including river catchments) would be the best basis for considering the various functions and uses of sediment, operating at different spatial locations within a River-Sea System and operating at different time scales.

Effective sediment management requires a holistic approach that takes into account: 1) system understanding both in terms of quality and quantity; 2) the integrated management of soil, water and sediment; 3) upstream-downstream relationships; and 4) supra-regional and transboundary collaboration (SedNet, 2014). Managers of River-Sea Systems must have adequate sediment management plans, which require several preconditions to be fulfilled: First, all sediment management must be based on accurate knowledge about erosion, the pathways of sediment transport into the river system and sediment movement within the river system. Second, sediment quality is crucial for any kind of management. Contaminated sediments often pose serious problems to water management authorities because disposal can be costly. Thus, the first step towards a sound management plan is a survey of pathways, a screening for contaminants and putting in place a monitoring system that captures sediment quantity, dynamics and quality with adequate spatial and temporal resolution.

The sediment budget concept (Dietrich and Dunne, 1978) provides an invaluable framework to assist in managing and controling diffuse-source sediment pollution and associated problems, by identifying the key sources, demonstrating the importance of intermediate stores and determining the likely impact of upstream mitigation strategies on downstream sediment and contaminant fluxes (Walling and Collins, 2008). Historically, sediment management was driven by quantity issues and sediments were dredged to maintain waterways, or extracted as a resource (i.e. sand and gravel). Currently, much of the thinking on sediment management and sediment risk assessment focuses on sediment quality and on the role of sediments in sustaining a river's hydro-morphology and ecology. It is the interdependence between the management of sediment quantity and quality that has to be effectively addressed in up-to-date sediment management concepts that address the entire River-Sea System (Owens, 2005, SedNet, 2007, Heininger and Cullmann, 2015).

Erosion and sedimentation have further impacts over different temporal and spatial scales. The large scale sediment regime of a River-Sea System affects general ecological conditions like habitats and near shore aquatic biota. Locally, erosion and sedimentation can be critical to bridge pillars or culverts. Consequently, a sediment management plan should consider different scales and integrate the overall benefit of sediment management. A further step in the design of a management plan is a thorough risk analysis for different single objectives in the overall objective function. This means that priority areas, critical infrastructure, threshold values for sediment quality and/or scouring/sedimentation and ecological indicators need to be agreed and given a relative value in the overall objective function.

Different actors (nations, organizations, stakeholders) may have different objectives when they consider sediment problems. A framework must be devised that allows goals and priorities to be balanced in a transparent manner. Therefore the management plan must provide concrete advice on how the different objectives can be achieved; how they will impact each other, and should include an estimate of the costs of the measures required to achieve set objectives. The latter could include: 1) to guarantee certain shipping channel geometry and 2) to enhance sediment transport through locks and weirs. These objectives might be contradictory and, if pursued in isolation, a single objective might prejudice the other objective(s). Therefore, management plans must encompass tangible measures that will together address a multi-objective target. For example, the member states in the International Commission for the Protection of the Elbe River (ICPER) decided to develop a sediment management concept in preparation for the 2nd management cycle (2016 to 2021) of the Water Framework Directive. For the first time, an integrated sediment management concept was developed to support management planning in a large international river basin (ICPER, 2014, Heininger et al., 2015).

SEDIMENTS & THEIR MANAGEMENT: Selected Research Needs & Questions

DRIVERS
- What are the implications of human interventions to the sediment regime and sediment quality of River-Sea Systems?
- What are the effects of climate change on sediment regimes in River-Sea Systems?

PRESSURES
- How can legacy effects in River-Sea Systems be identified, quantified and managed?
- How can ecological boundaries for minimum and maximum sediment fluxes be determined?
- What are the effects of sediment management measures on sediment transport budgets, morphology, nutrient and contaminant fluxes, and on the community?

STATE CHANGES
- How is dredging and relocation of dredged material affecting suspended particulate matter dynamics?
- How is changing land-use in the headwaters/catchment affecting water sufficiency and sediment dynamics further downstream in River-Sea Systems?
- How are fast processes of suspended matter interacting with slower sedimentary processes within turbidity zones?
- How are dams and reservoir lakes affecting sediment quantity and quality (e.g. retention of nutrients and sediment, eutrophication in reservoirs, settling tanks for pollutants)?
- How are sediment regime changes relating to changes in hydromorphology?
- How can sediment transport budgets in different temporal and special scales be estimated efficiently?
- How are dredging and relocation of dredged material influencing the sediment dynamics and budget?

IMPACTS
- What is the fate and impact of dredged material, which is relocated further downstream or at sea? What is the impact on water quality, sediment transport and morphodynamics? How is that impacting River-Sea (Eco)System functioning?
- What is the impact of the ever-increasing human demand for sand on the functioning of River-Sea Systems?
- How is a disturbed sediment regime relating to water sufficiency?
- How are changes in sediment regime affecting (sediment related) ecosystem services provision in River-Sea Systems?

HUMAN RESPONSES
- How can negative impacts of dams and reservoirs on the sediment regime of a River-Sea System be minimized?
- How can cost-effective (e.g. nature-based) measures to restore sediment regimes in River-Sea Systems be achieved?
- How can we reduce maintenance dredging without affecting the navigability?
- How might wetlands (deltas, marshes) be managed sustainably given sediment starvation?
- How can common approaches on the assessment of integrated sediment budgets in River-Sea Systems be created?
- How can we improve knowledge transfer regarding process and system dynamics, e.g. with politicians, industry, citizens etc.?
- What are the best concepts to better manage cumulative pressures on sediments?
- How can stakeholders be best involved in sediment management at the local, regional, national and transnational (full River-Sea Systems) scale?
- How can we increase (public) awareness for sediment management?

2.4 Ecosystem Health

River-Sea Systems are complex and heterogeneous environments, that encompass a wide range of habitats and supporting ecosystems with a high biodiversity, and which in turn provide valuable ecosystem services. All freshwater (and marine water) environments ultimately depend on continued healthy functioning of ecosystems, and recognizing the water cycle as a biophysical process is essential to achieving sustainable water management (UN-Water, 2017c). A healthy ecosystem is considered stable and sustainable, maintaining its organization and autonomy over time and its resilience to stress, whereas stressed ecosystems are unable to support valuable ecosystem services to the same level as previously (Rapport et al., 1998). Biodiversity is the foundation for ecosystem structure and functioning, and thus ecosystem services. Species richness and diversity have been related to ecosystem functioning by a number of theories such as the redundancy theory (Walker, 1992). Given the hierarchical nature of ecosystems, habitat diversity and habitat heterogeneity are also important in structuring biodiversity (Connor and McCoy, 1979) and enhancing ecosystem functionality (Turner, 1989).

Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (de Groot et al., 2010). Maintaining biodiversity and ecosystem structure and functioning is the prerequisite for sustaining valuable ecosystem services, such as fish production, habitat provision, filtering and detoxification services, flood and storm protection (Barbier et al., 2011) and drought mitigation. Ecosystem services can contribute to wastewater treatment as an alternative or supplement to conventional water treatment systems. The water purification process provided by aquatic and terrestrial ecosystems supplies water suitable for drinking, industry, recreation, and wildlife habitat (UN-Water, 2017c). River-Sea Systems provide a diversity of provisioning, regulating, supporting and cultural ecosystem services (Butchart et al., 2005, Pinto et al., 2013):

1) Provisioning: products obtained directly from individual ecosystems, such as water, food, energy;
2) Regulating: benefits obtained from regulating ecosystem processes, such as regulation of water and sediment flow, water quality, climate;
3) Supporting: benefits necessary for the production of other ecosystem services, such as oxygen production and habitats for nursery;
4) Cultural: non-material benefits people obtain from ecosystems, such as recreation and tourism.

Threats related to maintaining ecosystem structure and functioning in River-Sea Systems include e.g. habitat fragmentation, pollution, eutrophication, invasive species, decrease in biodiversity, overfishing, impact of climate change and extreme events.

Changes in Hydro- and Morphodynamics

Pressures of river regulation, channelization, deepening and widening, as well as diking and bank stabilization, lead to habitat changes and losses. These activities reduce lateral connectivity between rivers and floodplains, altering river flows and associated matter fluxes. Similarly, dams and reservoirs diminish longitudinal connectivity, fragmenting habitats, impeding the movement of species, sediments and nutrients, as well as altering river flows. These and other effects have been directly linked to loss of populations and entire species of fish (Nilsson et al., 2005). About 65% of global river discharge and the aquatic habitat supported by water is under moderate to high threat (Vorosmarty et al., 2010). Floodplains and marshes have been dramatically reduced worldwide, mainly due to dyke construction and drainage. One of their widely acknowledged functions is the sequestration of sediment and associated substances. This ecosystem function has been severely reduced by the loss of floodplains (Ciszewski, 2001, Walling et al., 2000).

Eutrophication, Hypoxia & Pollution

Nutrient loading and chemical pollution due to agriculture, urbanisation and industry further challenge ecosystem structure and functioning in River-Sea Systems. Surplus nutrients can result in eutrophication and oxygen depletion (see also *2.2.2 Eutrophication*), which in turn can kill aquatic biota and alter trophic interactions. Organisms, which are chronically exposed to low and/or fluctuating oxygen concentrations, may suffer from impaired reproduction, immune responses and growth (Breitburg et al., 2009). Eutrophication contributes also to the temporal and spatial expansion of some harmful algal bloom species (Glibert et al., 2005) and changing nutrient ratios may shift communities towards harmful algal species. Chemical pollution affects water and sediment quality (see also *2.2.3 Pollution*), and may also have ecotoxicological effects (Heydebreck et al., 2015, Schäfer et al., 2015, Vink, 2009).

Invasive Species

Invasive species from ships ballast water, artificial connecting channels or due to shifting climate are a threat to ecosystem structure and function in River-Sea Systems. The speed of invasion appears to be accelerating with increasing globalization. Biodiversity, spatial heterogeneity, connectivity, succession, stability and resilience can all be changed by invasive species (Levin and Crooks, 2011). Changes in ecosystem structure and functioning often in turn change ecosystem services, with positive or negative effects for humans. Invasive species affect fisheries, aquaculture, shoreline stabilization, remediation and restoration, and carbon sequestration (Levin and Crooks, 2011).

Fisheries

Most estuaries are, biologically and economically, highly productive due to a combination of shallow waters and high riverine nutrient inputs. Globally, more than 90% of the wild fisheries catch is from the sea and less than 10% come from freshwaters (Blaber, 2011). The vegetation in and adjacent to estuaries, such as salt marshes, contributes to this productivity acting as nursery and feeding areas for fishes. The effects of fishing include not just overfishing, but also habitat alterations and the indirect effects of changing fish community structure by selectively removing some species.

Climate Change

The pressures of climate change and extreme events also affect ecosystem structure and functioning in River-Sea Systems. Warming may change the onset and duration of individual seasons and algal blooms, as well as species migration. Higher freshwater discharge and rising sea surface temperatures may enhance stratification in coastal waters affecting the flux of nutrients and oxygen, and ultimately changing ecosystem structure and functioning.

Multiple and Interacting Pressures

Determining how changes in ecosystem structure and functioning relate to ecosystem services and ecosystem health are major challenges at the interface of natural and social sciences (Rapport et al., 1998). The European Union has adopted ambitious water policies to reduce pressures and achieve a good ecological status for all water bodies (e.g. Water Framework Directive, Marine Strategy Framework Directive). However, assessing multiple and interacting pressures on River-Sea Systems and understanding their combined impact on ecological status is challenging, particularly at the large scale (Grizzetti et al., 2017). This raises key questions, such as what constitutes a healthy River-Sea System in the Anthropocene? In this context, it has to be recognized that most River-Sea Systems cannot return to their undisturbed past. Therefore, there is a pressing need to understand how "modern" River-Sea Systems are functioning and providing valuable ecosystem services to society nowadays and in the future (Large et al., 2017).

Carpenter et al., 2009 advocate expanding basic research on social-ecological systems and building on disciplinary strengths whilst at the same time bridging disciplinary divides to create the new knowledges required to build our River-Sea Systems in the Anthropocene into resilient social-ecological systems. Current observational records suggest that changes in parts of some River-Sea Systems are even more complex and pervasive and occurring at faster rates than anticipated (Cloern et al., 2016). Already Vitousek et al., 1997 concluded that "we are changing Earth more rapidly than we are understanding it". The change in River-Sea Systems will most probably accelerate given increasing population per capita resource use, and climate change (Cloern et al., 2016). Long time observations, experimentation and modelling are needed to observe, understand and predict these state changes due to interactive effects of human impacts.

ECOSYSTEM HEALTH: Selected Research Needs & Questions

DRIVERS

- How will climate change (e.g., warming, shifting seasons) affect ecosystem structure, functioning and services?
- What are the major drivers, vectors and pathways for invasion of non-native species? How can we depict potential invasion scenarios, e.g. ballast water, climate change, colonization corridors, pre-adaptations of possible invasive species?

PRESSURES

- What are the effects of multiple pressures on ecosystem structure, functioning and services?
- How are changes in biodiversity and habitat diversity affecting ecosystem functions and services?
- How can we maintain sufficient longitudinal and lateral habitat connectivity along the River-Sea continuum to protect ecosystem health?

STATE CHANGES

- What constitutes a healthy River-Sea System in the Anthropocene?
- What is the status of habitats and species and their interrelation along the River-Sea continuum? What are the keystone species/habitats?
- How does biodiversity and ecosystem function (including trophic chain) change along the River-Sea Continuum? Is there a commonality between River-Sea Systems?
- How are biodiversity and ecosystem services interrelated?

IMPACTS

- What is the impact of pollution on aquatic biota?
- What causes regime shifts ecosystem structure and functioning? Can we detect early warning signs for regime shifts in River-Sea Systems?
- Scenarios and process understanding to foresee and assess downstream – coast-upstream effects and impacts of man-made changes on hydro-morphology, river-sea connectivity and matter fluxes on ecosystem structure and functioning and ecosystem services.

HUMAN RESPONSES

- How can we harmonize ecosystem conservation, restoration, and intensive human use of River-Sea Systems?
- How can the requirements of the quality descriptors for good environmental status of the MSFD be achieved, especially the quality elements for good ecological status in the WFD?
- What are effective measures to restore and maintain longitudinal and lateral habitat connectivity along River-Sea continuum?
- How to overcome the deconstructive structural approach of the WFD and harmonize with the holistic functional approach of the MSFD as a basis for a new, joint directive for environmental status assessment?
- Understand “modern” aquatic ecosystem functioning

3. Outlook - Towards DANUBIUS-RI's Science and Innovation Agenda

Interdisciplinary research is a prerequisite to achieve the breakthrough, or step-change, in our understanding of the functioning of River-Sea Systems that is necessary to 'Make River-Sea Systems work' (*see 1. Introduction*). Interdisciplinary research has been defined by the US National Academy of Sciences as: "a mode of research by teams of individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (National Academy of Sciences et al., 2005). The definition provides two reasons for knowledge integration: 1) to advance fundamental understanding and 2) to solve problems.

DANUBIUS-RI will satisfy both reasons, but will do so in such a way that four fundamental requirements defining knowledge production are also satisfied: 1) grasp the complexity of problems; 2) take into account the diversity of scientific and life-world perceptions of problems; 3) link abstract and case-specific knowledge; and 4) develop knowledge and practices that promote what is perceived to be a common good (Pohl and Hirsch Hadorn, 2007). DANUBIUS-RI's systematic approach to problem solving is summarised in Figure 5. Here interdisciplinary research is conceived as a system where academic researchers and social actors closely interact for the benefit of shared aims, e.g. to ensure water sufficiency, balanced sediment conditions and environmental health in River-Sea Systems. The key academic disciplines necessary for solving a problem and real world sectors are represented by individual actors that in total, constitute the system and sustain it through the collaborative research process.

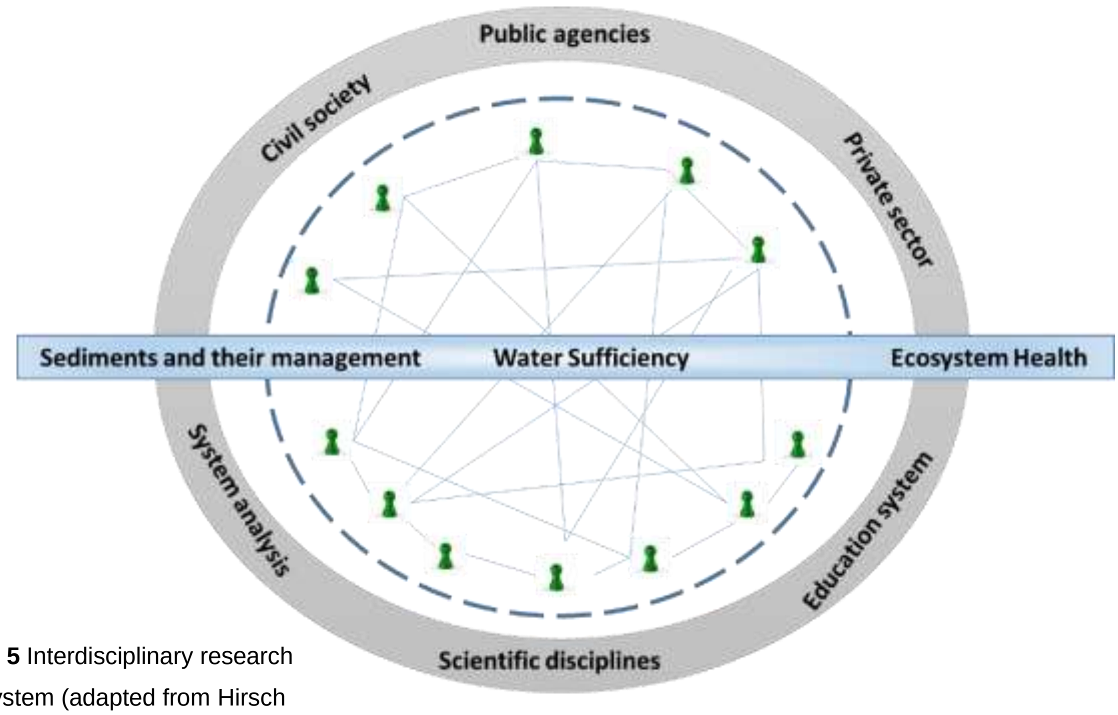


Figure 5 Interdisciplinary research as a system (adapted from Hirsch Hadorn et al., 2010)

The general methodological approach of DANUBIUS-RI in striving to achieve a deeper understanding of the functioning of River-Sea Systems and address the key societal challenges associated with, and opportunities of, River-Sea Systems (DANUBIUS-PP, 2016). Therefore, DANUBIUS-RI's scientific work will be recursive with respect to the three principal phases of: 1) problem identification and structuring; 2) problem investigation; and 3) implementation of the results (Pohl and Hirsch Hadorn, 2007). The overarching goal for integrating academic research with socio-economy is the mission of enhancing River-Sea System understanding in order to make them work, e.g. to comply with the UN Sustainable Development Goals (SDG)[3]. The intention is to seek to achieve this goal by permanently improving the management of River-Sea Systems based on a holistic perspective. It is intended also, that DANUBIUS-RI's research will lead to decision/management options that have to be implemented in the private and public sector and in the civil society. Inevitably, this will require work to address key uncertainties, resolve conflicting values and identify appropriate alternatives. The decision processes as well as gaining knowledge will become a joint effort between all actors involved (Figure 5) instead of being one of researchers solely.

DANUBIUS-RI's Vision on Research and Innovation

By integrated application of the following three principles (Brils et al., 2014), DANUBIUS-RI will enable River-Sea Systems to work, i.e. to tackle the challenges described in the previous chapter:

- **Get well informed**: The better we understand and exploit the available understanding of the functioning of natural River-Sea Systems, and how they are affect by human interventions, the more effective our societal response can be. This includes addressing critical knowledge gaps in terms of 'known unknowns' and 'unknown unknowns' (EEA, 2015) as to the factors controlling the mid- and long-term evolution of River-Sea Systems under changing scenarios;
- **Manage adaptively**: Learning-by-doing, thus allowing experimentation, as the natural systems with which we are intervening are complex and dynamic and can respond in non-linear and unexpected ways. Hence, apply an iterative approach: plan → do (implement measure) → check (monitor/learn) → act (improve plan);
- **Pursue a participatory approach**: Achieving a sustainable balance between human interventions that obstruct, and measures that mitigate drivers or restore River-Sea Systems, depends on constructive dialogue between various stakeholders, better policy coordination and effective trans-boundary cooperation. Furthermore, stakeholders can bring in essential understanding/expertise.

[3] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

ANNEX I: RELEVANT ACTORS & EVENTS

Actors

Actors dealing with River-Sea Systems are national environmental ministries, research institutes and universities, NGOs as well as other research infrastructures (so far not listed here). Regional and national actors associated with individual Supersites are listed in *Annex III: Research Needs in Selected Supersites* in the respective questionnaires of each Supersite. The following list includes international organizations, associations and programmes concerned with River-Sea Systems, and is continuously updated:

- Coastwatch Europe
- DG Research
- DG Environment
- DG Maritime Affairs and Fisheries
- Estuarine and Coastal Sciences Association (ECSA)
- European Association of Environmental and Resource Economists
- European Environment Agency (EEA)
- European Environmental Bureau (EEB)
- European Marine Board (EMB)
- Food and Agriculture Organization (FAO)
- Future Earth Coasts
- Global Environment Facility (GEF), International Waters
- Intergovernmental Oceanographic Commission (IOC)
- Intergovernmental Panel on Climate Change (IPCC)
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
- International Association for Hydro-Environment Engineering and Research (IAHR)
- International Association for Sediment Water Science
- International Council for the Exploration of the Sea (ICES)
- International Maritime Organization
- International Programme on the State of the Ocean (IPSO)
- International Union for Conservation of Nature (IUCN), Water Programme
- International Water Association
- Joint Programme Initiative Oceans (JPI Oceans)
- Joint Programme Initiative Water (JPI Water)

- OSPAR
- United Nations Convention on the Law of the Sea
- United Nations Development Programme (UNDP)
- United Nations Environment Programme (UNEP)
- World Resources Institute (WRI)

Events

The following list of major conferences are considered to be relevant for the scientific development of DANUBIUS-RI, and is further updated, if needed:

- Estuarine and Coastal Science Association (ECSA) Conference (annually in changing locations)[4]
- European Geosciences Union (EGU) General Assembly (annually in Vienna, Austria)[5]
- International Conference on River Basin Management (biennially in changing locations)[6]
- International Association for Danube (IAD) Research Conference (biennially in changing locations)[7]
- International Conference on Estuaries and Coasts (ICEC, triennially in changing locations)[8]
- International Conference Water Resources and Wetlands (biennially in changing locations)[9]
- International Conference on Research Infrastructures (ICRI, biennially in changing locations)[10]
- World Water Week (annually in Stockholm, Sweden)[11]

[4] www.ecsa.international/conferences-and-meetings
[5] www.egu.eu/meetings/general-assembly
[6] www.wessex.ac.uk/conferences/2019/river-basin-management-2019
[7] www.iad.gs/index.php?item=conferences&PHPSESSID=0e6044b1950a04a0c252aa546cc7ab5e
[8] www.waser.cn/waser/df/A5612index_1.htm
[9] www.limnology.ro/Ro/ARLG%20legaturi%20utile.html
[10] www.lter-europe.net/events/icri-2018
[11] www.worldwaterweek.org/

ANNEX II: METHODOLOGY OF DRIVER-PRESSURE-STATE-IMPACT-RESPONSE (DPSIR) FRAMEWORK

The Driver-Pressure-State-Impact-Response (DPSIR) framework is a widely adopted key conceptual framework (OECD, 1993). The EU adopted the DPSIR framework as an overall mechanism to analyse environmental problems, through the European Environment Agency and EUROSTAT (EC, 1999, Smith et al., 2016). DPSIR has been successfully applied around the world to analyse environmental problems and to support sustainable management of mostly coastal and marine systems (Lewison et al., 2016, Borja et al., 2006). The central idea of the DPSIR framework is a cause-effect continuum (Oesterwind et al., 2016).

The DPSIR framework is based on a Stress-Response Model, which was developed in the 1970s. The Organization for Economic and Cooperation Development (OECD) adapted it into a Pressures-State-Response Model in the early 1990s, while the European Environment Agency (EEA) developed the DPSIR framework as it is known today, by adding two new components: drivers and impact. These components helped in identifying cause - effect relationships between natural and anthropogenic processes, and thus making progress towards sustainable development (Lewison et al., 2016). The DPSIR framework has been widely applied by “Land Ocean Interactions in the Coastal Zone” (LOICZ) and several EU projects (e.g. ELME and KNOWSEAS). The United Nations Environment Programme (UNEP) have also adopted a version of the framework for their Global Environment Outlook Reports. We follow the definition of the terms “Driver”, “Pressure”, “State Change”, “Impact” and “Response” as suggested in (Wolanski and Elliott, 2015, Scharin et al., 2016, Patrício et al., 2016, Oesterwind et al., 2016).

Traditionally a driver is understood as a demand from the basic human needs such as e.g. food, water, shelter, employment, energy, security. (Oesterwind et al., 2016). **Drivers** refer either to exogenic forces (, e.g. natural hazards) or human activities (e.g. fisheries, urbanisation) originating from economic and social fundamental needs. These drivers create pressures. Both natural forces and human activities exert cumulative effects on the system, either reinforcing or alleviative. **Pressures** refer to mechanisms by which an activity has an actual or potential effect on any part of the ecosystem, and hence, contributes to change in ecosystem state, which can be either positive or negative. Unlike drivers, the intensity and direction or even the occurrence of pressures can be directly influenced through appropriate management (Oesterwind et al., 2016).

The effects on the components of the ecosystem are **State Changes.** State Changes encompass e.g., alterations to sediments, water column or their constituent biota due to the occurrence of a pressure. Hence, the state is the actual condition of the ecosystem and its components established in a certain area at a specific time frame. Ecosystem states are attributes reflecting ecosystem integrity (or not). The state can be described based on physical, biological, and chemical characteristics as highlighted also in the Marine Strategy Framework Directive (Oesterwind et al., 2016). Changes in ecosystem states are having **Impacts** on the ecosystem services and on human welfare. Impacts can be defined as consequences of environmental state change in terms of substantial environmental and/or socio-economic effects which can be both, positive or negative (Oesterwind et al., 2016). **Response** refers to the human/societal intervention intended to reduce the impacts through e.g., policy measures, information, behaviour change or management to reduce or prevent an unwanted change or to develop a positive (desirable) change in the ecosystem.

The DPSIR framework has many strengths but also some shortcomings, which need to be considered when applying the DPSIR framework to complex systems, such as River-Sea-Systems. First, the five categories D-P-S-I-R need to be defined clearly and specifically. Spatial and temporal scales are not covered in the model per se, therefore, defining the systems boundaries in the model is important. Although the DPSIR framework is extremely useful for structuring and conceptualizing complex problems, the real world is far more complex (Atkins et al., 2011). In reality, cause-effect relationships are neither always linear nor unidirectional and synergy plays an important role in environmental changes (Gari et al., 2015). For example, one driver can cause one or more pressures and one pressure can be based on one or more drivers (Oesterwind et al., 2016). Sometimes there is also a lack of knowledge on causal links between pressures and impacts on particular ecosystem components which might hinder the straight-forward application of the framework (Oesterwind et al., 2016).

ANNEX III: RESEARCH NEEDS IN SELECTED SUPERSITES

The Supersite-specific analysis of challenges and research needs supports the development of Supersite-overarching as well as Supersite-specific R&I to address the identified challenges. DANUBIUS-RI will combine interdisciplinary research and knowledge from Supersites along the River-Sea Continuum and within a range of River-Sea Systems to enhance respective process and system understanding. The following list of Supersites is an evolving list, which will be further complemented with additional Supersites and their research needs in the course of DANUBIUS-PP.

List of Supersites included in this deliverable:

1. Upper Danube Supersite, Austria
2. Middle Danube / Szigetköz Supersite, Hungary
3. Danube Delta Supersite, Romania
4. Elbe – North Sea Supersite, Germany
5. Nestos Supersite, Greece
6. Po Delta – North Adriatic Lagoons Supersite, Italy
7. Thames Estuary Supersite, United Kingdom

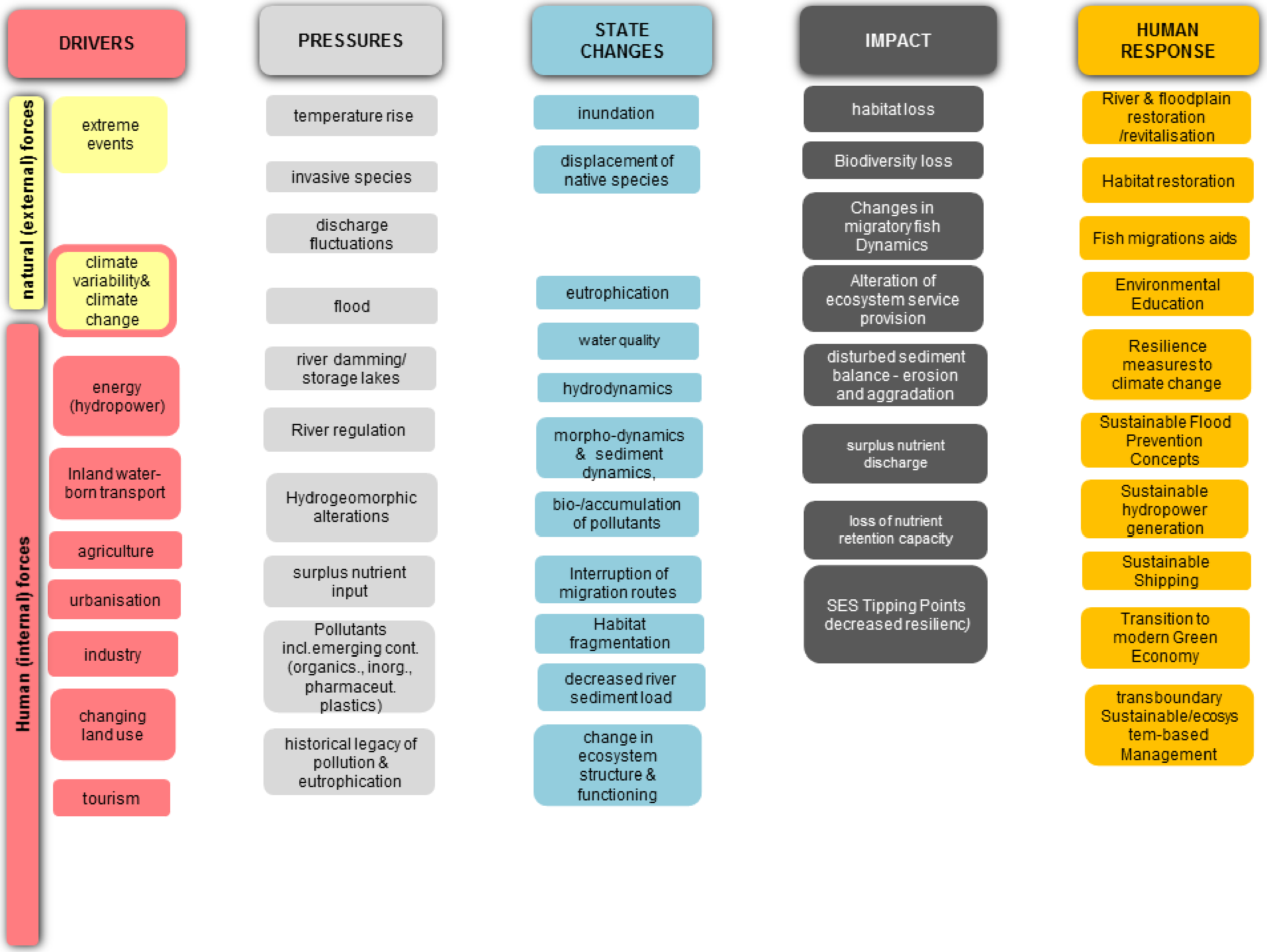
For each Supersite listed above, it follows:

- **DPSIR scheme**: The schemes were derived from interviewing the respective Supersite experts. The drivers and pressures refer to the whole River-Sea System; they are not just limited to the Supersite. For the Danube Delta - Black Sea Supersite and the Elbe - North Sea Supersite, links (displayed by arrows) for the causal chain analysis of the drivers to pressures to state changes to impacts and to human responses were drawn to analyse the interrelations of causes and effects, and to illustrate the complexity interacting drivers and their associated pressures in the respective River-Sea System. These links can also be developed upon request for the other Supersites in dialogue with the respective Supersite experts.
- **Table 1**: From the DPSIR analysis, we derived environmental challenges for the Supersites (column 3), scientific challenges, research needs and questions (column 4), as well as required research methods and tools (column 5).
- **Table 2**: From the environmental challenges, we derived in turn human responses and societal challenges to manage the drivers (column 1), scientific challenges, research needs and questions (column 2), as well as research methods and tools (column 3).

- **Questionnaire**:
  - Human activities (drivers) and resulting pressures
  - What are the resulting environmental/socio-ecological problems of the River-Sea System (current, anticipated, which of them are currently tackled)?
  - Current state of research? Research gaps and future research needs?
  - Which institutes, authorities, commissions are active in your region?
  - Whom do you consider as partners/stakeholders/users?
  - Open questions to support sustainable management of the River-Sea System?
  - Major scientific topics/questions addressing the Supersite

Supersite-specific research needs were provided by the respective Supersite representatives and by D5.9. Empty cells in the tables mean either no input was provided or the topic will not be covered in the Supersite. Supersite experts did not specify this.

1. Upper Danube Supersite, Austria – DPSIR Overview



Upper Danube Supersite, Austria – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Climate Change & Climate Variability	Warming	- long term changes in temperature patterns, changes in terrestrial inputs; - change in ecosystem structure and function	- effects on ecosystem structure and function - changes in trophic chains; impacts of new predators and prey - influence on carbon dynamics; biodiversity; - long-term changes in different ecosystems, e.g. stream-lake systems	- long-term measurements - time-series analysis of long-term development - develop models of ecosystem response - experimental approaches in large-scale mesocosms and flumes - metacommunity ecology - habitat modelling, species distribution modelling - stable isotope investigations of ecological processes (sources of organic matter, food web interactions) using light isotopes (H,C, N); modelling change and cascading effects
		Invasive Species	- displacement of native species - change in ecosystem structure and function - loss of biodiversity	- effects on native communities - effects on ecosystem structure and function - changes in trophic chains; impacts of new predators and prey	- analysis of existing data sets - field surveys - habitat modelling, species distribution modelling - stable isotope investigations; - modelling change and cascading effects

		Discharge Fluctuations	- changes in precipitation patterns (dry periods during the vegetation period, higher discharge in winter times) - changes in sediment dynamics - erosion during high flow, aggradation of (fine) sediments during low flow - water scarcity and drought - causing regime shifts from perennial streams to intermittent streams in temperate regions - habitat and biodiversity loss - alteration of ecosystem service provision	- influence on carbon dynamics; biodiversity; - long-term changes in different ecosystems, e.g. stream-lake systems - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks - effects of changes in natural flow regime on ecosystem structures and functions, biodiversity and habitats, e.g. : - medium- and long-term effects of drought on ecosystem structures and functions determining the water quality; - effects of desiccation on the self-purification capacity of headwater streams; - effects of desiccation and rewetting on biogeochemical cycles and biodiversity	*see also Warming Research Methods & Tools* - hydrological models for long-term predictions and simulations
	Extreme Events	Flood	- inundation - erosion of river banks, sediment transport and transformation of riverbed - loss of habitat - loss of biodiversity - alteration of ecosystem service provision	- effects of extreme events on aquatic ecosystems - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks	- field surveys before and after floods - hydrological models for long-term predictions and simulations
HUMAN	Energy Generation	River Damming	- increase in frequency and magnitude of extreme events such as catastrophic floods causing ecological and economic alterations;	- effects of hydromorphological alterations on biodiversity and biogeochemical cycles; - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks	- water quality monitoring and modelling - habitat modelling, species distribution modelling - field studies and experimental work - stable isotope investigations

			- change in hydrogeomorphology - change in hydrodynamics - discharge fluctuations, hydropeaking - interruption of migration routes - habitat fragmentation - disturbed sediment balance, decreased river sediment load leading to riverbed incision causing i.a. floodplain disconnection and descending groundwater levels - change in ecosystem structure and function - alteration of ecosystem service provision	- changes in trophic chains; impacts of new predators and prey - effects on ecosystem structure and function - restoration options	- modelling change and cascading effects
		River Regulation	- river regulation at different scales - hydropeaking - river fragmentation - floodplain degradation - habitat degradation - biodiversity loss	- combined effects of multiple pressures (changing hydrology, temperature) - effects on biodiversity and biogeochemical cycles - effects on ecosystem structure and function - restoration options	- experimental work in large-scale mesocosms and flumes - habitat modelling - water quality monitoring and modelling

	Transport	**River Regulation / Hydrogeomorphic Alterations**	- channelling, dams, levees; floodplain disconnection - change in hydrodynamics - erosion of river banks - habitat fragmentation and loss - change in ecosystem structure and function Alteration of ecosystem service provision - shipping demands, e.g. dredging fairway depths, wave actions depending on speed	- influence of ship-induced wave action on periphyton; - changes in trophic chains; impacts of new predators and prey - effects on biodiversity and biogeochemical cycles - effects on ecosystem structure and function - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks - restoration options	- experimental investigations - develop integrated hydrological and water quality models - analysis of existing large data sets - habitat modelling, species distribution modelling - field studies of multiple pressures and specific riverine landscape elements - stable isotope investigations (light isotopes) to follow organic matter cycling, elemental cycling (C and N) and food web changes - modelling change and cascading effects (interlinked ecological and hydraulic models)

	Agriculture & Forestry (in Catchment and Supersite)	Nutrient Loading & Pollution	- diffuse nutrient and organic matter inputs - eutrophication - alteration of ecosystem service provision - pesticides and pharmaceuticals from industrial crop production and livestock farming - siltation effects/high fine sediment input due to intensified erosion; - nutrients, pollutants accumulated in sediments, biomass from past events	- quantify implications for organic carbon cycling and quantity & quality of inorganic nutrients, fine sediments, DOM inputs - effects on ecosystem processes (metabolism, benthic processes); instream ecosystems - implications for self-purification capacity of streams effects on biodiversity and biogeochemical cycles - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks - changes in trophic chains; impacts of new predators and prey - effect of long-term and pulsed nutrient inputs on aquatic communities and combined effects with other stressors (e.g. flow, temperature) Effects on ecosystem processes (metabolism, benthic processes), instream ecosystems - connection to stream morphology - effects on biodiversity, habitats and biogeochemical cycles	- water quality monitoring and modelling (incl. in-situ DOM sensors; long-term investigation of hyporheic and surface-water conditions) - measurement of CO_2 production - field experimentation - experimental approaches in large-scale mesocosms and flumes - metacommunity ecology - stable isotope investigations - modelling change and cascading effects - water quality monitoring and modelling - hydrological models for long-term predictions and simulations
	Industry	Nutrient Loading & Pollution	- hazardous substances & emerging pollutants	- effects on biodiversity and biogeochemical cycles	

	Urbanisation		- river regulation at different scales - habitat fragmentation and loss - alteration of ecosystem service provision - nutrient and organic matter inputs	- effects on biodiversity and biogeochemical cycles	- develop integrated hydrological and water quality models
	Changing Land Use		- diffuse nutrient and organic matter inputs - alteration of ecosystem service provision	- effects on biodiversity and biogeochemical cycles	- develop integrated hydrological and water quality models
		Multiple Stressors	- multiple stressors interaction	- effects of multiple stressors (pollution, hydrogeomorphology; temperature) on aquatic ecosystem (SES tipping points) - investigation of local and regional processes governing community assembly and biodiversity in aquatic networks - changes in trophic chains; impacts of new predators and prey	- experimental approaches in large-scale mesocosms and flumes - metacommunity ecology - stable isotope investigations - modelling change and cascading effects

Upper Danube Supersite, Austria – Table 2

Human Response & Societal Challenges	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
River and Floodplain Restoration / Revitalisation	- impact on key ecosystem functions and services; - effects on biodiversityand biogeochemical cycles in aquatic and terrestrial habitats (nutrient balance and nutrient retention capacity; self-purification capacity) GHG emissions	- field investigations - ecohydrological studies - stable isotope investigations - experimental approaches - development of predictive models
Habitat Restoration	- effects of measures on biodiversity and habitat diversity	- experimental approaches in large-scale mesocosms and flumes - habitat modelling
Fish Migration Aids	- efficiency of migration aids, preferences of fish species, requirements on flow volume and velocity	- experimental approaches in large-scale mesocosms and flumes
Environmental Education	- ensure data quality in citizen science projects, bridge the gap between demands of science and volunteers	- research-education cooperation - citizen science approach
Resilience Measures to Climate Change	- effects of natural water retention measures on water quantity, quality, habitats and biodiversity	- catchment modelling - field investigations
Sustainable Flood Prevention Concepts	- impact on key ecosystem functions and services	- experimental approaches in large-scale mesocosms and flumes
Sustainable Hydropower Generation	- impact on key ecosystem functions and services	- experimental approaches in large-scale mesocosms and flumes
Sustainable Shipping	- impact on key ecosystem functions and services	
Transboundary Sustainable/Ecosystem-Based Management	- analysis of relationships between ecosystem function and service provision	- measurements and analysis

Upper Danube Supersite, Austria - Questionnaire

1) Human activities (drivers) and resulting pressures:

- Hydropower -> hydrogeomorphological and hydrological alterations
- intensive agriculture and forestry -> pollution, high nutrient loads (diffusive sources), floodplain disconnection, habitat and biodiversity loss
- Shipping -> hydrogeomorphological alterations
- Climate change impacts, hydrological extremes -> habitat and biodiversity loss, fragmentation and biodiversity changes (invasive species)

2) What are the resulting environmental/socio-ecological problems of the RSS (current, anticipated, which of them are currently tackled)?

- Climate change: changes in precipitation patterns (dry periods during the vegetation period, higher discharge in winter times), long term changes in temperature patterns, changes in terrestrial inputs; increase in frequency and magnitude of extreme events such as catastrophic floods causing ecological and economic alterations;
- Agricultural: diffuse nutrient and organic matter inputs, harmful substances (e.g. pesticides, pharmaceutics, etc.), siltation effects/high fine sediment input due to intensified erosion;
- River regulation at different scales, river fragmentation, floodplain degradation, habitat degradation, biodiversity loss
- Invasive alien species
- Hydropower generation (damming, channeling), hydropeaking
- Shipping demands
- Alteration of ecosystem service provision

3) Current state of research? Research gaps and future research needs?

- How do different aspects of climate change (precipitation, discharge patterns, temperature changes, in-creased catchment inputs and extreme events) influence aquatic ecosystems, their role in the catchment, ecological functions and ecosystem service provision?
- How do different aspects of connectivity within riverine landscapes control ecological processes (nutrient and carbon cycling) and biodiversity patterns at different scales (longitudinal and lateral aspects)?
- How do climate change and land use change affect stream ecosystem functioning (e.g. nutrient and carbon cycling, sediment composition, hydrological dynamics) and biodiversity (periphyton, stream communities)?
- How do multiple stressor interactions (hydrology, morphology, temperature, nutrients) affect aquatic ecosystems and their communities?
- What determines the resilience and resistance of benthic communities to single and multiple stressors, to a change in stressor dominance, as well as to restoration efforts? What is the importance of key habitats (e.g. large woody debris)?

4) Which Institutes, authorities, commissions are active in your region?

- Provincial governments of Austria: Lower Austria, Vienna, Upper Austria
- Ministries: Austrian Federal Ministry of Education, Science and Research; Austrian Ministry for Agriculture, Forestry, Environment and Water Management; Federal Ministry for Transport, Innovation and Technology
- UBA (Environmental Agency Austria)

- Viadonau (Federal Waterway Agency)
- Hydropower Companies: e.g. Verbund, EVN,
- NGOs (e.g. Birdlife, WWF ...)
- LTSER Research platform (UBA)
- University of Natural Resources and Life Sciences (BOKU), Vienna
  University of Vienna
  Danube University, Krems
- Nationalpark Donau-Auen
- ICPDR- The International Commission for the Protection of the Danube River
- IAD – International Association for Danube Research
- Network of Alpine research stations

5) Whom do you consider as partners/stakeholders/users?

At the Supersite "Upper Danube Supersite" WasserCluster Lunz – Biological Station GmbH, Austria (WCL) is cooperating with the Institute for Hydrobiology and Aquatic Ecosystem Management (IHG) at the University of Natural Resources and Life Sciences (BOKU Vienna).
As WasserCluster Lunz is a non-profit research centre shared to equal amounts by the University of Vienna, the Danube University Krems, and the University of Natural Resources and Life Sciences Vienna (BOKU Vienna), research at the institute in Lunz is also performed by the University of Vienna and the Danube University Krems. Research cooperation also exists with non-university research institutes (e.g. Bundesamt für Wasserwirtschaft) and national parks (e.g. Nationalpark Donau-Auen).
The research centre is financially supported by the Provincial Government of Lower Austria and the Municipality of Vienna, additionally, national and international third-party funding plays an important role. Research projects within the Supersite are partly also funded by e.g. hydropower companies and the Austrian Waterway Agency.

6) Open questions to support sustainable management of the RSS?

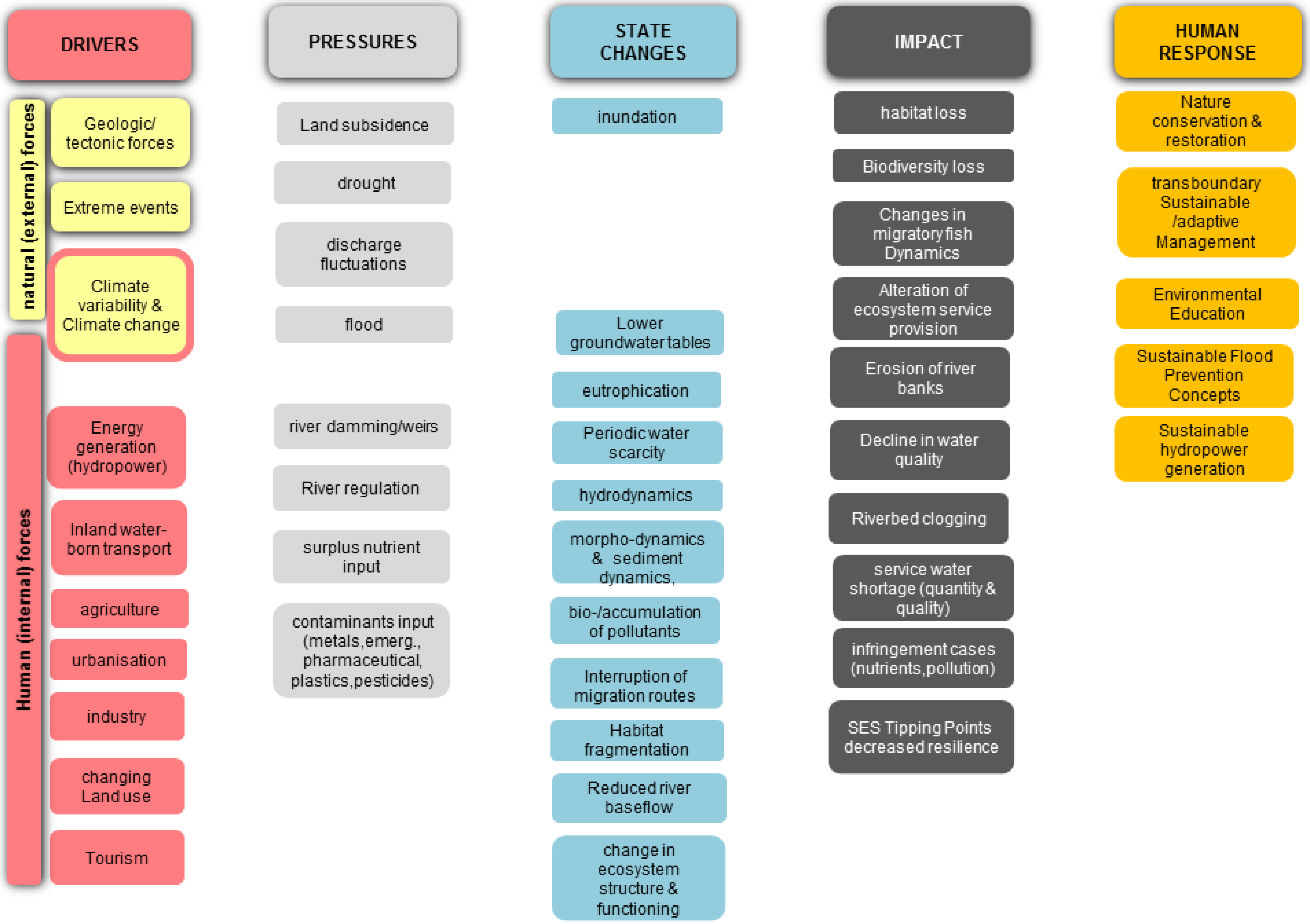
Interactions between current and emerging multiple (human) pressures on aquatic ecosystems
Structure, functions of aquatic ecosystems and provision of services of aquatic ecosystems

7) Major Scientific topics/questions addressing the Upper Danube Austria & pre-alpine network of tributaries Supersite:

see 3) – summarized:

- Climate change effects on aquatic ecosystems
- Role of aquatic ecosystems in global matter cycles (carbon/nitrogen/phosphorus)
- Effects of multiple (human) pressures on aquatic ecosystems
- Aquatic biodiversity and its drivers at different scales
- Ecological effects of river renaturation and restoration measures

2. Middle Danube / Szigetköz Supersite, Hungary – DPSIR Overview



Middle Danube / Szigetköz Supersite, Hungary – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Geologic / Tectonic	Land Inundation	- sinking basin of Kisaföld		
EXTERNAL DRIVERS	Climate Change & Climate Variability	Discharge Fluctuations	- drought - reduced baseflow - drop in groundwater table	Assess the: - understanding implications of future climate change on river groundwater interactions at Szigetköz and its local and regional-scale effects on river-groundwater system - effects of climate change on (ground)water residence time - effects of altered fluxes on pollutant transport	- improve environmental monitoring - quantify changes in recharge (reflecting changing precipitation) - complex knowledge-based environmental assessment - development of an expert system model - groundwater flow model
EXTERNAL DRIVERS	Extreme Events	Flood, Drought	- inundation - erosion of river banks - drying up of river arms - lower groundwater tables - periodic water scarcity - reduced baseflow - shortage of service water - riverbed clogging	Assess the: - changes in food web and community structure - effects of altered fluxes on contaminant transport - impacts of riverbed clogging on operation and yield of groundwater wells (NO_3, PO_4, SO_4)	- biological monitoring - monitoring of riverbed sediment (grain size) and riverbed morphology - numerical simulation of river – groundwater interaction
HUMAN DRIVERS	Energy Generation	River Damming /	- change in hydrodynamics - change in morphodynamics and sediments dynamics - interruption of migration routes	Assess the: - effect of submerged weir? - local and regional impacts of dams - effects on river ecosystems - changes in food web and community structure	- river and groundwater monitoring (flow; levels; sediment; water quality)

			- habitat loss - biodiversity loss - change in migratory fish species - change in ecosystem structure and functioning - alteration of ecosystem service provision	- revise and harmonize river basin monitoring systems	- numerical simulation of groundwater – surface water interactions - groundwater flow model - quantify ecological services - biological monitoring - standard sampling frequency - optimise environmental monitoring
		River Regulation	- decrease in river discharge due to diversion of water to hydropower plants - drying up of river arms - lower groundwater tables - periodic water scarcity - reduced baseflow - shortage of service water - riverbed clogging - river regulation at different scales - hydropeaking - floodplain degradation - habitat degradation - biodiversity loss - change in ecosystem structure and functioning - alteration of ecosystem service provision	Determine: - sustainable utilization of the natural environment - short and long-term effects on ecosystems - effects on river ecosystems - changes in food web and community structure - revise and harmonize river basin monitoring systems - effects of altered fluxes on contaminant transport - impacts of riverbed clogging on operation and yield of groundwater wells (NO_3, PO_4, SO_4) - effect of river regulation on groundwater residence time	- river and groundwater monitoring (flow; levels; sediment; water quality) - numerical simulation of groundwater – surface water interactions - quantify ecological services - biological monitoring - standard sampling frequency - optimize environmental monitoring - monitoring of riverbed sediment (grain size) and riverbed morphology

	Transport	**River Regulation**		- revise and harmonize river basin monitoring systems	- standard sampling frequency - optimize environmental monitoring
	Agriculture & Forestry (in Catchment and	**Nutrient Loading & Pollution**	- eutrophication - pesticides from crop farming, pharmaceuticals from industrial livestock production - bioaccumulation of pharmaceuticals, pesticides	- pollution transport and dispersion in RSS	- harmonize chemical monitoring - transport modelling (incl. effects of damming and river diversion)
	Industry	**Nutrient Loading & Pollution**	- effluents from waste water treatment plants - decline in water quality - hazardous substances & emerging pollutants, organic & inorganic pollutants - bioaccumulation of pollutants - decline in water quality	- pollution transport and dispersion in RSS	- harmonize chemical monitoring - transport modelling (incl. effects of damming and river diversion)
	Urbanisation	**Nutrient Loading**	- eutrophication - decline in water quality		

Middle Danube / Szigetköz Supersite, Hungary - Questionnaire

1) Human activities (drivers) and resulting pressures:

The fact that the river section was diverted into a cemented power-canal to support the hydropower plant in Slovakia. The resulting pressure is the vast restructuring of the local ecosystem due to the 80% drop in runoff in the old branch of the river. In addition, tourism, water supply and irrigation of agricultural land are the main continuous anthropogenic activities forming the face of the region.

2) What are the resulting environmental/socio-ecological problems of the RSS (current, anticipated, which of them are currently tackled)?

The significant drop in runoff on the Hungarian side of the Danube (old Danube branch), the discussions with the Slovakian side are ongoing, as well as a joint monitoring campaign to investigate the consequences of the diversion of the river on its both sides. It is anticipated, that the drop in water level caused by human activity resembles what conditions are anticipated by climate change in the case of a warming climate.

3) Current state of research? Research gaps and future research needs?

- Assessment of the effects of the drop in river discharge due to the diversion of the Danube (Trásy et al., 2018 Anthropocene)
- Comparing the current situation (water level dynamics) to ones predicted by climate change models
- Assessment of the spatiotemporal dynamics of infiltration/tapping of the groundwater (Trásy et al., 2018 Open Geosciences)

4) Which Institutes, authorities, commissions are active in your region?

- Hermann Ottó Institute (related to the Ministry for Agriculture)
- Eötvös Loránd University
- Széchenyi University
- Hungarian Academy of Sciences

5) Whom do you consider as partners/stakeholders/users?

Supersite Partners:

- **Széchenyi István University (SZE)**
- Eötvös Loránd University - Institute for Geography and Geology
- Hungarian Academy of Sciences - Research Centre for Astronomy and Earth Sciences - Institute for Geological and Geochemical Research
- Hungarian Academy of Sciences - Centre for Ecology - Danube Research Institute:

Users and Stakeholders:

- National Research, Development and Innovation Office
- Ministry of Agriculture - State Secretariat for Environmental Affairs (and Agricultural Development and Certified 'Hungaricum' Treasures)
- Ministry of Inner Affairs – (Deputy) State Secretariat of Water Management (and Public Employment) and supervised by the Ministry
- General Directorate of Water Management

- President's Office, Directorate for Environmental Sustainability
- Hungarian Water Cluster – Water and Wastewater Association
- Hungarian Hydrological Society
- Global Water Partnership
- Hungarian Chamber of Engineers – Sections of Environmental Protection as well Water-management and Engineering
- Hungarian Chamber of Agriculture
- Hungarian Central Statistical Office
- European Union – Danube Region Strategy [EU – DRS] Secretariat in Budapest
- Settlements on and in the vicinity of the Supersite Szigetköz

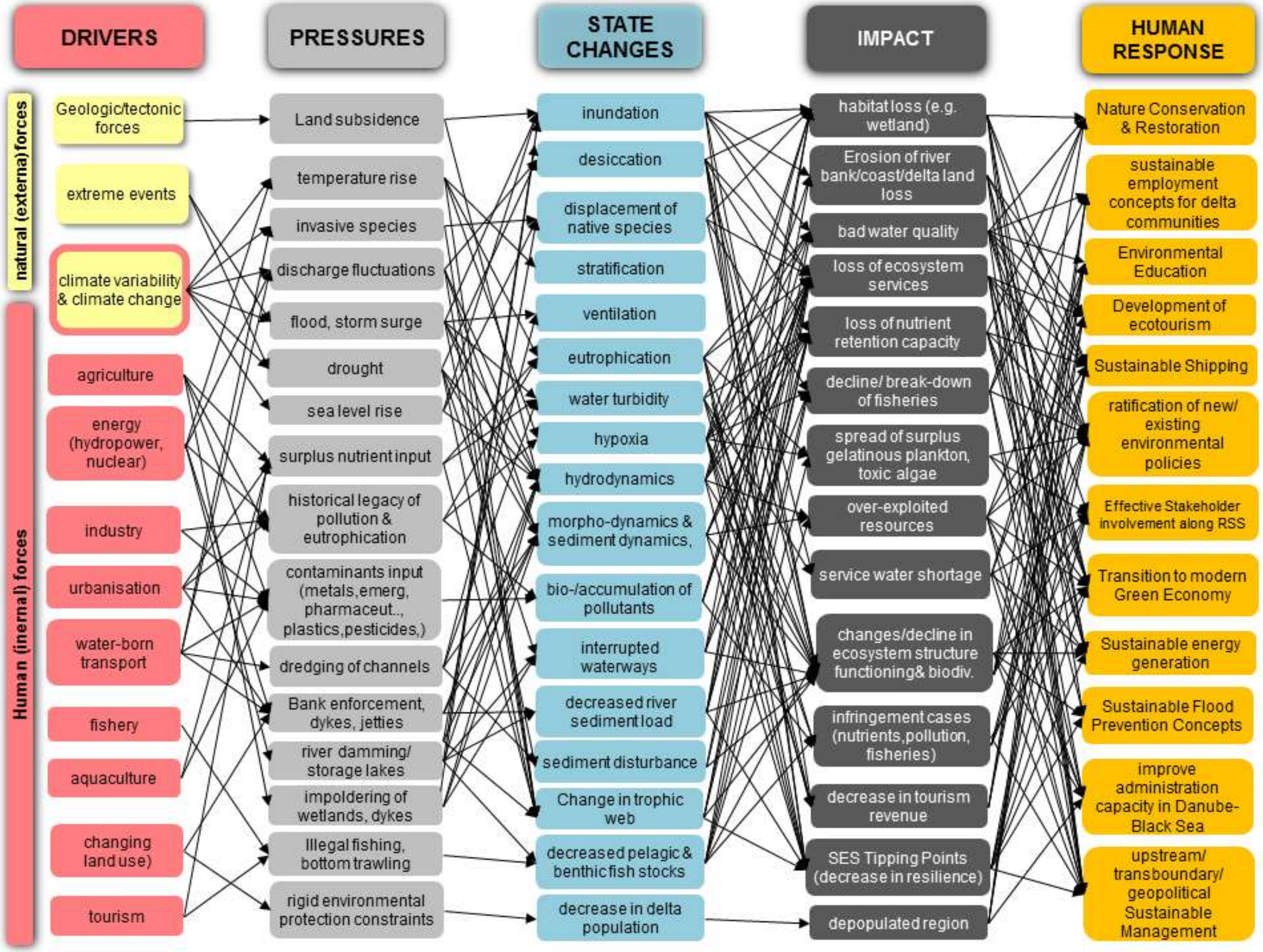
6) Major Scientific topics/questions addressing the Szigetköz Supersite

The Supersite mimics a river delta, specifically functions as an inner delta of the Danube. The changed water regime conditions (decreased runoff) mirror a scenario anticipated by climate change models. Thus, by studying the area, analogous information can be gained to river delta-sea systems.

The specific focal points of interest/reasons for specific interest are:

- Assess the water flow in the region, infiltration of groundwater to the river and vice versa incl. riverbed clogging. The drop in water level significantly decreased the amount of water accessible by the plants effecting agriculture. In the meanwhile the irrigational usage of groundwater causes further problems.
- Since, the Supersite mimics a river delta, specifically functions as an inner delta of the Danube; assess the changed water regime conditions (decreased runoff) mirror a scenario anticipated by climate change models. Thus, by studying the area, analogous information can be gained to river delta-sea systems
- Assessment of the effects of the drop in river discharge due to the diversion of the Danube
- Comparing the current situation (water level dynamics) to ones predicted by climate change models
- Assessment of the spatiotemporal dynamics of infiltration/tapping of the groundwater
- Place the results in a complex environmental evaluation model [CEKAM] (Bulla 2012, Bulla and Zseni 2011)
- Genesis and evolution of the inner-Danube Delta, under the influence of humans and in a changing climate
- Assess the water and sediment dynamics in the Szigetköz, with a special focus on riverbed clogging
- Provide a conceptual model/framework and exact knowledge on the processes obtaining in a surface/subsurface water system of an inner delta highly affected by anthropogenic activity.

3. Danube Delta Supersite, Romania – DPSIR Overview



Danube Delta Supersite, Romania – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Geologic/ Tectonic	Land Subsidence	- inundation - erosion - soil salinization - change in hydrodynamics and sediment dynamics - habitat loss	- How to prevent soil salinization due to land subsidence and inundation? - Impact assessment of soil degradation for environment, economic and social aspects	- analysis of long-term data series to study process changes - Earth Observation data from satellites valided with in-situ data (ground based sensors)
	Climate Change & Climate Variability	Sea Level Rise	- inundation - soil salinization - change in hydrodynamics and sediment dynamics - displacement of species - habitat loss	- development of preventive measures to reduce the impact of climate change - Which factors control discharge (e.g., climate variability, teleconnections and extreme events) - saltwater intrusions into delta, into groundwater due to sea level change?	- analysis of long-term data series to study process changes - development of climate impact scenarios - high resolution Earth Observation from satellite or aircraft - groundwater and surface water hydraulic modelling by using hindcast climate change impacts
		Warming	- displacement of native species, changes in trophic web - summer stratification/reduced ventilation - increase in summer oxygen depletion	- combined effect of temperature, nutrient input from Danube on eutrophication in Black Sea (multiple stable states) - influence of changes in temperature regime/seasons on onset/duration/breakup of stratification, water ventilation - influence of changes in temperature regime on spread of alien species	- analysis of long-term data series to study process changes

		Discharge Fluctuations	- low discharge - high discharge - service water shortage	- effect of increasing/decreasing freshwater discharge into Black Sea on stratification, nutrient budgets - enforcing/weakening effect of decadal climate patterns on regime shifts (e.g. due to eutrophication) - climate change impact to the quality and quantity of groundwater resources and prognosis for different scenarios - analysis of conflicting socioeconomic interests/demands (e.g., national vs. international; agriculture vs. ecology; manufacturing trade vs. drinking water) - resulting states of water shortage: poor drinking water quality, O_2 depletion, enrichment of pollutants	- elaboration of the trends for decadal periods in order to determine the variability - statistical analyses of the decadal data in order to compare different periods values - high resolution Earth Observation from satellite or aircraft - stakeholders conflict analysis tool - stakeholders cross-cutting tool - participatory rural appraisal (PRA) methods
		Invasive Species	- displacement of native species - changes in trophic web	- pathways of spread? (e.g., ballast water, climate change) - analysis of colonization corridors, pre-adaptations of possible invasive species - impact of invasive species on indigenous species/ecosystems function - analysis of and management concepts for invasive species - studies of biological traits and ecological behaviour of RSS species in their native biogeographic habitat in order to depict potential invasiveness scenarios	- conventional and molecular taxonomic analyses - molecular, physiologic and genomic labelling of species - habitat and process related physiological models - monitoring species development - ecosystem observations the Danube Delta Biosphere Reserve at hotspots for ecosystem types
	Extreme Events	Flood , Storm	- inundation - erosion - sediment disturbance - water turbidity	- understanding the triggering mechanisms of extreme events, at different scales (floods, draughts, landslides, storms; slope instability - understanding the effects of major natural hazards	- automated observation stations along RSS (e.g., gauges, ferry boxes, radar – wave heights)

			- drastic short-term change in hydrodynamics & sediment dynamics - damage of human goods and wellbeing - desiccation - change hydrodynamics & sediment dynamics - interruption of waterways - service water shortage - loss of wetland habitat	- flood prevention concepts (e.g., maintaining flood-plain river connections) - impact of management choices , e.g., mountain storage water basins on drought events - comparative risk assessment	- mutual benefit of research infrastructures, e.g., DANUBIUS-RI and EMSO - Extreme Value Analysis of historic hydro-meteorological data collected from in-situ sensors, remote sensing databases and GCMs/RCMs - meteorological forecast scenarios - forecast of hazards effects - nested landslide and meteorological models - comparative risk assessment of natural hazards
HUMAN DRIVERS	**Agriculture (in Catchment & Supersite)**	**Nutrient Loading**	- nutrient input into ground- and surface waters from industrial livestock production, fertilizer use - eutrophication in Danube, Delta and western BS shelf - water turbidity resulting from eutrophication - bottom water hypoxia resulting from eutrophication - change in foodweb - change in ecosystem structure and functioning	- risk assessment of nutrients loads as a main source for eutrophication - How effective are the current policy instruments in preventing accidents? - How the eutrophication influences the supply of goods and services (fish - as food, tourism)?	- Monitoring based on WFD requirements - Analysis of structural and functional changes of biota due to increased nutrients concentrations

			- nutrients accumulated in sediments, biomass from past events		
		Pollution	- pesticides, pharmaceuticals input into ground and surface water - insufficient waste water treatment - bad water quality - pollutants accumulated in sediments, biomass from past events	- What is the historical legacy of past eutrophication/pollution events stored in sediment? - Does it decrease the resilience of ecosystems and affects current ecosystem services?	
	Energy Generation	**Hydropower**	- damming of rivers, storage lakes - decrease in river sediment load due to damming - discharge fluctuations during energy generation - interrupted water ways - erosion of parts of the delta due to sediment deficiency	- Can we re-instore the river-sea continuum for water, sediments and life, whilst trying to maintain the benefits of reservoir lakes? - How can we understand the role of reservoir lakes and accumulated sediments as potential ecological time bombs? - Which are the surface water / ground water disequilibria caused by dams? - Could we find alternative means of harnessing the energy from water instead of blocking the river-sea continuum?	- analysis of long-term data series to study process changes
		Fossil Fuels	- offshore oil & gas extraction on BS shelf - oil spill on shelf and Danube delta coastline in case of accident	- How can we support the development of effective real-time warning systems and emergency interventions in case of accidental oil spills?	

		Nuclear	e.g., Cernavoda power plant nuclear pollution in case of accident		
	Industry	**Nutrient Loading & Pollution**	- insufficient waste water treatment - eutrophication in Danube, Delta and western Black Sea shelf - bottom water hypoxia resulting from eutrophication - bad water quality - environmental accidents/spills - metals, organic substances, emerging contaminants, flame retardants, pesticides, micro-/nanoplastics, life-style chemicals, pharmaceuticals, pathogens - nutrients, pollutants accumulated in sediments, biomass from past events		
	Urbanisation		- population growth rural sustainability and food security - living in isolated areas without access infrastructures societal challenges		

			- wastewater (municipal treatment & management)		
	Transport	Dredging	- navigation, shipping and related hydroengineering works - mechanical sediment disturbance - changes in hydrodynamics - changes in morphodynamics, sediment dynamics		
	Fishery		- fisheries are currently decreasing (in the delta? Black Sea?)		
	Aquaculture		- currently underdeveloped		

Danube Delta Supersite, Romania – Table 2

Human Response & Societal Challenges	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
Nature Conservation and Restoration - Danube Delta Biosphere Reserve - migratory species (e.g. fish - Danube sturgeon) - protection and restoration of marshlands - underwater heritage	- assessment of competing needs of restoration/protection and human needs for ecosystem services(e.g., shipping) - concepts for integrated environmental directives and nature conservation conventions - assessment of status of species, structure and functioning of habitats to improve habitats for native and endemic species, biodiversity - real-time and permanent environmental quality assessment in RS systems - guidelines to conserve endangered species & habitats - restoration concepts for degraded habitats - bioremediation, restoration of river connectivity, floodplains - assessment of coastal erosion - the role of migration barriers - What is the effect of the Danube Delta Biosphere Reserve on the improvement of ecosystem functioning of the delta? - habitat connectivity along the marine – freshwater continuum - study changes in sediment budgets - water level changes (also in connection with (shipping and water shortage) - flocculation processes not understood	- improve the assessment methods for environmental flows related to river water abstractions, river diversions and damming - high resolution Earth Observation from satellite or aircraft - habitat mapping, analysis of connectivity - sediment management plan - development and application of mixed models of sediment/ soil/habitat establishment and processes - mapping, assessing and modelling climate change relevant elements like C-balances - balancing of various needs and interests using the ecosystem services concept - protocols and technological innovation (e.g., bottom echolocation, habitats characterization and modelling)

	- interplay of sediments and soil in the processes of sedimentation, erosion, flora/fauna habitat succession and soil genesis on the marsh edge - efficiency of estuarine aquatic and (semi)terrestrial environments in controlling climate change relevant element fluxes like. e.g. carbon - socio-economic benefit of restoration measures - location and characterization of paleo-settlements and wrecks and impacts of RS environmental dynamics (CONNECTION E-RIHS)	
Sustainable Development of Local Communities **Adaptive Ecosystem Management**	- scientific support for management plans - interdisciplinary and holistic approach for new strategies of sustainable management - integration of the studies and increased results transparency - assessment of cumulative impacts on RSS - integration of social, economic and strategic value of RS systems at different spatial and temporal scales - interaction & causalities between biodiversity, ecosystem functions and services - assess drivers and pressures - forecast of biodiversity and ecosystem service provision - effects of multiple & interacting pressures on aquatic ecosystems - interdisciplinary cooperation & knowledge brokering: science-science as well as science-policy/practice - dealing with uncertainties and surprises - societal cost-benefit analysis - scenario studies	- use of best scientific knowledge to create management guidelines for ecosystems; - involve environmental lawyers to ensure compliance with EU environmental Legislation; - integration of previous and ongoing monitoring studies on environmental and socio-economic factors - logical framework approach - practice of procurers to keep a ‘risks register’ in the management project to incorporate innovation related risks - predictive tools to assess environmental response - definition and assessment of cumulative impacts and ecosystem services indicators - improvement of integrated modelling (river, drainage basin, delta, ground waters, sea) - H2020 Aquacross project http://aquacross.eu/ - FP7 MARS project http://www.mars-project.eu/ - tools to calculate effect of measures adaptation pathways - scenario modelling

	- re-sketching of established performance indicators of the Danube Delta Sustainable Management Plan and related indicators to allow the development of performing plans	- interactive planning & visualization tools - knowledge brokering instruments (e.g. serious or role playing games, group model building, scenario planning, communities of practice) - joint fact finding, stakeholder participation - interactive or participatory modelling - pilot projects / living labs, citizen science
Environmental Education & Human Resources Development	- practical approaches of environmental education in the RSS - environmental education materials for different levels of education - finding common language - elaborate boundary spanning - to join-fact finding - to realize mutual education and learning	- environmental education of local communities - ontology reference document - joint development of conceptual framework(s) & group model building - boundary spanning objects - collaborative or participatory modeling - serious and role playing games - stakeholder participation
New / Ratification of Existing Environmental Policies - river basin management	- scientific support of the Implementation of DRBMP (cooperation with national DRBM agencies and ICPDR)	- participation in the national working group of Danube River Base Management agencies and international cooperation (ICPDR)
Effective Stakeholder Involvement	- improvement of the cooperation with stakeholders in Danube River Water Management activities	- discussions with all stakeholders - online platform with active members - interdisciplinary committees, composed of experts and from different stakeholder groups for monitoring and early warning
Transition to Green Economy	- policies that mitigate environmental degradation, reduction of environmental pressures - ecosystem services assessment	- concept of circular economy, bio-economy - implementation of EU environmental legislation; - integrate social and economic forecasts in scenarios development - interdisciplinary and transdisciplinary approach

Improve Administration (Capacity) in Danube-Black Sea Area	- administrative gaps evaluation	- participation Danube River Base Strategy programme on national and international levels
Transboundary Sustainable Management	- transboundary conflicts assessment	- long term perspectives in international cooperation - establish cross-border management boards for transboundary watersheds responsible for the implementation of EU Directives (WD, MSFD)

Danube Delta Supersite, Romania – Questionnaire

1) Human activities (drivers) and resulting pressures:

- Agriculture -- intensive agriculture, generating pollutants
- Naval transport -- generating pollutants, transport of alien species, shipway dredging
- Industry/urbanisation – release of toxic substances and their ecotoxicological effects
- Insufficient or lack of sewage systems for rural settlements -- untreated waste
- Tourism -- touristic infrastructure development, unauthorised access in strictly protected areas
- Power plants' activities and their influence on reducing biodiversity
- Fishery -- illegal fishing, poaching (large scale (industrial) fisheries using a trawler fleet currently only Turkey and Russia in the Black Sea)
- Industrial based hydro-engineering is harmful for the river's natural course
- overexploitation of Danube resources. Impact is decreasing biodiversity with consequences in the fishing sector
- Historical pollution accumulated in river-sea sediments with potential harmful role.
- Historical hydrotechnic interventions (cutting of canals, river embankments, etc. with impact on dramatic change of hydrological equilibria.

2) What are the resulting environmental/socio-ecological problems of the RSS (current, anticipated, which of them are currently tackled)?

- Biodiversity loss
- Habitat fragmentation
- Coastal erosion and habitat changes (including clogging of delta lakes and meanders) due to the alteration of hydrologic regime
- Endangered cultural specificity
- Pollution of the environment
- Population health problems
- Cumulative effects are not enough known

- Unbalanced relation between the economic development and environmental protection.
- Currently tackled: NGOs initiatives to find modern solutions and to create environmentally friendly occupational alternatives for the locals.
- With increasing population density, increasing water use and climate change, it is anticipated that the risk of algal blooms and cyanobacterial concentrations will increase. This causes problems for Water Companies, in terms of water quantity and quality. Algal blooms greatly increase their operational costs.
- A low level of regional management leads to the accumulation of pollution in the Danube basin and its inland waters (lakes and wetlands), the dissemination of knowledge, courses of lectures and practical exercises is necessary.
- At a good level - hydrometeorological parameters of the aquatic environment are monitored.

3) Current state of research? Research gaps and future research needs?

- Currently, there is no management plan based on an updated hydrological analysis.

- There is no updated sociological information from the human-nature perspective. The community-environment relationship is underdeveloped.
- New model of human-nature updated to the realities of the 21st century, using a modern perspective.
- How to ensure the quality of drinking water in the Danube basin?
- Monitor & assess pathways of excess intake of nitrogen and phosphorus compounds from agriculture to the river, and to the sea: collapse of benthic and pelagic ecosystems on the BS western shelf in 1970s to 1990s due to bottom water hypoxia mediated by a combination of eutrophication supporting climate conditions and overfishing. Current state of BS shelf ecosystems (recovery, resilience) is not fully resolved
- Hydrological, sedimentological, hydrochemical (Danube and fragment of the mouth of the sea) and biological monitoring (the protected part of the delta and the fragment of the estuary part of the sea) are conducted.
- There are few investigations of the mouth of the sea in the zone of influence of the Danube water at depths exceeding 20 m. This is the most important area for the development of hypoxia and the permanent death of benthic organisms. It is very necessary to know the modern environmental status of this aquatic system.
- There is a need to understand which are the pathways of emerging pollutants (including micro plastics) in the Danube Delta-Black Sea and which are the expected impacts on the ecosystems, biota and humans.
- Which are the cimate change expected impacts on the Danube Delta ecosystems? (in terms of increased impact of storms, increased sea level rise, modified areals of species and ecosystems due to changes in temperatures and air circulation)
- Geological (sedimentation patterns, neotectonics and subsidence) investigation is needed to understand the morphological changes and present-day evolution of the Danube Delta.
- Which are the effective Nature Based Solutions that can be implemented to improve the state of the environment and protect local communities.

4) Which Institutes, authorities, commissions are active in your region?

<u>Ukraine</u>

- The Danube Hydro –meteorological Observatory (Ismail)
- The Danube Biosphere Reserve, Odessa State Environment University, Odessa National University, Institute of Marine Biology (National Academy of Sciences)
- Institute of Ecological Problems (Kharkov)
- Ukrainian Center of Ecology of the Sea (Odessa)

<u>Romania</u>

- Danube Delta Biosphere Reserve Authority
- National Research and Development Institute for Marine Geology and Geoecology
- National Research and Development Institute for Biological Science
- National Institute for Marine Research and Development “Grigore Antipa“ Constanta
- “Danube Delta” National Institute for Research and Development
- Tulcea Municipality and Tulcea County Council
- Tulcea Environment Protection Agency

- Constanta County Council
- Constanta Environmental Protection Agency
- National Administration Romanian Waters
- Emergency Situations Inspectorates (Tulcea and Constanta)
- Lower Danube Fluvial Administration
- Administration of the Danube Harbours
- Administration of the Maritime Harbours
- National Administration of Meteorology
- OVIDIUS University of Constanta
- University of Bucharest (Sf. Gheorghe and Braila locations)
- University POLITEHNICA of Bucharest
- “Lower Danube” University of Galati
- 3DBS Cluster
- “Ivan Patzaichin – Mila 23” Association
- Romanian Academy - Institute of Biology (Sulina location)
- ICEM “Gavrila Simion” Tulcea
- National Agency for Environmental Protection
- The “Romanian Waters” National Administration – Dobrogea Littoral Water Directorate
- Oceanic Club
- Mare Nostrum and other NGOs (Save the Danube and the Delta)

Republic of Moldova

- Academy of Science institutions: Institute of Chemistry, Institute of Zoology, Institute of Ecology and Geography, Institute of Geology and Seismology
- Ministry of Agriculture, Regional Development and Environment
- Institute of Pedoligy, Agrochemistry and Soil Protection “Nicolae Dimo”
- Agency “Apele Moldovei” with Nistru and Danube River Basin Agencies
- State Enterprise for irrigation technology Cahul
- Local authorities of Cahul raion
- Moldavian State University (Chisinau)
- Cahul State University

5) Whom do you consider as partners/stakeholders/users?

Ukraine

- Ministry of Environment
- Ministry of Science and Education
- Ministry of Agriculture and Ministry of Transport

Romania

- Danube Delta Biosphere Reserve Authority
- Romanian Waters National Administration – Dobrogea – Littoral Basin Administration
- Lower Danube Fluvial Administration
- National Administration of Meteorology

- 3DBS Cluster
- “Ivan Patzaichin – Mila 23” Association
- Tulcea Municipality and Tulcea County Council
- Constanta Municipality
- All municipalities in the Danube Delta
- Tulcea Environment Protection Agency
- National Administration Romanian Waters
- Emergency Situations Inspectorate
- AQUASERV and RAJA Constanta (Regional operators for water and sewage public services)
- All universities and high schools in the region – but also in the entire country

Republic of Moldova

- Ministry of Agriculture, Regional Development and Environment
- Agency “Apele Moldovei” with Dniester and Danube River Basin Agencies
- State Enterprise for irrigation technology Cahul
- Local authorities of Cahul county

6) Open questions to support sustainable management of the RSS?

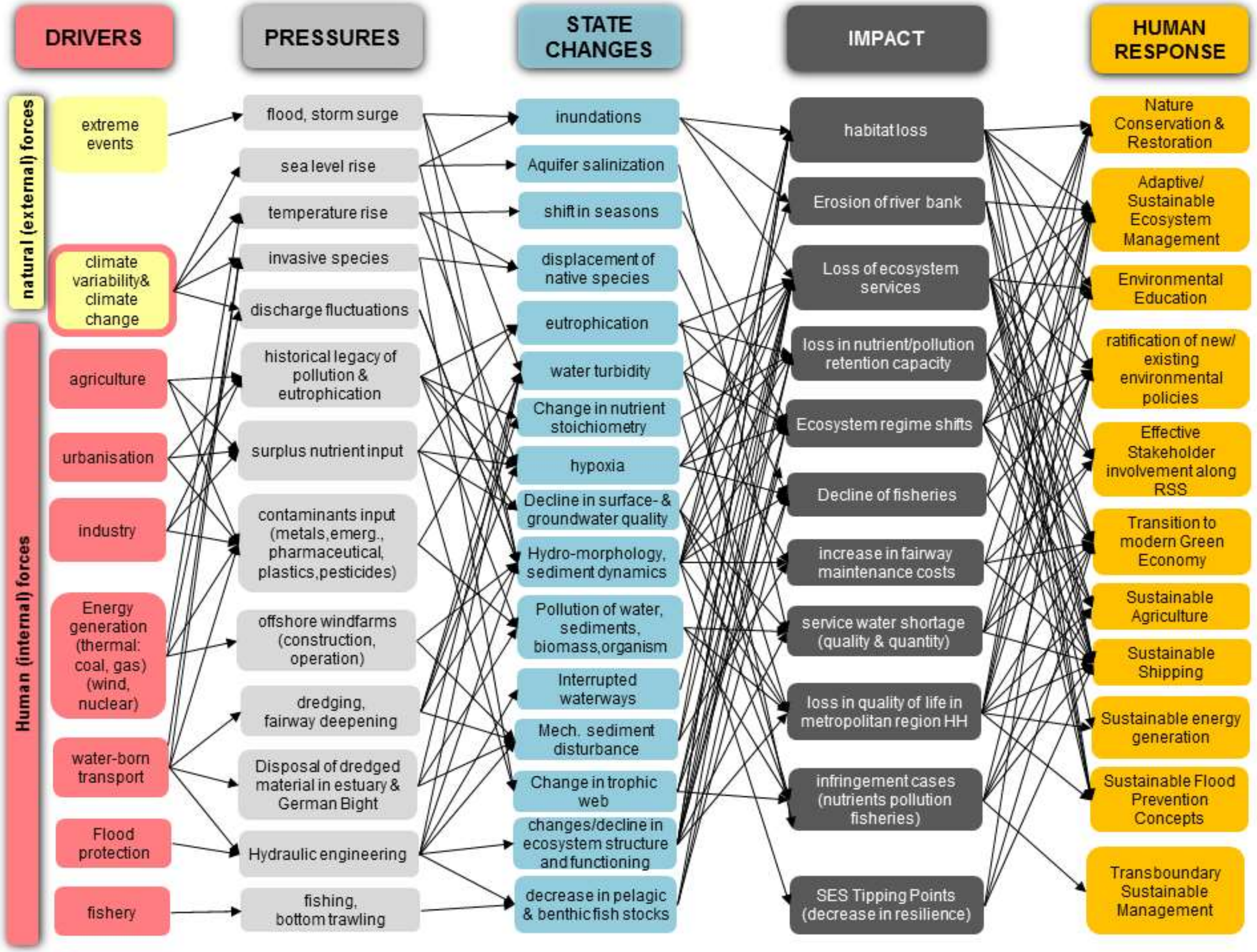
- Ways of building/strengthening bridges between all stakeholders?
- What are the acceptable trade-offs? (e.g. negotiation for policies to address the communities’ needs for improved livelihoods while mitigating societal pressures on the environment and promoting preservation of cultural landscape)?
- How can the management plans of the RSS include the idea of protecting archaeological and historical heritage?
- Building up a responsible community of Danube riverine people based on a strong knowledge and empathy for the river.
- Conducting lectures, seminars on the ecology of various sections of the Danube for the overall picture of communication and dependence between them. For example, the dependence of the populations of migratory fish on the quality of the spawning grounds of the Middle Danube

7) Major Scientific topics/questions addressing the Danube Delta – Supersite

- Genesis and evolution of the Danube Delta, under the influence of humans and in a changing climate
- Understanding Water and Sediment dynamics in the Danube River- Delta – Black Sea continuum
- Which parts of the Danube Delta can be sustained under the current sediment transport regime of the Danube river and what can be done to save the delta from drowning?
- Hydrogeological assessment of and hydrological model for the modern Danube Delta
- Define the limits of transitional waters at the Danube – Black Sea interface and understand biogeochemical processes from these environments
- Eutrophication/Hypoxia in the north western Black Sea (Danube Delta Supersite)
- Cumulative impacts of man-made drivers and climatic drivers on ecosystem function and services

- Plans for a sustainable use of biological resources (prevent depletion of stocks of marine, freshwater and migratory organisms)
- Solutions to deal with external environmental pressures (either from upstream or from updrift).
- Nature-Based (“green”, or eco-engineering) solutions for the sustainable management of the Danube Delta – Biosphere Reserve
- How to achieve a balance between nature conservation in the Danube Delta and sustainable development of local communities?

4. Elbe – North Sea Supersite, Germany – DPSIR Overview



Elbe – North Sea Supersite, Germany – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXOGENIC DRIVERS	Climate Change & Climate Variability	Sea Level Rise	- inundation - salinization - changes in riverine and estuarine hydrodynamics and morphodynamics - displacement of native species - habitat loss - obstruction of lowland drainage - cumulative effects of various drivers & pressures	What is the effect of sea level rise and associated challenges in RSS on: - loss of intertidal habitats - release of soil nutrients on aquatic nutrient budgets - suspended matter and sediment dynamics - particle and nutrient cycling in changing salinity gradients - biogeochemical cycling - pattern of bank- and marsh habitats - bank stability and development - Are the effects of anthropogenic drivers (e.g. agriculture, industry, urbanisation, shipping) stronger than of climatic drivers (climate change, extreme events)? What would be appropriate adaptation measures?	- stations at relevant locations for nutrient and suspended matter measurements - transect campaigns along River-Sea Continuum for measurements along salinity gradient - microcosms experiments with changing salinity - wave sensors for bank and marsh observations - remote sensing - analysis of long-term data - modelling
		Warming	- increase in summer oxygen depletion - influence of shifting seasons on ecosystem functioning - displacement of native species, changes in trophic web - impact on settlement potential of introduced species	- What would be the effect on pattern of bank- and marsh habitats? - What are the effects on pelagic biodiversity? How does warming change the potential for settlement of introduced species? - What is the cumulative effect of temperature rise and eutrophication on oxygen and nutrient cycling, as well as respective budgets?	- field mesocosms in marsh for warming experiments - microcosms experiments simulating warming (and nutrient loading) - modelling - benthic flux chambers

			- overall higher biogeochemical process rates - change in greenhouse gas emissions	- How are sediment and suspended matter composition changing over time (e.g. seasonal change in particulate carbon substances)? E.g. important for modelling organic carbon and matter budgets - What are turnover rates of processes and exchange/transport rates between water and sediment? - different time scales of process and exchange rates are important for budgets - How much greenhouse gases are emitted from salt marshes in a warming world? - How much greenhouse gases are dissolved in water along the salt gradient? - How much greenhouse gases are outgassing of the water? (e.g. CO_2, CH_4, N_2O) - How to quantify better the dissolution of gases from the atmosphere in the water?	- greenhouse gas "towers" in salt marshes and at selected stations along River-Sea Continuum - analysis of long-term data
		Discharge Fluctuations	- variability in precipitation - low discharge: siltation of fairway - high discharge - service water shortage	- How to predict discharge fluctuations, also in the long-term? (important for the tidal Elbe regime and the maintenance of the ship fairway)	- hydrology and climate modelling
		Invasive Species	- displacement of native species - changes in trophic web	- What is the effect of decrease/loss of native species and an increase in non-native species on trophic chain and ecosystem functioning?	- field studies in sub-systems where invasive species are already present - ecosystem modelling

	Extreme Events	Riverine Flood , Storm Surge	- inundation - erosion - sediment disturbance - water turbidity - drastic short-term change in hydrodynamics and sediment dynamics - damage of human goods and wellbeing	- What would be the effect of measures for flood risk assessment and flood prevention, - What options are feasible to combat loss of intertidal habitats? What would be the effect of extreme events on: - interaction with nutrient and oxygen budgets, sediment and suspended matter dynamics - pollution release and transport - impact on the North Sea/Wadden Sea system - bank and marsh development (e.g. accretion vs. erosion, soil development) - coastal protection - navigation	- stations at relevant locations - plus mobile system, which can be used on demand - transect campaigns along River-Sea Continuum - tracing suspended matter and sediment with non-traditional isotope systems
HUMAN DRIVERS	Agriculture (in Catchment and Supersite)	Nutrient Loading	- nutrient input into ground- and surface waters from industrial livestock production, fertilizer use - nutrients input from land drainage and insufficient waste water treatment - resulting phytoplankton blooms and other effects of eutrophication - increased oxygen demand, low oxygen zones - change in ecosystem structure and functioning - decrease in water quality - infringement cases (nutrients) in river and groundwater	- nutrient and oxygen budgets, - biological interactions, (grazing, predation, estuary as a sink of primary produced organic matter) - connectivity between land based measures and the coastal response - nutrient cycling, release of reduced substances from sediment - interaction with global change - What would be adequate nutrient concentrations in groundwaters of the catchment, in headwaters and in tributaries in order to comply with EU regulations in estuary and coastal sea? - How are measures regarding e.g. nutrients and pollutants in the freshwater affecting	- stations at relevant locations - transect campaigns along River-Sea Continuum - modelling - microcosms experiments nutrient loading - benthic flux chambers - remote sensing

			- nutrients accumulated in sediments, biomass from past events	estuary and coastal sea, particularly biota and food web?	
		Pollution	- pesticides, pharmaceuticals input into ground and surface water - insufficient waste water treatment - bad water quality - infringement cases (nutrients) in river and groundwater - pollutants accumulated in sediments, biomass from past events	*See pollution under industry*	*See pollution under industry*
	Industry	**Nutrient Loading**	- insufficient waste water treatment - bad water quality - nutrients, pollutants accumulated in sediments, biomass from past events	*See nutrient loading under agriculture*	*See nutrient loading under agriculture*
		Pollution	- environmental accidents/spills - metals, organic substances, emerging contaminants, flame retardants, pesticides, micro-/nanoplastics, life-style chemicals, pharmaceuticals, pathogens - anti-fouling spread on ships	- What are the effects of pollutants on biota? What are cumulative effects? - effects from pharmaceuticals, multi resistant microbes and emerging contaminants, which are currently not monitored - development of ready to use, standardised passive samplers for pollutants - How can tracer patterns be combined with pollutant patterns (e.g. organic pollutants)? development of indicators necessary	- ecotoxicological assessments and experiments with different pollutants, mixtures and biota under various conditions (different salinity, suspended matter, microplastics etc.) - stations and regular sampling at relevant locations - transect campaigns along River-Sea Continuum, particularly for emerging contaminants

				- develop methods to detect emerging pollutants, such as pharmaceuticals - What are the interactions of suspended matter and sediments and their pollutant composition? How is it influenced by flow velocity? - What are catchment specific patterns of organic and inorganic pollutants? How are they distributed along the RSS? - What are pollutant patterns characteristic for rivers? How are these patterns changing in estuary and coastal sea? - Are changes in the pollutant patterns related to changes in toxicity? - What role play mixing toxicities for pollutant loads and effects? - How can distribution patterns of traditional pollutants be used to predict patterns of emerging contaminants? - What are the sources and pathways of micro/nanoplastic? - What role does plastic play in the distribution of pollutants? - What role play new, not regulated pollutant classes?	- tracing suspended matter and sediment with non-traditional isotope systems - modelling
	Urbanisation		- population growth - surplus nutrient input from insufficient waste water treatment and management -habitat loss	-see nutrients, habitat loss, hydrological changes, pollution	- analysis of long-term data - modelling - sampling at waste water treatment plants discharging into river - mobile system, e.g. during/after extreme events (heavy rain periods)

			Increased loads of pharmaceuticals		
	Transport	**Deepening & Dredging**	- dredging to maintain navigation channel - navigation channel deepening to allow Hamburg port access of ultra large container ships - mechanical sediment disturbance - changes in hydrodynamics - changes in morphodynamics, sediment dynamics increased oxygen demand, turbidity, release of potential pollutants - habitat loss, turbidity, low O_2 zones - accelerated transport of contaminated sediments to the North Sea due to dredging - relocation of dredged material (North Sea or within tidal Elbe) - increased oxygen demand, turbidity, release of potential pollutants	What is the effect/influence of fairway deepening and maintenance, and associated challenges on: - morpho- and hydrodynamics - river bank stability (expansion vs. erosion) - river bank plant habitats (succession and development) - river bank erosion and river bank fauna and flora - sediment dynamics - suspended matter dynamics - nutrients and oxygen dynamics - contaminant dynamics - pelagic processes - What determines the formation of turbidity zones in the salt wedge and in the upstream freshwater area? When are multiple turbidity zones formed? - How fast are turbidity zones adapting to changing drivers? - What are the interactions between faster suspended matter processes in the water column and slower processes in the sediment	 - modelling - analysis of long-term data - wave sensors for river bank measurements - assessment of river bank fauna and flora - analysis of sediment, suspended matter, nutrients, oxygen and contaminants at specific locations before and after dredging events or periods - tracing suspended matter and sediment with non-traditional isotope systems - stations at relevant locations for suspended matter and sediment, nutrient, oxygen and pollutant measurements - transect campaigns along River-Sea Continuum - modelling

			- habitat loss, turbidity, low O2 zones	within turbidity zones? Saturated turbidity zones may cause enhanced maintenance activities of the ship fairway - What are the spm-fractions in turbidity zones composed of? e.g. riverine, marine, dredged material - Which processes cause the transition to hyperturbid estuaries? Which role play e.g. dredging and narrowing? (How) can hyperturbid estuaries become clear again? - What is the role of lateral processes for the longitudinal convergence? - flocculation processes - What is the composition of suspended matter (mineral and organic fraction)? - Which processes are happening in and at suspended matter (e.g. anaerobic ones in the particles)? Which effects have these processes on nutrient and oxygen dynamics? - How fast is suspended matter sinking? - Which factors determine the generation of dredging hot spots (= sedimentation hot spots)? - How can the depth of the nautical riverbed be determined better? Separate the fluid mud signal from nautical bed signal e.g. to decrease maintenance costs - How are sediment disturbances through dredging, disposal of dredged material and	- microcosms experiments with sediment and suspended matter to analyse e.g. processes affecting nutrient and oxygen dynamics; producing gases - benthic flux chambers - mapping of sediments and their properties - analysis of relocated dredged material and the area is was relocated in terms of organic matter, nutrient and oxygen dynamics, release of pollutants, further transport of material - assessment of benthic fauna in dredged and non-dredged areas

				sand removal affecting sediment-water fluxes (e.g. nutrients and pollutants)? - How are suspended matter and sediment dynamics in river and estuary changing due to engineering measures, which cause changes in erosion? Which measures for a sustainable management can be derived? e.g. sediment connectivity issues - What are the effects on the salinity gradient in the estuary due to engineering measures (e.g. ship fairway adjustment) considering the input from tributaries, middle waters and coastal sea, as well as from dischargers (waste water treatment plants, chemical and paper industry)? - morphodynamics: Which changes at the river mouth account for changes in the estuary? Is the tidal dynamic changing due to this? How is it influencing the tidal pumping of sediments? - How would a further deepening affect the development of floods, flood plains, ecology etc.? - Is this changing the highest water level during flood events? - Can dredged sediment be used to enhance desired morphological trends? - Crucial for the management of dredged material in the tidal Elbe river is speciation of sediment between fluvial and marine sediments.	

				- Where are the sediments in the Hamburg port coming from? How is the material distributed during/after disposal? Where is it transported? What are suitable tracer to trace origin and transport? different time scales (geologic and recent) What is the effect/influence of relocation of dredged material on: - oxygen consumption - release of toxic substances / pathways of pollutants (dissolved and particle bound) - benthic fauna - nutrient release from sediments -return flow of suspended matter from North Sea into estuary by tidal currents?	
		Invasive Species	- ballast water: contaminants and alien species	- What is the effect/influence of shipping on introducing species?	- analysis of ballast water and sessile biota on ship surfaces
	Energy Generation	**Fossil Fuel**	- thermal power plants (gas, coal) - return flow of warmed cooling water	What is the effect of river water warming on: - species composition - biogeochemical cycles	- measurements at cooling water discharge from power plants
		Nuclear	- nuclear pollution in case of accident - return flow of warmed cooling water		

Elbe – North Sea Supersite, Germany – Questionnaire

1) **Human activities (drivers) and resulting pressures:**
   - Waterborne Transport: Elbe is an important federal waterway; Port of Hamburg is largest port in Germany and third largest in Europe
     → construction of port and associated infrastructure, as well as artificial waterways for further distribution of goods
     → river regulation (channelization, deepening, widening, diking etc.)
     → waterway maintenance (dredging and relocation of dredged material)
   - Industry:
     → pollution
     → water abstraction
   - Energy Generation:
     → thermal pollution of water
   - Agriculture:
     → nutrient loading, mainly from catchment
     → eutrophication
     → oxygen minimum zones sometimes during summer months downstream of Hamburg
   - Fisheries:
     → overfishing of some species
     → bottom trawling in German Bight
   - Urbanisation:
     → waste water treatment plants, nutrient loading
     → pollution
     → soil sealing
   - Climate Change:
     → changes in temperature, precipitation and wind patterns
     → sea level rise
     → extreme events (e.g. high discharge events, storm surges, low discharge periods)

2) **What are the resulting environmental/socio-ecological problems?**
   - changes in hydro- and morphodynamics due to engineering measures (diking, straightening, deepening, widening, construction of port areas and a weir upstream etc.)
   - tidal pumping of sediments from downstream to upstream
   - dredging and relocation of dredged material
   - nutrient loading, algae blooms, eutrophication, oxygen minimum zone
   - pollution from organic and inorganic contaminants, particularly in sediments
   - loss of wetlands and floodplains
   - invasive species
   - sea level rise and storm surges
   - land subsidence and groundwater salinisation
   - extreme high discharge and low discharge events/periods
   - changes in temperature and precipitation patterns due to climate change

3) Current state of research? Research gaps and future research needs?
Currently, hardly any research is carried out in the estuarine part of the Supersite. In contrast, several projects tackle on both the national and international level issues like habitat, non-native species and sea level rise.

4) Which Institutes, authorities, commissions are active in your region?

Overarching Communities, Commissions and Secretariats

- German River Basin Community Elbe
- International Commission for the Protection of the Elbe River
- Common Wadden Sea Secretariat

Research Institutes

- Helmholtz-Zentrum Geesthacht, Institute of Coastal Research
- Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

Universities

- University Hamburg
- Technical University Hamburg Harburg
- Hamburg University of Applied Sciences
- Leuphana University Lüneburg
- University Kiel
- University of Applied Sciences Lübeck
- University Oldenburg

Federal Institutions

- Federal Institute of Hydrology
- Federal Waterways and Engineering Research Institute
- Federal Maritime and Hydrographic Agency
- Federal Waterways and Shipping Administration
- Federal Agency for Nature Conservation
- Federal Research Institute for Rural Areas, Forestry and Fisheries
- German Environmental Protection Agency

Hamburg

- Hamburg Port Authority
- Ministry for Environment and Energy
- Institute for Hygiene and Environment, Ministry for Health and Consumer Protection
- Waterway and Shipping Office
- State Office for Roads, Bridges and Waters

Schleswig-Holstein

- Ministry for Energy, Agriculture, Environment and Rural Areas
- State Office for Coastal and Sea Protection, National Parks
- State Office for Agriculture, Environment and Rural Areas
- Waterway and Shipping Office Brunsbüttel and Lauenburg

Lower Saxony

- Ministry for Environment, Energy and Climate Protection
- State Office for Water Management, Coast and Nature Protection
- Waterway and Shipping Office Cuxhaven

5) Whom do you consider as partners/stakeholders/users?

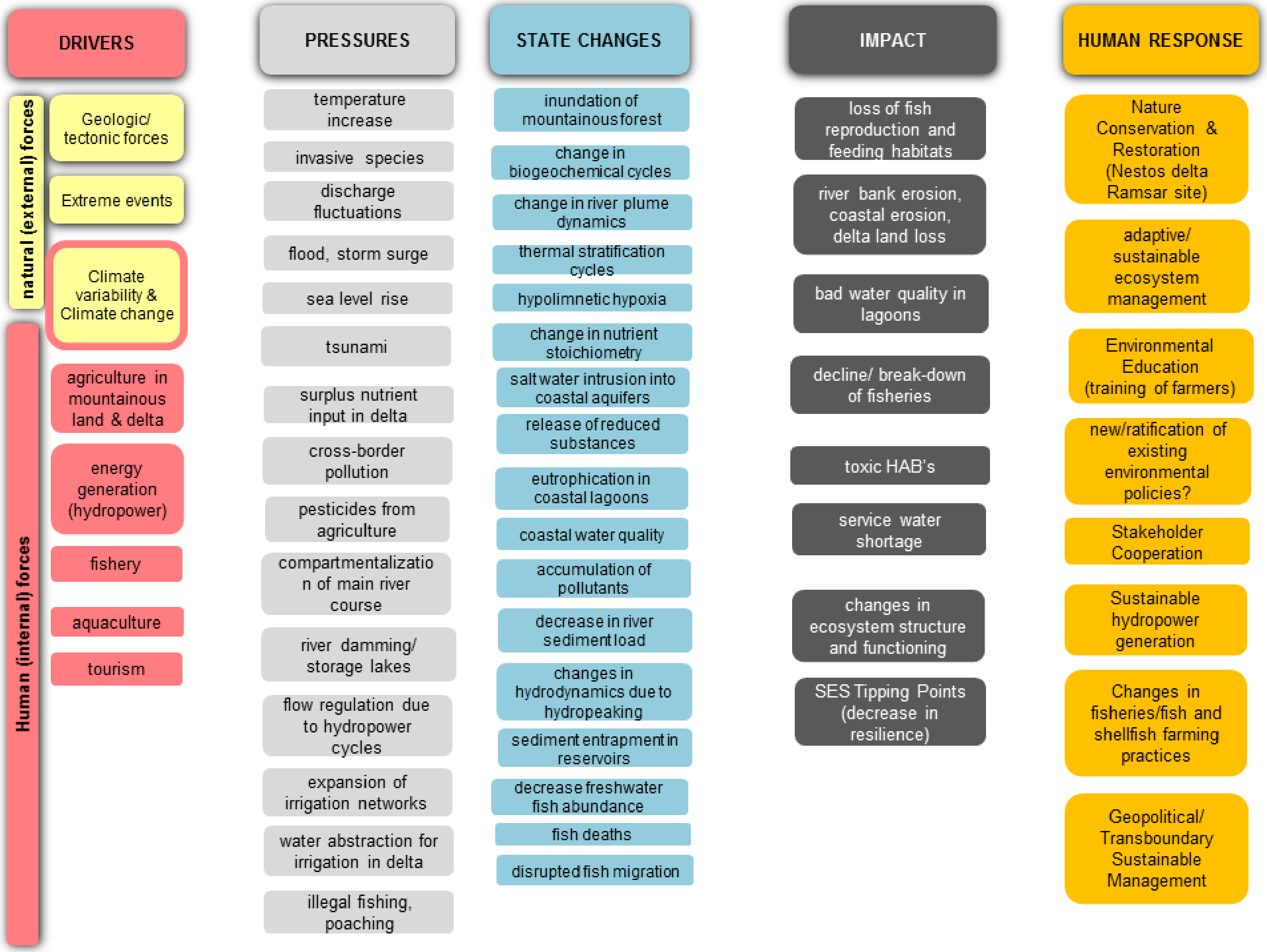
All above mentioned

The Helmholtz-Zentrum Geesthacht is the Hosting Institution of the Elbe-North Sea Supersite. Currently, the Federal Institute of Hydrology and the Federal Waterways and Engineering Research Institute are Supersite Partners. Discussions with others have started.

6) Major Scientific topics/questions addressing the Supersite

- Understanding the impact of global change (sea level rise, extreme events and temperature increase) as well as their interactive effects on the River-Sea Continuum.
- Investigate budgets and cycles of matter (nutrients, sediment, oxygen, contaminants) and their modifications.
- Conceptual understanding of the coupling of terrestrial, estuarine and marine systems as a basis for integrated models (including data assimilation, suspended matter, biogeochemistry and higher trophic levels).

5. Nestos Supersite, Greece – DPSIR Overview



Nestos Supersite, Greece – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Geologic/ Tectonic Forces	Earthquakes	- Nestos lies in the vicinity of the North Aegean Trough – Anatolia Fault, a region affected by earthquakes with high potential for tsunamis - inundations	- What will be the potential impact of a submarine earthquake inducing a tsunami on the coastal zone?	- numerical models simulating tsunamis - inundation impact
	Climate Change & Climate Variability	Sea Level Rise	- sea level rise may enhance salinity intrusion to coastal aquifers	- To what extent will sea level rise enhance saltwater intrusion at the coastal aquifers of Nestos delta and impact on the coastal aquifer? (salinity the coastal aquifers of Nestos delta has been reported by several reports attributed to surface freshwater abstraction, groundwater overuse)	- continuous monitoring of aquifers level and water quality (conductivity, EC, pH, N & P compounds) and models studying the potential impact of sea level rise in future
		Warming	- summer stratification/reduced ventilation - increase in summer oxygen depletion - change in precipitation - changes in water column stratification/mixing conditions at the two reservoirs - bottom anoxia, increase in methane and hydrogen sulphide emissions from hypolimnion at reservoirs.	- main challenge: Hypolimnetic challenge at Nestos reservoirs (Thissavros, Platanovrisi) and its relation to the thermal stratification/mixing cycle	- long CTD records to assess the impact - climatic models - continuous CTD profiles - thermal cycle models

			- thermal stratification cycles		
		Discharge Fluctuations	- fluctuations in freshwater discharge: - freshwater discharge reduction - gradual decrease in precipitation during 1981-1993 - intense increase in precipitation during 1994-2010 (GPCC). - expected increase in air temperature by 3.2 deg by 2100. - expected decrease in number of snow - river discharge reduction by 52% compared to that during 1960s - important issue for hydropower production - during drought periods the dams are unable to operate - change in river plume dynamics	- river flow reduction due to damming and climate change will affect the river plume dynamics - plume dynamics affect the water renewal of the nearby Kavala Gulf	- network of meteorological and hydrological stations - river discharge gauges - remote sensing /ground observations and modelling - river-river plume-open sea nested hydrologic/hydrodynamic and biogeochemical modeling forced by regional/local meteorology

		Invasive Species	- displacement of native species - changes in trophic web - invasive species have been reported in the coastal waters of Nestos mouth - no invasive species so far in Nestos/Mesta River watershed	- trophic web changes related to climate change and human interventions	- regular fish sampling recording fish species abundance and diversity. - food web models assessing potential changes driven by human activities and climate change
	Extreme Events	**Flood , Storm Surge, Drought**	- coastal floods and storm surges affect the area as it is the northern boundary of Aegean Sea - due to river damming the area is not affected by flood originating in the river	- understanding the triggering mechanisms of extreme events, at different scales (floods, draughts, storms) - understanding the effects of major natural hazards - flood prevention concepts (e.g., maintaining flood-plain river connections) - impact of management choices, e.g., mountain storage water basins on drought events - comparative risk assessment	- automated observation stations along RSS (e.g., gauges, ferry boxes, radar – wave heights) - extreme Value Analysis of historic hydro-meteorological data collected from in-situ sensors, remote sensing databases and GCMs/RCMs - meteorological forecast scenarios - forecast of hazards effects - comparative risk assessment of natural hazards
HUMAN DRIVERS	**Agriculture (in Catchment and**	**Nutrient Loading**	- at the river deltaic zone, especially at transitional waters as lagoons, the impact of agriculture is important - in Mesta catchment (mountains: tobacco, potatoes, vegetables, corn, grain, cattle breeding)	- impact of agriculture nutrients on surface & groundwater water quality - pathways of fertilizer-(manure) based nutrients into RSS - concepts for sustainable use of fertilizers - pathways of pesticides in water cycle - impacts related to intense Agriculture at the Nestos delta (water abstraction for cultivations, eutrophication in coastal lagoons leading to massive fish deaths in	- biogeochemical monitoring of river, reservoir and coastal zone water to assess these changes based on WFD and MSFD requirements

			- in Nestos delta area (cereals, rice, tobacco, sugar beet, asparagus, kiwi fruit) - changes in biogeochemistry at deltaic region due to the influx of agricultural residues. - toxic HAB's due to eutrophication - massive fish deaths have been reported, especially at the deltaic zone, due to the influx of agricultural residues and the decrease in the water flow and level	fish productive lagoons, regular toxic blooms affecting coastal mussel cultures, raised levels in pesticides)	
		Pollution	- increased levels of pesticides have been occasionally reported at the Nestos delta	- What are the pathways of these compounds in Nestos Rivers ?	- develop regular monitoring scheme for priority substances - currently there exists the standard monitoring for WFD
		Water Abstraction	- expansion of irrigation networks will exert pressure on the River, as in spring and summer it will operate with the environmental base flow of 6 m^3/s	- we have redefined the environmental flow of the river at 13 m^3/s based on hydrologic, morphometric and habitat methodologies for environmental flow determination	- regular implementation of hydrologic, morphometric and habitat methodologies to assess the environmental flow levels
	Energy Generation	**Hydropower**	- damming of rivers, storage lakes - sediment entrapment in reservoirs - changes in morphodynamics, sediment dynamics, decrease of	- risk assessment of dam failure - ecohydrologic principles to mitigate river damming effects? - re-assessment of impact of dams; determine ecological flow through mesocosm-mesohabitat studies	- monitoring of sediment and nutrients upstream and downstream reservoirs and within - remote sensing /ground observations and modelling - regular sediment sample analysis for toxic pollutants

			sediment load in rivers due to damming - discharge fluctuations due to flow regulation due to hydropower generation cycles - thermal stratification cycles in storage lakes - hypolimnetic hypoxia - interrupted water ways - river damming isolates fish populations - reservoir stratification and bottom water withdrawal from dams reduces water temperature downstream -> fish species downstream live in permanent winter conditions - fish species downstream live under stress due to hydropeaking - decrease in freshwater fish abundance (Due to hydropeaking most fish populations migrated to Nestos tributaries and irrigation channels) - changes in morphodynamics, sediment dynamics, decrease of	- impacts related to reservoir filling (inundation of mountainous forested land, alterations in the hydrologic, biogeochemical and ecological conditions) - impact assessment of reservoir lakes on river-sea ecosystem (e.g., retention of bedload and sediment, nutrient retention, eutrophication in reservoirs) - assess the role of dams as settling tanks for emerging pollutants and accumulation in biota - impacts related to Flow Blockage (entrapment of bedload and suspended sediment in reservoirs leading to coastal erosion, accumulation of dissolved and suspended pollutants (organic matter, nutrients, heavy metals and toxic substances) into the upstream part of the reservoir, changes of water physico-chemical characteristics downstream, geographic departmentalization of main river course disrupting fish movement - Assessment of bed load and suspended sediment entrapment at reservoirs - coastal parts will not be sustainable due to soil and water salinization - study the impacts of hydropeaking, especially on river banks erosion, - evaluate River flow reduction due to damming and climate change and its effect on the river plume dynamics - assess river plume dynamics and its relation to river discharge change as it affects the water renewal of the nearby Kavala Gulf	- estimation of the sediment loads trapped in dams - assessment of coastal erosion along the watershed coastal zone - models and indicators assessing the impact of climate change (increase in frequency of storm waves and surges) on the coastal zone - sediment transport and hydrological modelling - continuous monitoring of aquifers (especially along the coastal zone) for water quality and level. - sediment transport and hydrological modelling - results from "GREEN ELECTRICITY CERTIFICATION FOR HYDROPOWER PLANTS" Green Power Publications, Issue 7, C. Bratrich and B. Truffer (by Eawag) - plume water circulation models - plume water quality models - plume expansion through satellite monitoring - benthic DO sensors for long-term monitoring - biogeochemical modelling, including input functions

			sediment load in rivers due to damming - increased saltwater intrusion at coastal aquifers over the latest years, after flow regulation due to dams' operation	- report Toxic HABs at the coastal zone in relation to water quality and nutrient stoichiometry changes at river plume water - impacts related to Flow Storage (changes into lacustrine environment, water column thermal stratification/destratification cycles, - hypolimnetic releases under anoxic conditions, - stoichiometric changes in nutrients - fish artificial reproduction and enrichment to mix genetically fish stocks isolated after damming - changes in freshwater fish abundance and diversity, changes in morphological characteristics of freshwater fish, loss of feeding and reproduction habitats - the operation of Thissavros and Platanovrisi changed the sediment dynamics of the river - Toxotes Dam retains the sediments at the river delta	- river-river plume-open sea nested hydrologic/hydrodynamic and biogeochemical modeling forced by regional/local meteorology - continuous CTD profiles - thermal cycle models - continuous monitoring of aquifers (especially along the coastal zone) for water quality and level
	Urbanisation	**Waste Water**	- limited human presence in the watershed - two medium sized settlements (Paranesti and Stavroupolis) should improve their urban waste (Eutrophication incidents have not been reported along the river route or at the reservoirs) - impact of urbanisation in the Nestos delta is limited		- continuous monitoring at the sewage system of both villages

	Industry	Cross-border Pollution	- metals, organic substances, emerging contaminants, pesticides, micro-/nanoplastics)	- improve knowledge on pollutant sources & sinks - development of pollution abatement standards (air pollution, climate, waste and water sectors) - How are effective are the current policy instruments, especially in an international basin context, in preventing accidents? - impact & risk assessment of microplastics and emerging contaminants (e.g., from pesticides, flame retardants, anti-fouling substances, medicals)	- monitoring based on WFD and MSFD requirements and beyond (monitor emerging pollutants in biota throughout the food web) - analysis of policies in basin countries and oversight of commission - modelling of pollution events (distribution of pollution, e., g. oil spill) - risk assessment by pollution (basin and sector-wide) - FP 7 SOLUTIONS project http://www.solutions-project.eu
	Fishery	Decline of Fisheries	- illegal fishing near coastal zone, and in protected areas, poaching - eutrophication in coastal fishery lagoons - loss in fish reproduction and feeding habitats - decrease in freshwater fish abundance - fisheries declined and fish species do not use Nestos plume as nursery, due to biogeochemical changes and river plume reduction, especially during spring	- coastal lagoons functioning, inlet modification to improve water residence time and scenarios under variable water uses in agriculture - due to hydropeaking most fish populations migrated to Nestos tributaries and irrigation channels	- modelling the water circulation and biogeochemical cycles in the lagoon environments - regular fish sampling reporting fish species abundance and diversity

	Aquaculture	Nutrient Loading	- at the river deltaic zone, especially at transitional waters as lagoons, the impact of agriculture is important - eutrophication and hypoxia in coastal lagoons leading to massive fish deaths in fish productive lagoons, regular toxic blooms affect coastal mussel cultures, raised levels in pesticides - low water quality levels have been reported at Nestos river lagoons - habitat loss at the lagoons and their periphery, due to salinization of their basins and intense farming	- improve water renewal at lagoons through inlet hydroengineering (modifications in depth, width, etc) - improve ventilation at deeper parts of lagoons - study the influence of freshwater abstraction and lagoons salinization - study the seabed/water column exchange of substances - study lagoons benthic flora and fauna in relation to environmental conditions	- apply numerical models to simulate water circulation and water quality at various tidal inlet scenarios. - continuous monitoring of DO and other water quality parameters at lagoon bottom - lagoon habitat studies
	Tourism		- limited touristic activity into the watershed - environmental sustainable tourism concepts		
	Cumulative Drivers	Tipping Points	- river-sea system resilience / vulnerability		- system modelling - resilience analysis - interactive planning tools - visualization - building/increasing of adaptive capacity - stakeholder participation

Nestos Supersite, Greece – Table 2

Human Response & Societal Challenges	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
Nature Conservation and Restoration (Nestos delta is RAMSAR site)	- assessment of competing needs of restoration/protection and services - concepts for integrated environmental directives and nature conservation conventions	- protocols and technological innovation (e.g., bottom echolocation, habitats characterization and modelling)
Sustainable Adaptive Ecosystem Management	- scientific support for management plans - interdisciplinary and holistic approach for new strategies of sustainable management - integration of the studies and increased results transparency - assessment of cumulative impacts on RSS - integration of social, economic and strategic value of RS systems at different spatial and temporal scales - interaction & causalities between biodiversity, ecosystem functions and services - assess drivers and pressures - forecast of biodiversity and ecosystem service provision - effects of multiple & interacting pressures on aquatic ecosystems - interdisciplinary cooperation & knowledge brokering: science-science as well as science-policy/practice - dealing with uncertainties and surprises - societal cost-benefit analysis - scenario studies	- use of best available scientific knowledge to create management guidelines for relevant ecosystems - involve environmental lawyers to ensure compliance with EU environmental Legislation; - integration of previous and ongoing monitoring studies on both environmental and socio-economic factors - logical framework approach - practice of procurers to keep a 'risks register' in the management project to incorporate innovation related risks - predictive tools to assess environmental response - definition and assessment of cumulative impacts and ecosystem services indicators - improvement of integrated modelling (river, drainage basin, delta, ground waters, sea) - tools to calculate (adaptation) effect of measures - adaptation pathways - scenario modelling - interactive planning tools

		- visualization tools - knowledge brokering instruments (such as: serious or role playing games, group model building, scenario planning, communities of practice) - joint fact finding - interactive or participatory modelling - pilot projects / living labs -stakeholder participation - citizen science - Key Performance Indicators (KPIs)
Environmental Education (training of farmers)	- training and education of target groups at the watershed	- programs to educate farmers and fishermen to resolve conflicts
Sustainable Hydropower Energy Generation	- discussions with the hydropower management to reduce the impact of hydropeaking and use the the dam as a potential source of water to flash away toxic algal blooms at the coastal zone	
Changes in fisheries/fish and shellfish farming practices		
Transboundary Sustainable Management	- transboundary conflicts assessment	- long term perspectives in international cooperation - establish cross-border management boards for transboundary watersheds responsible for the implementation of EU Directives (WD, MSFD)

Nestos Supersite, Greece – Questionnaire

1) Human activities (drivers) and resulting pressures:

- Agriculture, at the Nestos deltaic zone -> irrigation in the Nestos Delta
- Water abstraction and diversion for irrigation
- Hydropower generation -> River damming, two hydropower dams at Nestos altering downstream hydrology, flow alterations, habitat changes, river morphological changes and biogeochemistry -> decrease in river sediment load -> coastal erosion, delta erosion
- Cross-border pollution: incidents and transport of solid wastes, mostly related to floods
- Fishery: illegal fishing, poaching at the reservoirs and along the river, Illegal fishing near the coastal zone
- Urban wastewater -> discharges from municipalities along the river
- Tourism -> touristic development along the coastline
- Aquaculture along the river -> Mussel cultures along the river plume, toxic HABs related to river water biogeochemistry changes

2) What are the resulting environmental/socio-ecological problems?

Environmental Impacts related to River Damming

- ✓ Impacts related to reservoir filling (inundation of mountainous forested land, alterations in the hydrologic, biogeochemical and ecological conditions)
- ✓ Impacts related to Flow Blockage (entrapment of bedload and suspended sediment in reservoirs leading to coastal erosion, accumulation of dissolved and suspended pollutants (organic matter, nutrients, heavy metals and toxic substances) into the upstream part of the reservoir, changes of water physico-chemical characteristics downstream, compartmentalization of main river course disrupting fish movement).
- ✓ Impacts related to Flow Storage (transition into lacustrine environment, water column thermal stratification/destratification cycles, hypolimnetic oxygen depletion, releases under suboxic/anoxic conditions, stoichiometric changes)
- ✓ Impacts related to Flow Regulation (rapid changes in water temperature, hydropeaking, river banks erosion, changes in freshwater fish abundance and diversity, changes in morphological characteristics of freshwater fish, loss of feeding and reproduction habitats, changes in river plume dynamics, changes in coastal water quality)

Environmental Impacts related to Intense Agriculture at the delta

- ✓ Impacts related to water abstraction for cultivations, expansion of existing irrigation networks, salt water intrusion to coastal aquifers.
- ✓ Continuous conflicts between fisheries and agriculture, eutrophication in coastal fishery-productive lagoons leading to massive fish deaths, regular toxic blooms affecting coastal mussel cultures, raised levels in pesticides.

Based on these impacts, the following challenges related to the future of RS system functioning:

- Changes in Water, nutrients and other substances (e.g., trace metals) fluxes in RS system, due to dams blockage

- Interruption and changes in the sediment cycle (source-transfer-sink)
- Bio- & geo-chemistry of water & sediment.
- Biogeochemical and elemental ratio (N:P:Si) changes along the river, the reservoirs and the River-Sea Continuum.
- Hydrodynamic processes at the RS interfaces and in coastal wetlands and combined anthropogenic effects due to damming and agriculture pressures.
- Identification of new feedback processes that link biology and geochemistry, biology and hydrology, sediment and hydrology-Ecological flows

3) Current state of research? Research gaps and future research needs?

Current Research

- ✓ Research on hydrology, water quality, river morphology, ecology and fish fauna populations in Nestos River has been performed in the past.
- ✓ Extensive monitoring of the Greek part of the Nestos basin has been carried out in accordance to WFD requirements. Hydrologic models, water quality models and habitat models have been applied in the system.
- ✓ Ecohydrologic solutions have been proposed and some applied to mitigate the above described environmental impacts.
- ✓ Ongoing research focuses on the reassessment of dams' environmental flow following mesohabitat analysis and modelling.

Research Gaps

- Climate change impacts on the whole drainage basin
- Biogeochemical changes due to river damming – the role of dams on the cycling of nutrients, heavy metals, priority substances, etc.
- Impacts of biogeochemical changes on river and coastal fish populations
- Drought scenarios and impacts on ecosystems and human activities in the drainage basin

4) Which Institutes, authorities, commissions are active in your region?

- Department of Environmental Engineering, Democritus University of Thrace
- Fisheries Research Institute, ELGO Demeter
- Management Body of the Natura 2000 Nestos Delta – Vistonis Lagoon area.

5) Whom do you consider as partners/stakeholders/users?

- Water Management Department, Regional East Macedonia – Thrace Authority
- Hydropower Division, Public Electricity Cooperation
- Farmers Associations and Cooperatives
- Ecotourism Enterprises active in Nestos River
- Municipal Authorities along Nestos River
- Ministry of Environment
- Ministry of Energy
- Ministry of Education
- Ministry of Agriculture

6) Open questions to support sustainable management of the RSS?

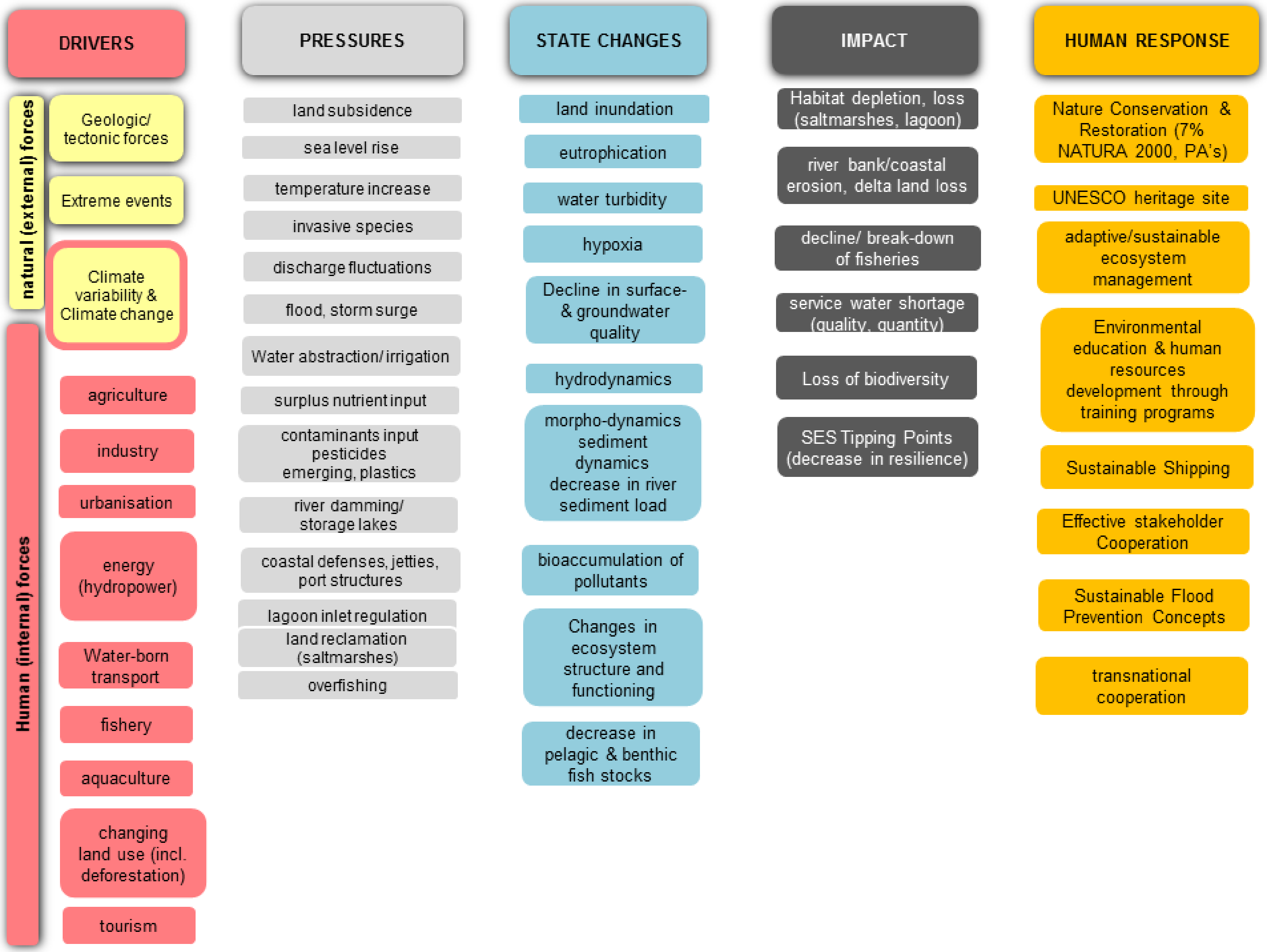
- Stakeholders integration towards sustainable management

- Train farmers on the use of precision farming (less water, less agrochemicals, higher yield)
- Mitigate the adverse effects of hydropower dams operation in close collaboration with dams manager
- Changes in fisheries/fish and shellfish farming practices

7) Major Scientific topics/questions addressing the Supersite:

- Continuous water, nutrient, other substances and sediment flux measurements upstream/downstream from dams
- Assessment of bed load and suspended sediment entrapment at reservoirs
- Assessment of coastal erosion (annual/aggregate rates)
- River plume dynamics (remote sensing /ground observations and modelling)
- Coastal lagoons functioning, inlet modification to improve water residence time and scenarios under variable water uses in agriculture
- Changes in biogeochemistry of coastal zone due to water storage at reservoirs
- Re-assessment of impact of dams; determine ecological flow through mesocosm-mesohabitat studies
- Measurements in compliance with WFD and MSFD requirements and beyond
- River-River plume-open sea nested hydrologic/hydrodynamic and biogeochemical modeling forced by regional/local meteorology

6. Po Delta – North Adriatic Lagoons Supersite, Italy – DPSIR Overview



Po Delta – North Adriatic Lagoons Supersite, Italy – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Geologic/Tectonic Forces	Land Subsidence	- interaction of land subsidence and sea level rise - river bank/coastal erosion / delta land loss	- What is the interaction of land subsidence and sea level rise? - study of evolution of land subsidence and definition of most vulnerable zones - impact of changed rate of erosion/deposition - change in morphodynamics involving sediment transport and bottom evolution (bathymetry)	- SAR interferometry by satellites numerical models, drones historical sea level time series - analysis of long-term data series to study process changes - development of climate impact scenarios - continuous monitoring of coastline changes - SAR interferometry by satellites - numerical models, drones, GIS - high resolution Earth Observation from satellite or aircraft
	Climate Change & Climate Variability	Warming	- temperature and precipitation variation	- influence of changes in temperature regime on spread of alien species - influence of changes in temperature regime/seasons on onset/duration/breakup of stratification, water ventilation	- high resolution Earth Observation from satellite or aircraft - analysis of long-term data series to study process changes - development of climate impact scenarios
		Sea Level Rise	- land inundations - salt water intrusions - river bank/coastal erosion/ delta land loss	- increase linked to climate change, in coastal areas, in the lagoon, in historic lagoon centers. - identification of management measures to safeguard environmental health, biodiversity and ecosystem services - interaction of land subsidence and sea level rise	- high resolution Earth Observation from satellite or aircraft - analysis of long-term data series to study process changes - development of climate impact scenarios

				- climate change relevant element fluxes like. e.g. carbon - saltwater intrusions into lagoons, into groundwater due to sea level change - sea level variation - study the degradation of historical materials, in particular the exposed architectural surfaces of the main buildings - development of preventive measures to reduce the impact of climate change - how sea level rise affects the geomorphological features in transitional areas (i.e. salt marshes) - mechanism that change ecosystem services due to sea level rise - connectivity between coastal systems - climate change and coastal morphodynamics - impacts on coastal ecosystems on land, in transitional areas and along the coast	- development of early warning systems - monitoring and modelling sea level rise scenarios in RSS and transitional environments - monitoring and modelling salt intrusion - ecosystem monitoring - monitoring and modeling hydro-ecological dynamics in the lagoon - monitoring the degradation of historical materials, in particular the exposed architectural surfaces of the main buildings
		Invasive Species	- change in flora and fauna populations - changes in ecosystem structure and functioning - displacement of native species	- analysis of the relationships between the different components of the system at multiple levels (physical, biogeochemical, biological communities and global ecological functioning) in order to find responses to anomalous phenomena, extreme events or particular management choices. - reason for the increase in invasion (e.g., ballast water, climate change) - analysis of and management concepts for invasive species	- Hydrodynamic-biogeochemical-ecological model - Modeling of relations between species (food chain). - Quantify and map ecosystem services - conventional and molecular/genetic taxonomic analyses - molecular, physiologic and genomic labelling of species - habitat and process related physiological models

					- monitoring species development
		Discharge Fluctuations	- river bank/coastal erosion / delta land loss	- Which factors control discharge (e.g., climate variability, teleconnections and extreme events)? - effects of the increase in extreme flooding events on the coasts - changes connected with discharge fluctuation on salt intrusion	- high resolution Earth Observation from satellite or aircraft - development of early warning systems - analysis of long-term data series to study process changes - development of climate impact scenarios - monitoring of discharge status - monitoring and modelling salt intrusion - River-River plume-open sea nested hydrologic/hydrodynamic and biogeochemical modeling forced by regional/local meteorology - River plume dynamics (monitoring and modelling)
	Extreme Events	Flood , Storm Surge, Drought	- meteorological extreme events	- understanding triggering mechanisms of extreme events, at different scales (floods, draughts, storms), even at different spatial scale (Northern Italy or drainage system + lagoon + sea or city of Venice) - understanding the effects of major hazards - flood prevention concepts (e.g., maintaining flood-plain river connections): spatial distribution / zonal analysis of ecosystem services provided by the Venice lagoon with focus on regulation services in relation to climate change - impact of management choices (e.g. MOSE System), e.g., mountain storage water basins on drought events - comparative risk assessment	- automated observation stations along RSS (e.g., gauges, ferry boxes, radar – wave heights) - extreme Value Analysis of historic hydro-meteorological data collected from in-situ sensors, remote sensing databases and GCMs/RCMs - meteorological forecast scenarios - forecast of hazards effects - nested landslide and meteorological models - comparative risk assessment of natural hazards (multi scenarios)

				study and monitoring of the degradation of historical materials, in particular the exposed architectural surfaces of the main buildings	- vulnerability of built heritage and urban landscape - high resolution Earth Observation from satellite or aircraft - development of early warning systems - monitoring of discharge status (from drainage basin and the sea) - monitoring and modelling salt intrusion - extreme events analysis - scenario studies (i.e., modelling, GIS, …)
HUMAN DRIVERS	**Agriculture (in Catchment and Supersite)**	**Nutrient Loading**	- agriculture and eutrophication Po Valley - intensive agriculture (35% of Italian agricultural production) (-> only 7% area protected) - main income farming & fishing Venice lagoon - on Sant Erasmo Island Marano-Grado - in drainage basin - hypoxia - surplus nutrient discharge river to lagoon to sea	- impact of agriculture on surface & groundwater water quality - pathways of fertilizer-based nutrients into river and lagoons - concepts for sustainable use of fertilizers - pathways of emerging contaminants in water cycle (e.g., pesticides) - dynamics of phytoplankton blooms (eutrophication) - improve nutrient retention and elimination from the field through the catchment to the sea - effect of eutrophication on ecosystem function´ - cumulative effects of eutrophication, climate variability on oxygen regime in RSS - changes in hypoxia dynamics - impacts of nutrient fluxes, identification of sources and rate of dispersion - eutrophication studies	- source-pathway-sink investigation with stable isotope techniques - pathway modelling (e.g., MONERIS) - monitoring based on WFD and MSFD - develop and validate early warning and rapid assessment systems for anoxic events, by remote sensing methods and artificial intelligence systems - in field monitoring, satellite images, - chemical modeling in the lagoon - analysis of ecosystem services that can improve the quality and health of the lagoon - use of sentinel species - laboratory analyses

			- deterioration of water quality - changes/decline in ecosystem structure and functioning	- quantification of impact due to environmental changes on different communities in terms of structure and functioning	- genetic studies - food chain modeling - analysis of ecosystem services to contrast it
		Pollution	- contaminants / pollution of groundwater, river and marine waters (including environmental accidents/spills) - metals, organic substances, emerging contaminants, flame retardants, pesticides, micro-/nanoplastics	- improve knowledge on pollutant sources & sinks - development of pollution abatement standards (air pollution, climate, waste and water sectors) - how are effective are the current policy instruments, especially in an international basin context, in preventing accidents? - impact & risk assessment of microplastics and emerging contaminants (e.g., from pesticides, flame retardants, anti-fouling substances, medicals)	- monitoring based on WFD and MSFD requirements and beyond (monitor emerging pollutants in biota throughout the food web) - analysis of policies in basin countries and oversight of commission - modelling of pollution events (distribution of pollution, e., g. oil spill) - risk assessment by pollution (basin and sector-wide) - FP 7 SOLUTIONS project http://www.solutions-project.eu
		Water Abstraction	- service water shortage - changes in ecosystem structure and functioning	- study of changes on river discharge variation due to irrigation - impact of decreasing water level due to water abstraction (e.g., irrigation)	- scenario modelling for DSS
	Industry	**Pollution**	- 40% of Italian industrial production is in the Po valley - industrial poles along river - Venice lagoon - industrial zone on saltmarshes (Marghera),	- presence of pollutant in sediments and water - how pollutant distribute inside the studied systems - how pollutant transfer through the different matrices and their pathways - emerging pollutants - improve knowledge on pollutant sources & sinks	- classification and mapping of polluted sediment - lagrangian tracking of micropollution, through observation and modelling

			- Treviso airport - Marano Grado lagoon - 2 industrial sites on mainland - Torviscosa pole - pollution of ground- and surface waters - deterioration of water quality - bioaccumulation of pollutants - mercury mining in the past - study changes in water quality	- development of pollution abatement standards (air pollution, climate, waste and water sectors) -understanding the ecological effects of new pollutants such as microplastics, micro-fibers, pharmaceuticals - groundwater quantification in terms of location and discharge, pollution… - emerging contaminants from the Po River - trends of pollutant loads from the Po river and effects on the Adriatic (e.g. eutrophication) - fate of contaminants and ecological + human health risk (i.e. Mercury in the Grado-Marano Lagoon) - study changes in water quality	Monitoring based on WFD and MSFD requirements and beyond (monitor emerging pollutants in biota throughout the food web) - analysis of policies in basin countries and oversight of commission - modelling of pollution events (distribution of pollution, e., g. oil spill) - risk assessment by pollution (basin and sector-wide) - FP 7 SOLUTIONS project http://www.solutions-project.eu - specific biomarkers - metal mercury transformation model - in field monitoring, satellite images - chemical modelling in the lagoon - analysis of ecosystem services that can improve the quality and health of the lagoon - analysis on sentinel species, such as bioaccumulation, specific biomarkers, etc.
	Urbanisation		- Po delta - Venice lagoon >1000 years urbanisation history of Venice Marano Grado	- assessment of social and economic conditions of local communities inhabiting RS systems - concepts for wastewater and waste treatment - concepts for sustainable urbanisation based on green economy	- inquiries on socio-economic conditions - participatory approaches (Participatory rural appraisal, Citizen Observatories etc.)

			- settlement inside the lagoon - wastewater (municipal and industrial waste treatment & management) - surplus nutrients from insufficient industrial/urban waste water treatment - deterioration of water quality	- concepts for harmonious development of human habitats near RSS - long-term trends of population development and habitat evolution	
	Energy Generation	Hydropower	- hydropower (272 power plants) - disruption of river connectivity - damming of rivers - storage lakes - sediment retention - changes in morphodynamics, sediment dynamics, sediment disturbance - e.g., decrease of sediment load in rivers due to damming - changes/decline in ecosystem structure and functioning - disruption of river connectivity	- impact of hydropower plants biodiversity (e.g., frequent changes in river water level on downstream ecosystems and flood-plain inundations, species migration) - impact assessment of reservoir lakes on river-sea ecosystem (e.g., retention of bedload and sediment, nutrient retention, eutrophication in reservoirs) - consequences of incision and disconnecting floodplains from river channel - risk assessment of dam failure - assess the role of dams as settling tanks for emerging pollutants - assess the impact of storing emerging pollutants for biota in reservoirs - impact assessment of reservoir lakes on river-sea ecosystem (e.g., retention of bedload and sediment, nutrient retention, eutrophication in reservoirs) - assess the role of dams in changes in hydrodynamics and in sediments fluxes - study changes in sediment budgets	- monitoring of sediment and nutrients upstream & downstream reservoirs and within - sediment transport and hydrological modelling - biogeochemical modelling, including input functions - results from “GREEN ELECTRICITY CERTIFICATION FOR HYDROPOWER PLANTS” Green Power Publications, Issue 7, C. Bratrich and B. Truffer (by Eawag) - analysis of the quality of water and sediments - scenario modelling with dams included

				- water level changes (also in connection with (shipping and water shortage) - flocculation processes not understood - interplay of sediments and soil in the processes of sedimentation, erosion, flora/fauna habitat succession and soil genesis on the marsh edge - efficiency of estuarine aquatic and (semi)terrestrial environments in controlling - quantification of impact due to environmental changes on different communities in terms of structure and functioning	
	Transport	**River Regulation, Port Structures, Shipping**	Venice lagoon - heavily engineered water ways - shipping main means of transport - industrial Port 25 Mio t of freight per year. 1.6 Mio passengers on cruise ships per year Marano-Grado - internal water way "litoranea Veneta" - commercial harbour - changes in hydrodynamics	- impact of pollutants (oil, anti-fouling substances) - nutrients and oxygen dynamics due to dredging - cumulative effects of hydro-engineering works (dredging, channelling & deposition of dredged material, sediment transport) on RSS functions (ecosystem functions, hydrodynamics, morphodynamics) and GES - cumulative effects of diking on RSS functions - risk assessment of hydroengineering works - guidelines to conserve endangered species & habitats despite hydro-engineering - socio-economic analyses on changing practice in waterborne transport modes - environmental impact assessment of hydro-engineering works and shipping - What are the mechanisms that lead to flux changes, morphodynamic changes (especially linked to sediments fluxes) - variation due to hydrodynamic changes with effects on ecosystems	- mapping and assessing ecosystem services in estuaries related to sustainable management of estuarine waterborne transport infrastructure - assessment of the ecological status of river-sea-systems - scenario modelling with possible hard structures included - monitoring of hydrodynamics and sediment loads - River-River plume-open sea nested hydrologic/hydrodynamic and biogeochemical modeling forced by regional/local meteorology - River plume dynamics (monitoring and modelling)

		Dredging	- change in nutrient and oxygen dynamics - water turbidity - changes in hydrodynamics - changes in morpho-dynamics, sediment dynamics, sediment disturbance - changes/decline in ecosystem structure and functioning	- nutrients and oxygen dynamics due to dredging - cumulative effects of hydro-engineering works (dredging, channelling & deposition of dredged material, sediment transport) on RSS functions (ecosystem functions, hydrodynamics, morphodynamics) and GES - cumulative effects of diking on RSS functions - risk assessment of hydroengineering works - guidelines to conserve endangered species & habitats despite hydro-engineering - socio-economic analyses on changing practice in waterborne transport modes - environmental impact assessment of hydro-engineering works and shipping - changes in the spatial and temporal distribution of the hydrodynamic parameters through the RSS, to determine where the sediment exchanged is eroded or deposited - study changes in hydrodynamics - study of feedbacks on hydrodynamics due to morphological changes - study changes in sediment budgets - water level changes (also in connection with (shipping and water shortage) - flocculation processes not understood - interplay of sediments and soil in the processes of sedimentation, erosion, flora/fauna habitat succession and soil genesis on the marsh edge - efficiency of estuarine aquatic and (semi)terrestrial environments in controlling	- long-term monitoring of: turbidity/sediment dynamics and morphodynamics, biota, physical & chemical properties incl. pollution along RSS by automated monitoring stations/field campaigns) - underwater & in-situ observatories - state-of-the-art sensor techniques (including micro- and mesocosm techniques - development of novel monitoring techniques and methods - chemical and ecotoxicological characterization of sediment, suspended particulate matter and water - model-based monitoring approaches - hydrodynamic modelling - numerical modelling of sediment transport combined with chemistry of pollutants - in field monitoring, satellite imagines, drones, Modelling - analysis of the related ecosystem services - use of sentinel species - sediment management plan - development and application of mixed models of sediment/

				- quantification of impact due to environmental changes on different communities in terms of structure and functioning - sediment budget in RSS and transitional areas- effects on the rimobilisation of contaminats - effects on the ecosystem - problem of re-use of the contaminated sediments	soil/habitat establishment and processes - mapping, assessing and modelling climate change relevant elements like C-balances - balancing of various needs and interests using the ecosystem services concept -pre and post dredging monitoring of sediment distribution and load -updated bathymetries for channels-habitat mapping Integrated model and indices of ecological risk - monitoring sediment quality
	Fishery	Overfishing	- changes in trophic web - decrease in fish stocks - decline / break-down of fisheries - changes/decline in ecosystem structure and functioning	- role of overfishing on food web changes and enforcing factor for eutrophication - impact of overfishing - concepts for protection of native species - how this activity affect ecosystem and lead to changes in fish stocks - changes in Trophic web - changes in fish stocks - impact of overfishing on the resources and feedbacks on ecosystems	- evaluation of indicator species trends - individual based models - food web models - study on nursery areas - ecosystem monitoring: microbial community, benthic communities, necton community, etc. - food web modelling - stocks monitoring

	Aquaculture	**Fish and Clam Farming**	- Po valley - Venice lagoon - Marano-Grado - surplus nutrients - changes/decline in ecosystem structure and functioning - loss of biodiversity	- changes in spawning and nursery areas due to human activities - concepts for sustainable aquaculture / fish farming - best siting and solutions for aquaculture development	- connectivity tools (delta-sea, lagoon-sea, lagoon-lagoon) - evaluation of lagoon productivity
	Changing Land Use	**Land Reclamation**	- due to climate change, deforestation, agriculture, exsiccation of wetlands - habitat depletion, loss (e.g. of saltmarshes, lagoons) - loss of biodiversity - changes/decline in ecosystem structure and functioning	- how do changing societal demands affect RSS? - impact of changing land-use (climate change, deforestation, agriculture, exsiccation of wetlands) on RSS on nutrient loading, on delta development - role of land reclamation in changes in transitional environments' hydrodynamics, tidal propagation, increased risk of flooding, habitat changes - impact on biodiversity due to habitat loss in wetlands/river branches/coastal zone - impact on changes in ecosystem services - role of wetlands on storms, surge, waves, tides and circulation of a semi-enclosed sea	- drainage basin models - spatial planning (adaptation of maritime spatial planning tools to transitional areas - GIS) - hydrodynamic Monitoring and modelling - ecosystem monitoring and ecosystems services mapping
	Tourism		Po Valley Venice lagoon ->10 Mln tourists per year plus "day" tourists Marano Grado - beaches - sea resort	- environmental sustainable tourism concepts - sustainable urban mobility	- socio-economic analyses on tourism fluxes in historical and naturally relevant sites - drafting of a Sustainable Urban Mobility Plan

	Cumulative Effects		- change in flora and fauna - changes/decline in ecosystem structure and functioning - loss of biodiversity - socio-ecologic system (SES) tipping points - system resilience / vulnerability	- analysis of the relationships between the different components of the system at multiple levels (physical, biogeochemical, biological communities and global ecological functioning) in order to find responses to anomalous phenomena, extreme events or particular management choices - quantification of impact due to environmental changes on different communities in terms of structure and functioning - interdisciplinary science - systems approach - physical, societal, economic resilience - tipping points - quantification of coastal lagoons effects on the main basin and feedbacks - presence of transitional areas modulates the RS dynamics: role of lagoons for the sediment trapping, pollutant, nutrients, ecosystems and fishery (nursery etc.)	- hydrodynamic-biogeochemical-ecological model - modelling of relations between species (food chain) - quantify and map ecosystem services - system modelling - resilience analysis - interactive planning tools - visualization - building/increasing of adaptive capacity - stakeholder participation

Po Delta – North Adriatic Lagoons Supersite, Italy – Table 2

Human Response & Societal Challenges	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
Nature Conservation & Restoration (7% NATURA 2000, PA's) Po Valley - 7% NATURA 2000 or PA sites Venice lagoon - UNESCO heritage site - SPA (Directive 79/409/EEC - Community important sites (Directive 92/43/EEC) adjacent to inlets - protection of underwater cultural heritages	- assessment of competing needs of restoration/protection and needs (e.g., shipping) - concepts for integrated environmental directives and nature conservation conventions - assessment of status of species and habitats, improvement of habitats for native and endemic species, biodiversity - structure and functionality of species and habitats (biodiversity) - real-time and permanent environmental quality assessment in RS systems - guidelines to conserve endangered species & habitats - restoration concepts for degraded habitats - bioremediation, restoration of river connectivity, floodplains - assessment of coastal erosion - the role of migration barriers - habitat connectivity along the marine – freshwater continuum - socio-economic benefit of restoration measures	- improve the assessment methods for environmental flows related to river water abstractions, river diversions and damming - high resolution Earth Observation from satellite or aircraft - habitat mapping, analysis of connectivity - protocols and technological innovation (e.g., bottom echolocation, habitats characterization and modelling)
Adaptive Ecosystem Management/ Sustainable Development	- scientific support for management plans - interdisciplinary and holistic approach for new strategies of sustainable management - integration of the studies and increased results transparency - assessment of cumulative impacts on RSS	- use of best available scientific knowledge to create management guidelines for relevant ecosystems - involve environmental lawyers to ensure compliance with EU environmental legislation

	- integration of social, economic and strategic value of RS systems at different spatial and temporal scales - interaction & causalities between biodiversity, ecosystem functions and services - assess drivers and pressures - forecast of biodiversity and ecosystem service provision - effects of multiple & interacting pressures on aquatic ecosystems - interdisciplinary cooperation & knowledge brokering: science-science as well as science-policy/practice - dealing with uncertainties and surprises - societal cost-benefit analysis - scenario studies - integrated analysis of the anthropic pressure system to support planning and management (ICZM-MSP) - sustainable fishery in coastal areas - MAB-Unesco management plan	- integration of previous and ongoing monitoring studies on both environmental and socio-economic factors - logical framework approach - practice of procurers to keep a ‘risks register’ in the management project to incorporate innovation related risks - predictive tools to assess environmental response - definition and assessment of cumulative impacts and ecosystem services indicators - improvement of integrated modelling (river, drainage basin, delta, ground waters, sea) - H2020 Aquacross project http://aquacross.eu/ - FP7 MARS project http://www.mars-project.eu/ - tools to calculate (adaptation) effect of measures adaptation pathways - scenario modeling - interactive planning tools - visualization tools - knowledge brokering instruments (such as: serious or role playing games, group model building, scenario planning, communities of practice) - joint fact finding - interactive or participatory modeling - pilot projects / living labs - stakeholder participation - citizen science - Key Performance Indicators (KPIs)

Sustainable Shipping	- assessment of impact from different size ships in RSS and transitional environments (particularly Venice Lagoon) - management of ballast waters in ports and coastal waters	- scenario modelling - monitoring of ship passages (depression wave and suspended sediment) and pleasure boats (itineraries and impacts on neighbours ecosystems)
Environmental Education & Human Resources Development	- practical approaches of environmental education in the RSS - environmental education materials for different levels of education	- environmental education of local communities - ontology reference document - joint development of conceptual framework(s) & group model building - boundary spanning objects - collaborative or participatory modeling - serious and role playing games - stakeholder participation
Effective Stakeholder Involvement - the Venice lagoon is managed by various institutions and belongs to two provinces of the Veneto Region - coordination of these institutions is a major task for governance	- definition of best practices for increasing coordination among stakeholders	- discussions with all stakeholders - online platform with active members - interdisciplinary committees, composed of experts and from different stakeholder groups for monitoring and early warning
Transition to Green Economy	- policies that mitigate environmental degradation, reduction of environmental pressures - ecosystem services assessment	- concept of circular economy, bio-economy - implementation of EU environmental legislation - integrate social and economic forecasts in scenarios development - interdisciplinary and transdisciplinary approach
Sustainable Flood Prevention Concepts	- administrative gaps evaluation	- online platform with active members - integrated committees

Po Delta – North Adriatic Lagoons Supersite, Italy – Questionnaire

1) Human activities (drivers) and resulting pressures:

- Agriculture - intensive agriculture in the Po valley, generating pollutants and surplus nutrients
- Energy generation – hydropower - Power plants' activities and their influence on reducing biodiversity
- Industry - Po valley (40% of Italian industrial production), industrial poles along river, in Venice lagoon industrial zone on saltmarshes (Marghera), - Treviso airport, Marano Grado lagoon, 2 industrial sites on mainland, Torviscosa pole, mercury mining in the past releasing pollutants, slat marshland reclamation for industrial sites
- Shipping – naval transport major means of transport, industrial port of Venice, cruise ship port, generating pollutants, fairway dredging, heavy alteration of river and coast banks and hydrodynamics due to port structures, river diversion, channaelization, jetties coastal defenses
- Urbanisation – since > 1000 years, heavily altered ecosystem, soil sealing
- Insufficient or lack of sewage systems for rural settlements - untreated waste
- Tourism – dramatic increase in tourists numbers to Venice, related waste
- Fishery – overfishing of sturgeon
- Aquaculture for clams and fish

2) What are the resulting environmental/socio-ecological problems (current, anticipated, which of them are currently tackled)?

Environmental/Socio-Ecological Problems	Status
Effects on food chain, overfishing, impact on specific fish species in the river (example river sturgeon)	Interregional plans for repopulation (through LIFE projects and other initiatives)
Water sequestration for irrigation purposes; nutrients load into the hydric system and eutrophication	Current, under monitoring from the local environmental entities – no present info on specific activities
Changes in the capability of the drainage basin to handle water loads, higher exposure to flooding and lower capability of the system to cope with high discharge events	To be investigated - no present info on specific activities
Influences on internal deltaic lagoons ecosystems, water supply, water renewal	Current, under investigation by EU and national projects – info on the involvement of local entities to be completed in the future
Sediment load in open sea Modification of river bed, impacts on benthos and on the impacts of high discharge events (bottom friction, corresponding sediment load and resuspension)	Current, under investigation by EU projects – info on the involvement of local entities to be completed in the future

Subtraction of coastal and deltaic areas for intensive aquaculture, impacts on ecosystems	Current, under investigation by EU projects – info on the involvement of local entities to be completed in the future
Pollution in coastal areas, increase in waste waters, microplastics and nutrients loads.	Current, under investigation by EU projects – info on the involvement of local entities to be completed in the future
Modification of erosion/deposition paths, changes in the coastline, effects on bathing areas and therefore touristic uses, need for replenishment	Current, under investigation by EU projects – info on the involvement of local entities to be completed in the future
Groundwaters vulnerability and drinking water supply	Current, under monitoring by local authorities

List of projects tackling presently or in the recent past these issues are:

- Life projects - Conflupo, Life Seresto, Life Vimine, Life Ghost, Life Redune, etc;
- EU EMFF Supreme Project co-funded by the EC – DG Maritime Affairs and Fisheries (DG MARE)
- EU FP7 Collaborative project Risk-kit
- EU H2020 Muses Project, SubCULTron
- INTERREG-MED Co-evolve Project
- European Commission, DG-ECHO Humanitarian Aid And Civil Protection: ResCult
- National Flagship project RITMARE
- Adrion Programme: I-STORMS project
- Programma di Ricerca Provveditorato Interregionale per le OO. PP. di Venezia-CORILA: Venezia 2021: Programma di ricerca scientifica per una laguna “regolata”.

3) Current state of research? Research gaps and future research needs?

Current Research:

- The presence of transitional areas modulates the RS dynamics: role of lagoons for the sediment trapping, pollutant, nutrients, ecosystems and fishery (nursery etc.)
- Connectivity between coastal systems
- Role of Wetlands on storms, surge, waves, tides and circulation of a semi-enclosed sea.
- Coastal Aquifer salinization
- Climate Change and coastal morphodynamics. Impacts on coastal ecosystems on land, in transitional areas and along the coast
- Integrated analysis of the anthropic pressure system to support planning and management (ICZM-MSP)
- Emerging contaminants from the Po River
- Fate of contaminants and ecological+human health risk (i.e. Mercury in the Grado-Marano Lagoon)
- Sustainable fishery in coastal areas
- Best siting and solutions for aquaculture development
- Management of ballast waters in ports and coastal waters
- Trends of pollutant loads from the Po river and effects on the Adriatic (e.g. eutrophication)
- Solid transport from rivers and, for the lagoons, through the inlets

- MAB-Unesco management plan
- Who to prevent and mitigate the impacts of disasters on cultural heritage sites

Research Gaps:

- The Po river is a inter regional geographical entity. Homogenization on the river management and common governance is a field of work in aligning River Basins and Authorities
- Full from mountain to sea (as a continuum) approach to the full range of studies (for the River)
- The Venice lagoon is managed by various institutions and belongs to two provinces of the Veneto Region. Coordination of these institutions is a major task for governance.
- Quantification of coastal lagoons effects on the main basin and feedbacks

4) Which institutes, authorities, commissions are active in your region?

- UNESCO BRESCE
- Council of Europe
- Ministry of Infrastructure and Transports
- Ministry of Environment and protection of Land and Sea
- ISPRA Italian National Institute for Environmental Protection and Research
- MIBACT
- ANMS Associazione Nazionale Musei Scientifici
- MPAs
- AIPO - Interregional Agency for Po River
- Hydrographic District Authority for the Oriental Alps
- Hydrographic District Authority for Po river
- The Interregional Board on Public Works for the Veneto, Trentino Alto Adige and Friuli Venezia Giulia regions
- Reclamation Consortia
- Ente Parco Delta Po Emilia Romagna Region
- Ente Parco Delta Po Veneto Region
- Veneto Region Authority
- Emilia Romagna Region Authority
- Friuli Venezia Giulia Region Authority
- Lombardia Region Authority
- Piemonte Region Authority
- Liguria Region Authority
- ARPA (Veneto, Emilia Romagna, Friuli Venezia Giulia Regions) Regional Environmental Agency
- Regional Secretariat of the Ministry of Cultural Heritage and Tourism of Veneto (MiBACT)
- Superintendence for the Architectural and Landscape Heritage of Venice and the Lagoon.
- Reclamation Consortia
- CONFAGRICOLTURA
- Universities (Padova, Venezia, Bologna, Ferrara, Trieste, Parma, Udine, etc)
- Port Authorities (Venice, Trieste, etc)
- Padua-Treviso-Venice metropolitan area
- Municipality of Venice, etc

- Private SMEs
- Natural History Museums
- NGOs
- CNR
- OGS
- CORILA

5) Whom do you consider as partners/stakeholders/users?

- Partners: CNR, OGS, CORILA, Universities,
- Stakeholders: Hydrographic District Authority for the Oriental Alps,Hydrographic District Authority for Po river, Ministries, Regions, UNESCO, Ente Parco Delta Po Emilia Romagna Region,Ente Parco Delta Po Veneto Region etc.
- Users: AIPO, ARPA, ISPRA, Regions etc.

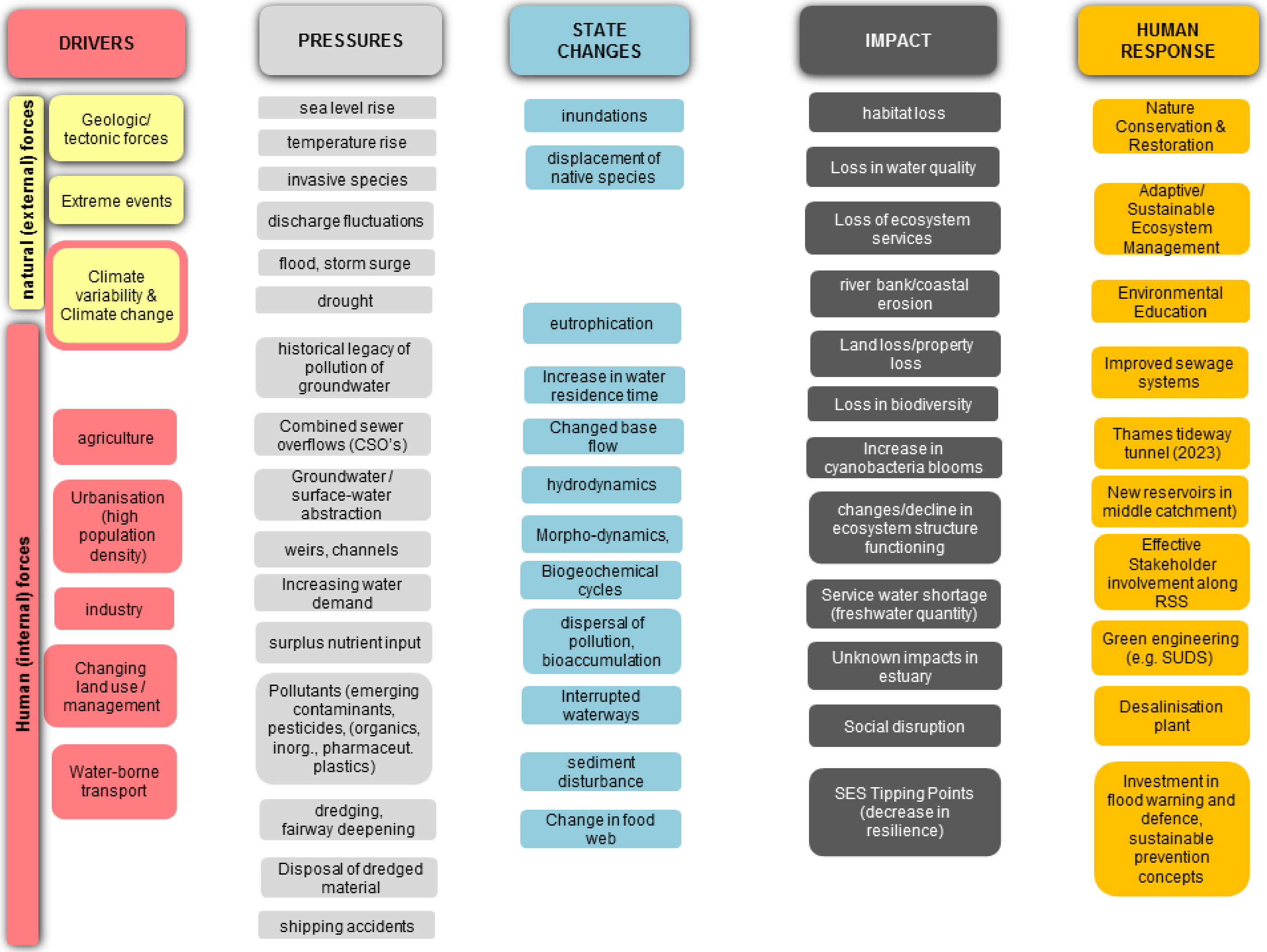
6) Open questions to support sustainable management of the RSS?

- New methodologies for governance, creation of broad and conscious stakeholder community to be involved in management
- Land use effects on the system and quantification of the cumulative impacts taking into account the future needs for a sustainable management
- Ecosystem services perception and quantification of the whole system (from mountain to sea)
- Enhancement of scientist–managers-stakeholders participation processes

7) Major Scientific topics/questions addressing the Supersite

- Studies on processes and feedbacks between freshwater and marine systems, and on the role of transitional environments with co-existence of natural and highly humanized areas over the centuries, for a step change in the adaptation concept.
- Identifying the role of transitional environment in the interface between the river and the sea, quantifying feedbacks between the different components of the system. Lagoons, in particular, play a role for sediment and pollutant trapping and release. The connectivity between the different coastal systems present in the Supersite helps in understanding the interaction processes (physical and ecological).
- Studying the deltaic lagoon ecosystems and fishery (nursery function, sustainable management of fishing activities, etc) to state resilience and capability to cope with RSS changes, in the present state and in a climate change perspective.
- Studying the complex system of land use to identify major drivers for pollution (from water and sediments), water quality (waste waters, microplastics and emerging pollutants, nutrients loads) and water and groundwater exploitation and their effects on biota, in a climate change perspective.
- Studying for the preservation of natural habitats in transitional environments and the maintenance of their diversity (seagrass meadows, salt marshes, inter-tidal flats habitats, freshwater habitats). Studying the presence of Invasive Alien Species and their influence on the autochthones ones, expecially in depending on climate change.
- Studying the anthropic adaptation in such an impacted and changing environment, evaluation of new concepts, in a climate change perspective.

7. Thames Estuary Supersite, United Kingdom – DPSIR Overview



Thames Estuary Supersite, United Kingdom – Table 1

Drivers & Pressures			Environmental Challenges (State Changes & Impact)	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
EXTERNAL DRIVERS	Geologic/ Tectonic		- due to high porosity bedrock (oolitic limestone) groundwater aquifers are polluted by nitrate (fertiliser, manure) from 20th century	- quantifying catchment hydrology (flow attenuation; water recharge/discharge) - sediment fluxes	- environmental monitoring and modelling
	Climate Change & Climate Variability	Warming	- temperature and precipitation variation	- influence of changes in temperature regime on spread of alien species and timing of algal and cyanobacterial blooms	- temperature monitoring - algal and bacterial monitoring
		Sea Level Rise	- land inundation - loss of habitat	- understanding climate drivers (event, seasonal, inter-annual) - changes in relative sea level	- environmental monitoring and modelling

		Invasive Species	- change in flora and fauna populations - changes in ecosystem structure and functioning - displacement of native species - harming ecological status - change in ecosystem structure and function	- How do invasive species impact local population structure? - physical habitat change (i.e. digging of signal crayfish)	- invertebrate and macrophyte surveys
		Discharge Fluctuations, Drought	- more winter flooding predicted - more summer droughts predicted - regular drought in headwaters - reduced flow velocity, increased water residence time - changed base flow - loss of Habitat - change in ecosystem structure and function - service water shortage (freshwater) - loss in water quality	- What are the impacts on ecology and water quality? - Reduce water demand - Ensure equitable allocation of available water - Impact on ecology	- flow, water quality and ecological monitoring - algal and bacterial monitoring

	Extreme Events	**Flood, Storm Surge**	- coastal, groundwater pluvial, riverine flooding - land inundation, land loss, property loss - river bank/coastal erosion - loss of habitat - unknown impacts in Thames estuary	- increase flood resilience; - improve flood forecasting and protection	- flow monitoring network - remote sensing to estimate flood extents
HUMAN DRIVERS	**Agriculture (in Catchment)**	**Nutrient Loading**	- algal blooms - eutrophication - cyanobacteria blooms - change in ecosystem structure and function - loss of habitat	- nutrient and pesticide flux	- chemical and biological monitoring and modelling - site specific experiments (microcosms)
		Pollution	- pesticides, pharmaceuticals - dispersal of pollution, bioaccumulation - unknown impacts in Thames estuary	- pathways of contaminants in water cycle (e.g., pesticides, emerging contaminants) - Identify and quantify multiple pollution sources across the catchment and understand the processing /storage / chemical transformations occurring in the estuarine environment - quantification of multiple pollutant exports from land to sea - seasonality of exports - identify land-uses / activities that are causing the pollution - evaluate new technologies to monitor pollutants / ecosystem responses and verify against traditional monitoring methods	- use of standard monitoring and analytical methods from freshwater to marine, and across all Supersites - Earth observation, new water quality probes and auto-analysers

		Water Abstraction	- service water shortage - changes in ecosystem structure and functioning - reduced flow velocity, increased water residence time - changed base flow Unknown impacts in Thames estuary	- How will surface waters be affected by increased abstraction?	- general environmental monitoring and groundwater quality / level monitoring
	Industry	Pollution	- dispersal of pollution, bioaccumulation - water quality (emerging contaminants; metaldehyde) - unknown impacts in Thames estuary	- identify and quantify multiple pollution sources across the catchment and understand the processing /storage / chemical transformations occurring in the estuarine environment - quantification of multiple pollutant exports from land to sea. - seasonality of exports - identify land-uses / activities that are causing the pollution - evaluate new technologies to monitor pollutants / ecosystem responses and verify against traditional monitoring methods	- use of standard monitoring and analytical methods from freshwater to marine, and across all Supersites - Earth observation, new water quality probes and auto-analysers
		Nutrient Loading	- algal blooms - eutrophication - cyanobacteria blooms - due to High porosity bedrock (oolitic limestone) groundwater aquifers are polluted by nitrate (fertiliser, manure) from 20th century	- How do changing nutrient concentrations impact on algal / cyanobacterial blooms? - What is rate of decrease in groundwater and river N concentrations? Other organic pollutants?	- water quality and environnemental monitoring - high-frequency automated monitoring stations in lower river and estuary - microcosm experiments - modelling - river, estuary and groundwater pollution monitoring

	Urbanisation	Weirs, Channels	- reduced flow velocity, increased water residence time - changed base flow Interrupted water ways - change in ecosystem structure and function - loss of Habitat	- How do these within-channel features affect river ecology?	- flow and ecological monitoring - river habitat surveys for affected reaches
		Water Demand	- service water shortage (freshwater) - loss in water quality	- increasing water demand; pressure on water infrastructure - impacts of major drinking water schemes to supply London, such as the proposed inter-basin water transfers, desalination and wastewater reuse	- general catchment scale monitoring and site specific monitoring - modelling
		Combined Sewers Overflow	- effluent of sewage treatment plants - algal blooms - eutrophication - cyanobacteria blooms - change in ecosystem structure and function	- quantifying environmental impacts	- site-specific surveys
		Water Abstraction	-service water shortage (freshwater) - loss in water quality	- How will surface waters be affected by increased abstraction?	- general environmental monitoring and groundwater quality / level monitoring

	Transport	Dredging	- damage to benthic ecology - release of pollutants / sediment - impact of international shipping to port of London on transfer of invasive species to the estuary and river - changes in morphodynamics, sediment dynamics, sediment disturbance - changes/decline in ecosystem structure and functioning	- How does this activity affect river and estuarine ecology? - How are invasive species transported to and throughout the river network (including river boat traffic and canal network?	- general environmental monitoring scheme plus site-specific studies during dredging operations - remote sensing to pick up sediment plumes?
	Changing Land Use		- related to climate change and economy	- impact on water quality of river sea system?	- general environmental monitoring scheme and detailed land cover (obtained using remote sensing and agricultural statistics)

Thames Estuary Supersite, United Kingdom – Table 2

Human Response & Societal Challenges	Scientific Challenges, Research Needs & Questions	Research Methods & Tools
Nature Conservation & Restoration Adaptive Ecosystem Management/ Sustainable Development	- How effective are these? What works and what doesn't? How do we maximise the benefits?	- general chemical and ecological monitoring programme - site specific studies, before and after remediation - modelling to predict impact of larger scale remediation
Thames Tideway Tunnel (operational by 2023)	- How will the reduced sewage pollution loading to the estuary impact on water quality and ecology?	- estuarine monitoring - remote sensing
Environmental Education & Human Resources Development	- Impact of anti-littering campaigns; septic tank stewardship; improving farmer training, to reduce nutrient, sediment and pesticide loadings to watercourses?	- link with monitoring programmes already conducted by Thames21 in London (littering) - monitoring at subcatchment scale, before and after training intervention
Effective Stakeholder Involvement	- using citizen science to increase our density of data points for ecology, habitat and simple water quality	- engage with current citizen science campaigns, such as the Thames water-blitz
Green Engineering (e.g., SUDS)	- impact on pollutants and flow regime?	- monitoring focus on the many new housing developments that are employing SUDS
Desalinisation Plant	- What will be the effect of changing salinity in the estuary? - impacts on estuarine current patterns? - sedimentation and geochemistry?	- chemical monitoring - estuarine high-frequency monitoring stations - site-specific monitoring around outfalls - remote sensing?
Improved Sewage Systems	- What is the impact on water quality? - Is the impact immediate or is there a lag (recovery time)? - How does the ecology respond and how long does it take?	- chemical and biological monitoring programme - site specific monitoring (upstream / downstream and before after intervention) - high frequency monitoring stations - microcosm experiments

	- What P and N concentrations need to be attained before we get an improvement in ecological status?	
Sustainable Flood Prevention Concepts, Investement in Flood Warning and Defence	- How does flood mitigation affect ecology and sediment loads / deposition?	- monitoring and modelling

Thames Estuary Supersite, United Kingdom – Questionnaire

1) Human activities (drivers) and resulting pressures:

- rapidly increasing population and urbanisation has impacts on flow regime, pollution loadings etc.
- agricultural intensification, and impacts on water quality / sediment loadings
- large infrastructure projects (Thames Tideway, New reservoirs, Inter-basin transfers

2) What are the resulting environmental/socio-ecological problems (current, anticipated, which of them are currently tackled)?

- lack of drinking water for London region in the near future
- water stress resulting in low flows and increasing drought problems

3) Current state of research? Research gaps and future research needs?

- River Thames catchment is probably the most studied catchment in the UK. The Thames Estuary is less studied, and a research gap that DANUBIUS-RI will fill.
- The future research needs are understanding the impacts of urbanisation, land use change and climate change, and how proposed infrastructure projects (aimed at supplying London with drinking water) will impact on the RSS environment.
- Future water stress and drought will impact on flow and groundwater levels. We need to establish environmental flows required to sustain the river and estuarine ecosystem, and how we can ensure that this water will be available to the river.

4) Which Institutes, authorities, commissions are active in your region?

Thames Water, Affinity Water, Anglian Water, Environment Agency, Port of London Authority, Local councils, Catchment Partnerships, Defra, Canal and Rivers Trust

5) Whom do you consider as partners/stakeholders/users?

<u>Partners:</u>

- host institution is Centre for Ecology & Hydrology
- other organizations: PML, University of Stirling and Birmingham to be involved in the estuary monitoring / research and remote sensing

<u>Stakeholders and Users:</u>

- Local Universities (Oxford, Reading, Brunel, Portsmouth, Southampton Universities), environmental modellers, remote sensing experts.
- Monitoring instrument developers can use the high-frequency monitoring stations as a test bed for prototype instruments.
- The Environment Agency (EA), UK Government Environment Department and Water Companies will benefit from the data, system understanding and models generated within DANUBIUS-RI. The EA will probably be directly involved in supporting the automated monitoring sites along the river and into the estuary.
- Local Rivers Trusts (Action for the River Kennet, Freshwater Habitats Trust). Thames21, Wild Oxfordshire, local catchment management groups.

6) **Major Scientific topics/questions addressing the Supersite**

- How are algal blooms generated / transported along the river –sea system?
- full understanding of the multiple-stressor controls of algal blooms in the Thames, through the river network, estuary and into the North Sea, using the latest high-frequency chemical and biological monitoring techniques
- develop remote sensing techniques (groundtruthed by manual observations) to extend our knowledge of river blooms, and extend it into the marine environment
- What impact does management of the Thames freshwater system have on the estuary and coastal waters?
- How will the improved water quality of the estuary due to the Thames Tideway Tunnel scheme, and the proposed wastewater reuse, desalination schemes, directly impact on ecology, chemistry and hydrology of the estuary?
- What will be the impact of future growth of London?
- How effective are the UK's efforts to supply drinking water to London, in the face of ever growing population and water usage, and reducing water supply due to climate change?
- How do schemes such as inter-basin transfers / reservoir construction etc. compare with similar projects across the other Supersites?
- Can we develop “best practise” management by taking a Europe-wide view?

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